APPENDIX A

LITERATURE SEARCH / ANNOTATED BIBLIOGRAPHY

DOCUMENTS REVIEWED IN SUPPORT OF THIS RSM PLAN

Winds, Waves, Tides, and Currents

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). 2010a. Datums for Nawiliwili Harbor, HI. Also available online at: < http://co-ops.nos.noaa.gov/data_menu.shtml?stn=1611400 Nawiliwili, HI&type=Datums >

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

National Oceanic and Atmospheric Administration (NOAA). 2010b. Mean Sea Level Trend: 1611400, Nawiliwili Harbor, HI. Also available online at < http://co-ops.nos.noaa.gov/sltrends/sltrends_station.shtml?stnid=1611400 Nawiliwili, HI>

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., 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 re-sampled 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.

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 Hawaiʻi, including Poipu, Waimea, and Kekahain 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 Hawaiʻi.

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

In Hawaiʻi, 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.

University of Hawai'i Coastal Geology Group. 2010 Kauai Shoreline Study Erosion Maps. <http://www.soest.hawaii.edu/coasts/kauaicounty/KCounty.html>.

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

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*.

Kauai – General

Manoa Mapworks. 1983. Kaua'i Coastal Resource Atlas. Prepared for the United States Army Corps of Engineers, Pacific Ocean Division. October.

Maps within this report provide classification of the bottom type, shoreline type, special (recreational) uses, and topographic and hydrographic detail along all Kauai shorelines. The maps are based on aerial imagery (1975) and qualitative marine biological surveys performed by the USACE in 1981. The Kekaha study area is covered within Sections 13 and 14. The Poipu study region is within Sections 17 and 18. The altas accompanies the Kauai Island Coastal Resource Inventory (KICRI) prepared by the AECOS, Inc (September 1982).

United States Army Corps of Engineers, Pacific Ocean Division. 1979. Hawaii Sandy Shoreline Inventory.

Provides baseline information for selected beaches for future changes in shoreline position can be measured. Topographic maps are provided of Poipu and Waimea beaches.

Department of the Army, Pacific Ocean Division. 1974. Beach Erosion Control Projects, Hanapepe and Waimea, Hawaii.

Miscellaneous correspondence related to the Hanapepe Bay and Waimea Bay Beach Erosion Control Projects. The project was reclassified from active to deferred in 1965 due to insufficient Federal and State funding. Requests are made in this document to reclassify the project from deferred to active in 1974 because erosion problems were said to not have been abated. The County of Kauai provided some temporary measures such as a rock barrier, which were removed by strong ocean currents and wave action.

AECOS, Inc. 1982. Kauai Island Coastal Resource Inventory (KICRI). Prepared for the U.S. Army Corps of Engineers, Pacific Ocean. September.

The report provides descriptions of specific coastal reaches in Kauai. Coastal structures, beach type, sand type and offshore reefs are described for each of these reaches.

Kauai - Kekaha Region

U.S. Army Corps of Engineers, Honolulu District. 1978. Final Detail Project Report and Environmental Statement for the Kekaha Beach Shore Protection, Kekaha, Hawaii. February.

Report describes the cause of beach erosion at Kekaha Beach and evaluates alternatives to protect the beach from erosion. The study reach is 6,000 feet beginning at Kala Road and extending westward. The reconnaissance report for this project was completed in 1976, which recommended construction of a 5,700 feet rubble revetment along this shoreline as the most feasible plan. The sand dunes at Barking Sands were evaluated as a sand source. Nearby gulches were also investigated for use as rock revetments and breakwater construction. The report provides information of the study area related to: wave exposure, sediment transport direction, volumetric shoreline change rates between 1936 and 1976, currents, tides, littoral grain size distribution, longshore effects of the Kikialoa Small Boat Harbor (built in 1959), history and development of the Kekaha area. Plans given for the proposed revetment design.

U.S. Army Corps of Engineers, Honolulu District. 1980. General Design Memorandum and Final Environmental Impact Statement for Navigation Improvements for Kikiaola Light – Draft Harbor, Waimea, Kauai, Hawaii. September.

Describes the feasibility and environmental impacts of navigation improvements to Kikiaola Harbor. Four alternatives were evaluated. All alternatives entail the construction of a 12-foot deep entrance channel, a turning basin and modifying the existing breakwater structures. The construction history of Kikialoa Harbor is described along with general shoaling information for the entrance channel. Dredged material from the project was proposed to be placed at a county landfill site.

U.S. Army Corps of Engineers, Honolulu District. 1998. General Re-evaluation Report and Environmental Assessment. Navigation Improvements at Kikiaola Light Draft Harbor, Kekaha, Kauai, Hawaii. August.

Report analyzed six alternative improvement plans for the Kikiaola Harbor. The recommended plan included the modification of the breakwaters and dredging of the entrance and access channels. The total volume to be dredged from the harbor was approximately 38,000 cy, which was to be disposed of on adjacent lands. The report discusses sediment inputs to the

harbor from an existing drainage ditch (estimated at 1,600 cy/yr) and longshore sediment transport. Although an actual harbor sediment infill rate from longshore transport is not given, the estimated longshore transport rate in the vicinity is estimated at 3,500 cy /yr to the west calculated via historic aerial images. A two-foot infill maintenance dredging criteria was adopted. Based on this criteria, dredging is estimated to occur every 10 to 14 years. Implementation of a sand bypassing program was discussed that would remove sediment from the eastern (accreted) shoreline and place it along the western (eroded) shoreline via truck. The program's intent would be to mitigate sand loss to the west and reduce sediment deposition into the harbor. Sand bypassing was estimated to be required every 4.5 years at a volume of 16,000 cy.

State of Hawaii, Department of Transportation . 1980. Contract No. DACW 84-78-C-0030 Construction of Kekaha Shore Protection, Kekaha, Island of Kauai, Hawaii. December.

Agreement between the USACE and the State of Hawaii for the construction of a revetment on Kekaha Beach. The project was completed in May 1980. Project financial and cost share information provided.

State of Hawaii, Department of Transportation. Miscellaneous correspondence and financial data related to the completion of the Kekaha Beach Project.

Notification of completion and final inspection report of the Kekaha Beach Project (repair of 5,800 feet of revetment). The revetment was said to be damaged by Hurricane Iwa on November 1982. Construction plans, costs, material quantities provided.

Sea Engineering, Inc. 1986. Hurricane Vulnerability Study for Kauai Vicinity of Waimea and Kekaha, Storm Wave Runup and Inundation. Prepared for the U.S. Army Engineers. February.

Study assesses wind and wave fields, water level rise, wave runup and inundation associated with four hypothetical (modeled) hurricane scenarios. The study predicts the limits of coastal flooding associated with these hypothetical events. Study provides information about the historical hurricane record in the region and damage associated with these events.

Sea Engineering, Inc. 1996. Sediment Transport at Kikiaola Harbor; Island of Kauai, Hawaii. Prepared for the U.S. Army Engineer Division, Pacific Ocean. August.

Examines the physical factors and geologic processes affecting sedimentation in the vicinity of the harbor. Quantitative results are presented as derived from historical rates of accretion and from energetics-based sediment transport theories. Bathymetric "sink" located offshore of the harbor is discussed.

Sea Engineering, Inc. Kikiaola Light Draft Harbor West Breakwater Root Extension and Sand Bypass Study, Island of Kauai, Hawaii. Prepared for the U.S. Army Corps of Engineers, Honolulu District. September 2008.

The report discusses erosion in the vicinity of the Kikiaola Harbor west breakwater, whose landward end had become flanked by erosion since the construction of the Harbor. The study was divided into Breakwater Root Extension and Sand Bypass sections. The root extension portion discussed improvement design options to the west breakwater. Alternatives included the landward extension of the breakwater or creation of a shore parallel breakwater spur. Wave and general oceanographic conditions (i.e. wave run-up, overtopping, wave exposure, etc) are discussed as they relate to the formulation of the breakwater improvement design.

The sand bypass study builds on prior sediment studies in the vicinity, which are listed in the report, and proposes a sand bypass plan on the order of 6,000 cy per year delivered via hydraulic or mechanical excavation. The proposed volume is based on the total sand deficit west of the harbor, which is estimated to be approximately 80,000 cy in the 1,500-ft reach between the Harbor and Mamo Road. The sand borrow area will extend approximately 1,200 ft east of the harbor. Shore protection, historical shoreline change, and beach nourishment history in the vicinity is given.

Other Islands and Other Areas of Kauai

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 Moloka‘i 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

Sea Engineering, Inc. November 2008. Kahului Bay Sub-Bottom Survey.

In May, 2008, Sea Engineering, Inc. conducted a sub-bottom survey, using geophysical methods, of Kahului Bay on the north shore of the island of Maui. The survey was designed to investigate the nature of sand deposits in the bay. Previous benthic surficial mapping by NOAA had indicated the broad presence of sand deposits within the bay, however there were no data available to determine the thickness of the sand deposits. The presence of sand deposits 10 to 20 feet in thickness over much of Kahului Bay was confirmed by the Sea Engineering sub-bottom survey.

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 (Hawai‘i Beach Management Plan) to conserve and restore Hawai‘i’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 Hawai‘i. 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 – KEKAHA REGION
(USACE 2011)

Kekaha is on the southwest shore of the Kauai with exposure to waves arriving from approximately 170 to 300 deg. The closest Wave Information Studies (WIS) save point is Station 120 located at 21.5 deg North and 160 deg West in a depth of 3438 m. Station 120 is shown in Figure B-1 with a yellow circle. A wave rose for Station 120 for 1981-2004 is given in Figure B-2. The wave rose shows distribution of wave height with wave direction. The largest wave heights come from storms out of the northwest.

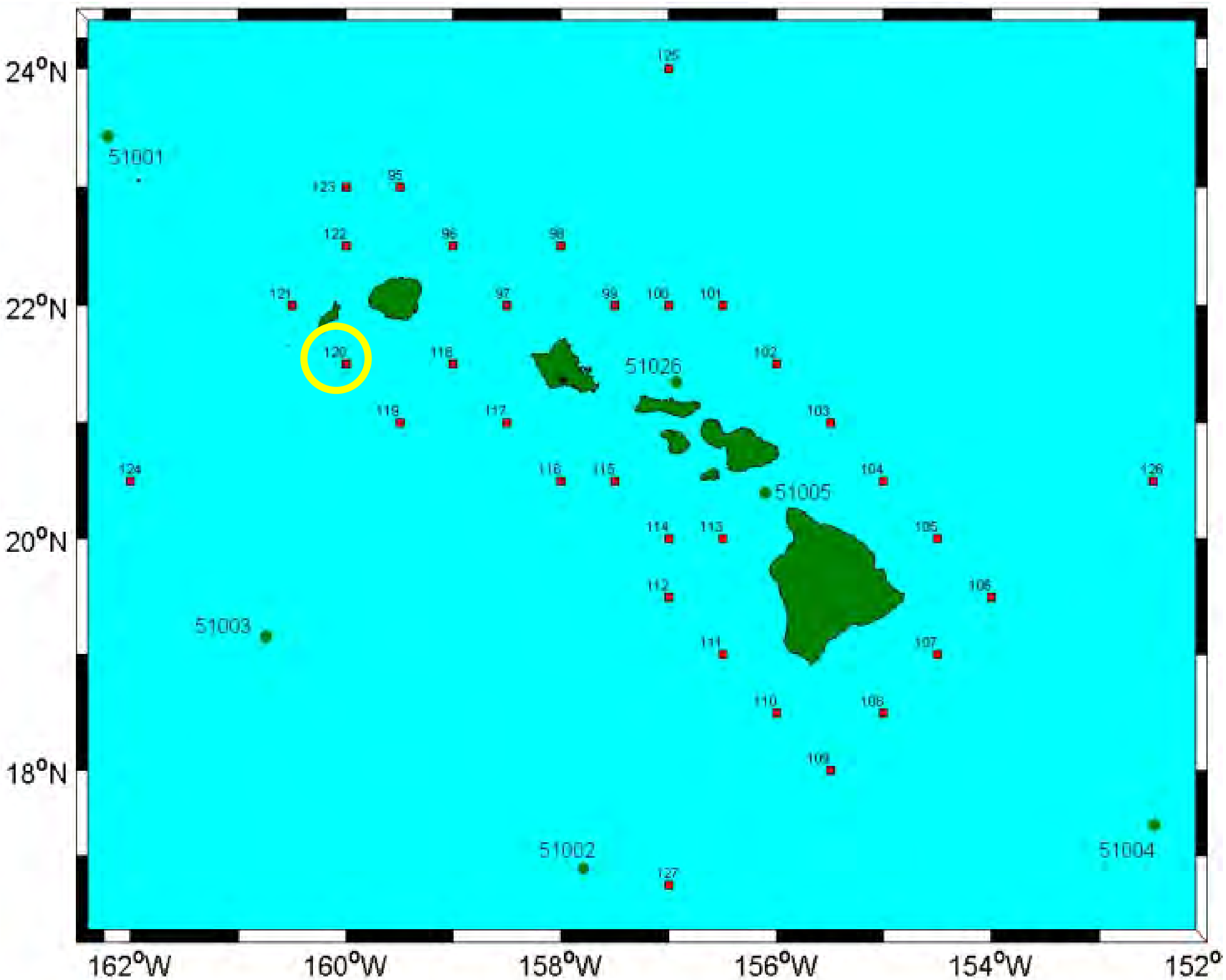


Figure B-1. WIS Station map.

Three representative years were chosen for further study and nearshore wave transformation. The three years include a low wave condition year (1984), a medium wave condition year (1992) and a high wave condition year (1994). Figures B-3 and B-4 show compressed time series of the years 1984 and 1994 at Station 120 (the 1992 is not available on the WIS website).

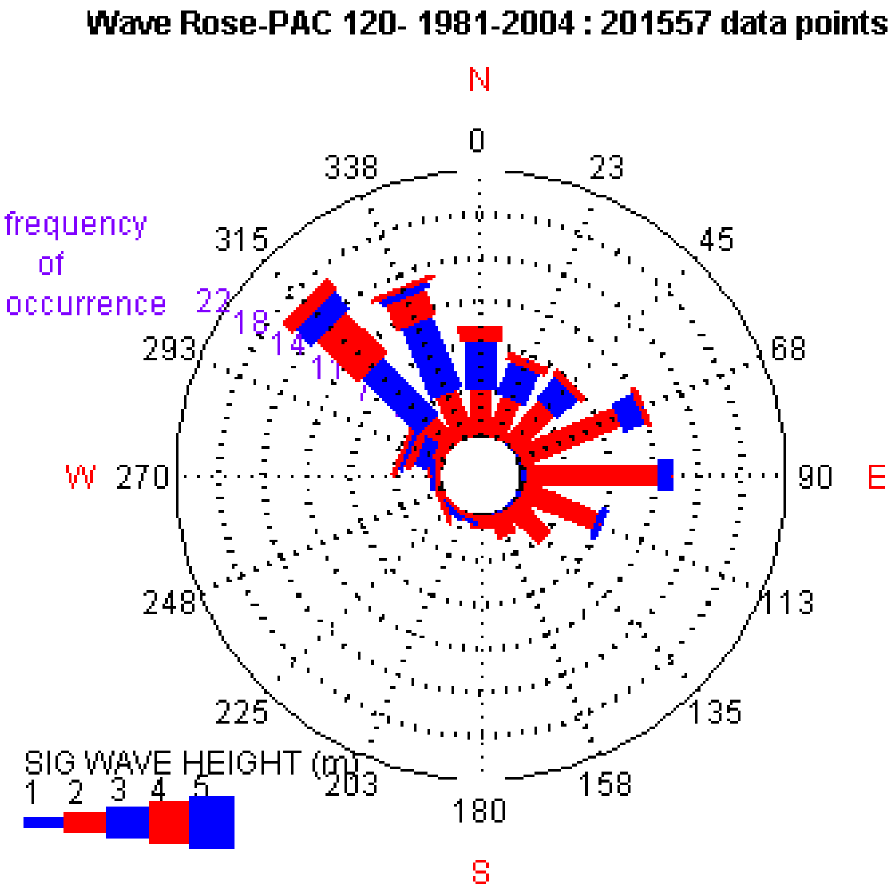


Figure B-2. Wave Rose for 1981-2004 for WIS Station 120.

Since the WIS save points are in deep water and away from Kauai, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Kekaha, the WIS spectra for these three years were truncated to include only energy from 167.5 to 342.5 deg (255 deg +/-87.5 deg). Then, the truncated spectra were used to recalculate wave height, peak wave period, and mean wave direction. These wave parameters from the truncated spectra were then analyzed using the Coastal Engineering Design and Analysis System (CEDAS) to quantify the distributions of wave height period and direction. ASCII files with the hourly date, wave height, peak wave period, and mean wave direction were imported to CDAS Beach model under STWAVE using the WWWL Data utility. The units of meters were set under the “waves” tab and the time history was saved in a NetCDF format. Then this file was opened using the WSAV utility under STWAVE. The data were then binned and plotted.

Percent and number of occurrence plots are shown in Figures B-5 through B-11 for 1984, in Figures B-12 through B-18 for 1992, and Figures B-19 through B-25 for 1994. The directions on these plots are relative to the normal of the local wave grid (0 deg in the relative system is a wave from 255 deg clockwise from north, +45 deg is 210 deg, and -45 deg is 300 deg). The plots are useful is assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

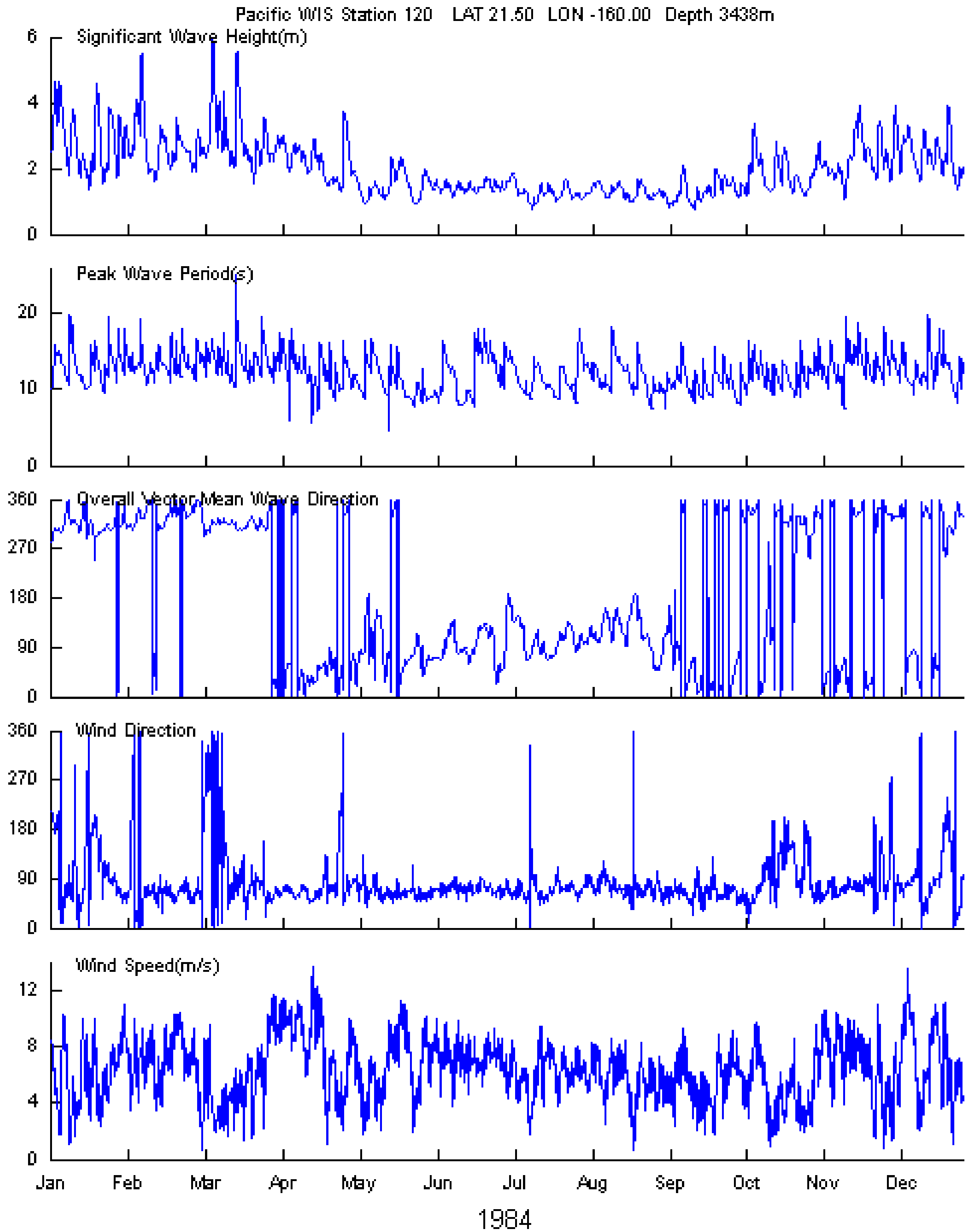


Figure B-3. 1984 wave and wind time histories for WIS Station 120.

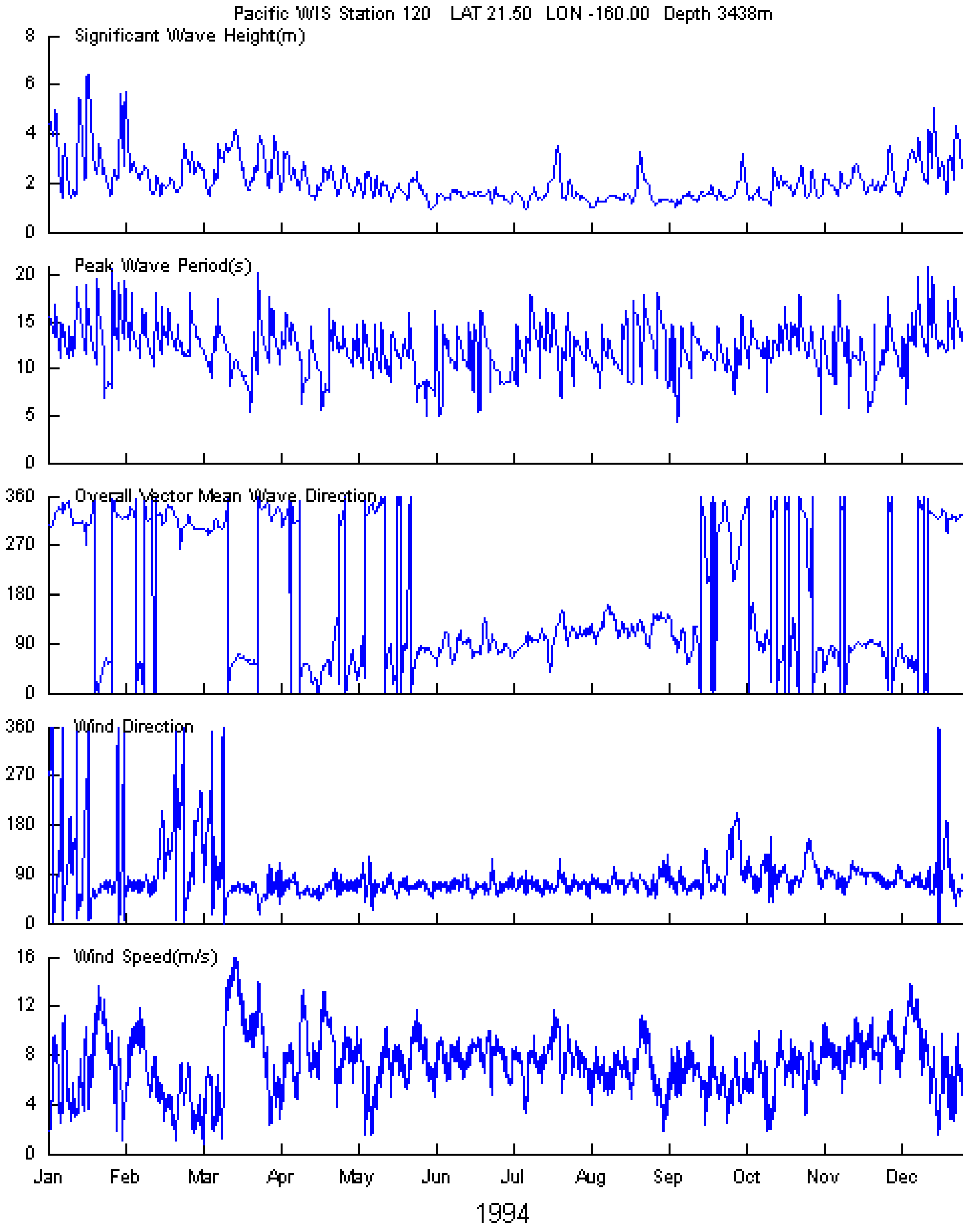


Figure B-4. 1994 wave and wind time histories for WIS Station 120.

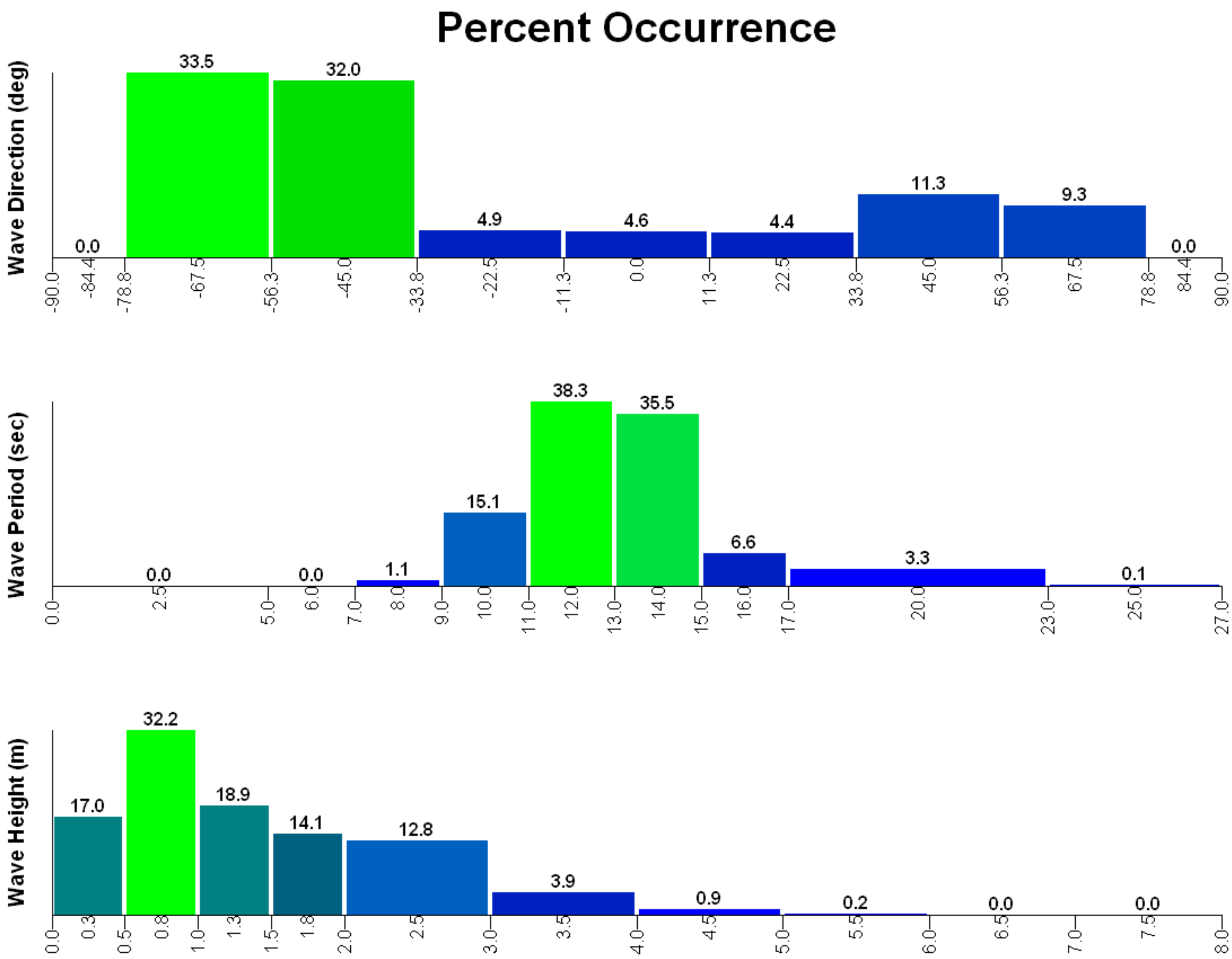


Figure B-5. 1984 percent occurrences for wave height, peak period, and mean direction for WIS Station 120.

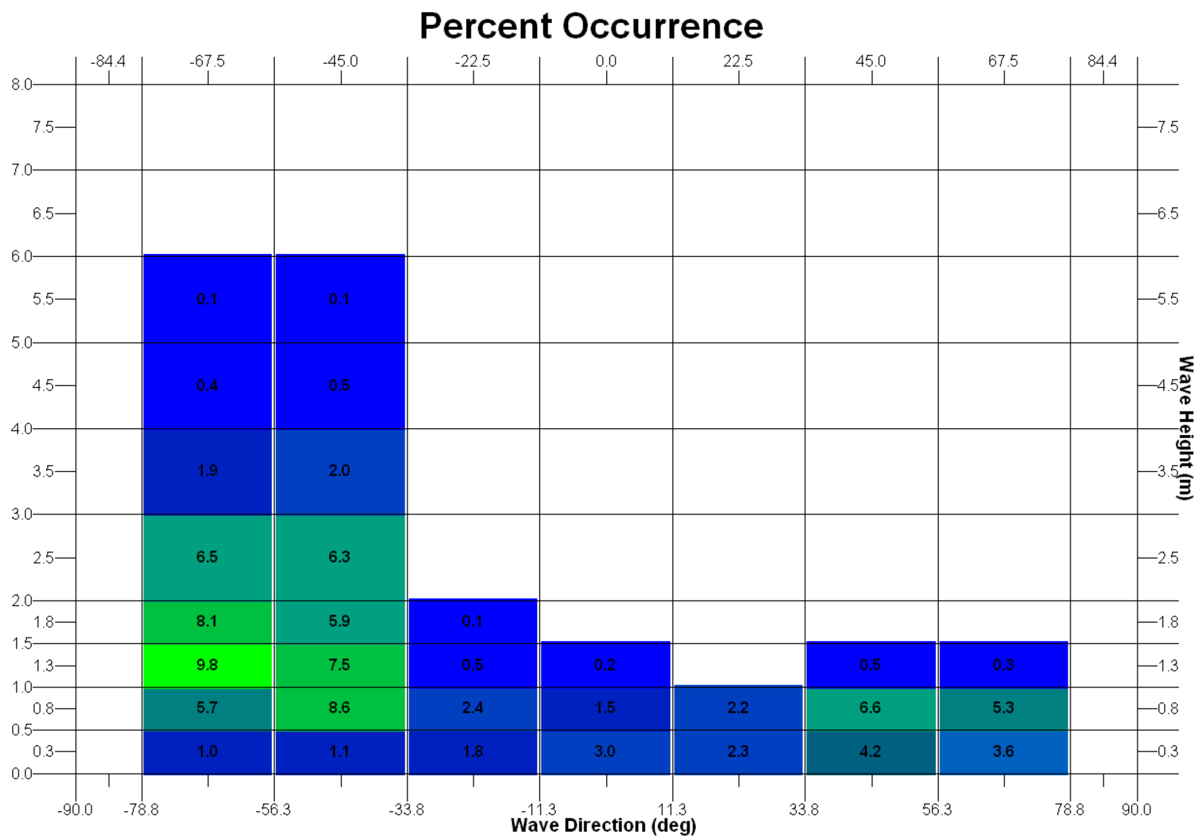


Figure B-6. 1984 percent occurrences for wave height and mean direction for WIS Station 120.

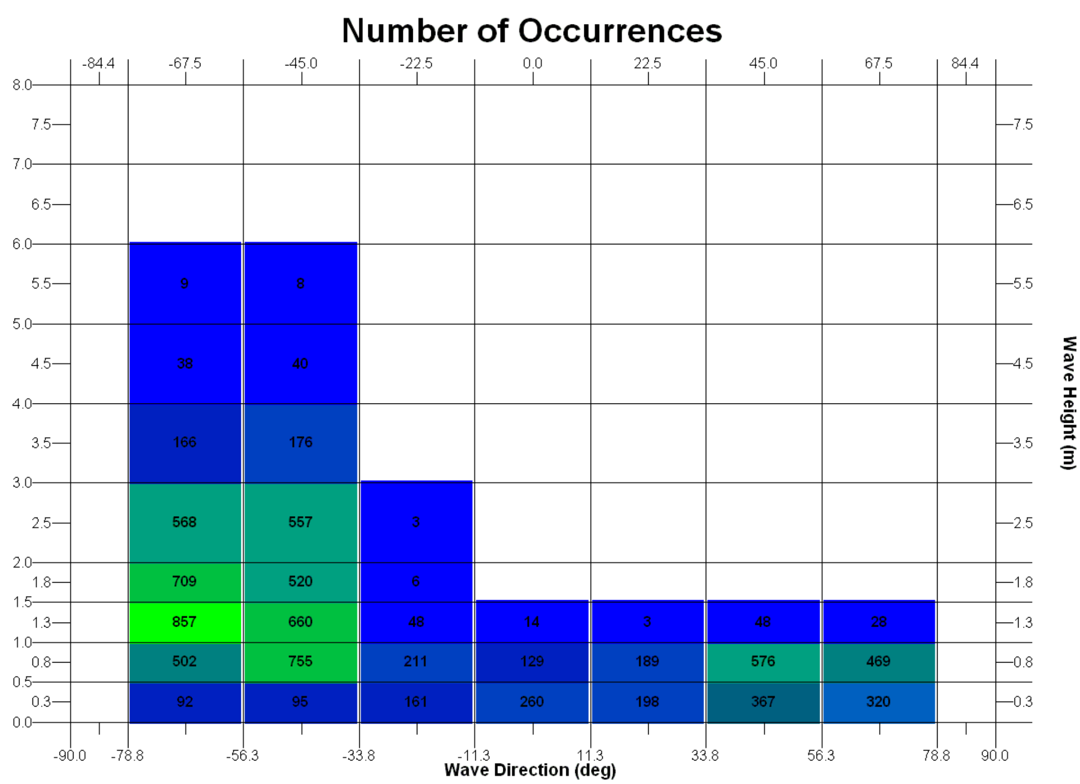


Figure B-7. 1984 number of occurrences for wave height and mean direction for WIS Station 120.

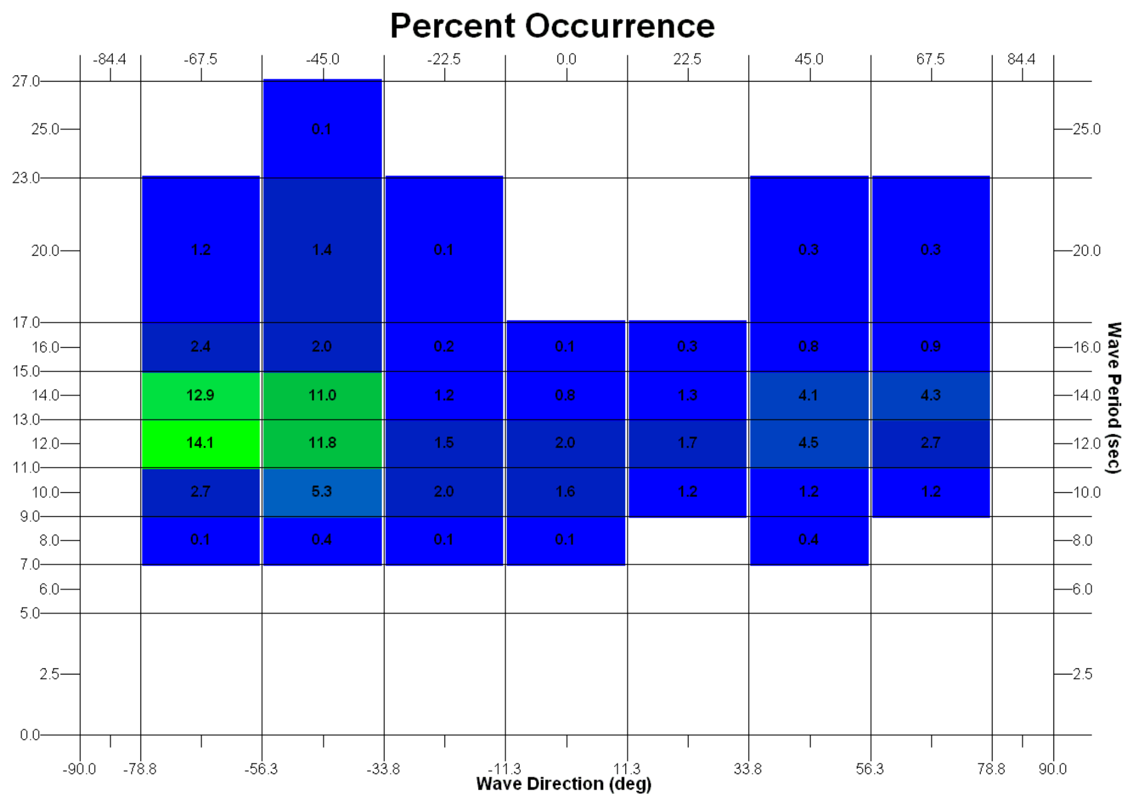


Figure B-8. 1984 percent occurrences for peak period and mean direction for WIS Station 120.

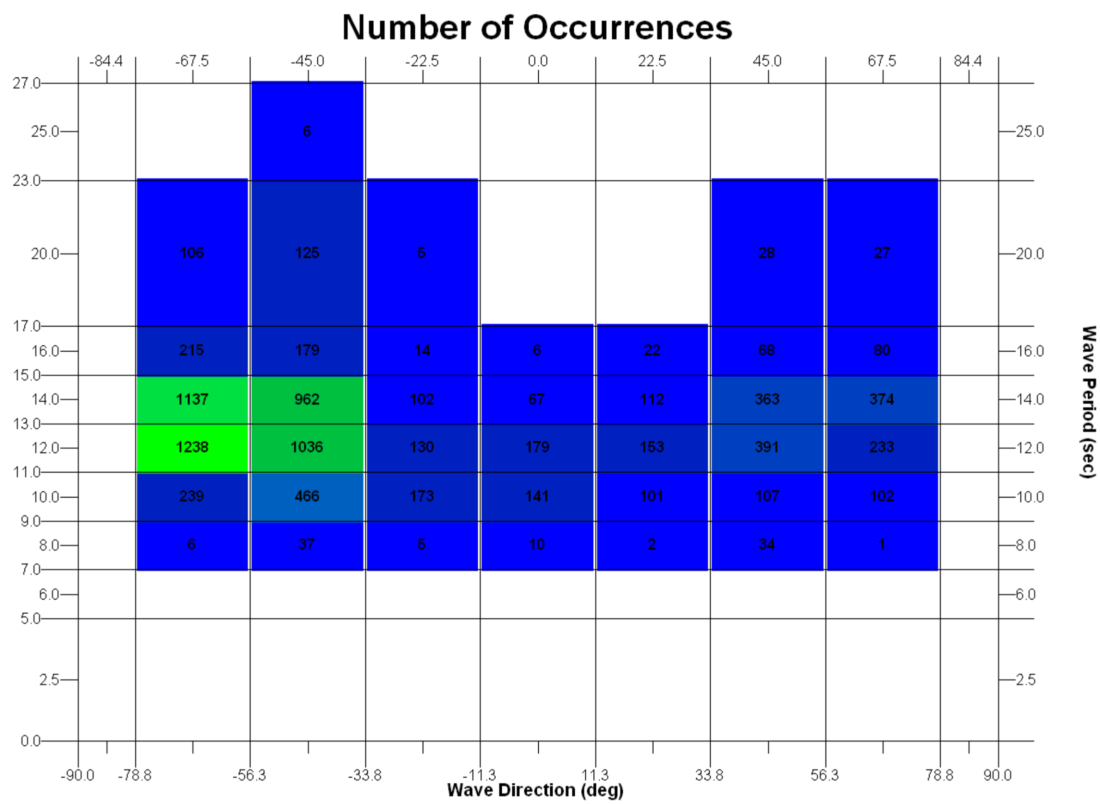


Figure B-9. 1984 number of occurrences for peak period and mean direction for WIS Station 120.

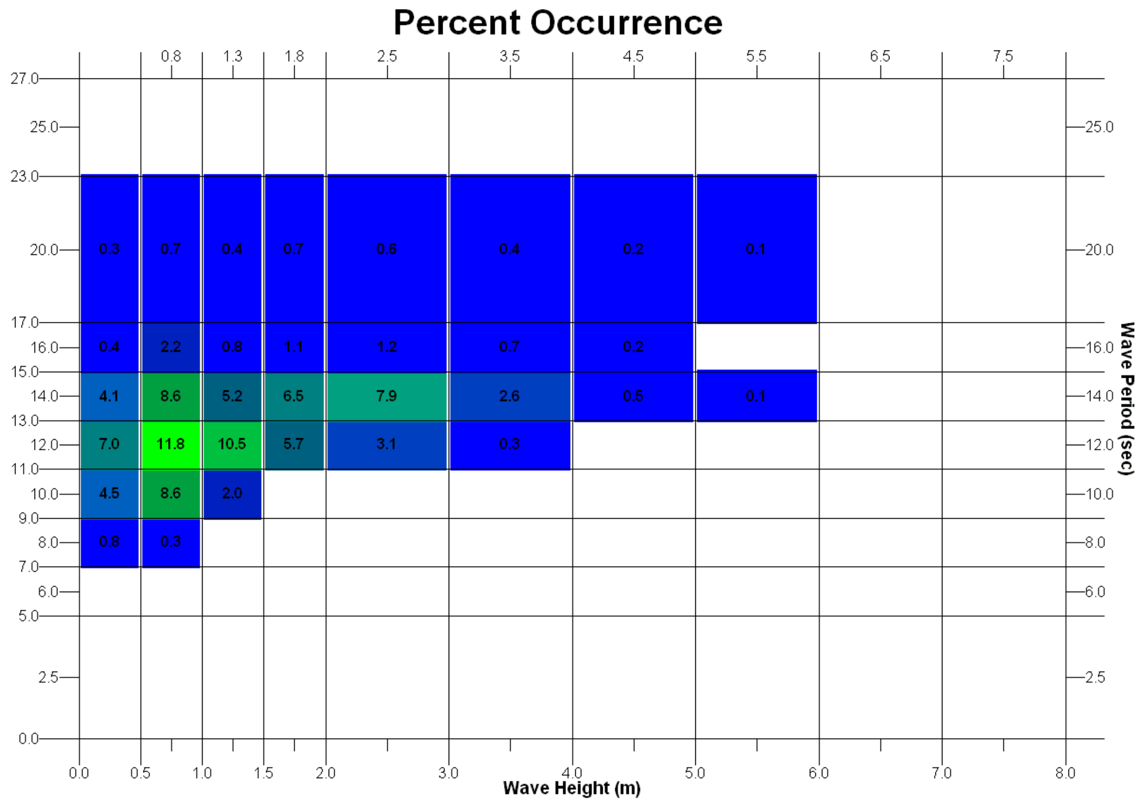


Figure B-10. 1984 percent occurrences for peak period and wave height for WIS Station 120.

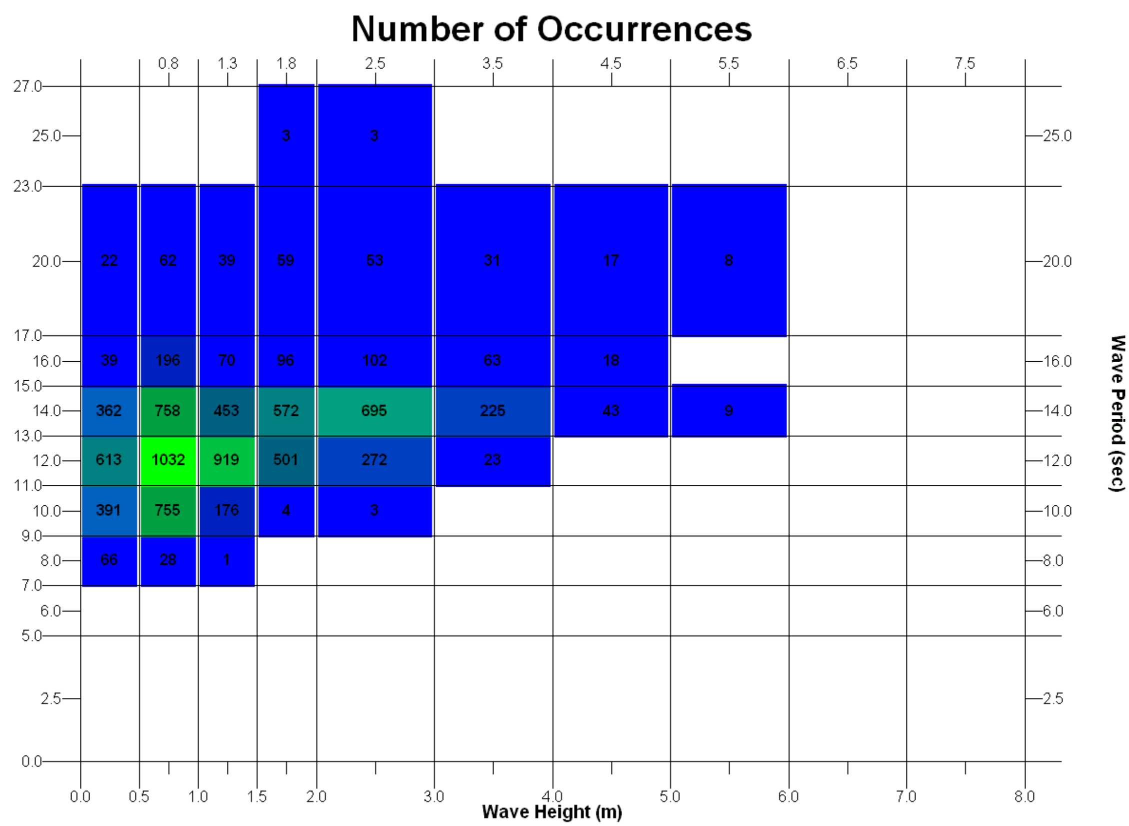


Figure B-11. 1984 number of occurrences for peak period and wave height for WIS Station 120.

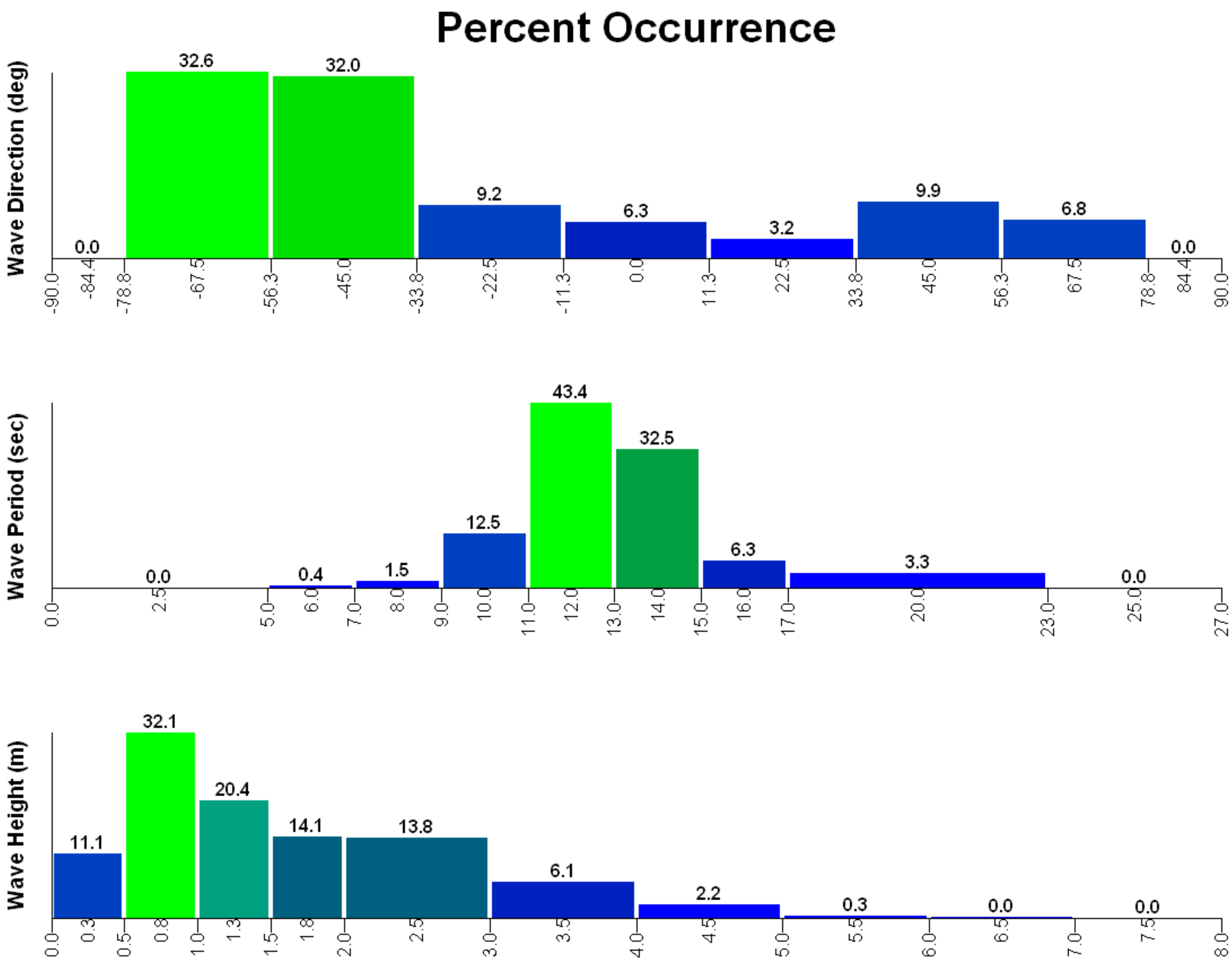


Figure B-12. 1992 percent occurrences for wave height, peak period, and mean direction for WIS Station 120.

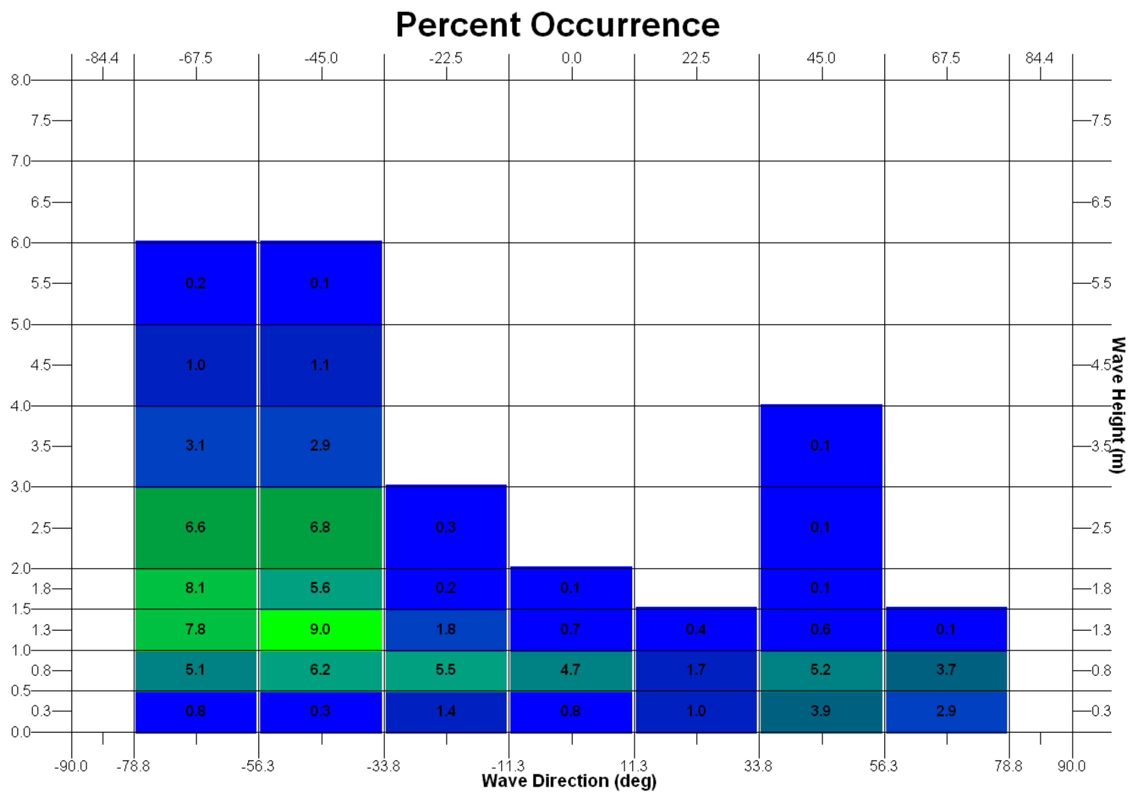


Figure B-13. 1992 percent occurrences for wave height and mean direction for WIS Station 120.

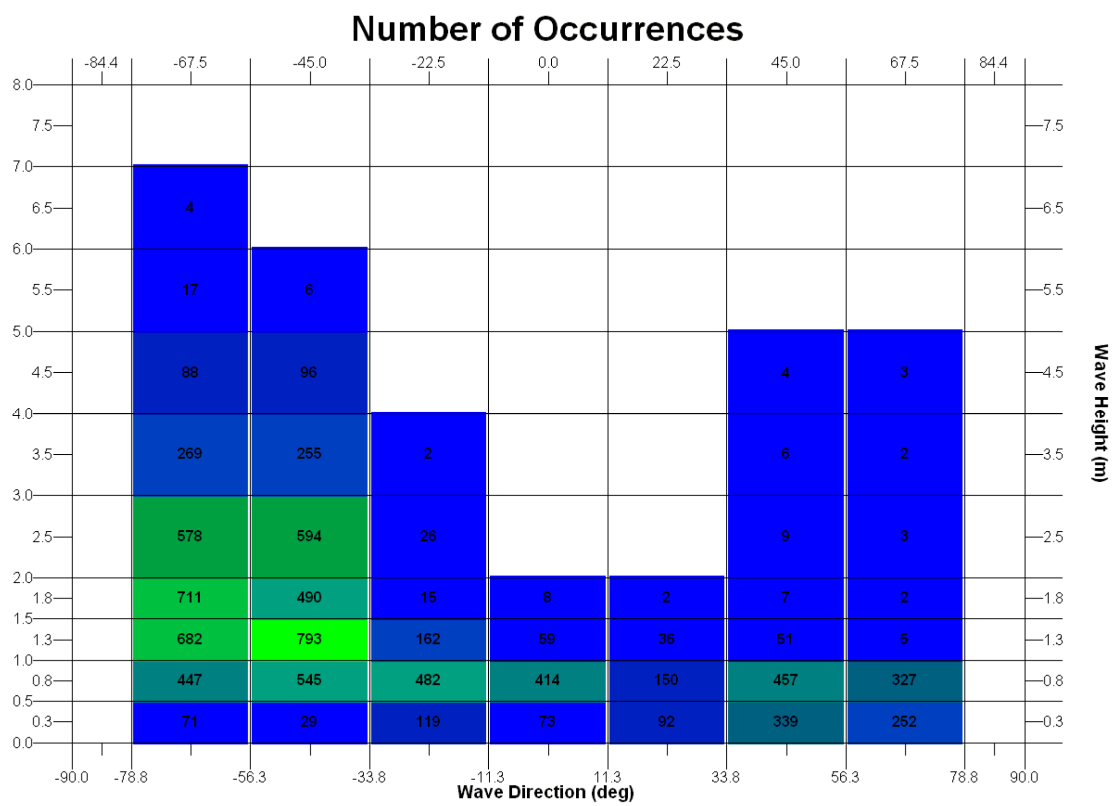


Figure B-14. 1992 number of occurrences for wave height and mean direction for WIS Station 120.

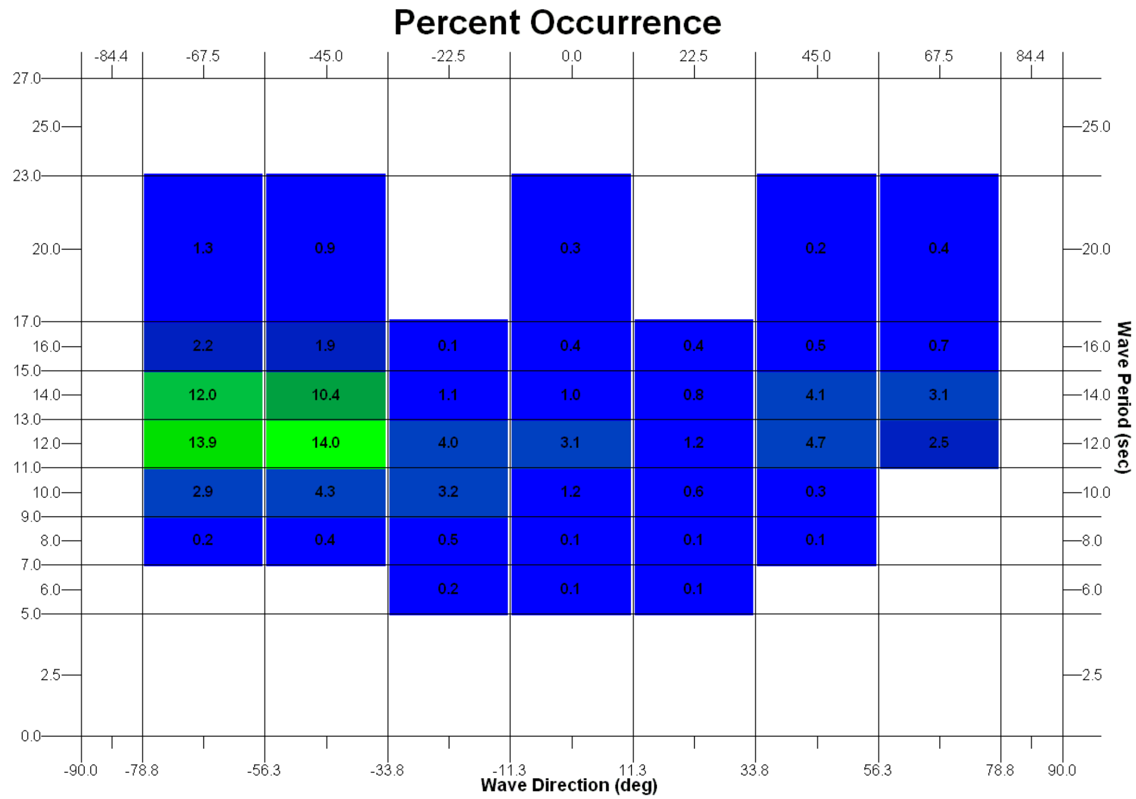


Figure B-15. 1992 percent occurrences for peak period and mean direction for WIS Station 120.

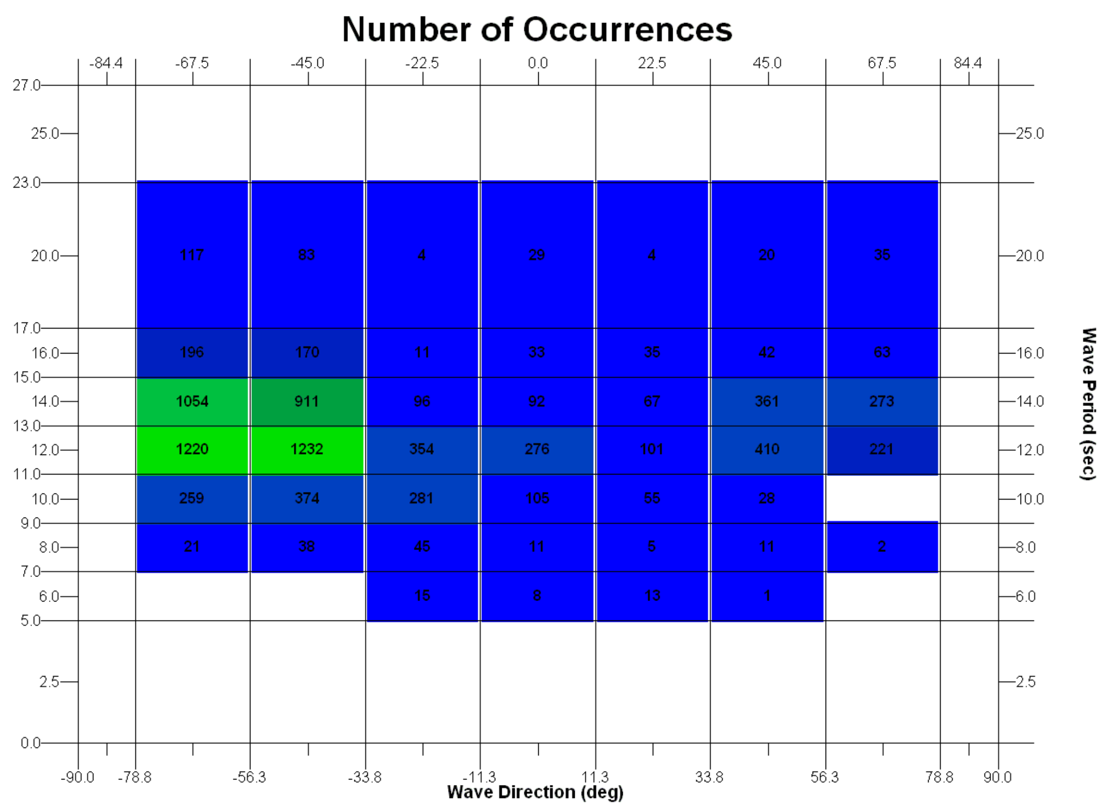


Figure B-16. 1992 number of occurrences for peak period and mean direction for WIS Station 120.

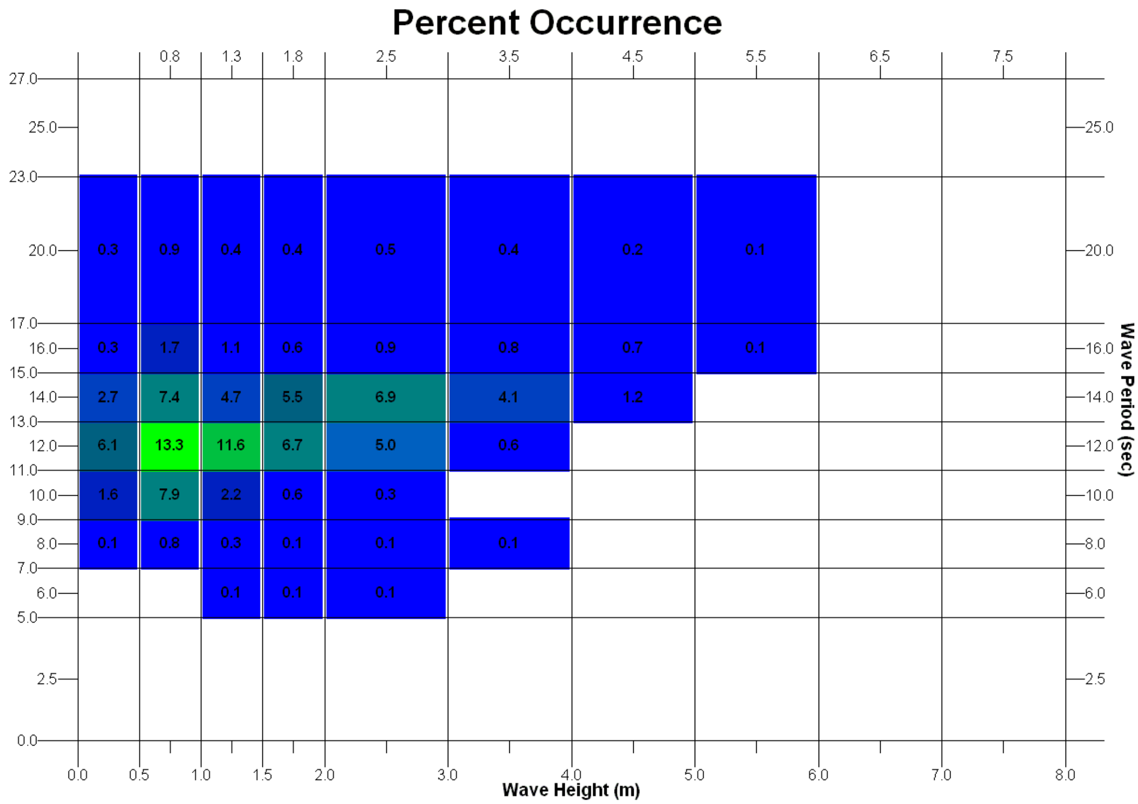


Figure B-17. 1992 percent occurrences for peak period and wave height for WIS Station 120.

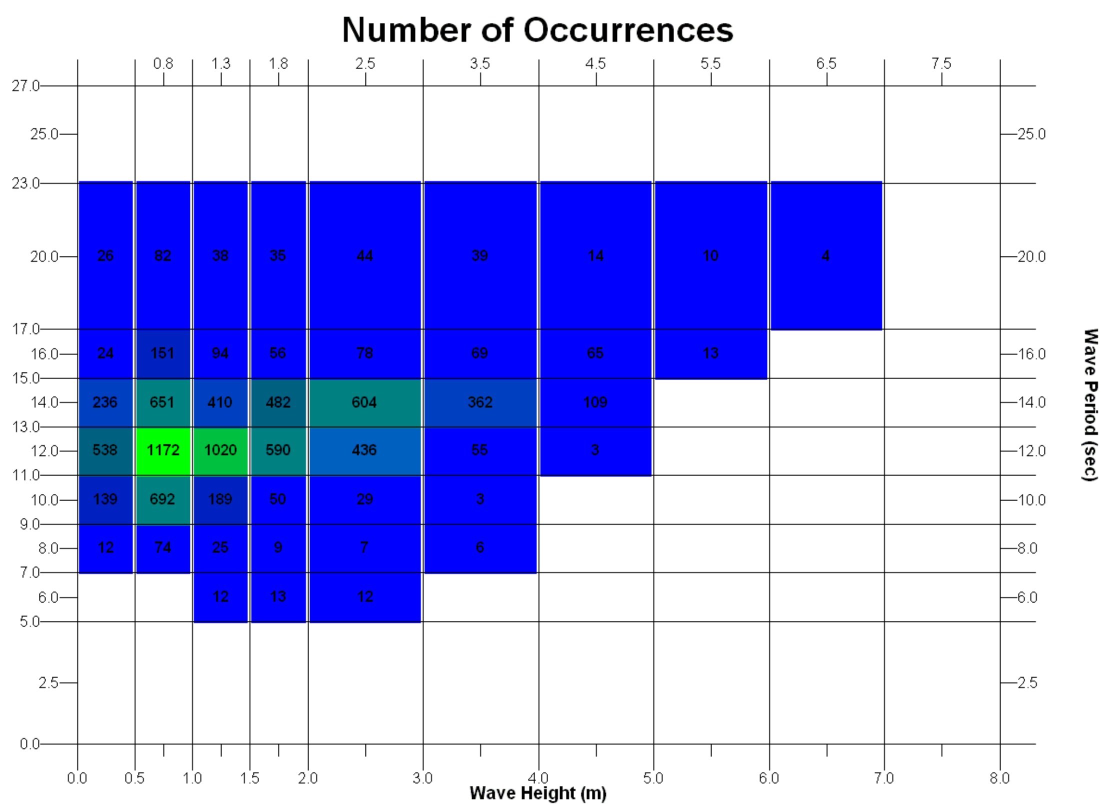


Figure B-18. 1992 number of occurrences for peak period and wave height for WIS Station 120

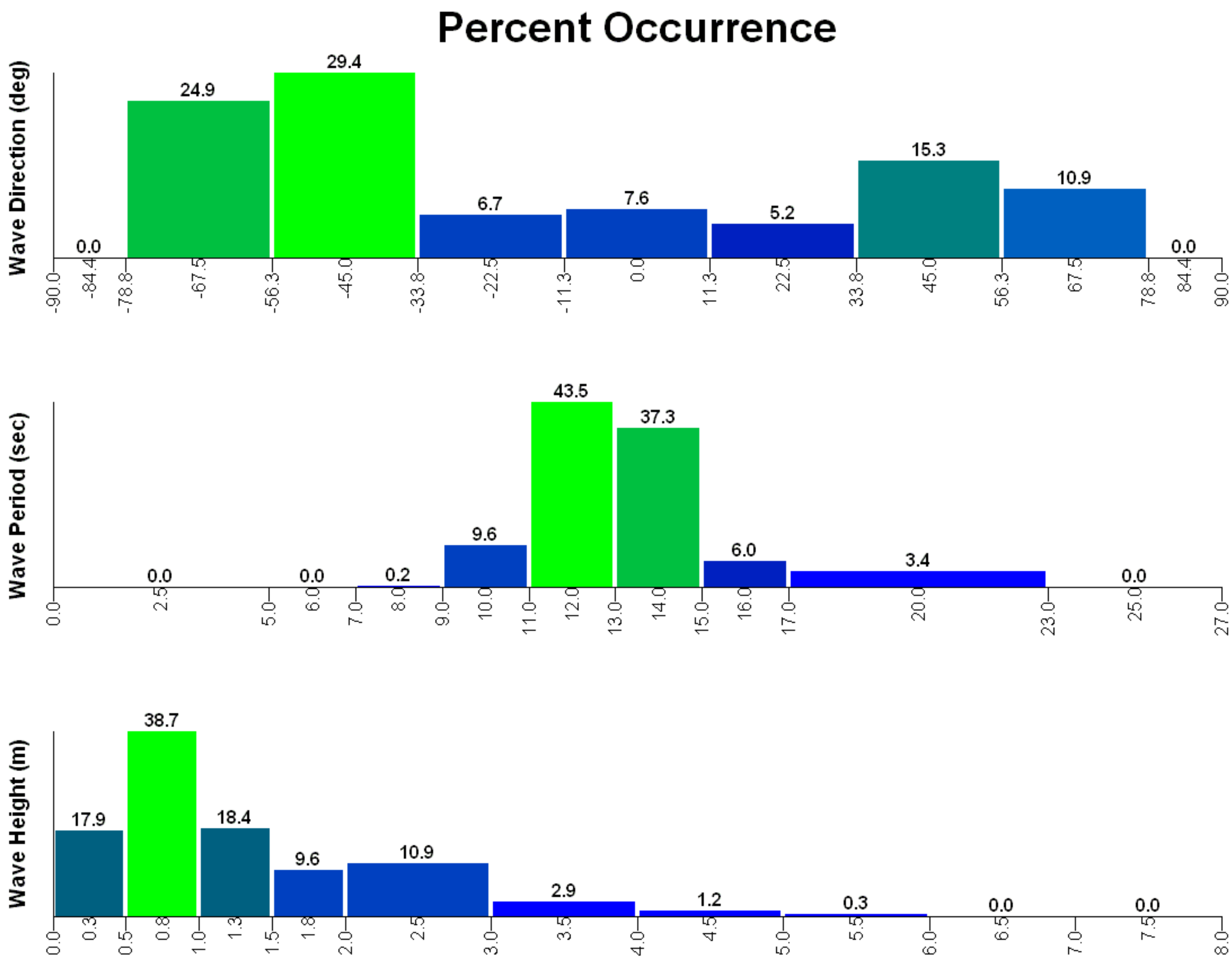


Figure B-19. 1994 percent occurrences for wave height, peak period, and mean direction for WIS Station 120.

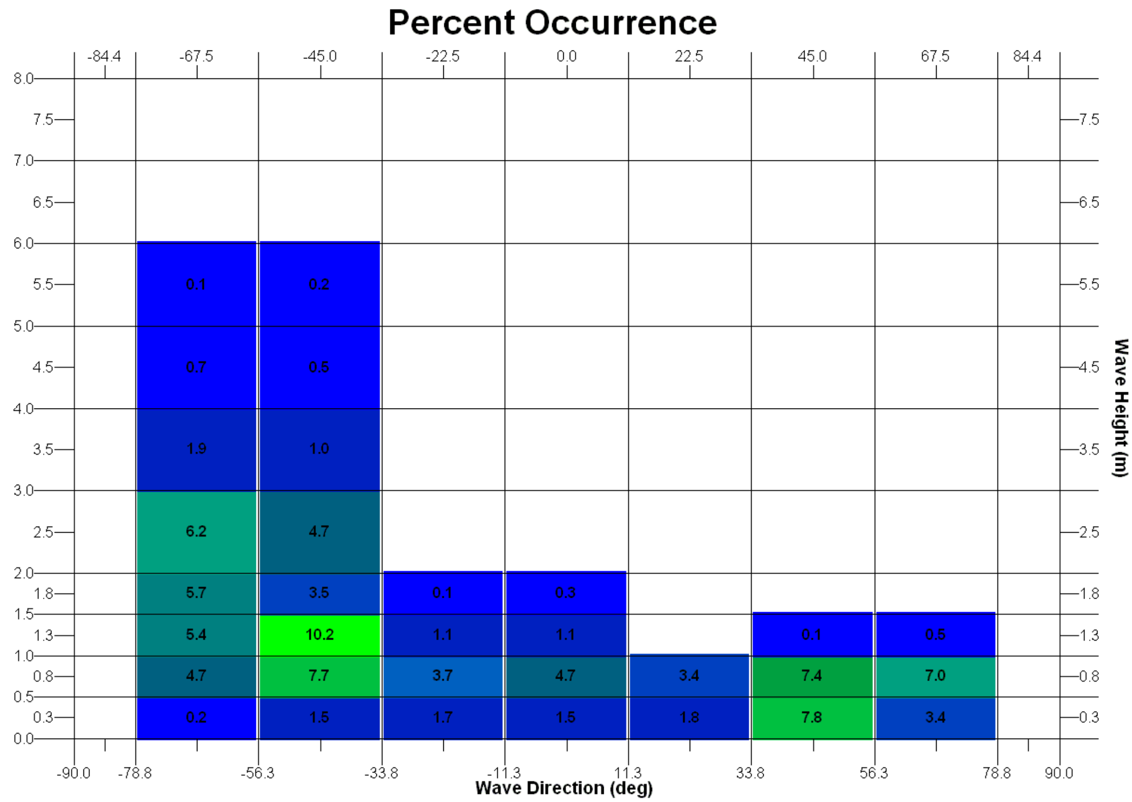


Figure B-20. 1994 percent occurrences for wave height and mean direction for WIS Station 120.

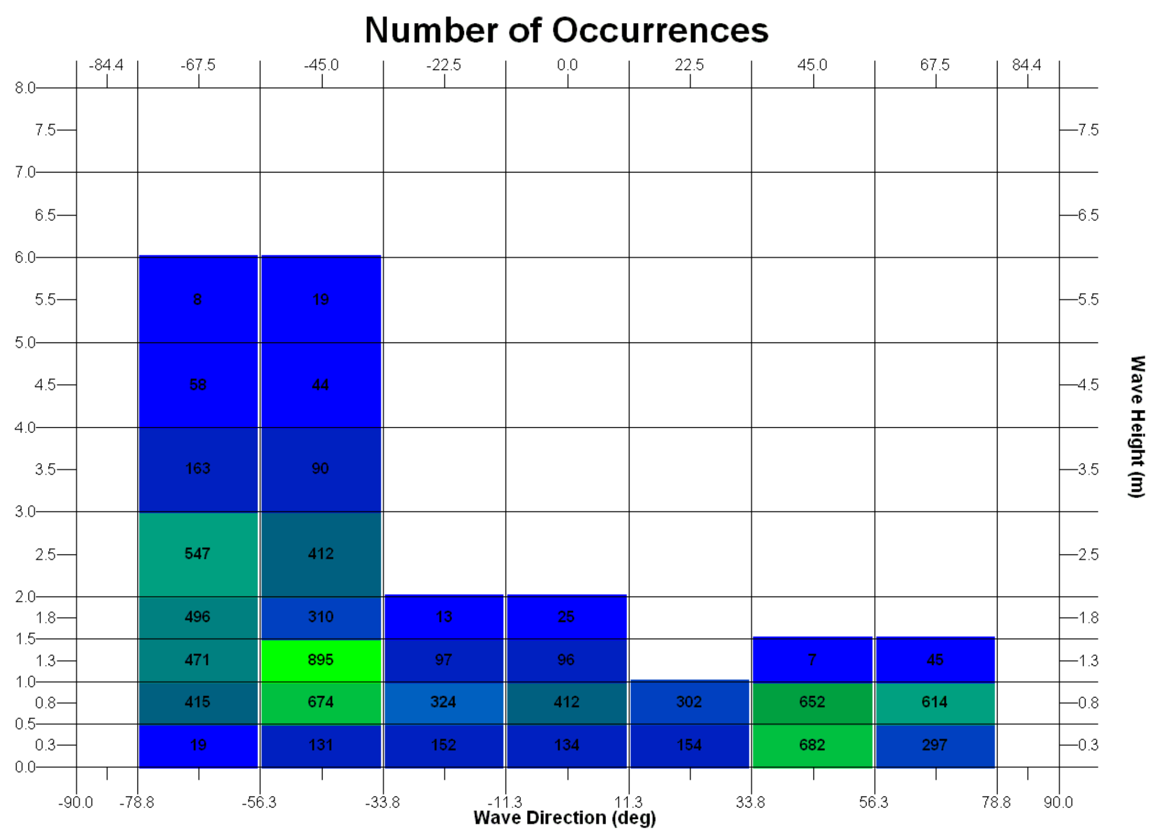


Figure B-21. 1994 number of occurrences for wave height and mean direction for WIS Station 120.

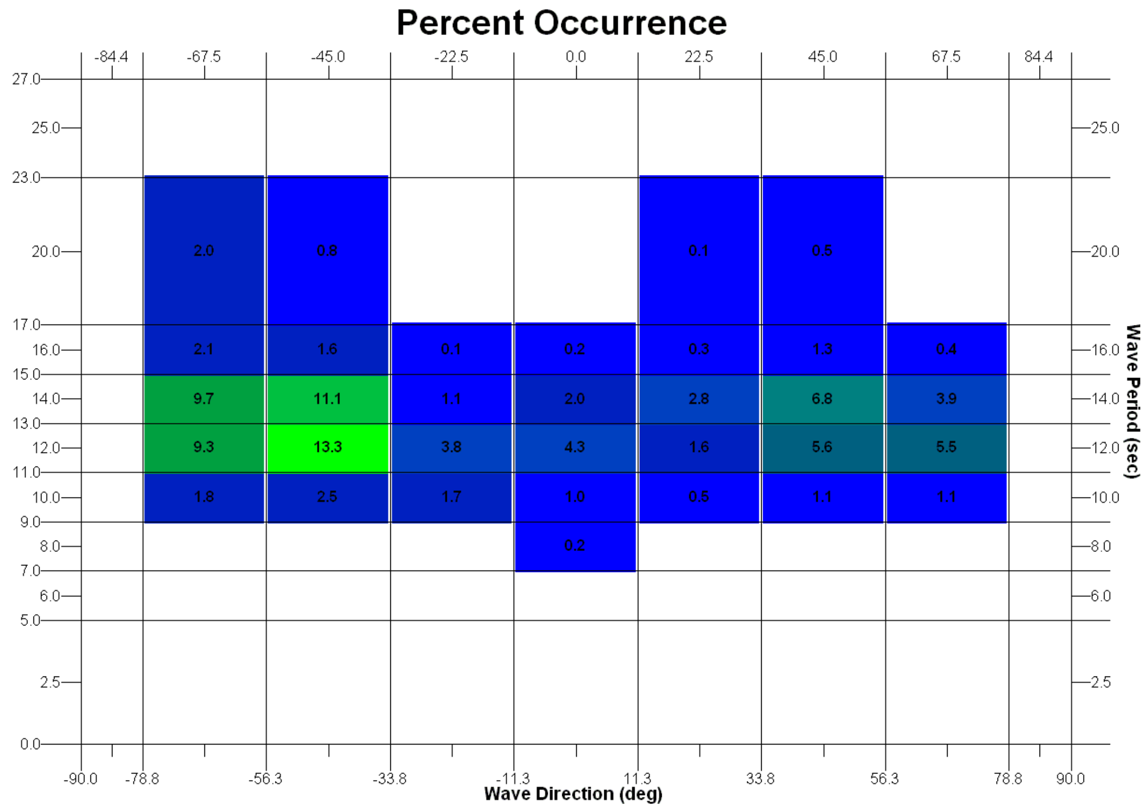


Figure B-22. 1994 percent occurrences for peak period and mean direction for WIS Station 120.

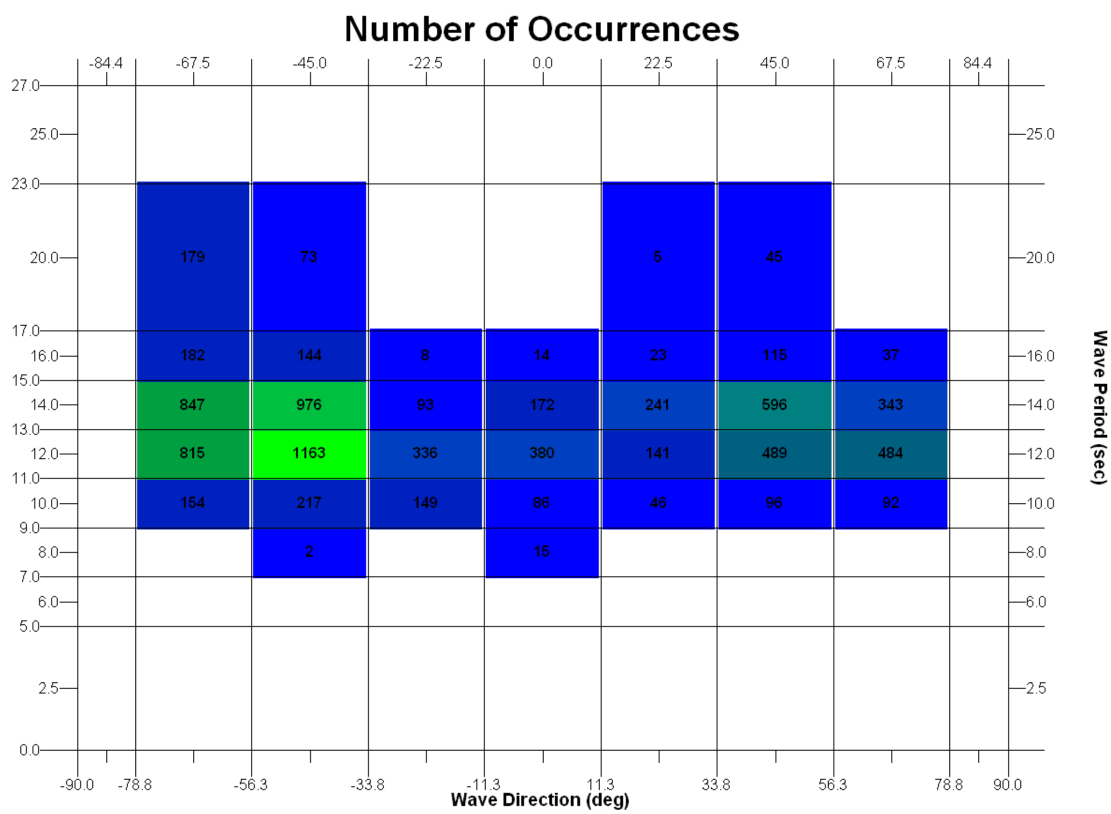


Figure B-23. 1994 number of occurrences for peak period and mean direction for WIS Station 120.

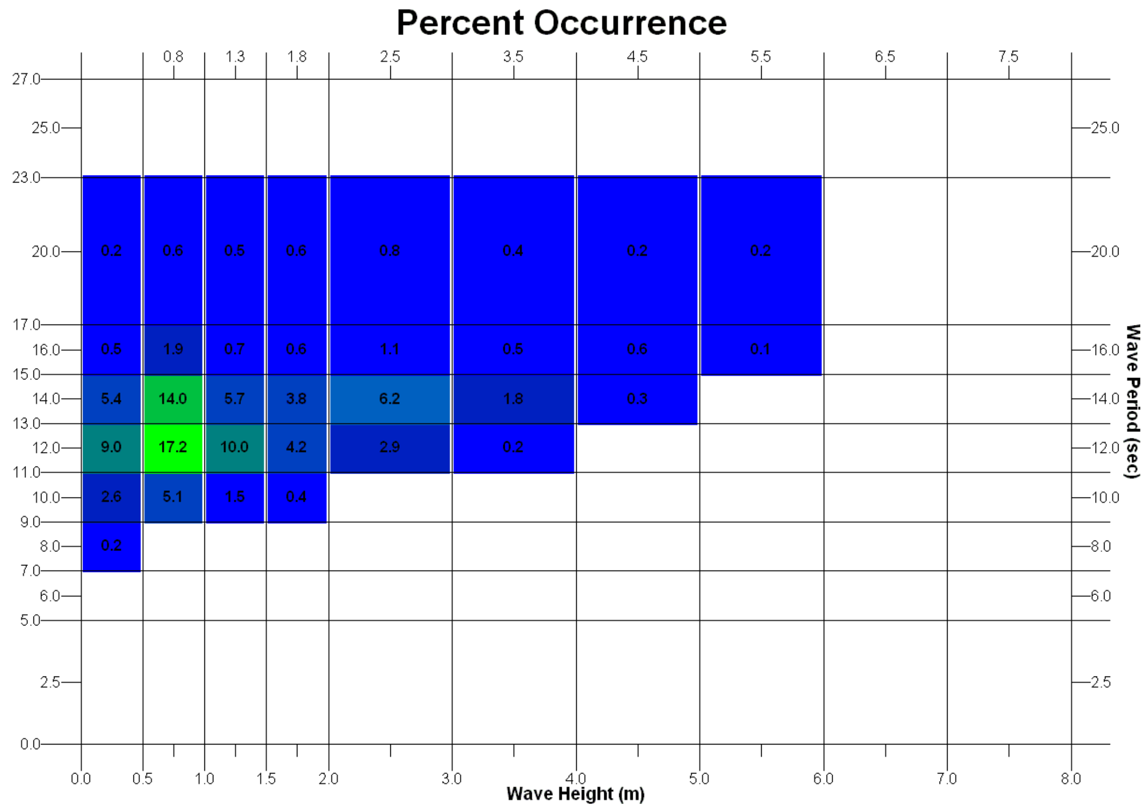


Figure B-24. 1994 percent occurrences for peak period and wave height for WIS Station 120.

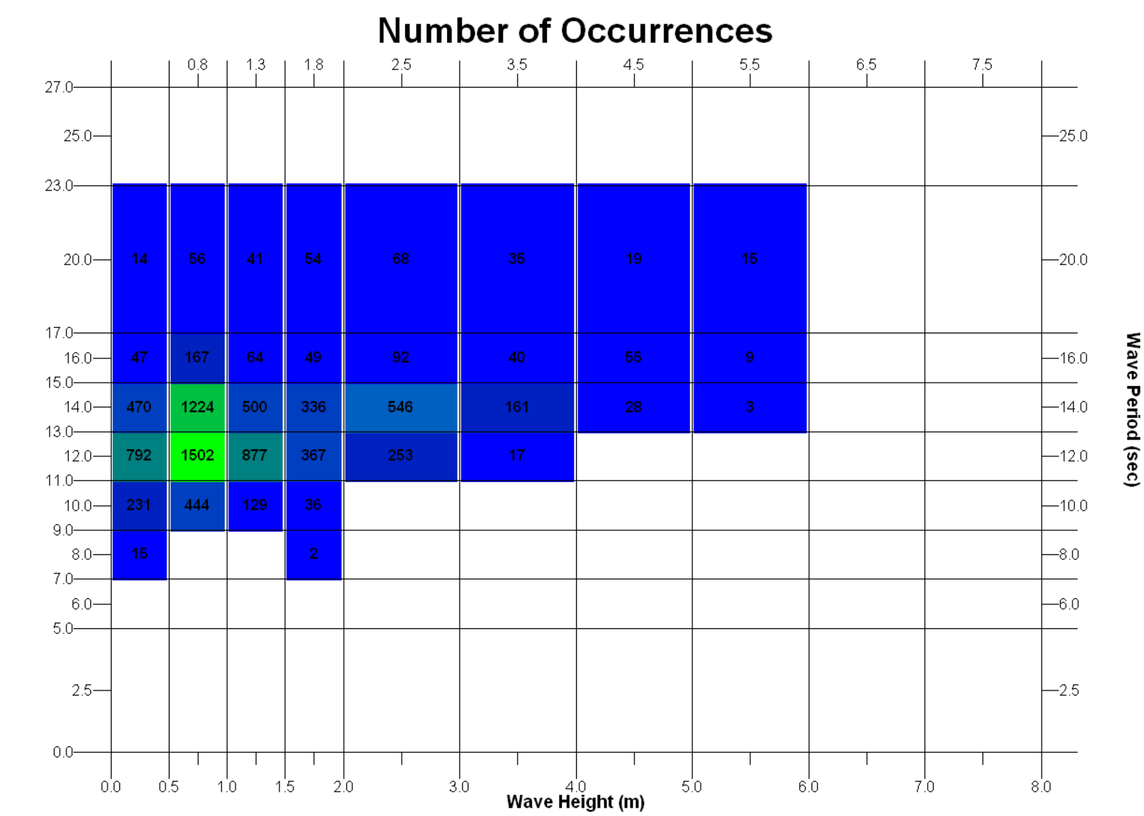


Figure B-25. 1994 number of occurrences for peak period and wave height for WIS Station 120.

Table B-1 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables B-2, B-3, and B-4 provide suggested nearshore wave model runs to build a lookup table to be used in simulating nearshore wave climatology.

Table B-1. Mean and Maximum Statistics

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

Table B-2. Typical Conditions (392 conditions)

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

Table B-3. Extreme Conditions (16 conditions)

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

Table B-4. Long-period Conditions 4 conditions)

Significant Wave height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
1.5 (3)	25 (8)	-45 (2)	from 305 deg
2.0 (4)			
2.5 (5)			
3.0 (6)			

Nearshore STWAVE grids were generated for the Kekaha and Poipu regions using the island-wide bathymetry data developed for the Surge and Wave Island Modeling Studies (SWIMS) being conducted by the US Army Corps of Engineers, the University of Hawaii, and Notre Dame University in combination with high-resolution Light Detection and Ranging (LiDAR) data in the nearshore (from USACE Joint Airborne LiDAR Bathymetry Technical Center of Expertise). The SWIMS dataset incorporates various sources of data and was used for areas of deep water (> 30m), because it has relatively low resolution (~300 meters). The LiDAR data was used to augment shallow, nearshore areas, and has resolution as fine as 1 meter. The STWAVE grid encompasses the entire Kekaha RSM region, as shown in Figure B-26 below, with a grid resolution of 50m.

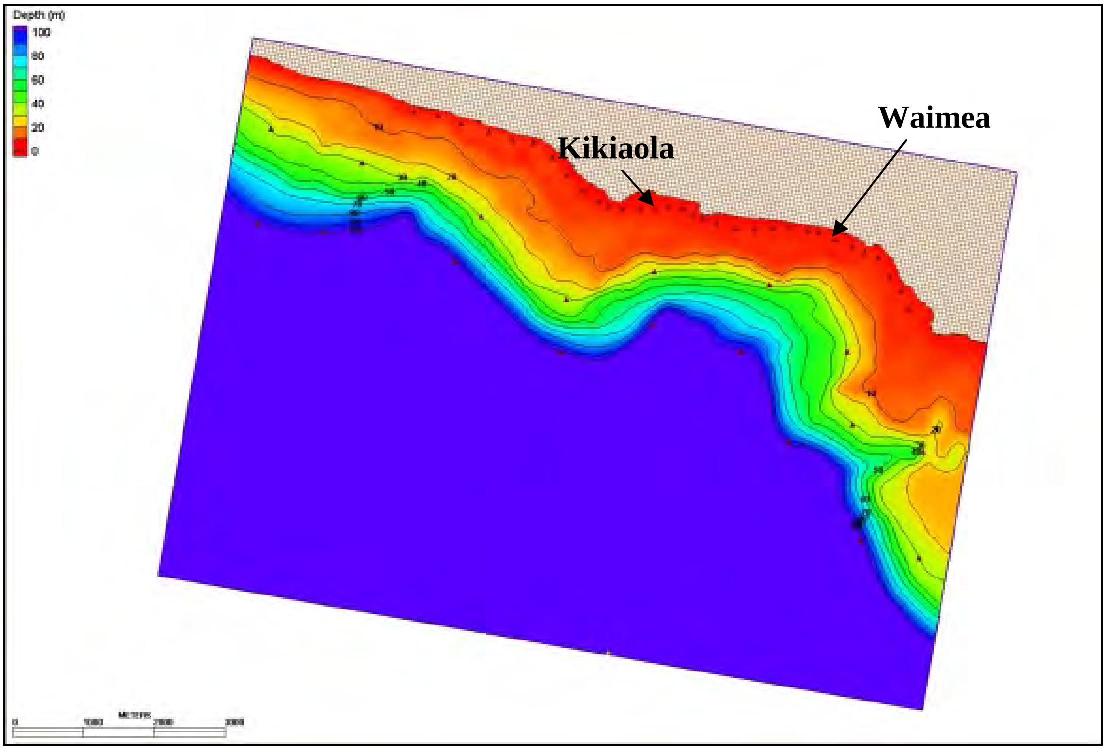


Figure B-26. STWAVE grid extents for Kekaha Region (10 m contours shown)

The Kekaha region grid is oriented such that its offshore boundary (at approximately 500m depth) faces south-southwest at 190 degrees True North (TN). The bathymetry along the nearshore areas includes the well-resolved features of the reef and other features such as channels and headlands. Figure B-26 shows the features along the Kekaha coast including the shallow reef offshore of the harbor. A detailed view of the STWAVE grid in the nearshore areas adjacent to Kikiaola Harbor is shown in Figure B-27.

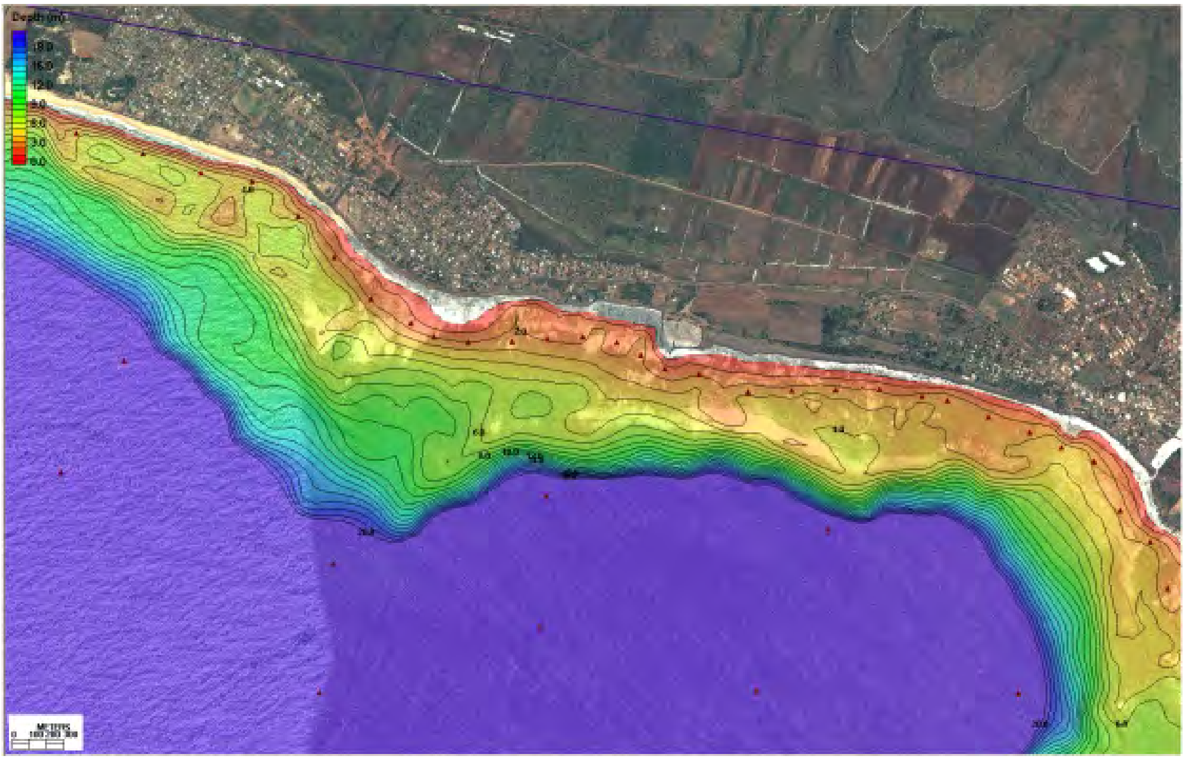


Figure B-27. STWAVE Nearshore Grid Adjacent to Kikiaola Harbor in Kekaha Region (1m contours shown)

Wave parameters from Tables B-3, B-4 and B-5 were used to generate wave input spectra for the Kekaha grid. The parameters were entered into the Surfacewater Modeling System (SMS) and wave spectra files were generated for each case using the TMA (named for TEXEL, MARSEN and ARSLOE storm data sets) shallow water spectra option and the recommended values of n (directional peak spreading factor) and gamma (spectral peak spreading factor). These wave spectra were used to force the offshore boundary of each grid, and the wave transformation was carried out by STWAVE. Wave height (meters), wave period (seconds) and wave direction (degrees) were saved for each wave case at all ocean cells within the grid. An example of the resulting wave height information (in color) and wave direction (arrows) for the Kekaha grid is shown in Figure B-28. In addition, observation points were placed along the nearshore at approximately 1 to 3 meters depth, and along the 30 m and 100 m contours (also visible in Figure B-28 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

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

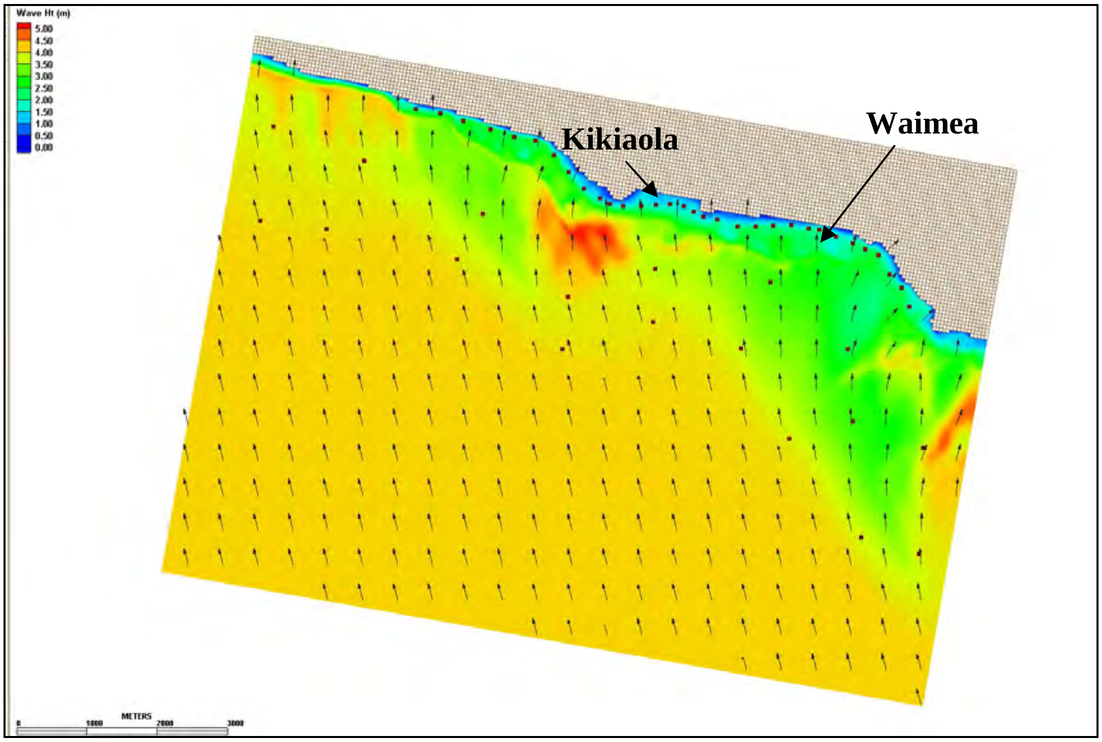
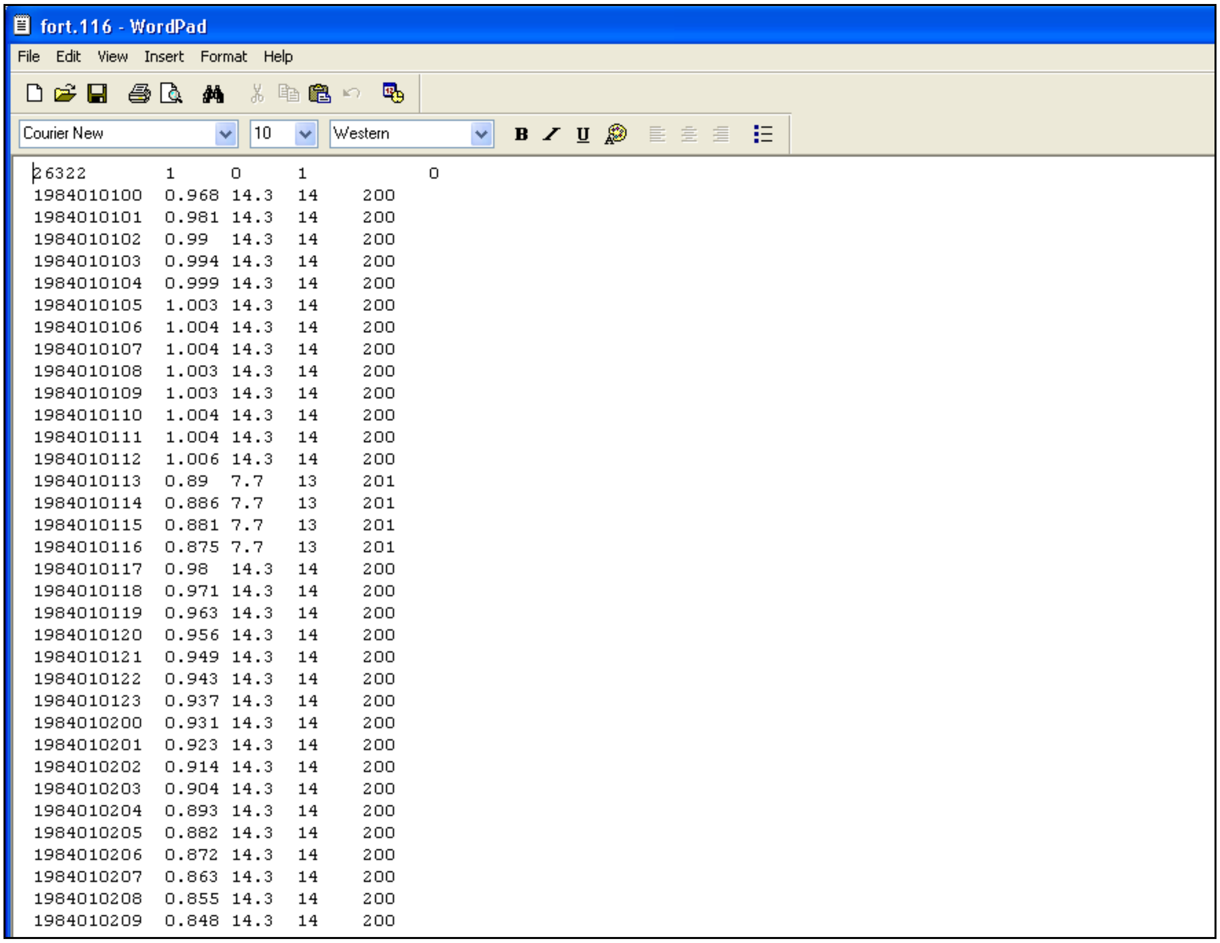


Figure B-28. Resulting Wave Height (color scale) and Wave Direction (arrows) in Kekaha Region for Case 754 (Ho = 4m, T= 14s, Dir=190) and Location of Observation Points (black squares)

The next step carried out was to develop a FORTRAN program to automate the “lookup table” process, so that the hourly time series of wave data from the three representative years (1984, 1992, and 1994) of WIS data could be converted to nearshore wave parameters at each observation point. This program required inputs of the WIS time series data, the output wave parameter file from the STWAVE runs, as well as a file denoting the angle of the “onshore” direction (relative to TN) at each nearshore observation point so that a relative wave angle could be determined. Since it was not possible to model each specific wave case that occurs in the WIS time series, the hourly parameter data was binned to find the closest matching wave case that was defined in the model runs. If no such case existed, the program returned a result of 0.0 and the nearshore wave parameters were not calculated for that time step. Since the most frequent wave occurrences were determined as described previously, it is assumed that this condition does not represent a significant quantity of the WIS time series, and therefore the nearshore wave climate. A cursory examination of output files suggests this condition occurred < 5% of the time. An output nearshore time series including all three years of WIS data was calculated for each nearshore observation point, in both the Kekaha and Poipu grids. A portion of an output file resulting from the application of the FORTRAN program is shown in Figure B-29 for reference. Output parameters are date/ time, wave height, wave period, wave direction (relative to shoreline) and wave direction (relative to TN).



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


Figure B-29. Sample Nearshore Observation Point Time Series Output File from FORTRAN Program (date/time, wave height (m), wave period (s), wave direction (relative degrees), wave direction (relative TN))

Finally, the time series for each observation point was used to develop a histogram for that location indicating the percent occurrence of wave approach direction (separated into 10 degree direction bins) as well as the frequency of significant wave height within each wave bin (separated into 0.5m wave height bins). An example histogram for an observation point near east of Kikiaola Harbor is shown in Figure B-30. This figure shows that 9% of waves during the 3 selected years approached from 160-170 degrees TN, and that the significant wave heights at this location were in the 0.0 to 0.5m range. Similarly, 12% of waves approached from 170– 180 degrees TN, with waves in the 0.0 to 0.5m and 0.5 to 1.0 m ranges, and so on. The column on the far right of the figure shows that 58% of waves approached from 200-210 degrees TN, however the wave heights from this direction range from less than 0.5m up to the 2.0 to 2.5m range. Another histogram of an observation point to the west of Kikiaola Harbor is shown in Figure B-31, and indicates a similar directional spread but slightly less variability in significant wave height. This may be due to differences in the offshore bathymetry at the observation points.

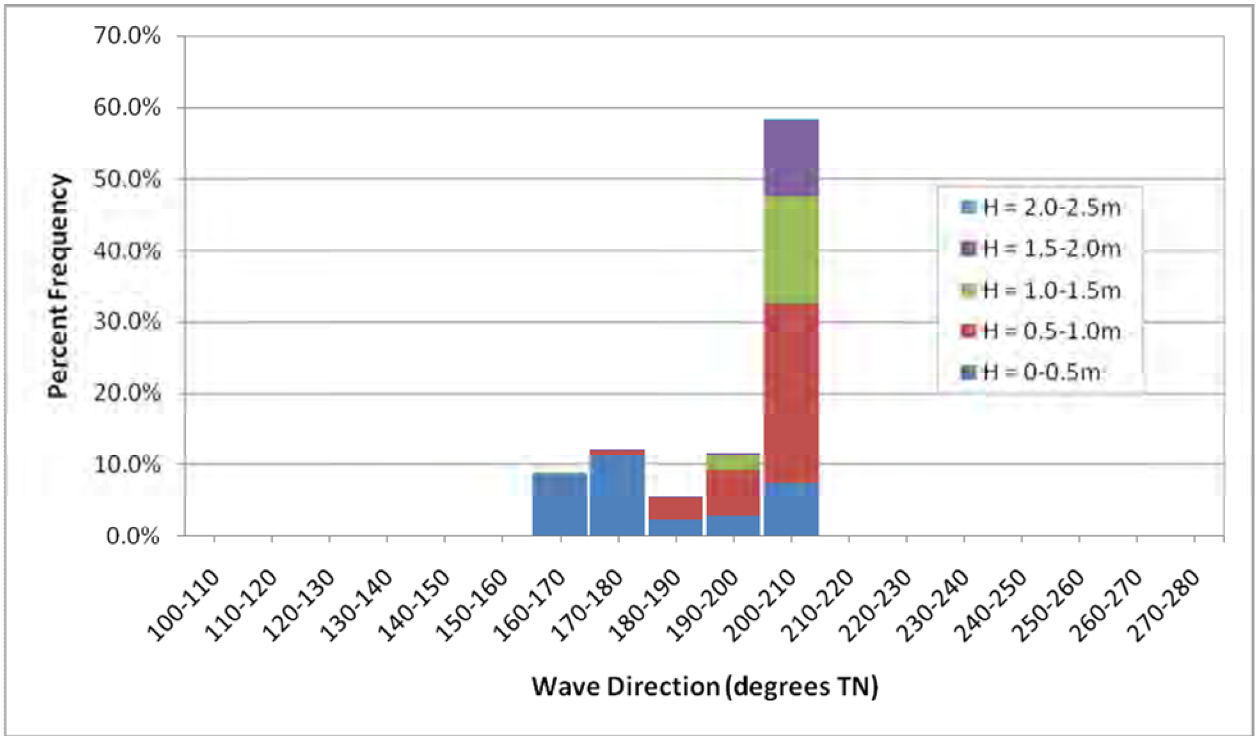


Figure B-30. Histogram of Wave Height and Direction at Nearshore Observation Point East of Kikiaola Harbor (Shore normal = 187 degrees TN)

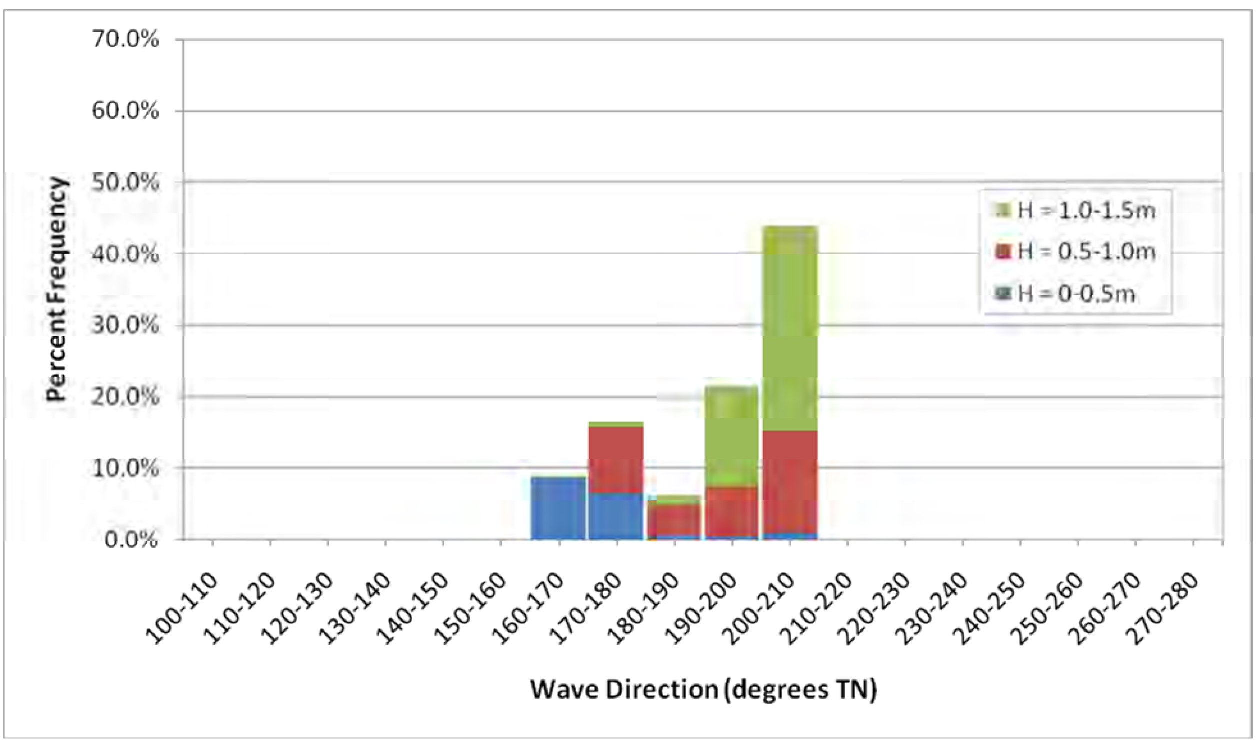


Figure B-31. Histogram of Wave Height and Direction at Nearshore Observation Point West of Kikiaola Harbor (Shore normal = 184 degrees TN)

APPENDIX C

WAVE TRANSFORMATION MODELING – POIPU REGION
(USACE 2011)

Poipu is on the south shore of the Kauai with exposure to waves arriving from approximately 90 to 270 deg. The Wave Information Studies (WIS) save point directly south of Poipu is Station 119 located at 23 deg North and 159.5 deg West in a depth of 4530 m. Station 119 is shown in Figure C-1 with a yellow circle. A wave rose for Station 119 for 1981-2004 is given in Figure C-2. The wave rose shows distribution of wave height with wave direction. The largest wave heights come from storms out of the northwest.

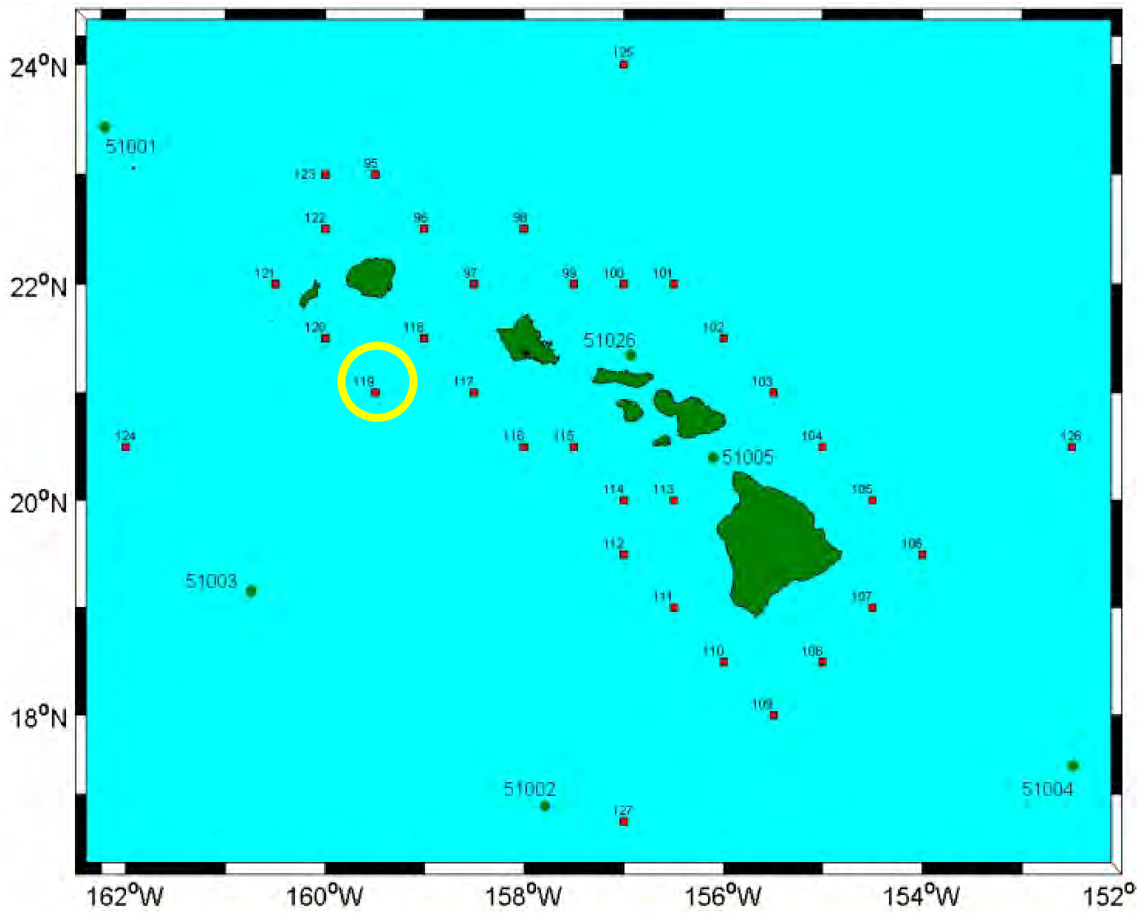


Figure C-1. WIS Station map.

Three representative years were chosen for further study and nearshore wave transformation. The three years include a low wave condition year (1984), a medium wave condition year (1992) and a high wave condition year (1994). Figures C-3 and C-4 show compressed time series of the years 1984 and 1994 at Station 119 (the 1992 is not available on the WIS website).

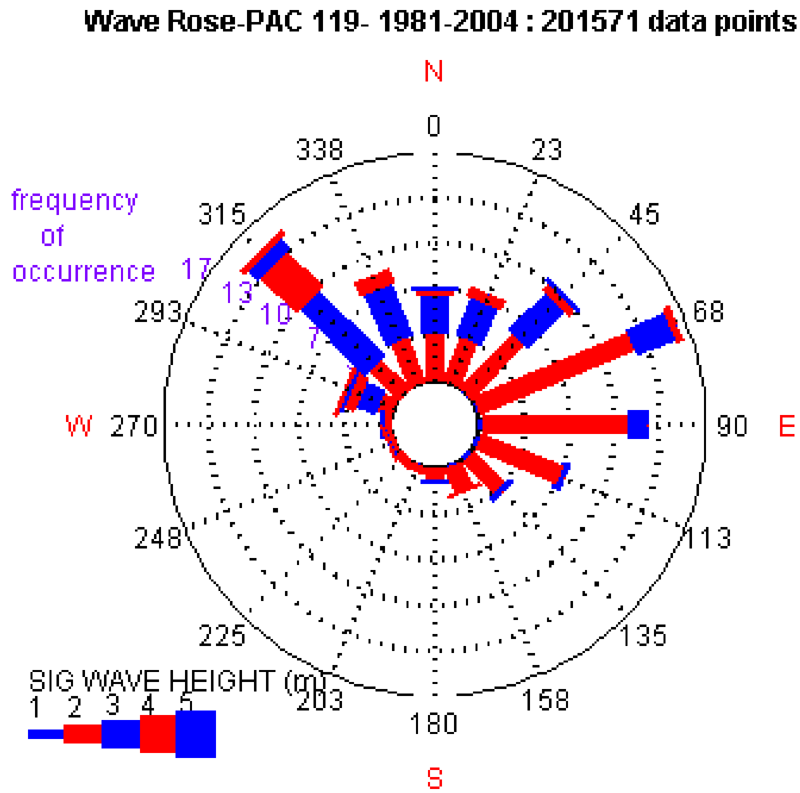


Figure C-2. Wave Rose for 1981-2004 for WIS Station 119.

Since the WIS save points are in deep water and away from Kauai, the wave heights include energy from both waves moving toward and away from the island. To eliminate energy moving away from Poipu, the WIS spectra for these three years were truncated to include only energy from 92.5 to 267.5 deg (180 deg +/-87.5 deg). Then, the truncated spectra were used to recalculate wave height, peak wave period, and mean wave direction. These wave parameters from the truncated spectra were then analyzed using the Coastal Engineering Design and Analysis System (CDAS) to quantify the distributions of wave height period and direction. ASCII files with the hourly date, wave height, peak wave period, and mean wave direction were imported to CDAS Beach model under STWAVE using the WWWL Data utility. The units of meters were set under the "waves" tab and the time history was saved in a NetCDF format. Then this file was opened using the WSAV utility under STWAVE. The data were then binned and plotted.

Percent occurrence and number of occurrence plots are shown in Figures C-5 through C-11 for 1984, in Figures C-12 through C-18 for 1992, and Figures C-19 through C-25 for 1994. The directions on these plots are relative to the normal of the local wave grid (0 deg in the relative system is a wave from 180 deg clockwise from north, +45 deg is 135 deg, and -45 deg is 225 deg). The plots are useful is assessing wave height, period, and direction combinations to be run for the nearshore wave transformation analysis.

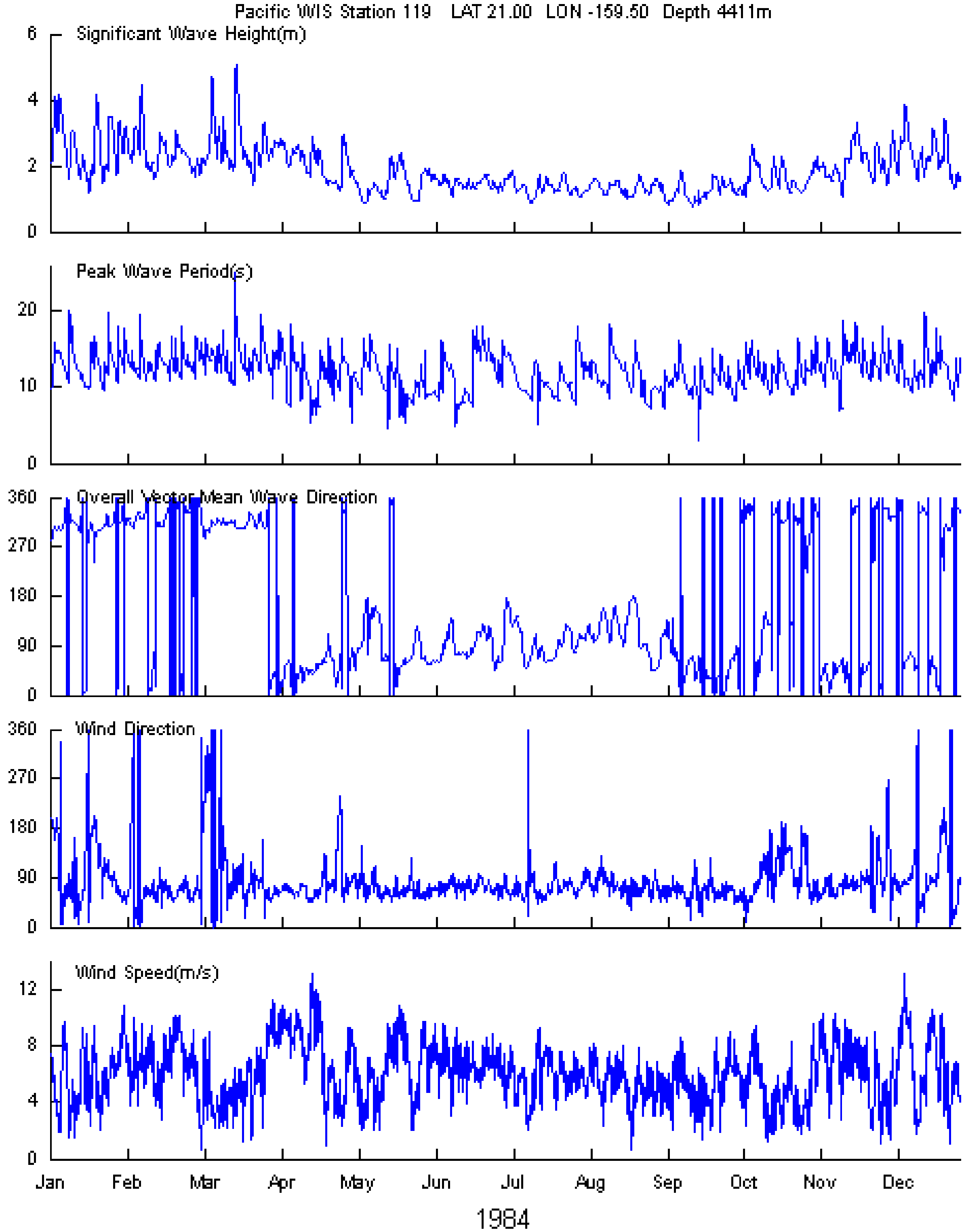


Figure C-3. 1984 wave and wind time histories for WIS Station 119.

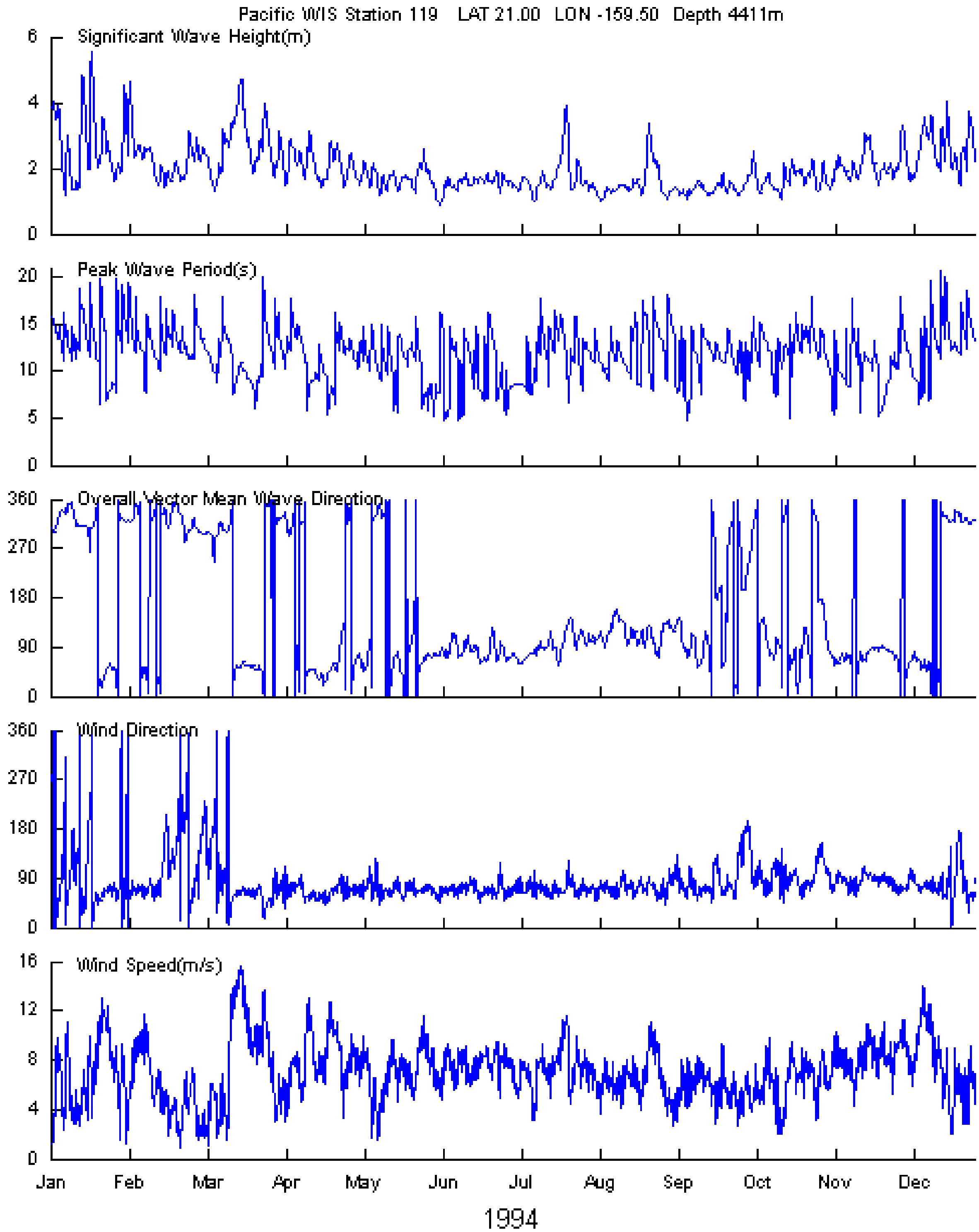


Figure C-4. 1994 wave and wind time histories for WIS Station 119.

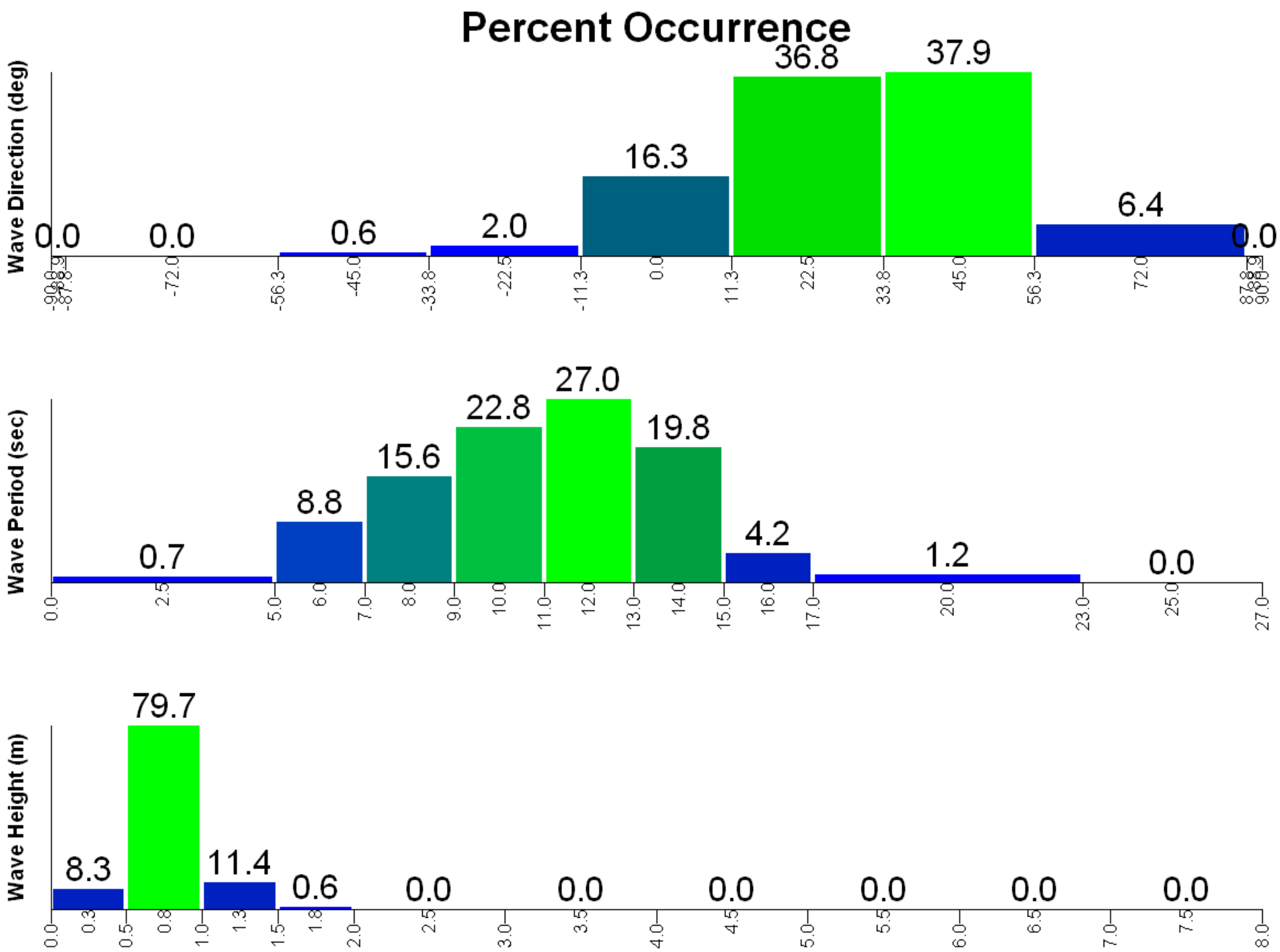


Figure C-5. 1984 percent occurrences for wave height, peak period, and mean direction for WIS Station 119.

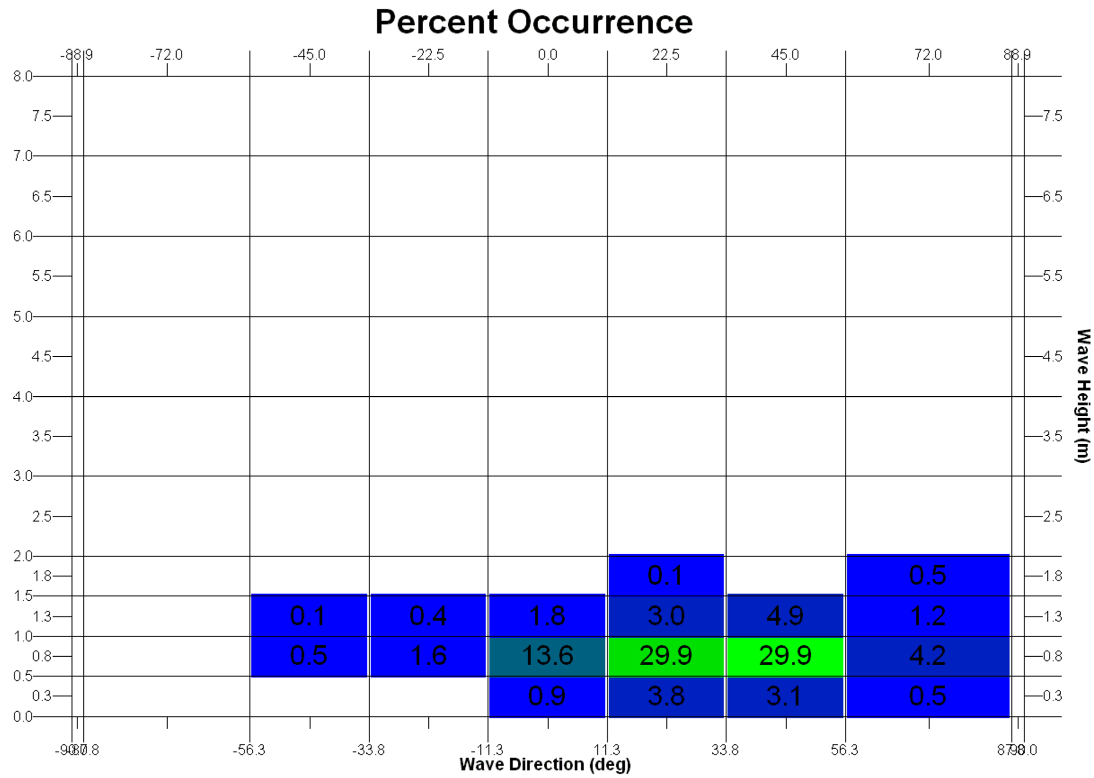


Figure C-6. 1984 percent occurrences for wave height and mean direction for WIS Station 119.

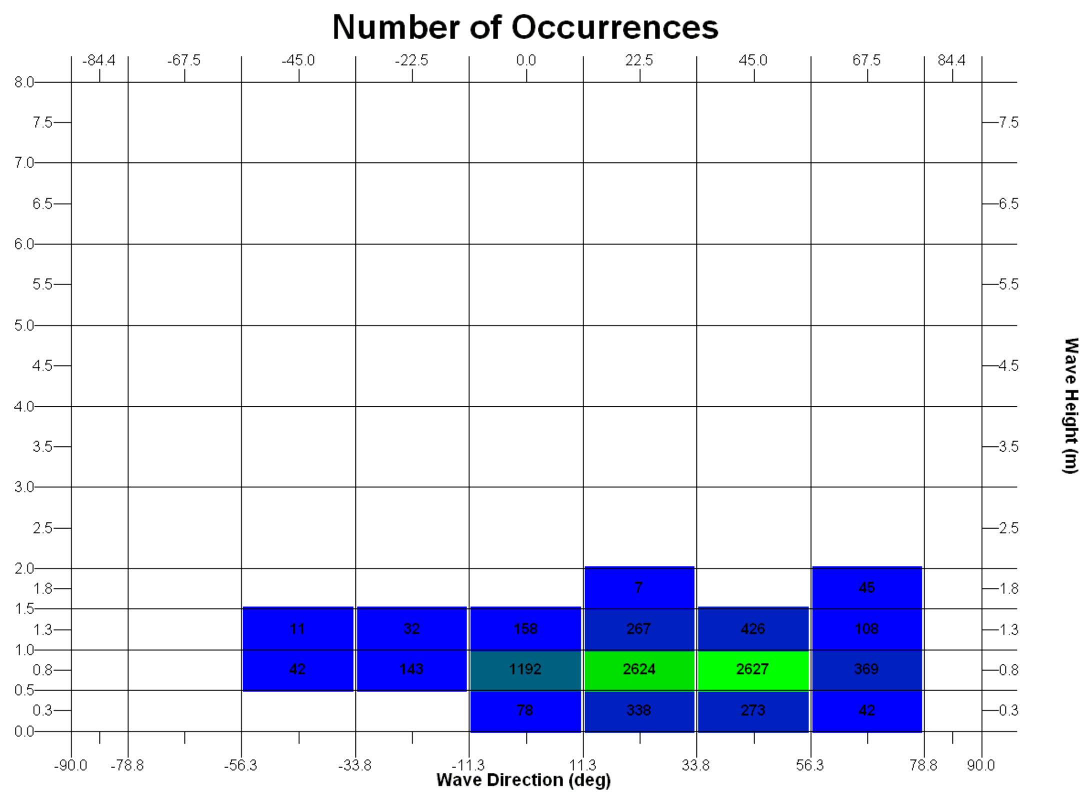


Figure C-7. 1984 number of occurrences for wave height and mean direction for WIS Station 119

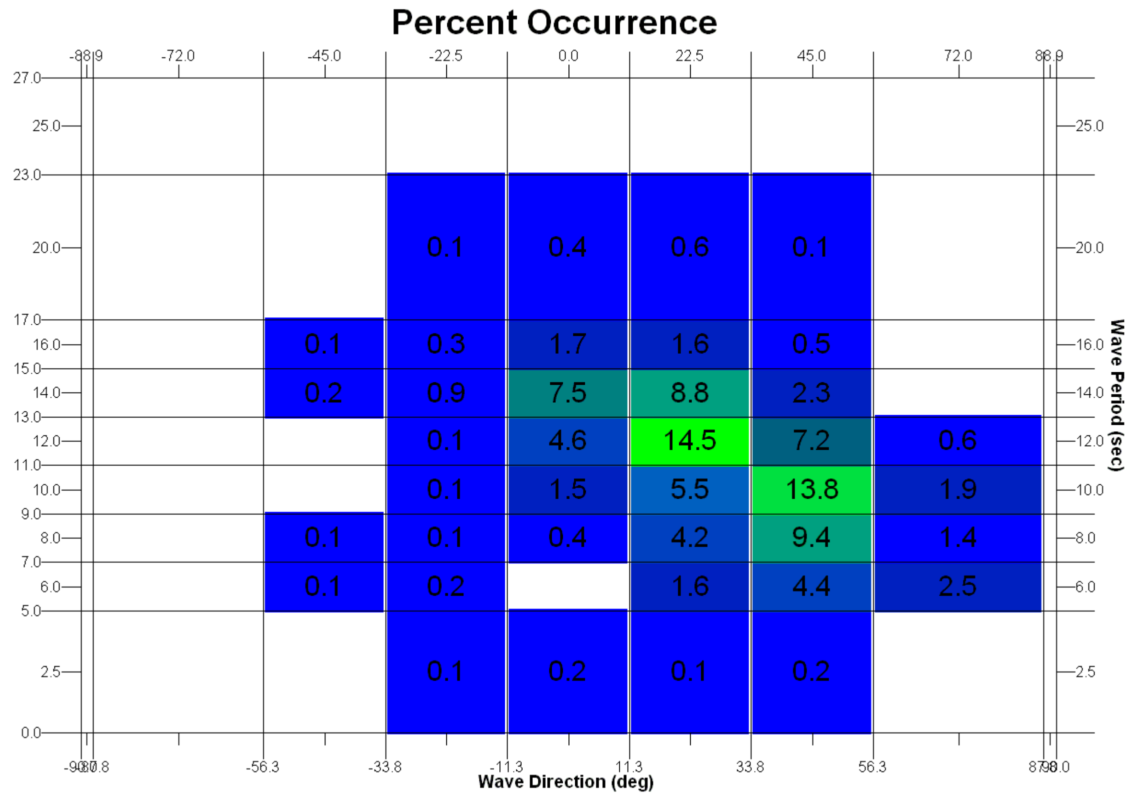


Figure C-8. 1984 percent occurrences for peak period and mean direction for WIS Station 119

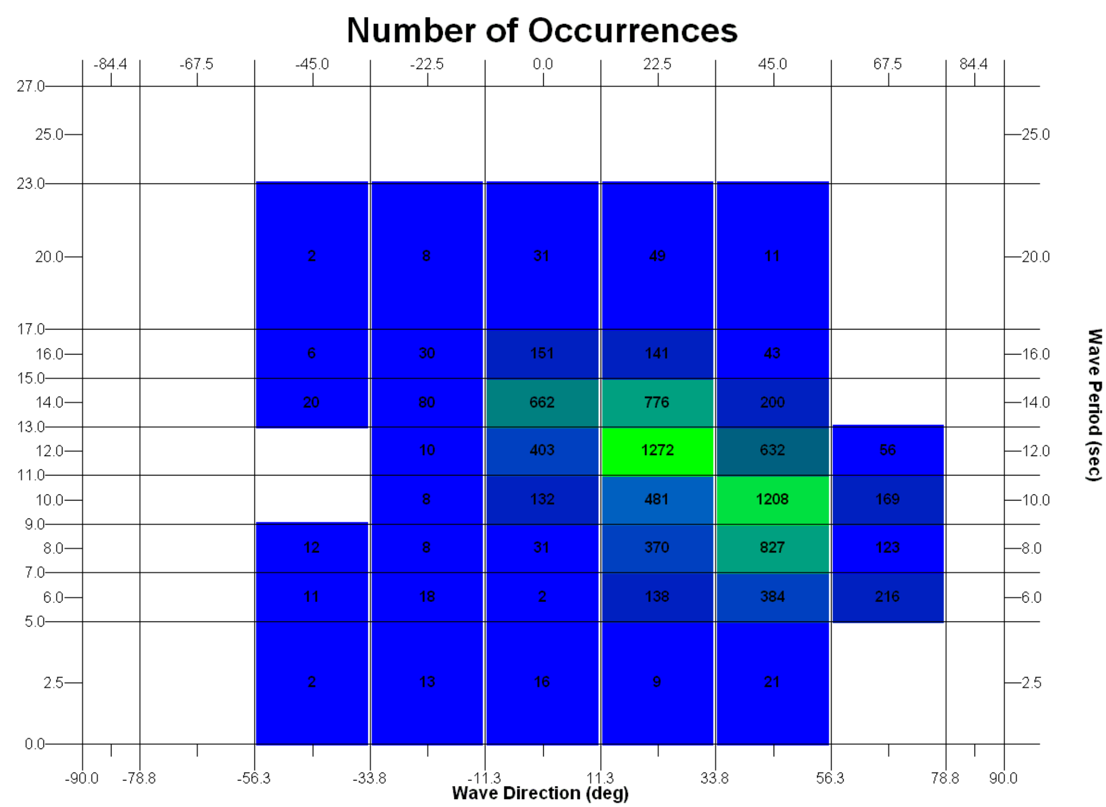


Figure C-9. 1984 number of occurrences for peak period and mean direction for WIS Station 119

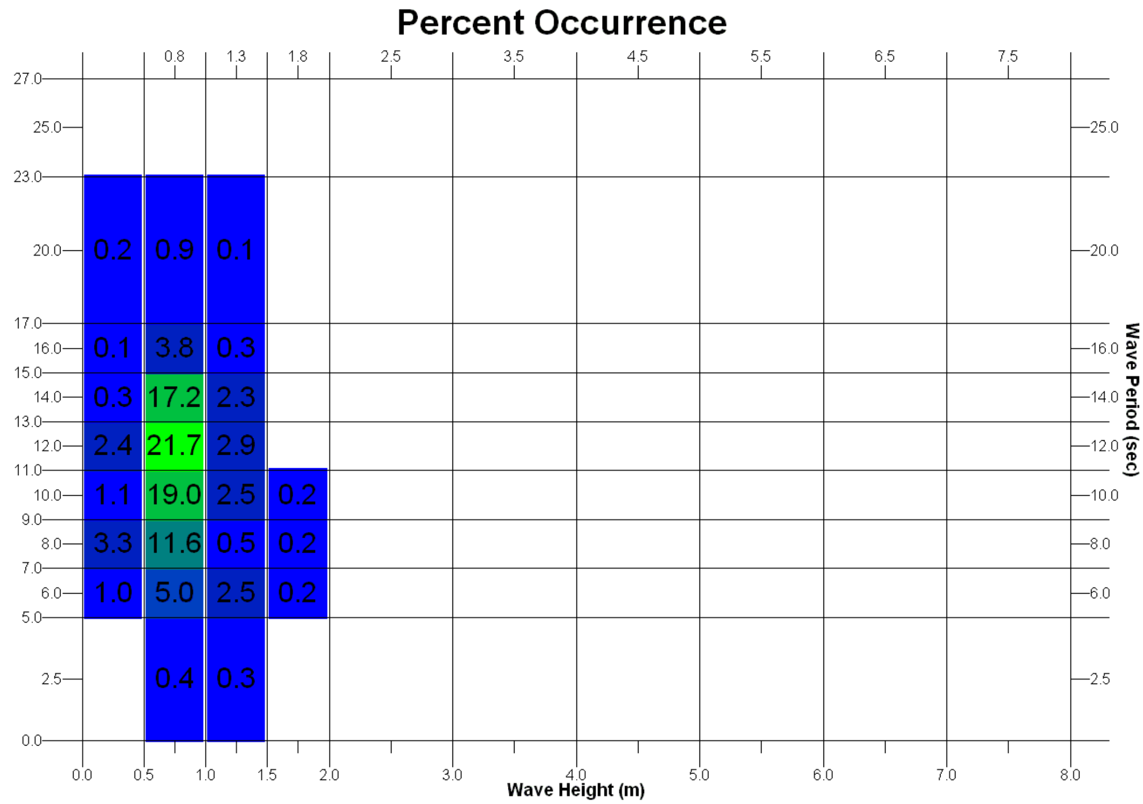


Figure C-10. 1984 percent occurrences for peak period and wave height for WIS Station 119.

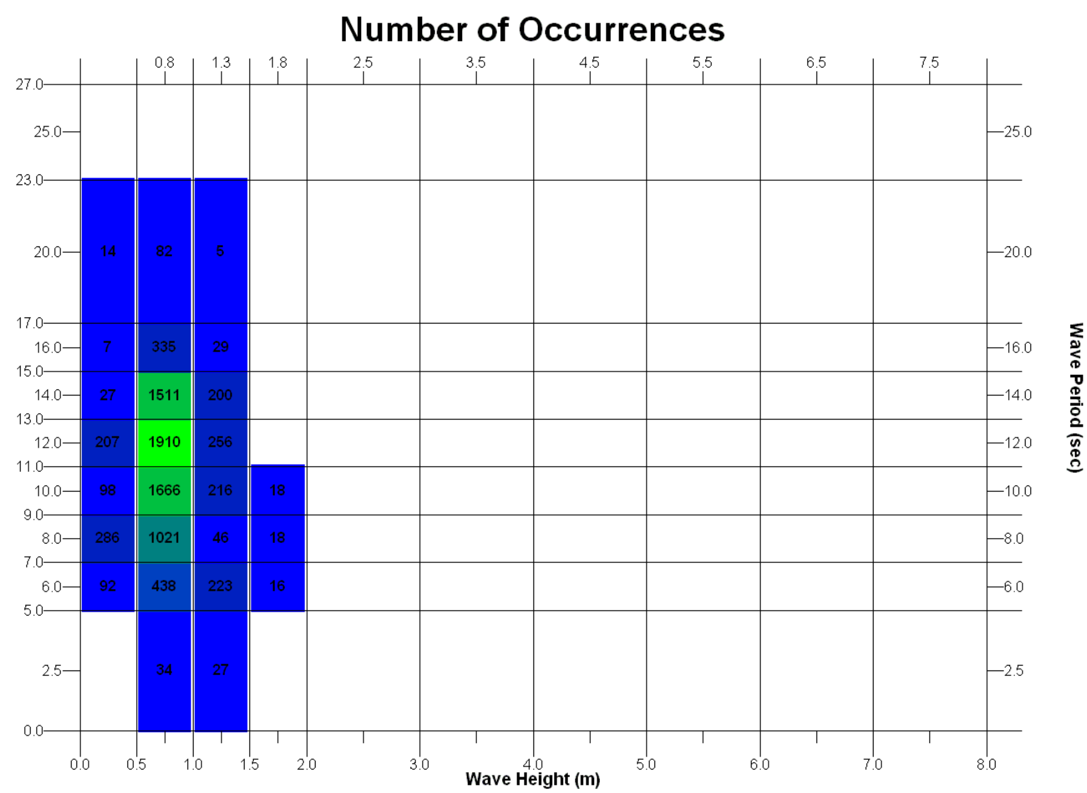


Figure C-11. 1984 number of occurrences for peak period and wave height for WIS Station 119

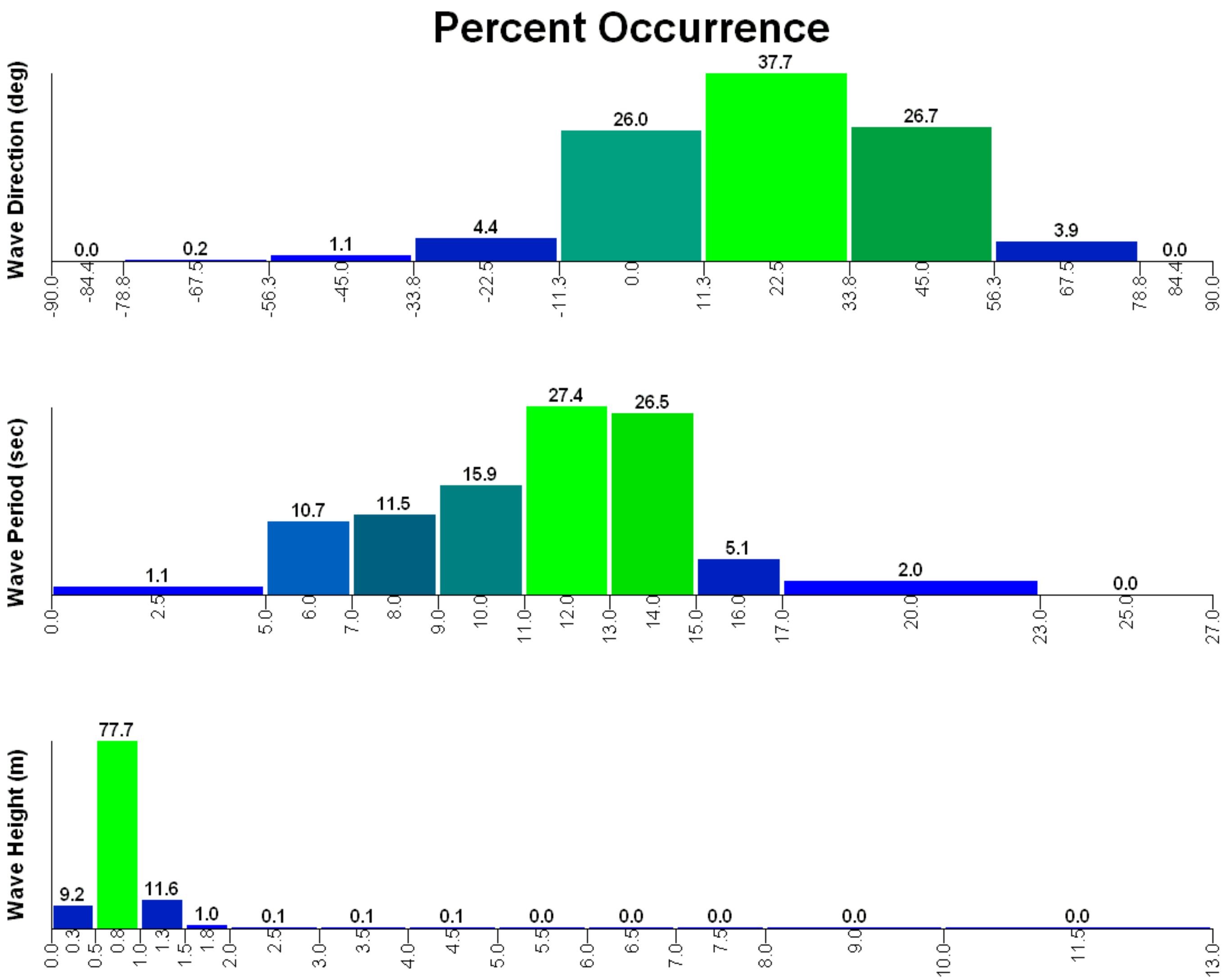


Figure C-12. 1992 percent occurrences for wave height, peak period, and mean direction for WIS Station 119.

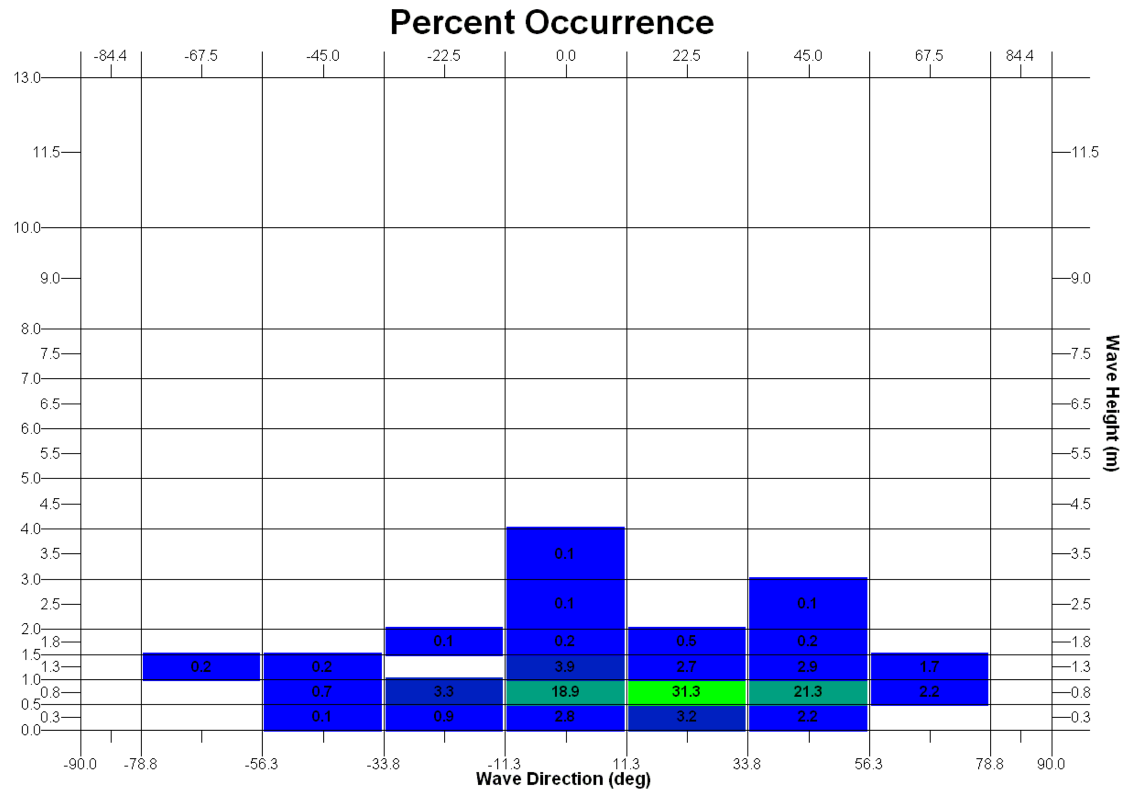


Figure C-13. 1992 percent occurrences for wave height and mean direction for WIS Station 119.

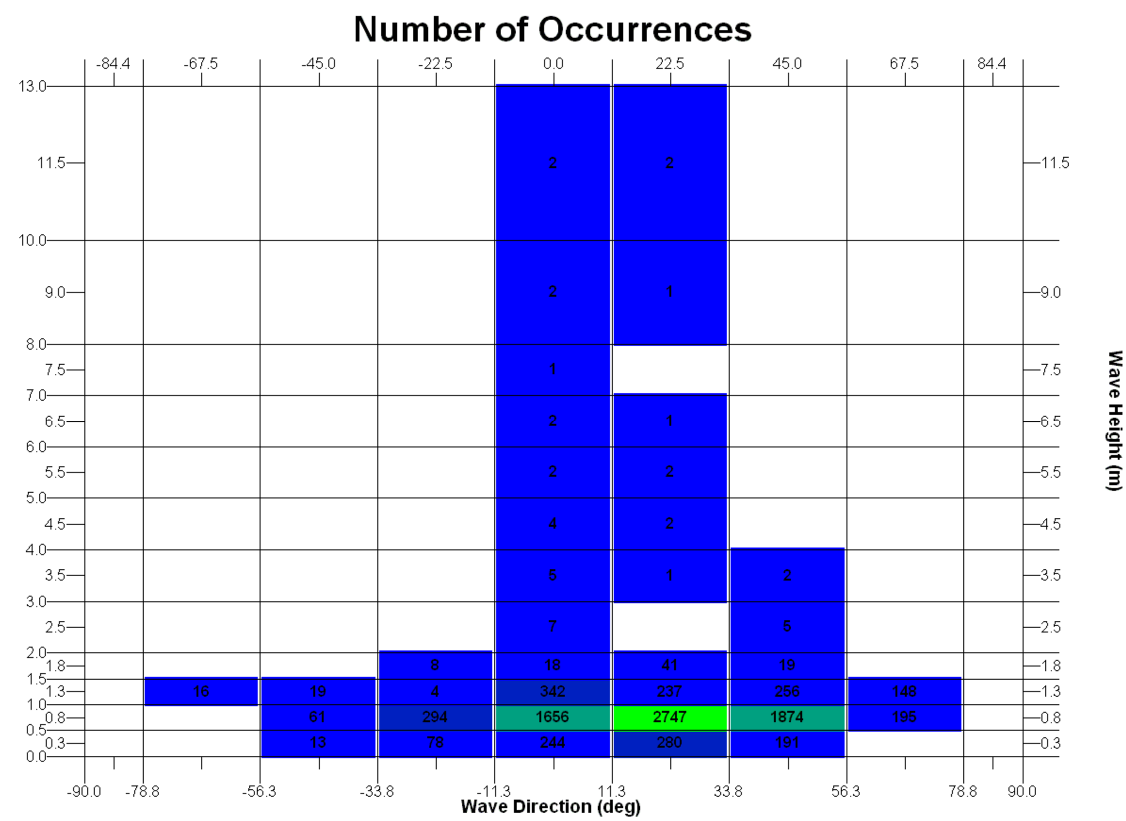


Figure C-14. 1992 number of occurrences for wave height and mean direction for WIS Station 119

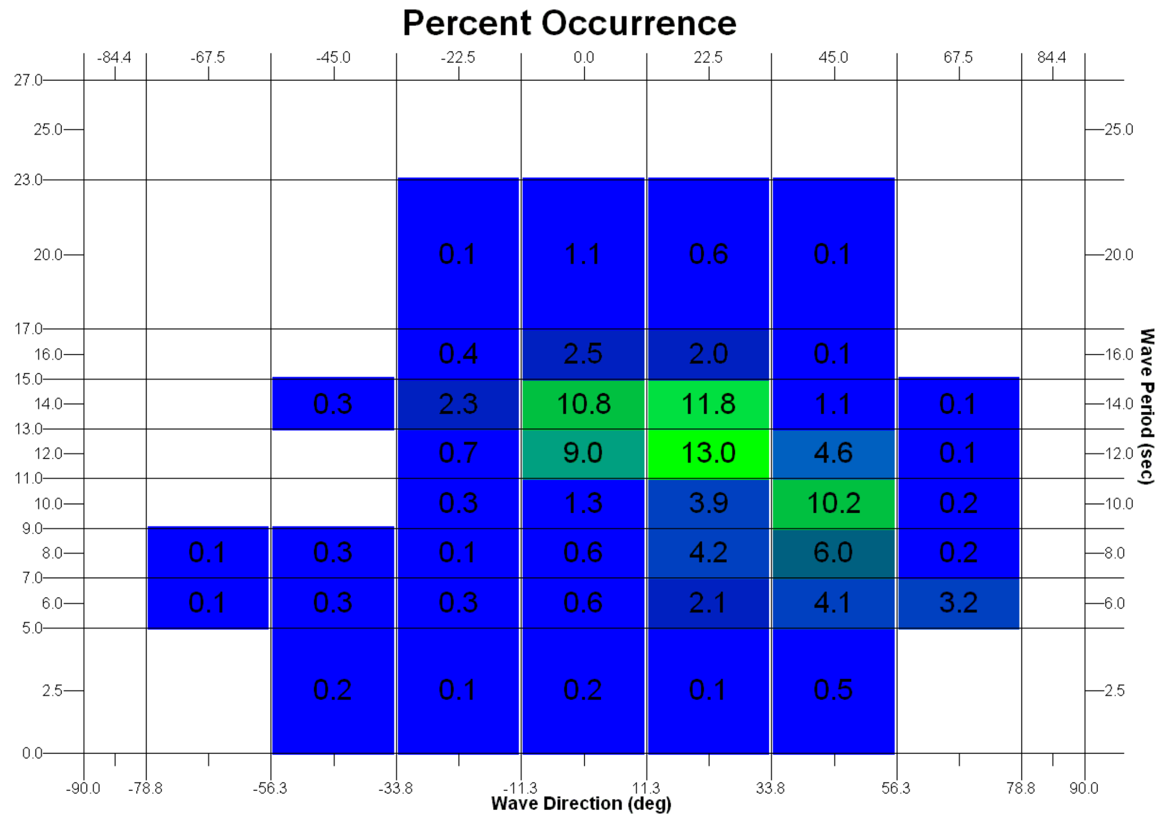


Figure C-15. 1992 percent occurrences for peak period and mean direction for WIS Station 119.

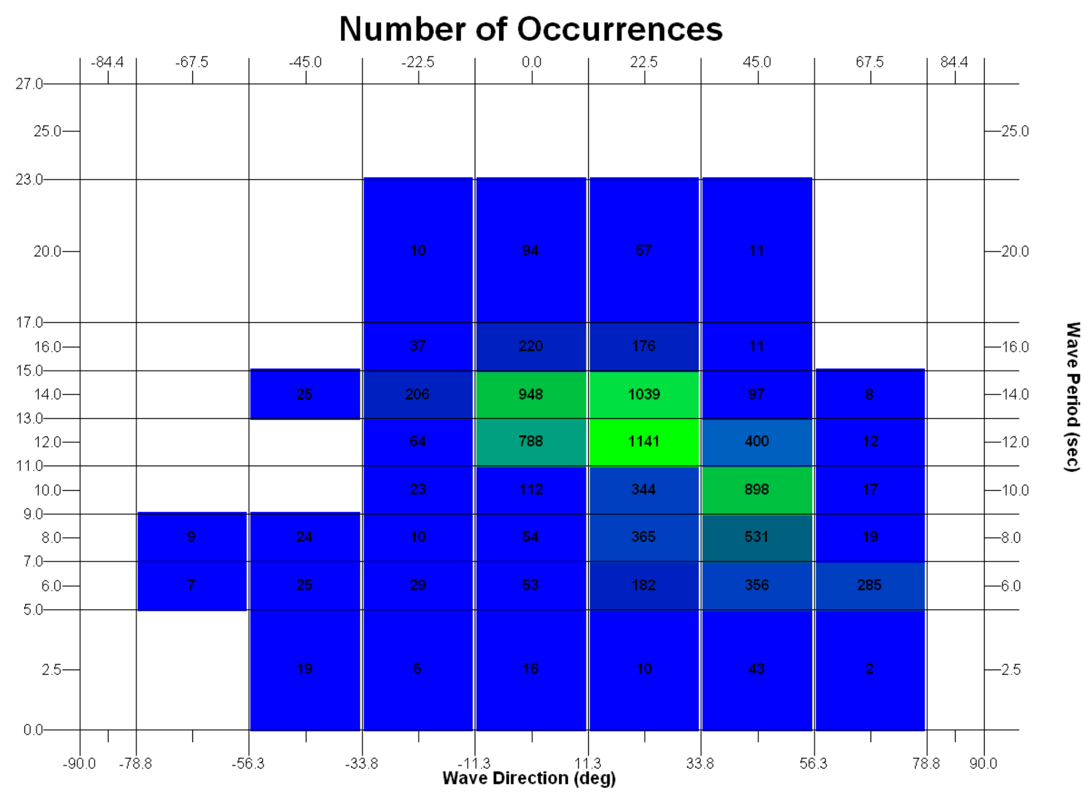


Figure C-16. 1992 number of occurrences for peak period and mean direction for WIS Station 119

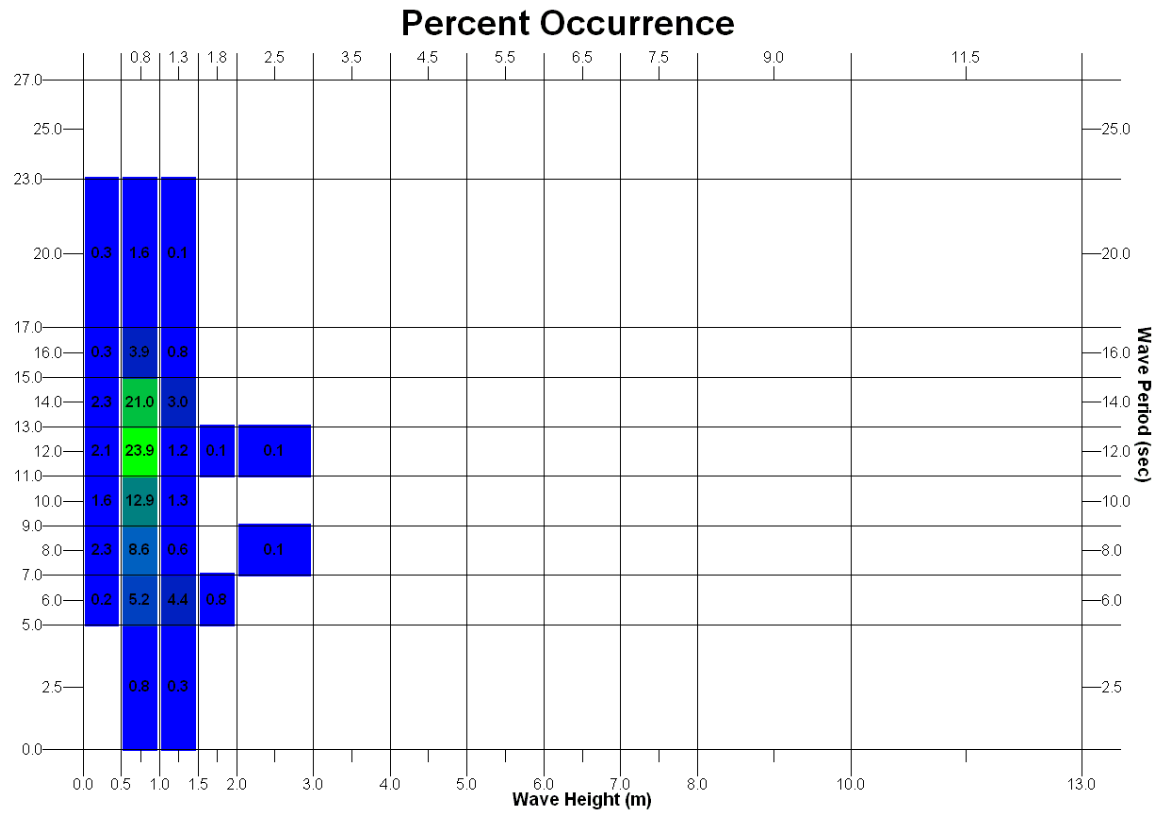


Figure C-17. 1992 percent occurrences for peak period and wave height for WIS Station 119.

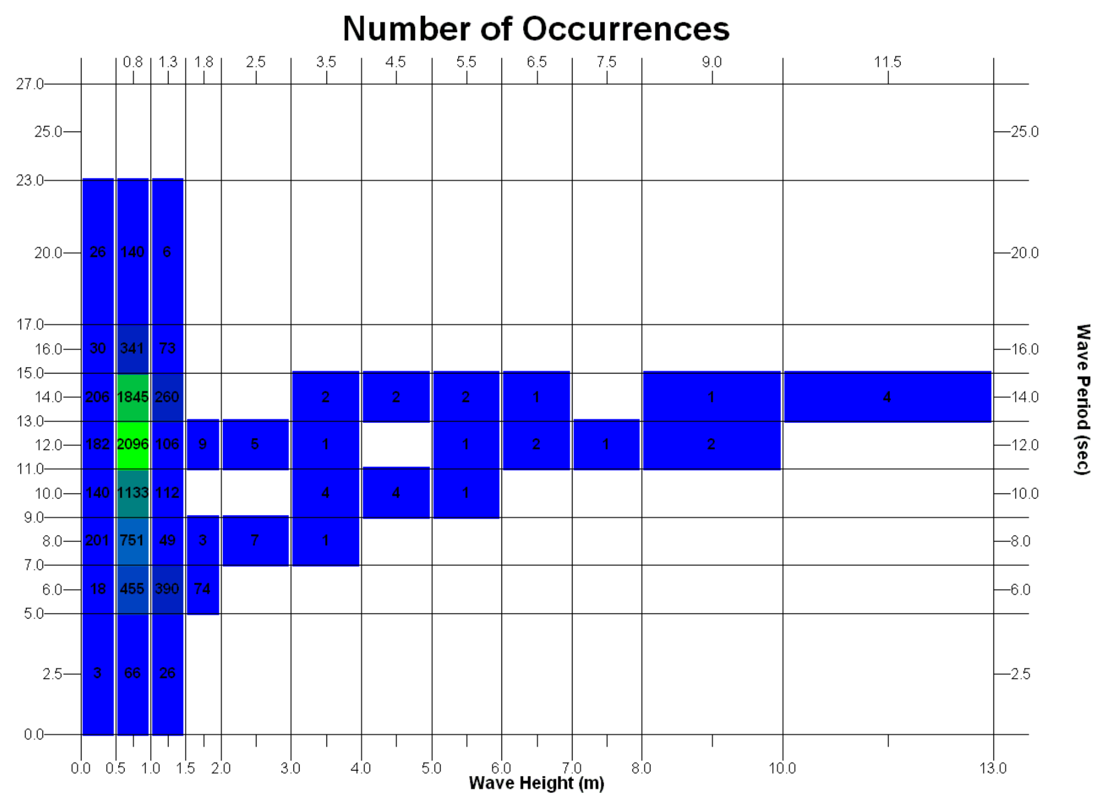


Figure C-18. 1992 number of occurrences for peak period and wave height for WIS Station 119.

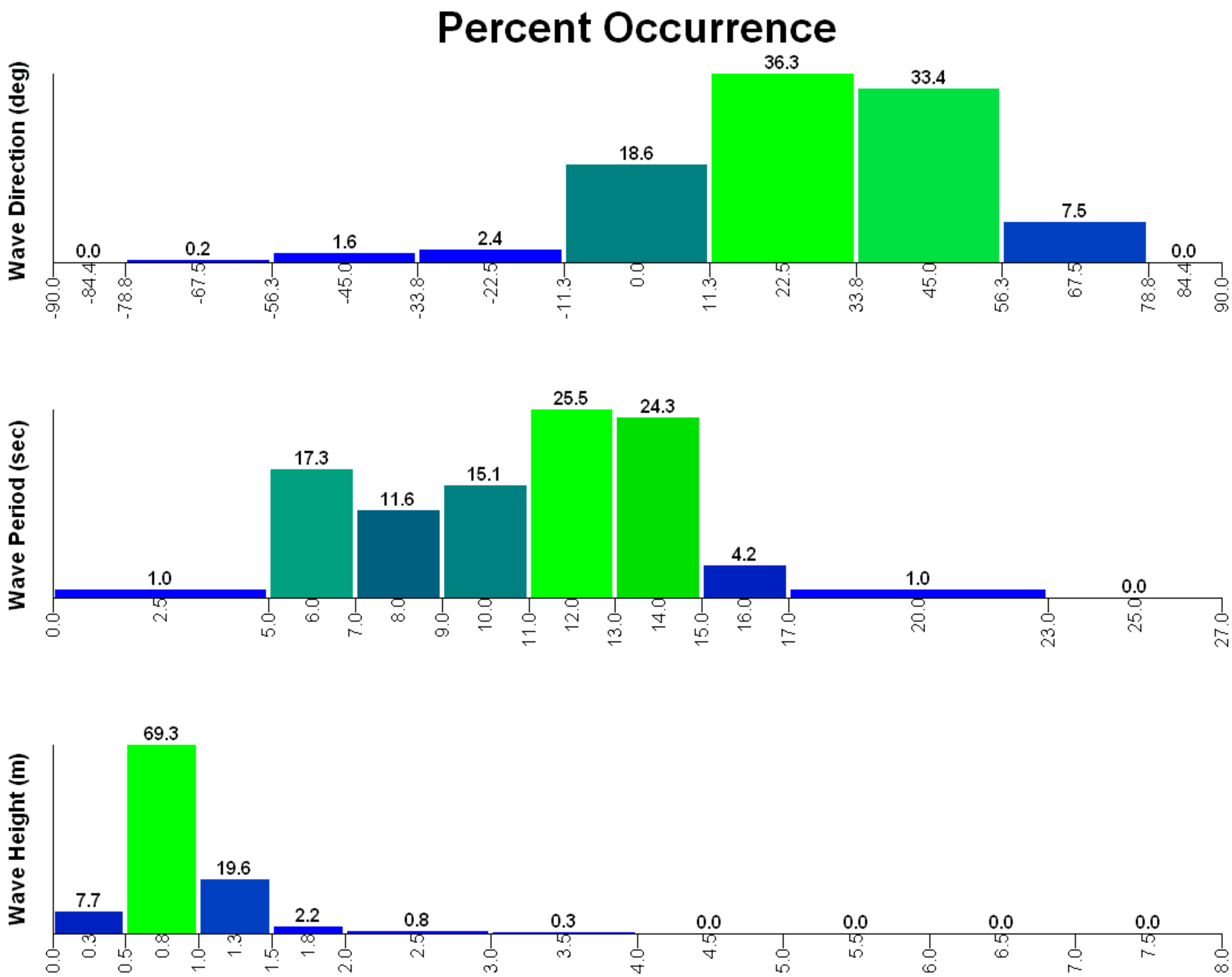


Figure C-19. 1994 percent occurrences for wave height, peak period, and mean direction for WIS Station 119.

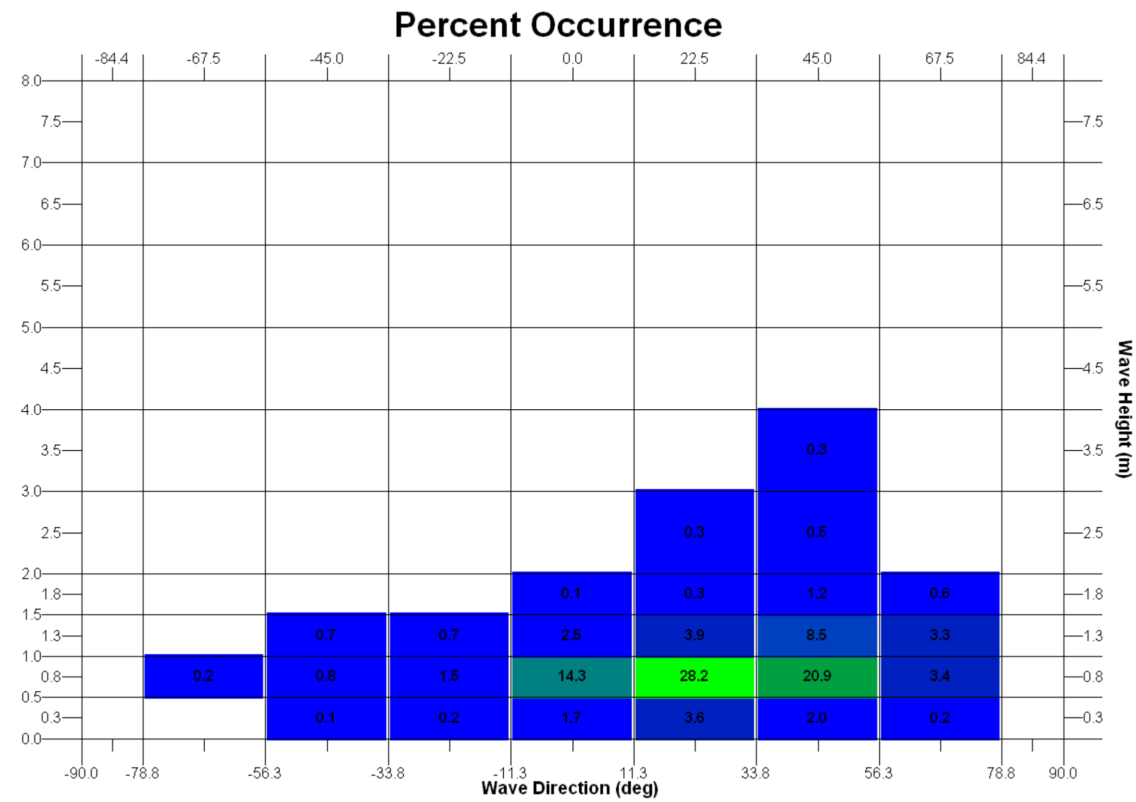


Figure C-20. 1994 percent occurrences for wave height and mean direction for WIS Station 119.

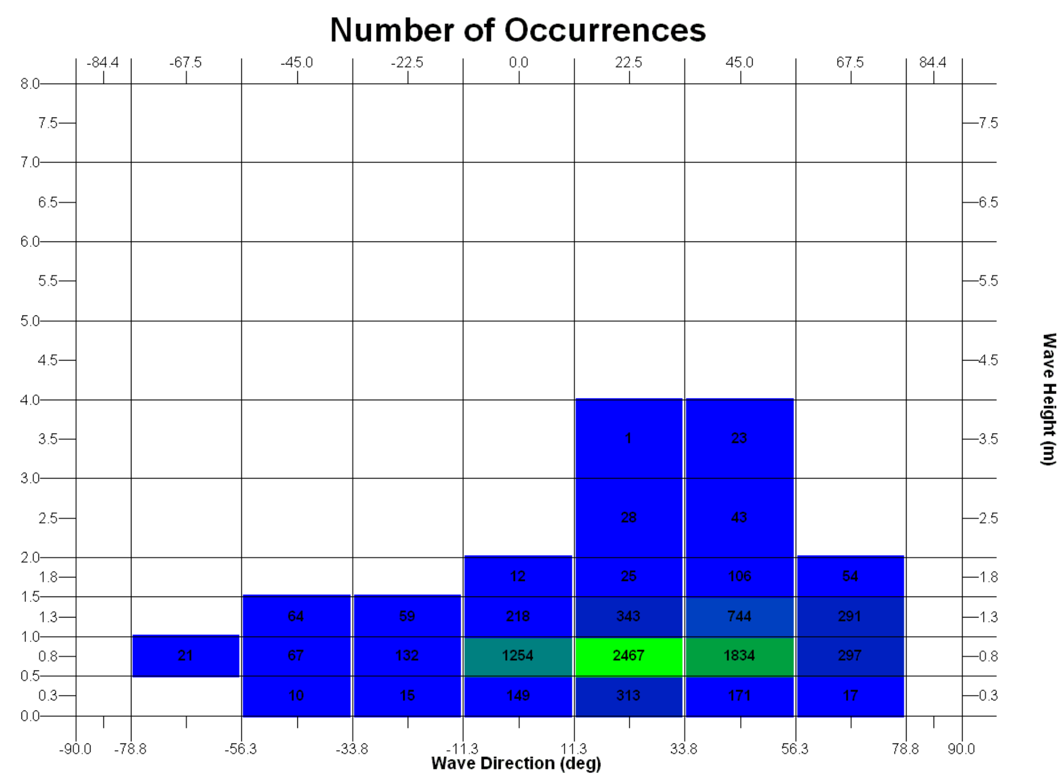


Figure C-21. 1994 number of occurrences for wave height and mean direction for WIS Station 119

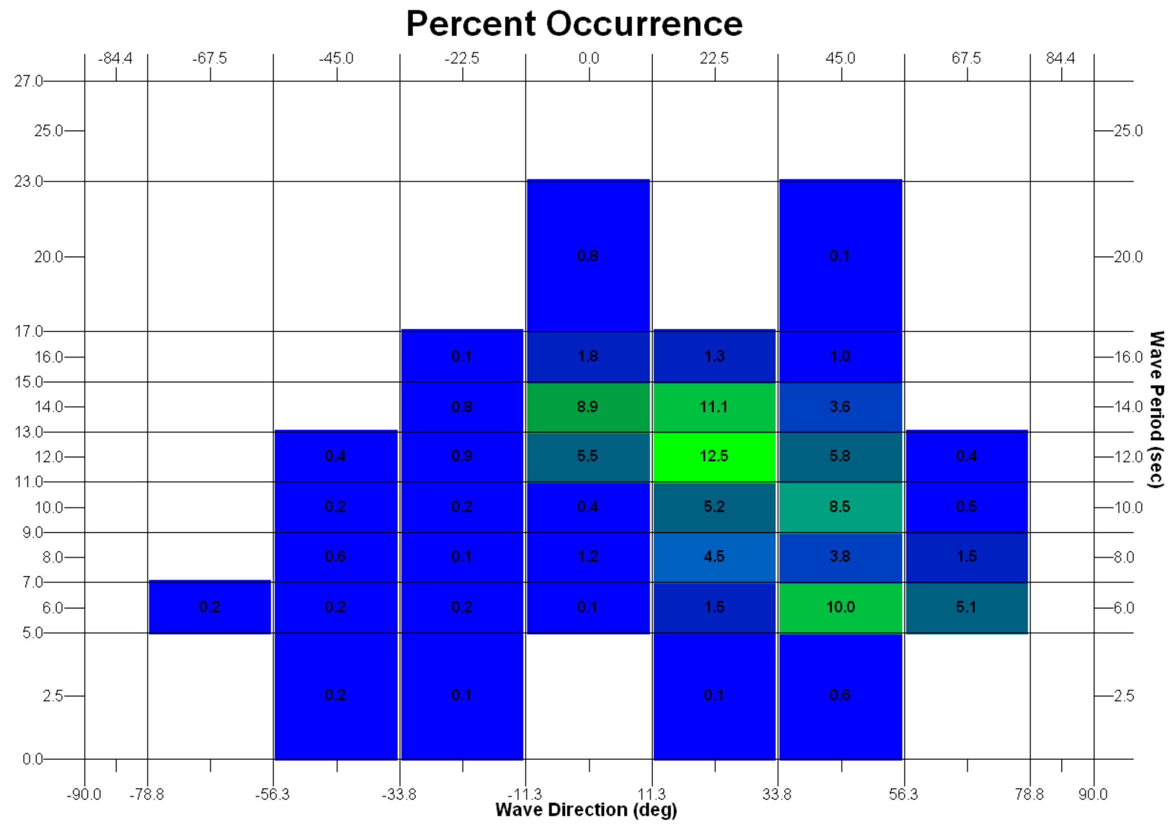


Figure C-22. 1994 percent occurrences for peak period and mean direction for WIS Station 119

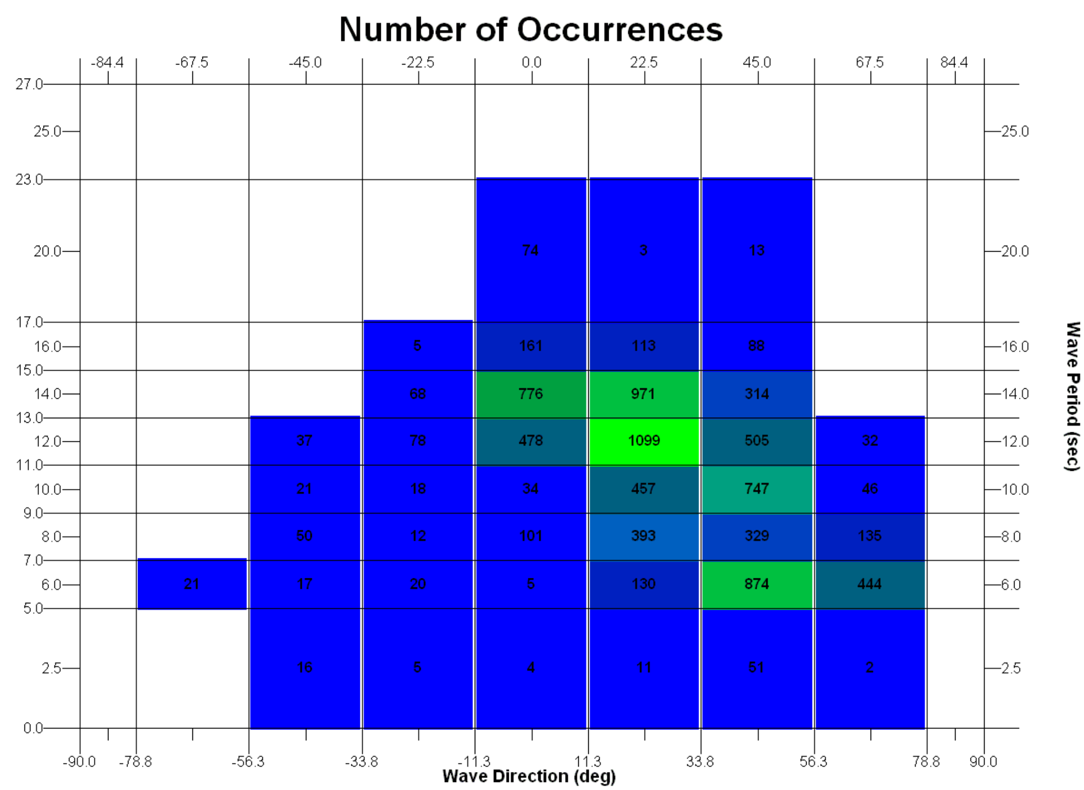


Figure C-23. 1994 number of occurrences for peak period and mean direction for WIS Station 119

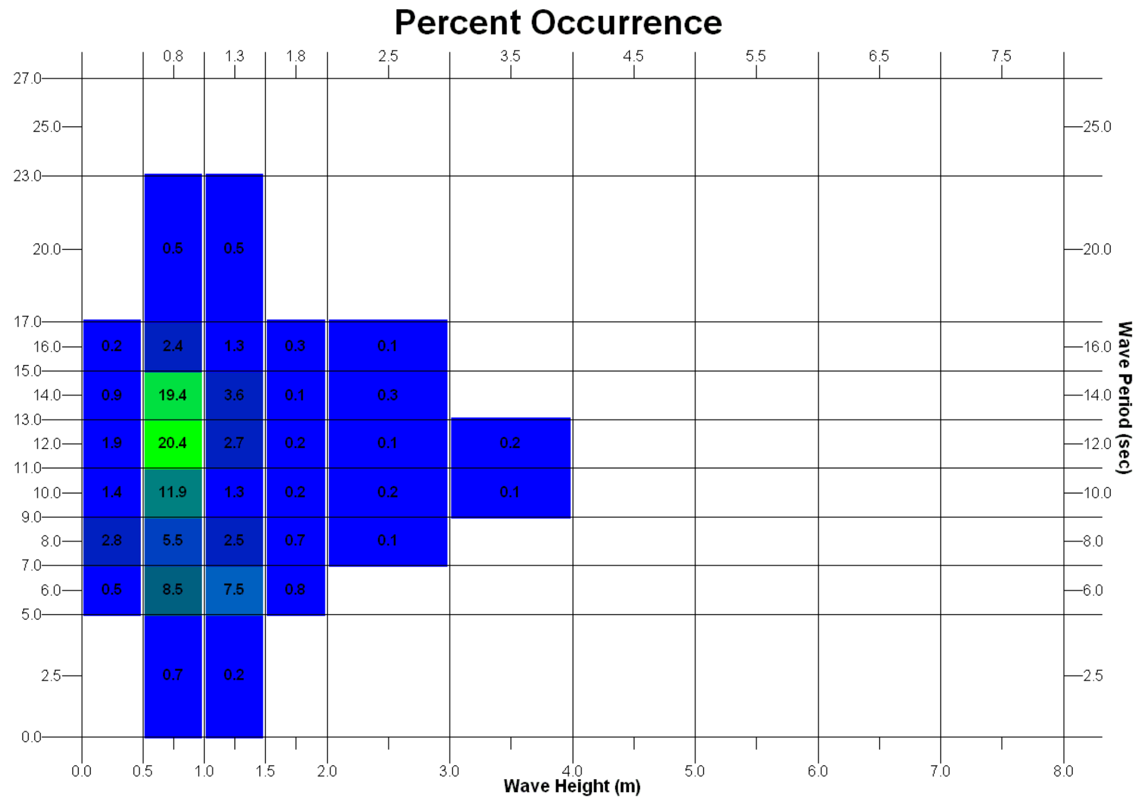


Figure C-24. 1994 percent occurrences for peak period and wave height for WIS Station 119.

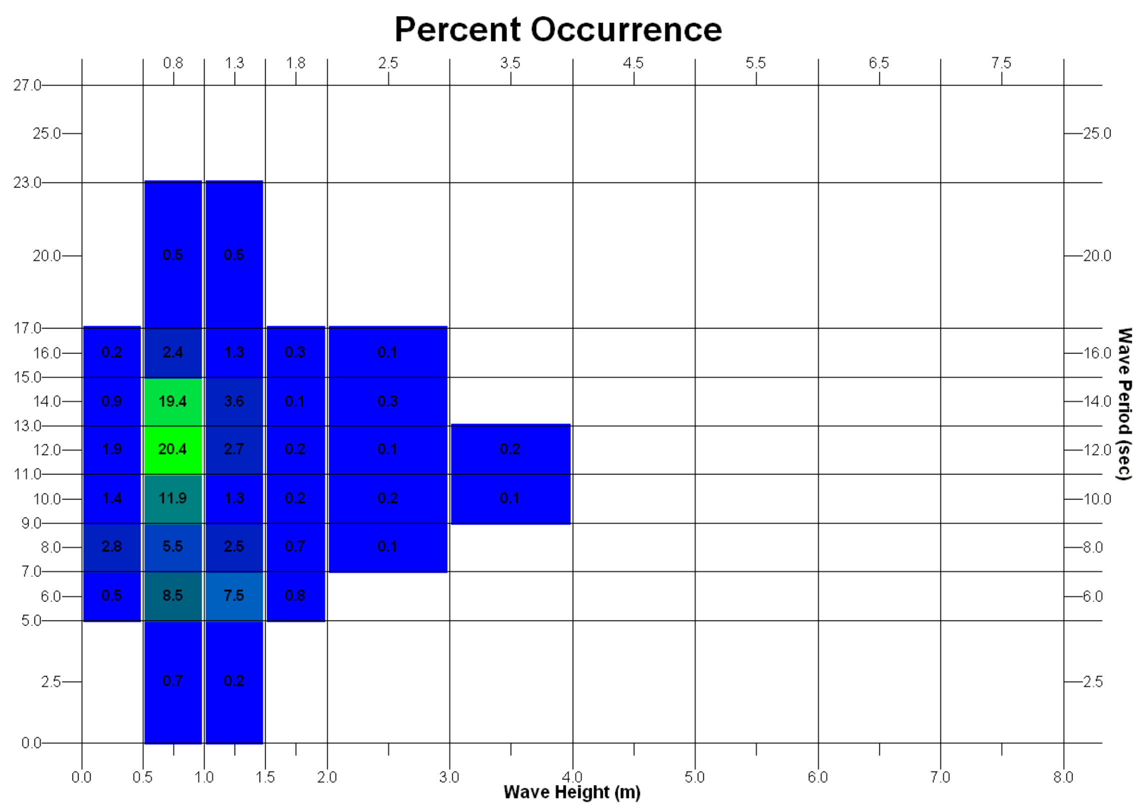


Figure C-25. 1994 percent occurrences for peak period and wave height for WIS Station 119.

Table C-1 provides a summary of the mean and maximum wave statistics for the years 1984, 1992, and 1994. Tables C-2 and C-3 provide suggested nearshore wave model runs to build a lookup table to be used in simulating nearshore wave climatology. Before the runs on finalized, some sensitivity runs should be made with the nearshore model to determine if the binning is fine enough to resolve nearshore transformation trends or if fewer may be used.

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

Table C-1. Mean and Maximum Statistics

Year	1984	1992	1994
Mean Wave Height (m)	0.8	0.8	0.9
Mean Peak Period (s)	10.9	11.3	10.8
Largest Wave Height (m)	1.7	12.3	3.4
Peak of Largest Height (s)	7.6	13.5	11.2
Direction of Largest Height (deg)	112.5	157.5	135

Table C-2. Typical Conditions (343 conditions)

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

Table C-3. Extreme Conditions (36 conditions)

Significant Wave Height, m	Wave Period, sec	Wave Direction, deg from STWAVE axis	Wave Direction, deg met convention
5 (8)	10 (3)	0 (4)	from 180 deg
6 (9)	12 (4)	22.5 (5)	from 157.5 deg
7 (10)	14 (5)		
8 (11)			
9 (12)			
12 (13)			

The STWAVE grid encompasses the entire Poipu RSM region, as shown in Figure C-26 below, with a grid resolution of 50m. The Poipu grid is oriented such that its offshore boundary (at approximately 300 m depth) faces south at 180 degrees TN. The bathymetry along the nearshore areas includes the well-resolved features of the reef and other features such as channels and headlands.

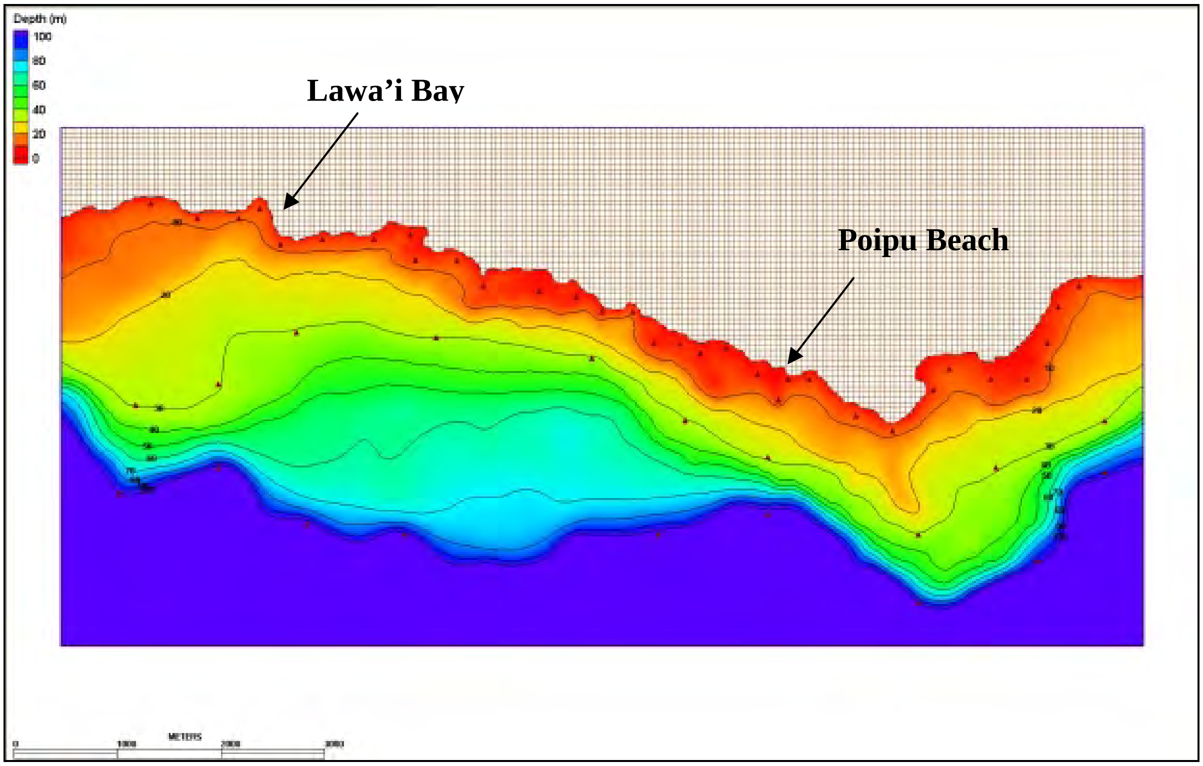


Figure C-26. STWAVE Grid Extents for Poipu Region (10 m contours shown)

Figure C-26 shows the rocky and jagged shoreline of the Poipu area. A detailed view of the STWAVE grid in the nearshore areas adjacent to Poipu Beach Park is shown in Figure C-27.

Wave parameters from Tables C-2 and C-3 were used to generate wave input spectra for the Poipu grid. An example of the resulting wave height information (in color) and wave direction (arrows) for the Poipu grid is shown in Figure C-28. In addition, observation points were placed along the nearshore at approximately 1 to 3 meters depth, and along the 30 m and 100 m contours (also visible in Figure C-28 as black squares). Wave parameters for these selected locations were saved in a separate file for use in the next step of the process.

Figure C-27. STWAVE Nearshore Grid Adjacent to Poipu Beach in Poipu Region (1m contours shown)

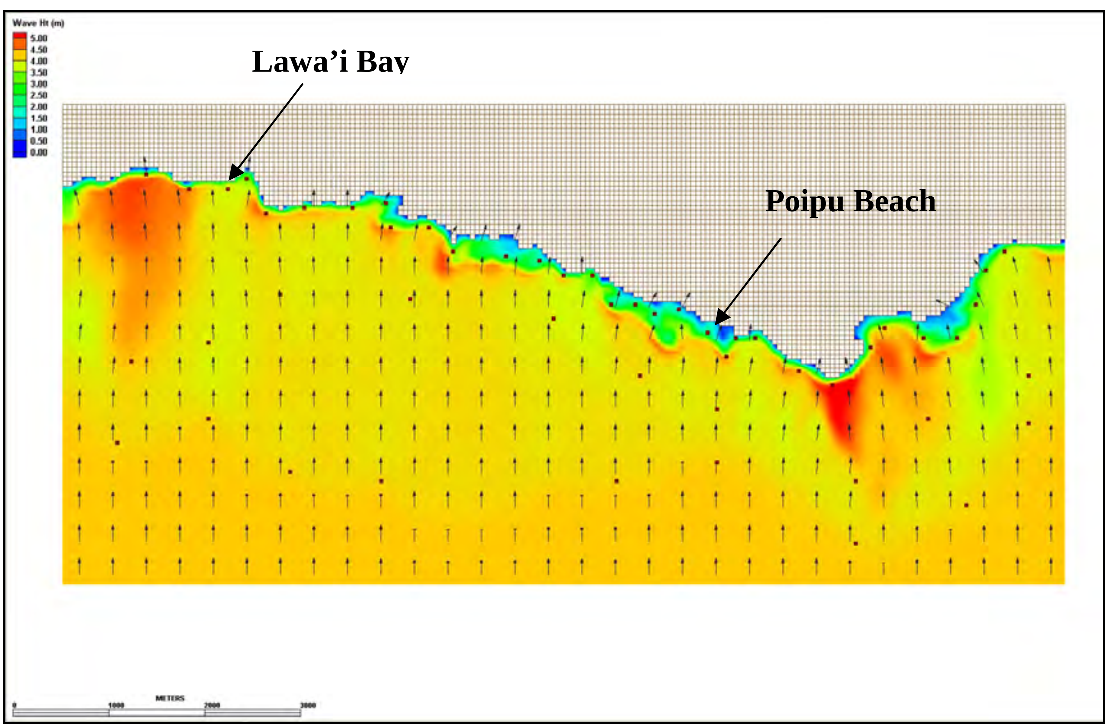


Figure C-28. Resulting Wave Height (color scale) and Wave Direction (arrows) in Poipu Region for Case 754 (Ho = 4m, T= 14s, Dir=180) and Location of Observation Points

A database (or "lookup table") of wave parameters that correlates the most frequent offshore wave conditions at the WIS station (from Tables C-2 and C-3 for Poipu) to the resulting nearshore wave conditions at the selected observation points has been developed from the application of STWAVE for several hundred wave transformations for each region.

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

Finally, the time series for each observation point was used to develop a histogram for that location indicating the percent occurrence of wave approach direction (separated into 10 degree direction bins) as well as the frequency of significant wave height within each wave bin (separated into 0.5m wave height bins). Histograms of two locations in the Poipu region, east and west of the Poipu Beach Park and Brennecke Beach areas, are shown in Figures C-29 and 30, respectively.

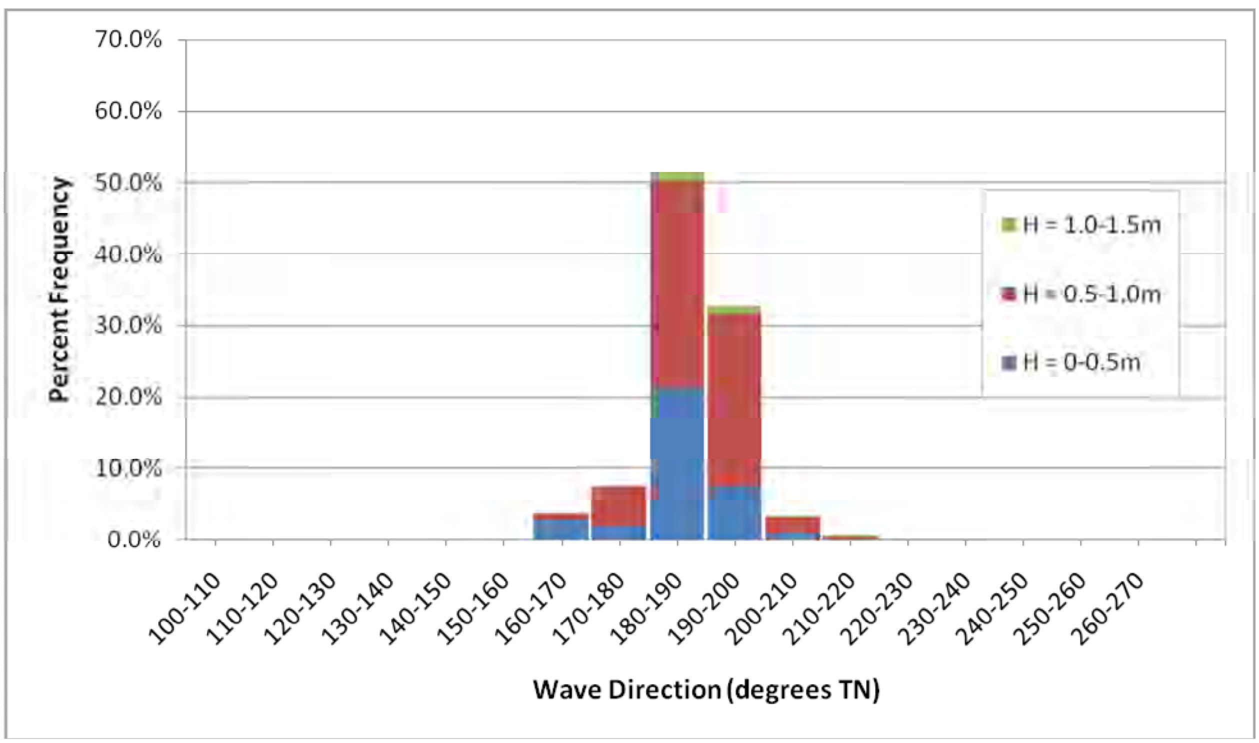


Figure C-29. Histogram of Wave Height and Direction at Nearshore Observation Point East of Poipu Beach Park (Shore normal = 153 degrees TN)

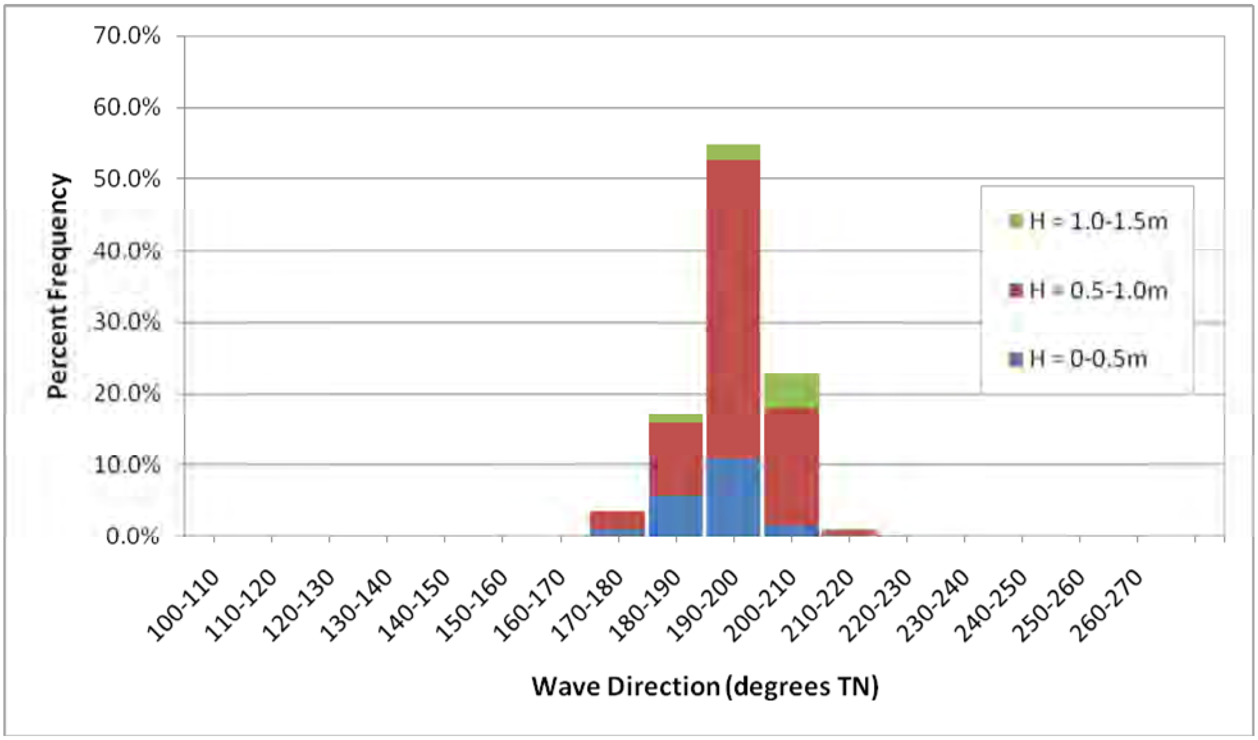


Figure C-30. Histogram of Wave Height and Direction at Nearshore Observation Point West of Poipu Beach Park (Shore normal = 201 degrees TN)

This information (in combination with the shoreline orientation angle) may be useful in determining the dominant direction of wave approach at the selected observation points, and from that an estimate of sediment transport direction may be inferred and used to add arrows to the sediment budget. In addition, comparison of histograms for various locations indicates how much variability exists in the wave height directional spread of the nearshore waves. As an example, Figure C-30 indicates that while the onshore normal direction at this observation point (Brennecke Beach) is approximately 153 degrees TN, most of the nearshore waves are approaching from an angle of 160 degrees TN or greater. This would seem to indicate that sediment transport at this location is from west to east, because of the obliquity of the incoming waves with the shoreline. However, since this area is a “pocket beach” with headlands on either side and complex bathymetry, this scenario is not supported or refuted by examination of aerial photography.

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

APPENDIX D

SHORELINE EROSION MAPS – KEKAHA REGION (UH 2010)

Kokole Point, Kauai, Hawaii

The preparation of this poster was financed in part by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Ocean Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, through the Office of Planning, State of Hawaii.

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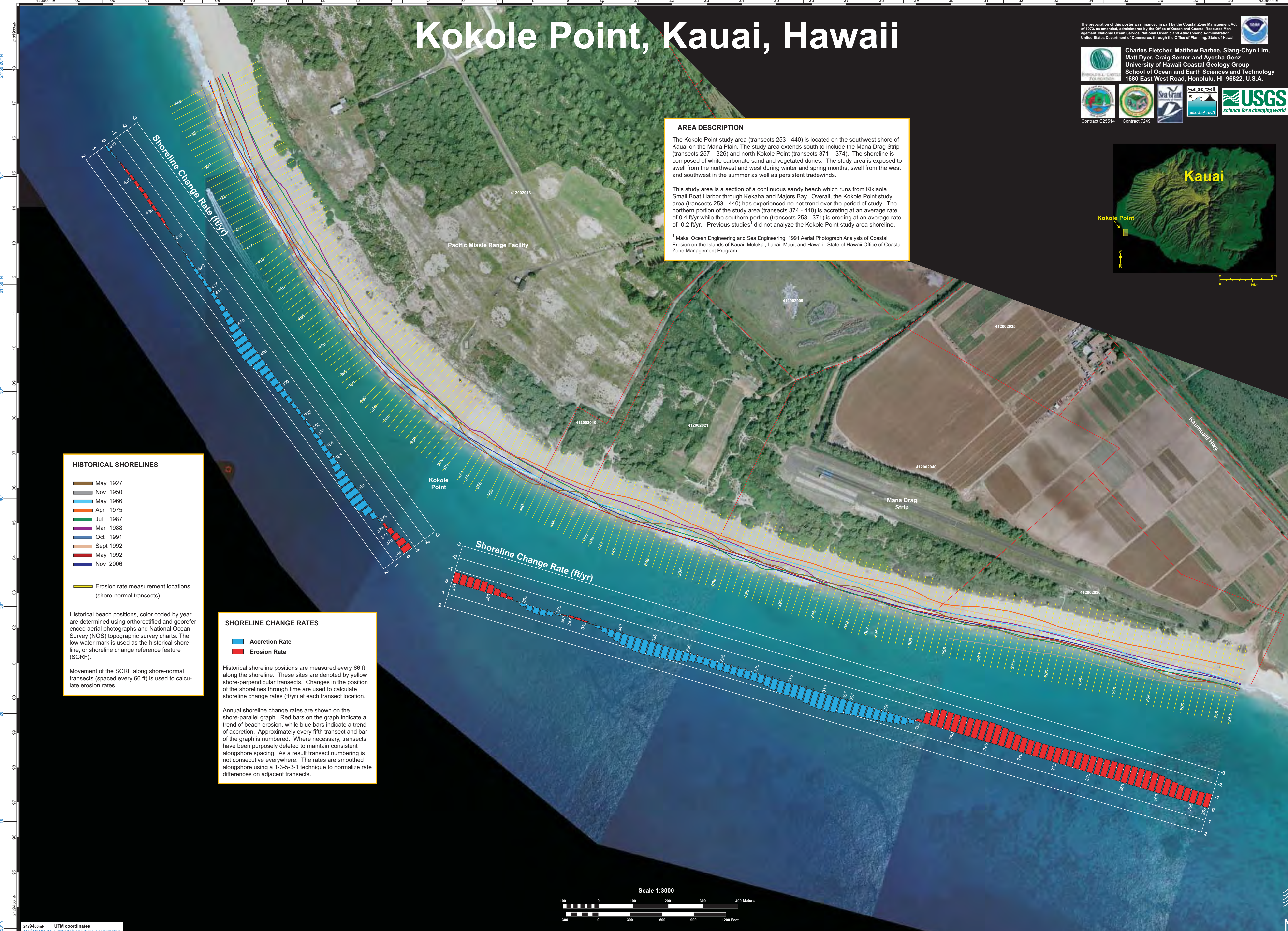


AREA DESCRIPTION

The Kokole Point study area (transects 253 - 440) is located on the southwest shore of Kauai on the Mana Plain. The study area extends south to include the Mana Drag Strip (transects 257 – 326) and north Kokole Point (transects 371 – 374). The shoreline is composed of white carbonate sand and vegetated dunes. The study area is exposed to swell from the northwest and west during winter and spring months, swell from the west and southwest in the summer as well as persistent tradewinds.

This study area is a section of a continuous sandy beach which runs from Kikiaola Small Boat Harbor through Kekaha and Majors Bay. Overall, the Kokole Point study area (transects 253 - 440) has experienced no net trend over the period of study. The northern portion of the study area (transects 374 - 440) is accreting at an average rate of 0.4 ft/yr while the southern portion (transects 253 - 371) is eroding at an average rate of -0.2 ft/yr. Previous studies[1] did not analyze the Kokole Point study area shoreline.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

HISTORICAL SHORELINES

- May 1927
- Nov 1950
- May 1966
- Apr 1975
- Jul 1987
- Mar 1988
- Oct 1991
- Sept 1992
- May 1992
- Nov 2006

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.

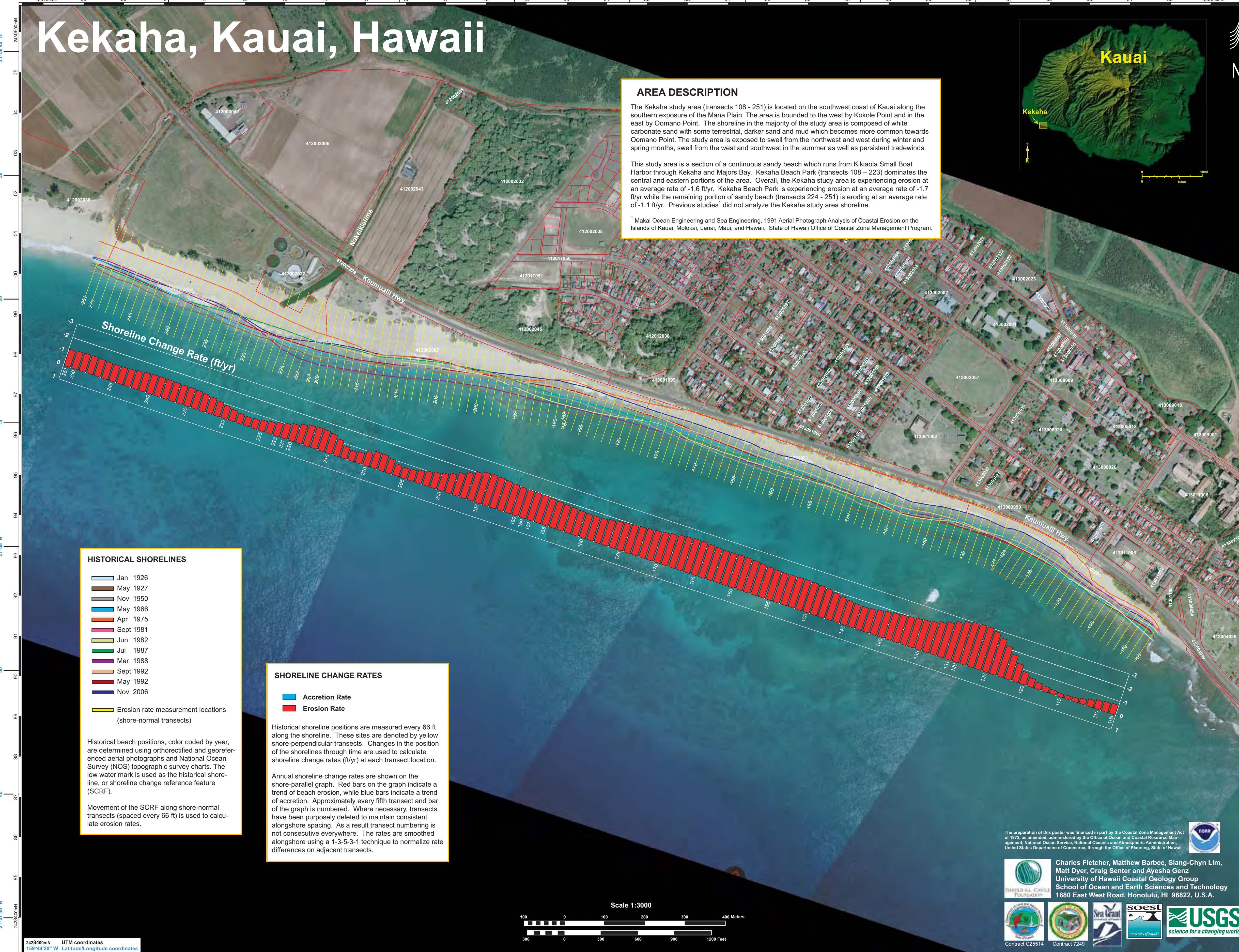
SHORELINE CHANGE RATES

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

Kekaha, Kauai, Hawaii



AREA DESCRIPTION

The Kekaha study area (transects 108 - 251) is located on the southwest coast of Kauai along the southern exposure of the Mana Plain. The area is bounded to the west by Kokole Point and in the east by Oomano Point. The shoreline in the majority of the study area is composed of white carbonate sand with some terrestrial, darker sand and mud which becomes more common towards Oomano Point. The study area is exposed to swell from the northwest and west during winter and spring months, swell from the west and southwest in the summer as well as persistent tradewinds.

This study area is a section of a continuous sandy beach which runs from Kikiaola Small Boat Harbor through Kekaha and Majors Bay. Kekaha Beach Park (transects 108 – 223) dominates the central and eastern portions of the area. Overall, the Kekaha study area is experiencing erosion at an average rate of -1.6 ft/yr. Kekaha Beach Park is experiencing erosion at an average rate of -1.7 ft/yr while the remaining portion of sandy beach (transects 224 - 251) is eroding at an average rate of -1.1 ft/yr. Previous studies[1] did not analyze the Kekaha study area shoreline.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

HISTORICAL SHORELINES

- Jan 1926
- May 1927
- Nov 1950
- May 1966
- Apr 1975
- Sept 1981
- Jun 1982
- Jul 1987
- Mar 1988
- Sept 1992
- May 1992
- Nov 2006
- 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.

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

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Oomano Point, Kauai, Hawaii

AREA DESCRIPTION

Oomano Point study area is characterized by a narrow sand beach and hardened shoreline. The area is bounded by Kekaha Beach to the west and Kikiaoloa Small Boat Harbor to the east. The beach is composed of black volcanic sand, mud, and calcareous sand. Terrestrial material is primarily delivered by the Waimea River which is located to the east.

The shoreline is exposed to south wave swell during the summer and occasional wrapping of northwest waves during the winter as well as persistent tradewinds. Oomano Point (*aka* Davidson's Point, transects 59 - 61) lies central to the area and effectively divides the area into two sections for description purposes. Previous studies[1] discuss the impact of Kikiaoloa Small Boat Harbor, built in 1959, which interrupts alongshore sediment transport from the east. The resulting erosion at and near Oomano Point has threatened Kaumualii Hwy. and led to the construction of an extensive revetment by the U.S. Army Corps of Engineers to mitigate further erosion.

Overall, the Oomano study area (transects 0 - 106) is experiencing erosion at an average rate of -2.1 ft/yr. The eastern section of the area (transects 0 - 59) is experiencing erosion at an average rate of -2.7 ft/yr while the western section (transects 61 - 106) is eroding at an average rate of -1.3 ft/yr.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

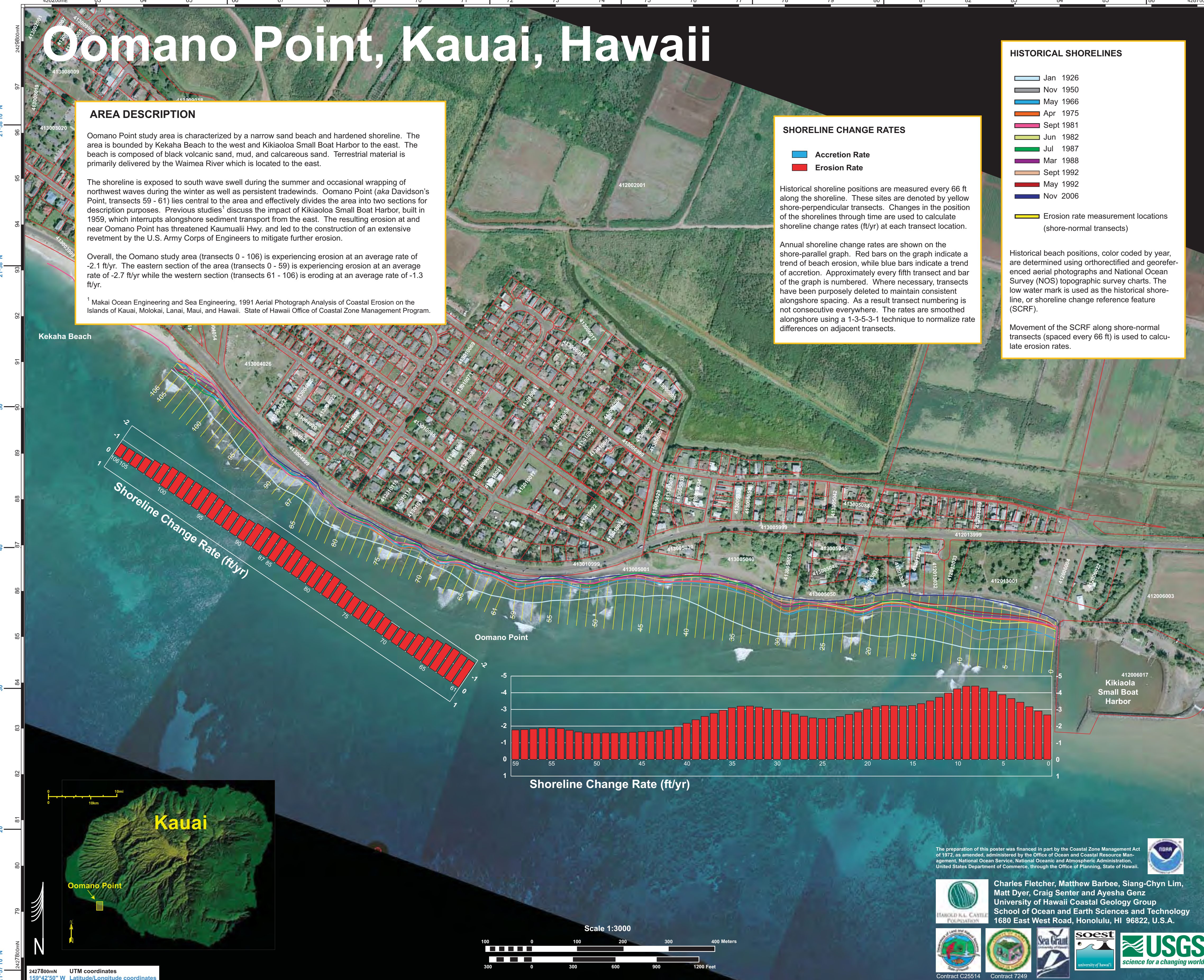
HISTORICAL SHORELINES

- Jan 1926
- Nov 1950
- May 1966
- Apr 1975
- Sept 1981
- Jun 1982
- Jul 1987
- Mar 1988
- Sept 1992
- May 1992
- Nov 2006

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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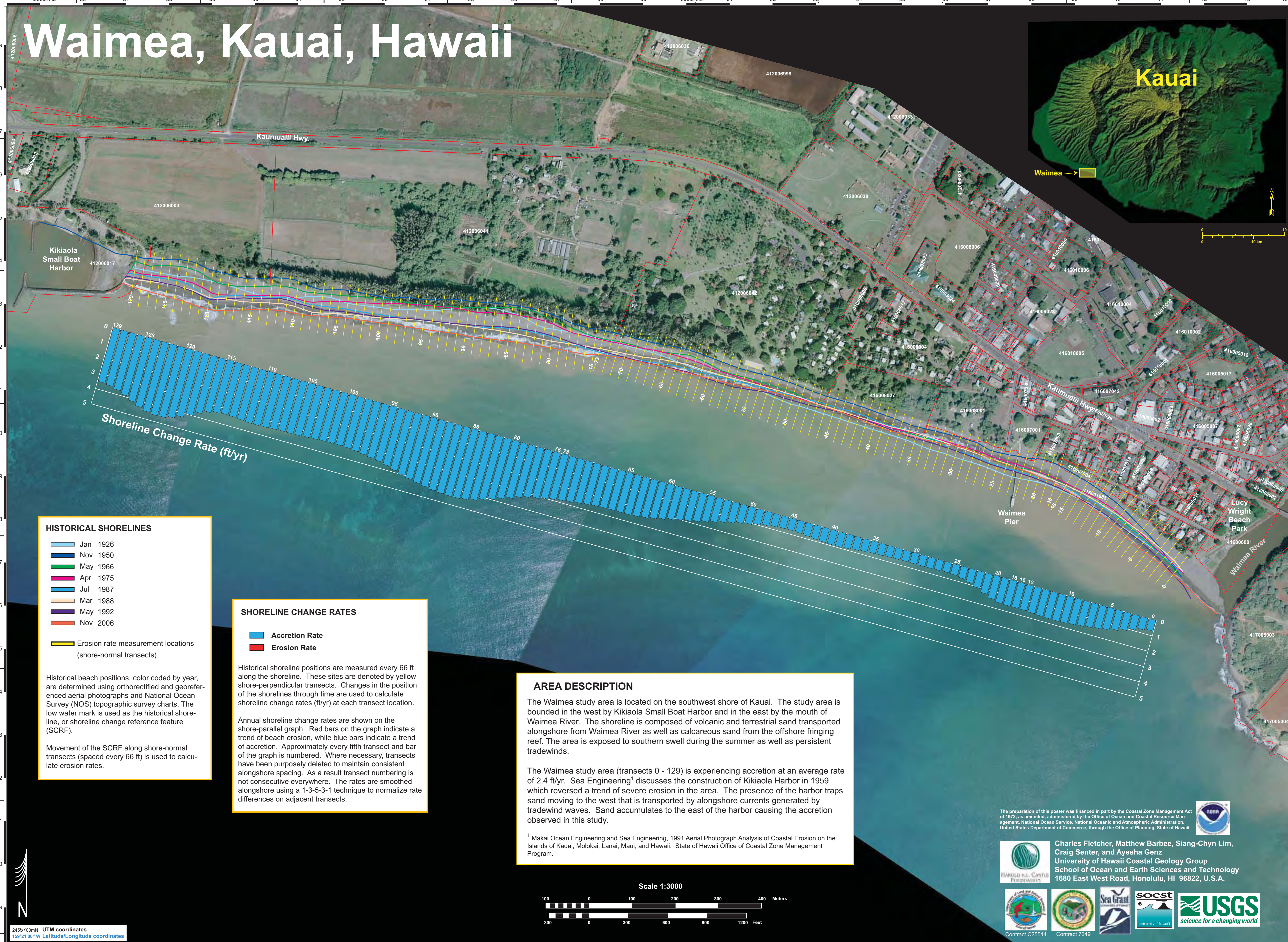
Waimea, Kauai, Hawaii



HISTORICAL SHORELINES

- Jan 1926
- Nov 1950
- May 1966
- Apr 1975
- Jul 1987
- Mar 1988
- May 1992
- Nov 2006

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.

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

AREA DESCRIPTION

The Waimea study area is located on the southwest shore of Kauai. The study area is bounded in the west by Kikiaola Small Boat Harbor and in the east by the mouth of Waimea River. The shoreline is composed of volcanic and terrestrial sand transported alongshore from Waimea River as well as calcareous sand from the offshore fringing reef. The area is exposed to southern swell during the summer as well as persistent tradewinds.

The Waimea study area (transects 0 - 129) is experiencing accretion at an average rate of 2.4 ft/yr. Sea Engineering[1] discusses the construction of Kikiaola Harbor in 1959 which reversed a trend of severe erosion in the area. The presence of the harbor traps sand moving to the west that is transported by alongshore currents generated by tradewind waves. Sand accumulates to the east of the harbor causing the accretion observed in this study.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

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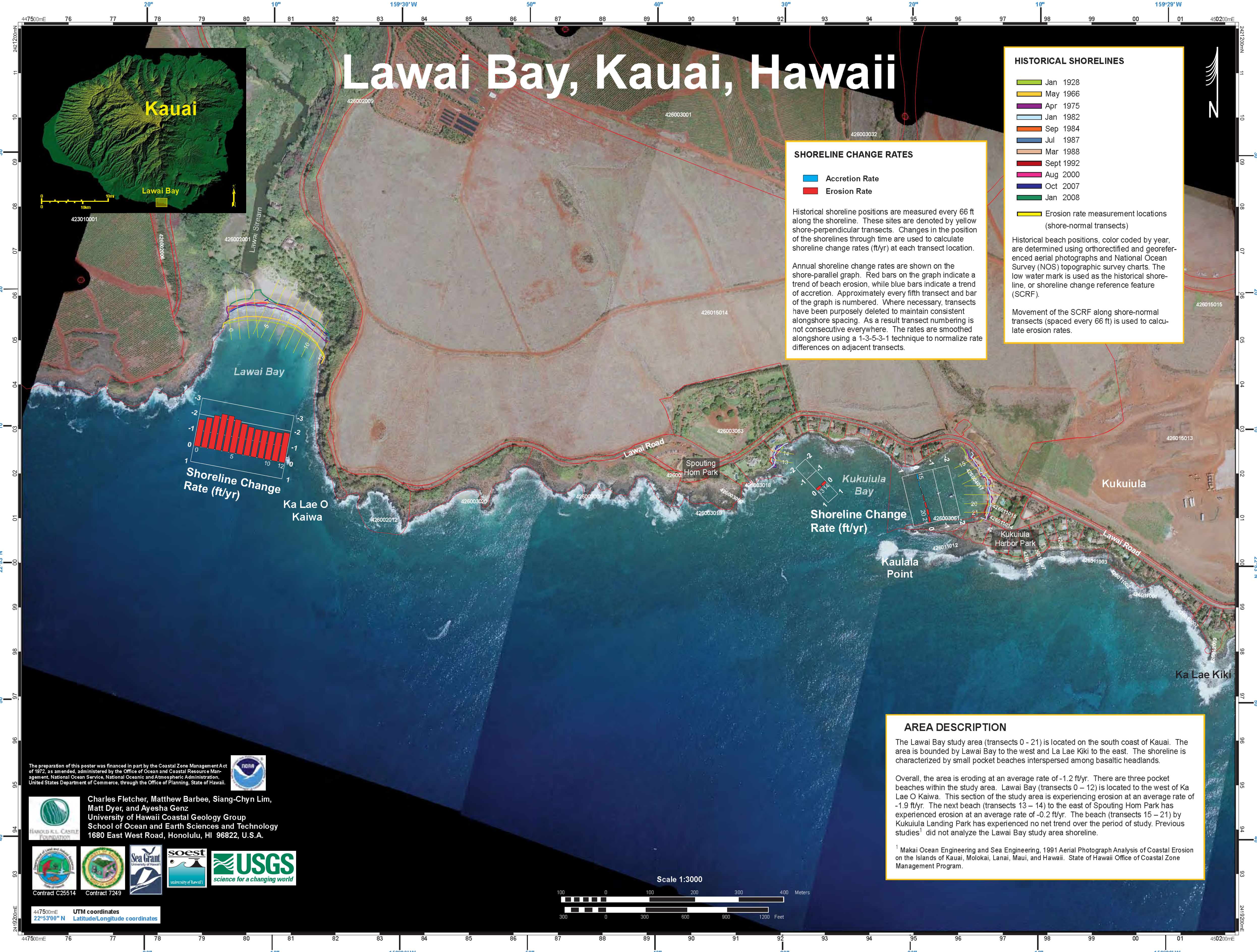
APPENDIX E

SHORELINE EROSION MAPS – POIPU REGION (UH 2010)

Lawai Bay, Kauai, Hawaii



HISTORICAL SHORELINES

- Jan 1928
- May 1966
- Apr 1975
- Jan 1982
- Sep 1984
- Jul 1987
- Mar 1988
- Sept 1992
- Aug 2000
- Oct 2007
- Jan 2008
- 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.

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.

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AREA DESCRIPTION

The Lawai Bay study area (transects 0 - 21) is located on the south coast of Kauai. The area is bounded by Lawai Bay to the west and La Lae Kiki to the east. The shoreline is characterized by small pocket beaches interspersed among basaltic headlands.

Overall, the area is eroding at an average rate of -1.2 ft/yr. There are three pocket beaches within the study area. Lawai Bay (transects 0 – 12) is located to the west of Ka Lae O Kaiwa. This section of the study area is experiencing erosion at an average rate of -1.9 ft/yr. The next beach (transects 13 – 14) to the east of Spouting Horn Park has experienced erosion at an average rate of -0.2 ft/yr. The beach (transects 15 – 21) by Kukuiula Landing Park has experienced no net trend over the period of study. Previous studies[1] did not analyze the Lawai Bay study area shoreline.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

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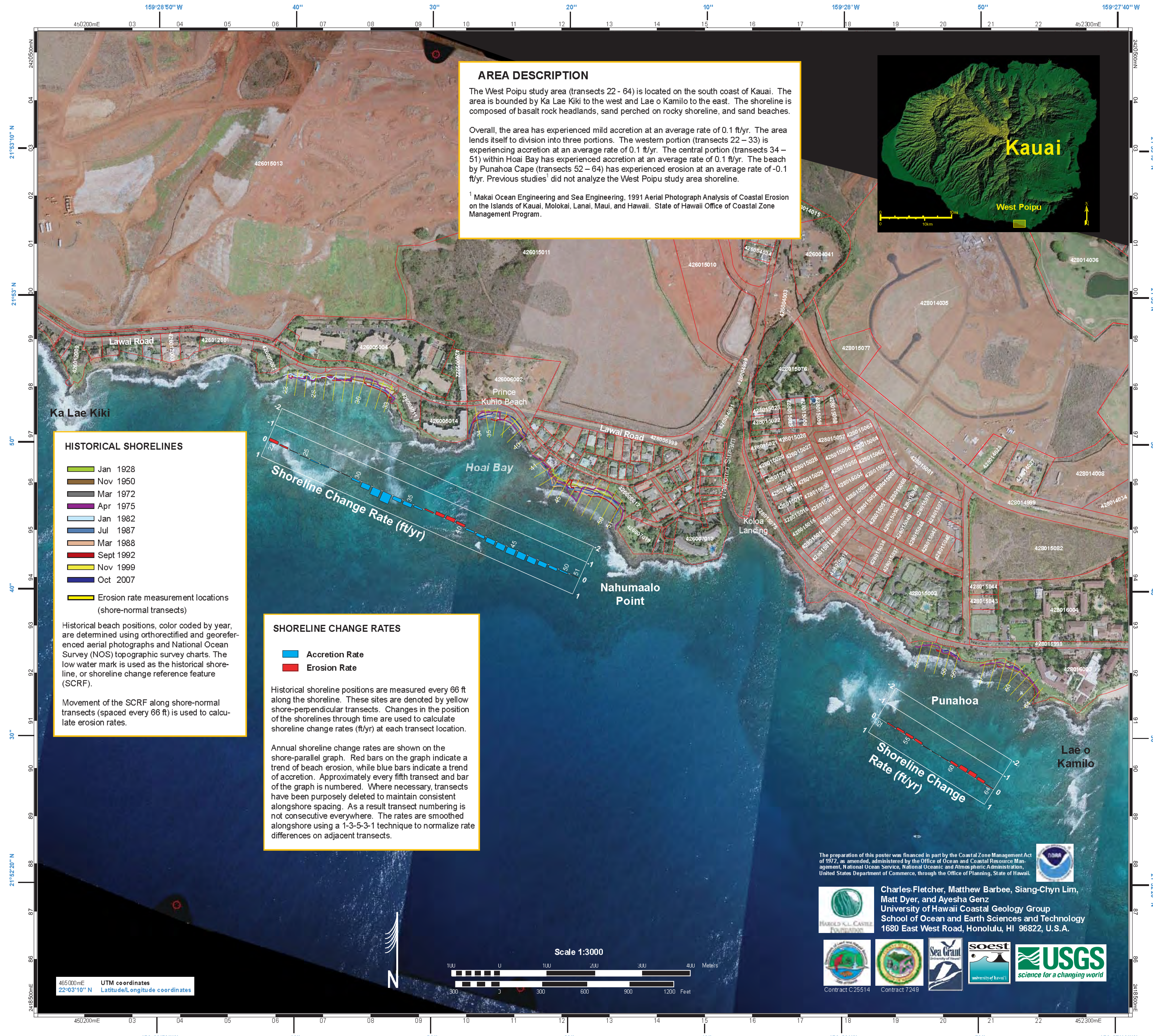
Contract 7249

447500mE UTM coordinates
22°53'00" N Latitude/Longitude coordinates

West Poipu, Kauai, Hawaii



AREA DESCRIPTION

The West Poipu study area (transects 22 - 64) is located on the south coast of Kauai. The area is bounded by Ka Lae Kiki to the west and Lae o Kamilo to the east. The shoreline is composed of basalt rock headlands, sand perched on rocky shoreline, and sand beaches.

Overall, the area has experienced mild accretion at an average rate of 0.1 ft/yr. The area lends itself to division into three portions. The western portion (transects 22 – 33) is experiencing accretion at an average rate of 0.1 ft/yr. The central portion (transects 34 – 51) within Hoai Bay has experienced accretion at an average rate of 0.1 ft/yr. The beach by Punahoa Cape (transects 52 – 64) has experienced erosion at an average rate of -0.1 ft/yr. Previous studies[1] did not analyze the West Poipu study area shoreline.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

HISTORICAL SHORELINES

- Jan 1928
- Nov 1950
- Mar 1972
- Apr 1975
- Jan 1982
- Jul 1987
- Mar 1988
- Sept 1992
- Nov 1999
- Oct 2007

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.

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

The preparation of this poster was financed in part by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Ocean Service, National Oceanic and Atmospheric Administration, United States Department of Commerce, through the Office of Planning, State of Hawaii.

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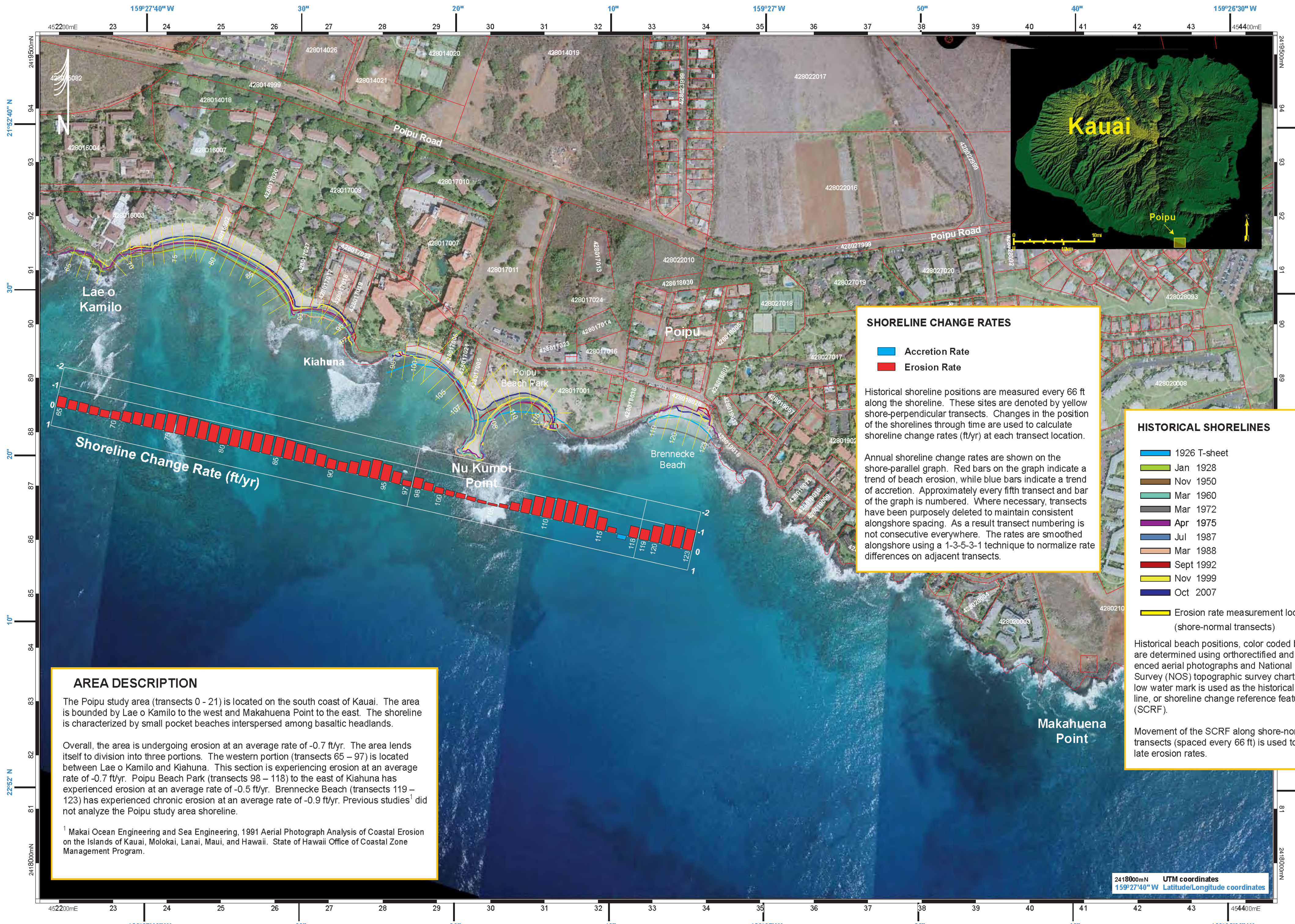
Poipu, Kauai, Hawaii



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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

HISTORICAL SHORELINES

- 1926 T-sheet
- Jan 1928
- Nov 1950
- Mar 1960
- Mar 1972
- Apr 1975
- Jul 1987
- Mar 1988
- Sept 1992
- Nov 1999
- Oct 2007
- 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 Poipu study area (transects 0 - 21) is located on the south coast of Kauai. The area is bounded by Lae o Kamilo to the west and Makahuena Point to the east. The shoreline is characterized by small pocket beaches interspersed among basaltic headlands.

Overall, the area is undergoing erosion at an average rate of -0.7 ft/yr. The area lends itself to division into three portions. The western portion (transects 65 – 97) is located between Lae o Kamilo and Kiahuna. This section is experiencing erosion at an average rate of -0.7 ft/yr. Poipu Beach Park (transects 98 – 118) to the east of Kiahuna has experienced erosion at an average rate of -0.5 ft/yr. Brennecke Beach (transects 119 – 123) has experienced chronic erosion at an average rate of -0.9 ft/yr. Previous studies[1] did not analyze the Poipu study area shoreline.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

Scale 1:3000

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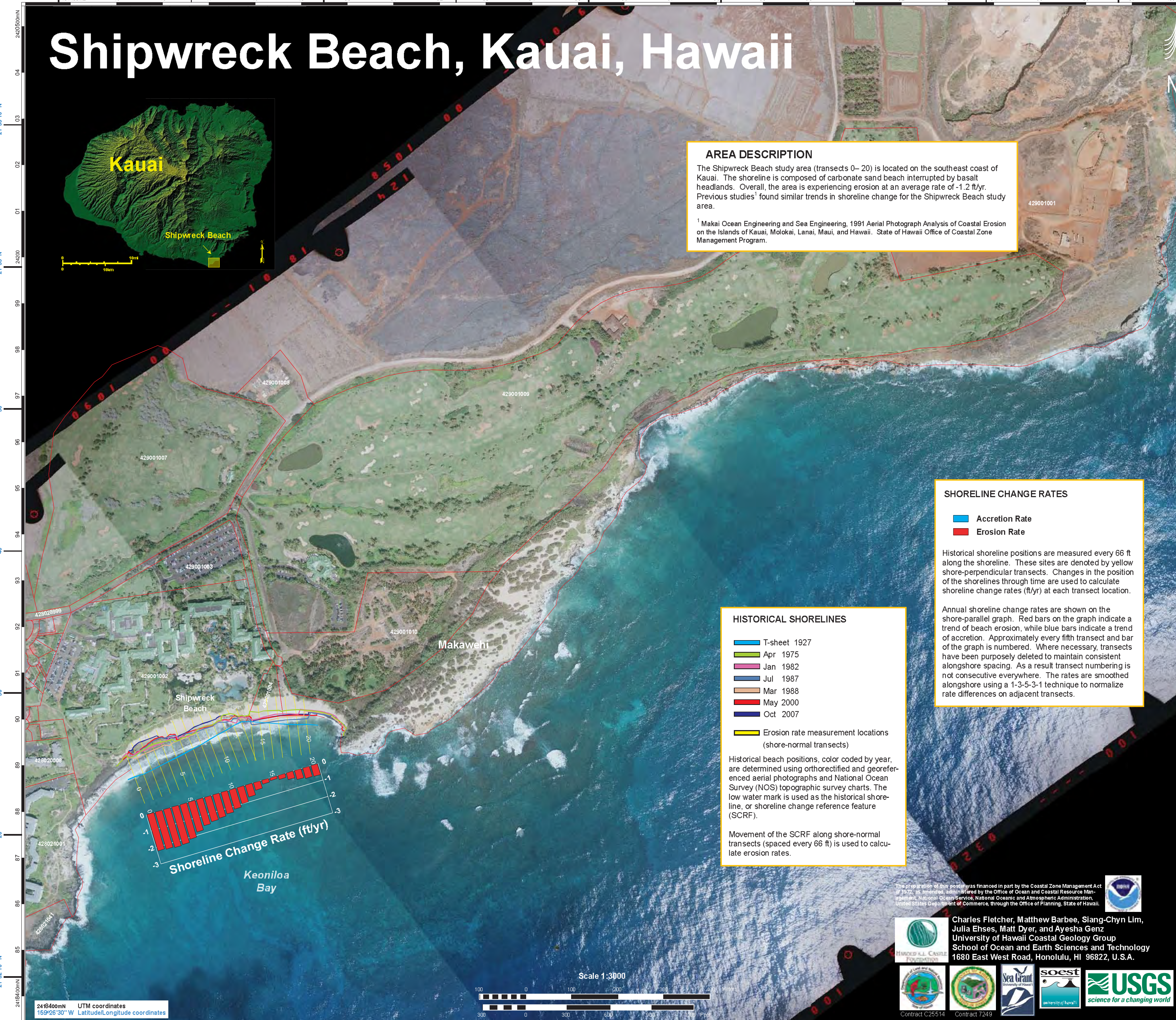
Shipwreck Beach, Kauai, Hawaii



AREA DESCRIPTION

The Shipwreck Beach study area (transects 0– 20) is located on the southeast coast of Kauai. The shoreline is composed of carbonate sand beach interrupted by basalt headlands. Overall, the area is experiencing erosion at an average rate of -1.2 ft/yr. Previous studies[1] found similar trends in shoreline change for the Shipwreck Beach study area.

[1] Makai Ocean Engineering and Sea Engineering, 1991 Aerial Photograph Analysis of Coastal Erosion on the Islands of Kauai, Molokai, Lanai, Maui, and Hawaii. State of Hawaii Office of Coastal Zone Management Program.

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 alongshore spacing. As a result transect numbering is not consecutive everywhere. The rates are smoothed alongshore using a 1-3-5-3-1 technique to normalize rate differences on adjacent transects.

HISTORICAL SHORELINES

- T-sheet 1927
- Apr 1975
- Jan 1982
- Jul 1987
- Mar 1988
- May 2000
- Oct 2007

- 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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APPENDIX F : SEDIMENT TRANSPORT BUDGETS – KEKAHA REGION

I. Sediment Budget Methodology

A. Overview

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

Section B below describes an approach commonly used in sediment budget analyses, but which was proven to be not useful from the Oahu D2P Sediment Budget Report (M&N 2009). Conventional sediment transport rates are actually potential rates, based on the assumption that a sandy bottom is present throughout the study reach: a more sophisticated sediment transport analysis would be needed to provide insight into the Kauai regions because of the presence of the reef bottom.

Since this sediment transport rate analysis was found not to be useful, the sediment budget was developed based on volumetric changes over the past few decades, or after all significant structures were constructed in each region. The timeframe for the analysis varies by littoral cell, based on the extent of recent human modifications. The general approach to budget development was as follows.

- The historical volumes of sediment on the beaches was estimated based on the historical shoreline positions developed by the University of Hawai‘i (Hawai‘i Coastal Geology Group 2009 and using a conversion factor of 0.40 cubic yards per square foot of beach, based roughly on the results of analysis performed in the Oahu D2P study.
- The beach volume graphs were studied, relative to historical events and erosional versus accretional trends, to calculate representative average erosion or accretion rates for appropriate time periods for each littoral cell. In some cases, rates were calculated for more than one time period. This rate was based on a linear fit of the beach volume data using a weighted least squares approach.
- The rates take into account historical beach nourishment which would be included in the historical beach volumes of the graphs below, however beach nourishment on Kauai seems to be limited. There were only two projects found: 1) a 15,000 cubic yard nourishment (sand bypassing) within the Kekaha region in 1998-2001 (Sea Engineering 2008), and 2) a 1,000 cubic yard nourishment of Poipu Beach in 2007(DLNR 2010).
- The rates take into account seasonal fluctuation to some extent by use of the least squared regression analysis, which includes a seasonal variation uncertainty error.

These steps are described further below. The resulting preliminary sediment budgets for the different littoral cells are provided in Section II of this appendix.

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

B. Potential Sediment Transport Rates

The rate of longshore sediment transport is often modeled as a function of such inputs as breaker wave height, period, approach direction, and sediment parameters. A typical model – far from the only one of its type – is known as the CERC Equation, which is based on the assumption that the longshore sediment transport rate is proportional to the longshore energy flux. It is expressed by Smith, Ebersole, and Wang 2004 as follows:

$$Q = \frac{K}{16\sqrt{g}} r_w g^{3/2} H_{sb}^{\ 5/2} \sin 2a$$

where *Q* is the longshore sediment transport rate expressed as an immersed weight, *K* is an empirical coefficient, r_w is the density of water, g is the acceleration due to gravity, H_{sb} is the significant wave height at breaking, γ is the breaker index (often set equal to 0.78), and α is the angle between the breaking wave crests and the shoreline. The calibration coefficient *K* has been obtained for different conditions based on field measurements.

Models of this type produce potential transport rates – that is, the rate of sediment transport under the assumption that plentiful sediment is available throughout the breaker zone. This is not the case in the presence of a fringing reef, which introduces a hard bottom over much of the breaker zone (e.g., Eversole and Fletcher 2003). In addition, breaker dynamics are affected by the large bottom friction that results from the very rough reef surface (Hearn 1999). Therefore, it is likely that the straightforward application of standard potential transport rate equations region will vastly overpredict the actual transport rates. This was proven out in the Oahu D2P Sediment Budget Report (M&N 2009) and is assumed to be the case for Kauai.

C. Beach Erosion and Accretion

Volumetric erosion and accretion rates were based on the shoreline erosion mapping work prepared by the University of Hawai‘i (University of Hawai‘i Coastal Geology Group 2010; methods are described in Fletcher et al. 2003). Measured shoreline positions along each transect (spaced at 20 meters) were provided to M&N. M&N performed a beach area analysis, calculating the changes in total beach area for individual littoral cells and some subcells (in contrast to the work by UH, which focused on retreat distances along the shoreline). The result of this work was an estimate of total beach area, relative to the latest vegetation line, for each cell. The area was converted to beach volume using a factor of 0.40 cubic yards per square foot of beach.

D. Structures, Storms, and Historical Sand Placement

Table F-1 provides an overview of the known sand placement activities, along with a chronology of other significant coastline activities, There was only one project found in the Kekaha region - a 15,000 cubic yard nourishment (sand bypassing) on Kikiaola Beach in 1998-2001 (Sea Engineering 2008)

Table F-1. Kekaha Region Structures, Storms, Historical Sand Placement

Date	Activity	Volume (cy) where relevant	Comments
1865	Waimea Pier built		relatively insignificant structure
1959	Kikioala Harbor built		
3/24/1964	Alaska tsunami		
1964	Kikiaola Harbor - stub breakwaters added		
1958	State "dumps" rock along Kekaha Beach		
May-1980	Original Kekaha Beach revetment built		completed in May 1980
1980+	Oomano Point revetment built		
11/23/1982	Hurricane Iwa		
Oct-1983	Kekaha Beach revetment repaired/extended		repairs as a result of Hurricane Iwa
9/11/1992	Hurricane Iniki		
1998-2001	Beach Nourishment of Kikiaola Beach (west of harbor, east of Oomano Pt)	15,000	Sand removed from Waimea Beach
2007-2009	Kikiaola Harbor dredging	30,000	Assuming a 10-yr dredge cycle, this would equate to a sedimentation rate of 3,000 cy/year
Sep-2009	Kikiaola Harbor improvements		

E. Seasonal Trends

Seasonal trends in beach characteristics are common worldwide. Seasonal changes in wave energy can bring about onshore-offshore transport, with beaches typically becoming narrower during periods of high wave energy and recovering when the wave energy decreases. Seasonal changes in wave direction can bring about longshore transport, with different areas accreting and eroding at different seasons.

Limited beach profiles are available for the Kauai RSM areas. Some beach profiles have been developed by the University of Hawaii (2010) and are shown in Figures F-1 and F-2. The Kekaha region profiles appear to indicate seasonal fluctuation, but opposite fluctuations for the two areas within the region: 1) the Kekaha Beach Park profile is generally wider during the August timeframe and narrower during the following January/February timeframe (the Jan-06 Kekaha Beach profile is an exception to this), versus 2) the Waimea Pier profile is opposite, i.e. the profile is generally wider during the January/February timeframe and narrower during the following August timeframe (the Feb-08 profile is an exception to this).

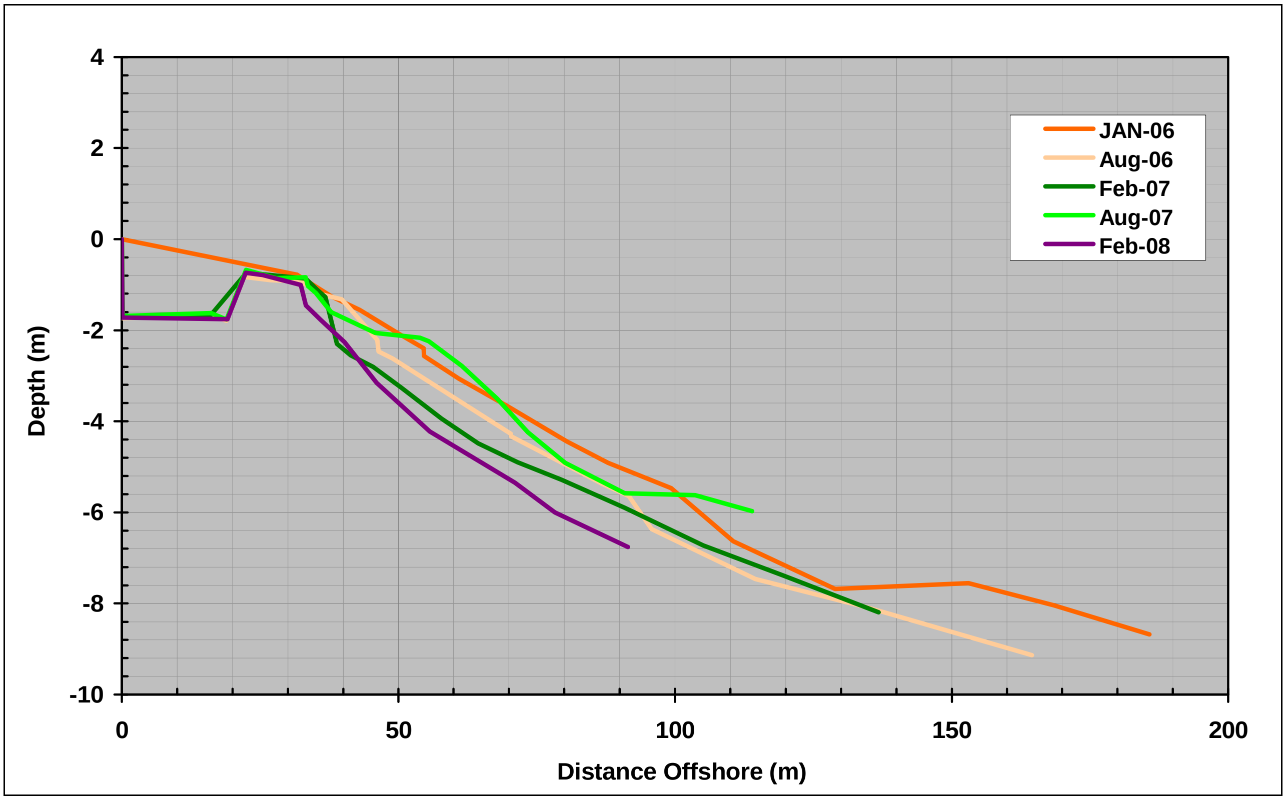


Figure F-1. Beach Profile at Kekaha Beach Park

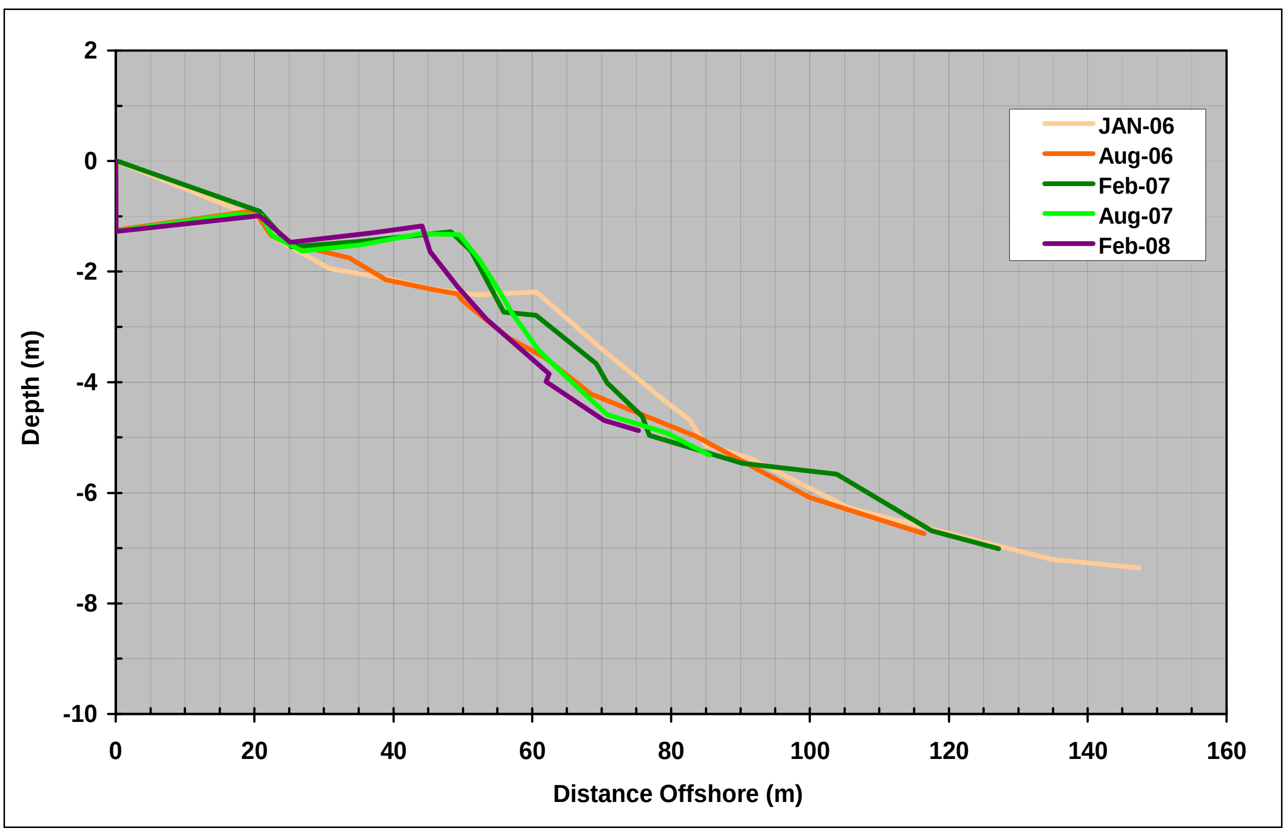


Figure F-2. Beach Profile at Waimea Pier

For the calculated volumetric erosion/accretion rates, seasonal variation is addressed by the linear regression / weighted least squares analysis of the volumes. The analysis is based on the total position uncertainty error provided by UH for each of the erosion maps, and the total position uncertainty error includes a factor for the seasonal fluctuation. This calculated seasonal fluctuation error is on the order of 50 feet for the Kekaha region.

The estimated potential error band associated with seasonal variation, and other uncertainty errors, is shown on each line graph as an error bar. This bar is an attempt to bound the potential range of beach volume within a given year and thus account for seasonal variation when comparing the limited shoreline data points.

F. Sand Loss Mechanisms

Although directional sediment budgets were not prepared for this study, it is assumed that any loss of sand is offshore; into offshore channels or into the dredged areas of the harbors. In general, these losses are used to balance the budget – they are not estimated independently. Additional modeling and analysis work would be valuable to confirm these general rates.

Sand loss mechanisms that are considered small, and therefore not usually included explicitly in sediment budgets, are as follows.

- **Sea level rise**. This is not strictly a sand loss mechanism. However, it must be considered in a sediment budget analysis, because the shoreline will retreat as the sea level rises unless additional sand is available to build the beach up.

  The nearshore profile for Hawaiian beaches is often stated to have a typical slope of 1 percent (e.g., Fletcher *et al.* 2008). This means that a sea level rise of 1 inch would cause the shoreline to retreat by 100 inches, or about 8 feet. However, this is not typical of the shorelines in the study area. The Kauai region shorelines have active profiles that range from approximately 5 to 10 percent slope, based on limited beach profiles analyzed. Therefore, a sea level rise of 1 inch would cause the shoreline to retreat by, at most, 20 inches or less than 2 feet. Sea level rise in the study area is approximately 0.06 inches per year (NOAA 2010b), which corresponds to a horizontal retreat rate of up to 1.2 inches or 0.1 feet per year. This is very small compared with the typical rates of shoreline retreat in the study area. Therefore, the effects of sea level rise upon the near-term sediment budget are very small.

- **Beachrock**. Beachrock is formed by cementation of beach sand in the intertidal zone. Beachrock can consist of sand or gravel cemented by calcium carbonate – which in turn is formed from, and impounds, calcareous sediments. There is some beachrock found in the Poipu region, but any beachrock would remain on the beach – and would not be removed from the beach volume. Therefore, its formation is not believed to be a significant component in coastal erosion in that area, and it may actually help to stabilize the beach in certain instances.

- **Abrasion and dissolution of calcareous sand grains**. This is believed to be important for calcareous beaches over the long-term (millennial scale). However, it has not been adequately quantified for use in a short-term sediment budget. Any uncertainties in this loss mechanism can be incorporated into the uncertainties in reef sediment production.

G. Climate Change

Over the longer term – possibly over a timescale as short as 50 years – the sediment budget could be affected by climate change. There are a number of contributing factors:

- The potential for increased sea level rise, possibly as much as 4 to 5 feet over the next century;
- The potential for changes in the wave climate;
- The potential for degradation to the reef structure (e.g., bleaching);
- The potential for increased dissolution of calcareous grains as the seas acidify.

These potential changes are not incorporated into the preliminary sediment budget given here, which describes the littoral system as in a steady state apart from changes in the rate of beach nourishment. The potential for these effects to change the sediment budget presented here should be addressed as this RSM Plan progresses and the science presents quantifiable changes.

II. Sediment Budget Results – Kekaha Region

A. Descriptions of Littoral Cells

The Kekaha study area spans approximately six miles on the southwest coast of Kauai from the Waimea River mouth to Kokole Point to the west. The study area is subdivided into the following three littoral cells (Figure F-3), listed below from east to west:

1. Waimea
2. Kikialoa Harbor, and
3. Kekaha Beach

These cells are described below and shown in the following figures. Each of the littoral cell figures includes the shoreline features which possibly affect the shoreline sediment transport.

Waimea Littoral Cell

The Waimea littoral cell extends from the Waimea River mouth and is bounded to the east by the eastern jetty of Kikiaola Harbor. Beaches in this cell are sandy and moderate in width, with the widest beaches typically in the western portion of this cell. The shoreline is composed of volcanic and terrestrial sand transported alongshore from the Waimea River as well as calcareous sand from the offshore fringing reef. The Waimea River provides approximately 5,000 cy/yr of sediment to the cell (Inman et.al. 1963).

The Waimea Pier is the only notable shoreline feature in this cell, and it has little impact on the sediment budget.

Kikiaola Harbor Littoral Cell

The Kikiaola Harbor Littoral Cell is confined to the area between the east and west breakwaters of the Kikiaola Small Boat Harbor. The boat harbor was constructed in 1959 and improvements were made to the breakwater structures, including re-alignment of the entrance channel, in 2009. The harbor has relatively shallow channels and only accommodates light draft vessels. The harbor is dredged on an approximately 10 year frequency by the USACE to maintain acceptable depths for navigation. The last harbor dredging occurred in 2009, which removed 30,000 cy of material from the channels.

Sediment inputs to the Kikiaola Harbor include deposition of sand via longshore sediment transport and an existing drainage ditch (Kikiaola Harbor Gulch), which is estimated to transport 1,600 cy/yr to the cell. Studies document that the harbor results in a disruption to the longshore transport regime, which is predominantly from the east to west. This is supported by review of historic aerials which show that the shoreline is typically wider in the vicinity of the east jetty and narrower in the vicinity of the west jetty. One sand bypassing project has been conducted in which 15,000 cubic yards of sand was removed from Waimea Beach, just east of the harbor, and placed on Kikiaola Beach, just west of the harbor.

Kekaha Beach Littoral Cell

The Kekaha Beach littoral cell captures an approximately four mile stretch of sandy beach from Kokole Point to the western jetty of the Kikiaola Harbor. This cell is the furthest west in the Kekaha study area and is characterized by wide sandy beaches with vegetated dunes on the western end to narrow to non-existent beaches on the eastern end.

Kekaha Beach Park is located in the central portion of this cell and shoreline protection in the form of a rock revetment exists along approximately 5,800 feet of the landward boundary of this beach. Starting in 1958, the State of Hawaii “dumped rocks” along Kekaha Beach to protect the highway, but the makeshift revetment was not successful in controlling erosion (USACE 1978). In 1980, the USACE and State of Hawaii Department of Transportation constructed the 5,800-foot-long engineered revetment and it was later repaired in 1983 as result of damage from Hurricane Iwa.

This area is exposed to swell from the northwest during winter and spring months, swell from the west and southwest in the summer, as well as persistent tradewinds.

Oomano Point Littoral Cell

A 4,600-feet-long revetment, contiguous to the one along Kekaha Beach exists along the shoreline in the vicinity of Oomano Point, which was constructed by the USACE to protect the Kaumualii Highway from erosion. This revetment also protects residential-lined shoreline in the east of Oomano Point region.

Erosion studies show that Kikiaola Small Boat Harbor has in part impeded the sediment transport to this cell from the east. Recession of the shoreline in the vicinity immediately west of the Kikiaola Harbor is particularly apparent.

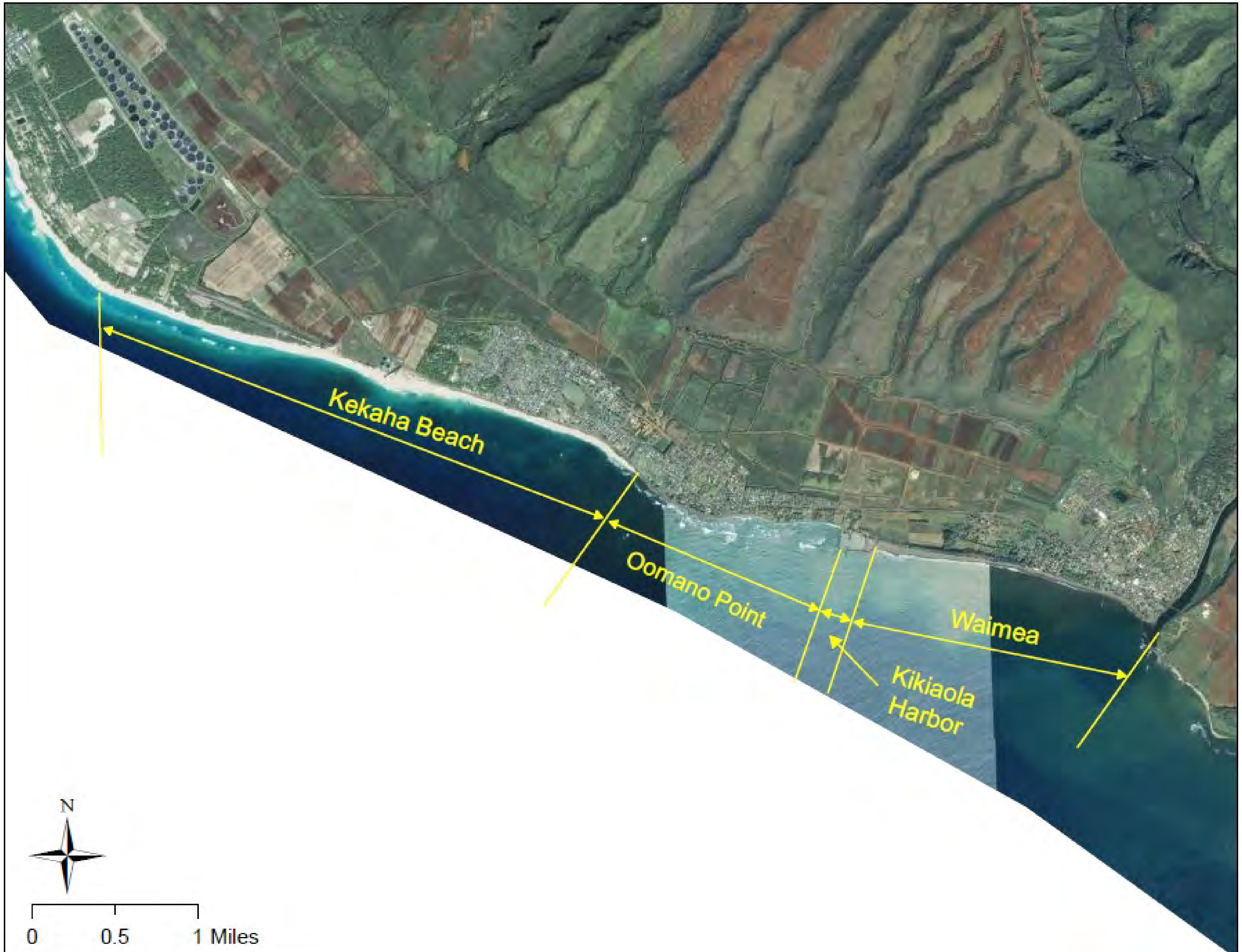
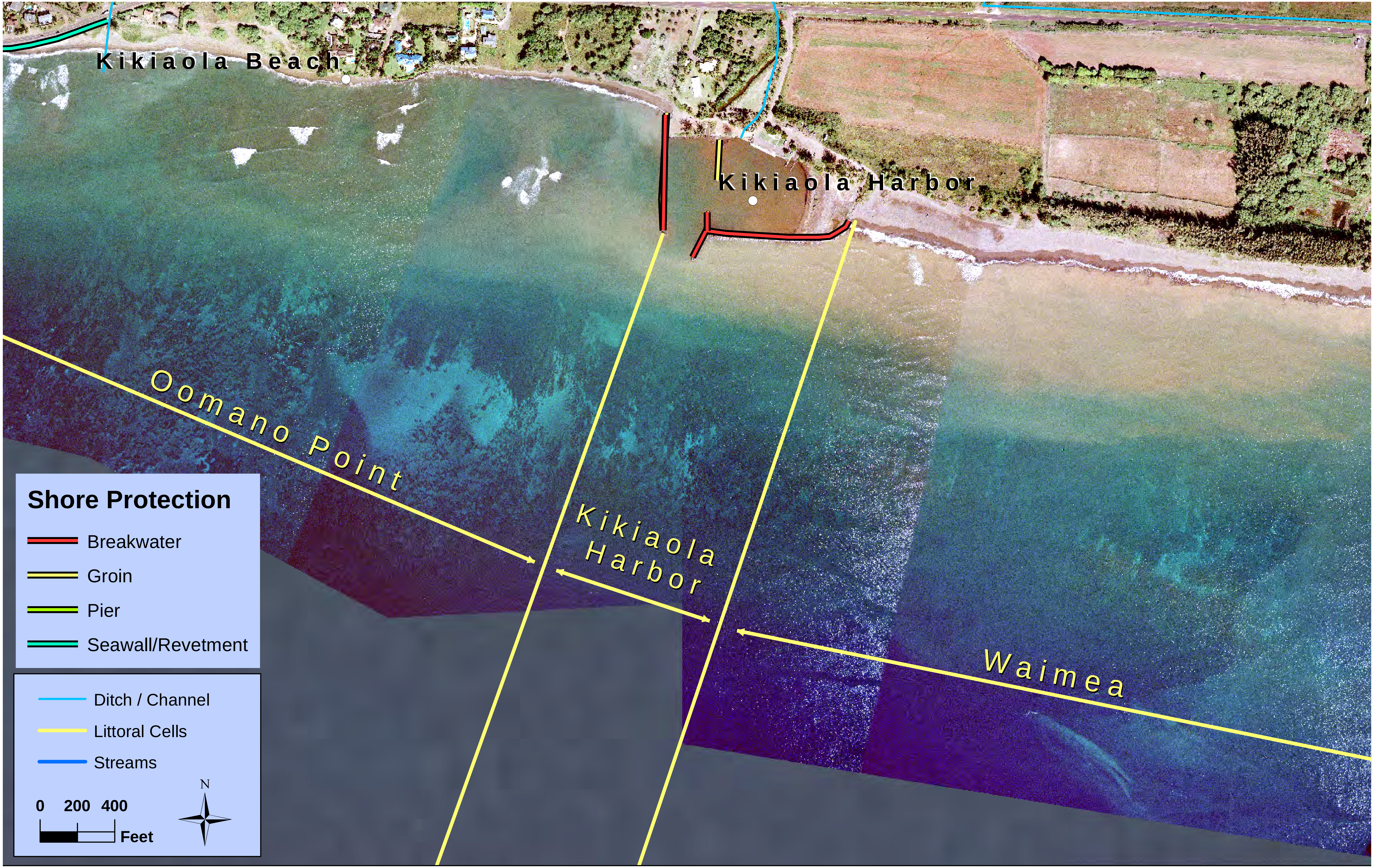
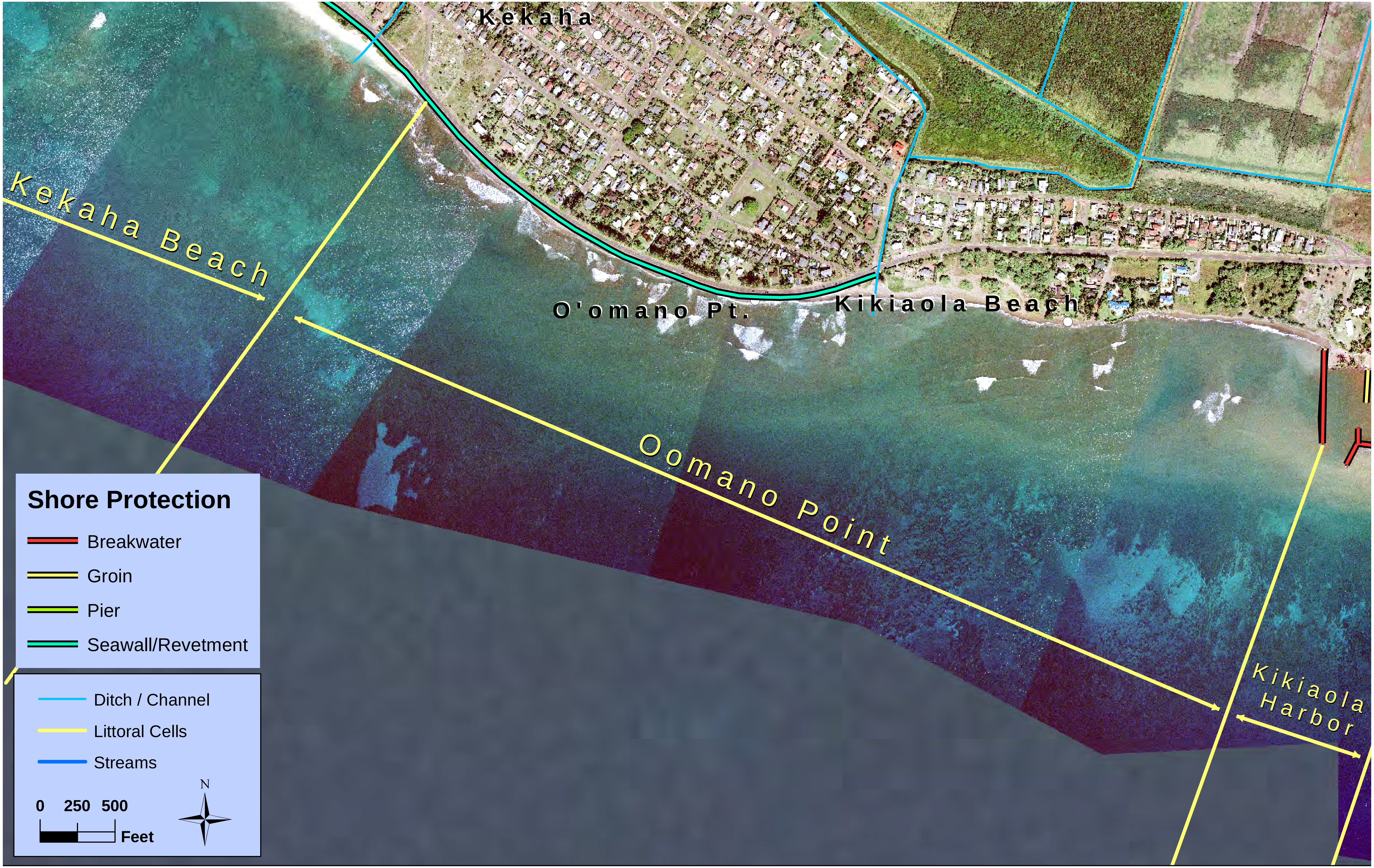
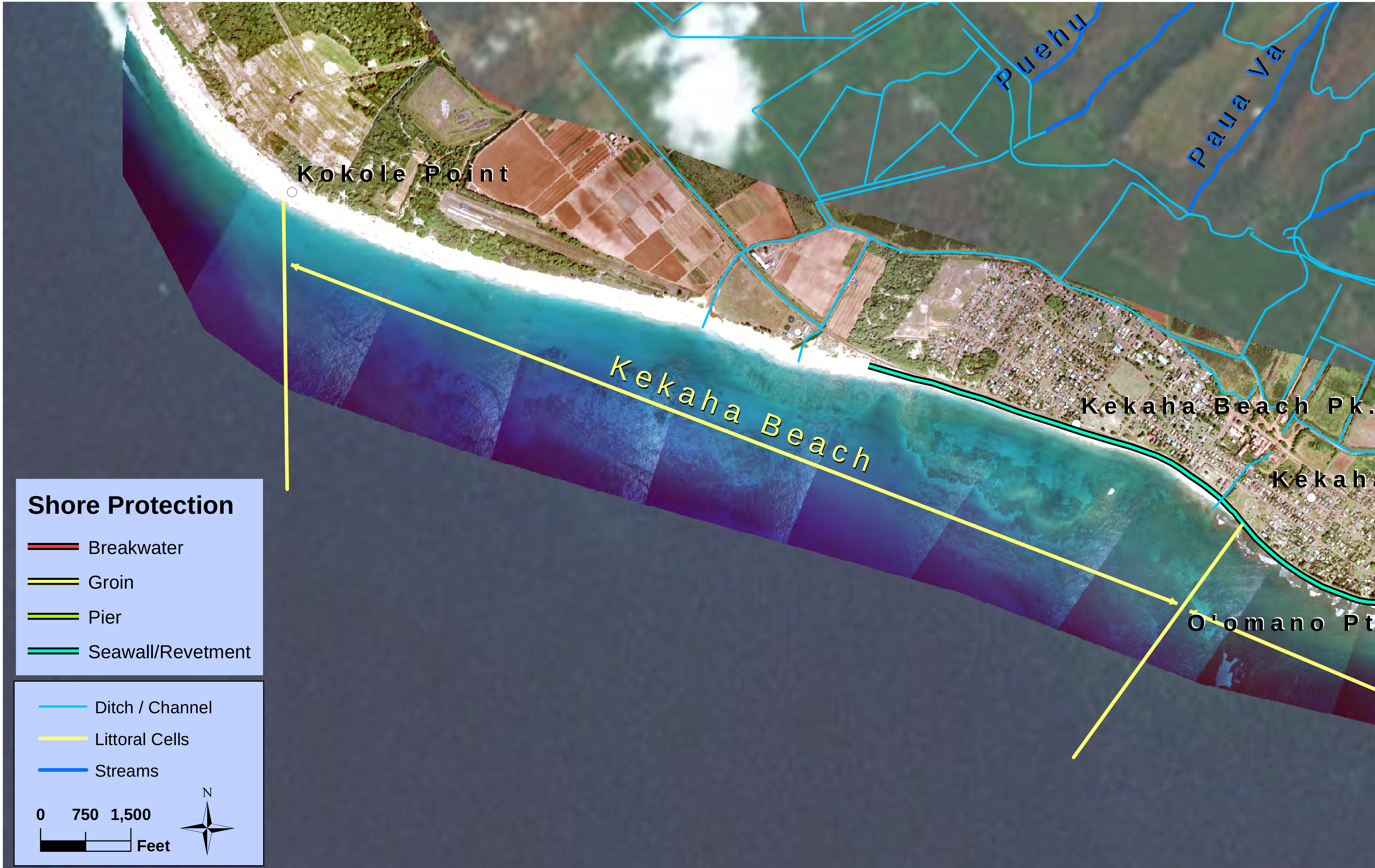


Figure F-3. Kekaha Region Littoral Cells

Kikiaola Harbor
Waimea Pier
Waimea R.
Kikiaola Harbor
Waimea
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
N
0
500
1,000
Feet


Kikiaola Beach
Kikiaola Harbor
Oomano Point
Kikiaola Harbor
Waimea
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 200 400
Feet
N


Kekaha
Kekaha Beach
O'omano Pt.
Kikiaola Beach
Oomano Point
Kikiaola Harbor
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 250 500
Feet
N


Kokole Point
Kekaha Beach
Kekaha Beach Pk.
Kekaha
O'omano Pt.
Puehu
Paua Va
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 750 1,500
Feet
N

B. **Beach Volumes**

For each littoral cell, except for Kikiaola Harbor, a graph of beach volume versus time was developed based on historical shorelines provided by the University of Hawaii (2010) and using a conversion factor of 0.40 cubic yards per square foot of beach.

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

- The points do not necessarily bound the minimum and maximum beach volumes.
- It is probable that the chronological transitions from erosional to accretional conditions (and vice versa) are not at the exact date shown by the break in the line in the graph. As an example, the Waimea littoral cell graph seems to indicate that the area's transition from erosional to accretional occurred in 1950. However, it is likely that the erosional trend continued beyond 1950 and turned accretional (transitioned) in the early 1960s when Kikiaola Harbor was built.

Following are graphs of each of the cells within the Kekaha region (Figures F-5 to F-7), as well as a summary graph which includes all cells in the region (Figure F-4). The line graphs show the estimated historical beach volumes over the time period of shoreline data records and the bar graphs show the change rates (cy per year) over different time periods of interest. Potentially significant events are shown on the line graphs. Table F-2 summarizes the associated erosion and accretion rates over the time period of record and over the most recent time period for each of the littoral cells. Figures F-8 through F-11 show the most recent change rate (sediment budget) for each of the littoral cells.

Table F-2. Kekaha Region Beach Sand Volume Change Rates

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

It is interesting to compare these long-term average change rates with volume changes due to only seasonal fluctuation. Based on the median seasonal fluctuation calculated by University of Hawaii (2010) and assuming this median fluctuation occurred along the entire length of beach, the potential seasonal volume fluctuations for Waimea and Kekaha Beach cells are an order of magnitude higher than the long-term average change rates.

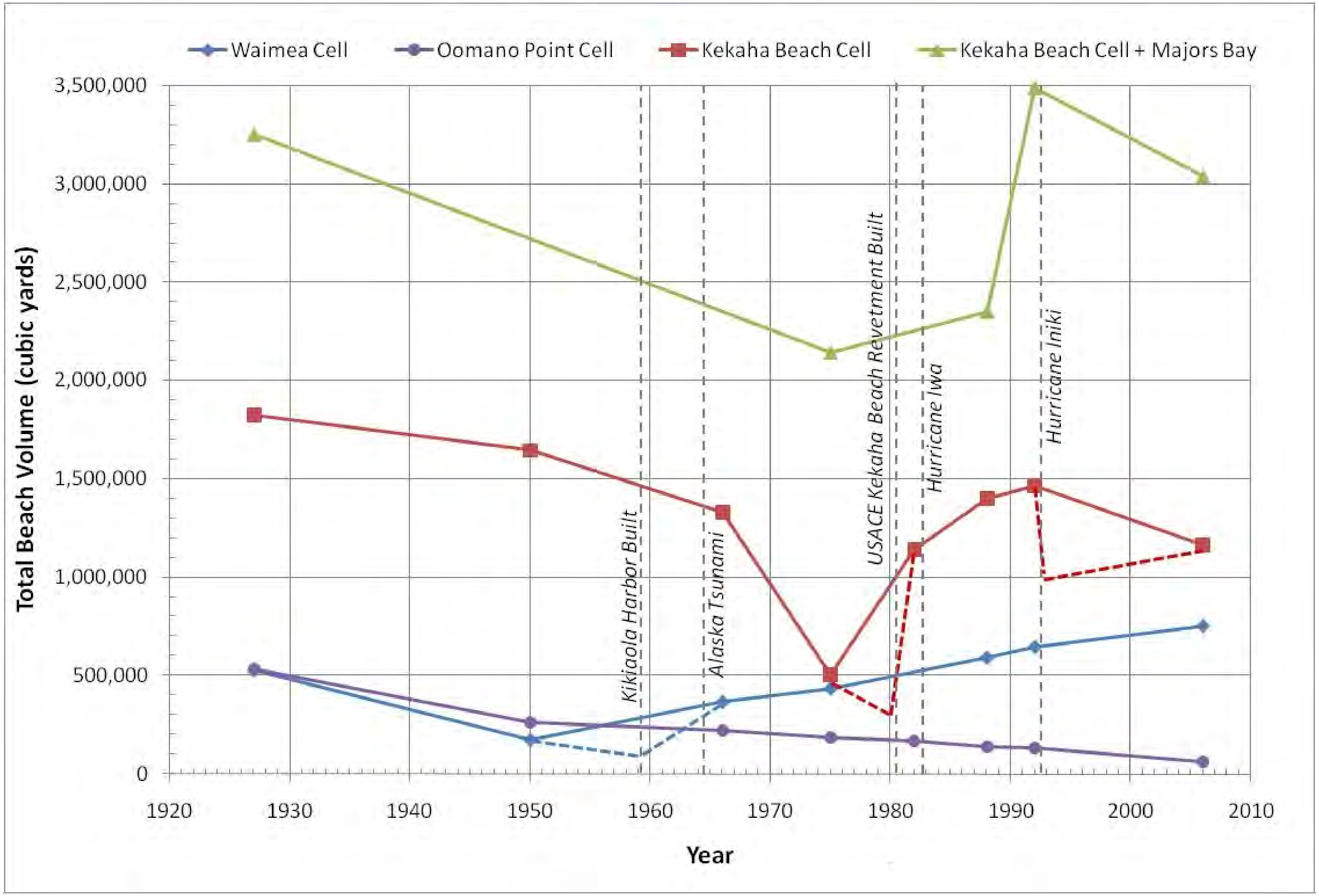


Figure F-4. Historical Beach Volumes of Kekaha Region Littoral Cells

Results for the Kekaha Region littoral cells indicate the following:

- The **Waimea** littoral cell demonstrates a classic reaction to the introduction of a shore-perpendicular structure on the downdrift end of the cell. The dominant transport in this area is from east to west, so when the Kikiaola Light Draft Harbor jetty was built, the cell switched from being erosional to accretional. The cell has been accreting at a relatively significant rate (over 10,000 cy per year) since the construction of the harbor.
- A main source of sediment is likely the Waimea River (estimated yield rate of 5,000 cy per year) which is transported to the west and trapped by the Kikiaola Harbor breakwater. Inman et al (1963) estimates an additional carbonate sand input to this area of 7,000 cy per mile per year, which could equate to an additional 11,000 cubic yards of sand to the Waimea area. The accretion rate based on this RSM analysis is higher than the impoundment rates calculated by previous studies, including a USACE-POH estimate of 4,000 cy per year (Sea Engineering, 2008b). The Sea Engineering report notes though the uncertainties involved, and that the rates could be off by orders of magnitude.
- Dredge records suggest that sediment accumulates within **Kikiaola Harbor** at a rate of 600 to 3,000 cubic yards per year. This compares relatively well to the assumed only source of sediment to the harbor, Kikiaola Harbor Gulch which has an estimated yield of 1,600 cubic yards per year and which discharges directly into the harbor. It is assumed that longshore littoral sediment does not make its way into the harbor. A potential project for future consideration is to reroute the Kikiaola Harbor Gulch to discharge downdrift (to the west) of the harbor and thus minimize the amount of maintenance dredging of the harbor.
- The **Oomano Point** cell has been in a relatively steady erosional state over the last decade. Comparison of the line graphs of the two littoral cells indicate that the Oomano Point and Kekaha Beach cells have separate littoral transport processes.
- The **Kekaha Beach** cell has experienced both erosion and accretion over the study period. In recent geologic history, Kekaha Beach was the southeastern extent of the portion of the Mana Coastal Plain which had been accreting (USACE 1978). Analysis of the volumes generated by this study indicates: a) an erosional trend in the study period prior to 1975, b) a significant accretion period from 1975 to 1992, and then c) back to an erosional trend from 1992, based on a single data point (2006) since that time. The latter “trend” may have been a single event loss during Hurricane Iniki, however the data are insufficient to identify this loss. It is not known what caused the Kekaha Beach erosional pattern to switch to an accretional pattern from the mid 1970’s to the end of the 1990s. A USACE (1978) analysis also indicates that Kekaha Beach was eroding during the period of 1950-1976, but cites an accretion period from 1936-1950. The latter is probably related to the 1928 shoreline data and its associated larger beach volume.
- The beaches in this region did not seem to have lasting damage from Hurricane Iwa.

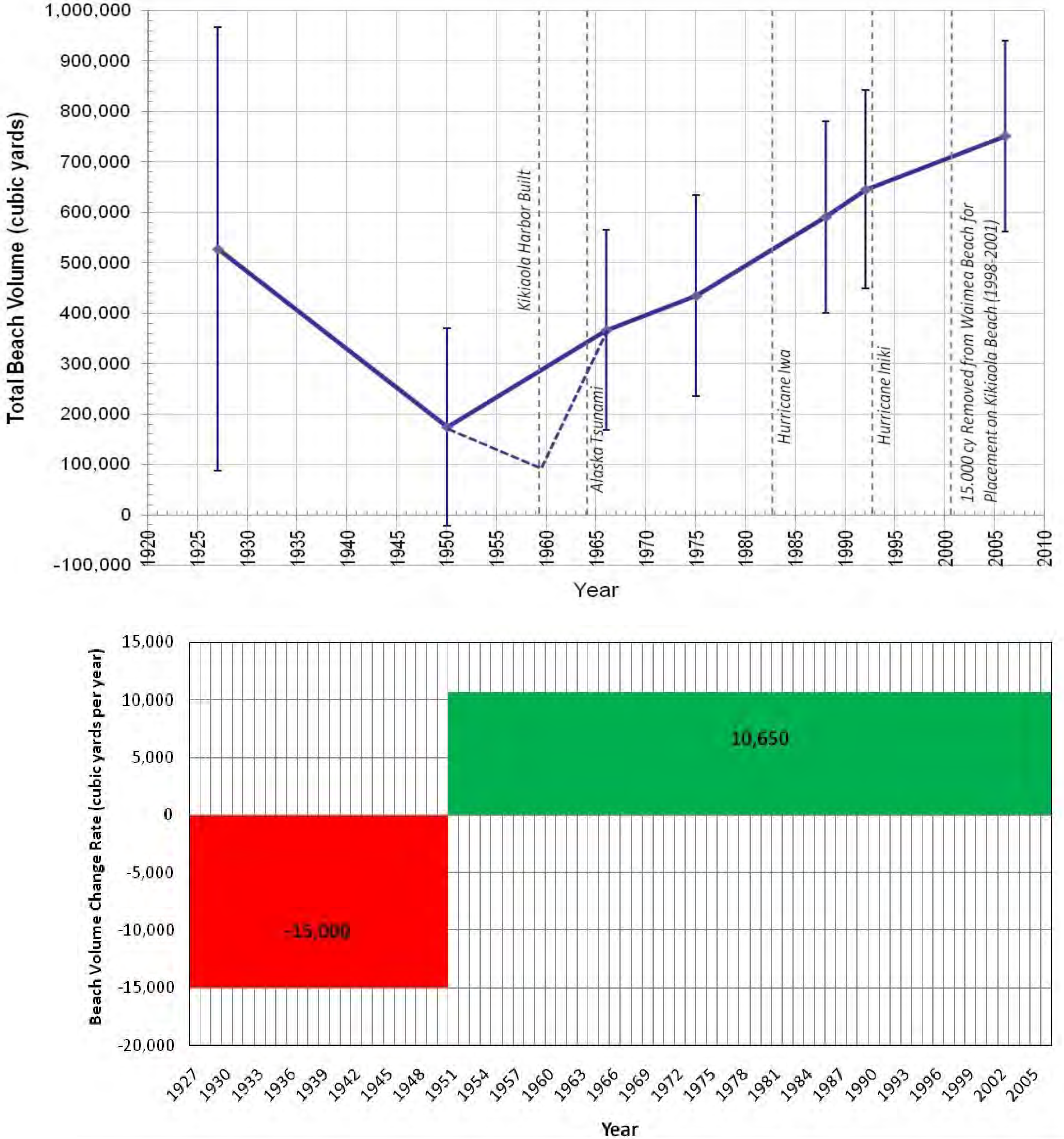
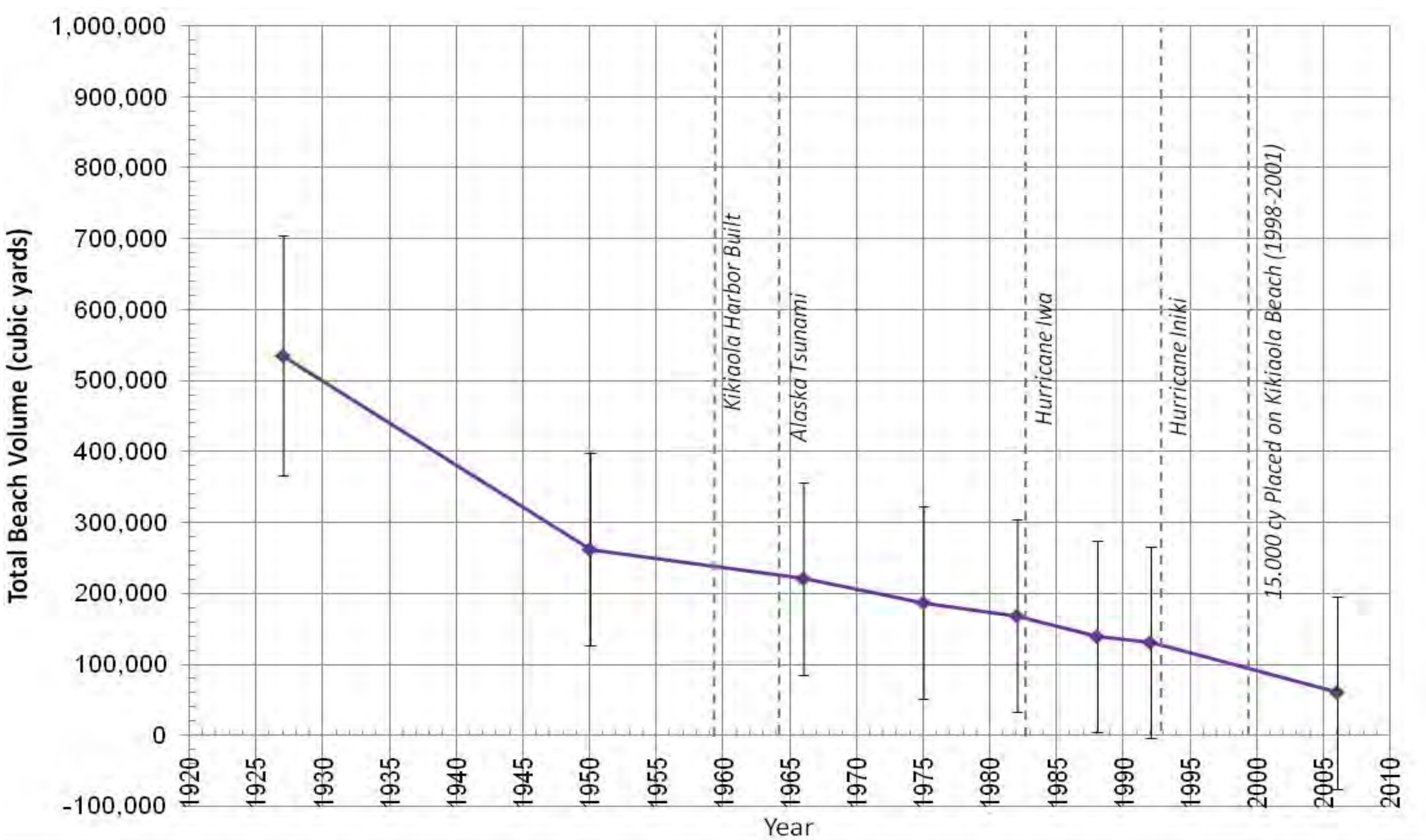


Figure F-5. Historical Beach Volumes / Change Rates for Waimea Littoral Cell



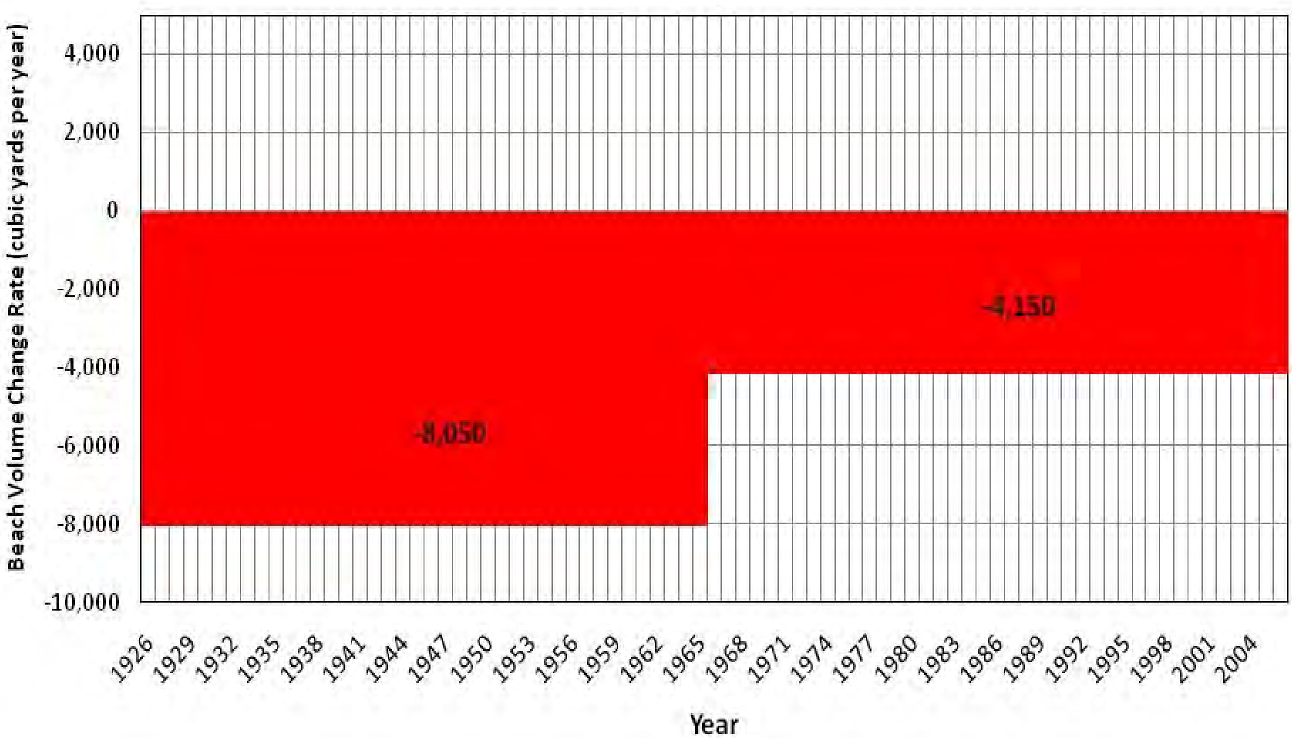


Figure F-6. Historical Beach Volumes / Change Rates for Oomano Point Littoral Cell

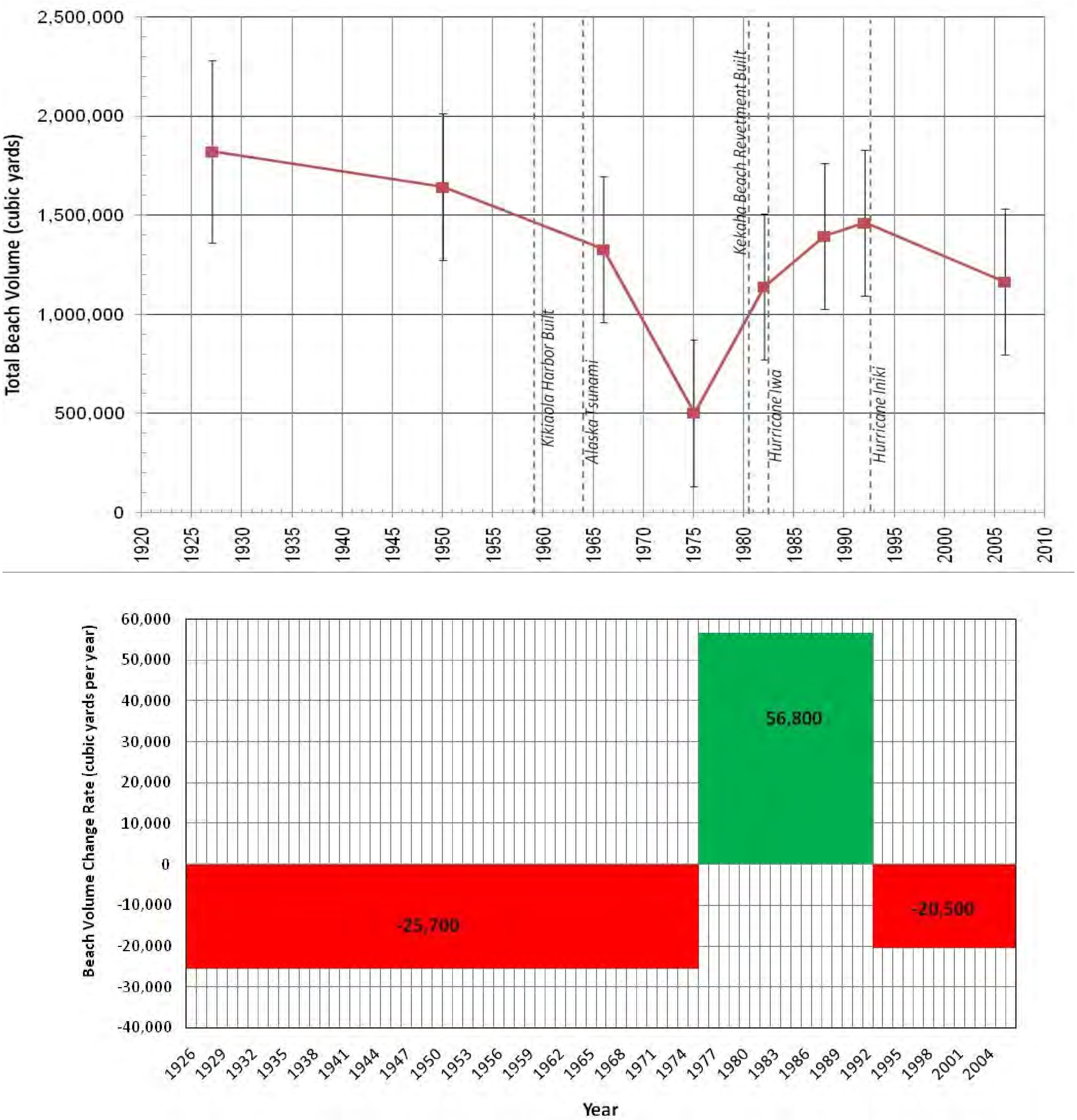


Figure F-7. Historical Beach Volumes / Change Rates for Kekaha Beach Littoral Cell

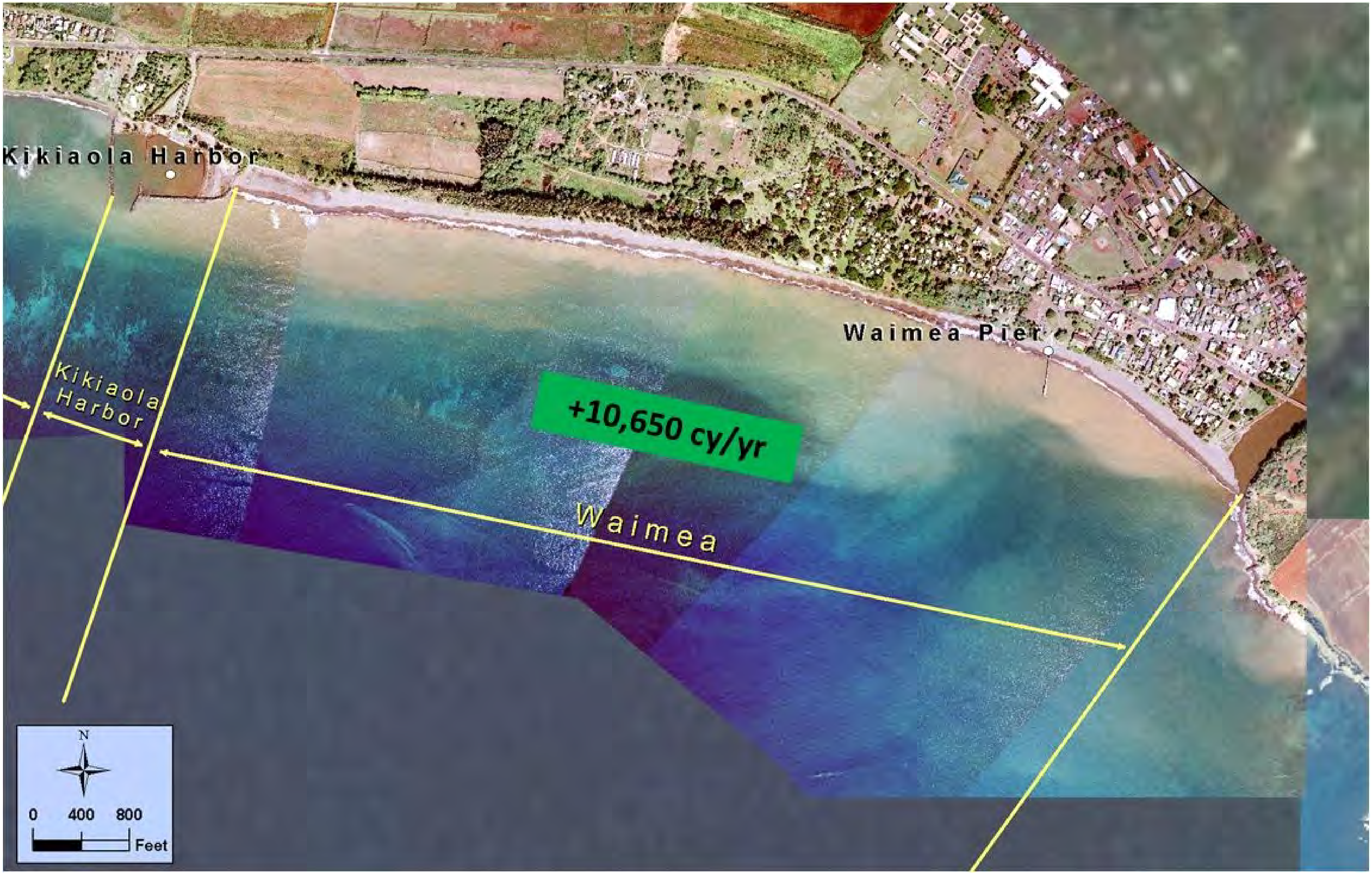


Figure F-8. Beach Volume Change Rate for Waimea Littoral Cell

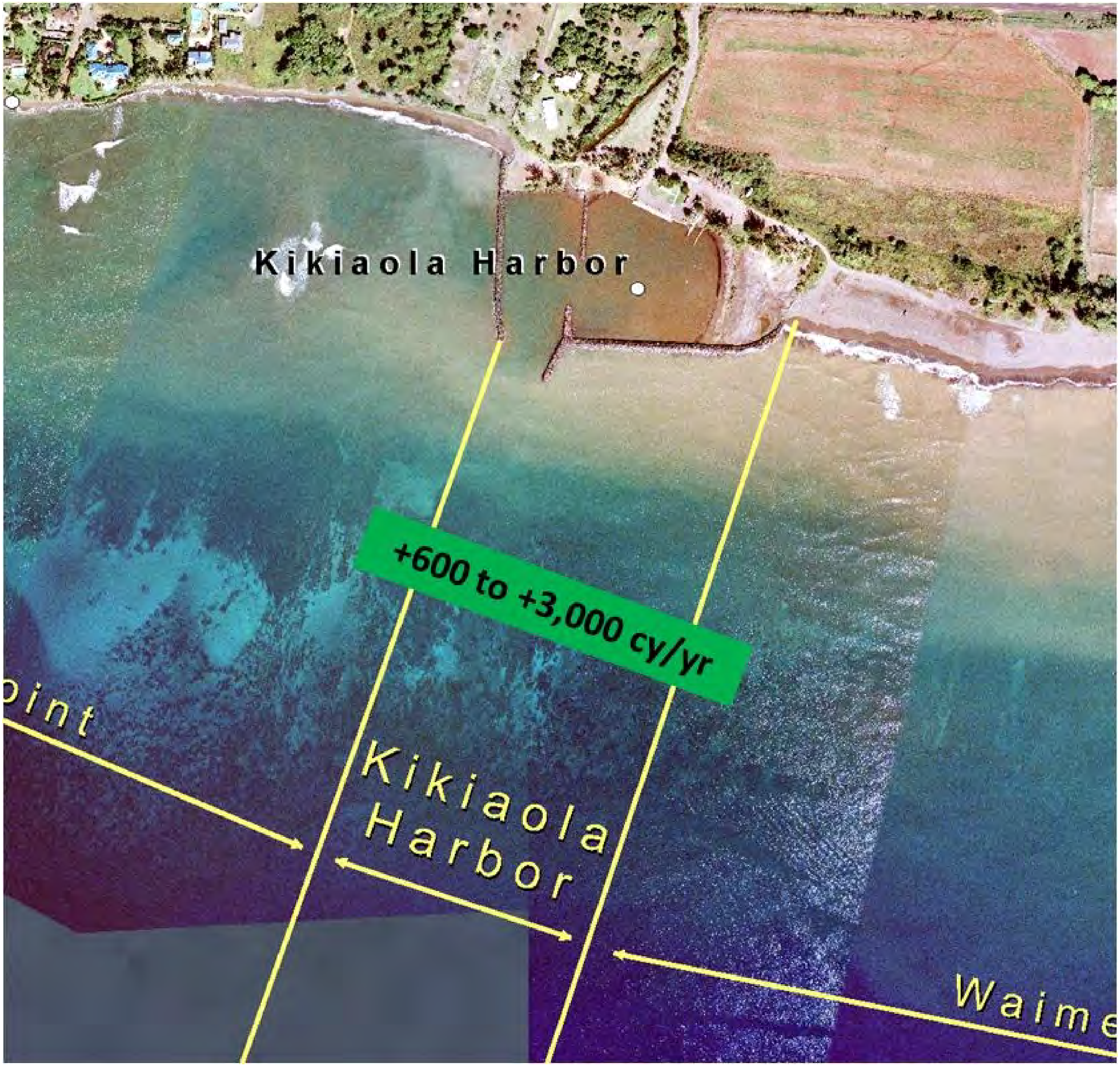


Figure F-9. Beach Volume Change Rate for Kikiaola Harbor Littoral Cell

Figure F-10. Beach Volume Change Rate for Oomano Point Littoral Cell

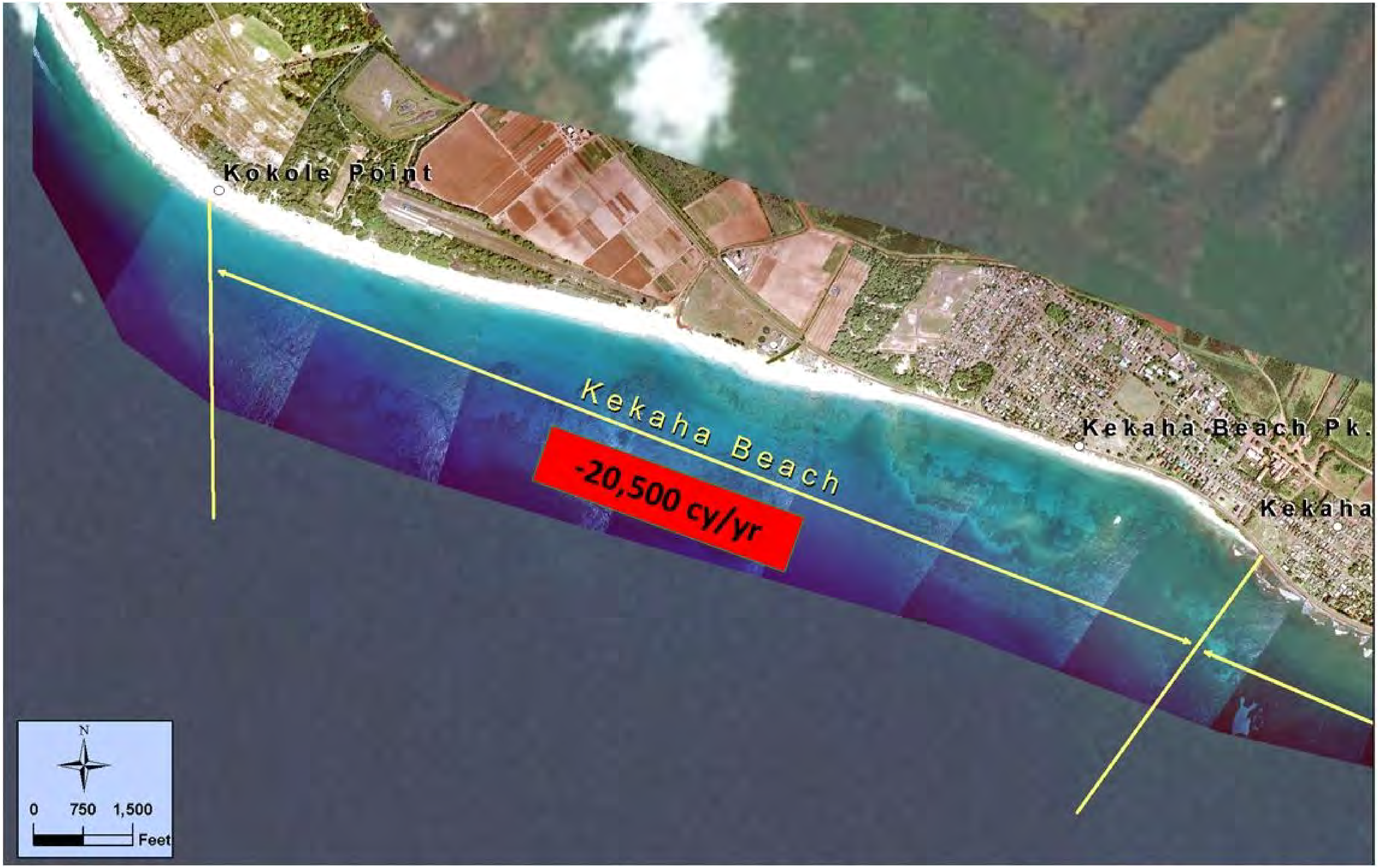


Figure F-11. Beach Volume Change Rate for Kekaha Beach Littoral Cell

APPENDIX G SEDIMENT TRANSPORT BUDGETS – POIPU REGION

I. Sediment Budget Methodology

Sections A, B, C, F, G - See description provided in previous appendix (Kekaha Region Sediment Transport Budgets)

D. **Structures, Storms, and Historical Sand Placement**

Table G-1 provides an overview of the known sand placement activities, along with a chronology of other significant coastline activities, in the Poipu region. Beach nourishment on Kauai seems to be limited. There were only two projects confirmed in the Poipu region, a 1,000 cubic yard nourishment of Poipu Beach in 2007(DLNR 2010) and a 500 cy nourishment of Kukui'ula Beach in 2001 (DLNR 2011).

Table G-1. Poipu Region Structures, Storms, Historical Sand Placement

Date	Activity	Volume (cy) where relevant	Cell	Comments
	Kukui'ula Small Boat Harbor built		Kuku'iula	
3/24/1964	Alaska tsunami			
11/23/1982	Hurricane Iwa			
9/11/1992	Hurricane Iniki			
1990s	Brennecke Beach Nourishment	8,000	East Poipu	workshop participant recalled this, but could not be confirmed.
w/in last 10 yrs	DLNR Maintenance dredging of Kuku'iula Small Boat Harbor		Kuku'iula	
2001	Kukui'ula Beach Nourishment	500	Kuku'iula	
Oct-2007	Poipu Beach Nourishment	1,000	Central Poipu	not sure if this ever happened

E. Seasonal Trends

Seasonal trends in beach characteristics are common worldwide. Seasonal changes in wave energy can bring about onshore-offshore transport, with beaches typically becoming narrower during periods of high wave energy and recovering when the wave energy decreases. Seasonal changes in wave direction can bring about longshore transport, with different areas accreting and eroding at different seasons.

Limited beach profiles are available for the Kauai RSM areas. One beach profile within the Poipu region has been developed by the University of Hawaii (2010) and is shown in the Figure G-1. It does not appear to indicate a significant seasonal variation.

For the calculated volumetric erosion/accretion rates, seasonal variation is addressed by the linear regression / weighted least squares analysis of the volumes. The analysis is based on the total position uncertainty error provided by UH for each of the erosion maps, and the total position uncertainty error includes a factor for the seasonal fluctuation. This calculated seasonal fluctuation error is on the order of 8 feet for the Poipu region.

The estimated potential error band associated with seasonal variation, and other uncertainty errors, is shown on each line graph as an error bar. This bar is an attempt to bound the potential range of beach volume within a given year and thus account for seasonal variation when comparing the limited shoreline data points.

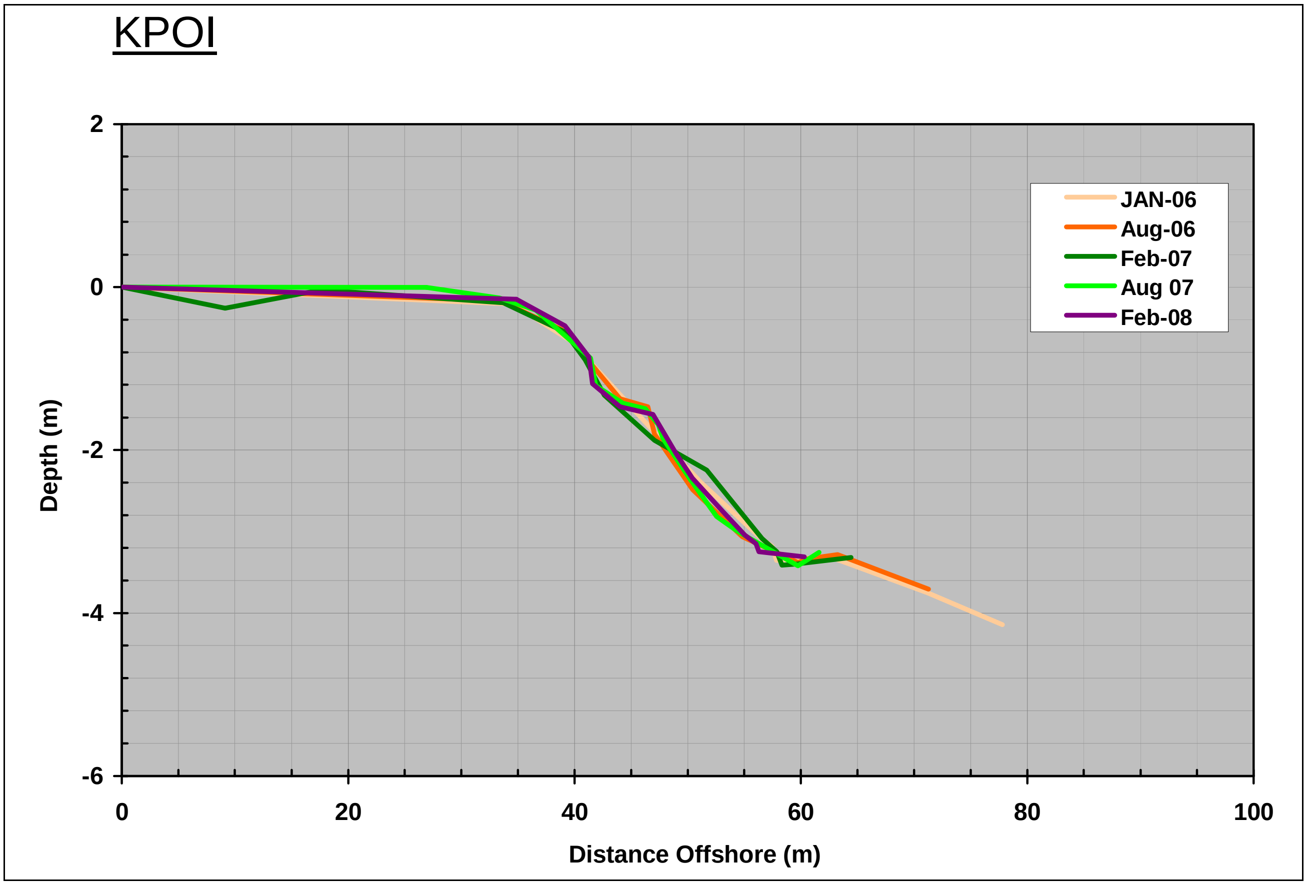


Figure G-1 Beach Profile at Poipu Beach Park

II. Sediment Budget Results – Poipu Region

A. Descriptions of Littoral Cells

The Poipu study area extends approximately five and a half miles along the southern Kauai coastline from Lawa'i Bay in the west to Shipwreck Beach to the east. The coastline along this reach is rocky with offshore reefs and numerous headlands and pocket beaches. The reach is divided into the following littoral cells (shown in Figure G-2), listed below from west to east:

1. Lawa'i
2. Kukui'ula
3. Ho'ai
4. Punahoa
5. West Poipu
6. Central Poipu
7. East Poipu
8. Shipwreck Beach

These cells are described below and shown in the following figures. Each of the littoral cell figures includes the shoreline features which possibly affect the shoreline sediment transport.

Lawa'i Littoral Cell

The Lawa'i Littoral Cell is small at only approximately 1,000 feet in length and extends from the Lawa'i Bay to the west and Ka Lae O Kaiwa to the east. The shoreline is characterized as a small pocket beach bounded by basaltic headlands on either end. The Lawa'i Stream discharges to the bay, but its sediment yield rate is not known. High relief cliffs and the Manoloa Stream are located immediately west of the Lawa'i Bay littoral cell.

Kukui'ula Littoral Cell

The Kuku'ula Littoral Cell extends from Ka Lae O Kaiwa to the west to Kalaekiki Point to the east. The cell consists of rocky shoreline with two pocket beaches (Sprouting Horn Park and Kukui'ula Landing Park). The Aepo Stream discharges into the cell in the vicinity of the Kukui'ula Small Boat Harbor. A jetty protects the southern end of the Kukui'ula Harbor and shoreline revetment exists from Aepo Stream to the west to protect oceanfront residential homes.

Ho'ai Littoral Cell

Ho'ai Littoral Cell extends from Kalaekiki Point to Nahuma'alo Point. The shoreline is composed of basalt rock headlands, sand perched on rocky shoreline, and sand beach. Shoreline protection in the form of a rock revetment exists to the north of Ho'ai Bay. Additionally, vertical seawalls front some of the beach front residential homes along this reach.

Punahoa Littoral Cell

The Punahoa Littoral Cell spans from Nahuma'alo Point to Laeokamilo Point. The shoreline is composed of basaltic rock headlands, sand perched on rocky shoreline, and sand beach. Waikomo River discharges to the western portion of the cell, but its sediment yield rate is not known.

West Poipu Littoral Cell

The West Poipu Littoral Cell is small (approximately 1,500 feet) and includes the area from Laeokamilo Point to the Waiohai Marriott Resort. The cell consists of a moderate width pocket beach called Kaihuna Beach.

Central Poipu Littoral Cell

The Central Poipu Littoral Cell is small (approximately 1,500 feet) and spans from the Waiohai Marriott Resort to west end of Brennecke Beach. Poipu Beach Park is in the center of this cell, which is a popular recreational beach. Nukumoi Point is the most prominent shoreline feature as it is a semi-detached headland with a large salient developed in its lee at Poipu Beach. The cell has the widest beaches within the study area.

East Poipu Littoral Cell

The East Poipu Littoral Cell extends from just east of Nukumoi Point to tip of the headland in the town of Poipu. The cell consists almost entirely of a rocky shoreline with the exception of the small pocket beach fronting the Poipu Beach County Park.

Shipwreck Beach Littoral Cell

The Shipwreck Beach Littoral Cell spans 1.3 miles from the tip of the headland in the town of Poipu to Shipwreck Beach in vicinity of Poipu Bay Resort Golf Course. This cell faces southeast and includes the rocky headland of Poipu, a small cobble beach within Keoniloa Bay and high relief bluffs in the vicinity of Makawehi Bluff on its northern end. No shoreline protection exists along the cell.

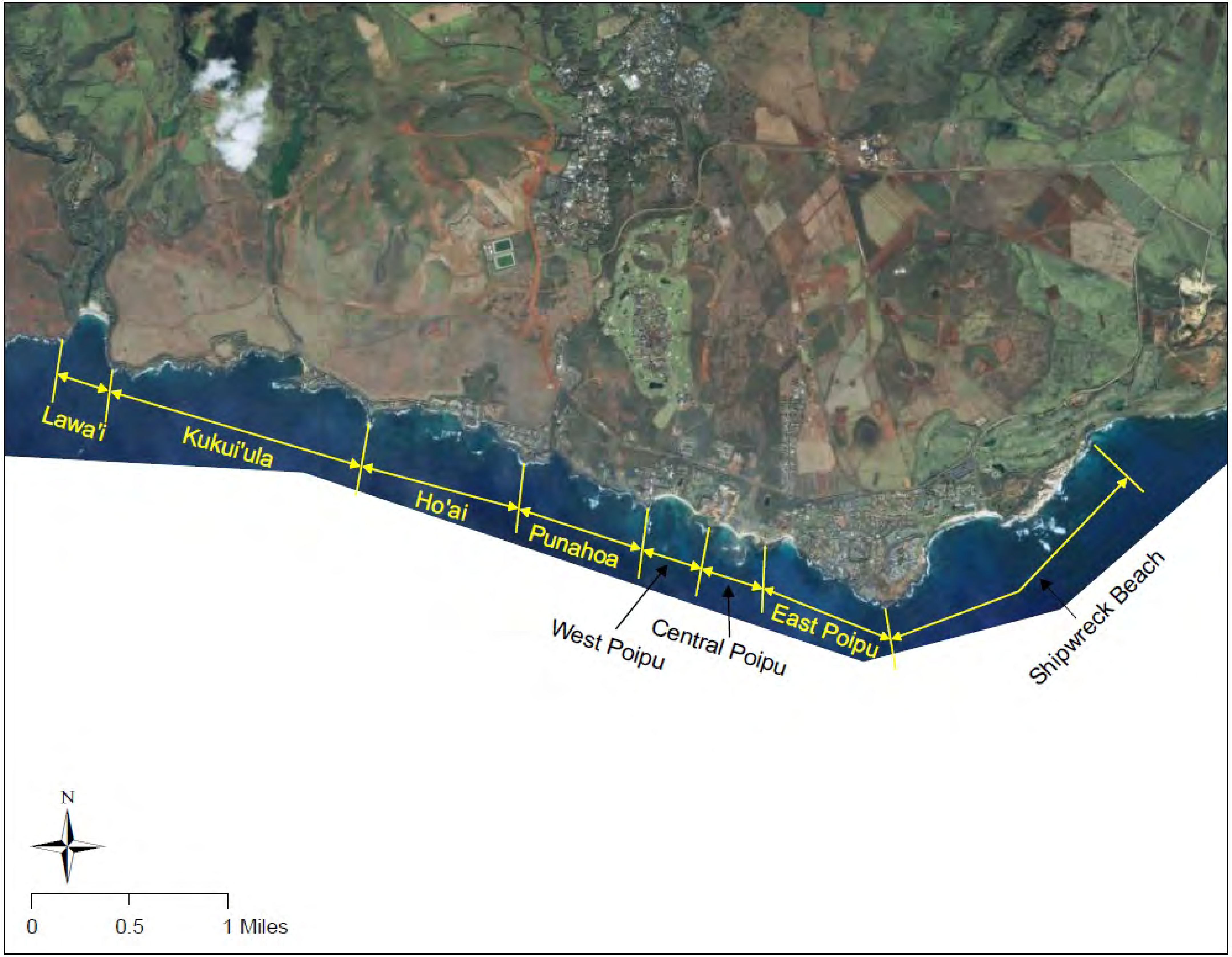
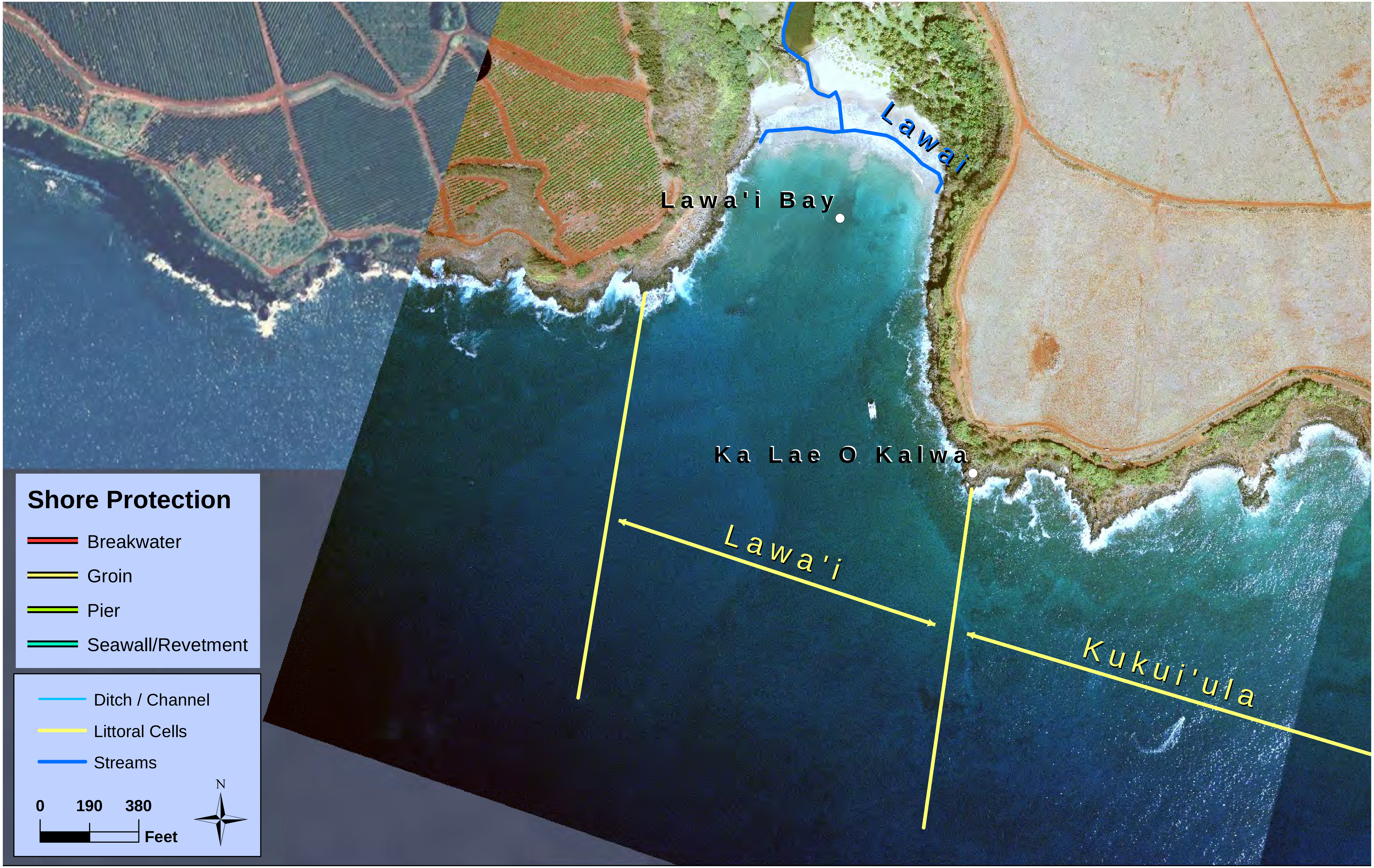
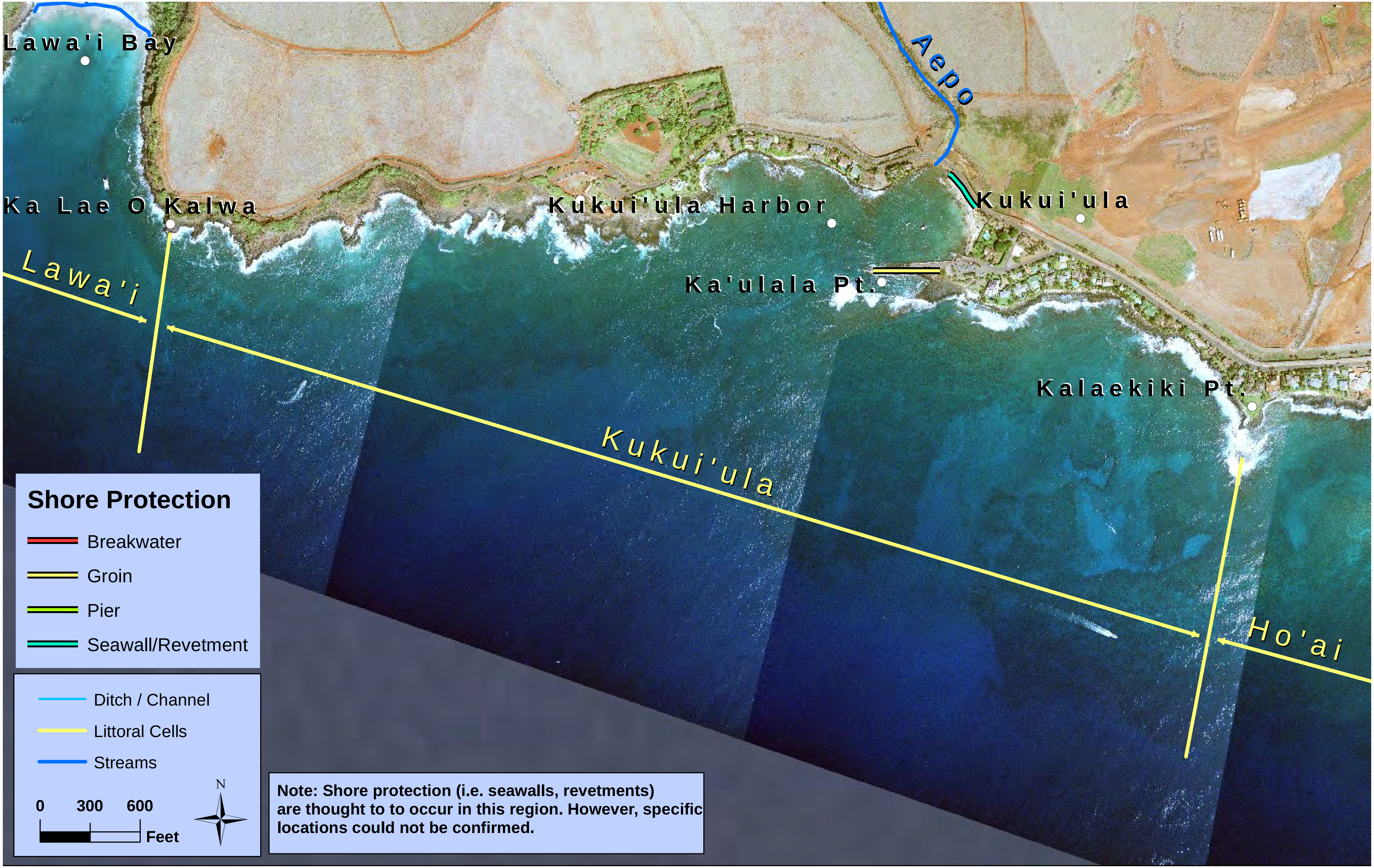
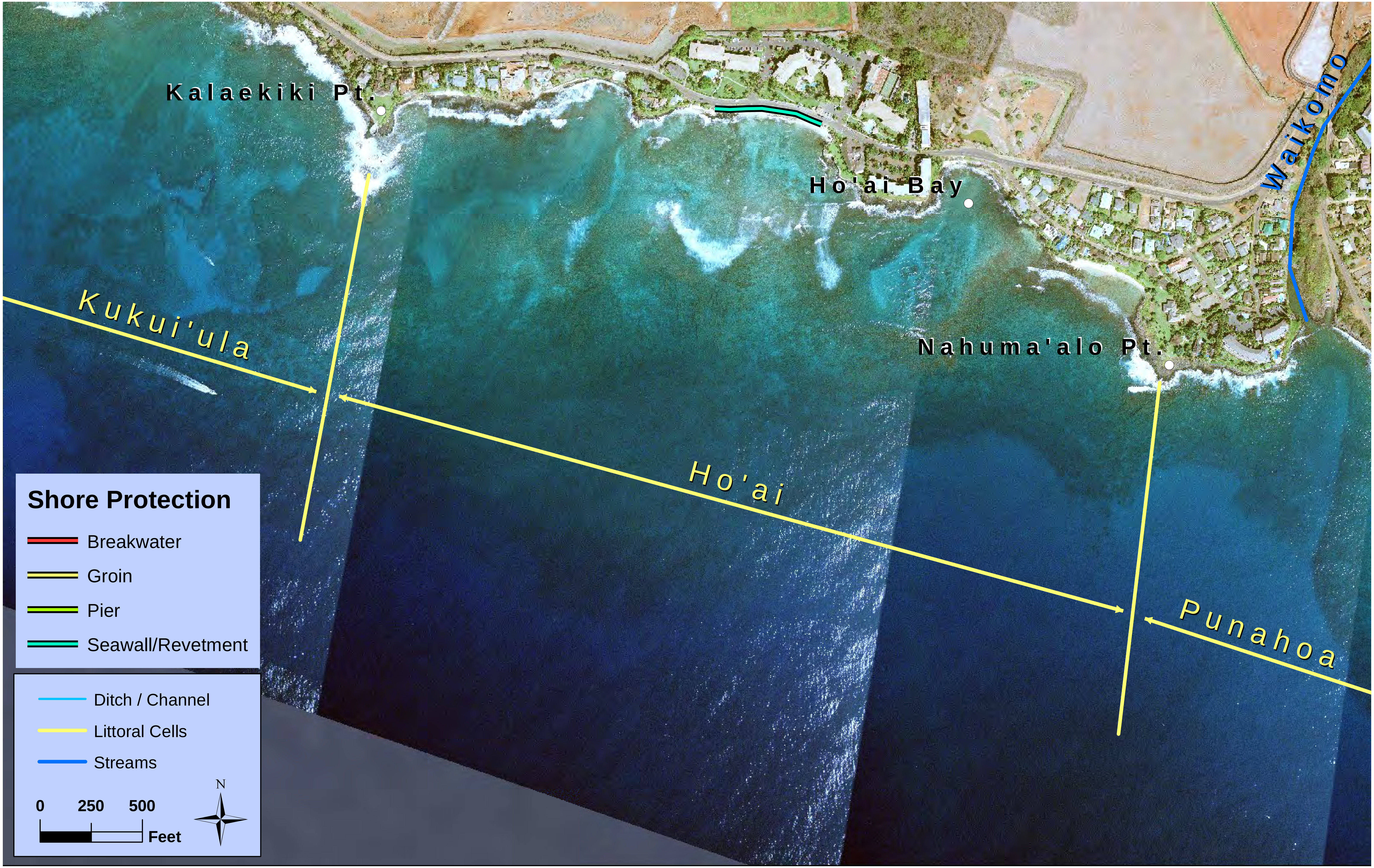


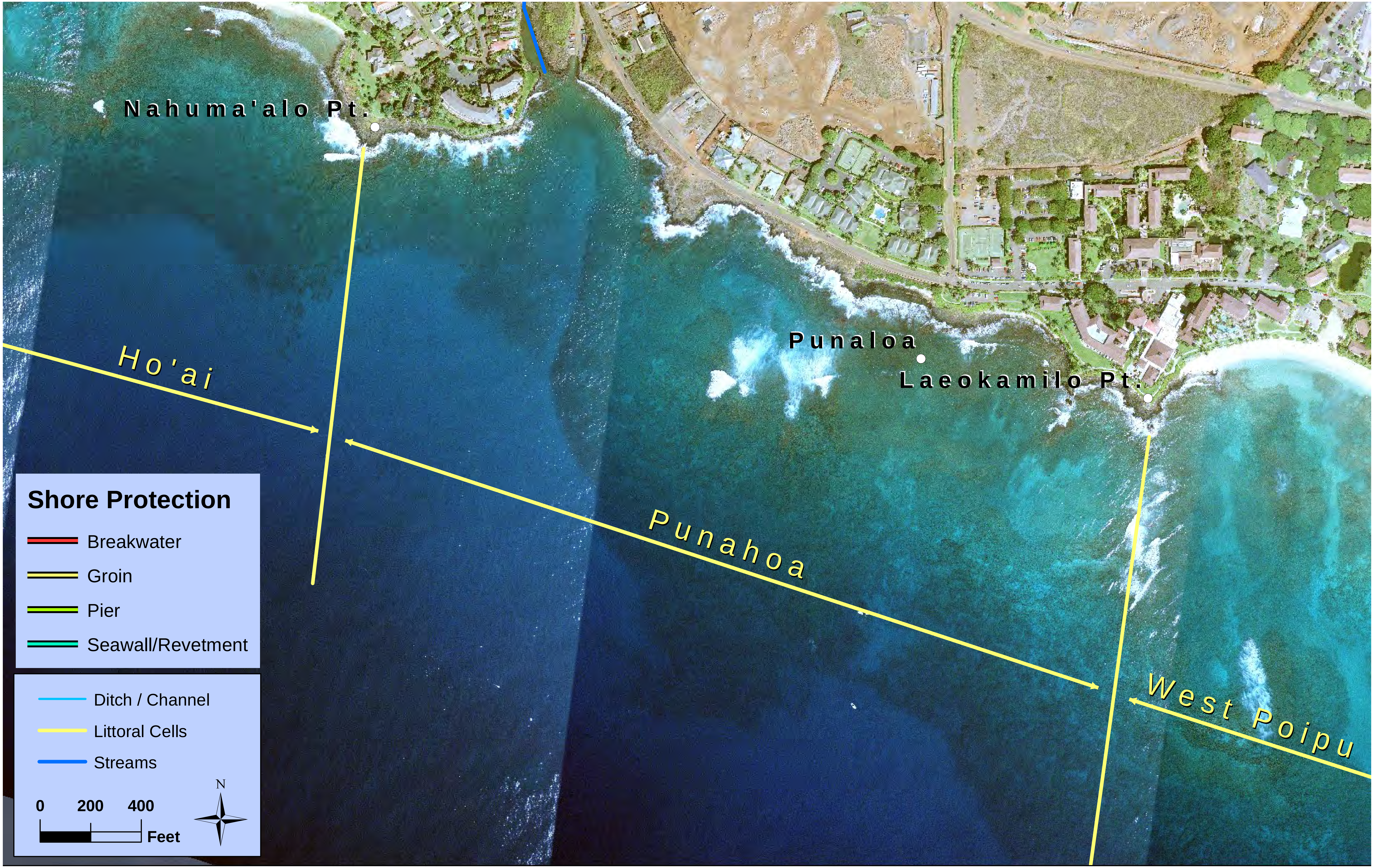
Figure G-2. Poipu Region Littoral Cells

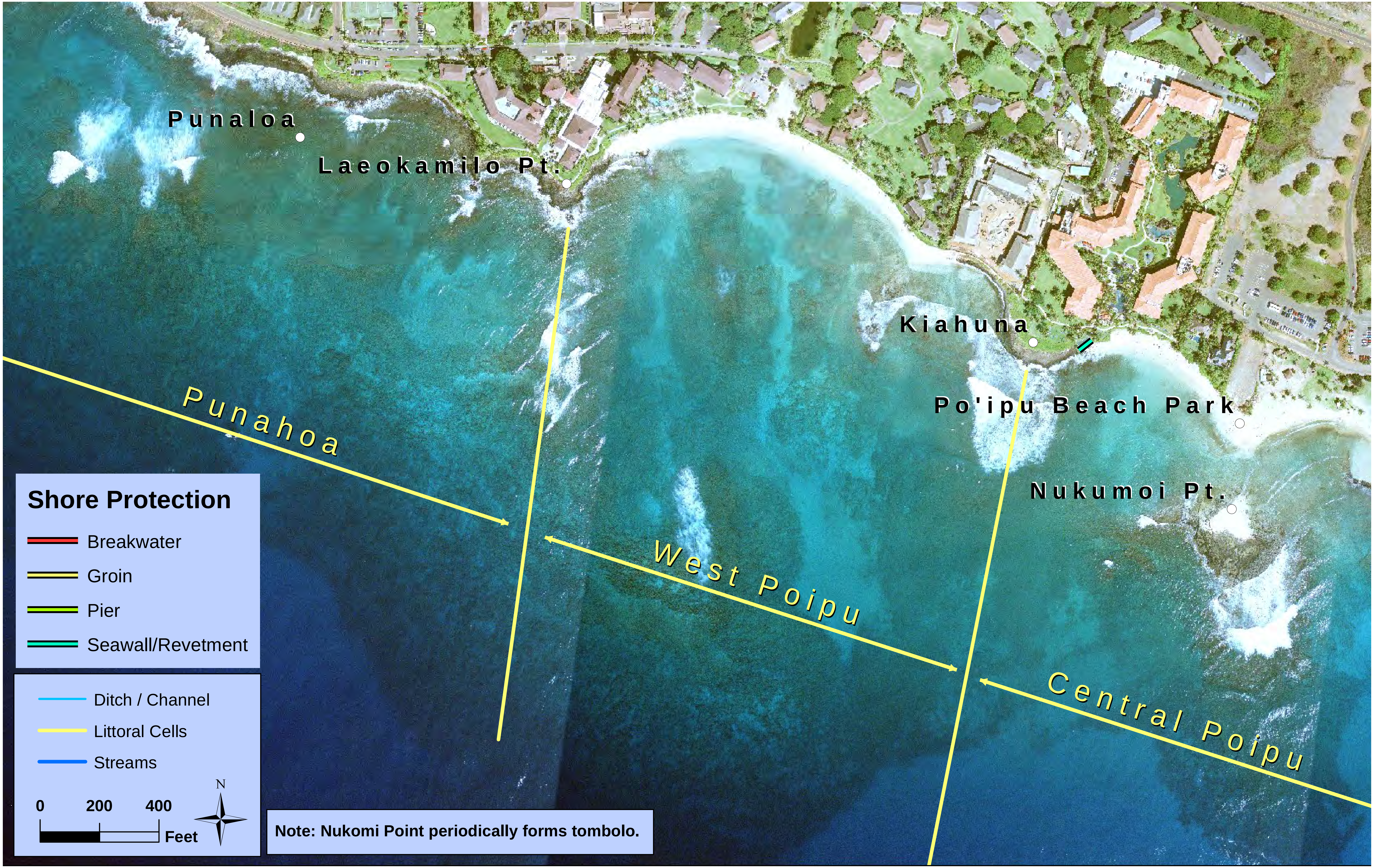

Lawai
Lawa'i Bay
Ka Lae O Kalwa
Lawa'i
Kukui'ula
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 190 380
Feet
N

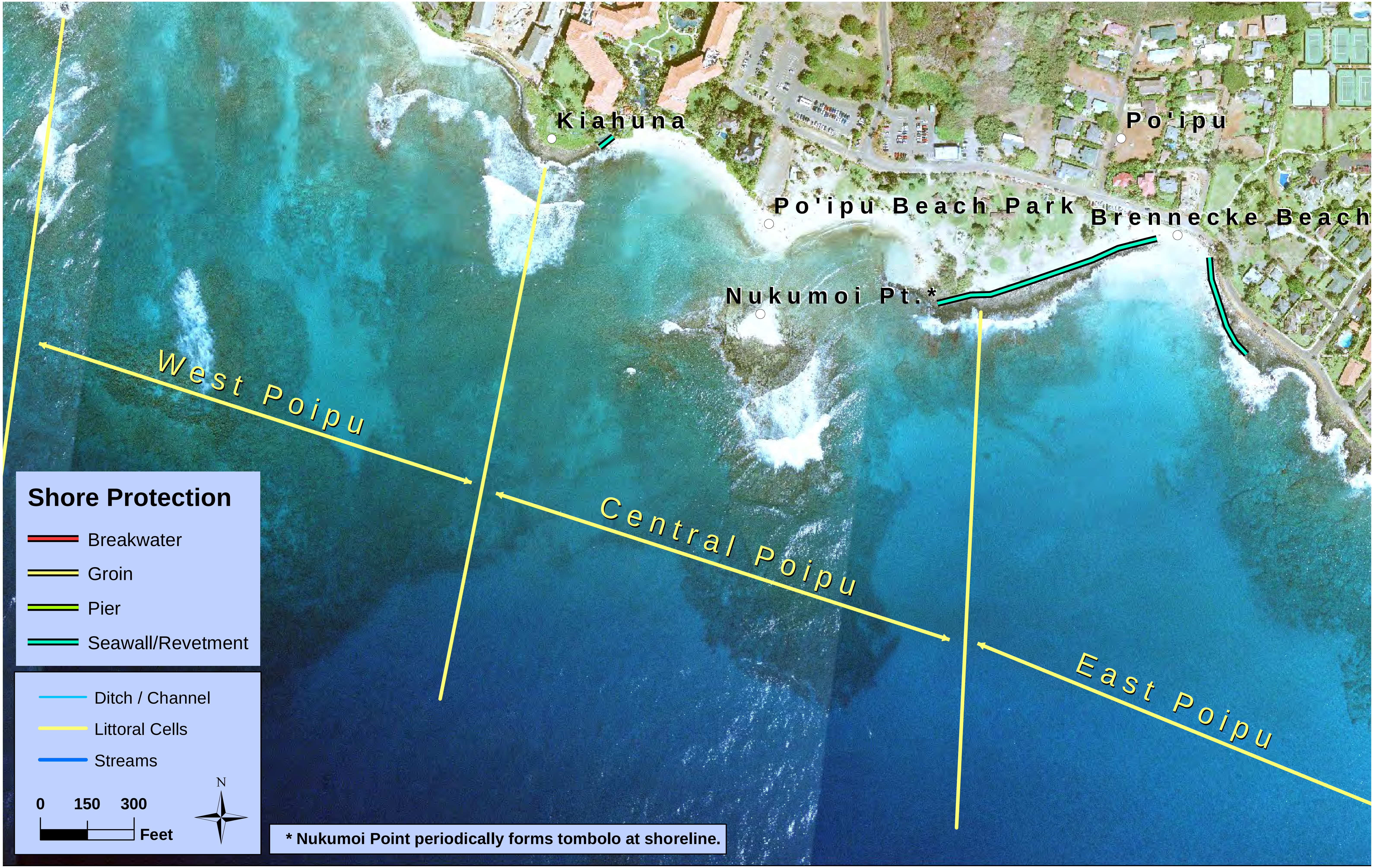


Lawa'i Bay
Ka Lae O Kalwa
Kukui'ula Harbor
Kukui'ula
Aepo
Ka'ulala Pt.
Kalaekiki Pt.
Lawa'i
Kukui'ula
Ho'ai
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0
300
600
Feet
N
Note: Shore protection (i.e. seawalls, revetments) are thought to to occur in this region. However, specific locations could not be confirmed.


Kalaekiki Pt.
Ho'ai Bay
Waikomo
Nahuma'alo Pt.
Kukui'ula
Ho'ai
Punahoa
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 250 500
Feet
N


Nahuma'alo Pt.
Ho'ai
Punaloa
Laeokamilo Pt.
Punahoa
West Poipu
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0
200
400
Feet
N


Punaloa
Laeokamilo Pt.
Kiahuna
Po'ipu Beach Park
Nukumoi Pt.
Punahoa
West Poipu
Central Poipu
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0 200 400
Feet
N
Note: Nukomi Point periodically forms tombolo.


Kiahuna
Po'ipu
Po'ipu Beach Park
Brennecke Beach
Nukumoi Pt.*
West Poipu
Central Poipu
East Poipu
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0
150
300
Feet
N
* Nukumoi Point periodically forms tombolo at shoreline.


Brennecke Beach
Po'ipu Beach Park
Nukumoi Pt.
Central Poipu
East Poipu
Makahu'ena Pt.
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0
200
400
Feet
N

Makawehi
Shipwreck Beach
Po'ipu
Brennecke Beach
Keoniloa Bay
Shipwreck Beach
Makahu'ena Pt.
East Poipu
Shore Protection
Breakwater
Groin
Pier
Seawall/Revetment
Ditch / Channel
Littoral Cells
Streams
0
500
1,000
Feet
N

B. Beach Volumes

For each littoral cell, a graph of beach volume versus time was developed based on historical shorelines provided by the University of Hawaii (2010) and using a conversion factor of 0.40 cubic yards per square foot of beach.

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

- The points do not necessarily bound the minimum and maximum beach volumes.
- It is probable that the chronological transitions from erosional to accretional conditions (and vice versa) are not at the exact date shown by the line in the graph.
- Note that the scale of each graph varies to provide clarity to the stable, limited transport cell plots.
- In general, the pocket beaches, headlands, and offshore reef severely limit the sediment transport in this area. Many of the beaches are stable and show little change.

Following are graphs of each of the cells within the Poipu region (Figures G-5 to G-12), as well as a summary graph which includes all cells in the region (Figure G-3). The line graphs show the estimated historical beach volumes over the time period of shoreline data records and the bar graphs show the change rates over different time periods of interest. Potentially significant events are shown on the line graphs. Table G-2 summarizes the associated erosion and accretion rates over the time period of record and over the most recent time period for each of the littoral cells. Figures G-13 through G-20 show the most recent change rate (sediment budget) for each of the littoral cells.

Table G-2. Poipu Region Beach Sand Volume Change Rates

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

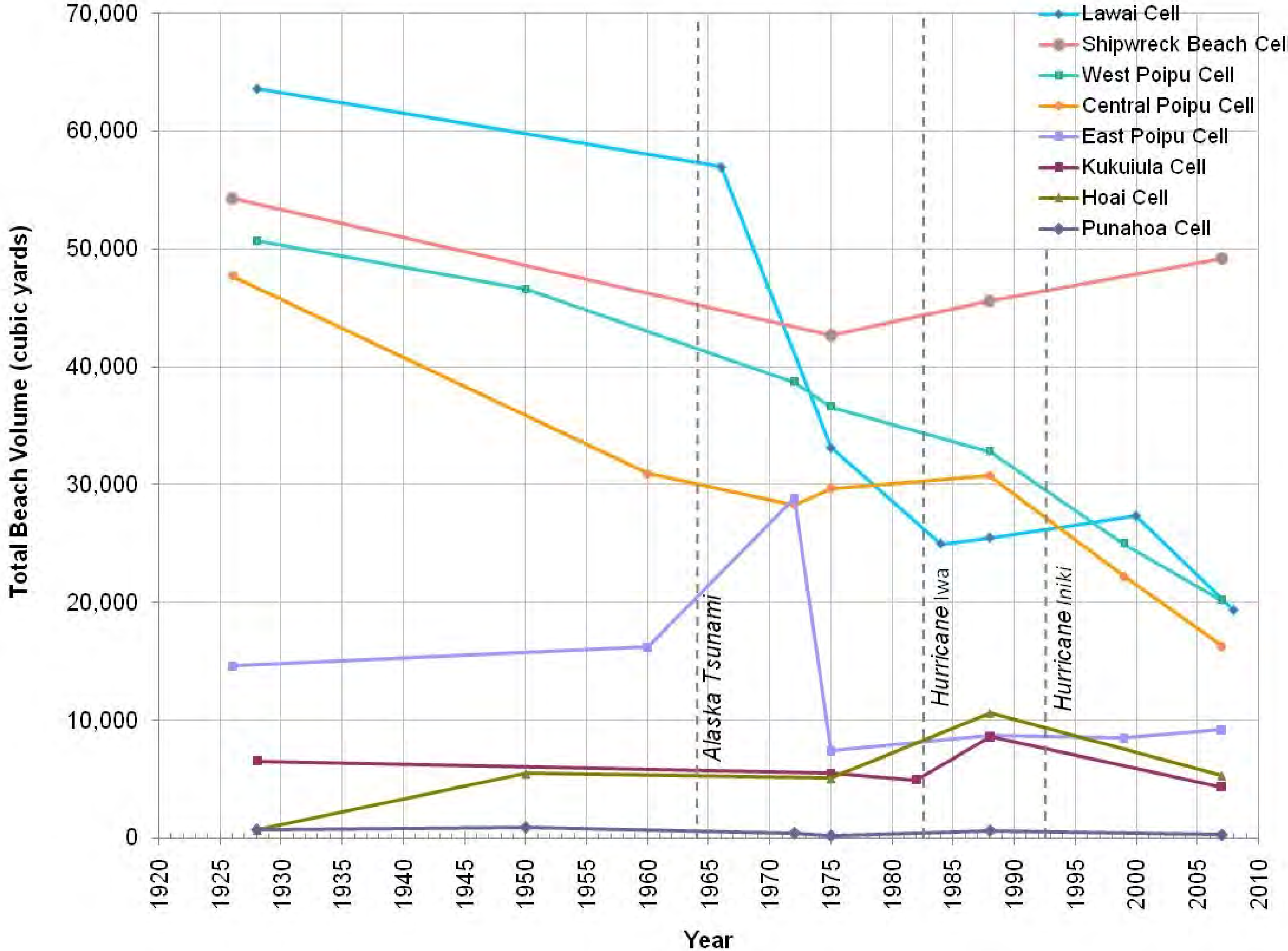


Figure G-3. Historical Beach Volumes of Poipu Region Littoral Cells

It is interesting to compare these long-term average change rates with volume changes due to only seasonal fluctuation. Based on the median seasonal fluctuation calculated by University of Hawaii (2010) and assuming this median fluctuation occurred along the entire length of beach, the potential seasonal volume fluctuations for the Central Poipu cell is 17,000 cy per year, for the Lawa'i cell is 10,000 cy per year and for Shipwreck Beach is 1,500 cy per year, i.e. the seasonal variations are significantly higher than the long-term average change rates.

Results for the Poipu Region littoral cells indicate the following:

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

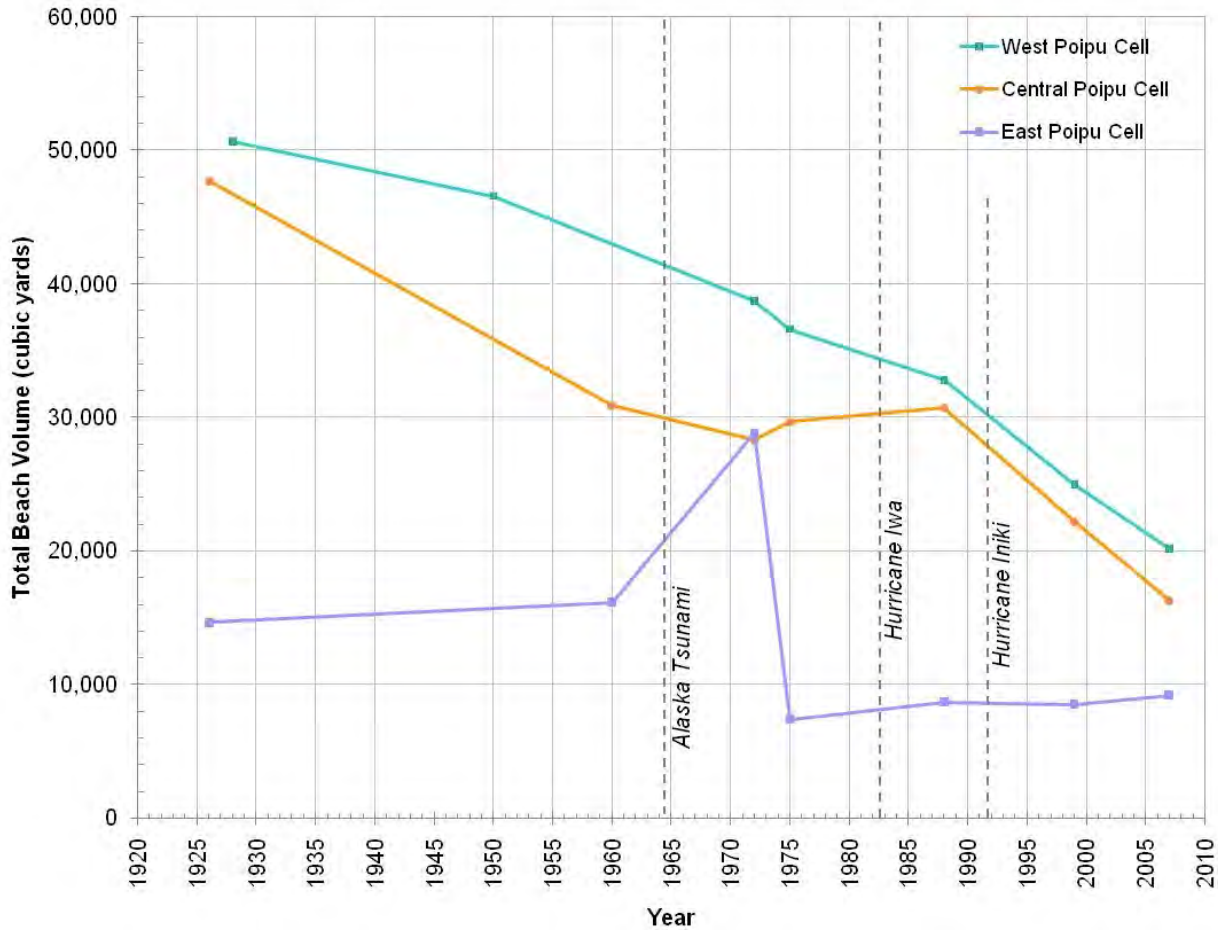


Figure G-4. Historical Beach Volumes of West, Central, and East Poipu Cells

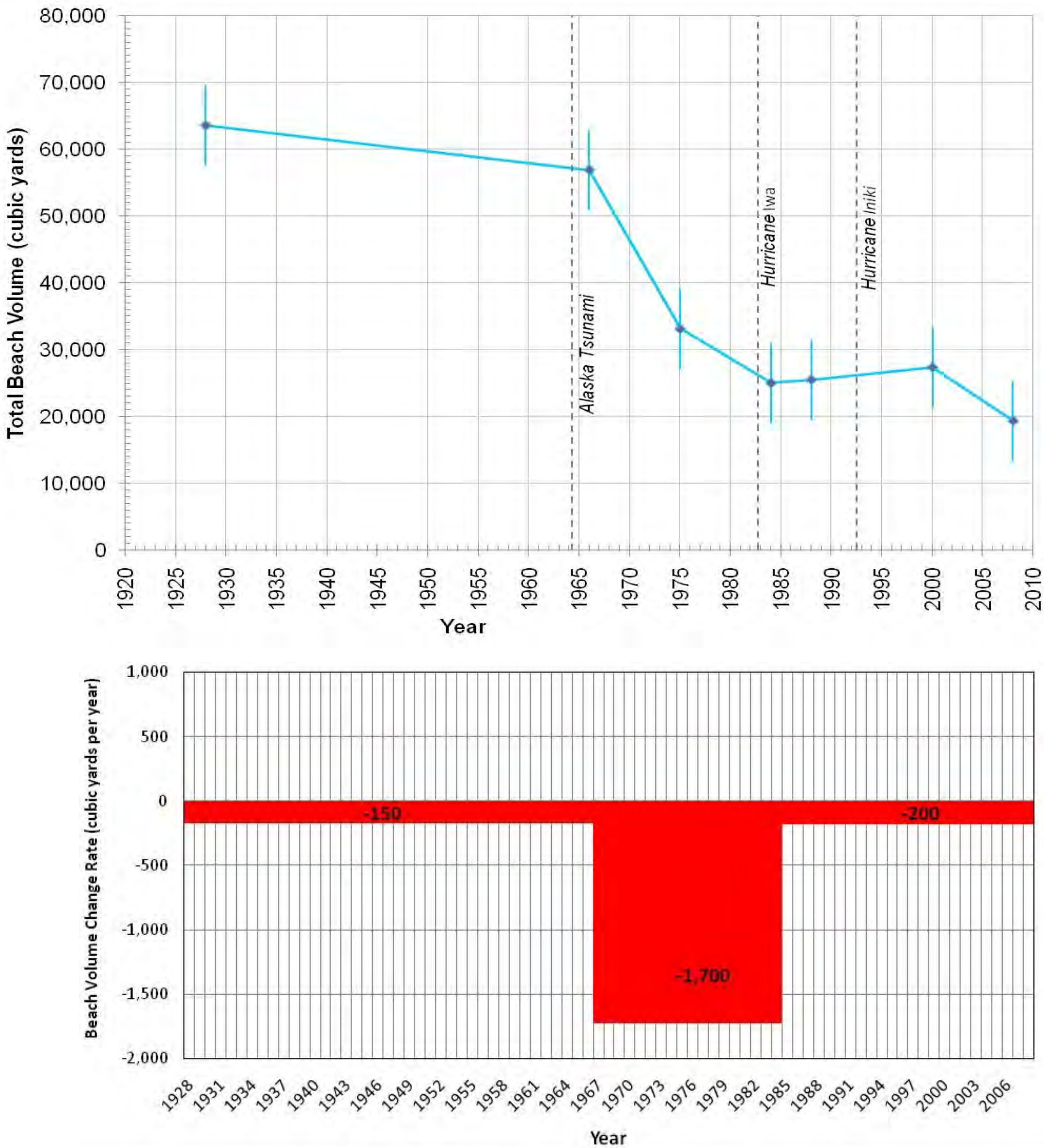
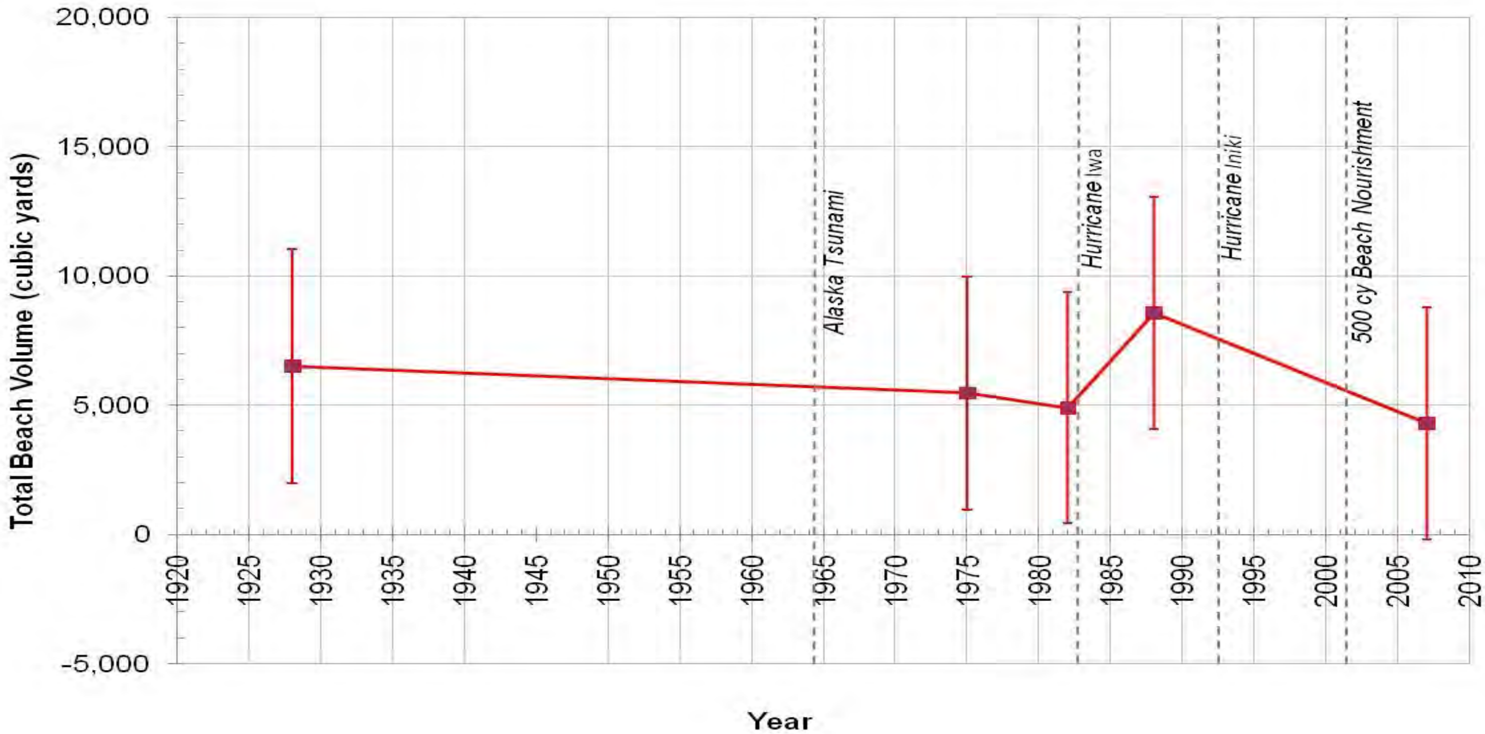


Figure G-5. Historical Beach Volumes / Change Rates for Lawa'i Littoral Cell



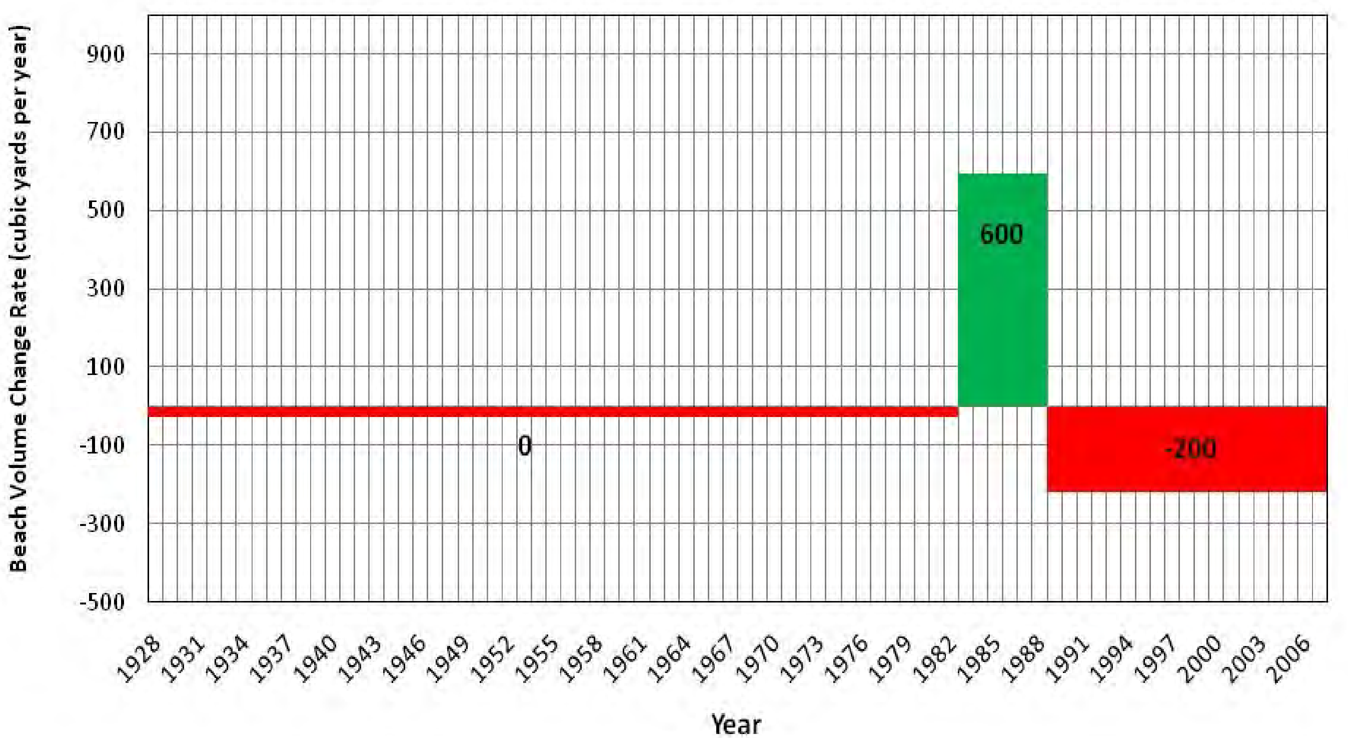


Figure G-6. Historical Beach Volumes / Change Rates for Kukui'ula Littoral Cell

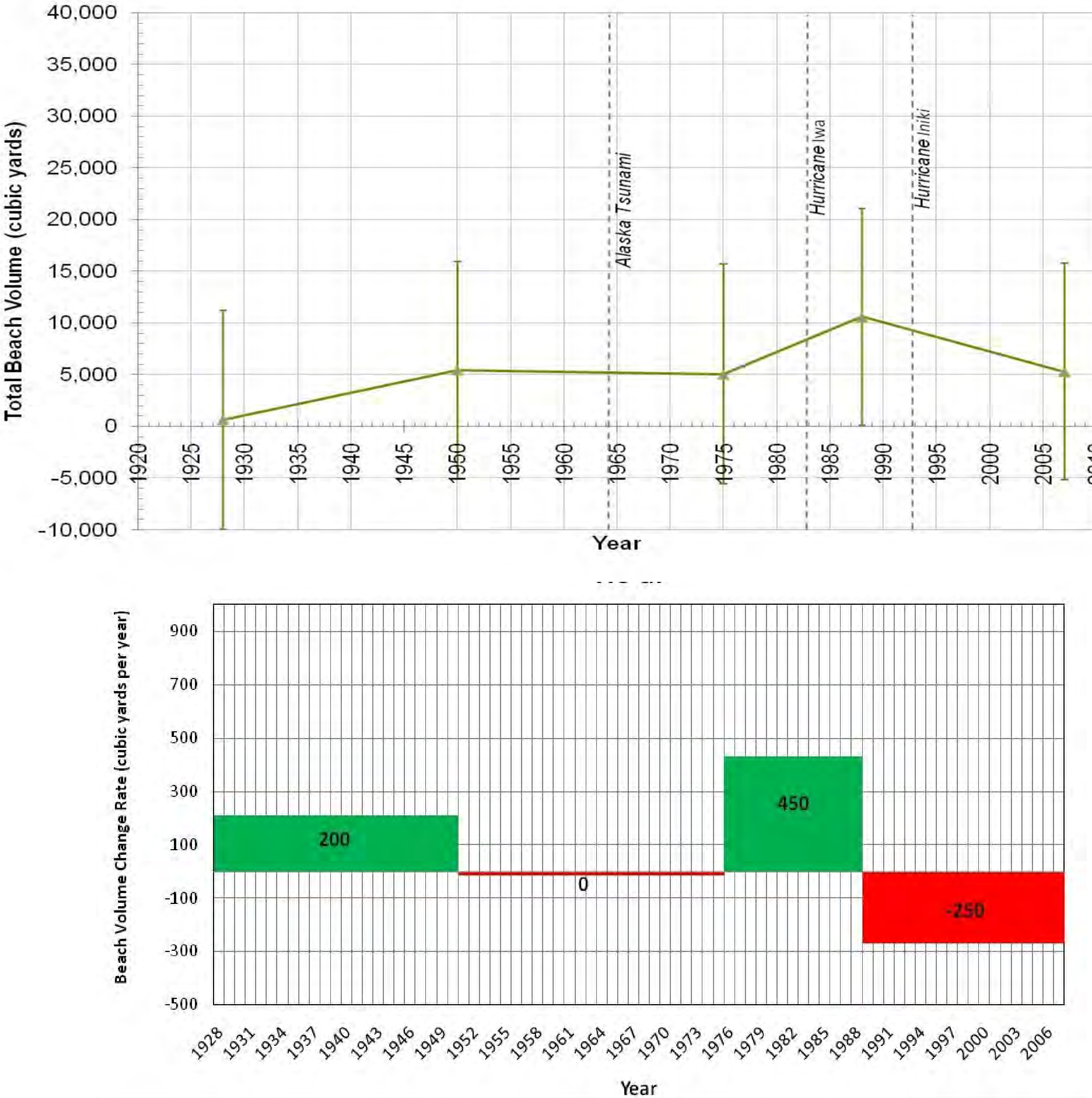


Figure G-7. Historical Beach Volumes / Change Rates for Ho'ai Littoral Cell

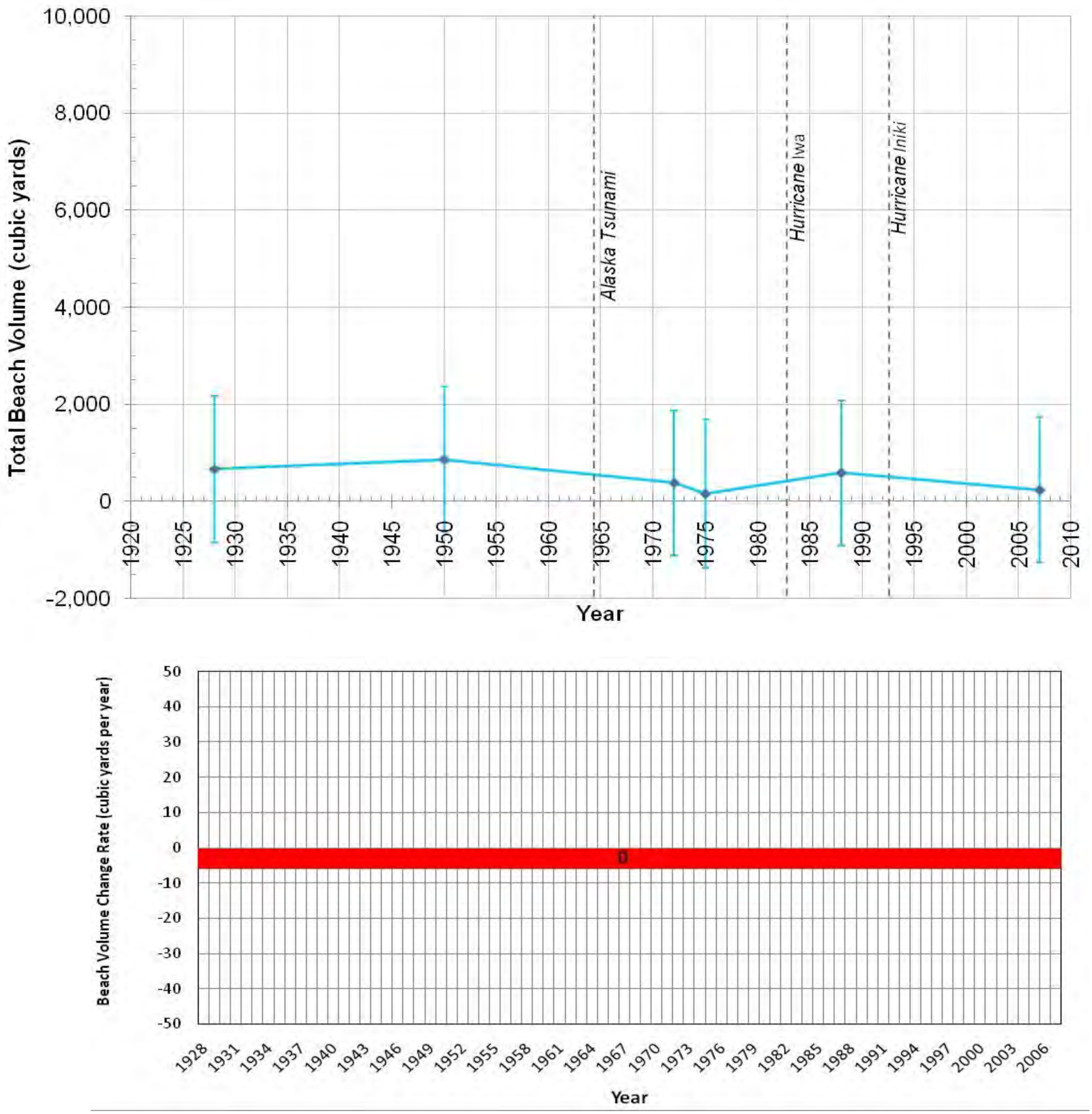
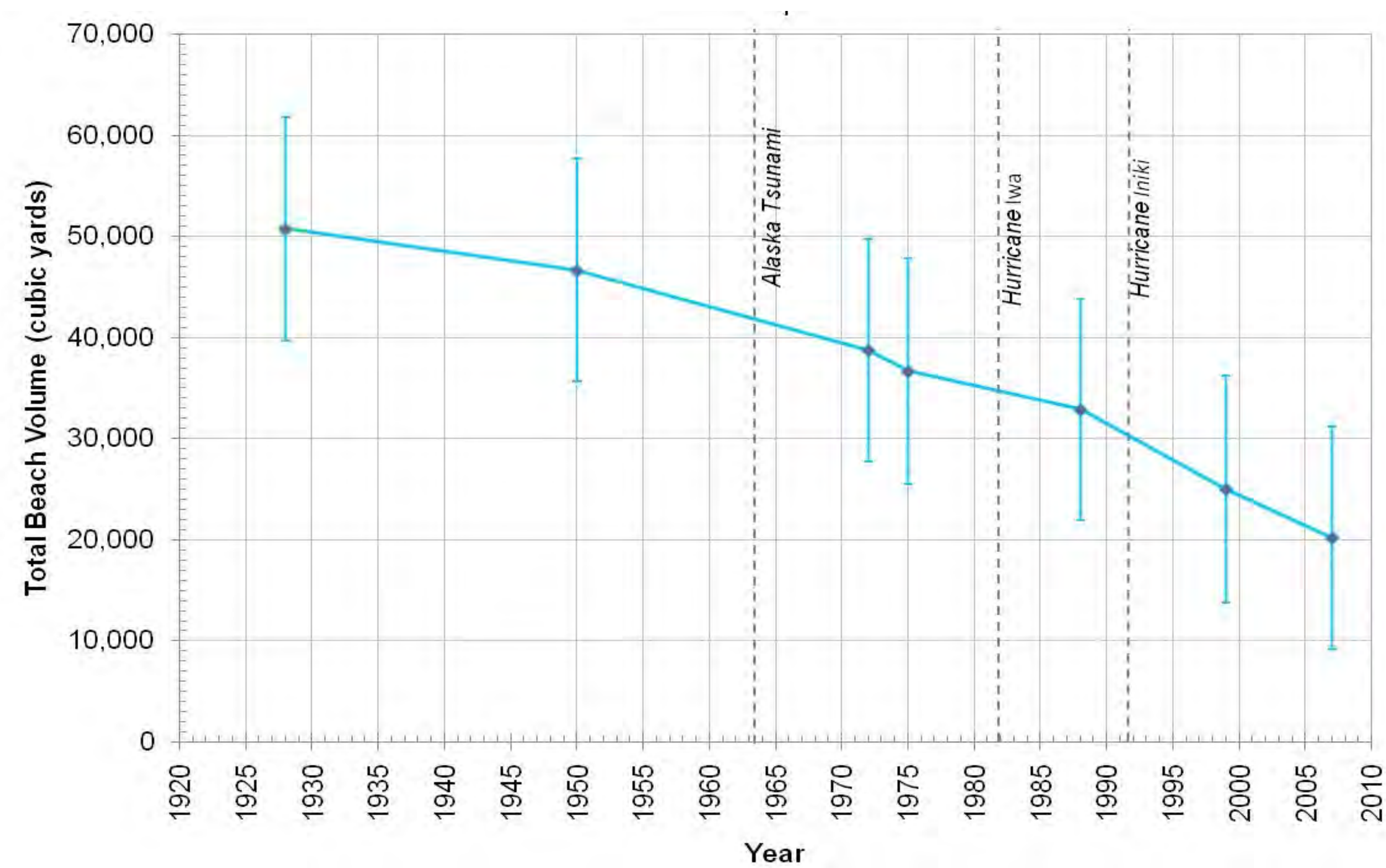


Figure G-8. Historical Beach Volumes / Change Rates for Punahoa Littoral Cell



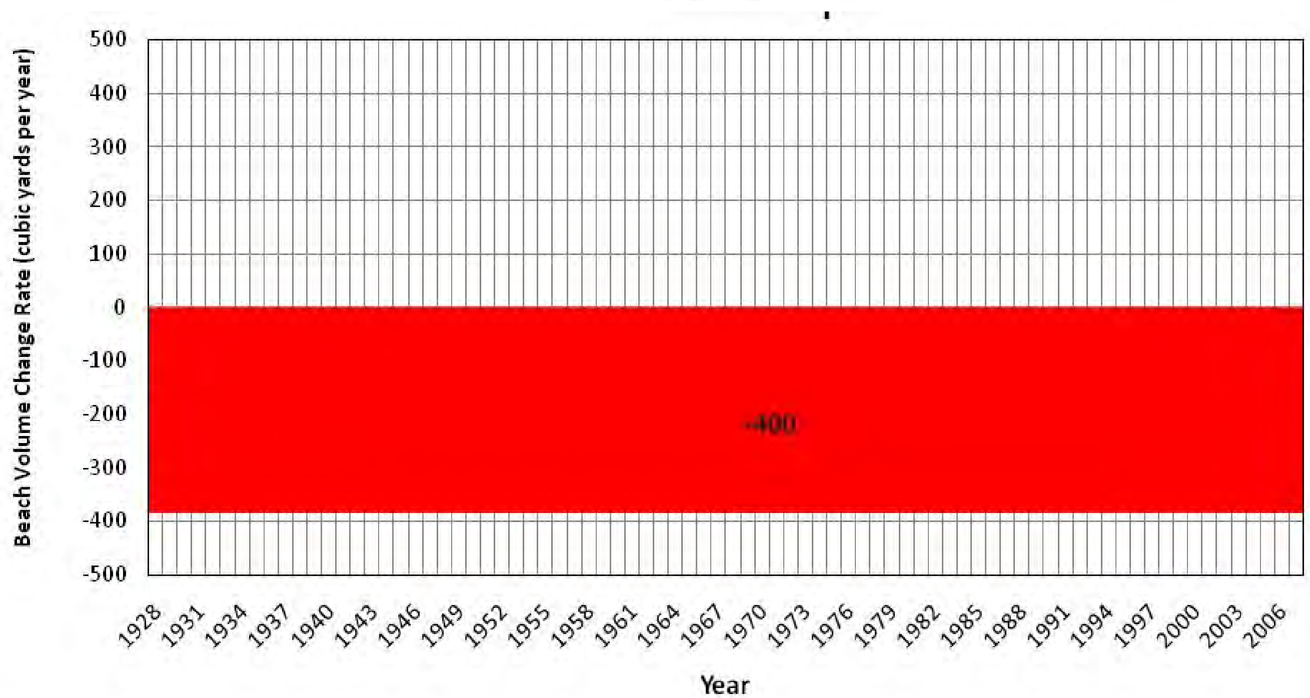


Figure G-9. Historical Beach Volumes / Change Rates for West Poipu Littoral Cell

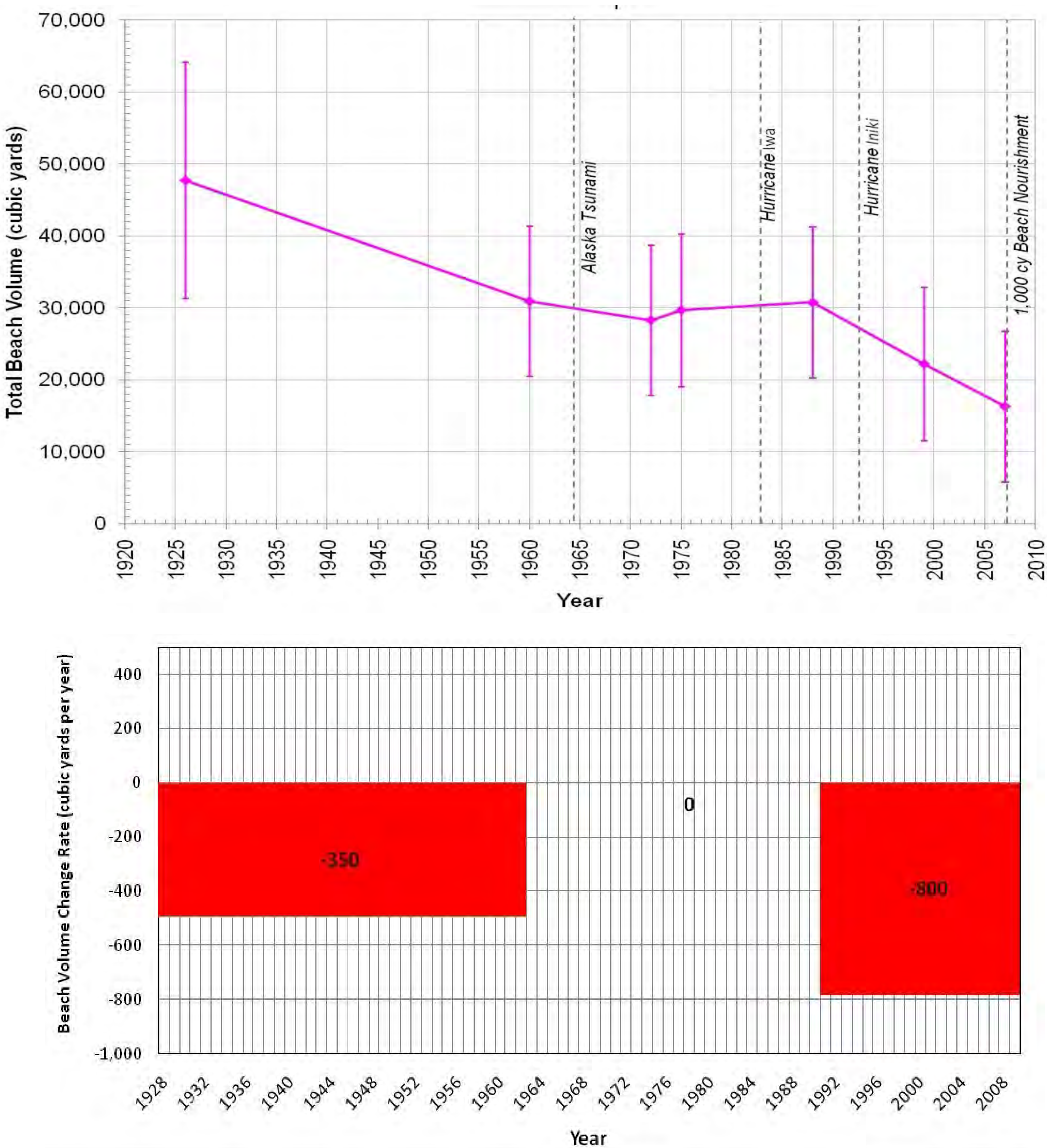
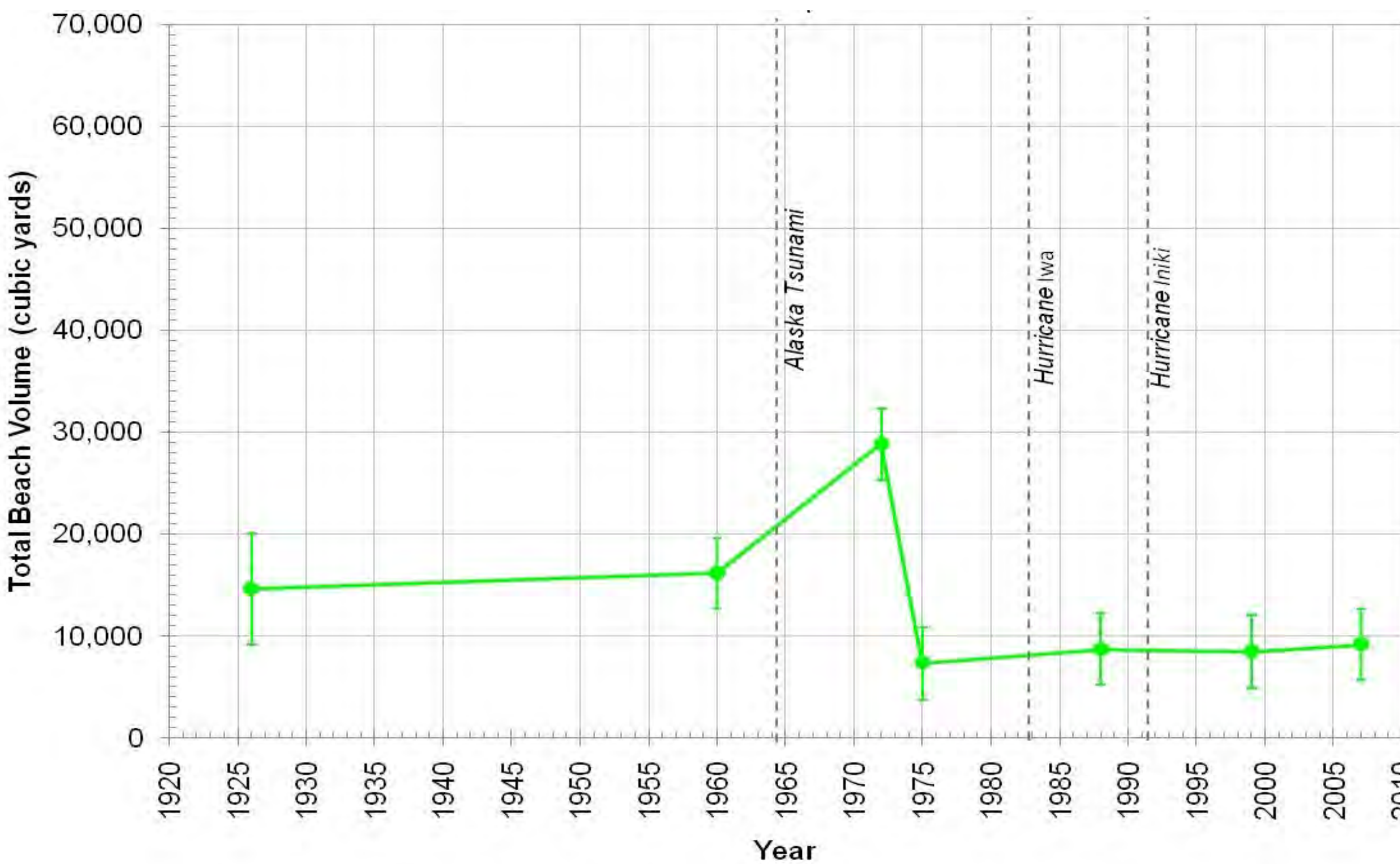


Figure G-10. Historical Beach Volumes / Change Rates for Central Poipu Littoral Cell



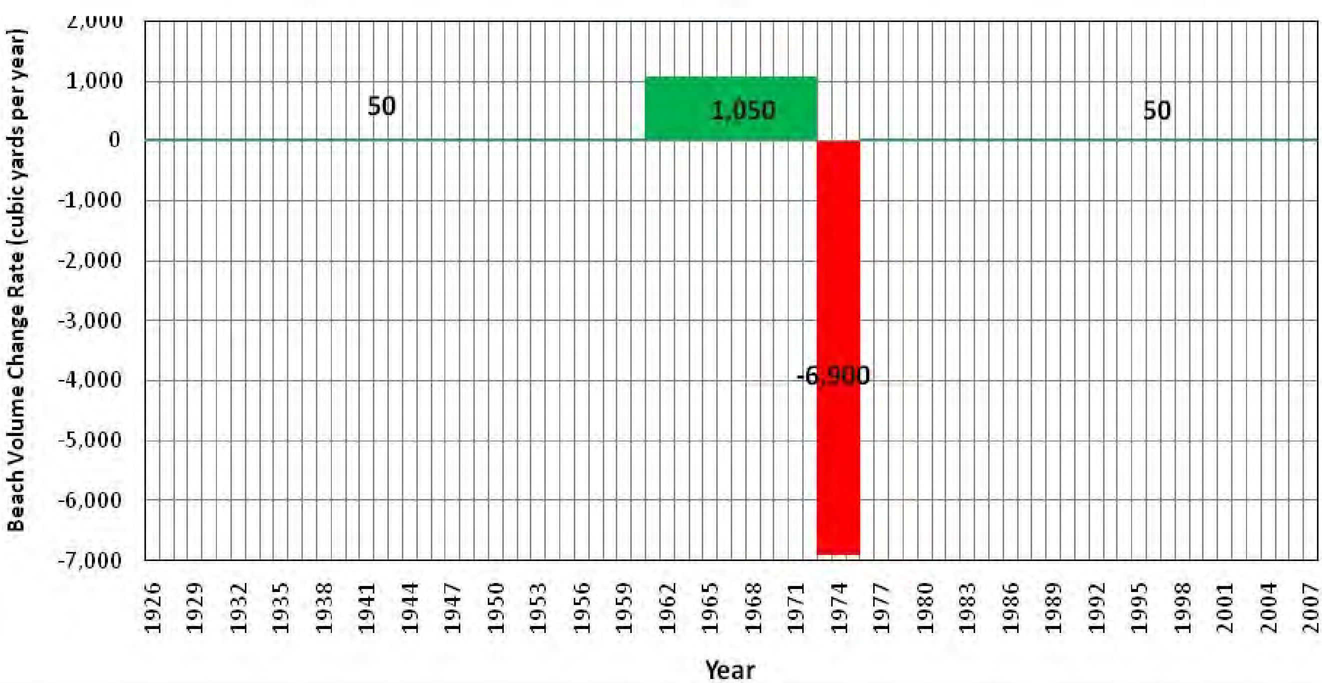


Figure G-11. Historical Beach Volumes / Change Rates for East Poipu Littoral Cell

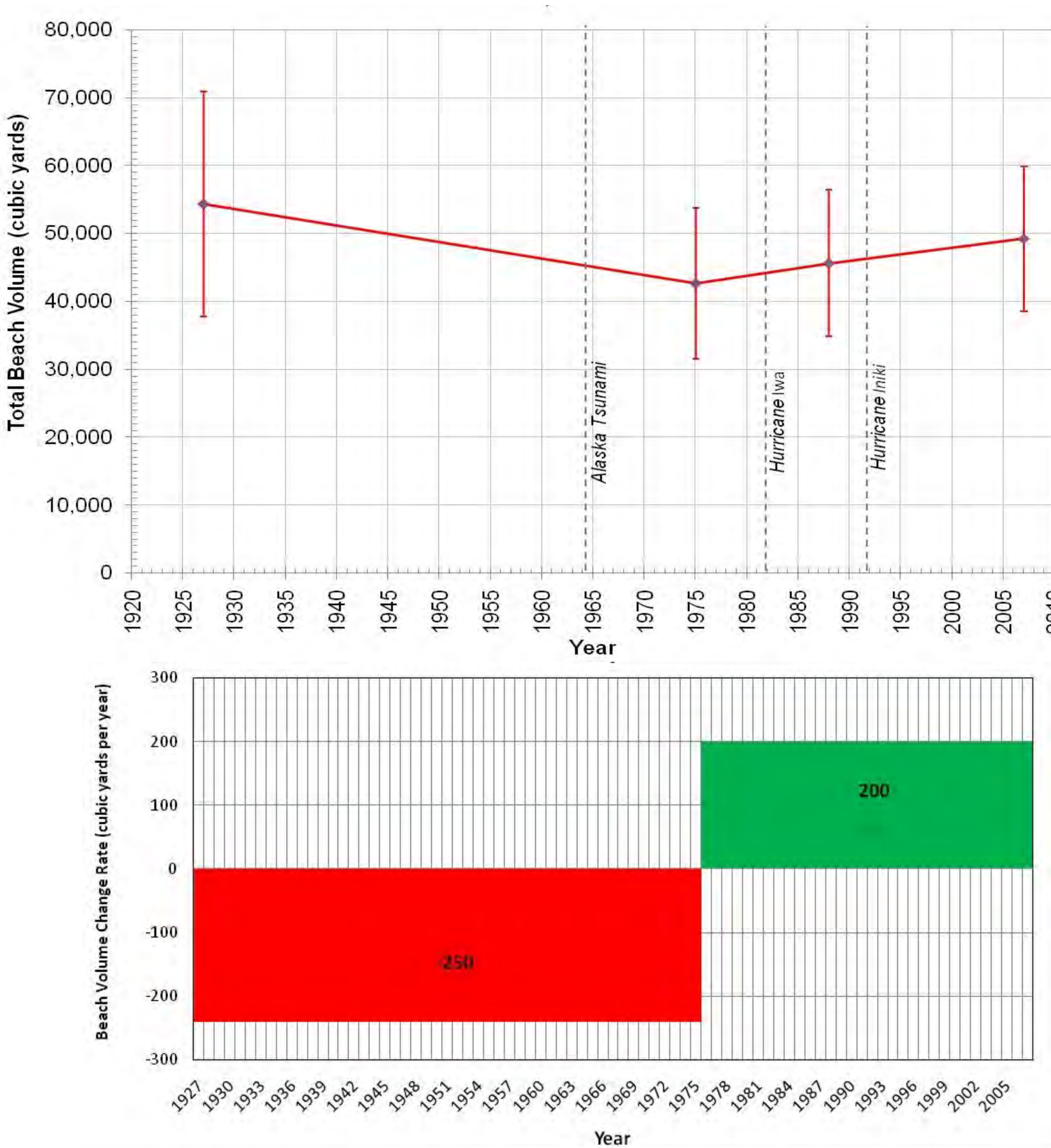


Figure G-12. Historical Beach Volumes / Change Rates for Shipwreck Beach Littoral Cell

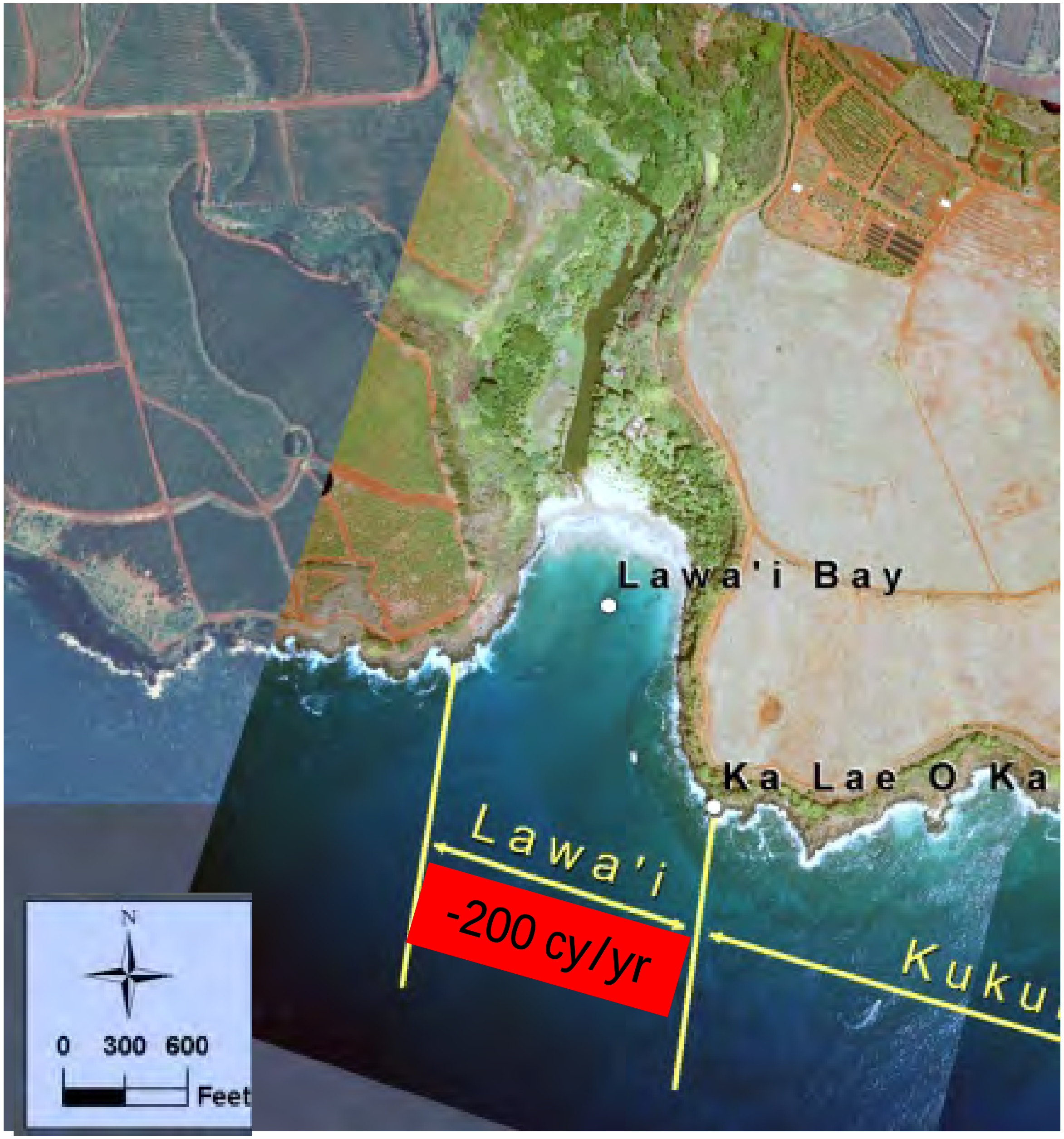


Figure G-13. Beach Volume Change Rate for Lawa'i Littoral Cell

Figure G-14. Beach Volume Change Rate for Kukui'ula Littoral Cell

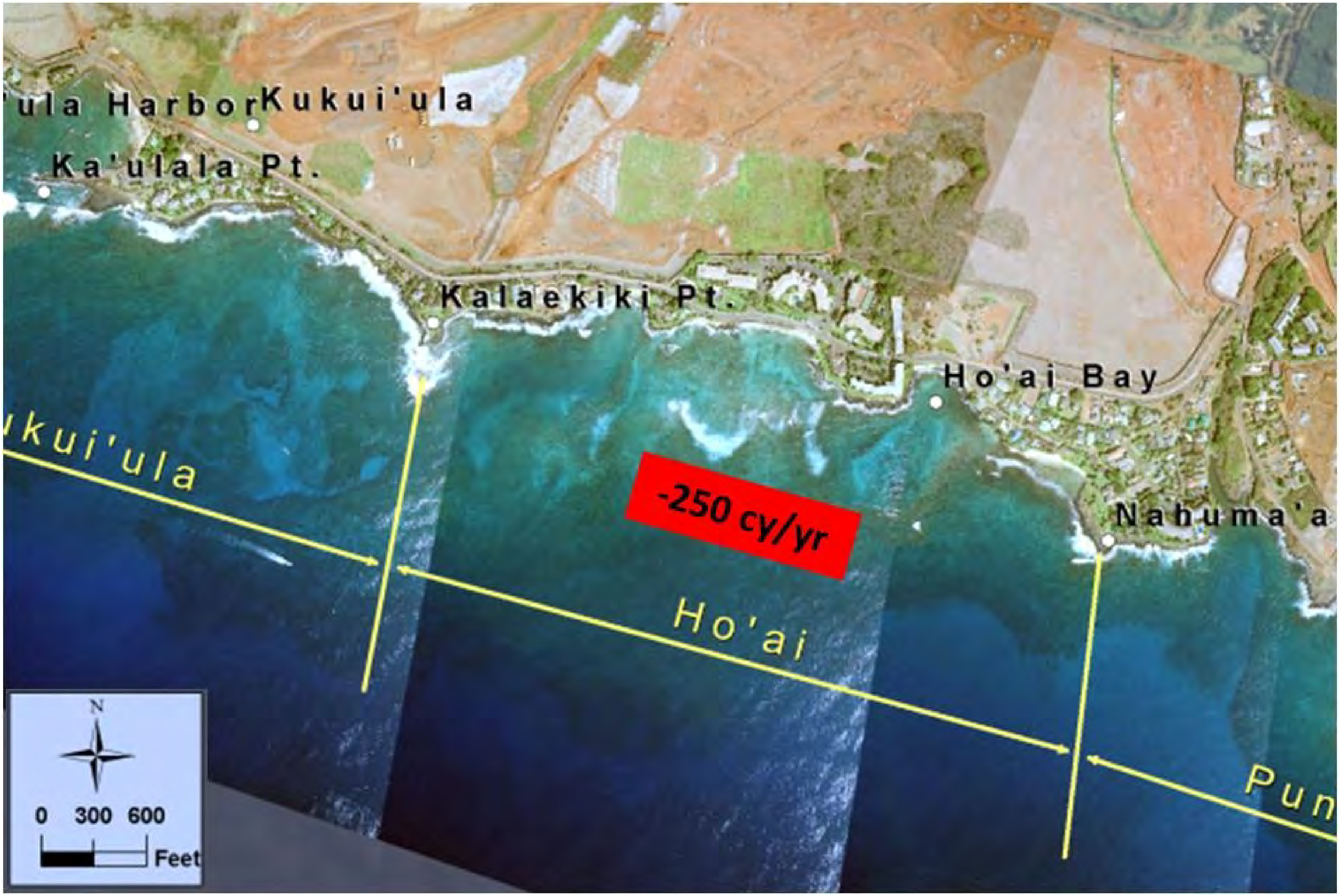


Figure G-15. Beach Volume Change Rate for Ho’ai Littoral Cell

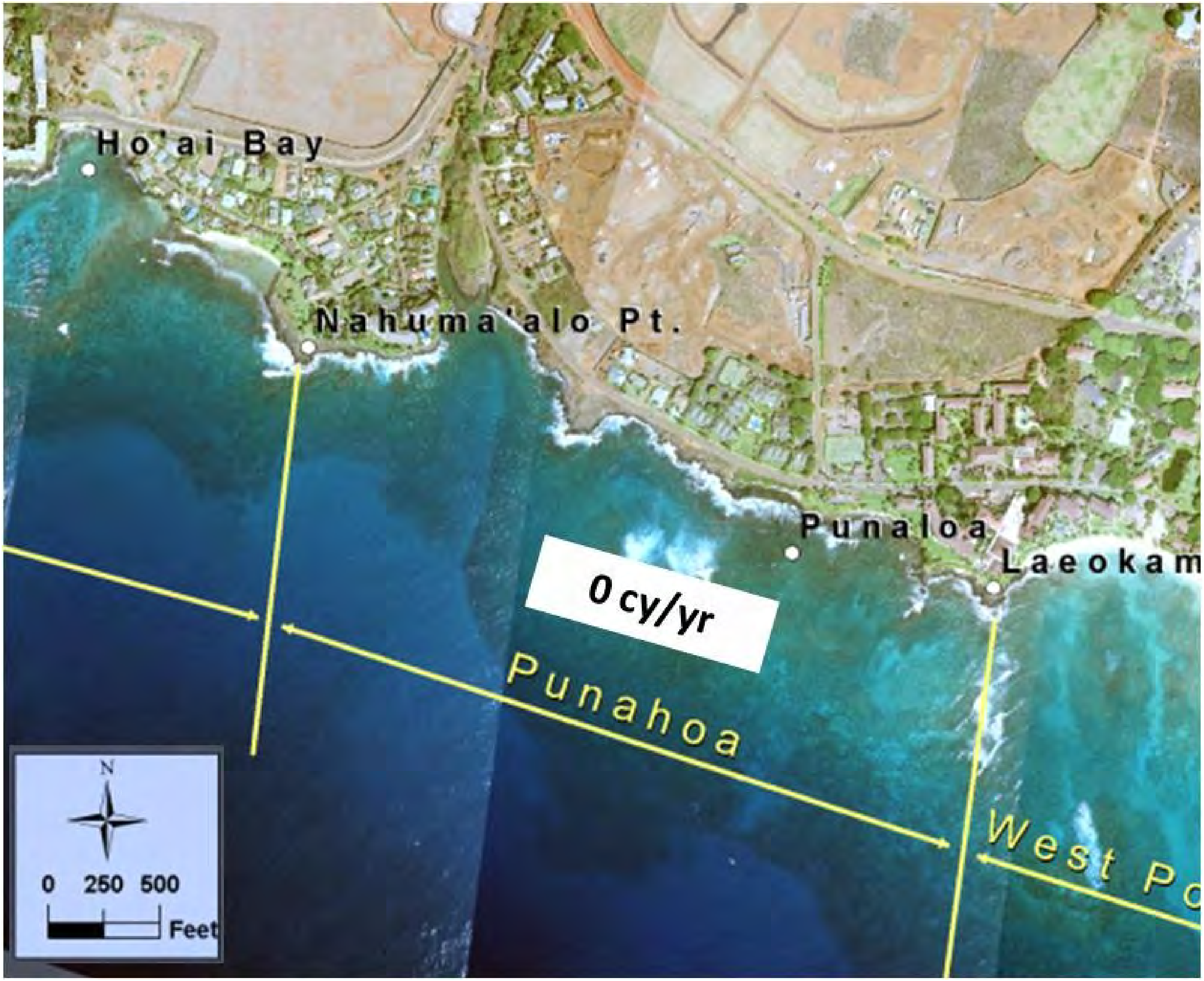


Figure G-16. Beach Volume Change Rate for Punahoa Littoral Cell

Figure G-17. Beach Volume Change Rate for West Poipu Littoral Cell

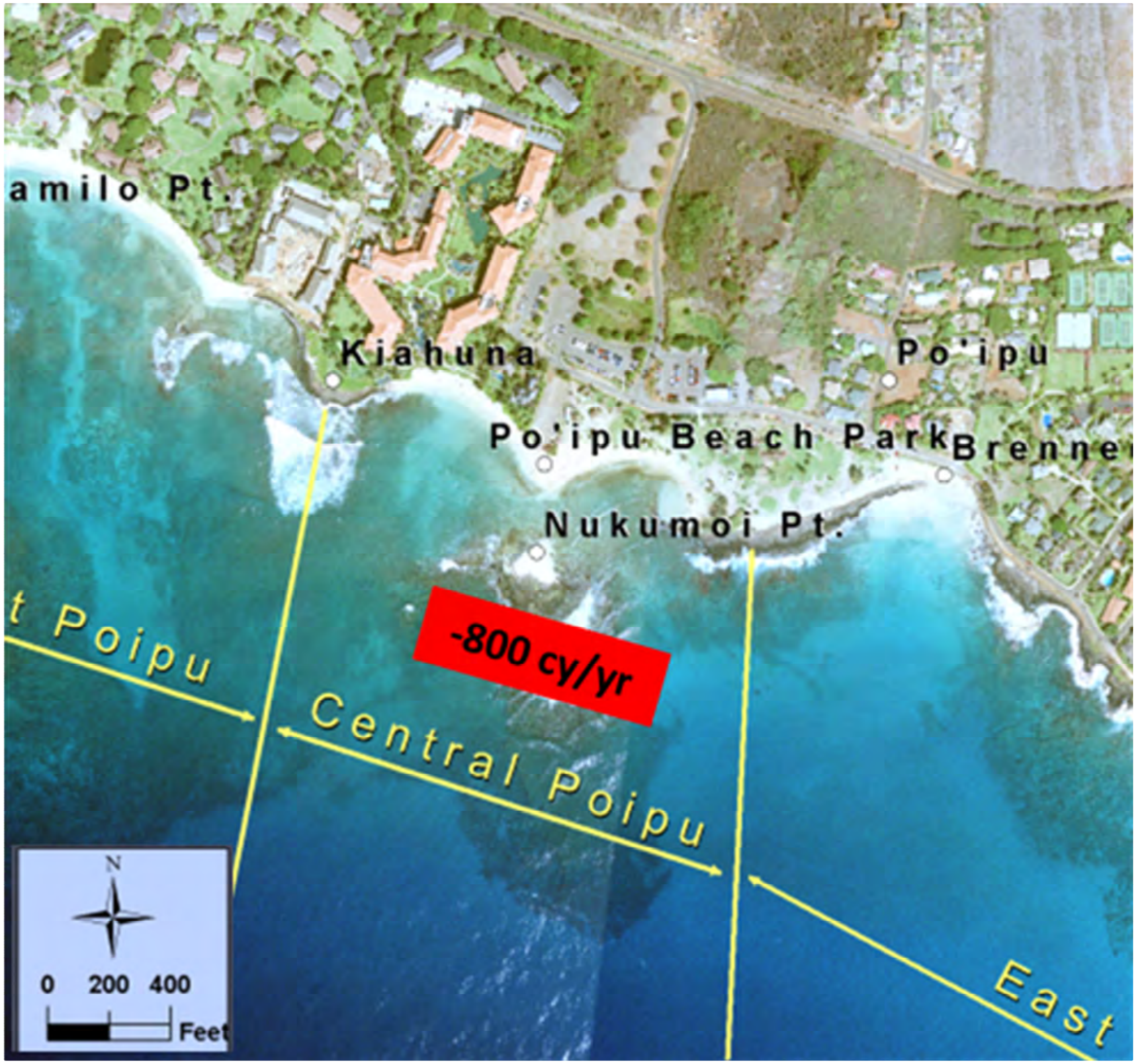


Figure G-18. Beach Volume Change Rate for Central Poipu Littoral Cell

Figure G-19. Beach Volume Change Rate for East Poipu Littoral Cell

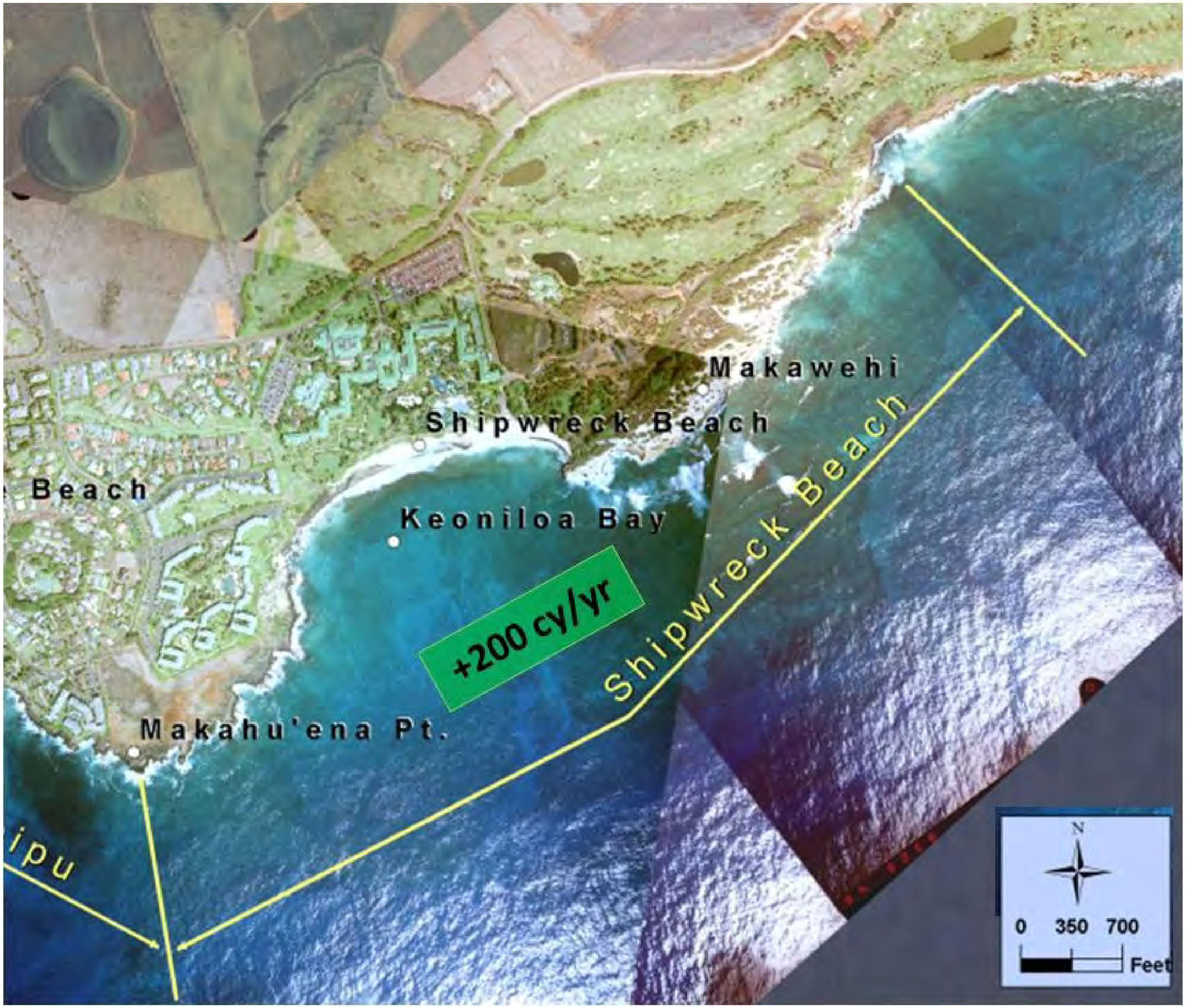


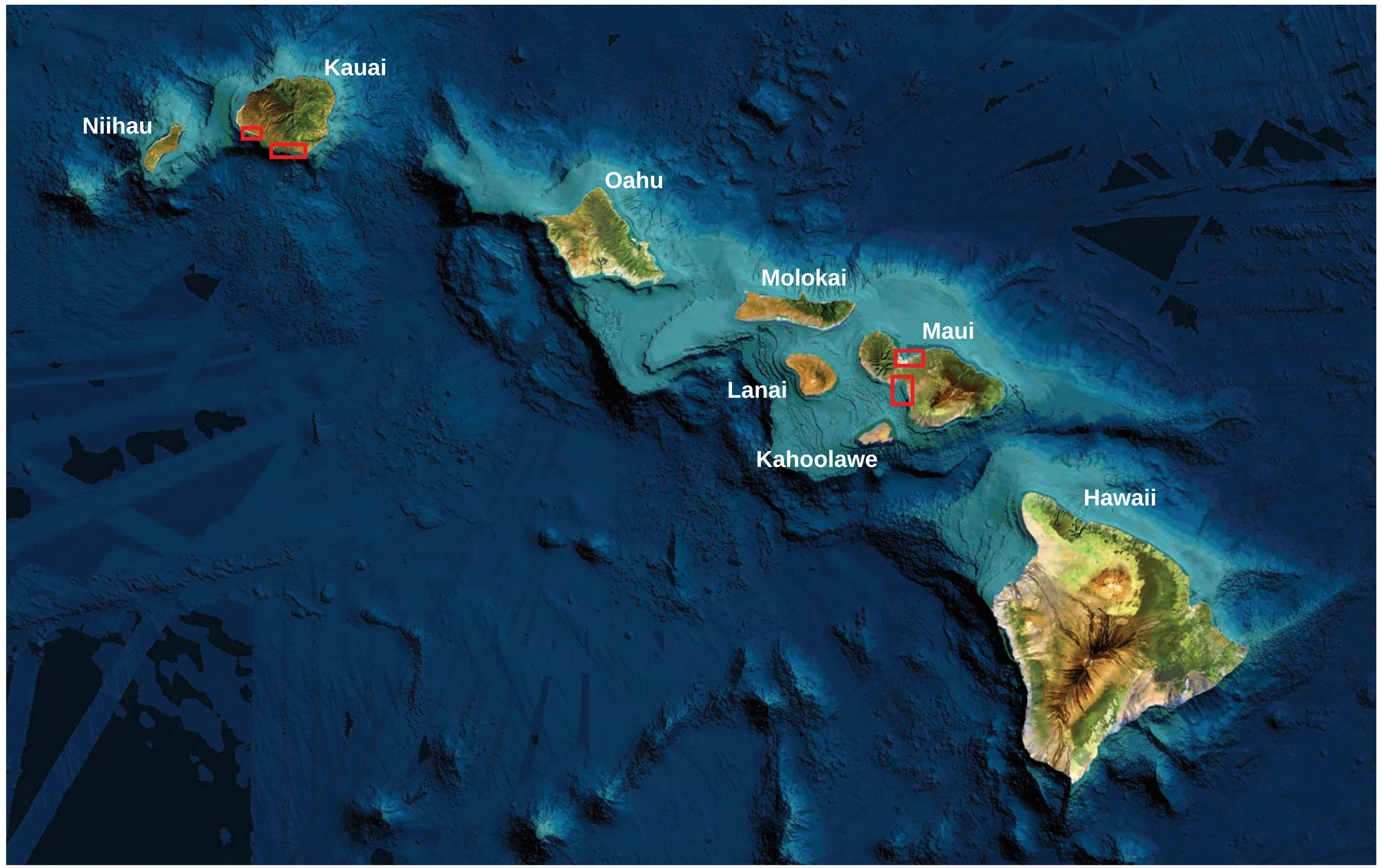
Figure G-20. Beach Volume Change Rate for Shipwreck Beach Littoral Cell

APPENDIX H

OFFSHORE SAND SOURCE INVENTORY
(UNIVERSITY OF HAWAII, JANUARY 2011)

Reef-top Sand Fields of Maui and Kauai

Kihei and Kahului, Maui: Poipu and Kekaha, Kauai



EA/HHF Joint Venture

US Army Corps of Engineers

School of Ocean and Earth Science and Technology

United States Army Corps of Engineers, Honolulu Engineering District
University of Hawaii at Manoa, School of Ocean and Earth Science and Technology
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Introduction

Beaches are critical to Hawai‘i lifestyle, culture, and economy. Coastal erosion threatens beaches but sediment management offers potential tools to mitigate the problem. Offshore sand fields have been used as a resource to replenish Hawai‘i’s eroding beaches – specifically in Waikiki (DLNR, 2010).

The purpose of this research, sponsored by the U.S.Army Corps Regional Sediment Management program is to identify stable, shallow water (reef top) sand fields in four locations and determine their surface areas. The field sites are Kihei and the north shore of Maui (Fig. 1), Poipu and Kekaha on the south coast of Kauai (Fig. 2).

Geologic Framework of Sand Bodies

Shallow, reef top sand fields are an accumulation of carbonate sediment in topographic depressions on shallow reefs (Bochicchio et al. 2009). These accumulations are typically thin and are classified as channels, fields, or patches (Conger et al. 2005). Biologic production, temporary and permanent storage, and loss (including offshore transport, bioerosion, dissolution, and abrasion) govern the accumulation of carbonate sands. The area and distribution of sand fields are determined by biologic productivity, water quality, wave energy, and storage space (Fletcher et al. 2008). Reef accretion due to rising sea level and dissolution (subaerial exposure) due to falling sea level also impact the area of storage available for sand.

Sand stored on reefs is mobile and may be transported seaward, landward, or captured by voids and interstices within the reef. Much of the sand within sand fields is stored temporarily; thus, the distribution and area of sand fields changes over time. Sand fields that undergo significant changes in surface area are more likely to consist of ephemeral, thin accumulations (and thus represent poor targets as borrow sites) compared to those that are stable over the same period. Stable sand fields are bodies of sand that have retained the same configuration over time, for example several decades. Ephemeral sand fields are bodies of sand that change configuration.

For this study, both stable and ephemeral sand fields were identified using historical and modern aerial photography with a clear view of the shallow seafloor. We assume that stable sand fields offer the best opportunities for characterization as resources, such as by jet probing, grain size analysis, or other methods.

Methodology

High-resolution orthophotomosaics of the field sites were produced to examine sand field extent. Aerial photos for this purpose were chosen based on their date, the area of coverage, the amount of surface glint and cloud cover, and water column clarity. Photomosaics from 1960

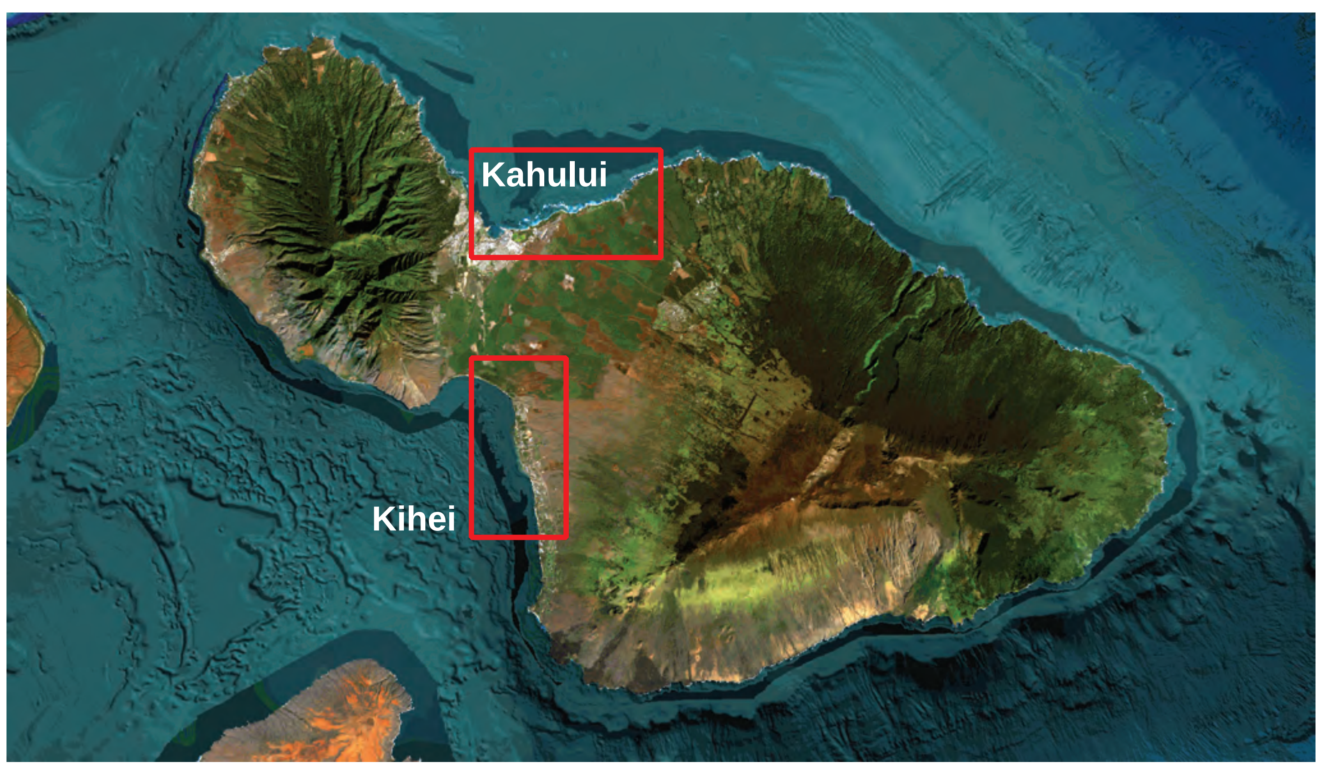


Figure 1. The red boxes indicate the two study sites on Maui: Kihei and Kahului

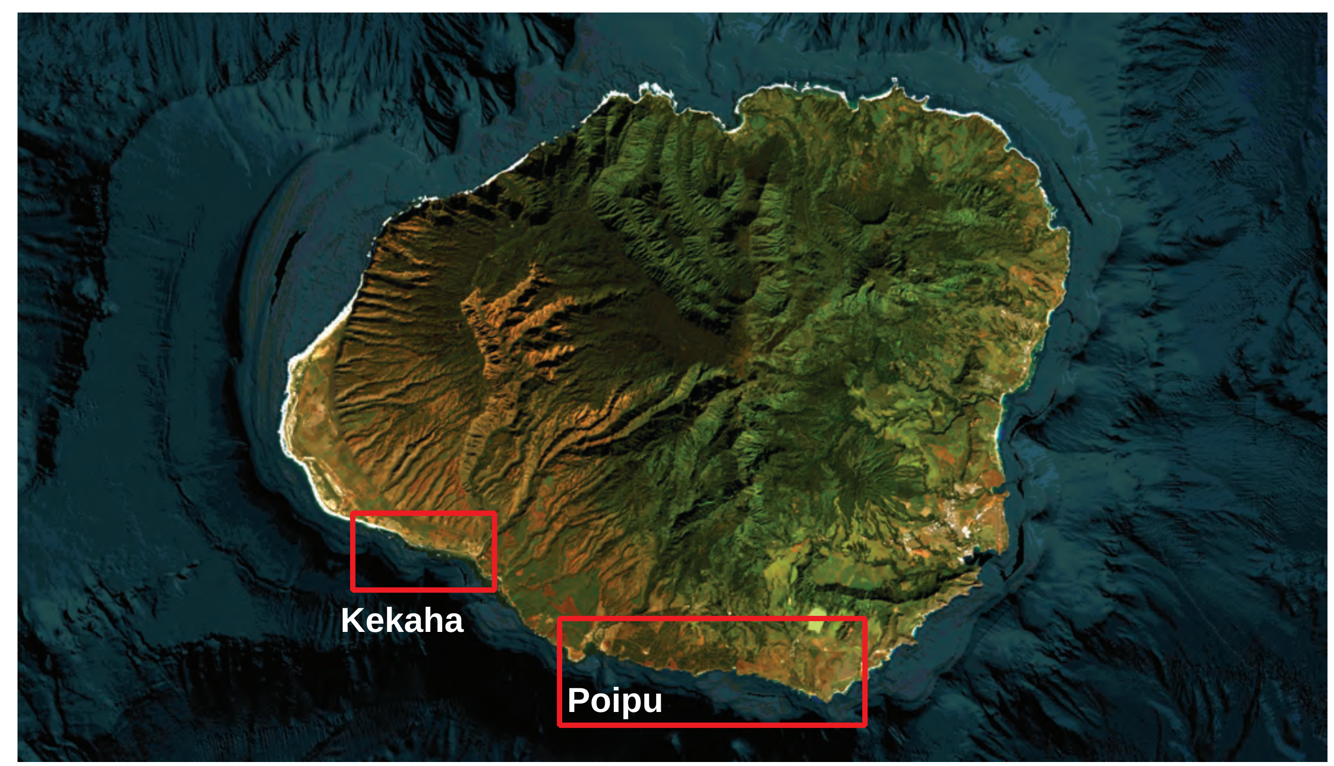


Figure 2. The red boxes indicate the two study sites on Kauai: Poipu and Kekaha

were used to provide historical coverage, and mosaics from 2002, 2006, and 2007 were used to provide modern coverage.

1. Kihei, Maui - Kamaole Beach Park to Kealia Pond. Mosaics from 1949 and 1975 were analyzed, but not used for historic coverage because of overall poor visibility of the seafloor. Therefore, photomosaics from 1960 and 1997 were used to provide historical coverage, and a 2007 mosaic was used to provide modern coverage.

2. Kahului, Maui - Kahului Harbor to Hookipa Park. For this field area, five mosaics (Kahului Harbor, Kanaha, Spreckelsville, Baldwin Park, and Kuau) provided coverage. Photomosaics from 1975 provided historical coverage, and mosaics from 2002 provided modern coverage.

3. Poipu, Kauai – Shipwreck Beach to Lawai Bay. Mosaics from 1999, 1992, 1988, 1982, 1960, 1950, and 1928 were analyzed; however these were not used because of incomplete coverage and/or poor visibility of the seafloor. A 1975 mosaic provided historical coverage, and a 2007 mosaic provided modern coverage.

4. Kekaha, Kauai – Waimea to Kekaha Beach Park. For this study area, two mosaics were used (one of Waimea and one of Kekaha). Photomosaics from 1950 and 1987 provided historical coverage. Mosaics from 2006 provided modern coverage. Several other years of mosaics were available, but were not analyzed due to poor water conditions because of suspended sediment from Waimea River. The mosaics that were chosen for this study had the best seafloor viewing conditions.

ArcGIS 9 was used for this research. Each photomosaic was imported into ArcGIS as a TIFF image file and used as a base map. To increase the visual contrast of the photomosaics, a standard deviation stretch was applied to each image. This made the sand easier to distinguish from other material, such as coral reef, reef rubble, limestone pavement, or volcanic pavement. Any continuous sandy area consisting mainly of sand with very little to no alternate material present was classified as a sand field.

All visible sand fields were digitized manually for each mosaic using ArcMap. This was done by manually tracing each sand field using individual vectors. Once an entire sand field was traced, a polygon was created. With all of the sand fields digitized as polygons, ArcToolbox was used to determine the overlapping extent of historic and modern sand fields, which represents stable sand fields. Lastly, the surface areas of the ephemeral and non-ephemeral sand fields were calculated using ArcMap.

Errors and Uncertainties

Photomosaic resolution produces an uncertainty of 0.5 m (the pixel size) for all imagery. There are image quality and spatial uncertainties associated with ortho-rectification of the photographs. Rectification errors are as follows:

- Kihei
  - 1960, ±0.67 m
  - 1997, ±0.73 m
  - 2007, ±0.66 m
- Kahului
  - 1975, ± 0. 96 m (avg.)
  - 2002, ± 0.10 m
- Poipu
  - 1975, ±1.25 m
  - 2007, ±0.73 m
- Kekaha (east)
  - 1950, ±1.28 m
  - 1987, ±0.75 m
  - 2006, ±0.75 m
- Kekaha (west)
  - 1950, ±1.99 m
  - 1987, ±1.27 m
  - 2006, ±0.78 m.

Uncertainty is also associated with digitizing the images. To determine the error in m^2 due to the digitization process, one large sand field and one small sand field from the 2007 Kihei base map were each manually digitized 30 times. The total area of each polygon was calculated, and standard deviations were determined for the small and large sand fields. The error associated with the digitization of small sand fields is ±25 m^2, and the error associated with the digitization of large sand fields is ±137 m^2. Overall, digitization produces a Root Mean Square Error of ±139 m^2. The RMS error represents 0.25% of the total area of stable sand identified.

Field Visits

Ground-truthing was performed in Poipu, Kauai to investigate possible sand resources. The areas of interest lay offshore of Brennecke Beach and Koloa Landing (Hanaka‘ape Bay). In the 2007 imagery, the depth of the water in both of the areas made it difficult to identify the composition of the seafloor. However, the color was slightly lighter, which suggested it was sand. Researchers swam about 250 m out from Koloa Landing to the presumed sand field. Some coarse sand was present in a channel leading out from shore; however this was an insignificant amount. From there, researchers swam west about 100 m. The sand field did not continue west as expected. The composition was mainly reef rubble and rock. It was concluded that the area off of Koloa Landing is not a viable resource for beach nourishment.

In addition, researchers swam out about 300 m from Brennecke Beach to the area of interest. The entire distance contained medium-grained sand. This sand field continued about 300 m west and ended before a tombolo where a rock shelf extends to the shore of Poipu Beach. This is a very large sand field that appears to be an excellent resource.

Visual assessment of Poipu Beach and Bay reveals that the mouth of the eastern bay is blocked by a shallow sill of less than 1 m depth. This prevents sand from entering the bay and renourishing losses due to currents carrying sand into the western bay. The offshore sand field immediately adjacent to the eastern bay appears to be a strong candidate for further investigation. Jet probing, the next likely step, should reveal whether the sand field has potential as a resource. It is recommended that the portion of the field closest to Poipu be targeted for use. This would likely eliminate any potential impacts to Brennecke Beach due to sand removal.

Results

Sandy area with no overlap between historic and modern coverage indicates that sand has been transported during the years of coverage. This sand is ephemeral, and it is not likely to be found in significant volume to be useful as a resource for beach nourishment. In contrast, any area of sand that is unchanging between historic and modern coverage represents non-ephemeral (stable) sand and is a potential target for further investigation as a resource for beach nourishment.

1. Kihei, Maui – A total of 521,034 m^2 of modern reef-top sand was identified along the Kihei coast (Fig. 3). Of this sand, 55,821 m^2 is stable reef-top sand. The largest non-ephemeral sand field has a surface area of 10,295 m^2, serving as a potential reservoir to replenish beaches. This sand field is located off of Kalama Beach Park. The next largest sand field is located off of Waipuilani Park and consists of 9,115 m^2 of stable sand.

2. North Shore, Maui – A total of 93,927 m^2 of modern reef-top sand was identified along the north shore of Maui (Fig. 4). Of this sand, about a third (31,656 m^2) is stable reef-top sand. The largest stable sand field has a surface area of 11,027 m^2 and is located just outside of Kahului Harbor (on the east side) in a channel leading out from the shore. In comparison to the other study areas, the north shore of Maui has the fewest number of stable sand fields and the smallest total area of stable sand. All of the stable sand fields identified are either small patches or channels, as opposed to large fields. However, it is possible that there is more stable sand along the north shore of Maui than estimated. This is because the imagery does not extend very far offshore. In some places, such as Kahului Harbor, the imagery only extends 600 m from the shore. In addition, there are several areas where turbidity of the water column obstructs the view of the seafloor.

3. Poipu, Kauai – A total of 581,419 m^2 of modern reef-top sand was identified along the coast of Poipu (Fig. 5). Of this sand, about half (292,104 m^2) is non-ephemeral, (stable) sand. The largest stable sand field is located off of Brennecke Beach and consists of 218,829 m^2. It is likely a significant resource for beach nourishment. The 2007 mosaic extends into deeper water than the 1975 mosaic. It is likely that the sand field off of Brennecke Beach extends further than the coverage of the 1975 mosaic. Thus, the sand field off Brennecke Beach may contain a greater area of sand than estimated.

4. Kekaha, Kauai – A total of 850,592 m^2 of reef-top sand was identified along the coast of Kekaha (Fig. 6). The majority of this sand (766,461 m^2) is non-ephemeral, stable sand. The largest sand field is located off of Kekaha Beach Park and consists of 638,448 m^2 of stable sand. It is a potential resource for beach nourishment, and should be further investigated. It is possible that this sand field has a greater surface area than estimated. The depth of the water in this area made it difficult to determine where the sand field ended. Therefore, the digitization performed was a conservative estimation of the size. The second largest sand field is also located off of Kekaha Beach Park and has a surface area of 76,952 m^2. No significant sand fields were found in the Waimea area. Suspended sediment from Waimea River caused poor water conditions and prevented the identification of sand in this area.

Discussion

Field visits for ground-truthing, to locations not yet visited, would be a beneficial next step in this research. This would help to decrease errors and uncertainties in the data. Surface glint, cloud cover, poor water quality, and depth were a major problem in the imagery. In particular, as the depth of water increased, visibility of the seafloor decreased. This resulted in many areas in the photomosaics where the composition of the seafloor was unclear. In many cases the seafloor may have been characterized by loose sand, however there was no way of determining this from the image. In these instances, no digitization was performed. Thus, it is possible that there are stable sand resources in the study areas that were overlooked. This can only be rectified by physically observing the composition in person.

In addition, jet probing, and sediment grain size analysis, targeting non-ephemeral (stable) sand fields as identified here, are recommended to determine the volume of sand available and its suitability as a beach resource. Surface area alone is not enough to determine if a sand field contains enough sand to be used as a resource. Jet-probing will determine the thickness, and therefore the volume of a sand field. Grain size statistics will provide valuable information on the suitability of various sand fields as resources for beaches needing nourishment.

Conclusions

1. 55,821 m^2 of stable sand is stored on the reef flat off the coast of Kihei, Maui, serving as potential resource for beach replenishment.
2. 31,656 m^2 of stable sand is stored on the reef flat off of the north shore of Maui.
3. 292,104 m^2 of stable reef-top sand is stored off the coast of Poipu, Kauai. The majority of this sand is located in a large sand field off of Brennecke Beach.
4. 766,461 m^2 of stable reef-top sand is stored off the coast of Kekaha, Kauai. The majority of this sand is located in two large sand fields off of Kekaha Beach Park.
5. Crucial future directions include field visits and jet probing.

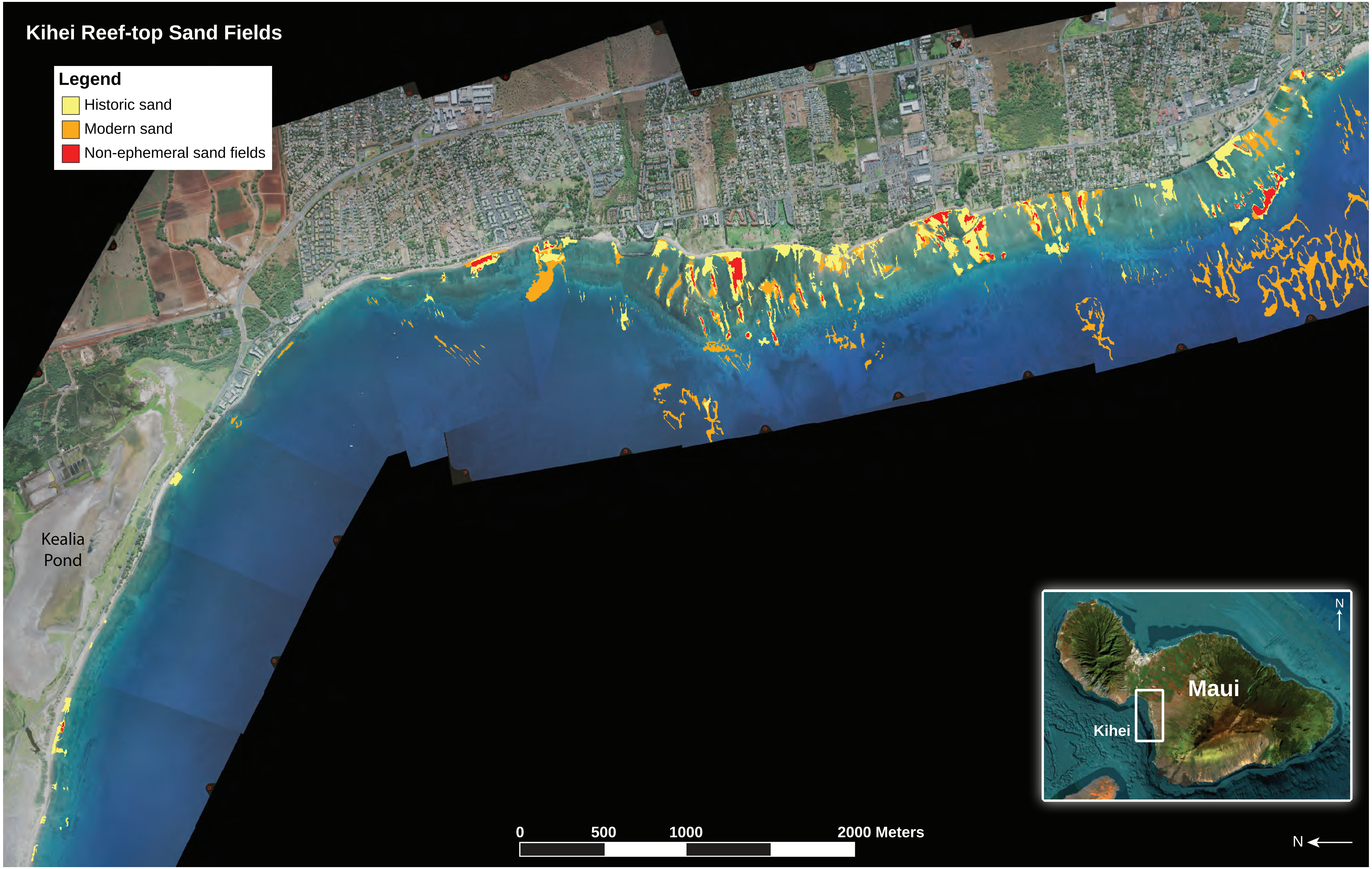


Figure 3. Reef-top sand fields located at Kihei, Maui.

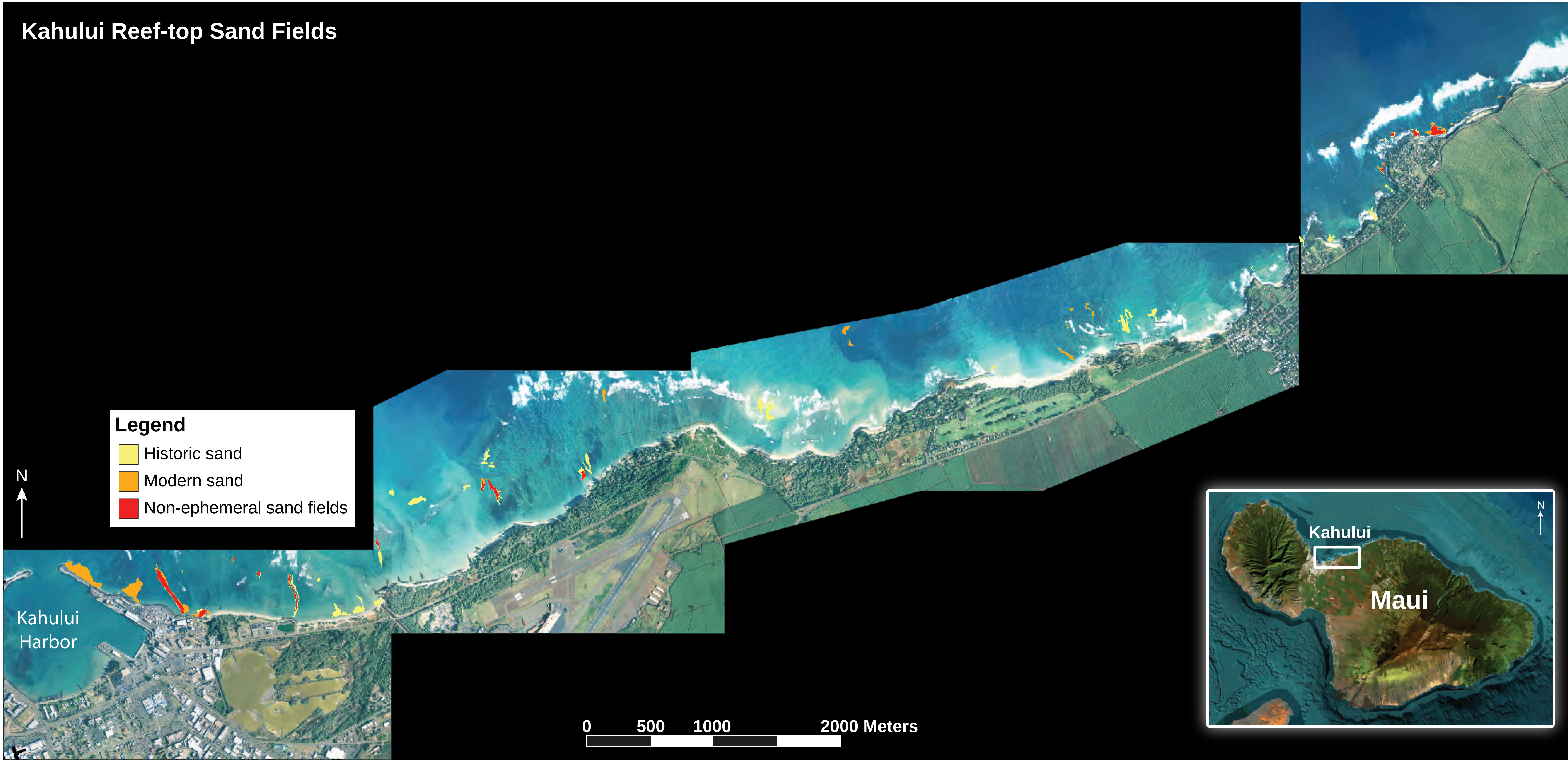


Figure 4. Reef-top sand fields located at Kahului, Maui

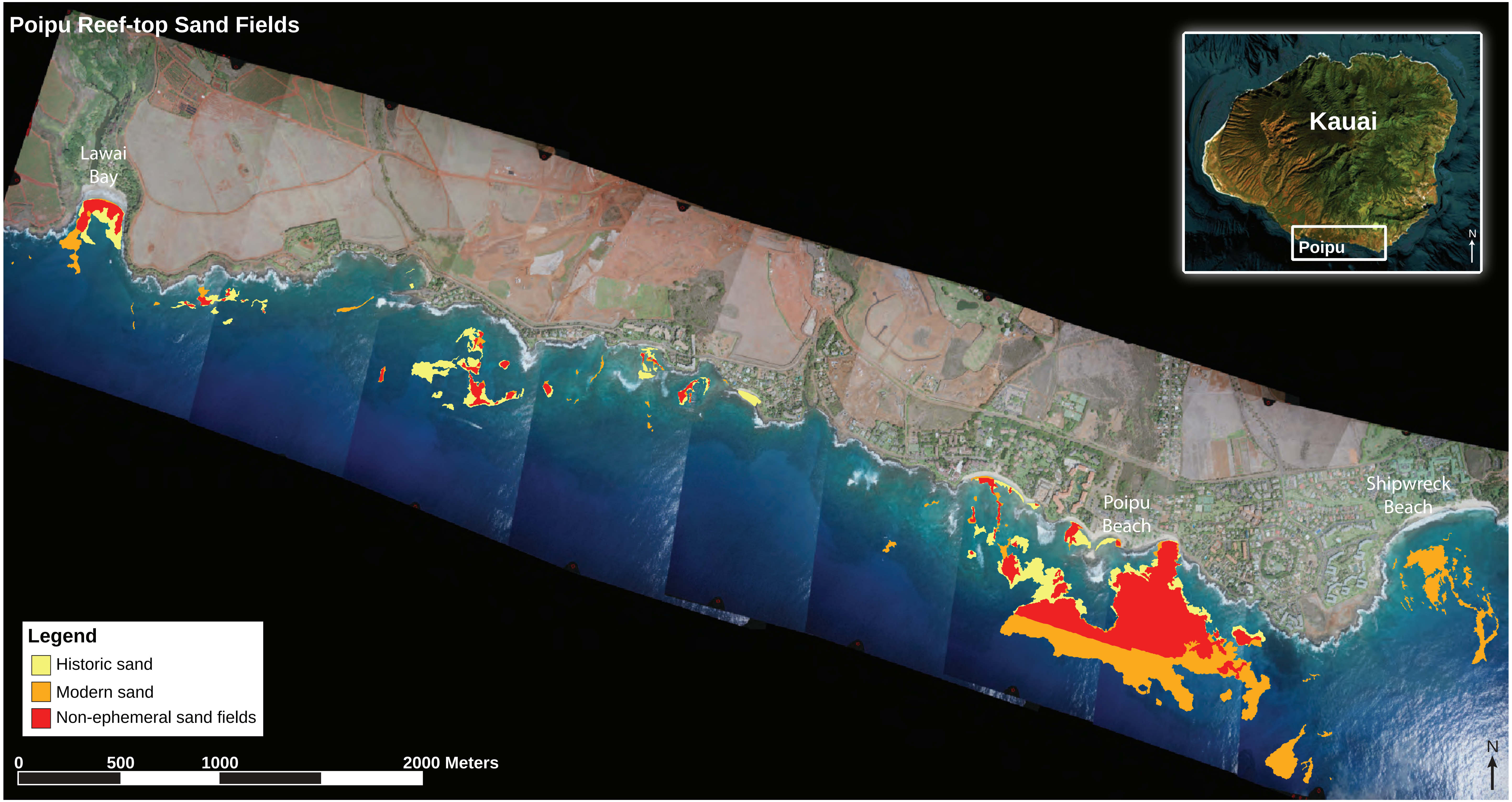


Figure 5. Reef-top sand fields located at Poipu, Kauai.

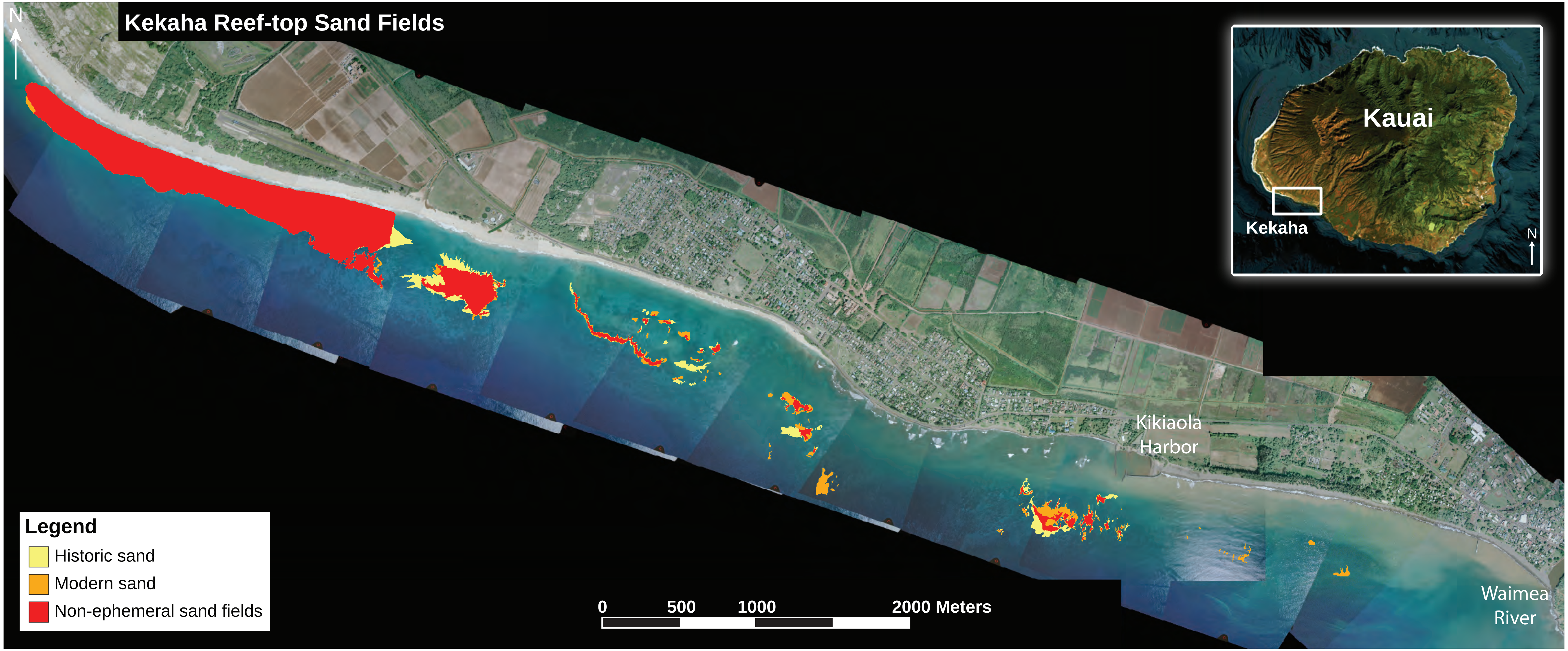


Figure 6. Reef-top sand fields located at Kekaha, Kauai.

Reference

Bochicchio, C., Fletcher C., Dyer, M., Smith, T. (2009) Reef-top Sediment Bodies: Windward O'ahu, Hawai'i. Pacific Science 63(1):61-82

Conger, C.L., Fletcher, C.H., Barbee, M., (2005) Artificial neural network classification of sand in all visible submarine and subaerial regions of a digital image. Journal of Coastal Research, 21.6, p. 1173-1177.

DLNR, 2010 Department of Land and Natural Resources, Office of Conservation and Coastal Lands, Beach Nourishment Projects: *http://hawaii.gov/dlnr/occl/projects/beach-nourishment*

Fletcher, C.H., Bochicchio, C., Conger, C.L., Engels, M.S., Feirstein, E.J., Frazer, N., Glenn, C.R., Grigg, R.W., Grossman, E.E., Harney, J.N., Isoun, E., Murray-Wallace, C.V., Rooney, J.J., Rubin, K.H., Sherman, C.E. (2008) Geology of Hawaii Reefs. Chapter 11 in "Coral Reefs of the U.S.A.", Springer, p. 435-488.

Bibliography of Sand Field Studies

1. Barry, J.H., Jr. (1995) Characterization of sand deposits on the insular shelf of southern Oahu, off western Molokai, and on Penguin Bank. SOEST Technical Report 95-02, Hawaii Natural Energy Institute, Marine Minerals Technology Center, Honolulu, HI, 128 p.

2. Bochicchio, C., Fletcher, C.H., Dyer, M., Smith, T. (2009) Reef-top sediment bodies: Windward Oahu, Hawaii. Pacific Science, vol. 63, no. 1:61-82.

3. Bodge, K. (2003) Design Aspects of Groins and Jetties. Advances in Coastal Structure Design, ASCE, p. 181-199.

4. Bodge, K. (2000) Independent Evaluation Study of the Proposed Kuhio Beach Improvements. Olsen Associates, Inc., Jacksonville, FL.

5. Bodge, K. (1998) Beach Fill Stabilization with Tuned Structures: Experience in the Southeastern U.S.A. and Caribbean. Proc. Coastlines, Structures, and Breakwaters '98. Thomas Telford Publishing, London, p. 82-93.

6. Calhoun, R.S., Fletcher, C.H., and Harney, J.N. (2002) A budget of marine and terrigenous sediments, Hanalei Bay, Kauai, Hawaiian Islands. Sedimentary Geology, 150, 1-2, 61-87.

7. Calhoun, R.S., and Fletcher, C.H. (1999) Measured and predicted sediment yield from a subtropical, heavy rainfall, steep-sided river basin: Hanalei, Kauai. Geomorphology, v. 30, p. 213-226.

8. Calhoun, R.S., Fletcher, C.H. (1996) Late Holocene coastal-plain stratigraphy and sea level history at Hanalei, Kauai, Hawaiian Islands. Quaternary Research. 45, p. 47-58.

9. Chamberlain, T. (1968) The littoral sand budget, Hawaiian Islands. Pacific Science, v. 22, no. 2, p. 161-183.

10. Chave, K.E., Tait, R.J., Stimson, J.S., and Chave, E.H. (1973). Waikiki Beach Erosion Project: Marine Environment Study. Hawaii Institute of Geophysics, University of Hawaii, Report No. HIG-73-12. Prepared for the U.S. Army Corps of Engineers.

11. Conger, C.L., Fletcher, C.H., Hochberg, E.J., Frazer, N., Rooney, J.J., (2009). Remote sensing of sand distribution patterns across an insular shelf: Oahu, Hawaii. Marine Geology, vol. 267, no. 3-4: 175-190.

12. Conger, Christopher L., Eric J. Hochberg, Charles H. Fletcher, III, and Marlin J. Atkinson (2006) A new method of decorrelating remote sensing color bands from bathymetry in optically shallow waters. IEEE Transactions on Geoscience and Remote Sensing. 44(6): 1655-1660.

13. Conger, C.L., Fletcher, C.H., Barbee, M., (2005) Artificial neural network classification of sand in all visible submarine and subaerial regions of a digital image. Journal of Coastal Research, 21.6, p. 1173-1177.

14. Coulbourn, W.T., Campbell, J.F., and Moberly, R., Jr., 1974, Hawaiian submarine terraces, canyons, and Quaternary history evaluated by seismic-reflection profiling. Marine Geology, v. 17, p. 215-234.

15. Coulbourn, W.T., Campbell, J.F., Anderson, P.N., Daugherty, P.M., Greenberg, V.A., Izuka, S.K., Lauritzen, R.A., Tsutsui, B.O., and Yan, C. (1988) Sand deposits offshore Oahu. Hawaii. Pacific Science, v. 42, p. 267-299.

16. Cox, D. C. (1978) Hawaii Coastal Zone Management Program technical supplement 12: Notes on Hawaiian sand beach management. Prepared for the State of Hawaii Department of Planning and Economic Development by the University of Hawaii Pacific Urban Studies and Planning Program.

17. Cruickshank, Michael J. (1991). Analysis of Options and Recommendations for the Recovery, Beneficiation and Transportation of Sand from Selected Offshore Deposits for Replenishment of Waikiki Beach. Consultants Report. Honolulu HI.

18. DLNR, 2010 Department of Land and Natural Resources, Office of Conservation and Coastal Lands, Beach Nourishment Projects: *http://hawaii.gov/dlnr/occl/projects/beach-nourishment*

19. Dollar, S.J. (1979) Sand mining in Hawaii: research, restrictions, and choices for the future. Sea Grant Technical Paper, UNIHI-SEAGRANT-TP-79-01, The University of Hawaii Sea Grant Program, Honolulu, HI, 106 p.

20. Engels, M.S., Fletcher, C.H., Field, M., Conger, C.L., Bochicchio, C. (2008) Demise of reef-flat carbonate accumulation with late Holocene sea-level fall: evidence from Molokai, Hawaii. Coral Reefs.

21. Ericksen, M.C., Barry, J.H., and Schock, S.G. (1997) Sub-bottom imaging of the Hawaiian shelf. Sea Technology, June 1997, p. 89-92.

22. 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, v. 19, p. 649-663.

23. 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

24. Fletcher, C.H. and Sherman, C. (1995) Submerged shorelines on Oahu, Hawaii: Archive of episodic transgression during the deglaciation? Journal Coastal Research, Special Issue 17

Holocene Cycles: Climate, Sea Level, and Sediment, p. 141-152.

25. Fletcher, C.H., Murray-Wallace, C., Glenn, C., Popp, B., Sherman, C. (2005) Age and origin of late quaternary eolianite, Kaiehu Point (Moomomi), Molokai, Hawaii. Journal of Coastal Research, SI 42, p. 97-112.

26. Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E. (2002) Atlas of natural hazards in the Hawaiian coastal zone. U.S. Geological Survey, Denver, CO, Geologic Investigations Series I-2761, 182p. *http://geopubs.wr.usgs.gov/i-map/i2761/*

27. Fletcher, C.H., Bochicchio, C., Conger, C.L., Engels, M., Feirstein, E.J., Grossman, Grigg, R., E.E., Harney, J.N., Rooney, J.J., Sherman, C.E., Vitousek, S., Rubin, K., Murray-Wallace, C.V. (2008) Geology of Hawaii Reefs. Chapter 11 in “Coral Reefs of the U.S.A.”, Springer, p. 435-488.

28. 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.

29. Fletcher, C.H. (2009) Sea level by the end of the 21st century: A review. Shore and Beach, v. 77, no. 4, pp. 1-9.

30. Gerritsen, F. (1978) Beach and surf parameters in Hawaii. University of Hawaii Sea Grant College Program Technical Report UNIHI-SEAGRANT-TR-78-02.

31. Gibbs, A.E., Richmond, B.M., Fletcher, C.H., and Hillman, K.P., 2001, Hawaii beach monitoring program: beach profile data. U.S. Geological Survey Open-File Report 01-308, CD. (See also: *http://geopubs.wr.usgs.gov/open-file/of01-308*)

32. Hampton, M.A., Fletcher, C.H., Barry, J.H., and Lemmo, S.J. (2002) The Halekulani sand channel and Makua shelf sediment deposits: Are they a sand resource for replenishing Waikiki's beaches? In: Robbins, L.L., Magoon, O.T., and Ewing, L. (eds.), Carbonate Beaches 2000: First International symposium on Carbonate Sand Beaches, Reston, VA, American Society of Civil Engineers, p. 67-81.

33. Hampton, M.A., Blay, C.T., Murray, C., Torresan, L.Z., Frazee, C.S., Richmond, B.M., Fletcher, C.H. (2003) DATA REPORT: Geology of Reef-Front Carbonate Sediment Deposits around Oahu, Hawaii, OFR 03-441, U.S. Geological Survey Open File Report. See at: *http://walrus.wr.usgs.gov/reports/ofr03-441.html*

34. Harney, J.N., Hallock-Muller, P., Fletcher, C.H., Resig, J.M., and Richmond, B.M. (1999) Standing crop and sediment production of reef-dwelling foraminifera on Oahu, Hawaii. Pacific Science, v. 53, no. 1, p. 61-73.

35. Harney, J.N., and Fletcher, C.H. (2003) A budget of carbonate framework and sediment production, Kailua Bay, Oahu, Hawaii. Journal of Sedimentary Research, v. 73, no. 6, p. 856-868.

36. Harney, J.N. and Fletcher, C.H. (2003) Modeling biogenic sediment production on carbonate coasts. Coastal Sediments ’03.

37. Harney, J.N., Grossman, E.E., Richmond, B.M., and Fletcher, C.H. (2000) Age and composition of carbonate shoreface sediments, Kailua Bay, Oahu, Hawaii: Coral Reefs, v. 19, pg. 141-154.

38. Hwang, D.J. and Fletcher, C.H. (June 1992). Beach management plan with beach management districts. Report prepared for Hawaii Coastal Zone Management Program, Office of State Planning, and Office of the Governor.

39. Isoun, E., Fletcher, C.H., Frazer, N., and Gradie, J. (2003) Multi-spectral mapping of reef bathymetry and coral cover; Kailua Bay, Hawaii. Coral Reefs, v. 22, p. 68-82.39. Marine Advisors, Inc. (1968) Sand survey at Waikiki and the Honolulu Harbor entrance, Oahu. Prepared for the State of Hawaii Department of Transportation, Harbors Division.

40. Miller, T.L. and Fletcher, C.H. (2003) Waikiki: Historical analysis of an engineered shoreline. Journal of Coastal Research, v. 19.4, p. 1026-1043.

41. Moberly, R. (1963) Coastal Geology of Hawaii. Hawaii Institute of Geophysics Report No.41. Prepared for Department of Planning and Development, State of Hawaii, under Contract No. 6031.

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

43. Moberley, R. (1968) Loss of Hawaiian littoral sand. Journal of Sedimentary Petrology, v. 38, no. 1, p. 17-34.

44. Moberly, R., Campbell, J.F., and Coulbourn, W.T. (1975) Offshore and other sand resources for Hawaii. Sea Grant Technical Paper, UNIHI-SEAGRANT-TR-75-03. The University of Hawaii Sea Grant Program, Honolulu, HI.

45. Noda, Edward K. (1991) Sand Source Investigations for Waikiki Beach Fill, Waikiki Beach Improvement Project. Prepared for State of Hawaii Department of Transportation Harbors Division. Report No. EKN-1201-R-4-1. Honolulu HI.

46. Norcross, Z.M., Fletcher, C.H., and Merrifield, M. (2002) Annual and interannual changes on a reef-fringed pocket beach: Kailua Bay, Hawaii. Marine Geology 190, p. 553-580.

47. Norcross, Z., Fletcher, C.H., Rooney, J.J.R., Eversole, D., and Miller, T.L. (2003) Hawaiian beaches dominated by longshore transport. Proceedings, Coastal Sediments ’03, Clearwater,

Florida, May 18-23, 2003.

48. Sea Engineering, Inc. (1993) Beach Nourishment Viability Study. Prepared for Office of State Planning Coastal Zone Management Program. SEI Report 92-26.

49. Sea Engineering, Inc. (2008) Lanikai Beach Restoration Study Conceptual Design Report. Prepared for the U.S. Army Corps of Engineers, Honolulu District.

50. Sea Engineering, Inc. (2008) Waikiki Beach War Memorial Natatorium Honolulu, Hawaii: Shoreline restoration study conceptual design review report. Prepared for the U.S. Army Corps of Engineers, Honolulu District.

51. Sea Engineering, Inc. and Precision Signal Inc. (1995) Development of a broadband FM subbottom profiler for seafloor imaging and sediment classification. Prepared for the National Defense Center of Excellence for Research in Ocean Science (CEROS).

52. Stahl, M.S. (1976) Hawaiian sand resources recommendation memo. University of Hawaii Pacific Urban Studies and Planning Program, Coastal Zone Management Program.

53. Stearns, H.T. (1935) Pleistocene shorelines on the islands of Oahu and Maui, Hawaii. Geological Society of America Bulletin, v. 46, p. 1927-1956.

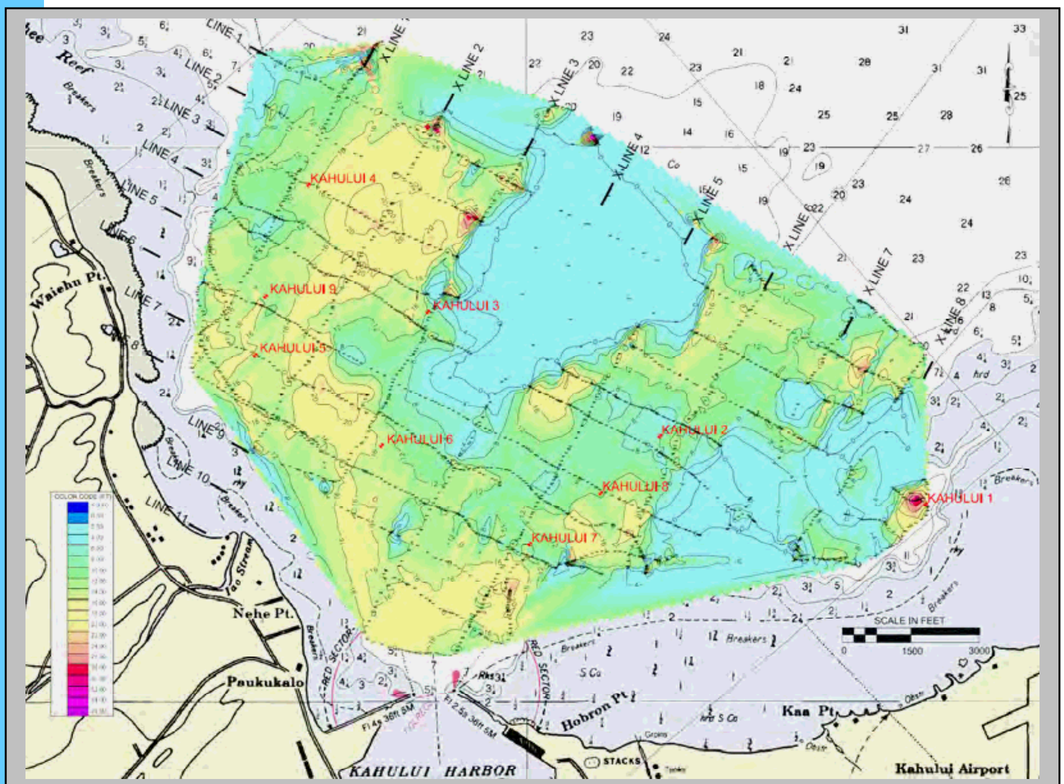
54. Wiegel, R.L. (2008) Waikiki Beach, Oahu, Hawaii: History of its transformation from a natural to an urban shore. Shore & Beach, Vol. 76, No. 2.

APPENDIX I

MAUI SAND SOURCE INVENTORY – REFERENCE DOCUMENT
(SEA ENGINEERING, 2008)

KAHULUI BAY SUB-BOTTOM SURVEY

November 2008



Prepared for:

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SEI Job No.25117

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1. INTRODUCTION

In May, 2008, Sea Engineering, Inc. (SEI) was retained by Moffatt & Nichol to conduct a sub-bottom survey using geophysical methods of Kahului Bay on the north shore of the island of Maui. The survey was designed to investigate the nature of sand deposits in the bay. Previous benthic surficial mapping by NOAA (National Oceanographic and Atmospheric Administration) had indicated the broad presence of sand deposits within the bay, however there were no data available to determine the thickness of the sand deposits.

The survey covered an area of approximately 5.5 square miles. Primary survey lines were run at 1,000-ft intervals, and survey cross-lines were run at 2,000-ft intervals. The project location and survey line plan is shown in Figure 1-1.

The geophysical work was conducted over the course of two days, May 13 and 14, 2008. In addition, a series of nine surficial sediment samples were collected using a Ponar grab sampler.

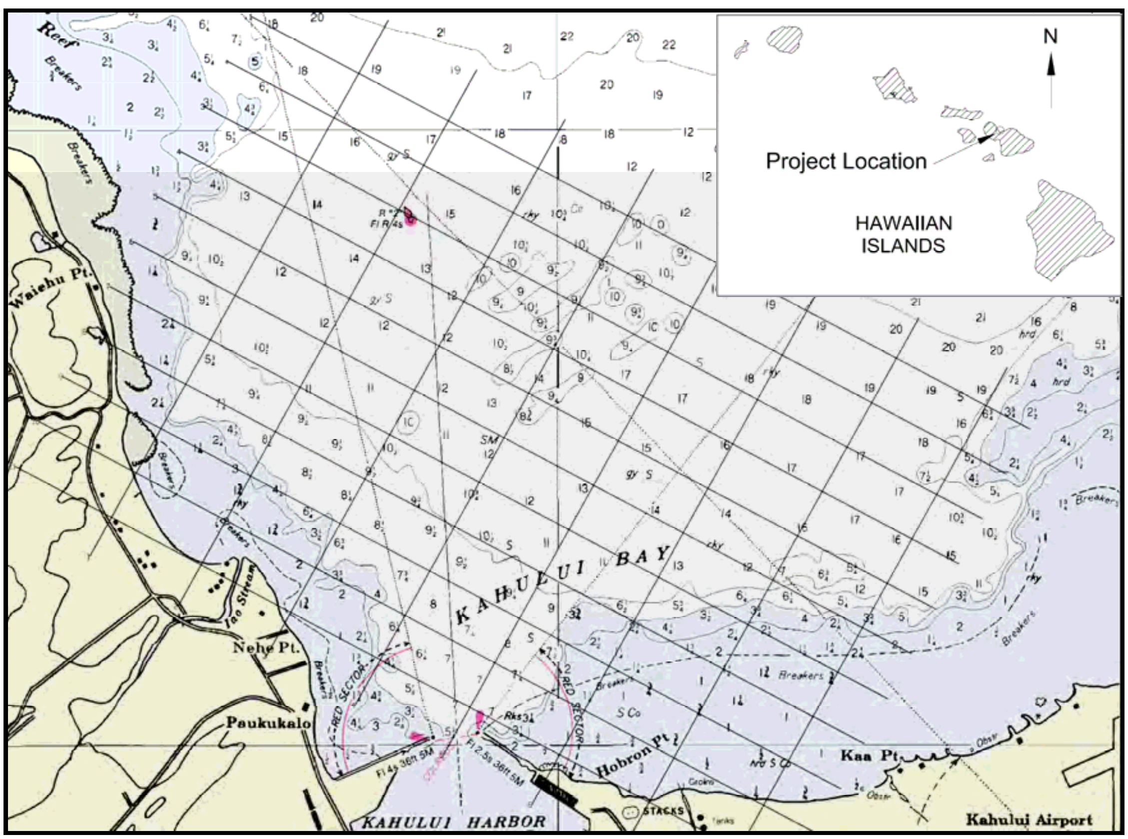

Figure 1-1 Survey Location and Plan

2. METHODOLOGY

2.1 Sub-Bottom Profiling Methods

Geophysical sub-bottom profiling systems are essentially echo-sounders that use lower acoustic frequencies to penetrate into the substrate. Where common echo-sounders may use an acoustic frequency in the vicinity of 200 kHz, sub-bottom system frequencies are typically between 500 Hz and 20 kHz. The term sub-bottom refers to a generally hard layer of sediment or rock that underlies recent soft sediment deposition. The lower the acoustic frequency, the deeper into the bottom the system can penetrate

For this survey, an EdgeTech 0512i "chirp" sub-bottom profiler was used with an EdgeTech 3200XS processing system. The chirp processors use signal processing to shape the acoustic wavelets used to image the substrate. They provide significantly greater image resolution than traditional impulsive systems such as boomers and sparkers. Different wavelets are available with the system for use in different terrains. After on-site system deployment, trial survey lines were conducted using various pulse configurations. The optimal pulse for the substrate in Kahului Bay was found to be a 20 ms pulse with a frequency range of 500 Hz to 7kHz. This is a relatively low frequency range, but necessary for penetration into the coralline limestone sands and gravels found in Hawaii. The EdgeTech 0512i system is in fact a specialty system for use in coarse sand environments.

2.2 Sub-Bottom Data Processing and Interpretation

The sub-bottom data were reviewed with EdgeTech software and sub-bottom horizons were digitized for processing. Sand thickness data were contoured using Digital Terrain Model (DTM) software, and final charts created using AutoCAD.

The offshore substrate around the Hawaiian Islands is complex, and can consist of different combinations of carbonate sand, coral gravels and cobbles, lithified or indurated sediment horizons, hard coralline limestone and some areas with volcanic rock features and terrigenous sediment. The sub-bottom horizons are therefore often difficult to interpret. As a generalized model, Kahului Bay appears to have a hard reef layer that is overlain by sediment layers 20 to 60 feet in thickness, and sometimes greater. The reef emerges from the bottom and outcrops in bathymetric high areas scattered throughout the survey area. However, the thick sediment overlying the reef has numerous acoustic reflectors that are indicative of hard layers. A conservative approach was taken for this study, and sand thickness was mapped to the first indication of a hard layer. Sand thickness in mapped areas is typically 10 to 20 feet. Sand deposits less than about 6 feet in thickness were difficult to map.

Figure 2-1 is a typical sub-bottom image showing the basal reef layer (acoustic basement – the limit of acoustic imaging) and overlying sediments, including about 15 to 20 ft of sand. The basal layer is approximately 40 to 60 feet below the seafloor. The intermediate sediments are likely to be an assortment of indurated sand, gravel, cobble and possibly even thin layers of coralline reef limestone. Figure 2-2 is a section showing the emergence of reef limestone into a bathymetric high.

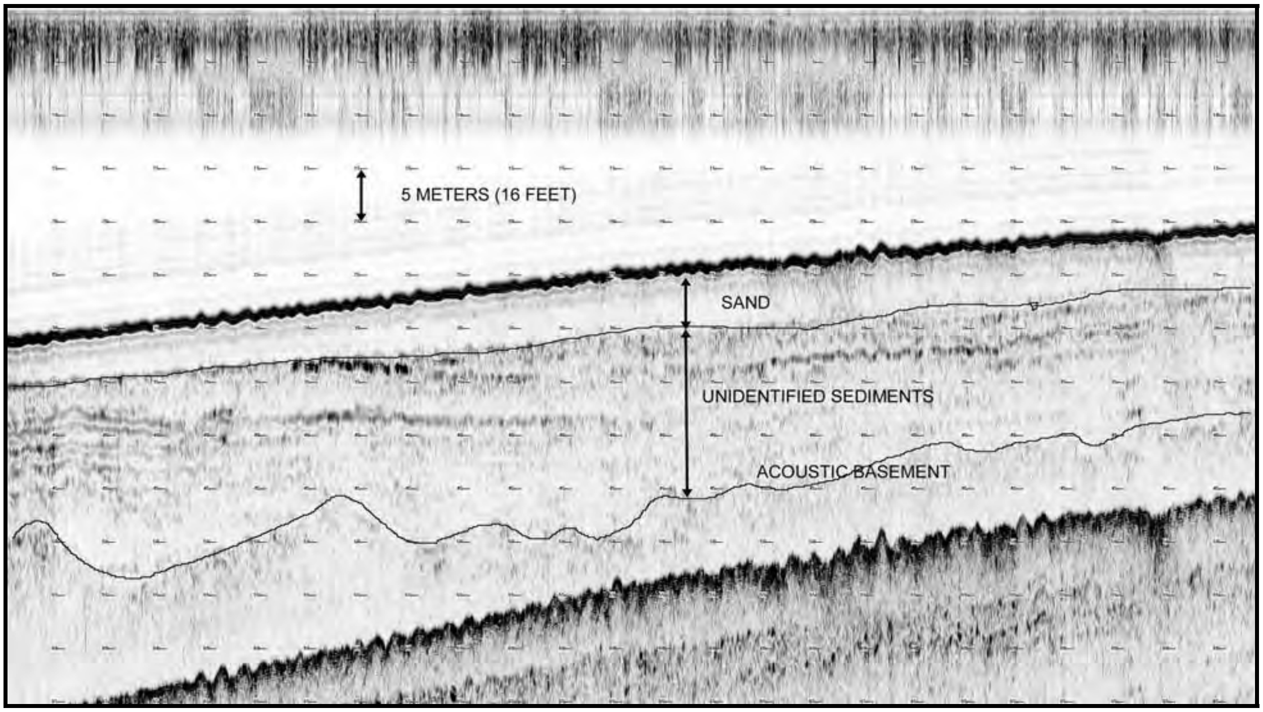

Figure 2-1 Typical sub-bottom imagery in Kahului Bay

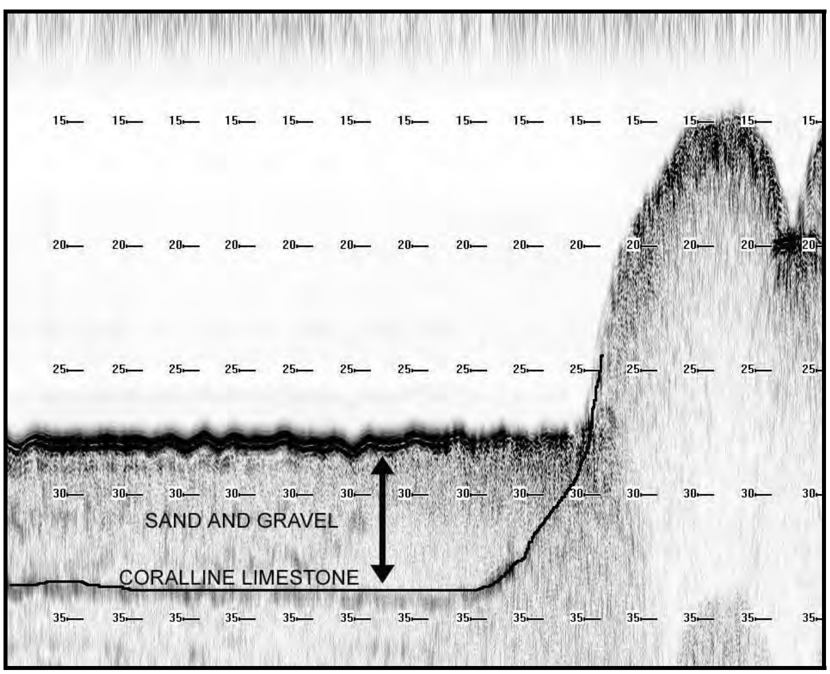

Figure 2-2 Sub-bottom imagery showing emergence of reef substrate

2.3 Bottom Sediment Samples

A total of nine bottom surface samples were retrieved using a Ponar sampler. Eight of the samples were analyzed for grain size by AECOS, Inc (note: sample Kahului 1 was not analyzed as it consisted of coral gravel and cobbles). Sediment descriptions and photographs are included as an appendix; size distribution results are shown in Table 2-1 and Figure 2-3.

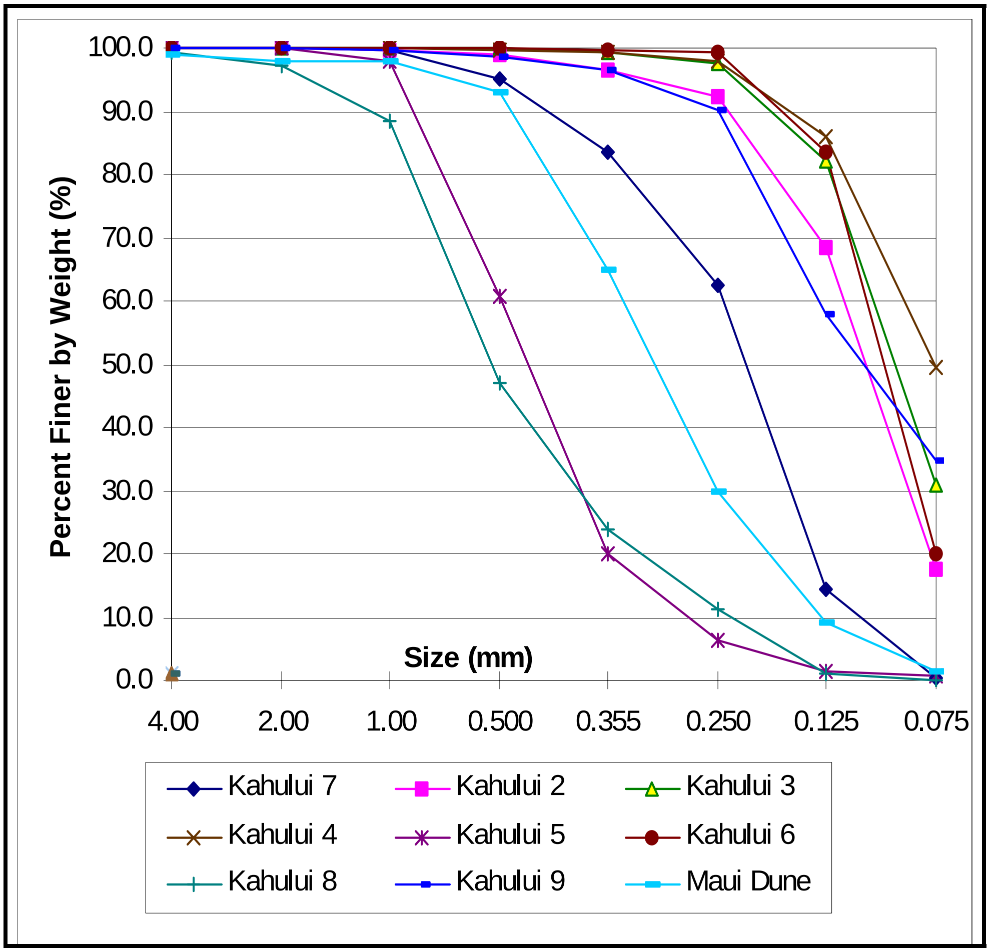

Figure 2-3 Graph of sample grain size distribution

Table 2-1 Sample grain size distribution

Percent Finer by Weight (%)								
size (mm)	**4.00**	**2.00**	**1.00**	**0.500**	**0.355**	**0.250**	**0.125**	**0.075**
Kahului 2	100.0	100.0	99.8	99.1	96.7	92.2	68.4	17.5
Kahului 3	100.0	100.0	100.0	100.0	99.2	97.4	82.1	30.8
Kahului 4	100.0	100.0	100.0	99.8	99.4	98.0	86.1	49.4
Kahului 5	100.0	99.8	97.8	60.6	19.8	6.4	1.6	0.8
Kahului 6	100.0	100.0	100.0	100.0	99.8	99.1	83.4	19.9
Kahului 7	100.0	100.0	99.8	95.0	83.7	62.4	14.3	0.4
Kahului 8	99.4	97.4	88.3	47.2	23.9	11.1	1.0	0.0
Kahului 9	100.0	100.0	99.6	98.4	96.5	90.2	58.1	34.7

3. RESULTS

3.1 Sub-bottom survey results

The presence of sand deposits 10 to 20 feet in thickness over much of Kahului Bay was confirmed by the sub-bottom survey. Figure 3-1 shows the results of the survey, with thickness contours highlighted in color. The bottom morphology of the bay is dominated by a broad central area with bathymetrically high reef areas (see Figure 2-2). With the exception of these emergent reef areas, it appears that most of the bay has at least 6 feet of sand substrate. As a conservative approach was taken during the interpretation process, it is possible that some areas have thicker sand deposits. As a general observation, the western portion of the bay appears to have somewhat thicker sand deposits. Differentiation between sand and gravel is difficult in sub-bottom images, and gravel areas were not mapped for that reason. However, what appear to be gravel deposits were more prevalent in the eastern portion of the bay.

The surface sand layers are commonly underlain by unknown sediment deposits that are stratified by acoustically reflective horizons. These sediments are likely to be inter-bedded layers of sand, gravel, indurated sand – in fact, any kind of coralline limestone reef derived deposits. It is also possible that viable sand deposits could be found underneath some of the hard reflectors that have been mapped as the base of the surficial deposits.

3.2 Sand sample results

Sand sample locations and photographs are contained in Appendix 1. Locations are also shown on the survey drawing, Figure 3-1 labeled as Kahului 1 through Kahului 9. Grain size distributions are shown in Figure 2-3 and Table 2-1. For comparison, Figure 2-3 also shows the distribution for Maui Dune Sand. The dune sand has been one of the major sources of sand for small-scale beach nourishment projects and sand bag protection projects on Maui. It is fine sand and barely meets grain size criteria for most beach projects, and is not really suitable for beach nourishment in energetic wave conditions.

Offshore sand deposits in Hawaii typically have two major limitations with respect to use for beach nourishment:

- Deposits are typically too fine-grained and,
- Deposits are often stained gray in color and therefore aesthetically un-pleasing.

Of the nine samples collected, two (Samples 5 and 8) had both good color and grain size characteristics. Sample 8 was coarse sand with a buff color that is attractive for beach sand. Sample 5 is exceptional in both color and grain size characteristics. It has a “salt and pepper” appearance due to a high percentage of terrigenous basalt fragments so it may not be suitable for all applications. Most of the samples (Samples 2, 3, 4, 6, 9) were both too fine and poorly colored. Sample 7 was too fine, although nicely colored, and Sample 1 consisted of large coral pieces.

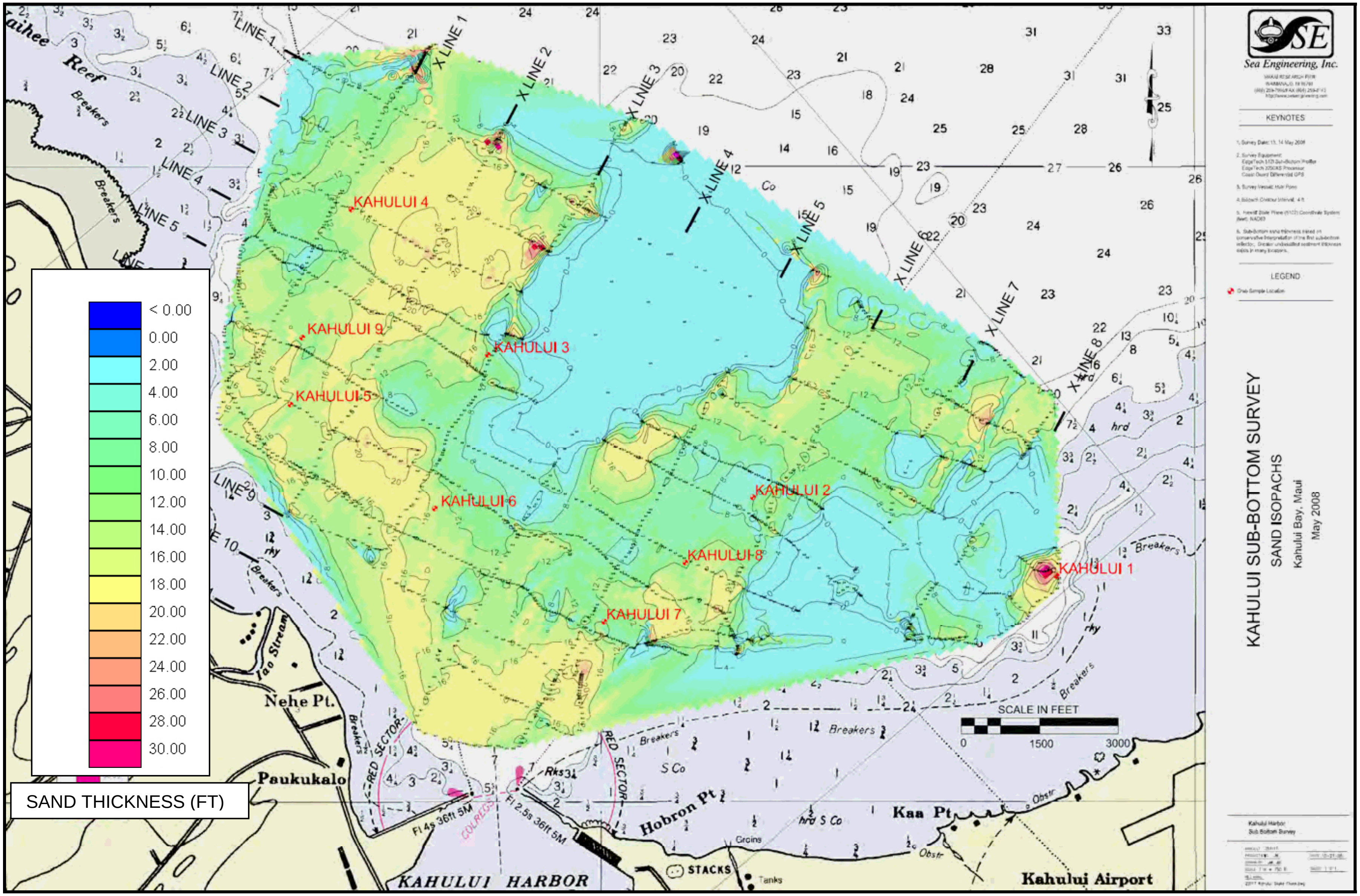

Figure 3-1 Kahului Bay sand thickness and sample locations

4. DISCUSSION

The survey results show the presence of widespread sand deposits in Kahului Bay. Most of the sand in the bay is probably too fine and poor in color for beach projects. However, two out of nine bottom samples indicated sand that would be suitable for beach nourishment, and in fact have excellent color and grain size characteristics. The extent of the suitable sand is not known and will require follow up investigations in order to characterize the areal extent of the deposits, and grain size and color characteristics below the surface.

Follow on work may include survey work in the form of side scan sonar and drop camera surveys for acoustic and visual imaging of the bottom surface, a more intensive bottom sampling effort, and vibracore sampling to collect deposits below the bottom surface. SEI recently completed a comprehensive study of this type off West Maui for the Kaanapali Operators Association.

Kahului Bay is on the exposed windward side of the island, and conditions are generally poor for ocean work. Much of the fieldwork mentioned above will require calm weather windows, such as light and variable or Kona wind conditions, in order to produce good quality field data.

APPENDIX 1. SAMPLE PHOTOGRAPHS AND DESCRIPTIONS

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 1		
Position **(NAD83 State Plane, ft)**		**Description**
1,717,194 E / 210,174 N		Coral gravel and cobble, 0.5 to 3 inch fragments

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 2		
Position **(NAD83 State Plane, ft)**		**Description**
1,7115,79 E / 211,654 N		Well sorted light gray fine sand

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 3		
Position **(NAD83 State Plane, ft)**		**Description**
1,706,510 E / 214,379 N		Well sorted gray fine sand

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 4		
Position **(NAD83 State Plane, ft)**		**Description**
1,703,902 E / 217,150 N		Well sorted gray fine sand

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 5		
Position **(NAD83 State Plane, ft)**		**Description**
1,702,734 E / 213,427 N		Well sorted coarse sand, “salt and pepper” mix of coralline components and approx. 30% basalt components.

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 6		
Position **(NAD83 State Plane, ft)**		**Description**
1,705,498 E / 211,443 N		Well sorted light gray fine sand.

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 7		
Position **(NAD83 State Plane, ft)**		**Description**
1,708,736 E / 209,290 N		Moderately sorted fine-grained buff colored coralline sand.

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 8		
Position **(NAD83 State Plane, ft)**		**Description**
1,710,287 E / 210,415 N		Moderately sorted coarse-grained buff colored coralline sand.

Ponar Surface Sample **Vessel: Huki Pono**		**Kahului Bay, Maui** **Date: 14 May, 2008**
Sample: Kahului 9		
Position **(NAD83 State Plane, ft)**		**Description**
1,702,960 E / 214,707 N		Well sorted gray fine sand.

APPENDIX J

KAUAI RSM WORKSHOP MEETING MINUTES

HAWAII REGIONAL SEDIMENT MANAGEMENT PROGRAM

Kauai Workshop Meeting Minutes
20 January 2011

I. Purpose

A workshop was held on Thursday 20 January 2011 to present the findings of the Hawaii Regional Sediment Management (RSM), focusing on Kauai in the Kekaha and Poipu regions. The meeting started at 1:00 pm and adjourned at 5:00 pm in the Kauai Veterans Center, 3215 Kapule Highway, Lihue.

Sections IV through IX below summarize the technical presentations and group discussions that took place at the workshop. These presentations are available on the U.S. Army Corps of Engineers Honolulu District public website at the following location:

http://gis.poh.usace.army.mil/rsm/index.htm

The workshop agenda is presented in Attachment A.

II. Attendees

The list of attendees is presented in Attachment B.

III. Introductions

Tom Smith, U.S. Army Corps of Engineers (USACE), Honolulu District, POH Technical Lead, presented introductory remarks to welcome everyone to the workshop. Representing the non-federal sponsor for the RSM Program was Chris Conger, University of Hawaii, Sea Grant Extension agent and technical advisor for the State of Hawaii Department of Land and Natural Resources (DLNR), Office of Conservation and Coastal Lands (OCCL). Mr. Conger, who was standing in for Sam Lemmo, administrator of the OCCL, briefly thanked the USACE, University of Hawaii, government agencies (local, state, and county), and private consulting firms for their support of this project, Jackie Conant, USACE Project Manager, then gave a brief introduction to each of the technical experts who gave the following presentations.

IV. Regional Sediment Management Overview (Presented by Tom Smith, U.S. Corps of Engineers, Honolulu District POH Technical Manager)

The remarks made by Tom Smith have been summarized below.

The U.S. Army Corps of Engineers' nationwide RSM Program has an integrated approach to sediment management taking a holistic view of coastal, estuary, and river sediments on a regional scale in the planning and maintenance of water resource projects to achieve balanced and sustainable systems. The program started in 2000 in the U.S. southern region – USACE, Mobile District, and over the past 10 years has spread throughout the east, west, and gulf coasts as well as in southeast Lake Michigan. Although there is not as much sedimentation in Hawaii and therefore not as much opportunity for RSM, the Honolulu District has gained funding for this initiative in Hawaii.

For the Southeast Oahu (SEO) RSM study, there were about 30 miles of coast covered on the island of Oahu: the first spanning from Mokapu Point to Makapuu Point and the second RSM study spanning from Diamond Head to Pearl Harbor (D2P), which includes Ewa Beach. Regional sediment budgets, historical shoreline change, modeling results, and GIS platforms have been compiled and have led to a RSM plan and identification of potential RSM projects.

The purpose of the SEO/RSM study was to optimize the use of sediment resources by gaining an understanding of complex sediment transport pathways; studying large portion of critically eroded shorelines; investigating armored shorelines; and discovering economical sand sources yet to be identified. Ultimately the goal of the study was to increase understanding of littoral processes with intentions of preserving and restoring beaches in the region with potential applications elsewhere.

It was discovered that in this region, the shoreline is highly variable due to seasonal changes causing sand loss. The University of Hawaii Manoa, School of Ocean and Earth Science and Technology (SOEST) is conducting various research efforts to support the Hawaii RSM Program. To identify offshore sand sources, graduate students have analyzed jet probe data (up to 10 feet in depth) to determine how thick the sand is in areas of Kailua Bay, Lanikai Beach, and Bellows Beach at Bellows Air Force Station. It was discovered that the sand in the Kailua stream channel is a major component of why the beach is so stable in this region. There are a number of isolated patches of sand that may be available for beach nourishment. Investigations further offshore are recommended for future study.

Wailea Point sediment sand transport analysis: This analysis was conducted by using the basic concept that sediment becomes better sorted in the direction of the transport. UH took grab samples and using various methods of analysis, such as the Gao-Collins (1992) and Roux method (1994), it was demonstrated that sand has historically been transported south to north around Wailea Point, with reversals in the southern portion of Lanikai beach. By combining the two analytical methods, it is understood that there is a northward transport and that Lanikai has historically received sand from the Bellows Beach area. Using historical analysis, modeling, and sediment trend analysis, the results indicate the following:

- In the 1950s, Bellows acted as a source for accretion in South Lanikai.
- In the 1970s, revetments stabilized Bellows and South Lanikai eroded.
- From 1970 to the present, Lanikai has a northern sediment transport without replenishment.

By studying volume and direction of sediment transport, the ultimate goal is to produce a regional sediment budget. Using the Mokapu Point to Makapuu Point offshore wave gauge data collected over the past seven years, nearshore conditions at ten points have provided input for analyzing gross and net sediment transport directions. Using the results of this information, maps have been created for each stretch of beach illustrating sediment erosion and accretion along the shoreline.

Potential RSM Projects (PRPs): PRPs identified in the region included Kaelepulu Stream, Bellows Air Force Station, Kaupo and Kaiona Beaches, and Lanikai Beach. Although the funds to perform these projects have not been secured, it is important to identify the projects with the highest potential for improving regional sediment issues. For example, Kaelepulu Stream is plugged with sand and there is shoreline erosion downdrift. At Bellows Air Force Station, the beach is wide to the south and narrows to a hardened shoreline in the north. Sea Engineering worked with the USACE on a pilot beach restoration project involving the construction of two geotextile fabric groins along with up to 10,000 cubic yards of beach fill adjacent to the Pokole Way beach access in Lanikai.

This work has been summarized in the RSM document for this region, along with interactive mapping capabilities, available on the following website:

http://gis.poh.usace.army.mil/rsm/index.htm

Questions:

Q1: What do you foresee for funding for RSM?

A1: The climate in congress currently will not allow any earmarks and therefore the USACE unfortunately does not anticipate any funding for RSM next year.

Q2: How did you determine what regions were to be studied?

A2: The first area was Lanikai because funding was requested by the Lanikai neighborhood association through Congressman Ed Case. On Maui and Kauai, the project is funded by O&M money for maintenance dredging of the ports in this area and therefore, focuses on study areas with port maintenance issues. In the future, if funding continues, the USACE would like to study all areas of the main Hawaiian Islands.

Q3: To what extent is there consideration for biological issues when doing these studies and identifying projects?

A3: The ultimate goal of RSM report is solely to identify potential projects. The RSM project is design and study focused only, not construction. While the overall RSM Program does take into consideration the ecological issues of the regions, if a project is taken into further consideration, ecological issues would need to be examined in detail through the National Environmental Policy Act (NEPA) and other appropriated processes.

Q4: Some of the locations on the coast that may be considered for projects may be adjacent to kuliana lands and these issues tend to be addressed more on a local level than through NEPA.

A4: DLNR OCCL reviews and approves coastal development activities. There is an extensive review before, during, and after the project by agencies evaluating all aspects of the project from ecological impacts to cultural resource impacts.

Q5: The opportunity for traditional ecological considerations used to happen prior to the NEPA process; however, the current process tends to address these considerations late in the game.

A5: Chris Conger gave the example that Office of Hawaiian Affairs (OHA) is an organization that the state has partnered with from the beginning of the Waikiki nourishment project and it is important to the state to include these types of organizations in the upfront planning process.

V. Kauai Wave Climate Overview (Presented by Jessica Podoski, POH Coastal Engineer)

Jessica Podoski, POH coastal engineer, has worked on the development of a wave information study (WIS) to generate hindcasts for each of the two study regions (Kekaha and Poipu regions).

There are WIS savepoints located throughout the Hawaiian Islands that provide hourly wave hindcast parameters for the 24-years from 1981 – 2004.

Wave modeling has been generated using computer models and observed wave fields. It has been compared to actual wave gage data for accuracy and provides a much longer term data set which is useful for establishing wave climate. Station 102 Kekaha deep water WIS Station was selected for comparison.

Wave roses show waves from all directions (dominated by NW and tradewinds) and large variations in wave height (2-6m). The wave roses also capture tradewind seas (ENE directions) and long-period swells (N&NW as well as South) directions. The data were truncated to capture only energy moving toward the island (280 degrees through 100 degrees). Three representative years (1984, 1992, and 1994) were transformed to 100 m contour using linear shoaling and diffraction, which were then analyzed in order to select most common wave cases.

For the Kekaha region, 326 discrete cases were analyzed using STWAVE to transform selected wave cases to shoreline. Wave data were saved at specific nearshore “savepoints” along coastline at areas of interest. The results were used to develop relationship between offshore/nearshore wave conditions and nearshore time series were created using WIS data for three selected years and STWAVE results.

For the Poipu region, data from deepwater WIS Station 119 were used from the same 24-year period. Wave roses show waves from all directions and mid-range wave heights (2 to 3 m) from most directions. The wave roses capture both tradewind seas (ENE direction) and long-period swells (N&NW directions and South). Data were truncated to capture only energy moving toward the island (90 degrees through 270 degrees). Again, WIS data was used for three representative years (1984, 1992, and 1994) and transformed to 100-meter contour using STWAVE.

For Poipu, 379 discrete WIS cases were used to transform waves to the region shoreline. Wave data were saved at specific nearshore “savepoints” along the coastline at areas of interest and results were used to indicate relationship between nearshore wave conditions and sediment transport.

For both regions, wave roses that were developed for nearshore locations will help to determine dominant wave direction. From this information, the direction of longshore sediment transport can be determined along the study area and this will provide valuable information for development of the regional sediment budgets.

VI. Kauai Shoreline Change studies (Presented by Tiffany Anderson as a representative for the work of Chip Fletcher, University of Hawaii, SOEST)

UH has been investigating long-term shoreline changes that have occurred over the past few decades, and has been measuring change using historical shoreline positions mapped from aerial photographs and coastal charts from as far back as the 1920s. This is a 10-year effort and there are numerous stakeholders that have supported this project including USACE, DLNR, county governments, USGS, the Castle Foundation, FEMA, Hawaii CMZ, and Sea Grant. The information gained through these studies will aid coastal managers in identifying coastal areas facing an increased risk of future beach erosion.

For these shoreline change studies, transects are generated at 20 meter intervals and by combining this with the historical shoreline the movement of the shoreline over time is shown. Data are used to orthorectify and map historical shoreline positions. Uncertainties are determined based on season variation of shoreline and other variables. These uncertainties are taken into account when running the shoreline regression analysis, in which the slope of the line (m/yr or ft/yr) with a positive or negative uncertainty indicates either accretion or erosion of the beach.

Shoreline change maps for southern Kauai were completed in 2010 for the Kauai Planning Department. In general, the entire coast is eroding except where there are barriers to longshore transport that cause localized accretion. Alternatively, breaching of certain areas of sediment mass, such as the Poipu tombolo cause beaches to destabilize. However, Poipu is mainly eroding except for one small area of accretion. In the Waimea area, there is strong accretion to the east of Kikiaola harbor and strong erosion to the west of Oomano Point. Further west in the Kekaha area, the shoreline is eroding and at Kokole Point there are intermittent areas of accretion and erosion.

Question:

Q1: If the erosion data is taken from shoreline erosion data including the 1927 data and area photos and is averaged to be an overall change, can the changes be broken out for different years to show how the change happened over time?

A1: Addition studies analyzing shoreline change in more depth will be further discussed in subsequent portions of the presentation.

Comment: Shoreline setback determinations are based on these erosion rates and policymakers should look at historical changes and apply them to future determinations on setback distances.

VII. Kauai Reef-top Sand Field Studies (Presented by Tiffany Anderson as a representative for the work of Chip Fletcher, University of Hawaii, SOEST)

The purpose of this study was to identify areas of sand sources to then address future studies of sand quality and quantity. This section of the presentation uses Waikiki to demonstrate the methodology of comparing old aerial photographs with modern aerial photographs to identify "stable" sand fields which may become targets for further testing.

Once sand sources are identified in modern imagery, they are compared with historical imagery to determine where the sand has been stable over time. A final map is created to depict three classes of sand – modern, historic and stable sand. The process of mapping these sand sources is dependent on water clarity and photo quality and therefore, the lack of sand source mapping off shore is not due to lack of sand but may be due to poor photo and water quality. Sand may potentially be taken from these areas; however, more studies are needed to determine if the sand is beach quality stand.

In Poipu the sand field only showed up well in modern photographs. Therefore, it is unknown if this sand source is stable; however, such a large area of sand which would most likely be stable. While there are no other notable sand sources in the region, this area has great potential for use in the nourishment of Poipu Beach.

VIII. Kauai Preliminary Regional Sediment Budget (Presented by Kim Garvey, Moffat and Nichol [M&N])

The study area was separated into different cells that are interrupted by some sort of barrier to sediment transport between the cells. The Kekaha Region was split into three littoral cells that are interrupted by some sort of barrier to sediment transport between the cells. An additional cell extending west from Kikiaola Harbor approximately 1.5 miles to where the color of the beach sand changes from black to tan will be added to the analysis. The Poipu region was divided into eight big cells and some of the main areas of interest were broken into smaller cells.

Beach volume is defined as beach between the stable backbeach line and the mobile shoreward toe line. First, sand sources were identified using UH erosion hazard maps that depict sand released by beach erosion, USGS beach profiles, historical records of beach nourishment, and reef production (the process and volume are poorly understood and estimated from reef area). These data were used to calculate beach widths for available historic shorelines and then beach area was calculated by multiplying the average beach width by the cell shoreline length. Volume changes were calculated by multiplying the local shoreline change rate by a factor of 0.40 and multiplying the resultant by the length of shoreline under consideration. On the graphs, the overall change can be seen; however between the data points, the changes from year to year cannot be seen. In addition, seasonal changes are not depicted.

Beach volume change rate is determined by selecting time periods of interest based on line graphs and historical events within each littoral cell. Change rates are calculated for each time period and over complete period of the record. Rates are calculated using regression analysis and lease squares fit, and factors in seasonal variations and other uncertainties. Rates are corrected for any historic beach nourishment that occurred in each littoral cell. For sand pathways, some sand sources and sinks have been identified but sediment transport direction have not been identified or quantified.

For each cell, the study first aims to identify each of the shoreline features using GIS. Next, each cell is analyzed for beach volume history. Then plots are compiled on the maps to show the beach loss and direction per year. Seasonal changes, in some cases, are greater than the overall change over the past 100 years.

For the Kekaha region, the harbor structures and wave patterns control the longshore transport pattern and significantly impact sediment transport. There was an erosional period in 1945 and has now been accreting and very recently may be eroding. Both Kekaha and Waimea cells have experienced reversals in trends.

Because there are limited data points, there could be a case when there was a more erosional period in a short amount of time, but this cannot be captured when compared to longer periods of accretion. Also, correction was made for any beach nourishment so that the graphs represent systematic changes.

In the Kikiaola cell, there was 6,000 to 3,000 cubic yards per year change in beach sediment volumes. For the Waimea cell, there are missing data points that make it difficult to discern the transition from erosion to accretion.

In the Poipu region, erosion rates are relatively small with good opportunities for beach nourishment. West and Central Poipu cells have experienced similar erosional trends with West Poipu having fairly steady, long term erosion at about 400 cy/yr.

In East Poipu, there has been accretion and then sometime between 1970 to 1975, there must have been an event which took sand out of the beach and from which it still has not yet recovered. It would be helpful to document history from the community to help determine what the effects of any historical events were on the beach.

Although the shoreline data are meager for the early years of the study, in recent years, there is very extensive data and aerial images for these areas.

It was reiterated that the purpose of this study is strictly one of preliminary investigations to identify and generalize past trends and potential resources for future projects. It does not propose specific plans or get into the minute details of each of the beaches.

Questions:

Q1: If sand is 15 feet from the beach in 20 feet of water, how much wave action does it take to get this sand back onto the beach?

A1: It is easier to bring sand off the beach because it has gravity working with it, but it depends on what types of actions and cumulative forces that are going on in the area to determine the impacts they will have on the movement of sediment.

Q2: Why don't you use satellite data for investigation?

A2: The original research by UH required very high resolution images as well as no cloud cover, etc. Note that satellite data could be considered to monitor large changes in a study area but it is not high enough resolution to use for a detailed shoreline change database.

Q3: What is jet probing (air or water)?

A3: Essentially jet probing is a water hose that is extended down into the ocean floor until it hits hard ground. The instrument does not provide specific measures; data gathered are based on observation. There is also a limit to how deep the investigation may proceed.

Comment 1: The indigenous names of each of the places have meaning that should be taken into account in these studies.

Comment 2: This workshop is not a good forum to solicit kupuna input on the coastal conditions. Traditional ecological knowledge is not represented at this workshop.

IX. <u>Kauai Regional Sediment Management Plan (Presented by Kim Garvey, M&N)</u>

As part of the RSM Plan for each of the regions in Kauai, existing federal projects have been taken into consideration. In the Kekaha region, projects include the Kekaha Beach shore protection project, the Kikiaola Light Draft Harbor navigation improvement project, and the Waimea River flood control project. Currently there are no federal projects in the Poipu Region.

In this region, long lengths of sandy beaches result in high volumetric rates (in comparison to along the south shore of Oahu). West and Central Poipu cells have experienced similar erosional trends and the East Poipu cell has experience significant erosion episodes between 1972 and 1975 and has not recovered since. Erosion rates are relatively small, which provides a good opportunity for beach nourishment. Based on UH offshore sand source investigations, it was found that the Kekaha region offshore sand sources are estimated to be around 189.4 acres. In the Poipu region, offshore sand sources are estimated to be around 72.2 acres.

Beach nourishment projects involve a number of different laws and regulations, including federal (Clean Water Act and Harbors Act under the USACE, and USFWS, and NMFS); State (Coastal Zone Management Act, work offshore of certified shorelines under DLNR, the Department of Health Clean Water Act, Historic Preservation Office, Office of Hawaiian Affairs, Department of Transportation, Highways and Harbors Divisions; and local (including County of Kauai, Public Works, Planning Department and Planning Commission). Inter-agency coordination is critical for efficient permitting. However, there are a variety of regulatory and coordination issues that arise in regards to beach nourishment projects.

In 2005, DLNR and USACE issued a State Programmatic General Permit (SPGP) to streamline small scale beach nourishment (<10,000 cy) in the State of Hawaii. However, the State Department of Health Section 401 Water Quality Certification component has lapsed. Therefore, there is now a consolidated permit within the DLNR which includes the Department of the Army, SPGP; the State Department of Health, Section 401 Water Quality Certification; the State CZM Federal Consistency Review; and DLNR Conservation District Use Permit.

The intent of the RSM Plan is to give federal, state, and local agencies and groups more information to pursue sediment management projects. The Kauai RSM Plan contains the following information for each region that can be easily accessed in the reports online at the USACE website:

- Existing federal projects
- Coastal processes
- Wave climate
- UH shoreline erosion maps
- Beach profiles
- Shoreline features (maps and descriptions)
- Beach volume graphs
- Beach volume change rates
- Historical events chronology
- Ocean sand sources
- Potential RSM projects

In summary, beach nourishment may be viable and the RSM projects that have been identified through these studies do have the potential to be implemented in the future, but require more study and analysis.

Potential RSM projects in this region include the Poipu Beach Park Restoration project in which there is the potential for beach nourishment of 6,000 cy.

Potential sand sources include Kekaha landfill and offshore sand sources. The County of Kauai Parks and Recreation is a proponent of this project.

Federal Input:

There are no Federal projects in this region right now because federal interest has not been demonstrated through a USACE conducted study. Therefore, it is suggested that non-federal proponents should contact their congressional representatives to gain support if there are problems and opportunities to enhance RSM in the region.

State Input:

The State would is supportive of beach nourishment as long as the sand to be used is demonstrated to be beach quality, which means that the nourishment sand has characteristics as the sand at the proposed project site.

When determining whether a project is worth doing, it is first a question of what the purpose of the project would be and who it would benefit, and at the same time, social, environmental and cultural factors should be taken into account.

Question:

Q1: Has anyone come to the conclusion on whether sand would stay in place if there were nourishment at Brenneckes?

A2: There have been small nourishments and these events would be studied in more detail before any design would be approached.

Comment 1: There is value in studying land use and how that affects changes in the beach over time. For example, there was a year in which the government bought up a bunch of the upland and cleared a lot of the vegetation and made it into a park. Their action then in turn led to the increase in sediments on the beaches.

Comment 2: Pictometry is a small company out of Rochester, NY that does low altitude aerial photography and over the past couple of years all of Kauai has been photographed, and these images could be used as part of this or other coastal studies.

Potential RSM projects in the Kekaha region include the Kikiaola sand bypassing. Kikiaola Harbor and offshore sand sink appear to block littoral sand transport. A potential project may include an initial bypassing project of 80,000 cy and future by-passing of 36,000 cy every 6 years.

State Input:

The State is very supportive of the Kikiaola Harbor sand bypassing and has also been working with some homeowners in the area on this project. The point of the project is to restore the natural flow of sand along the coastline; however, from a federal perspective the main reason for the project is to keep the sand out of the harbor.

Questions:

Q1: If the harbor affects the downdrift properties and decreases the value of their properties then do the property owners have the right to sue?

A1: It has happened in other locations.

Q2: Is there a connection between the preservation of the beach and the removal of the vegetation on the Kekaha revetment?

A2: No, in terms of O&M it is not preferable to have vegetation in the structure because it pushes the rocks apart.

Q3: Could global warming cause issues?

A3: There may be impacts by increased storms, temperature, greater swells. This impact is not addressed in study and evaluation needs to be longer term than a few years (on the order of 40 to 50 years).

Comment 1: There is a new methodology for moving sand which involved blowing dry or wet sand. This method is being evaluated for the next Waikiki beach re-nourishment. This removes problems associated with dewatering and the costs are somewhat comparable to other forms of transport.

Comment 2: Climate change may be having implications on these regions of the coastline.

Comment 3: The report needs to be written for more of a non-engineering audience and the Kauai report should focus more on Kauai rather than focused on the state as a whole, especially for the wave information. Work on readability and more visual representations. Report is missing ‘okina.

Comment 4: The work that the RSM team is doing is appreciated.

Comment 5: There is interest in work in Kapaa area. Sea Engineering is working in the area.

Chris Conger provided closing remarks and gave his thanks to all that participated.

Meeting was adjourned at 5:05pm

Attachment A: Meeting Agenda

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HAWAII REGIONAL SEDIMENT MANAGEMENT

KAUAI RSM WORKSHOP

Kauai Veterans Center, 3215 Kapule Highway, Lihue

January 20, 2011

1300 - 1310	Welcome and Introductions	Conger Conant
1310 - 1330	Regional Sediment Management Overview	Smith
1330 - 1500	Kauai RSM	
	Waves Climate	Podoski
	Shoreline Change	Anderson
	Offshore Sand Sources	Anderson
	Region Sediment Budget	Garvey
	Regional Sediment Management Plan	Garvey
1500 - 1515	Break	
1515 - 1615	Poipu Region: Potential RSM Projects	Garvey
	Federal Perspective	Podoski
	State Perspective	Conger
	General Discussion	All
1615 - 1630	Break	
1630 - 1725	Kekaha Region: Potential RSM Projects	Garvey
	Federal Perspective	Smith
	State Perspective	Conger
	General Discussion	All
1725 - 1730	Wrap-up and Adjourn	Conger Conant

HAWAII RSM WEB SITE: http://gis.poh.usace.army.mil/rsm/index.htm