Royal Hawaiian Beach: Replenishment, Monitoring, and History of Engineering

Interim Report, Year 1

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Table of Contents

Executive Summary

In 2012, a replenishment project was carried out on Royal Hawaiian Beach in Waikiki, Oahu, funded as a joint private public partnership. As part of the project, the University of Hawaii Coastal Geology Group was commissioned to monitor and evaluate erosion rates and morphological changes over a period of two years following the initial replenishment. Cross shore profiles were measured approximately quarterly using a Geodimeter total station and telescoping rod that was moved across the beach into near shore waters by a swimmer. One year following replenishment, a total of five surveys have been conducted. Survey data confirm the placement of approximately 24,000 yds^3 of fill on the Royal Hawaiian Beach with subsequent net volume loss of -6270 yds^3 or 27%. The beach remains an average of 20 ft wider than the pre-fill conditions, decreasing an average of 2.88 ft in width over year 1. Width change varies by location, ranging from +5.68 ft in the central segment of the beach to -9.38 ft at the western most extent of the beach. Berm retreat, typically under conditions of summer swell, produced net erosion in the eastern and western portions of the project. Net accretion offshore of the western portion of the project area is consistent with net westward transport under summer swell conditions. Offshore changes in sea floor elevation are dominated by high variability and/or uncertainties related to misalignment of profiles. An overview of the engineering history of Royal Hawaiian Beach is included in the second section of this report.

Royal Hawaiian Beach: 2012 Replenishment, Monitoring, and History of Engineering

Interim Report, Year 1

Section 1: Analysis of 2012 Replenishment Project

Introduction

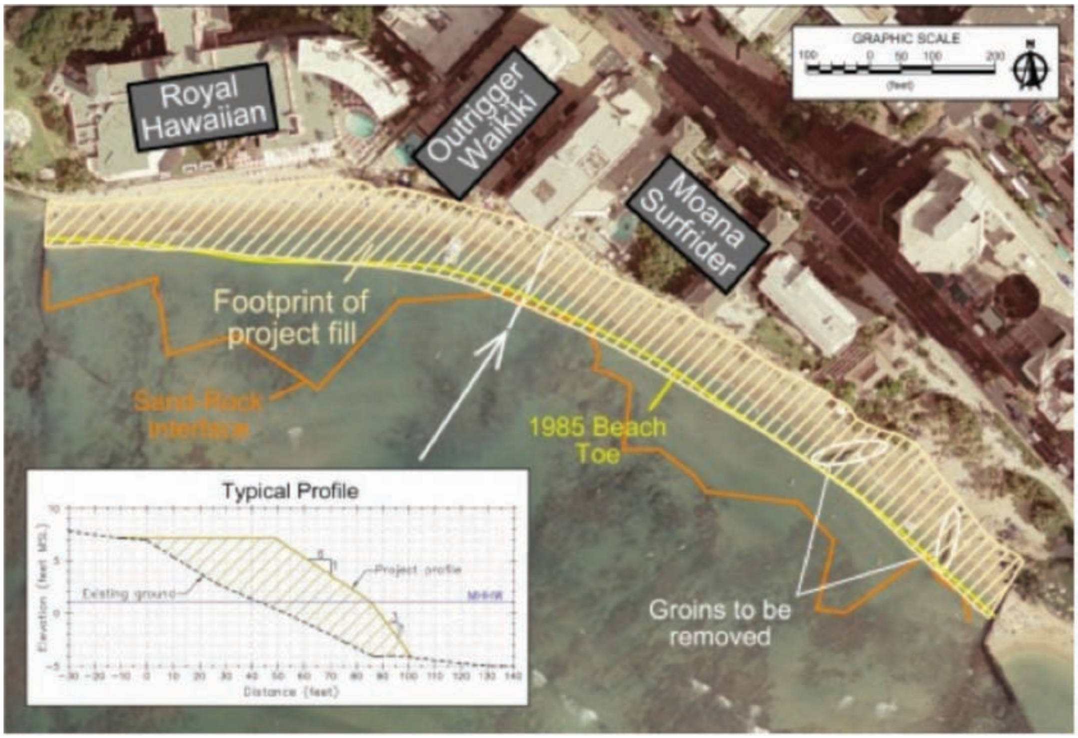
Waikiki is located on Oahu's southern shore, which lies in a heavily developed area on a predominantly low-lying coast. The beach is lined with hard structures including seawalls, revetments, and groins. Waikiki Beach has experienced significant change over the past century as a product of various engineering projects mainly intended to improve the beach for the tourism industry. These projects have included coral dredging, emplacement of hard structures in close proximity to shorelines, sand mining, and sand replenishment. Engineering projects have altered the physical dynamics of the coastline, which have in turn affected sand deposition causing erosion in some areas and accretion in others with an increased trend towards erosion (Miller and Fletcher, 2003; Sea Engineering, 2010).

Beach nourishment is the primary method used to maintain significant beach widths in Waikiki; it is the option that is most successful for maintaining usable beach widths while also protecting beachside property. Past nourishments have significantly slowed erosion rates as a result of reestablishing sediment budgets (Crane, 1972). Replenishment projects have been ongoing since the early 1900's; the most recent took place in 2012 along the 1,700 ft section fronting the Moana Surfrider and Royal Hawaiian hotels. The project location is shown in **FIGURE 1**.

FIGURE 1 *Aerial image of Royal Hawaiian Beach, the 2012 replenishment project site, and the dewatering site located inside the Crib Walls on Kuhio Beach.*

As part of the 2012 nourishment project, approximately 24,000 yds^3 of sand was placed along this section of beach with the goal of increasing the width by an average of 37 ft, (**FIGURE 2**). The sand was recovered from deposits located approximately 2,000 ft offshore. In addition to sand replenishment, two deteriorated groins were removed from the eastern section of the project area. The project includes a proposal to place additional sand in the future.

__FIGURE 2__ Illustration of the replenishment project. The intended width increase of the beach following replenishment is denoted with cross hatching and superimposed on the location of the 1985 toe line. Locations of the two groins removed as part of the project are circled in white. The plot in the lower left-hand corner shows a conceptual cross section of topographical changes along the toe that are expected to result from replenishment (Sea Engineering, 2010)



The section of beach, as well as an area directly offshore, is currently undergoing monitoring by the University of Hawai'i Coastal Geology Group (CGG) to evaluate erosion rates and morphological changes as they occur over time. This information will assist the State of Hawai'i in determining the effectiveness of the project and whether the method of replenishment is feasible as a long term answer to beach erosion issues in the Waikiki area. This is an interim report on the CGG monitoring project.

After 1 year of monitoring, it has been found that a volume of 23,308 yd^3 has been recovered and deposited on the defined beach with moderate erosion taking place thereafter.[1]

2012 Replenishment Project

The goal of the 2012 replenishment project has been to restore beach widths that had been diminished by chronic erosion since 1985 (Sea Engineering, 2010). The cost of the project amounted to $2.9 million, which was funded by a joint public partnership including contributions from the State of Hawai'i Beach Restoration Fund, the Hawai'i Tourism Authority, and Kyo-ya Resorts.

As part of this project, Sea Engineering was contracted to recover approximately 24,000 cubic yards of sand from offshore sand deposits. The sand was relocated by pumping a sand water slurry through a submerged 3,200 ft pipe to the shoreline for dewatering. Dewatering took place within a basin formed by temporary sand dikes located inside of the Kuhio Beach Crib walls. The project also included the removal of two cement sand bag groin structures at the east end of the area. Sand recovery took place 2000 m offshore at a depth of 10-20 ft, shown in **FIGURE 3**. Sand extraction was accomplished using a submersible slurry pump that relocated an average of 500 yds^3 of sand per day (Lemmo et al., 2013).

[1] This value represents a minimum value due to compaction.

FIGURE 3 The dredging barge illustrates the location of sand recovery approximately 2,000 ft offshore of Royal Hawaiian Beach.

The plan intended for sand to be transferred from the dewatering basin to the beach using a pneumatic conveyance system; however, the conveyance system was not able to relocate sand fast enough to meet time restraints. Sand was instead relocated using dump trucks that placed sand starting from the Kuhio Beach area and moved westward, shown in **FIGURE 4a**. The hauling system was devised in collaboration with Hawai'i Tourism Authority, as well as with associated stakeholders.

Truck hauling may have resulted in a 1-3 ft hardened berm (**FIGURE 4b**) that subsequently developed along the beach as a result of erosive wave action. The weight of the trucks likely caused compaction of the sand along the haul route.

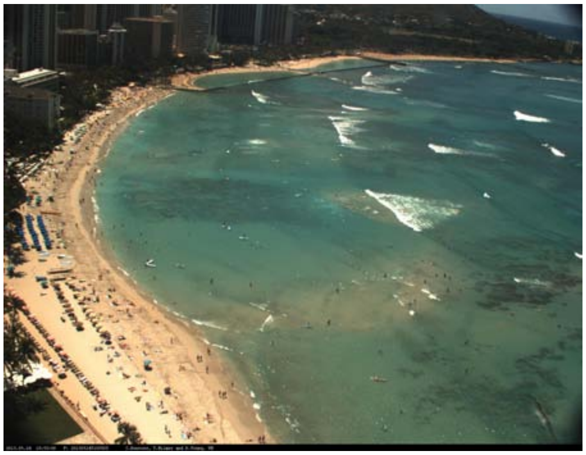
***FIGURE 4** (a.) Sand hauling on Royal Hawaiian Beach undertaken as the alternate sand distribution method. (b.) Hardened beach berm located at the eastern most end of the project area, taken on 12/14/12, about 8 months following completion of the replenishment project. The berm may be a result of compaction due to truck traffic.*

a. *b.*

Prior to the project, there was concern that the turbidity of water offshore would increase. Silt curtains were used to mitigate increases in turbidity, but despite these efforts, near-shore areas experienced increased turbidity. **FIGURE 5** shows the sediment plume that was observed extending several hundred meters offshore of the project site. In an attempt to reduce turbidity, a second silt curtain was installed; however, turbidity remained significantly elevated. The sediment plume is thought to have resulted from the release of micritic calcium carbonate produced by organisms such as boring clams and worms, and potentially by abrasion of friable carbonate material during pumping and handling (Lemmo et al., 2013). No risks or impacts to humans or the benthic habitat were observed (Forsman, et al., 2012). Turbidity increases in conjunction with increased wave energy (**FIGURE 6**).

__FIGURE 5__ Discharge of sediment plume from the project site. In this photo, sand is being placed in the middle of the project area. A NW flowing current is carrying a plume of micritic silt from the site.

__FIGURE 6__ Micrite (carbonate) silt originating from the beach fill increases in conjunction with increased wave energy. 5/24/13 http://oos.soest.hawaii.edu/pacioos/focus/conditions/livephotos.php



Analysis: Beach and Nearshore Profiles

The University of Hawaii Coastal Geology Group was contracted by the Department of Land and Natural Resources (DLNR) to assess the effectiveness of the replenishment project for a period of two years following the initial replenishment. The objective of this study has been to investigate the behavior of the shoreline and the stability of the beach following beach nourishment in addition to monitoring long term changes in beach width and volume. A methodology involving beach profiling was adopted from techniques established by the United States Geological Survey (USGS) for the Hawai'i Beach Profile Monitoring project (Gibbs, et. al., 2001), which follow Water Quality Certification (WQC) guidelines. Appendix 1 displays the time series of beach profiles.

Data Collection

Sand volume and beach width were measured by conducting surveys prior to and following completion of the replenishment project. Sea Engineering, Inc. surveyed control points prior to and following sand placement. Six of the control points were used as part of the CGG study in order to establish a similar reference frame for survey data.

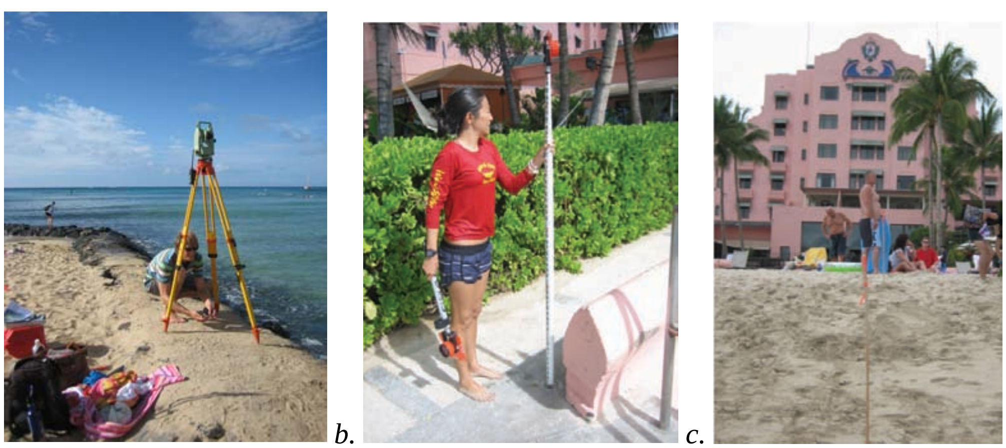
Eighteen cross-shore beach profiles were established at roughly 100 ft intervals along the 1,728 ft project study area, illustrated in **FIGURE 7**. Transects were defined along the beach by establishing predefined bearings that extend seaward from backshore reference points. Transects are denoted by letter from A to R alphabetically from east to west.

__FIGURE 7__ Eighteen cross-shore transect lines denoted by letter progressing sequentially from east to west. Surveys have been conducted on the following dates: 12/8/11, 5/4/12, 8/8/12, 12/14/12, and 4/17/13.

Transects were monitored to evaluate the behavior and stability of the beach following nourishment. An initial survey took place on 12/8/11, prior to replenishment, in order to establish a base line for post-fill analysis. At the time of this report, four post-fill surveys have been completed on the following dates: 5/4/12, 8/8/12, 12/14/12, and 4/17/13.

Thirty permanent reference points in addition to six Sea Engineering defined reference points were surveyed in order to establish position control relative to each profile line. Cross shore profiles were measured using a Geodimeter laser Total Station (**FIGURE 8A**) that tracks a reflecting prism on a telescoping rod (**FIGURE 8b**). The rod was moved across the beach and into nearshore waters by a swimmer. For each line, the swimmer would follow a predefined marked bearing (**FIGURE 8C**) to their best ability.

__FIGURE 8__ (a) Geodimeter total station setup on the western most Crib wall. (b) Swimmer positioning a telescoping rod atop a reference point for location data recording. (c) Markers used by the swimmer to identify the transect bearing.



a. *b.* *c.*

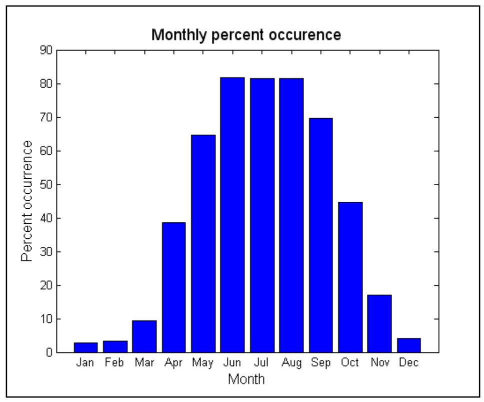
Elevation and position data were recorded every 3-5 m (10 to 16 ft) as well as at pertinent geomorphic features including berm crest, wet-dry line, sea level, top and base of beach toe, high swash, and offshore substrate (rock, sand). The total station was set up on the western crib wall of Kuhio Beach. Beach profile measurements were taken from the seaward edge of coastal armoring structures to positions offshore as conditions allowed, (typically roughly 3-4 m depth).

Raw survey data were downloaded from the Total Station memory as X, Y and Z point locations in meters relative to the Total Station location. Control points from Sea Engineering were located and included in surveys with varying success. The survey on 12/14/12 includes 5 Sea Engineering control points and is used to calculate a migration value for each profile line and each survey date. The migration value is an offset in the X, Y and Z (easting, northing and elevation) based on the average difference in the surveyed locations of the 5 Sea Engineering control points and their established locations in UTM NAD83 coordinate space. This migration value is applied to each profile reference point and subsequently each profile point.

Wave Conditions

The Waikiki wave environment is dominated by summer swell generated by storm activity in the Southern Ocean and local trade winds. **FIGURE 9** shows that the months of April through October are times of 40 to 80 percent probability of south swell occurrence. Thus it is over this period that project survey results should show the greatest changes in beach and offshore characteristics.

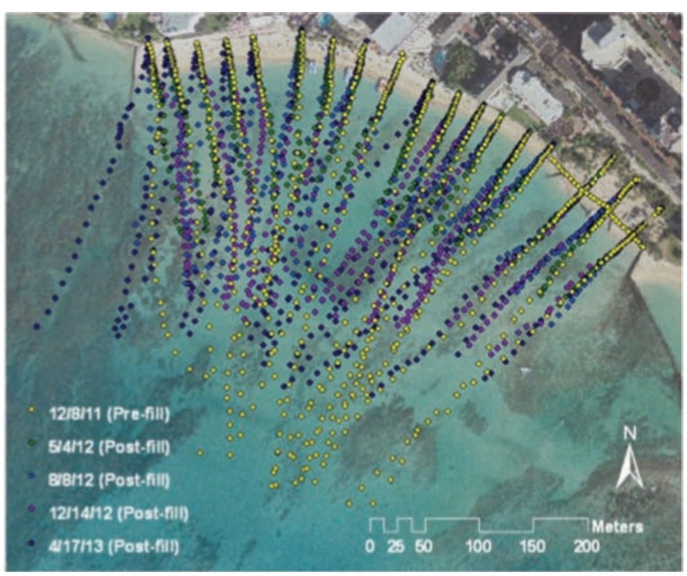
FIGURE 9 *Data indicate that the period of high waves in Waikiki is between the months of April to October. (from Sea Engineering, 2010)*



Elevation Maps

Elevation change maps of the study region were generated in ArcGIS. Survey point data were imported into ArcGIS; an image of projected data points is featured in **FIGURE 10**.

FIGURE 10 *Data points collected during each survey date projected on a satellite image of the project area. Note the substantial misalignment of profiles offshore. This source of uncertainty likely contributes to elevation variability observed offshore.*



Surfaces representative of the beach and offshore measured during each survey date were interpolated by generating a series of TINs. Each TIN was used to produce a raster of the surveyed surface. The ArcGIS tool "minus", a geoprocessing tool that subtracts the value of one raster input from another, was used to produce an image showing elevation change from one survey to another. To assess changes in shoreline, the beach toe was vectored and superimposed on elevation change maps using the identified toe locations recorded along transect lines for each survey date. These images are included in **FIGURES 11-14**.

FIGURE 11 *Change in elevation from 12/8/11 (pre-fill) to 5/4/12 (post-fill). Lines located nearshore indicate location of the top of the beach toe at both dates; notice significant seaward shift from the earlier to later toe position. The map shows strong increase in elevation on the sub-aerial beach and minor to moderate erosion and accretion offshore. Primary influences on elevation change include sand nourishment and winter wave conditions.*

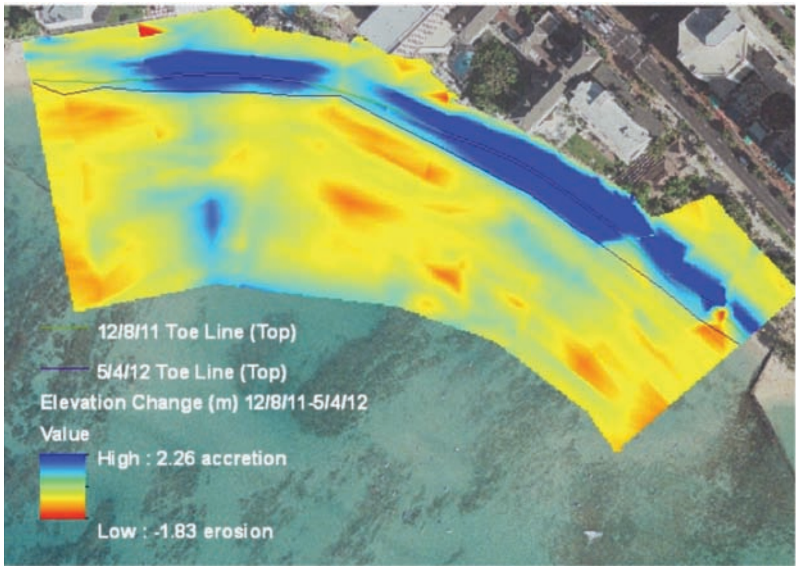


FIGURE 12 *Change in elevation from 5/4/12 (post fill) to 8/8/12 (post fill). Lines located nearshore indicate location of the beach toe at both dates; notice little change other than shoreline recession at east end of area. The map shows strong erosion on the sub-aerial beach at the east and west ends and moderate to strong accretion immediately offshore of the beach in middle and western project areas. Primary influences on elevation include summer wave conditions.*

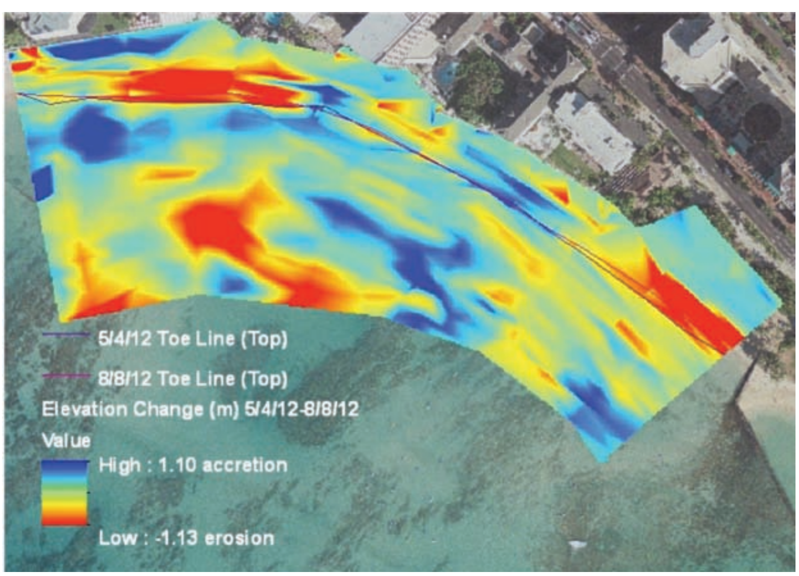


FIGURE 13 *Change in elevation from 8/8/12 (post fill) to 12/14/12 (post fill). Lines located nearshore indicate location of the beach toe at both dates; notice little change other than continuation of the trend of shoreline recession at east end of project area. The map shows strong erosion on the sub-aerial beach across the eastern half of the beach and strong accretion on the sub-aerial beach across the western half of the beach. Primary influences on elevation include summer changing to winter wave conditions.*

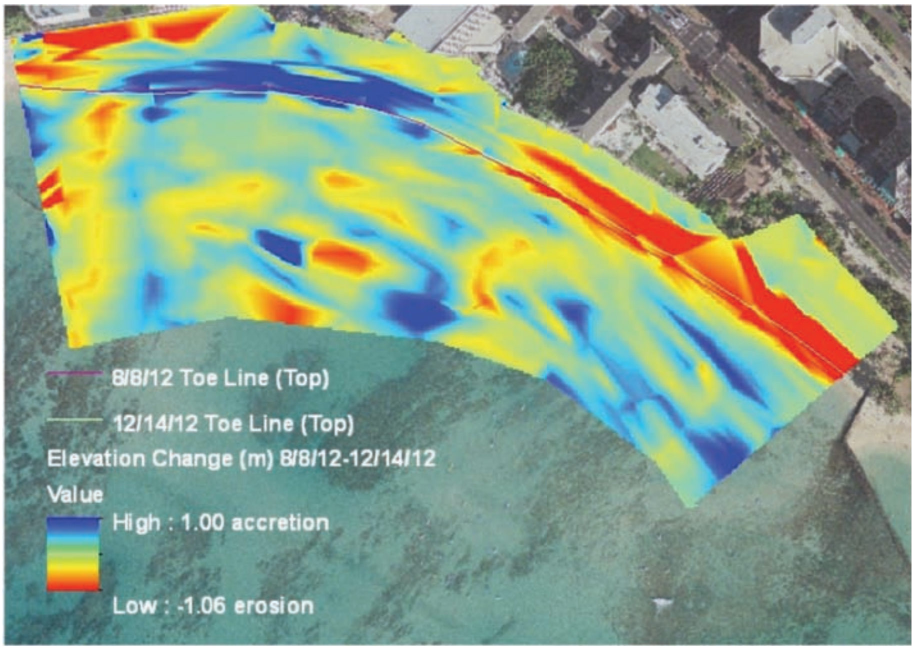
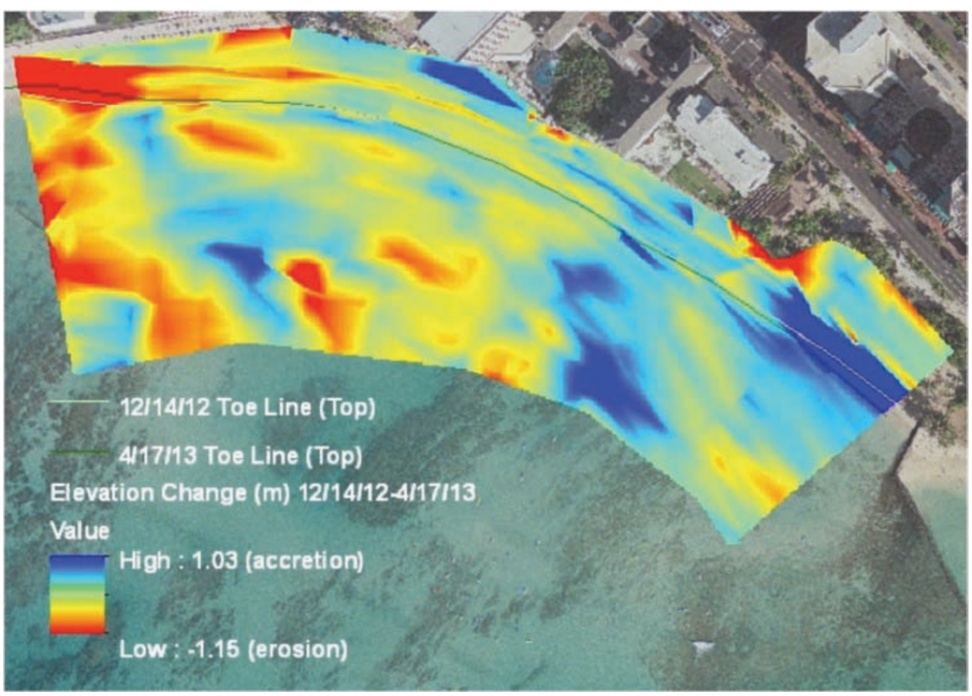


FIGURE 14 *Change in elevation from 12/14/12 (post fill) to 4/17/13 (post fill). Lines located nearshore indicate location of the beach toe at both dates; notice accretion in the east and erosion in the west regions of the project area. The map shows strong erosion on the sub-aerial beach at the western end of the project and strong accretion on the sub-aerial beach at the eastern end of the project. Immediately offshore of the eastern project area there is moderate accretion in shallow water. To the west, accretion transitions to erosion. Primary influences on elevation include winter wave conditions.*



Volume and Area Calculations

Beach Extent (subaerial to -20 m)

Beach parameters were calculated using various ArcGIS geoprocessing tools.

Volumetric data was extrapolated from elevation data by defining each pixel as a 1x1 m area and multiplied by the cell elevation value. By delineating a specified areal extent, the volume value for each cell was summed to produce a total volume for the defined area. For our purposes, the extent of beach area for each survey date was defined separately in order to account for changes in beach width.

The area defined as the "beach" includes the area that extends from hard structures located at the back of the beach to 20 m offshore from the top of the toe. The area is redefined for each survey based on the changing location of the toe. The western end of the Crib Walls marks the eastern extent of the project beach, and the Royal Hawaiian Groin marks the western extent of the beach. Each elevation map was clipped to the respective beach area.

The ArcGIS tool "raster calculator" was used to shift all data points into a positive reference frame to avoid calculation of negative elevation values. The elevation of the lowest recorded data point (-2.149m) was defined as the datum for this procedure and all points were shifted upward by 2.149 m.

The ArcGIS tool "zonal statistics", a geoprocessing tool that summarizes values of a raster, was used to calculate the areal extent of the beach as well as the volume. Area and volume change calculations, as well as conversion from meters to yards were completed using Excel. A series of plots were produced illustrating the results and are included in **FIGURES 15-17** and **TABLES 1** and **2** provide summary data.

TABLE 1
***CONSECUTIVE VOLUME AND AREA CHANGE OF BEACH** (subaerial to 20 m)*

Survey Date	***Area (m^2)***	***Area (yd^2)***	***Volume (m^3)***	***Volume (yd^3)***
12/8/11(Pre fill)	Reference	Reference	Reference	Reference
5/4/12 (Post Fill)	4,425	5,292	17,821	23,308
8/8/12 (Post Fill)	-1,234	-1,476	-3,779	-4,942
12/14/12 (Post Fill)	-461	-551	18	23
4/17/2013 (Post Fill)	347	415	-1033	-1351

***FIGURE 15** Area change for each survey with respect to previous survey.*

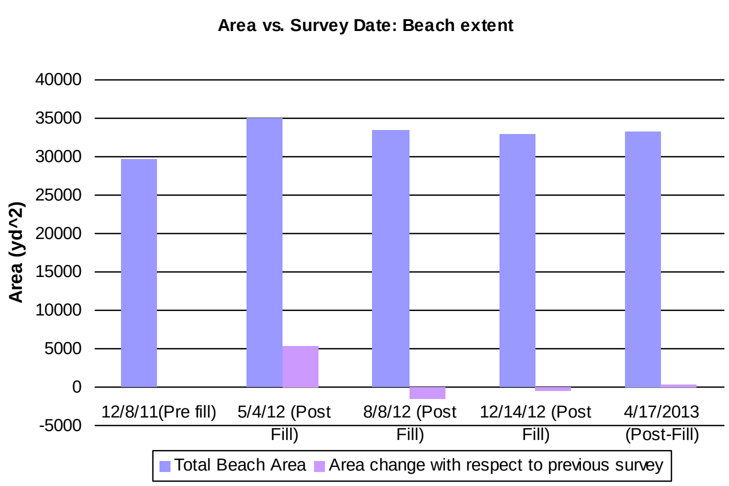
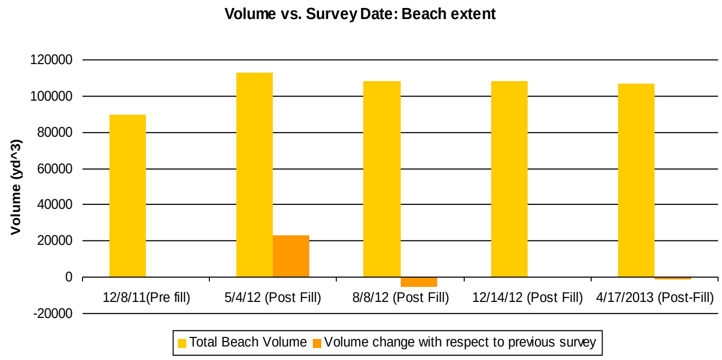


FIGURE 16 *Volume change for each survey with respect to previous survey.*



Beach Extent Including Area On and Offshore

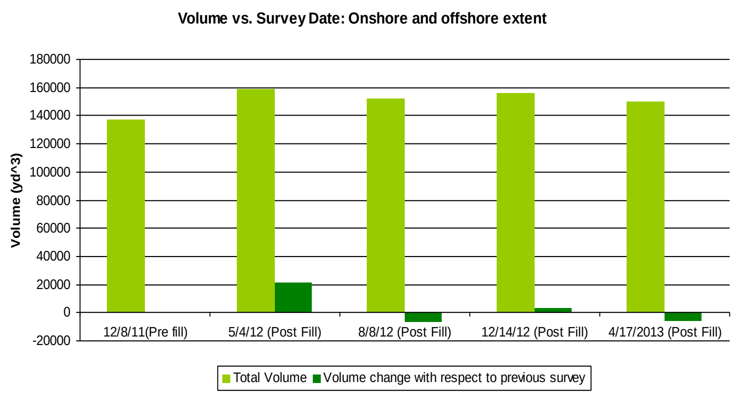
Similar methodology as described previously was used to determine volume change within a single defined area that includes the beach extent as well as the area offshore that encompasses data collection overlap for all surveys. Because the area was not redefined for each survey, only the volume calculation was considered. Volume change calculations and conversion from meters to yards were completed using Excel and are provided in **TABLE 2**. A plot was produced illustrating the results and included in **FIGURE 17**.

TABLE 2

VOLUME CHANGE *(entire project area)*

Survey Date	***Volume (m^3)***	***Volume (yd^3)***
12/8/11(Pre fill)	Reference	Reference
5/4/12 (Post Fill)	16,385	21,431
8/8/12 (Post Fill)	-5112	-6686
12/14/12 (Post Fill)	2704	3537
4/17/2013 (Post Fill)	-4433	-5798

FIGURE 17 *Total on and offshore volume for each respective survey. Note the trend of erosion through the summer months ending with the onset of winter months.*



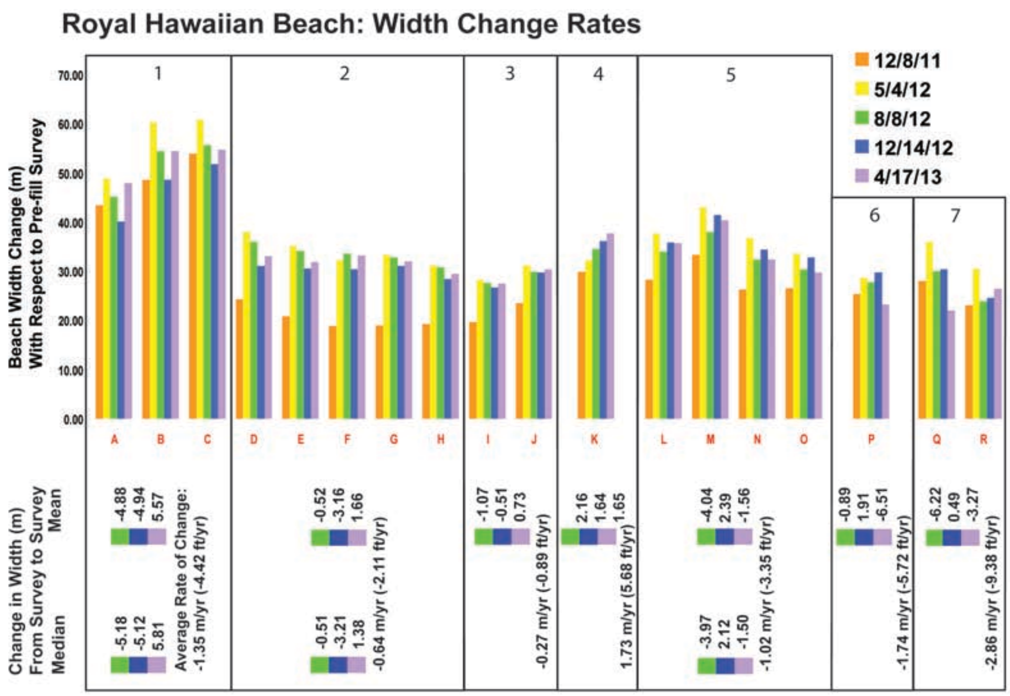
Beach Width Change Data

Beach widths were determined by calculating the distance between landward and seaward boundaries of the beach. A reference point was chosen for each transect that best identified the landward extent of the beach. The top of the toe was chosen as the front reference point due to the ease in identifying the feature as well as the consistency practiced by the swimmer when recording the location of the feature along every line. Beach width, then, is defined as distance from top of toe to back beach boundary.

Beach width change was calculated by subtracting post-fill transect width values from pre-fill transect width values. The data was compiled for each survey date and separated into bins that serve as estimates of self-similar behavior among groups of (or single) transects.

Mean and Median values of width change were calculated for all bins; mean and median values have been normalized with respect to time span between survey dates to express erosion/accretion rates in units of meters per year. A plot of width and rate data is included in **FIGURE 18**.

FIGURE 18 *History of beach width changes since project origin. Top – Beach width change and possible clustering (bins) of profile sites exhibiting self-similar change. Middle – Rate of beach width change (m/yr) from survey to survey; average 1 yr change also calculated. Bin 1 has a 1-year rate of change of -1.35 m/yr; bin 2, -0.64 m/yr; bin 3, -0.27 m/yr; bin 4, +1.73 m/yr; bin 5, -1.02 m/yr; bin 6, -1.74 m/yr; bin 7, -2.86 m/yr.*



Plotted data signifies width change for each post-fill survey with respect to the pre-fill survey. This plotting method was chosen in order to illustrate total width addition resulting from the replinishment project. Alternately, rate change data was calculated using width change between surveys in order to form a time series representation of erosional and accretional trends.
Bins are estimates of self similar behavior among groups of transects (open to interpretation)

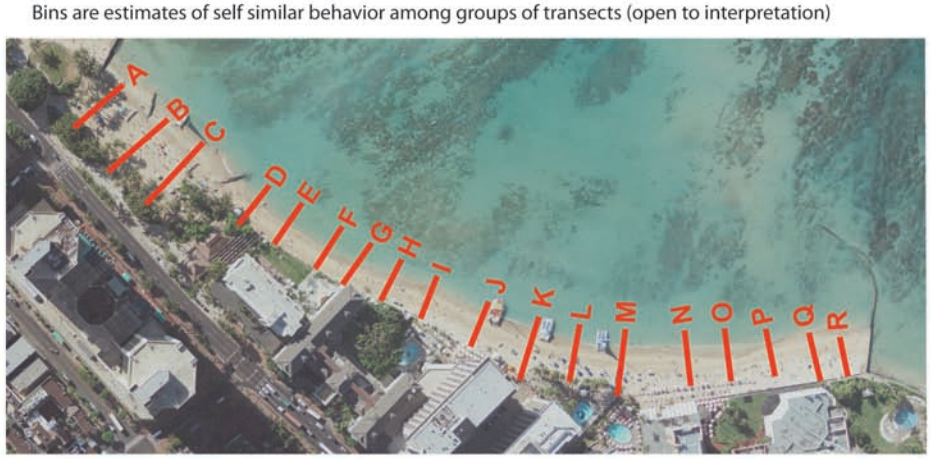
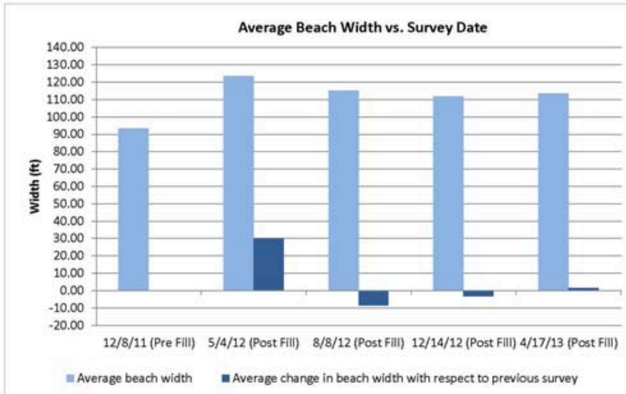


FIGURE 19 shows the history of beach width change over the course of the project. After one year, the beach is an average 20 ft wider (approximately 110 ft) than the prefill beach (approximately 90 ft).

FIGURE 19 *history of average beach width, and change from one survey to the next, over the course of the project.*



Results

5/4/12 survey Directly following replenishment (5/4/12 survey), total beach volume increased by 23,308 yds^3. Beach width increased by an average of 30.0 ft. All transects experienced increases in beach width; lines D-H experienced the highest width increases ranging from 39-46 ft. Moderate erosion took place directly offshore of the eastern most transect, likely as a result of groin removal. Elevation of the beach at that location was reduced by roughly 3 ft with respect to the pre-fill survey, perhaps due to reworking of sand during placement. Beach elevation remained roughly constant thereafter.

8/8/12 survey Three months following replenishment (8/8/12 survey), beach volume decreased by 4942 yds^3 with respect to the previous survey. Average beach widths decreased by an average of 8.5 ft. The strongest erosion was experienced on the western-most and eastern-most transects. Erosion experienced on the western-most transects likely resulted from sand loss through the relict Apuakehau stream channel while erosion experienced on the eastern most transects likely resulted from groin removal and flanking adjacent to Kuhio Beach groin.

12/14/12 survey Approximately 7 months following replenishment (12/14/12 survey), beach volume remained stable with respect to the 8/8/12 survey, gaining 23 yds^3. Average beach width decreased by 3.2 ft. The beach decreased in width along the eastern half and increased in width along the western half, likely as a result of the predominating NW current responsible for sand transport. Strongest erosion was on eastern-most transects. Accretion along the western half of the beach was strongest at transects L-P.

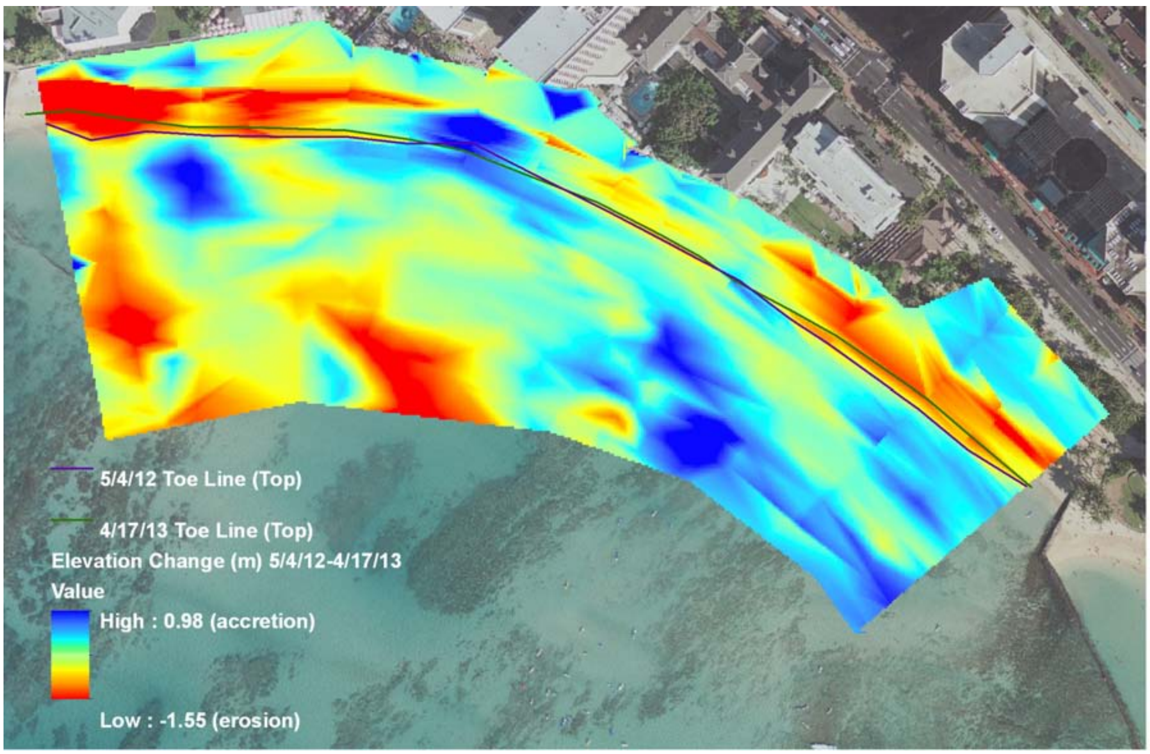
4/17/13 survey Approximately 11 months following replenishment (4/17/13 survey), beach width remained stable, slightly increasing by 1.6 ft. Volume decreased -1351 yd^3 with respect to the 12/14/12 survey. The beach increased in width along the eastern half, and decreased in width along the western half, likely resulting from seasonal current variations that switch from predominantly NW to SE in conjunction with swell conditions. The strongest accretion took place on the eastern-most transects, likely resulting from sand capture along the Ewa cribwall. The strongest erosion took place at the western-most transects.

5/4/12 to 4/17/13 - Year 1 The change in elevation across the time period 5/4/12 to 4/17/13, year 1 of the project, is shown in **FIGURE 20**. The map reveals erosion to the subaerial beach as the berm crest has retreated in conjunction with wave energy. The western and eastern ends of the project have experienced the greatest berm retreat, recorded in FIGURE 20 as loss of elevation in the seaward portion of the beach. There is accretion at Transect K. Both the loss and gain described above are evident in the location of beach toes as plotted on the map. This retreat of the berm crest is expected as the fill adjusts from its construction (oversteepened) geometry to its equilibrium profile condition.

The eastern offshore portion of FIGURE 20 reveals net shallowing immediately seaward of the beach toe. This accumulation may be sand lost from the subaerial beach as a result of berm retreat and subaerial beach erosion at that location. It may also be related to net alongshore transport in the Diamond Head direction in conjunction with short period high-energy kona waves that direct transport to the east. There is also net shallowing further offshore of the eastern region, the source of this shallowing is unknown as this is a highly dynamic and variable region as seen in FIGURES 11-14.

There is also shallowing offshore of the western end of the project in the form of a "salient" that has developed from westward transport along the shoreline. This salient is clearly evident in late May 2013 photographs of the beach acquired by the PacIOOS digital camera (see FIGURE 6) and is known to develop under conditions of strong western transport associated with typical summer swell events.

FIGURE 20 *Net change in elevation after year 1 of the project.*



Findings – Year 1

- Survey data confirm the placement of approximately 24,000 yds^3 of fill on the Royal Hawaiian Beach.
- During year 1 there has been a net volume loss of -6270 yds^3 or 27% from the beach (as measured from the back-beach to 20 m offshore of the toe).
- Berm retreat, typically under conditions of summer swell, produced net erosion in the eastern and western portions of the project.
- After 1 year, the beach is an average of 20 ft wider than the pre-fill condition.
- Filled beach width has decreased an average 2.88 ft over year 1.
- Depending on location, the change in filled beach width over year 1 varies from +5.68 ft (transect K) to -9.38 ft (transects Q and R).
- Offshore changes in sea floor elevation are dominated by high variability and/or uncertainties related to misalignment of profiles.
- Net accretion offshore of the western portion of the project is consistent with net westward transport under summer swell conditions.

Section 2: Engineering History of Royal Hawaiian Beach

Overview of Waikiki Beach

The purpose of this report is to outline the history of the Royal Hawaiian Beach. This section of beach is located in the central coastal region of Waikiki, on the island of Oahu, Hawaii. Royal Hawaiian Beach extends 1,660 ft. (~510 m) in a crescent shape from the Royal Hawaiian groin to the Ewa Crib Wall on Kuhio Beach.

Royal Hawaiian Beach (as of 2013) fronts the properties of the Royal Hawaiian Beach Hotel, Outrigger Hotel, and the Moana-Surfrider. Hotels located along Royal Hawaiian Beach are distinguished hotels with high occupancy rates that help to support the tourist-based economy of Waikiki.

The beach and reef along this stretch are used for a range of recreational activities both on and offshore. Recreational activities that take place along this section of beach include swimming, snorkeling, surfing, sunbathing, canoeing, and other ocean-oriented activities. Throughout the year this area sustains high occupancy and both tourists and residents heavily use the beach.

The coastal region of Waikiki has long been advertised as the home of wide sandy beaches. Ironically, Waikiki's shoreline is incapable of holding large amounts of sand in its natural state. Originally, Waikiki Beach was a barrier beach in which a thin ribbon of carbonate sand extended along the entire shoreline. Wetland and lagoon features dominated the area landward of the coastline prior to extensive engineering projects undertaken during the first half of the 20th century. Sand mining on Kuhio beach, located directly to the east of Royal Hawaiian Beach, initiated a long battle with erosion in Waikiki by decreasing the sand budget.

Engineering projects were initially encouraged due to an increased demand for wide beaches and sandy swimming areas by a flourishing visitor industry. To facilitate these requests sand mining was halted along Waikiki beach and coral dredging projects began along nearshore areas.

Coral dredging along shorelines was undertaken with the goal of producing a sandy floor for the comfort of beach bathers (Moberly, 1963). An unexpected effect of coral dredging was the alteration of currents and sediment transport in nearshore areas that exacerbated beach erosion.

Subsequent engineering projects focused on reducing erosion and included groin construction, sea wall construction, and sand replenishment. Engineering has been extensive along the entire south shore of Oahu, to the point that a natural shoreline no longer exists between Honolulu Harbor and Diamondhead (Sea Engineering, 2010). Overall, Waikiki is a naturally narrow beach that has been significantly altered by more than a century of engineering and sediment management efforts.

Engineering projects have altered natural processes to the extent that 7 individual sections of beach (littoral cells) within the Waikiki area operate essentially independent of one another. From the east to the west, these sections are known as: 1) Kaimana Beach, 2) Queens Beach, 3) Kapiolani Beach, 4) Kuhio Beach, 5) Royal Hawaiian Beach, 6) Halekulani Beach, 7) Ft. DeRussy Beach. Each cell is in an active state of flux, eroding in some areas while accreting in others with an overall trend of net loss (Miller and Fletcher, 2003). These trends can be altered during periods of extreme water movement caused by tides, seasonal swells, and currents.

In Waikiki's current state, regular replenishment is necessary in order to sustain high sand volumes. Without periodic maintenance, the beaches in the Waikiki area would likely narrow and essentially disappear over time as a result of chronic beach loss.

In the past, large volumes of sand were brought in from other land-based locations on Oahu and Molokai for beach nourishment, and for beach construction, where sand is placed on top of a base made of crushed coral rock dredged from the nearshore (Wiegel, 2002). Sand sources may have also included sand dunes in Manhattan Beach California; however, documentation regarding this sand source is scarce.

Recent sand replenishment projects have shifted strategy from off-site sand sources to offshore sand sources. This strategy reduces some associated environmental effects including the introduction of foreign species, and potential impacts to surfing characteristics due to excess sand. Two projects of this type have taken place on Kuhio beach, located east of the Royal Hawaiian Beach. The most recent replenishment project in 2012 was the first replenishment project of its kind to take place on Royal Hawaiian Beach.

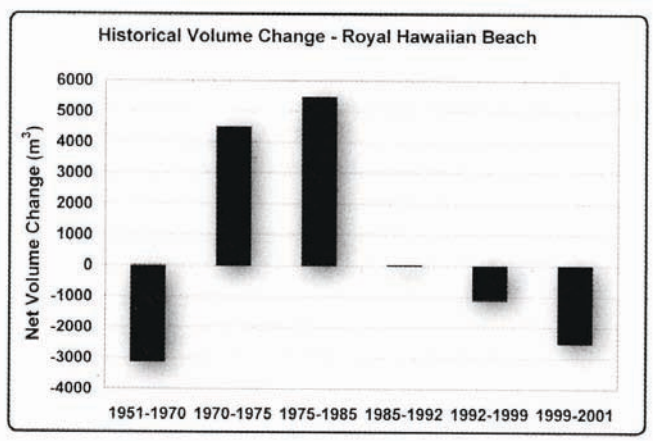
Sustaining high sand volumes on Waikiki's beaches remains a priority for the State of Hawaii. Hawaii's economy continues to rely heavily on a strong visitor industry. Negative impacts to the economy would likely occur if beaches were not regularly replenished and property damage caused by high storm and wave energy would occur (Sea Engineering, 2010).

Overview of Royal Hawaiian Beach

Historically, the shoreline at Royal Hawaiian Beach has shifted seaward since the onset of heavy engineering in Waikiki. In the late 1800's, Royal Hawaiian Beach was likely the widest beach in Waikiki and may have originally had a subaerial width of over 100 ft (Crane, 1972).

Kuhio Beach, located east of Royal Hawaiian Beach, has been the site of numerous sand replenishment projects. Net transport to the west was effective in transporting sand lost from Kuhio Beach onto Royal Hawaiian Beach until improvement of the "crib walls" and terminal groins in 1972. Increases in sand volume at Royal Hawaiian Beach are illustrated in **FIGURE 21**.

FIGURE 21 *Sand volume changes for historical time intervals (Miller and Fletcher, 2003)*



The construction of the Royal Hawaiian groin, forming the western boundary of the Royal Hawaiian Beach, has also been effective in increasing sand volumes by preventing sand from escaping to the Halekulani cell.

Two streams once flowed into the ocean at Waikiki; Apuakehau Stream and Ku'ekaunahi Stream. However, the input of fluvial sediment (a minor component of the beach sand) by river transport ceased with the construction of the Ala Wai Canal. This project was part of the Wetland Reclamation and Mosquito Control Project that began in 1921.

The mouth of Apuakehau Stream met the ocean where the Royal Hawaiian Hotel is currently located, on the "Ewa" side of the Moana Surfrider Hotel. Apuakehau Stream did not always flow to the ocean during times when it was dammed by a sand berm, forming a lagoon (a "huli wai"). At other times after rainstorms, floodwaters carried debris into the ocean. The streams flowed across the beach into the reef and transported large loads of eroded sediment and debris by runoff.

Ku'ekaunahi Stream flowed along what is currently Kapahulu Avenue and emptied into the ocean at Kuhio beach at the intersection of what are currently Kalakaua and Ohua Avenues. Because littoral currents generated by southerly swell, typically the strongest surf conditions of the year, flow toward the Royal Hawaiian groin, it is assumed that sediment discharged from both streams was transported along Royal Hawaiian Beach.

On the seafloor, the paleo-channel of Apuakehau Stream, located offshore of Royal Hawaiian Beach, constitutes a low-lying bathymetry that may provide a conduit for offshore sand loss. During heavy surf, the channel becomes the site of offshore-directed currents capable of transporting quantities of sand away from the beach.

According to Miller and Fletcher (2003), the Royal Hawaiian littoral cell accounts for 93% of the sediment loss in Waikiki partially resulting from sediment transport by strong currents through the channel; net volume loss of 5,200 m^3 was found in a study period between October 2000 and May 2002 (Miller and Fletcher, 2003).

Royal-Hawaiian Beach processes are further complicated by movement of water and sediment through channels that have been dredged in the reef during the early 20th century.

Beach accretion from 1925 until about 1975 was likely a product of the northwest transport of replenished sand from Kuhio beach and other littoral cells. Structural improvements to the crib walls took place in 1972 with the intention to reduce the escape of sand (Miller and Fletcher, 2003). It follows that beach loss on Royal Hawaiian Beach thereafter resulted from improvements to the structure of the crib walls.

The shoreline on Royal Hawaiian Beach has migrated 12 m seaward due to anthropogenic development, replenishment and reclamation from 1925 (Miller and Fletcher, 2003). Since 1985 the Royal Hawaiian Beach has been chronically eroding at a rate of 1.5 feet/year (Sea Engineering, 2010). Prior to the most recent replenishment along Royal Hawaiian Beach, wave run up during higher tides would almost completely submerge the beach.

Because of complaints that past sand nourishment impacted surf characteristics at Waikiki, the State has chosen to relocate sand from offshore sand fields rather than import sand from outside the general Waikiki littoral cell.

During the first half of 2012, a nourishment project took place on Royal Hawaiian Beach with the goal of nourishing 24,000 yds^3 of sand. The average beach width was expected to increase by 37 ft, restoring the approximate 1985 position of the beach (Sea Engineering, 2010).

Hardened Shorelines

Hard structures, including sea walls and groins, have been installed along nearly the entire length of Waikiki beach since the 1880’s (Crane, 1972). The purpose of sea wall construction has been to protect shoreline property, while the purpose of groin construction has been to capture and retain sand.

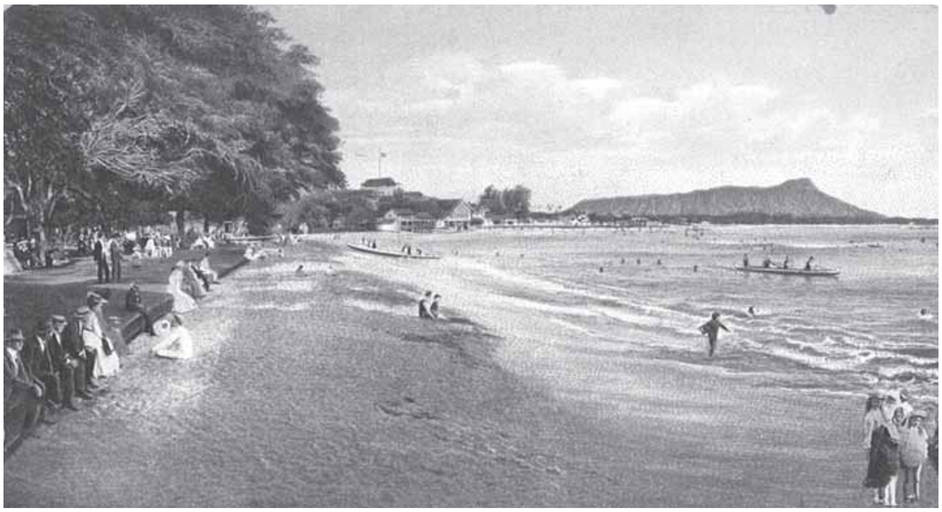
Installation of hard structures in the Royal Hawaiian Beach area began in 1890 with the construction of the Kuhio Seawall, located directly to the east on Kuhio Beach. The hardening of the shoreline resulted in substantial beach erosion during the early 1900’s, spurring a succession of nourishment projects on Kuhio Beach over the remaining century.

The relationship between hardening and erosion is complex. Hardening usually only arises because of existing erosion due to some deficit in the sand volume needed to maintain beach stability. However, in the face of erosion, hardening often leads to flanking (erosion of adjacent beaches or land) as well as wave reflection and scour, placement loss of beach under a seawall, and lack of sand input from a littoral dune. Thus, hardening can accelerate erosion; start erosion on adjacent beaches that had not been eroding; and produce a domino effect of proliferating erosion along a shoreline, ultimately affecting an entire littoral cell.

Kuhio Beach was heavily eroded in response to shoreline hardening in addition to extensive sand mining taking place at that time (Weigel, 2002). In a 1910 edition of the Pacific Commercial Advertiser, The state of Kuhio beach was reported as being in “deplorable condition” resulting from the “heavy removal of sand from Waikiki beaches”.

In 1905, Hawai'i's Supreme Court responded to the degradation of Waikiki Beaches by establishing the public trust doctrine. This piece of legislation aimed to prohibit the construction of seawalls seaward of the high water mark on Waikiki Beaches (Weigel, 2002). One year following application of the public trust doctrine, a low seawall was constructed fronting the Seaside Hotel, indicating a lack of implementation of regulations established by the doctrine (**FIGURE 22**).

FIGURE 22 *Postcard photo of beach fronting Seaside Hotel; present location of the Royal Hawaiian hotel circa 1910 (Anon. 1910, within Weigel, 2008).*



Beginning around 1915, sea wall construction along Waikiki Beach spiked. The seawalls were constructed for various reasons; the demarcation of the seaward boundary of land, the protection of development, and for leveling purposes.

In 1917, in an effort to halt the sprawl of shoreline hardening, the Board of Harbor Commissioners of the Territory of Hawaii prohibited the construction of seawalls along the shoreline (Miller and Fletcher, 2003); however by the early 1920s, it was reported that nearly all of Waikiki Beach had been hardened by seawalls (U.S. Army Corps of Engineers 1992; within Miller and Fletcher 2003).

By the mid 1920's much of Waikiki Beach had been eroded, resulting mainly from shoreline hardening. Only isolated stretches of sand remained on the beach fronting the Moana Hotel and the current site of the Royal Hawaiian Hotel. This section of beach was one of the few areas within Waikiki that had not been hardened in close proximity to the shoreline. In 1902, a 230 ft seawall had been constructed fronting the Moana Hotel; however the seawall did not initiate coastal erosion due to the increased proximity to the shoreline in comparison to other seawalls installed in Waikiki during this time (Weigel, 2008).

In recognition of the deteriorated state of Waikiki Beach, a report was made by the Engineering Association of Hawai'i, Committee on Waikiki Beach Improvements in 1927, commissioned by the Board of Harbor Commissioners, Territory of Hawai'i. Within the report, it was proposed that eroded beach in Waikiki be rehabilitated by sand replenishment. The report also proposed the dredging of coral along shorelines with the intent to improve the quality of the beach for public use. The report served as the impetus for the 1928 Waikiki Beach Reclamation Agreement, which initiated major engineering and nourishment projects along Waikiki Beach.

The 1928 property owner's-Territorial Government's Waikiki Beach Reclamation Agreement was passed thereafter with the intent of limiting seaward development along Waikiki Beach. As part of the agreement it was stated that the beach would be widened seaward of the existing high water mark and that a title of land ownership would be granted to the abutting landowner. Land was granted with the understanding that the landowner would refrain from building new structures on the beach and allow 75 ft of public beach access measured from the mean high water mark of the newly replenished beach (Sea Engineering, 2010).

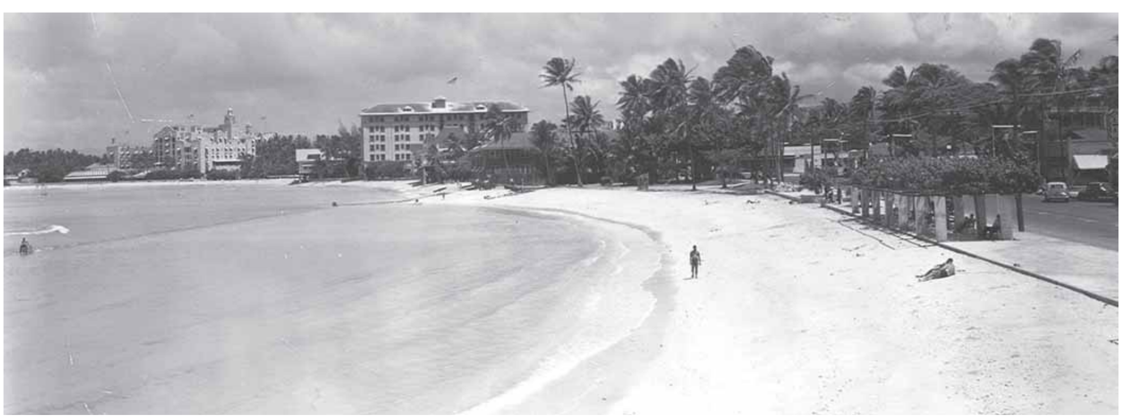
As part of the 1928 Beach Agreement, eleven groins composed of hollow tongue and concrete blocks were built along Waikiki Beach with the intent of capturing sand (Weigel, 2002). The Royal Hawaiian groin, a 170 ft long groin located at the western end of Royal Hawaiian Beach, proved to be the only groin that effectively captured sand. The groin was lengthened to 369 ft in 1930 and later heightened (Weigel, 2002; Miller and Fletcher, 2003).

During the following decade, deficient funds prompted by the Great Depression resulted in a lack of construction during the majority of the 1930's (Crane, 1972). Beach improvement projects during this decade mainly entailed the removal of deteriorated structures from beaches. In 1937, construction was spurred once more resulting from a large south swell that damaged seawalls and prompted major structural improvements.

In response to coastal damages, a 700 foot long shore-parallel breakwater was constructed 200 ft offshore of Kuhio beach in 1938, known as the crib wall (Gerritsen, 1978; within Miller and Fletcher 2003). This initial portion of the crib wall forms what is now known as the Ewa Basin. As part of the construction, the nearshore area was cleared of approximately 4000 yds^3 of coral and replaced by 7,000 yds^3 of sand, forming a 75 ft wide beach (Crane, 1972; Gerritsen, 1978; within Miller and Fletcher, 2003). Images of Kuhio beach prior to and following construction of the Crib wall are shown in **FIGURE 23**.

FIGURE 23 *(a.) Photo taken May 20, 1939 prior to construction of the Kuhio Beach cribwall breakwater and replenishment. (b.) Photo taken in 1939 following construction of the crib wall breakwater and sand fill (USACE Beach Erosion Board within Weigel, 2008).*


a)


b)

By the 1940's the state of Waikiki beach was severely degraded; the only remaining usable section of beach was that fronting the Moana Surfrider and the Royal Hawaiian Hotel. An oblique photo of the Royal Hawaiian Beach and adjacent beaches illustrates the degraded state of Waikiki beaches at that time (**FIGURE 24**). The Royal

Hawaiian Beach had gained sand since the 1920's due to the Royal Hawaiian groin's successful capture of replenished beach sand that had eroded from Kuhio Beach (Crane, 1972).

FIGURE 24 *Oblique image of the Royal Hawaiian Beach and adjacent beaches on April 3, 1933. Very little sand fronts beaches on either side of Royal Hawaiian Beach, likely as a result of near-shore seawall construction during the 1920's.*

In an attempt to slow the loss of replenished sand from the crib wall, a sandbag groin was constructed at the western end of Kuhio beach in 1948 (Weigel, 2002). The sandbag groin was found to be successful at blocking sand movement, and prompted by its success the groin was extended in 1963.

The early 1950's saw the introduction of public air transportation to Hawaii. The resulting increase in tourism provoked increased demand for beach improvements over the following decades. A beach erosion study completed in 1951, commissioned by the Board of Harbor Commissioners of the Territory of Hawai'i, recommended improvements to the shoreline at Waikiki Beach that initiated a series of restoration and construction projects (Miller and Fletcher, 2003).

From 1951-1957, a succession of restoration projects were undertaken including beach nourishment and the installation of the Kapahulu storm drain; a structure that was extended from a preexisting fortification to a length of 355 ft, a width of 19 ft, and a height of +8.5 ft above MLLW (Weigel, 2002).

In 1952, a 730 foot breakwater was built onto the southeast end of the crib wall with an elevation of +3 ft at MLLW, producing the Diamond Head Breakwater (Hawaii State DLNR in Honolulu Advertiser, 2007). As part of the construction, 12,000 yd^3 (9,174 m^3) of coral was dredged and replaced by 4,500 yd^3 (3440 m^3) of sand

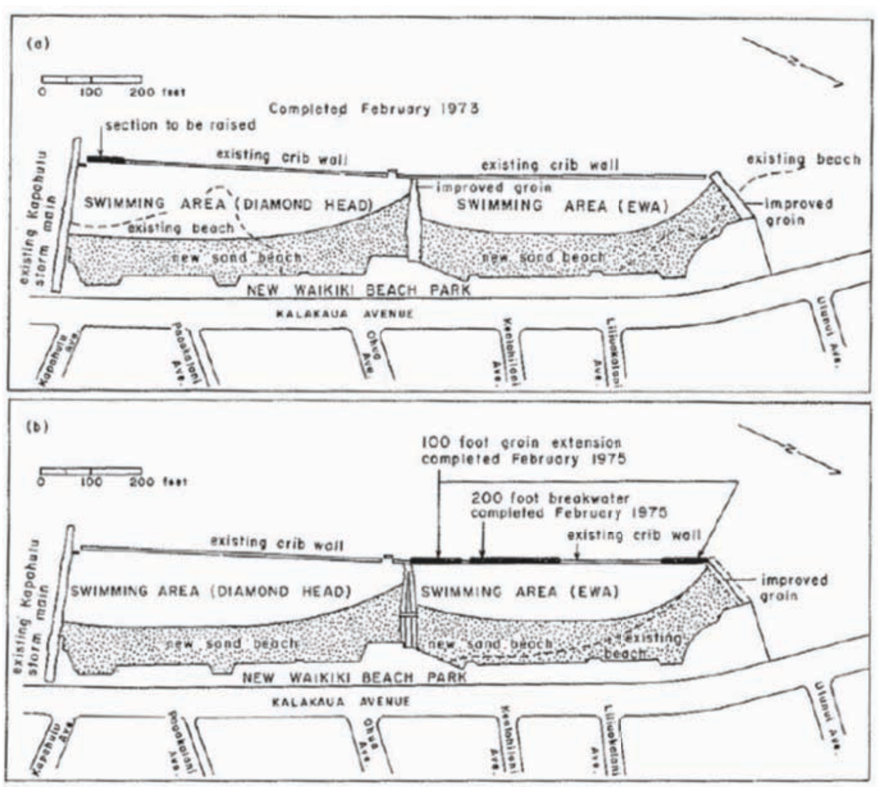
(Miller and Fletcher, 2003 cited Department of Public Works permit application to the Board of Harbor Commissioners, Territory of Hawaii).

In 1959, following construction of the Diamond Head Breakwater and associated sand replenishment, two groins were installed with the purpose of capturing NW drifting sand. The groins were constructed of bagged concrete and were only slightly successful at capturing sand (Crane, 1972).

The sand deposited inside the crib wall on Kuhio Beach tended to migrate to the northwest; driven by the prevailing current. The drifting sand was deposited on the Royal Hawaiian Beach as well as to areas offshore (Miller and Fletcher, 2003).

In an effort to enhance the sand retaining capacity of the crib wall, several improvements were made during the 1970's. In 1972, improvements were made to the central and terminal groin of the Ewa basin, in addition to the replacement of sandbag groins with rubble mound groins. In 1975, segments of the Ewa breakwater were extended to a height of approximately 3 ft. The fortifications made to the crib walls slowed the major drift of replenished Kuhio Beach sand to the Royal Hawaiian Beach, likely affecting the width of the Royal Hawaiian Beach thereafter. Improvement plans for Kuhio Beach area are shown in **FIGURE 25**.

FIGURE 25 *Kuhio Beach improvement diagram. a) 1972-1973 project b) 1975 project.*



Additional improvements to Kuhio beach included the removal of the highway retaining seawall along Kalakaua Ave., the removal of the Waikiki Beach Center (in the current vicinity of the Duke Kahanamoku statue), and the construction of a beach walk extending from Queens Beach to Kuhio Beach (Crane, 1972).

Following beach improvements in the 1970's, no further construction or removal was accomplished on Royal Hawaiian Beach or the adjacent Kuhio Beach until the 21st century "Waikiki Revitalization Project" under Honolulu Mayor Jeremy Harris (1994-2004). A network of artificial waterfalls, ponds, and a hula mound was built on the Kuhio beach shoreline. Following this, a sand replenishment project at Kuhio Beach installed approximately 10,000 yd^3 of sand in the combined basins. In 2011, as part of the Royal Hawaiian Beach nourishment project in 2011 and 2012, two sandbag groins were removed from the eastern most section of Royal Hawaiian Beach as they were considered hazardous to the public.

Dredging

Offshore dredging in Waikiki was undertaken during the early 1900's to produce channels and basins. These dredged features served various functions including navigation and harbor production.

Approximately one half of Waikiki's shoreline from the Kewalo Basin to the Elks Club is fronted by areas that have been dredged (Weigel, 2002). The closest site of dredging to Royal Hawaiian Beach fronts Halekulani Beach and Ft DeRussy, located directly to the west of Royal Hawaiian Beach. Dredging in this area took place from 1908 and 1911. For military purposes, reef was blasted away to form a temporary shipping channel, now known as the Halekulani Sand Channel. Dredged material was briefly deposited on nearby sand and coral, and removed shortly after to be used as wetland fill (Weigel, 2008).

Nearshore dredging was also popularized in the early 1900's as indicated in a 1910 article featured in the Pacific Commercial Advertiser. The article discusses statements made by the Superintendent of Public Works as follows: "…as far as the removal of coral is concerned, he believed funds would be forthcoming to prosecute the work. …He believed that the matter was of such public interest that the public would backup any effort to free the bathing places from coral." (Pacific Commercial Advertiser, 1910). Nearshore dredging of Royal Hawaiian Beach and adjacent beaches is largely undocumented; however, in a 1963 review of Hawaii's shorelines, it was reported that reef fronting the "hotels and Kuhio Beach" had been cleared of coral for the convenience of swimmers (Moberly, 1963).

Dredged features, both near and offshore, influenced natural processes such as waves, currents, sand transport and distribution. It had been reported by residents in Waikiki following major dredging projects, that the beach at Waikiki had changed significantly and that sand was swept from the beach to areas offshore. Property owners reported losses of 10-30 ft of beach width and in turn were forced to construct seawalls. (Weigel, 2002)

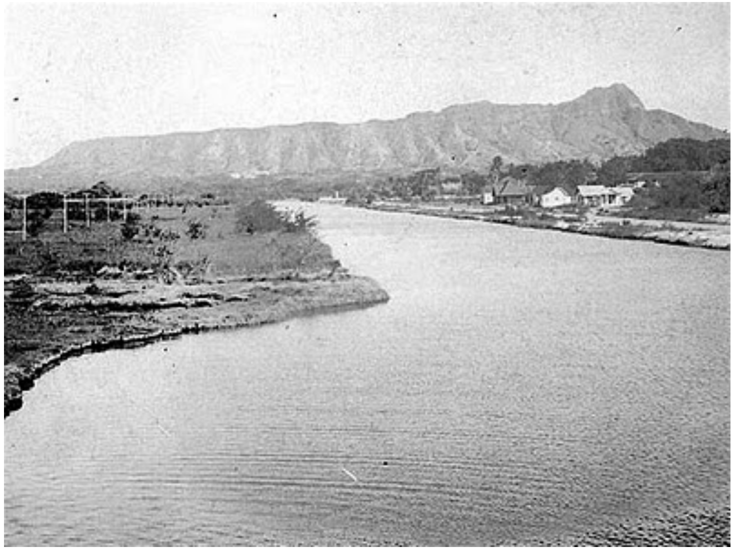
Wetland Reclamation

The transformation of Waikiki from an area dominated by wetlands into an urban community began in 1906 when planning was initiated for the construction of the Ala Wai Canal. At this time, President of the Board of Health of the Territory of Hawaii, Lucius Punkham, endorsed full development of the Waikiki district, stating that the wetland area was "deleterious to public health" (Lum and Cox, 1991; within Miller, 2003). Plans included the drainage of Waikiki's wetlands in addition to the diversion of the Apuakehau and Ku'ekaunahi streams; both of which flowed to the ocean at the shores of Waikiki.

In 1921, plans for the Wetland Reclamation and Mosquito Control Project were finalized and the Hawaiian Dredging Company was contracted to complete the project. Construction of the Ala Wai Canal took place from 1921-1924 and was later widened to obtain additional fill material. Dredging material was used to fill rice paddies, taro patches and fishponds. (Gonzalez, Jr., 1971; Hibbard and Franzen, 1986; Edward K. Noda and Associates Inc. 1992; in Weigel 2008).

In 1924, the Apuakehau and Ku'ekaunahi streams no longer flowed into the ocean at Waikiki (Weigel, 2008). As a product of diversion, sediments normally carried to the ocean were trapped and deposited in the Ala Wai Canal (**FIGURE 26**). It has been estimated that 8,000 – 10,000 yards^3 per year are trapped in the canal as a result of the diversion, which requires ongoing maintenance. Maintenance dredging projects were completed in 1966, 1978 and in 2002. Effects of the project have included the alteration in reef ecology and sediment deposition along parts of Waikiki beach (Grigg, 1995; 1996; Mamala Bay Study Commission April 1996; within Weigel 2008).

FIGURE 26 *Ala Wai Canal looking from the west towards Diamond Head, circa 1925 (Waikiki Time Machine: View of Hawaii From Another Time http://waikikitimemachine.blogspot.com/2010_06_01_archive.html)*



Replenishments

Sand replenishment projects in Waikiki have served two main purposes; to increase beach widths in response to a growing tourist industry, and to maintain Waikiki's significance as a historical site for surfing and swimming. Beaches in Waikiki are naturally narrow and require recurrent sand placement in order to sustain substantial widths.

Nourishment projects undertaken during the last century were accomplished by relocating sand from other Hawaiian beaches for placement on eroded sections of Waikiki beach (Lemmo, 2013). This style of nourishment is no longer employed due to sand shortages and community opposition of the methods employed out of concern that excess sand is impacting surfing conditions (Lemmo, 2013).
Modern sand replenishment projects no longer involve sand mining from other parts of Hawaii; replenished sand is now recycled from offshore Waikiki sand fields and pumped to shore for placement. A list of past nourishment projects is featured below based on various literature reviews (Weigel, 2002; Miller and Fletcher, 2003; Lemmo, 2013). Replenishment projects that have taken place up drift and in close proximity to Royal Hawaiian Beach are covered within this report.

TABLE 3 SAND REPLENISHMENT

YEAR	***LOCATION***	***VOLUME***
1939	Kuhio Beach	7,000 yd^3
1951-1957	Kuhio/Queens/Kapiolani Beach	160,000 yd^3
1959	Kuhio Beach	19,000 yd^3
1972-1973	Kuhio Beach	12,000 yd^3
1975	Kuhio Beach	9,500 yd^3
2000	Kuhio Beach	1,400 yd^3
2007	Kuhio Beach	10,000 yd^3
2012	Royal Hawaiian Beach	24,000 yd^3

List of replenishment projects that have taken place on or up current of Royal Hawaiian Beach since 1939. (Lemmo, 2013 amended Weigel, 2002)

Small replenishment projects began in the late 1920's as part of the 1928 Waikiki Beach Reclamation Agreement, which initiated major engineering and nourishment projects along Waikiki Beach (Sea Engineering, 2010). A temporary sand pumping system was installed in 1929 fronting the Halekulani Hotel. The system consisted of a centrifugal pump and pipeline about 600 ft long. The project was halted soon after due to the inefficiency of the system; however, the deteriorated concrete foundation of the system still remains, its highest sections lying 2 feet above MLLW (Crane, 1972).

In 1938-39, 7,000 yds^3 were placed on Kuhio Beach as part of the construction of the cribwall, shown in figure 2. This project served to reestablish Kuhio Beach following sand mining and dredging projects during the early 20^{th} century that resulted in its severe degradation (Sea Engineering, 2010; in Lemmo, 2013).

Replenishment projects of larger scale were undertaken in the 1950's in response to the spike in tourism that resulted from Statehood and the introduction of public air transportation to Hawaii. A beach erosion study completed in 1951, commissioned by the Board of Harbor Commissioners of the Territory of Hawai'i, recommended improvements to the shoreline at Waikiki Beach and initiated a series of replenishment projects (Miller and Fletcher, 2003).

From 1951 - 1957, a total of 160,000 yd^3 of sand was placed on Waikiki beach as part of the Waikiki Beach Development project; a cooperative restoration project between the State of Hawaii and the Federal government (Gerritsen, 1978; in Miller 2002). Sands used for the replenishment was mined from sand dune at Bellows Air Field located in eastern Oahu (Wiegel, 2002). Sand placed on Kuhio Beach as part of this project eroded heavily, prompting the additional placement of 18,757 $yards^3$ in 1959 (Wiegel, 2002).

In 1973 replenishment took place as part of a Kuhio Beach renovation project. As part of this project, 12,000 yds^3 of sand were placed. Two years following, renovation of the Ewa groin of the Kuhio Beach took place, which included the placement of 9,500 yds^3 of sand (Miller and Fletcher, 2013).

Modern Replenishment Projects

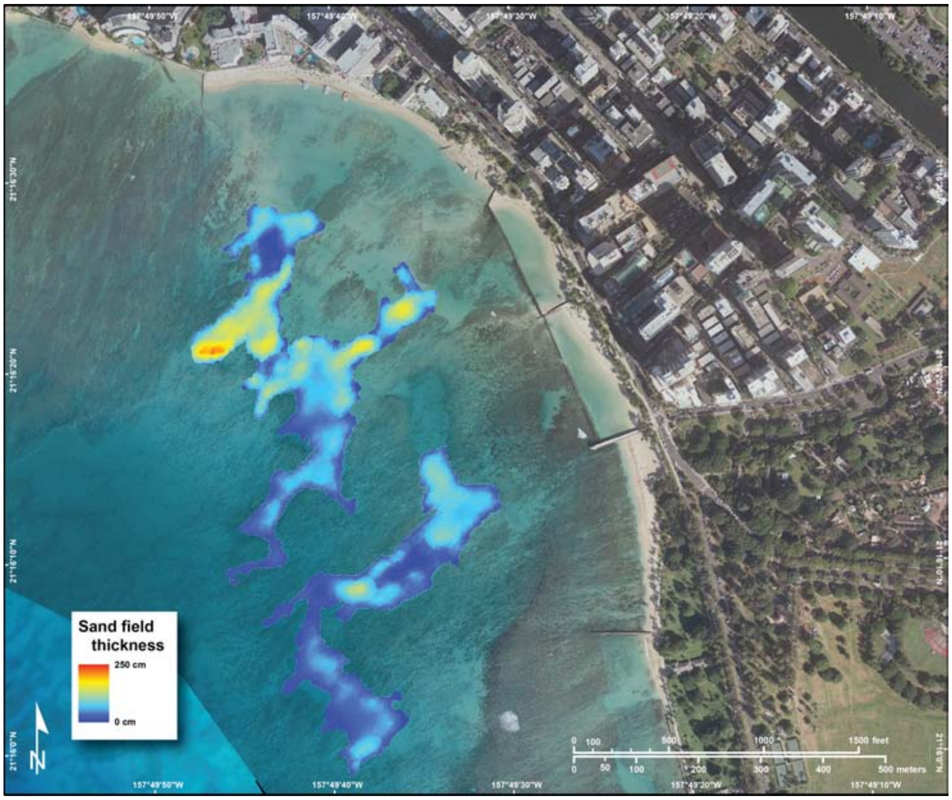
Beach nourishment ceased for nearly 20 years, resuming in 1991 with a nourishment project that increased the area of Kuhio beach by 3,981 ft^2 (Miller and Fletcher, 2003).

In February of 2000, a portion of Kuhio beach was closed for a pilot project with the goal of pumping 5,000 yds^3 from thin sand deposits offshore using a hydraulic dredge and a pipeline. The project did not pump as much sand as expected but demonstrated that the activity did not affect water quality or use of the beaches. (Sea Engineering, 2010) As part of this project, approximately 1,400 $yards^3$ of sand was successfully dredged from the reef flat and deposited at Kuhio Beach.

A larger demonstration project was completed on Kuhio beach in December, 2006. This replenishment project was successful in pumping 8,115yd^3 of sand from offshore using a jet pump to relocate sand into the confines of the "cribwalls". (Sea Engineering, 2010).

In 2009, a sand study was conducted to explore reef-top sand resources located offshore of Waikiki (**FIGURE 27**). As part of the study, sand thicknesses were measured using a jet probe to displace sediment; the depth of penetration of the jet probe determined the thickness. The length of the probe was 3.0 m; few sand fields exceeded this thickness. If thicknesses were exceeded, a measurement of 3.1 meters was recorded.

FIGURE 27 *Results from the 2009 jet probing study. Denoted color gradation indicates thickness of sand at the respective location.*



The most recent replenishment was conducted in 2012 on Royal Hawaiian Beach with the goal of maintaining beach access along the shoreline. The nourishment project was successful in relocating approximately 24,000 yds^3 of sand onto the beach. Replenishment was accomplished by pumping sand from offshore sand fields to the confines of the crib walls. In addition to sand replenishment, two deteriorated sandbag groins once located at the east end of the beach were removed as part of this project.

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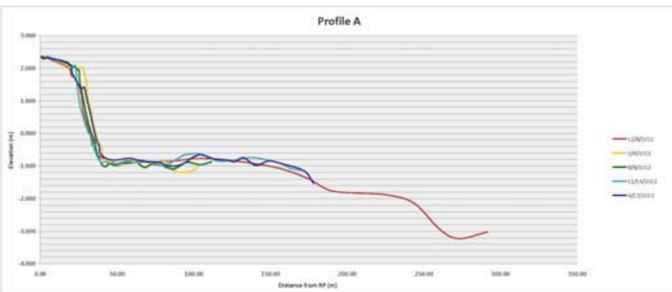
APPENDIX I - Chronology of Royal Hawaiian Beach.

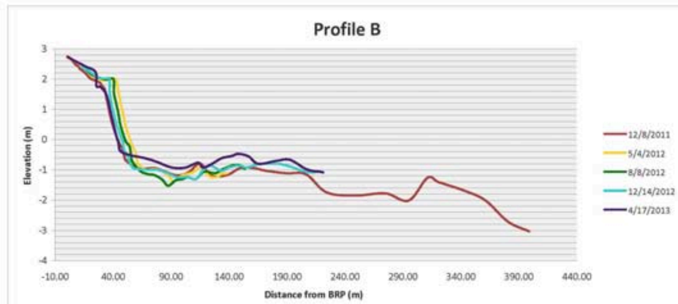
Partially compiled from Robert L. Wiegel, 2002. Other sources noted with each item.

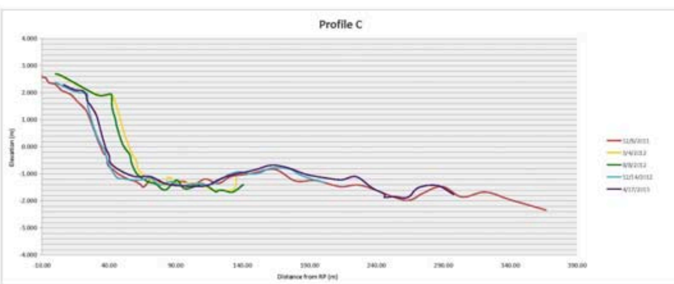
- 1837, 7 November. Tsunami (source, Chile)
- 1866. King Kamehameha V oceanfront house at Waikiki (sic. current location of the Royal Hawaiian Hotel)
- 1868 Tsunami. Reef bared at Waikiki
- 1881. Long Branch Baths built on beach, at the Water's edge. (sic. Close to the current site of the Moana Surfrider Hotel.)
- 1890, circa. Pier built at Queen Liliuokalani's beach property.
- 1890. W.C. Peacock pier built (later called Moana Hotel pier).
- 1900, prior to. 867-foot long highway retaining wall (seawall) built along Waikiki Rd. (renamed Kalakaua Av. In 1905)
- 1901. Moana Hotel opened. Restaurant on piles over beach and water.
- 1901. Seawall, 230 feet long, built at Moana Hotel.
- 1902. Trans-Pacific communications cable brought to shore along Kapua Entrance (channel).
- 1906 Honolulu Seaside Hotel opened; seawall; grounds encroached on beach.
- 1906-1910, sometime between. Concrete wall (groin) built between Moana Hotel and Outrigger Canoe Club on "Diamond Head" side of Apuakehau Stream.
- 1908. Outrigger Canoe Club located at beach front between Seaside and Moana hotels, "Ewa" side of mouth of Apuakehau Stream
- 1908 and later. Coral removed from some near shore sea-bathing areas.
- 1909, circa. Large quantities of sand removed from premises of Queen Liliuokalani, and Fort DeRussy.
- 1909. Channel probably dredged through reef, to get dredge to Fort DeRussy site.
- 1909-1914, and other. Apuakehau Stream flooded on occasions, with large quantities of silt and debris transported to shore. Proposals made to diver the stream.
- 1911-1919, sometime, several years. Cassidy's Point. Barrier built which trapped littoral sand; high water line advanced 300 feet;. seawall built to hold it.
- 1913. 69-ton coast artillery gun brought to Fort DeRussy through reef. Probably entrance channel was increased in depth to do this.
- 1914?,"prior to 1928". Seawall 430 feet long built in front of Gray's Hotel, and a seawall 225 feet long built on "Diamond Head side" of it.
- 1919. Pan Pacific Association Committee's report on Waikiki Beach problems.
- 1921-1924, 1928. Ala Wai Canal, draining, wetland reclamation and mosquito control projects.
- 1924, circa. Streams no longer flow into the ocean at Waikiki
- 1925-1927. Construction of Royal Hawaiian Hotel; new seawall built shoreward of old seawall.
- 1926-1929. Eight groins constructed between Royal Hawaiian Hotel and Fort DeRussy.
- 1927. Groin (170 feet long) built at northwesterly boundary of Royal Hawaiian Hotel property.
- *Late 1920's. (Unconfirmed) Unknown amount of sand brought from Manhattan Beach, California. This project was reported (C. Fletcher, pers. comm.) to have taken place over the span of almost ten years by the City of Manhattan Beach.
- 1927. Experimental groins built of sandbags or wood planks between Royal Hawaiian and Gray's Hotels.
- 1927. Concrete (groin, jetty) between Outrigger Canoe Club and Moana Hotel, removed.
- 1929. Experiment in pumping sand from reef flat through pipeline to shore for beach fill at Halekulani Hotel.
- 1930. Groin at westerly boundary of Royal Hawaiian Hotel rebuilt, and lengthened to 368 feet.
- 1930. Pier at Moana Hotel removed, after being declared unsafe.
- 1934. Queen Liliuokalani's pier removed, after being declared unsafe.
- 1938. Kuhio Beach. Coral patches cleared by dragline excavator shoreward of breakwater.
- 1938. Kuhio Beach. 7,000 cubic yards of sand placed on shore, in conjunction with the new breakwater. Sand brought from other part of Oahu.
- 1939. Kuhio Beach. Sandbag groin built at western end of sand fill.
- 1939. Kuhio Beach Construction of submerged offshore breakwater (-1.0 ft @ mllw). Creation of 210 m beach, forming today's north basin (Miller, 2002 cited Gerritson, 1978) Same as entry above??
- 1937. Severe wave action; beach eroded, seawalls overtopped.

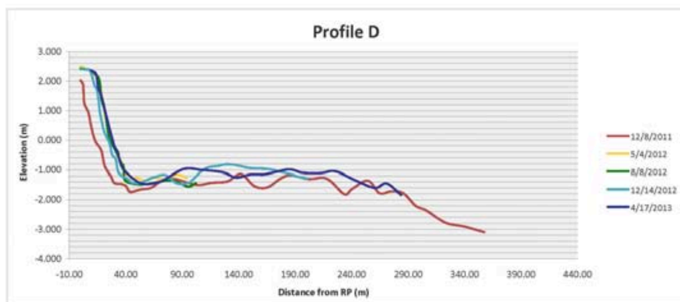
- 1946, 1 April. Tsunami (source, Aleutian Islands) caused reef to be “bared” during wave draw downs; seawalls overtopped during runups.
- *1951- 1970. Royal Hawaiian. Seaward shift of the vegetation line. (Miller, 2002)
- *1951 Kuhio Beach. Kapahulu storm drain installed. Construction of beach for south basin from 38,000 m^3 of sand fill (Miller, 2002) Part of Waikiki Beach Development Project?
- *1952 Installation of T-head groin centered in southern basin. Short-lived structure. (Miller, 2002). Part of Waikiki Beach Development Project
- *1953 Southern breakwater (+3 ft @ mllw) installed. Construction of two groins: one centrally located between basins and a terminal groin in the north basin. Removal of 9,174 m3 of coral by dredging. 3.440 m^3 of sand fill added (Miller, 2002) Part of Waikiki Beach Development Project
- 1951-1957. Waikiki Beach Development Project. A 1965 report to U.S. Congress says 159,000 cubic yards of sand were placed. This must include the 110,000 cubic yards of sand placed in 1951.
- 1952-1953. Kuhio Beach. 730-foot long shore-parallel extension built to the southeast of the ‘crib-wall” breakwater; crest about +3 feet above MLLW. Swimming area dredged inside the seawall. Sand brought from other parts of Oahu and placed on beach(what quantity?)
- 1952, 4 November. Tsunami (source, Kamchatka).
- 1957, 9 March. Tsunami (source, Aleutian Trench).
- 1959. Kuhio Beach. 14,335 m3 of sand fill placed. (Miller, 2002 cites US Army Corps of Engineers, 1992).
- 1959. Hurricane Dot
- 1960, 23 May. Tsunami (source, Chile) caused reef to be “bared” during wave drawdowns; seawalls overtopped during run-ups.
- 1963. Bagged concrete groin at northwest end of Kuhio Beach extended.
- 1968. Kuhio Beach. Sand bag groin at western end of beach extended.
- 1964, 24 March. Tsunami (source, Alaska).
- 1970. Storm drain box culvert extended in length from 150 to 418 feet. At eastern (“Diamond Head”) boundary of Fort DeRussy.
- *1970-1975. Kuhio Beach. Seaward shift of the promenade (Miller, 2002)
- 1972. Fort DeRussy, Rubblemound (stone-face) groin built from beach 160 feet seaward along Fort DeRussy side of the box culvert storm drain. Crest elevation +7 feet above MLLW.
- *1972. Kuhio Beach. Improvements to the central groin and the northern terminal groin. 9174 m^3 sand fill assed. Reconfiguration of the sandy beach (Miller, 2002) Same as entry below?
- 1972. Kuhio Beach and (?) Queen’s Surf Beach sand fill of 82,500 cubic yards (quantity not certain).
- 1972. Highway retaining seawall (Kalakaua Avenue) removed.
- 1975-1985. Royal Hawaiian. Landward shift of the vegetation line with elimination of the Waikiki Beach Center. (Miller, 2002)
- *1975. Kuhio Beach. Segments of the northern breakwater extended to +3 ft. Additional improvement of the northern terminal groin. 7,263 m^3 sand fill added. (Miller 2002)
- 1982. Hurricane Iwa
- *1991. Kuhio Beach. Beach area enlarged by 1,395 yd^2, 1066 m^3 with sand fill (amount of sand unknown?) (Miller, 2002).
- 1992. Hurricane Iniki.
- *2000. Kuhio Beach. 1,066 m^3 of sand dredged from this pocket in reef offshore and pumped through a pipeline to the beach as part of a demonstration project (Weigel, 2002; Miller, 2002).
- *2001. Seaward shift of the promenade and construction of seawalls on former beach. (Miller, 2002)
- *2005. Dredging of 10,000 cubic yards of sand from a thin pocket in the reef flat, and pumping it to shore at Kuhio Beach was planned for October 2005, but postponed owing to delay in obtaining the pumps. Project was further delayed for other reasons (After Action Report: Kuhio Beach Small-Scale Beach Nourishment, 2007).
- *2006, 4 December-5 January 2007. Kuhio Beach Nourishment Project; sand pumping to re-nourish beach and demonstrate the effects of offshore sand retrieved from the reef flat. 8,155 yd^3 of sand dredged and pumped to beach; grading completed.
- *2010, 27 Feb. Tsunami (source, Chili; Media outlet)
- *2011, 12 March. Tsunami (source, Japan; Media outlet)
- *2012, Jan. Sand Replenishment Project (first replenishment project to replenish sand on the Royal Moana Beach; Media outlet).

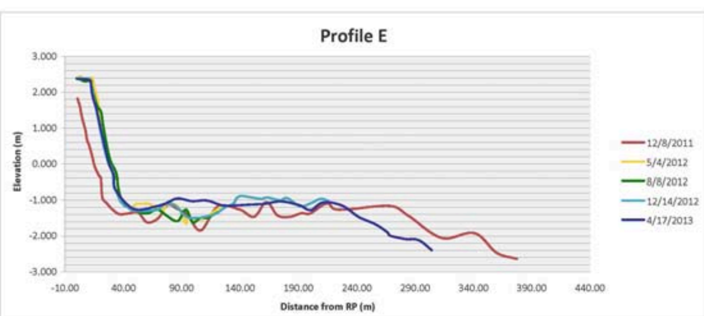
APPENDIX II - Beach Profiles

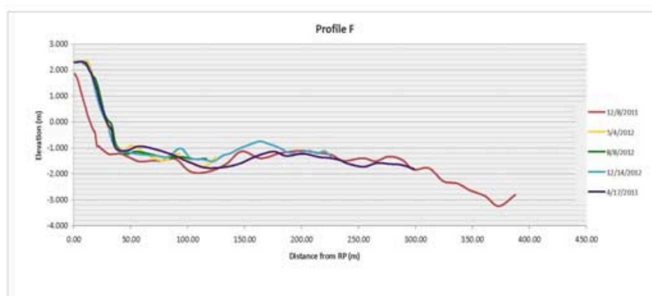


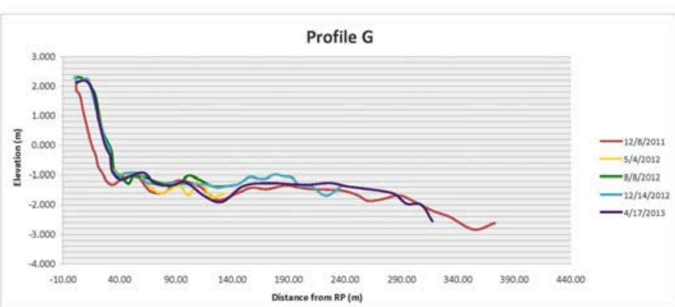


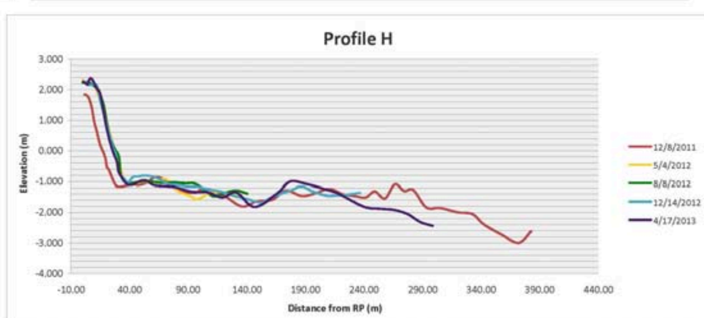


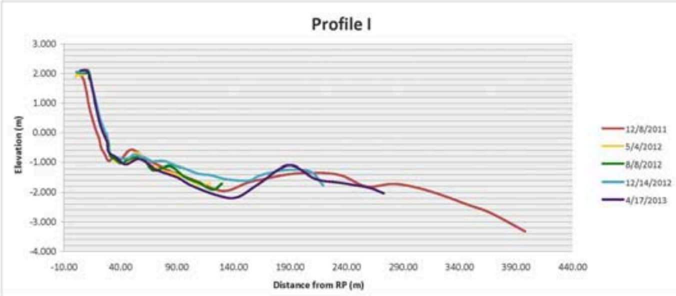








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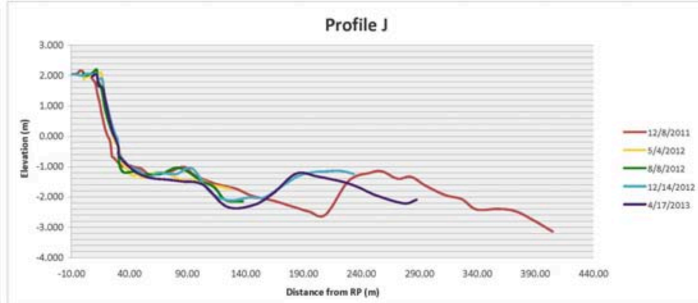
8/8/2012
12/14/2012
4/17/2013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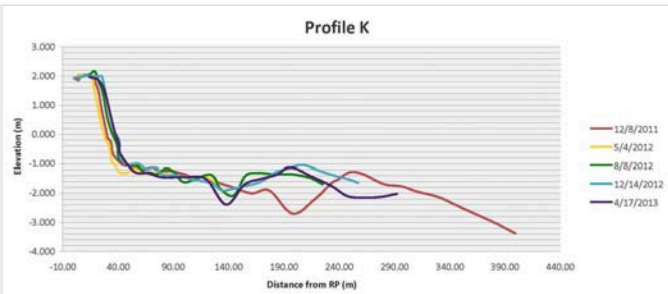
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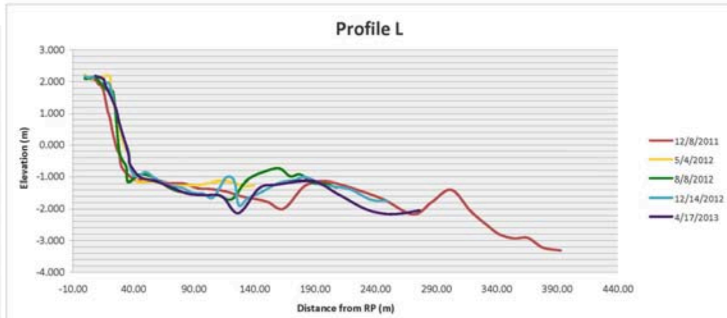
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Distance from RP (m)
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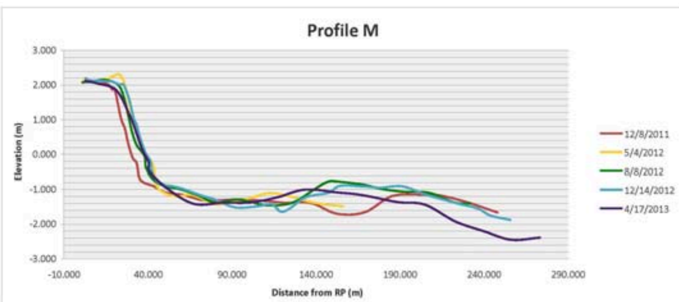
4/17/2013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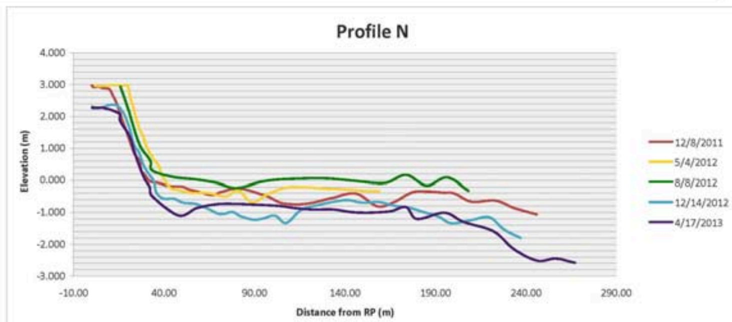
4/17/2013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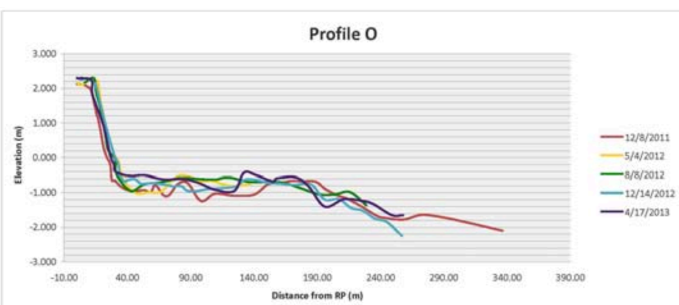
4/17/2013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Elevation (m)
Distance from RP (m)
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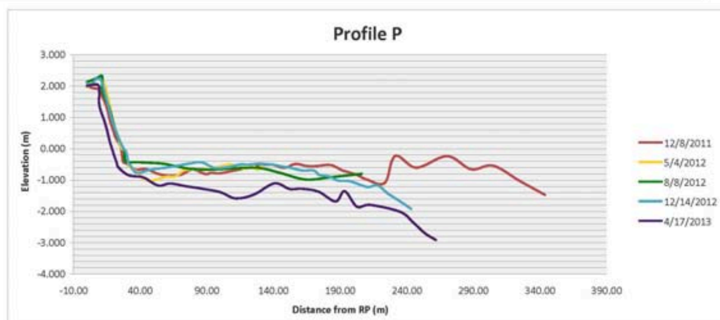
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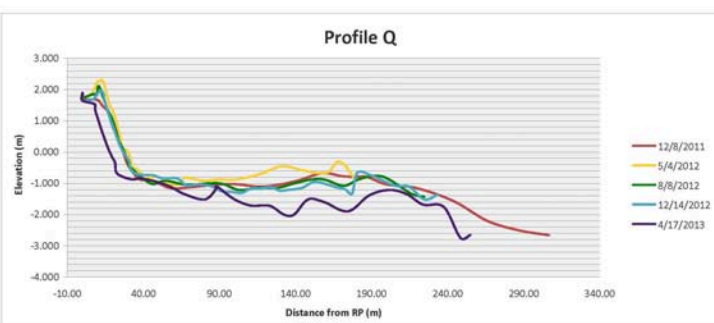
Profile Q
Elevation (m)
Distance from RP (m)
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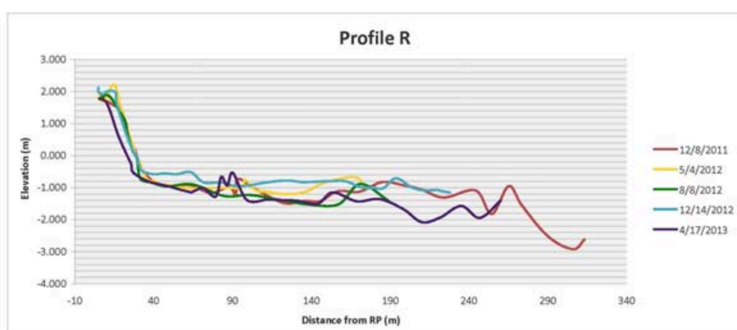
12/14/2012
4/17/2013


Profile R
Elevation (m)
Distance from RP (m)
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8/8/2012
12/14/2012
4/17/2013