

# 2012 Waikīkī Beach Maintenance

Waikīkī, Oahu, Hawai'i



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## Abstract

Due to a combination of natural processes and anthropogenic activities, many of Hawai'i's beaches suffer sediment deficiencies and are now narrow and eroded, resulting in reduced protection from tidal and wave inundation, and reduced recreational opportunities. As the trustee of Hawai'i's beaches and coastal lands, the Department of Land and Natural Resources (DLNR) is committed to the protection of these natural resources for the benefit of present and future generations. This effort is guided by the doctrine of sustainability promoting the conservation, management, and restoration of Hawai'i's beaches. Where appropriate, the DLNR utilizes beach nourishment as a strategy to mitigate beach loss.

Waikīkī Beach, the center of Hawai'i's tourism-based economy, has experienced significant erosion over the past several decades. Recognizing the potential for future economic losses due to erosion and beach loss, the DLNR conducted a beach maintenance project to restore sand volume at Waikīkī Beach. This paper discusses the 2012 Waikīkī Beach Nourishment Project including the history of beach nourishment in Waikīkī, the economic importance of beach resources at Waikīkī, project specifications, the regulatory framework for beach nourishment in Hawai'i, issues and challenges, the role of public outreach, and lessons learned. The experience gained through this project will help guide and improve future beach restoration efforts in Hawai'i.

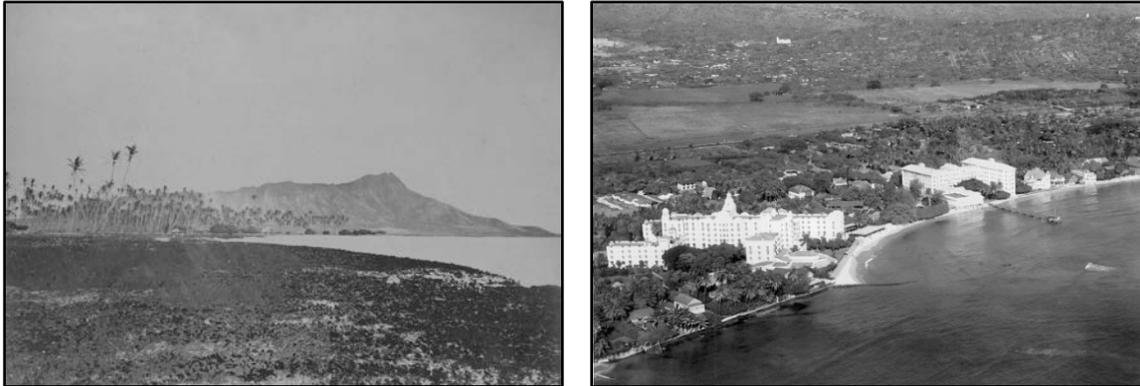


*“Before you can attempt to change her  
Understand the mistakes of the past  
Restore what can be restored, but  
Damage nothing more”  
Mamala Bay “Waikīkī” by George Downing*

## Introduction

Travel and tourism is America’s leading industry, employer, and earner of foreign exchange; and beaches are America’s leading tourist destination. There are approximately \$2.2 billion annual beach visits in the United States, compared with 1 billion annual visits to National Parks, State Parks and Recreational Areas combined (Houston, 2013). Beach erosion is a widespread issue threatening many of the high value sandy beaches in the U.S.

The beaches of Waikīkī are a central component of Hawai’i’s tourism industry, attracting more than 4 million visitors per year, accounting for over 6% of the Gross State Product and almost 8% of all civilian jobs statewide (Hospitality Advisors, LLC, 2008). Real estate values in Waikīkī are estimated to be in the several billions of dollars. On any given day, there are roughly as many visitors as there are residents concentrated within the approximately two square mile area of Waikīkī.



**FIGURE 1:** Waikīkī Beach; 1865 (left) and 1929 (right)

Over the past century, Waikīkī Beach and its surrounding marine and terrestrial environments have been dramatically transformed. Prior to its modern development, Waikīkī functioned as a traditional Hawaiian ahupua’a (watershed) where mountains, valleys, streams, marshes, beaches, and nearshore coral reefs formed a large interconnected ecosystem that provided habitat and sustenance for its ancient inhabitants. A variety of activities including sand nourishment, dredging, construction of groins and seawalls, construction of the Ala Wai Canal, and other coastal engineering projects have significantly altered Waikīkī (Wiegel, 2002). Historical photographs, engineering records, and Hawaiian Olelo (story telling) provide evidence and insight into the radical transformation of this coastal marshland into an engineered urbanized beach.

Waikīkī Beach has experienced chronic erosion and beach loss for many decades due to a combination of natural processes and anthropogenic activities. At high tide, the beach in many areas is submerged, and sections of the beach have been badly eroded or, in some cases, completely lost. Historical sand hauling from the beach and dredging/mining of the reef in Waikīkī during the early 20th century significantly reduced beach volume and changed the nearshore morphology (Conger, et.al. 2012).



**FIGURE 2:** Chronic erosion leads to beach loss

Significant portions of the Waikīkī shoreline were armored with seawalls in the early part of the 20<sup>th</sup> century in an effort to protect hotels, infrastructure, and parkland from erosion and wave inundation. In 1928, the “Waikīkī Beach Reclamation Agreement” set the stage for large-scale beach nourishment in Waikīkī (Office of the Commissioner of Public Lands, 1928). Approximately 307,400 yards<sup>3</sup> of sand were imported to Waikīkī, much of which was mined from other Hawaiian beaches (Wiegel, 2002).



**FIGURE 3:** Kuhio Beach 1939; pre-beach fill (left) and post-beach fill (right)



## History of Beach Nourishment in Waikīkī

Waikīkī Beach has undergone significant changes over the past century. An 1865 photograph of Waikīkī shows native grass covered dunes and marshlands. During this time, Waikīkī was a rich marshland with streams, springs and a beautiful fringing beach, with perfect surfing waves offshore. However, after the death of King Kamehameha the Great and the subsequent demise of the Hawaiian feudal land system, which culminated in the Great Mahele enacted in 1848, much of the land in Waikīkī transferred into private ownership. Subsequent years of uncoordinated development continued to transform Waikīkī resulting in the loss of beaches, marshlands and natural streams. Following WWII, in an attempt to restore diminishing beach resources and to promote the burgeoning tourism industry, hundreds of thousands of cubic yards of sand were imported to Waikīkī Beach.

Beach nourishment projects began in earnest in the 1950s. Table 1 lists sand nourishment projects by year and volume based on previous studies (Wiegel, 2002), Miller and Fletcher (2003). These are very likely conservative values. Since documentation for past projects is limited, it is impossible to verify the accuracy of these estimates. However, extensive beach profiling conducted in 2002 estimated a total volume of 167,000 cubic yards of sand for Waikīkī Beach, with an estimated uncertainty of 15 to 40% (Miller and Fletcher, 2003). Assuming minimal sand volumes prior to beach nourishment, and factoring in sand losses over the period of 1950-2002, we estimate that approximately 300,000 cubic yards of sand have been imported to Waikīkī beaches over the past 75 years.

<b>Year</b>	<b>Location</b>	<b>Volume (cubic yards)</b>
1939	Kuhio Beach	7,000yd <sup>3</sup>
1951-1957	Kuhio/Queens/Kapiolani Beach	130,000 - 160,000yd <sup>3</sup>
1959	Kuhio Beach	19,000yd <sup>3</sup>
1965	Outrigger Canoe Club	6,000yd <sup>3</sup>
1970	Fort DeRussy Beach	82,000yd <sup>3</sup>
1972	Kuhio Beach	12,000yd <sup>3</sup>
1975	Fort DeRussy Beach	16,000yd <sup>3</sup>
2003	Kuhio Beach	1,400yd <sup>3</sup>
2007	Kuhio Beach	10,000yd <sup>3</sup>
2012	Waikīkī Beach	27,000yd <sup>3</sup>
<b>TOTAL</b>		<b>310,400 – 340,400 cubic yards</b>

**TABLE 1:** History of Beach Nourishment in Waikīkī Beach

Major beach restoration efforts began in the 1950s post-WWII boom. In 1948, the Board of Harbor Commissioners of the Territory of Hawai'i commissioned a study focusing on beach erosion in Waikīkī (Wiegel, 2002). The study, which was completed in 1951, recommended a number of improvements to the shoreline at Waikīkī Beach. As a result of this study, the Waikīkī Beach Erosion Control Project was initiated which began "a 50-year series of uncoordinated attempts to restore Waikīkī Beach" (Miller and Fletcher, 2003).

## Economics of Beach Nourishment

In the post-WWII era, the Territorial Government of Hawai'i, along with many Waikīkī beachfront landowners, recognized the opportunity to establish Waikīkī as a world class beach destination. With significant advancements in air transportation and marketing, Waikīkī Beach experienced an exponential growth in annual visitors. Waikīkī is now the center of Hawai'i's modern tourism-based economy. A 2008 report entitled "*Economic Impact Analysis of the Potential Erosion of Waikīkī Beach*," estimated that the total loss of Waikīkī Beach would result in approximately \$2 billion reduction in annual visitor expenditures (Hospitality Advisors, LLC). The report also found that 58% of all westbound visitors (North American) indicated they would not consider staying in Waikīkī if the beach is completely lost.

<b>Total Estimated Impact on Total Waikīkī Visitor Expenditures</b>	<b>\$1,977,379,886</b>
Estimated Hotel Room Expenditure	\$503,823,828
Estimated Retail Expenditure	\$560,973,160
Estimated Entertainment & Recreation	\$224,790,053
Estimated Food & Beverage Expenditure	\$456,514,303
Estimated Total Transportation Expenditure	\$231,278,542
Estimated Job Loss	6,352

**TABLE 2:** Potential economic impact due to a complete erosion of Waikīkī Beach<sup>1</sup>

The 2010 Hawai'i State Data Book estimates that Waikīkī accounted for approximately 40% of total annual visitors and 42% of total visitor expenditures statewide (Hawai'i State Data Book, 2010). Total visitor expenditures in Hawai'i were estimated at over \$11 billion. Thus, a \$2 billion loss in visitor expenditures equates to approximately an 18% loss in visitor expenditures for the State. An earlier economic valuation study from 2002 indicated that a congested Waikīkī Beach could result in a net decrease of approximately 250,000 annual visitors, or 3.6 percent of total visitors for the state in a year, at an estimated value of \$181 million/year (Lent, 2002).

While the assumption of total loss of Waikīkī Beach is a highly-unlikely scenario, these reports clearly demonstrate that the potential economic impacts would be devastating to Hawai'i's economy. The findings of these studies provide justification for long-term solutions and funding to support beach management and maintenance in Waikīkī.

<sup>1</sup> State of Hawai'i DBEDT, Hospitality Advisors LLC



## Regulatory Framework for Beach Nourishment

Hawai'i has been characterized as one of the most heavily regulated of all the 50 states (Callies, 2010). The regulatory system is largely borne from a centralized state land use system, the federal regulations to protect public health and the environment, increased public participation in the planning process, and Hawai'i's unique environmental and cultural qualities and challenges. Thus, because of the uncertainty of permitting for beach restoration projects in Hawai'i, the entitlement process can be arduous, time consuming, and costly. As Callies notes, "clean water is particularly important to Hawai'i. Tourists are the consumers of the major state industry, and they flock to Hawai'i for the beaches, the waterfalls, the marine wildlife, and the diving and snorkeling. Hawai'i's regulators are aware of the importance of maintaining that experience for visitors." (Callies, 2010)

In Hawai'i, all submerged lands (i.e., lands located seaward of the shoreline<sup>2</sup>) are zoned in the Conservation District and are regulated and owned by the State of Hawai'i Department of Land and Natural Resources (DLNR). Congress granted state ownership over submerged lands out to three nautical miles from the coastlines in 1953 under the Submerged Lands Act.

A Conservation District Use Permit (CDUP) is required for beach nourishment because the activity occurs on submerged lands. The CDUP is a discretionary permit granted by the State of Hawai'i Board of Land and Natural Resources (BLNR). Issuance of the CDUP is contingent upon the project conforming to eight (8) criteria. One of the most critical criteria requires that "the proposed land use will not cause substantial adverse impact to existing natural resources within the surrounding area, community, or region," (Hawai'i Administrative Rules, Title 13-5). The CDUP may be issued after public hearings and acceptance of an Environmental Assessment (EA) or Environmental Impact Statement (EIS), which includes an assessment of potential impacts to cultural and archeological resources.

At the Federal level there are two primary agencies with regulatory authority for beach nourishment projects in Hawai'i, the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA). Projects taking place in navigable waters of the United States must comply with Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act. The permits are administered through USACE, Regulatory Section. Beach

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<sup>2</sup> "*Shoreline*" means the upper reaches of the wash of the waves, other than storm or seismic waves, at high tide during the season of the year in which the highest wash of the waves occurs, usually evidenced by the edge of vegetation growth, or the upper limit of debris left by the wash of the waves (HAR §13-222)



nourishment projects also require a Section 404 Dredge and Fill permit, otherwise referred to in Hawai'i as a Department of the Army (DA) permit.

The second Federal entity with regulatory authority for beach nourishment projects is the NOAA National Marine Fisheries Service (NMFS), which is part of the Department of Commerce. NMFS is the federal agency responsible for the stewardship of the nation's living marine resources and their habitat within the United States Exclusive Economic Zone, which extends from 3 to 200 nautical miles offshore (NOAA Website, 2013). Under the Marine Mammal Protection Act and the Endangered Species Act, NMFS covers protected marine species such as whales and turtles (NOAA Website, 2013). In Hawai'i, NOAA has a variety of programs dedicated to the protection of endangered species including Humpback Whales, Hawaiian Monk Seals, and sea turtles. In addition, the Essential Fish Habitat (EFH) provisions under the Magnuson-Stevens Fishery Conservation Act directs NMFS to protect EFH throughout the range of the federally-managed species. This includes State and Federal waters (Everson, NOAA). Thus, NMFS was required to consider the potential impacts that the Waikīkī Beach Nourishment project may have on EFH.

Beach nourishment projects must also comply with the provisions of the Federal Clean Water Act and the Coastal Zone Management Act. Compliance review and permitting for these two laws has been delegated to State authorities in Hawai'i. The Hawai'i State Department of Health, Clean Water Branch (CWB) administers the Clean Water Act through their Section 401 Water Quality Certification (WQC) and National Pollution Discharge Elimination System (NPDES) permits. In Hawai'i, compliance with the provisions set forth in the Section 401 WQC is challenging for beach nourishment projects because the CWB considers sand a pollutant under their Administrative Rules. Thus, even bypassing pollutant-free beach quality sand from one area of an active beach to another area requires a WQC and NPDES (NPDEP, for projects affecting more than one acre).

The purpose of the Clean Water Act is to eliminate releases of high amounts of toxic substances into water, eliminate additional water pollution, and ensure that surface waters would meet standards necessary for human sports and recreation. The Section 401 WQC is intimately tied to the Federal DA permit, which must also address Clean Water Act provisions. Thus, issuance of the DA permit is contingent upon of the issuance of the WQC by the Hawai'i CWB.

With respect to projects that require a federal permit, such as the DA permit, the State of Hawai'i Coastal Zone Management Office administers the provisions of the Coastal Zone Management Act through the issuance of a Coastal Zone Management (CZM) consistency determination. This is usually a straightforward and efficient process coordinated through the local CZM office. The Waikīkī Beach Nourishment project was determined to be consistent with the Coastal Zone Management Act and was therefore issued a CZM consistency determination by the State of Hawai'i Coastal Zone Management Office.



## Project Specifications

### ***Project Location and General Description***

The project site is located on Waikīkī Beach, along the shoreline of Mamala Bay on the south shore of the Island of O‘ahu. The project area extends approximately 1,700 linear feet from the west end of the Kuhio Beach crib walls, near the Duke Kahanamoku statue, to the existing Royal Hawaiian groin between the Royal Hawaiian and Sheraton Waikīkī hotels. The backshore area at the east end of the project area is open and landscaped with grass and palm trees, and provides space for three beach concession operations. The remainder of the project backshore is occupied by resort hotels. From east to west, the hotels on the backshore are the Moana Surfrider, Outrigger Waikīkī, and Royal Hawaiian.



**FIGURE 4:** Waikīkī Beach Maintenance Project overview map

Waikīkī Beach consists of primarily medium-coarse grain calcareous beach sand interspersed with larger-diameter coral cobble (Sea Engineering Inc., 2009). The beach experiences seasonal fluctuations in beach width due to seasonal variations in wave energy. During the winter months, when wave energy is relatively low, beach sand migrates from the west end of the beach toward the middle. During large wave events a strong offshore rip current pulls sand out of the ‘Āpuakehau Stream Channel. If sand is transported far enough offshore and into deeper water it becomes unavailable to the beach system, as waves and currents will no longer be able to return the sand to the beach. From 1985 to 2009, the primary trend has been shoreline recession, with the shoreline retreating at rates up to 2.4 feet per year, and an average annual rate of 1.5 feet (Sea Engineering, Inc., 2009).

In response to the chronic erosion, the goal of the project was to restore/widen the 1,700-foot-long segment of Waikīkī Beach between the Kuhio Beach crib wall and the Royal Hawaiian groin. Approximately 24,000 yards<sup>3</sup> of sand was to be recovered from deposits located approximately 2,000 feet offshore, and pumped to the shoreline where it would be dewatered and placed along the beach. The project would widen the beach by an average of 37 linear feet. The project also recommended additional nourishment of approximately 14,000 yards<sup>3</sup> of sand recovered from the same offshore deposits in approximately 10 years. The project also included the removal of two old deteriorated groin structures at the east end of the project area.

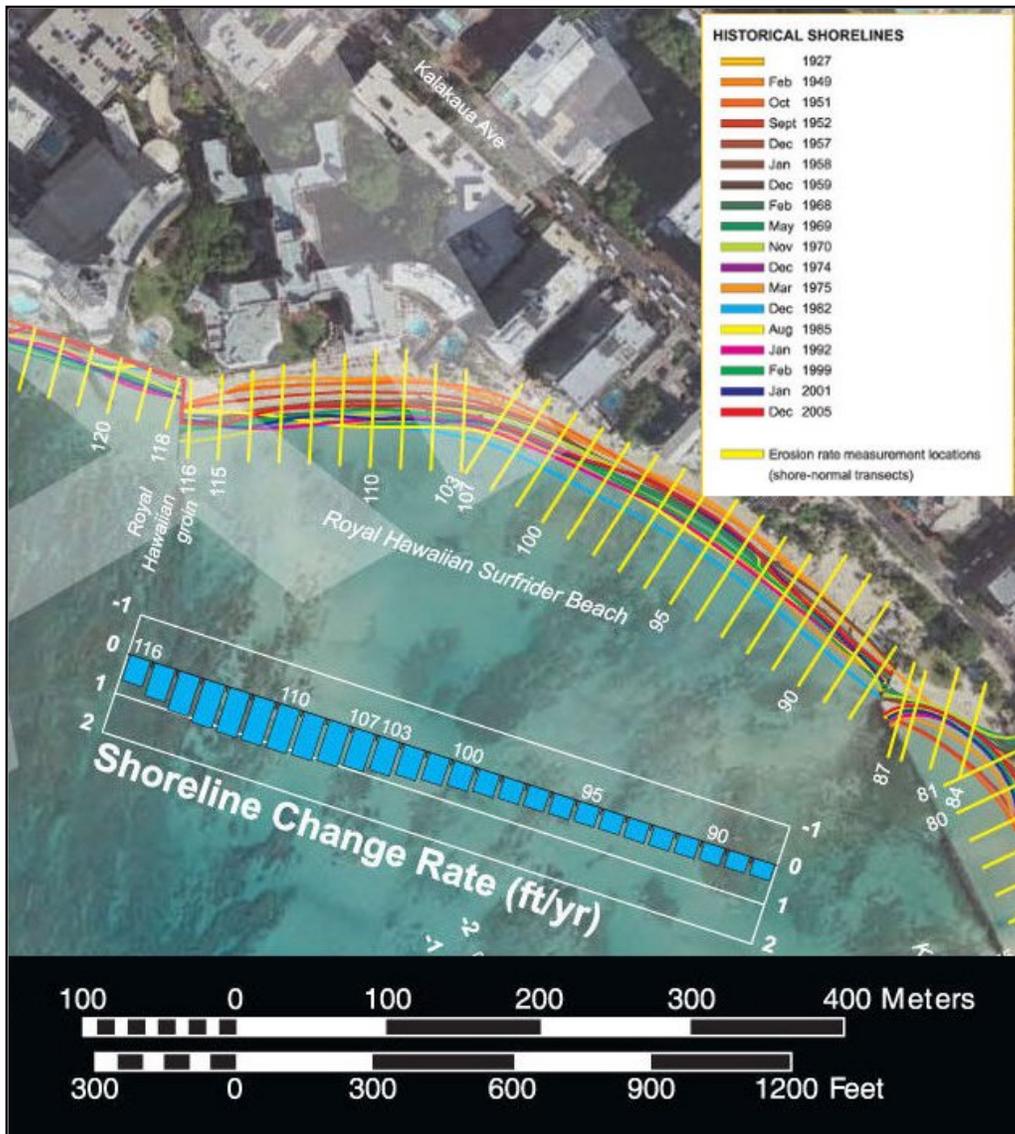


FIGURE 5: Historical shoreline positions and erosion trends for Waikki Beach



Construction Best Management Practices (BMP) were implemented to mitigate potential impacts to endangered species including green sea turtles and Hawaiian Monk Seals. No effects on historic, cultural and archaeological resources were anticipated. Construction was expected to result in some temporary disruption of beach use and recreational activities, increased noise, and short-term degradation of air quality from the operation of construction equipment. Localized increases in water turbidity were expected to occur in the immediate area of construction activity; however containment barriers and turbidity booms were deployed to control and minimize water quality impacts.

### ***Sand Recovery***

The sand recovery area is located in a sand-filled channel in the reef 2000 feet offshore at a depth of approximately 10-20 feet. Multiple studies assessed the quality and suitability of the offshore sand deposits for beach nourishment (Noda & Associates (2000), University of Hawai'i Coastal Geology Group (2005), and Sea Engineering, Inc. (2009) and found suitable sand sources. In 2005, the University of Hawai'i Coastal Geology Group used jet probes to measure sand thickness and estimate sand volume for three sand deposits with a total estimated volume of 86,000 yards<sup>3</sup> of sand within the proposed sand recovery area (Final Environmental Assessment, Waikīkī Beach Nourishment, 2010).



**FIGURE 6:** Marine surveys identify offshore ephemeral and non-ephemeral sand bodies

In 2009, Sea Engineering, Inc. used a sub-bottom profiler and jet probes to investigate the sand quantity and quality. The sub-bottom profiler created four track lines across the previously-identified sand fields to measure sand thickness. The track lines indicated some variability in the thickness of the sand deposits. Thickness was variable, ranging from 2-7 feet. The jet probing showed a strong correlation with the results of the sub-bottom profiling (Sea Engineering Inc., 2009). Sand samples were collected from the most viable sand recovery areas with a mechanical push-core device. An analysis of sand grain distribution found that the offshore sand had the same characteristics as the existing Waikīkī beach sand, with minor color discrepancy.

The potential dredging of coral rubble was addressed in the construction specifications. The contractor installed a rebar screen with a 1.5-inch grid over the suction head to screen for coral fragments greater than 1.5 inches in diameter. The grate worked well except that longer pieces of coral could get through, and there was much more coral rubble in the sand than was anticipated. As a result, the amount of coral rubble encountered during sand placement exceeded the project specifications. In response, the contractor performed rock picking with a sand rake along the dry portions of the beach. In addition, the Waikīkī Improvement Association organized volunteer efforts to remove coral rubble from the toe of the beach by hand. While the potential long-term impacts of coral rubble on Waikīkī Beach remain unclear, ongoing beach profile monitoring may inform decisions regarding the extent of the issue, if any.



**FIGURE 7:** Sand recovery barge and dewatering basin

Sand extraction was accomplished with the use of a Toyo DB 75B 8-inch pump with ring jet attachment suspended from an 80-ton capacity crawler crane. The pumping regime was staged on a barge that was towed to the site and stationed with a 4-point anchor mooring system. This system allowed the crane operator to continuously reposition the pump to adapt to changing water levels and variations in the thickness of the sand deposits. The average rate of sand recovery was approximately 500 cubic yards per day, which was consistent with the minimum estimates in the project specifications.

The sand discharge pipeline was an 8-inch high-density polyethylene (HDPE) pipe, with a total length of 3,200 feet. Pipe lengths of 50 feet were fused together and flanged at 400 foot intervals. The pipeline was assembled in the Ala Wai Canal and towed to the project site using an 800hp tugboat and two 500hp workboats. The pipeline was routed over a breakwater into a dewatering basin constructed in the east Kuhio Beach swim basin. The terminal end of the pipeline was positioned as close to shore as possible using a small workboat. A winch was then used to drag the pipeline over the breakwater to the dewatering basin. From the nearshore area to the barge, the pipeline was anchored using a system of metal plates and chains.



**FIGURE 8:** Dewatering basin (left) and sand recovery pipeline (right)

The dewatering basin measured approximately 100 feet in width and 400 feet in length and was constructed using sand from within the Kuhio Beach swim basin. The outer walls were fortified with filter cloth and a discharge weir was installed at the end of the basin opposite the sand discharge pipeline to allow water to drain from the basin. The area immediately outside the dewatering basin was surrounded by floating silt fences to provide additional water quality protection. A sand/water slurry was pumped into the basin. Sand was then pushed up into large piles with an excavator and bulldozer and then transported to the sand placement area on Waikīkī Beach.

The project site is located along the south shore of O’ahu and is therefore exposed to southern swell, tropical storms and hurricanes as well as Kona wind waves. The project area is sheltered from the full energy of trade wind waves by the southeastern end of O’ahu and Diamond Head. South swells typically affect the south shore between the months of April and September. Thus, the only reasonable time to dredge sand from the nearshore area is October to March. However, this window does not eliminate the possibility of large waves generated from local storms or unseasonable southerly swells. An independent wave forecaster was hired to provide daily forecasts for weather and ocean conditions, including thresholds for suspending sand recovery operations.



Sand recovery operations were constrained by wave action. A rocking motion, created by small swells, limited the productivity of the Toyo pump, adding additional time to the project. In some cases, production had to be stopped due to safety and risk of equipment damage. In several cases, sand recovery operations were suspended due to inclement weather and high surf conditions. However, even with substantial delays due to ocean conditions, sand recovery was successfully accomplished within the three month project window.



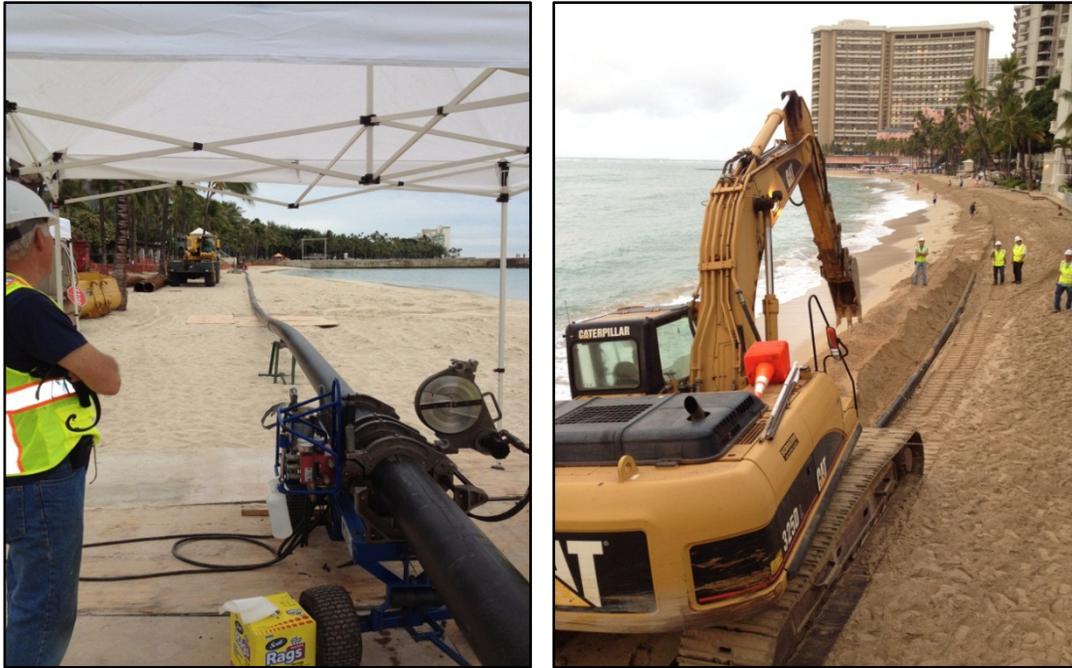
**FIGURE 9:** Weather and high surf affected sand recovery operations

### ***Sand Placement***

The original proposal called for the sand to be transferred from the dewatering basin to the sand placement sites through a pneumatic sand conveyance system utilizing a Vortex Low Pressure Pumping System. An 8-inch HDPE pipe was buried in the sand 2,500 feet along the beach from a sand hopper stationed at the sand stockpile area. The process involved loading the dewatered sand into the hopper where it would enter the pneumatic pipeline. Once the sand fill profile was achieved for a given segment of beach, the pipeline was to be cut with a saw and the next beach segment would be filled. Unfortunately, the pneumatic sand conveyance system was unable to achieve the minimum volume requirements for sand placement – e.g., 100 cubic yards/hour. After several failed attempts to increase sand conveyance rates, the pneumatic sand conveyance system was replaced with a conventional truck hauling approach.

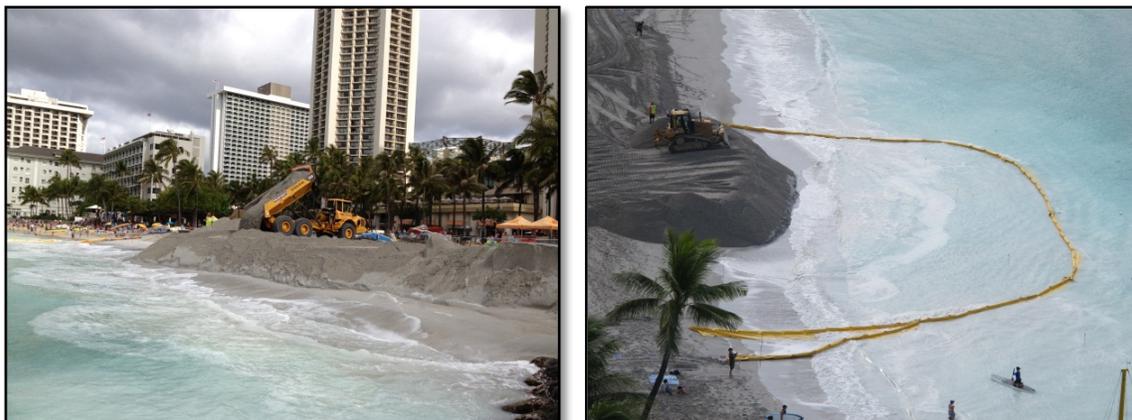
A truck hauling and sand placement plan was developed in collaboration with key stakeholders including the Hawai'i Tourism Authority (HTA), Hawai'i Ocean Safety, County authorities, the hotel industry, and beach concessionaires. Due to concerns relating to beach closures and noise impacts, it was determined that truck hauling would be conducted daily from 7:00am to 12:00pm in order to minimize disruption to beach users and hotel guests. A truck haul route was created along the length of Waikīkī Beach. To minimize the need for large-scale beach closures, steel barricades were deployed to prevent beach users from entering the truck haul route. Crossing guards were stationed at several locations along the truck haul route to escort beach users to and from the water. This approach allowed the majority of Waikīkī Beach to remain open for public use during the truck hauling operations.





**FIGURE 10:** Constructing the pneumatic sand conveyance system

Three CAT 725 articulated dump trucks were used to transport the sand from the dewatering basin to the sand placement site, starting from the southeast Kuhio Beach breakwater and finishing at the Royal Hawaiian Groin. A truck haul route was cordoned off with steel safety barriers to accommodate the articulated dump trucks and a bulldozer. Crossing guards were stationed at regular intervals to escort beach users across the truck haul route to the water. The beach was built from the southeast (Kuhio Beach) to the northwest (Royal Hawaiian). Sand was graded using a CAT DK6 Dozer. Truck hauling ended promptly at 12:00pm each day, after which the entire beach was available for public use.



**FIGURE 11:** Sand placement using dump trucks and bulldozers

One unexpected issue involved sand compaction, with a hardened berm forming along parts of the beach, particularly near the Kuhio Beach swim basins and the Royal Hawaiian Hotel and groin. While the origin of the berm is not certain, there is a general consensus that it likely resulted from compaction of the sand under the weight of the trucks as they made repeated passes along the truck haul route. This hypothesis seems reasonable in that the berm formed along the seaward edge of the truck haul route. Similarly, the sand landward of the berm crest appears significantly harder and more consolidated than the sand seaward of the berm. While this may be due to a lack of wave action in this area, it is plausible that the observed compaction occurred as a result of truck hauling. While further research is necessary to determine the cause of the berm, ongoing beach profile monitoring may provide insights into the long-term stability of the berm and the potential impacts to beach processes along Waikīkī Beach.



**FIGURE 12:** Sand compaction led to formation of a berm along the truck haul route

## Environmental Monitoring

Environmental monitoring was a requirement of the Waikīkī Beach Nourishment project and included monitoring changes in nearshore water quality, benthic habitat, and beach profiles. Monitoring was conducted by the University of Hawai'i, School of Ocean Earth Science and Technology (beach profiles) and the Institute of Marine Biology (benthic). Water quality monitoring was also performed.

### ***Water Quality Monitoring***

An independent contractor, Marine Research Consultants, Inc. (MRCI), conducted nearshore water quality monitoring before, during, and after construction. Requirements for water quality monitoring were identified in the Department of Health General Monitoring Guideline for Section 401 Water Quality Certification Projects and the approved data quality objectives (DQO). Water quality monitoring consisted of ten (10) days of pre-construction monitoring that took place prior to any construction activity, daily during-construction monitoring surveys conducted during phases of in-water work, and three post-construction surveys conducted at weekly intervals following completion of the project (Marine Research Consultants, Inc., 2010).



Water quality monitoring was conducted at five (5) sampling stations and included analysis of pH, turbidity, salinity, temperature, and dissolved oxygen. Values of pH remained consistent throughout the sampling program and did not exceed the decision criteria set forth in the DQOs. Values of salinity remained consistent at about 35‰ over the course of monitoring. The exception to this pattern occurred for several days in early March during a period of prolonged heavy rainfall. The depression of salinity occurred at both nearshore and offshore surface stations as a result of the storm. Following the period of heavy rainfall, salinity rapidly returned to values similar to those preceding the storm.

Of the monitoring constituents, turbidity showed by far the most response to construction operations of the beach nourishment work. Levels of exceedance of the decision criteria (DQOs) for turbidity were far higher at the nearshore stations at the site of sand placement than at the offshore control station. Turbidity remained elevated in the post-construction period relative to the pre-construction period. This elevation could be a result of either (or both) increased wave action during south swells that occurred during the post-construction period, and/or as a residual effect of re-suspension of the fine-grained fraction of the material placed on the beach (Marine Research Consultants, Inc., 2010).

The potential for increased turbidity was addressed in the Environmental Assessment (EA). Comparative analysis of grain size distribution for native sand samples (taken from Waikīkī Beach) and borrow sand (taken from the proposed dredging area) found that the borrow sand had the same grain size distribution, the same texture, and a similar color as the existing beach sand. Furthermore, the analysis found that the native and borrow sand was not finer in size than the native beach sand, thus no significant loss of finer material was expected to rapidly occur after sand placement.



**FIGURE 13:** Sediment plume formed despite the use of containment booms

The Department of Health, Clean Water Branch (CWB) rules require silt containment and may require a work stoppage if any “objectionable color” is observed in waters in or adjacent to the project area. Best Management Practices (BMP) were designed to minimize the potential for increased turbidity and to ensure permit compliance, including dewatering and deployment of floating silt containment devices in areas of active sand placement.

Despite the use of Best Management Practices (BMP), the sand placement process did result in increased turbidity in the nearshore waters adjacent to the project area. However, project work was never halted due to turbidity. Upon commencement of sand placement a sediment plume consisting of a milky white color extended alongshore and several hundred meters offshore of Waikīkī Beach. In response, a sand berm was constructed and a second silt curtain was installed, neither of which resulted in a measurable decrease in turbidity.

There was a general consensus that the sediment plume likely formed due to the release of micritic calcium carbonate (CaCO<sub>3</sub>). Micritic calcium carbonate is a product of bioerosion, a microbiological process by which organisms, such as boring clams and worms, bore through the reef producing a silt-like material that can become concentrated in topographic depressions in the reef. Despite the formation of the sediment plume, there were no human health risks or negative impacts to benthic habitat.

### ***Monitoring and Assessing Impacts to Benthic Habitat***

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Bottom composition of the nearshore environment off Waikīkī consists of a highly bioeroded fossil reef platform that is bisected by sand channels and sand pits (Burr, 2008). The University of Hawai‘i, Hawai‘i Institute of Marine Biology (HIMB) conducted independent benthic monitoring of percent cover of coral and algae, densities and distributions of corals and other macroinvertebrates, conditions of corals, rugosity, and the infaunal community of the sand deposit (Hawai‘i Institute of Marine Biology, unpublished raw data, 2012). Field surveys were conducted for one hundred 10x2 meter transects (50 pre-dredging, 50 post-dredging), yielding a total survey area of 4,000 square meters. Twenty-five (25) transects at depths of 0.5–3.0 meters were located in the impact zone, and twenty-five (25) were located across three control areas. All sites were surveyed on snorkel using a variety of sampling methods.

Overall, the multivariate analyses revealed changes in the biological communities over time and across sites. In general, the variability was higher in the impacted sites which increased after the dredging and coincided with a reduction in diversity and an increase in the amount of sand. Although changes in the benthic community were statistically detected in the Impact Zone relative to the controls, the spatial and temporal scope and the ecological significance of these changes is less clear (Forsman, unpublished raw data, 2012). The study found no significant change in coral percent coral or number of coral colonies, but there were very few coral observed in the Impact Zone. Detecting changes in the benthic environment at Waikīkī is challenging due to the heavily altered, variable, and dynamic nature of the nearshore environment.



### ***Beach and Nearshore Profiling***

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The University of Hawai'i Coastal Geology Group was contracted to conduct beach profiles for two years post-construction in compliance with the requirements of the WQC. The objectives of this project are to establish a baseline for pre-construction and post-construction beach conditions, evaluate the behavior and stability of the beach after nourishment, and monitor long-term changes in the beach profile. The methodology for the beach profiles is based on the techniques by the United States Geological Survey (USGS) for the Hawai'i Beach Profile Monitoring project (Gibbs, et.al. 2001).

Beach profile surveys were conducted prior to construction and will be conducted quarterly for a period of two (2) years. Control points were established in the pre-construction survey and will serve as controls for subsequent monitoring surveys. Eighteen (18) transects were established at 100 foot intervals along the 1,728 foot length of the project study area. Cross-shore beach profiles are conducted along each transect to identify and measure key features including beach width, berm crests, slope breaks, waterline, beach toe, and sediment type (Fletcher, unpublished raw data, 2012). Profiles extend horizontally from the back beach into the nearshore.

Approximately 11 months following replenishment, the beach increased in width along the eastern half, and decreased in width along the western half, likely resulting from seasonal current variations that switch from predominantly NW to SE. Accretion rates along the eastern half of the beach ranged from 15.9 ft/yr to 53.8 ft/yr. The highest rates of accretion took place on the eastern most transects, likely resulting from sand capture along the western crib wall. Erosion rates along the western half of the beach ranged from 15.1 ft/yr to 63.0 ft/yr. The highest rates of erosion took place at the western most transects (Fletcher, unpublished raw data, 2012). Beach profiling is scheduled to continue for another year. Additionally, there has been a digital video camera mounted on top of the Sheraton Waikīkī Hotel for several years which takes regular oblique photos of the project area. The camera is managed by the Pacific Islands Ocean Observing System (PACiOOS). The PACiOOS camera can be used, in addition to beach profiling to evaluate changes in beach shape.



## Planning & Design

As the funding agency with responsibility for managing beach resources in Hawai'i, the DLNR assumed primary responsibility for project planning and management. The DLNR Engineering Division was responsible for managing the permits and contracts, while the Office of Conservation and Coastal Lands was responsible for managing the contractors and day-to-day operations. Specific tasks, including monitoring, construction, and outreach were delegated to the appropriate contractors and members of the project team.

Project management can be challenging, especially for large-scale projects involving multiple organizations, contractors, and stakeholder groups. Given the complex nature of the Waikīkī Beach Nourishment project, emphasis was placed on a collaborative and adaptive management strategy. Planning was initiated two years prior to the start of the project. Planning activities included background research, preparation of the Environmental Assessment, acquisition of permits, selection of contractors, and preliminary stakeholder engagement. One of the key aspects of planning for the project was the early identification and thorough analysis of key issues including project funding, public safety, disruption of visitor services, potential impacts to surfing and surfing sites, cultural concerns (burials), public outreach and education, and other engineering concerns.

### ***Project Funding***

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The Waikīkī Beach Nourishment project was funded by a joint public-private partnership and did not require any appropriation of tax dollars. The total cost of construction amounted to \$2.4 million dollars with contributions of \$500,000 from the Hawai'i Tourism Authority, and \$500,000 from Kyoya Resorts. The remaining \$1.5 million dollars was appropriated from the State of Hawai'i Beach Restoration Fund, a Special Fund comprised of revenues generated from fines and easements issued to private land owners who have encroachments on submerged lands of the State of Hawai'i. Collaborative funding for beach nourishment represented a balanced approach to addressing both public and private interests in restoring and preserving beach resources in Waikīkī.

Funding remains a critical consideration for future beach nourishment and beach maintenance in Waikīkī, and throughout the State of Hawai'i. A recent report by the University of Hawai'i Sea Grant College Program and DLNR Office of Conservation and Coastal Lands emphasized the need for dedicated long-term funding to support future beach maintenance and improvements at Waikīkī. The report estimated the total funding needed for future beach maintenance and improvements at Waikīkī at approximately \$14 million for the next 10 years (State of Hawai'i Department of Land and Natural Resources, 2013).

### ***Public Safety***

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Public safety is a major concern in heavy construction projects. Due to the potential economic impacts associated with beach and ocean closures in Waikīkī, emphasis was placed on developing methods to balance existing uses and ensure public safety during sand placement



operations. Clark (2009) conducted a study to evaluate the various recreational and commercial uses in the project area including sunbathing, swimming, snorkeling, surfing, outrigger canoe paddling, catamaran operations, ocean recreation events, fishing and gathering, and boating. Construction activities inevitably disrupted many of these uses to varying degrees. Despite these disruptions, stakeholder and beach users demonstrated patience and support for the project.

Public safety was coordinated through a collaborative effort by local government agencies. Beach closures were coordinated and authorized by the City and County of Honolulu Department of Parks and Recreation. Hawai'i Ocean Safety provided in-water support with jet skis patrolling the barge and anchor lines, talking with people on the beach, and assisting with the design of the public access corridors. The contractor also deployed patrol boats and air horns around the barge and anchor lines to maintain a safety buffer around the barge. An officer of the City and County of Honolulu Police Department was hired to patrol the construction site to ensure that beach users adhered to the beach closures and to manage safety on-site safety issues. Despite the large number of beach users and occasional violations of the beach closure areas, there were no injuries reported during the project.

### ***Potential Disruption to Visitor Services***

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Conducting a large-scale construction project on high-use recreational beach will inevitably result in a variety of socioeconomic impacts. Significant effort was made to identify and mitigate, to the extent practicable, potential impacts to local businesses, visitors, and residents. Of particular concern were potential economic losses to local hotels, resorts, and beach concessionaires, all of whom rely on the availability of Waikīkī Beach to support their businesses.

Waikīkī Beach Boy concessions rent surfboards, boogie boards, umbrellas, beach chairs and mats. They also provide outrigger canoe rides and surfing instruction. The City and County of Honolulu Department of Enterprise Services manages leases for beach concessionaires in Waikīkī. Project managers worked with the City and County of Honolulu Department of Enterprise Services and the beach concessionaires in an effort to minimize potential economic losses associated with the required beach closures. Pathways were strategically placed along the truck haul route to maximize ingress and egress to and from the water near the beach concessions. Follow up conversations with concessionaires and their staff indicated that, despite the beach closures and the noise associated with construction, their businesses experienced little or no actual economic losses.

Audible and visual disruptions were another major concern identified by local businesses, particularly large oceanfront hotels and resorts, who voiced concern that construction activities would have a significant negative impact on the visitor experience. Measures were taken to minimize audible and visual disruption including removing backup alarms on the articulated dump trucks, and limiting the use of heavy equipment to the hours of 7:00am to 12:00pm when the beach is least populated.



### ***Cultural Concerns (Burials)***

It is customary in Hawai'i to conduct a *pule* (blessing ceremony) prior to large events, during which participants form a circle, hold hands, and a prayer is recited in *Olelo* (Native Hawaiian language) by a *Kahu* (priest). On January 14, 2012, a *pule* was conducted prior to the start of the Waikīkī Beach Nourishment project. Sand was taken from below the waterline, passed through a row of people and symbolically placed on the dry beach.

Burial at sea is a commonly practiced Native Hawaiian tradition. Shortly before the start of sand recovery operations, concerns were expressed that the offshore sand borrow site was located where the ashes of Native Hawaiians, including Duke Kahanamoku and past members of the Waikīkī Beach Boys, had been placed into the water for burial at sea. Recognizing the sensitivity of the issue, the contractor conducted a second blessing ceremony to honor the deceased where a DLNR Chairperson William Aila noted "We have infinite respect for the culture and ancestral issues related to the people who have been buried in the waters of Waikīkī".

### ***Potential Impacts to Surfing***

Waikīkī Beach was a favorite bodysurfing, surfing and canoe surfing site amongst Native Hawaiians for hundreds of years (Clark, 2009). A legendary story of the longest wave ever ridden in Hawai'i comes from Waikīkī. In 1917, on a day of very large surf, Duke Kahanamoku paddled out on his 16-foot wooden surfboard. The wave that he rode was estimated at 30 to 35 feet (9 to 11 m) in height. It is storied that Duke rode the wave for more than 1 mile (1.6 km), through the surf breaks now known as Publics and Queen's, and possibly as far down the coast as the Royal Hawaiian Hotel (Hawai'i Encyclopedia.com, 2013). The character of surfing waves varies not only from location to location, but also from day to day with tide level and swell. In fact, even successive waves can break with considerably different characteristics (Scarfe, et.al, 2003). Mead and Black (2001) identified the major bathymetric features that cause surfing breaks to form good surfing waves: ramp, platform, wedge, focus, ledge, ridge and pinnacle (Scarfe, et.al, 2003). Any alteration of these components by natural processes or human actions will change the surfing wave parameters at the surfing break (Scarfe, et.al, 2003).



**FIGURE 14:** Beach nourishment did not negatively impact surfing resources at Waikīkī Beach.

George Downing, a legendary surfer, Waikīkī local, and President of Save Our Surf (SOS), has written and spoken extensively about the effects of sand nourishment on Waikīkī surf breaks. Downing has stated that, “Queens surf site, which once had a single take-off peak, has developed three take-off peaks due to the excess sand. All of these changes are due to the sand filling in, changing the contours and depth of the reef bottom.”

The Waikīkī Beach Nourishment project was designed to avoid any impacts to surf sites. Given the high cultural and recreational value of Waikīkī’s surfing resources, and the perception that past sand nourishment projects have altered surf breaks, the importation of additional sand from sources outside of the Waikīkī littoral system was not considered for this project, at this time.

### ***Education and Outreach***

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Education and outreach was a critical component of the Waikīkī Beach Nourishment project. Outreach was coordinated by the University of Hawai’i Sea Grant College Program with support from project partners. The outreach program began approximately six (6) months prior to the start of the project. One of the challenges to conducting project outreach was the wide variety of audiences and stakeholder groups including: tourists, residents, hotel general managers, security officers, concierge services, beach concessions, local government, state government, lifeguards, media, and the general public.

Project outreach utilized a combination of targeted and opportunistic methods and products. Targeted outreach focused on communicating information about the project with known stakeholder groups including local businesses, the Waikīkī visitor industry, local residents, and visitors. Information products were designed to address specific user information needs. Targeted outreach methods included stakeholder meetings, press releases, project flyers, signage, posters, videos, social networking, and daily web-based project updates.

Stakeholder meetings were designed with an emphasis on two-way flow of information, with project staff communicating specific information about the project specifications, and stakeholders providing feedback to inform planning and implementation. Targeted outreach products were designed for specific audiences, such as: the Hawai’i Hotel and Visitor Industry Security Association (HH-VISA), and O’ahu Concierge Services. Other outreach products, including press releases, project flyers, posters, signage, and videos, were designed to communicate project information with broader disparate audiences.





## WAIKIKI BEACH MAINTENANCE PROJECT

The Hawaii Department of Land and Natural Resources (DLNR) is conducting a three month project to restore sand to approximately 1,730 feet of shoreline on Waikiki Beach with the goal of returning the beach to its condition in the mid-1980s. The project is a public and private partnership that will have significant beneficial impacts to recreation and the local beach and reef environment. The contractors are utilizing a state-of-the-art method to “recycle” beach sand that has been lost offshore due to chronic coastal erosion. Sand is pumped from offshore sand recovery areas, allowed to dry in a dewatering basin within the east Kuhio Beach Park swim basin, and blown through a buried sand conveyance pipe to the active beach maintenance area between the Royal Hawaiian Hotel and the west end of the Kuhio Beach Park swim basins. The east Kuhio Beach Park swim basin and active beach maintenance areas will be closed for the duration of the project.






Existing Beach
Nourished Beach

*Mahalo for your patience while we restore Waikiki Beach*



**FIGURE 16:** Multiple media formats were used to conduct outreach to a broad audience.

The Internet provided an effective means to expand the distribution of outreach products to a wider audience. Daily project updates provided a three (3) day summary of project activities and were delivered via multiple websites, including the DLNR Office of Conservation and Coastal Lands homepage, and the Hawai'i Ocean Safety website, the latter of which hosted a subscription-based email list-serve option to deliver project updates via email on a daily basis. Social networking sites provided an effective means to both communicate project information and to collect feedback and comments from a wider audience. Project profiles were established on common social networking platforms including Facebook, YouTube, and Vimeo.

Opportunistic outreach focused on communicating information about the project with audiences and groups that were difficult to identify or access consistently and reliably. Examples of opportunistic outreach included responding to information requests and complaints, and responding to inquiries from beach users along Waikiki Beach. Aloha Ambassadors and contractors were consistently approached by beach users who presented a wide variety of project-related questions and comments. Opportunistic outreach, while less formal than the targeted components of the outreach program, was no less important in terms of communicating project information.

Public perception and support for the Waikīkī Beach Nourishment project fluctuated over the course of the project. Public acceptance was generally low during the sand recovery process but improved noticeably as sand placement progressed and the results became visual and tangible.

While the outreach campaign was considered largely successful based on feedback from local stakeholders, beach users, and the general public, there were several lessons learned that will inform future projects. In order to gain support and address community concerns, emphasis should be placed on engaging stakeholders and the public very early in the process. During this process, the outreach campaign should focus on clearly defining the nature and scope of the project, and addressing concerns related to potential impacts.

Emphasis should be placed on communicating the positive benefits of beach nourishment (e.g. preservation of beach resources, habitat preservation, improved public access, maintaining the beach as a natural storm buffer, and the long-term economic benefits), while addressing the potential negative impacts of the project. The outreach campaign should emphasize that potential environmental impacts can be offset by applying Best Management Practices (BMP).

Furthermore, the outreach campaign should communicate the relationship between project costs and anticipated impacts to demonstrate the overall return on investment (ROI) and the long-term economic benefits of beach nourishment. In order to quantify and communicate the value of conserving, In addition to quantifying the environmental, social, cultural and economic value of Waikīkī Beach, effort should be made to quantify the actual economic value to natural resource functions using evaluation tools such as InVEST<sup>3</sup>. For future projects, it will be important for outreach staff to remain flexible, adaptive, and prepared to communicate changes to local stakeholders, beach users, and the general public.

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<sup>3</sup> <http://www.naturalcapitalproject.org/InVEST.html>



## Future Considerations for Beach Nourishment in Waikīkī

The experience gained through the successful completion of the 2012 Waikīkī Beach Nourishment project yielded many valuable insights that will inform future beach nourishment projects including aspects of planning, permitting, project management, implementation, and outreach.

In addition, to establishing a proactive timeline for construction activities, it will be important to identify potential strategies to mitigate potential adverse impacts, such as impacts to water quality, dredging of coral rubble, and sand compaction. While it is unclear what options may be available to address these issues, it is nonetheless important that they be adequately addressed in the revised EA. Future projects should explore alternatives to address known issues including: equipment modifications to reduce the uptake of coral rubble from the offshore sand borrow sites, techniques to minimize turbidity during sand placement, alternative approaches to sand recovery and sand placement, and methods to minimize the potential for sand compaction.

Based on historical erosion trends and observations made through the beach profile monitoring conducted during the year following completion of the project, erosion is expected to continue at Waikīkī Beach in the future. Sea-level rise is an emerging concern for beaches in Hawai'i. Hawai'i is expected to experience sea-level rise of one foot by 2050 and three feet by the end of the century (Codiga and Wager, 2011). Erosion in Waikīkī Beach is expected to accelerate under rising sea levels.

In order to mitigate the potential economic impacts associated with erosion and beach loss at Waikīkī Beach, the State of Hawai'i must identify reliable sources of compatible beach sand and long-term funding to support long-term renourishment and maintenance of Waikīkī Beach. DLNR is working in collaboration with local stakeholders and the State Legislature to establish a consistent funding source to support future beach nourishment at Waikīkī Beach. In addition, the University of Hawai'i has proposed a full-time position to support comprehensive beach management planning in Waikīkī.

In closing, the Waikīkī Beach Nourishment project exemplified the value of a balanced public-private approach to managing and preserving beach resources in Hawai'i. Despite the technical difficulties and challenging conditions, the project was successful in restoring Waikīkī Beach by an average width of 37 feet. As the benefits of this project are realized over the course of the next decade, the lessons learned and experience gained through the 2012 Waikīkī Beach Nourishment project will continue to inform planning for future beach nourishment projects in Hawai'i.



## References

1. Bodge, K.R. (2000). Independent Evaluation Study of Proposed Kuhio Beach Improvements, Olsen Associates, Inc., supplied to the State of Hawai'i, Department of Land and Natural Resources, dated October 1, 2012.
2. Burr, S. (2008). Marine environment monitoring for the Kūhiō Beach small-scale beach nourishment project, Waikīkī, O'ahu: An analysis of three-month and fifteen-month postdredging monitoring results. *AECOS*, Inc. *AECOS* No. 936G. July 23, 2008
3. Callies, D. L. (2010). *Regulating Paradise: Land Use Controls in Hawai'i*. 2<sup>nd</sup> Edition, Honolulu, Hawai'i: University of Hawai'i Press.
4. Clark, J. (2002). *Hawai'i Place Names: Shores, Beaches, and Surf Sites*. Honolulu, Hawai'i: University of Hawai'i Press, DU622.C546.
5. Clark, J. (2009). *Ocean Activities Report for the Waikīkī Beach Maintenance Project at Waikīkī*, Honolulu, Hawai'i; Report prepared for Sea Engineering, Inc.
6. Conger, C.L., Eversole, D.N. (2012). *Royal Hawaiian Beach, Waikīkī – A Result of Human Influence and Intervention*. University of Hawai'i Sea Grant College Program. UNIH-SEAGRANT-TT-11-01.
7. Finkl, C.W. (1981). Beach Nourishment, a Practical Method of Erosion Control. *Geo-Marine Letters*, Vol. 1, 155-161.
8. Fletcher, C.H. (2013). *Waikīkī Beach Profile Monitoring*. Unpublished raw data.
9. Fletcher, C.H., Mullane, R.A., and Richmond, B.M. (1997). Beach Loss Along Armored Shorelines of Oahu, Hawaiian Islands. *Journal of Coastal Research*. v.13. p. 209-215.
10. Forsman, Z.H., Peyton, K.A., Knapp, I.S.S., Toonen, R.J. (2012) *The Effects of Beach Sand Replenishment on Benthic Communities in Waikīkī*, Hawai'i Institute of Marine Biology, University of Hawai'i, supplied to the Department of Land and Natural Resources, dated November 29, 2012.
11. Gibbs, A.E., Richmond, B.M., Fletcher, C.H., Hillman, K.P. (2001). *Hawai'i Beach Monitoring Program*, United States Geological Survey, Open-file Report 01-308, Version 1.0, 2001.
12. Gonser, J. (2002, 1 May). *Waikīkī Beachboy Concessions Must Did Again*. Urban Honolulu Writer.
13. H. John Heinz III Center for Science, Economics, and the Environment. *Evaluation of Erosion Hazards*. Prepared for the Federal Emergency Management Agency. Contract EMW97-CO-0375. April 2000.
14. Hospitality Advisors, LLC. (2008). *Economic Impact Analysis of the Potential Erosion of Waikīkī Beach*, supplied to the Waikīkī Improvement Association, dated September 3, 2008.



15. Houston, J.R. (2013). The Economic Value of Beaches – A 2013 Update. Shore & Beach. Vol. 81, No. 1. Winter 2013.
16. KITV News (2012, 27 January). State to Hold Second Blessing for Waikīkī Sand Project. <http://www.kitv.com/State-To-Hold-Second-Blessing-For-Waikiki-Sand-Project/-/8906042/9658868/-/n4bra4/-/index.html#ixzz2Fcbz3QYb>.
17. Leatherman, S.P. (1986), Effect of Accelerated Sea-Level Rise on Coastal Ecosystems, U.S. Senate Publication, Senate Hearing. 99-723, Washington, DC, p. 141-153.
18. Marine Research Consultants, Inc. (2010). Applicable Monitoring and Assessment Program (AMAP) for Clean Water Act (CWA), Section 401 Water Quality Certification, Waikīkī Beach Maintenance Project, supplied to the State of Hawai'i, Department of Land and Natural Resources, dated May 20, 2010.
19. Mead, S.T. and Black, K.P., (2001). Field Studies Leading to the Bathymetric Classification of World-class Surfing Breaks. In: BLACK, K. P. (ed.), Natural and Artificial Reefs for Surfing and Coastal Protection. Journal of Coastal Research, Special Issue No. 29, pp. 5-20.
20. Miller, T. L., Fletcher, C.H. (2003). Waikīkī: Historical Analysis of an Engineered Shoreline, Journal of Coastal Research, 19, 4, 1026-1043.
21. Office of the Commissioner of Public Lands (1928). Waikīkī Beach Reclamation: Agreements Between the Territory of Hawai'i and Property Owners, dated October 19, 1928.
22. Sea Engineering, Inc. (2010). Final Environmental Assessment: Waikīkī Beach Maintenance, supplied to the State of Hawai'i, Department of Land and Natural Resources, SEI Job No. 25172, dated May 2010.
23. Scarfe, B.E., Elwany, M.H.S., Mead, S.T., Black, K.P. (7, March 2003). The Science of Surfing Waves and Surfing Breaks – A Review, Scripps Institution of Oceanography Technical Report, Scripps Institution of Oceanography, University of California San Diego, 2.
24. United States Army Corps of Engineers (2011). Waikīkī Camera Analysis, supplied to the State of Hawai'i, Department of Land and Natural Resources, dated February 22, 2011.
25. University of Hawai'i Sea Grant College Program, State of Hawai'i Department of Land and Natural Resources. (January 2013). Waikīkī Beach Management and Maintenance Plan, supplied to the Waikīkī Business Improvement District and Waikīkī Improvement Association, Honolulu, Hawai'i.
26. Codiga, D. and Wager, K. (2011). Sea-Level Rise and Coastal Land Use in Hawai'i: A Policy Tool Kit for State and Local Governments, University of Hawai'i Sea Grant College Program, Center for Island Climate Adaptation and Policy.
27. Vitousek, S., Fletcher, C.H. (2008). Maximum Annually Recurring Wave Heights in Hawai'i. University of Hawai'i Press. Pacific Science. Vol. 62, No. 4. P. 541-553.



28. Wiegel, R. L. (November 2002). Waikīkī, O'ahu, Hawai'i, An Urban Beach, Its History From A Coastal Engineering Perspective, Hydraulic Engineering Laboratory, University of California, Berkeley, California, UCB/HEL-2002-1.



