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# The influence of seasonal patterns on a beach nourishment project in a complex reef environment

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ABSTRACT

Royal Hawaiian Beach, located in Waikiki, Hawaii received sand nourishment of 17,551 $m^3$ during the spring of 2012. Carbonate sand, dredged from a reef-top sand field 0.6 km offshore, was placed along 520 m of shoreline. Post-nourishment monitoring of the beach and offshore quantifies performance and provides transferable information for future nourishment projects in the study area and in regions with similar fringing reef environments and wave climates. Elevation data were collected along cross-shore profiles prior to sand placement and quarterly thereafter for a period of 2.7 years. The time-sequence of profile data was used to construct digital elevation models (DEMs); a method designed for this study to achieve heightened spatial accuracy relative to two-dimensional profile comparisons that often ignore measurement inconsistency. Various analyses were performed using survey DEMs, including empirical orthogonal function (EOF) analysis and surface comparison. Monitoring data were analyzed in concert with seasonal incident wave conditions to further understand processes that drive beach movement. Overall, the beach lost volume at a rate of 760 ± 450 $m^3$/yr over the entire monitoring period, consistent with the design rate of 1070 $m^3$/yr. Seasonal cycles caused beach volume to fluctuate between 2000 $m^3$ to 4000 $m^3$, i.e., 15% to 30% of total nourishment additions.

In agreement with preceding studies, we confirm predominant westward transport that we describe as counterclockwise rotation. Cross-shore sand transport through an offshore channel is also evident, as we observe the channel acting as both a sediment source and sink depending on seasonal wave conditions: a source during seasonal and storm-related swell events, and a sink otherwise.



## 1. Introduction

Hawaii's beaches are popular destinations, used by residents and visitors to the islands as the principal source of recreation. Unfortunately, 70% of Hawaii's beaches are chronically eroding due to both natural and anthropogenic causes (Fletcher et al., 2012; Romine et al., 2013). The Waikiki region, in particular, is host to Hawaii's premier resort hub where beaches are crucial to the state's tourism economy (Miller and Fletcher, 2003). Yet the degraded state of beaches has caused surveyed visitors to indicate their reluctance to return (Lent, 2002; USACE, 2002). In response to the impact of beach degradation on the visitor industry, engineering efforts have been ongoing for more than a century in Waikiki with the goal of retaining sediment and improving access (Wiegel, 2008).

Beach nourishment is the preferred method of maintaining chronically eroding coastlines in Waikiki; this approach reestablishes the sediment budget and effectively maintains usable beach widths while protecting beachside property (Crane, 1972). Since the 1950‘s, more than 229,000 $m^3$ of sand have been imported and placed on beaches between Honolulu Harbor and Diamond Head (Wiegel, 2008). Following placement, much of the nourished sand is thought to have been transported seaward by nearshore dynamics (Environmental Assessment, 2010). Offshore sand deposits now provide a proximal and sustainable source of sediment for beach re-nourishment. The State is currently developing a long-term and cost-effective strategy for maintaining Waikiki's beaches that employs the quasi-periodic recycling of offshore sand deposits to eroded beaches. To date, three nourishment projects have been conducted in Waikiki since the year 2000 that utilize this offshore sediment source (Environmental Assessment, 2010). The third project was carried out in early 2012 and monitored for a period of 2.7 years following sand placement; this monitoring effort is the topic of the present study.

As sea level rise continues, erosional trends are expected to accelerate on Hawaiian beaches (Anderson et al., 2015). Efficient planning of future beach maintenance efforts will be crucial in mitigating prospective impacts. However, the development of a streamlined maintenance program requires a strong understanding of post-nourishment beach behavior. Monitoring studies improve our understanding of sediment transport within the unique reef-fronted, carbonate beach environments of Hawaii,

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and routinely provide observations employed in model calibrations. This allows continuing improvement in the design of subsequent nourishment projects (Dean, 2002). There are currently few published examples of carbonate beach fills where sediment transport is complicated by a fringing reef platform (Benedet et al., 2007; Muñoz-Perez et al., 2001). The results of this study, then, are valuable additions to the global literature pertaining to nourishment efforts within tropical regions. The primary objectives of the present study are (1) to evaluate the behavior and stability of the nourished beach, (2) to provide observations that can be used to establish an efficient schedule for future beach maintenance, (3) to link quantitative measures of beach change with wave forcing in the reef environment, and (4) to improve understanding of sediment behavior in reef environments.

## 2. Location description and nourishment project

### 2.1. Project background and objectives

In the spring of 2012, a beach nourishment project was completed along the Royal Hawaiian Beach segment of Waikiki on the island of Oahu, Hawaii. This was the largest nourishment effort to take place in 40 years within the Hawaiian Islands (Sullivan and Smith, 2014). The nourishment was completed at a cost of $2.9 million, funded by a joint public-private partnership including contributions from the State of Hawaii, the Hawaii Tourism Authority, and Kyo-ya Resorts. The Department of Land and Natural Resources (DLNR), the trustee of Hawaii beaches and coastal lands, oversaw the project. The objectives of the nourishment were to restore the esthetics and recreational usage of the beach in response to long-term chronic erosion, and to promote lateral access along the shore (Environmental Assessment, 2010).

As part of the nourishment project, the following components were proposed (Environmental Assessment, 2010):

- Recovery and dewatering of 18,350 $m^3$ (24,000 $yd^3$) of sand from sources located approximately 0.6 km offshore of the nourishment site.
- Emplacement of sand along a 520 m (1700 ft) segment of coastline with the goal of increasing the beach width by an average of 11.2 m (37 ft), restoring the beach width to the extent of the 1985 shoreline and not beyond.
- Increase of beach area above the high tide line by 6040 $m^2$ (7900 $yd^2$).
- Removal of two dilapidated sand bag groin structures located near the easternmost end of the project area. Groin removal was advised owing to their poor condition, blockage of access along the beach, and lack of significant effect on littoral processes for sand retention and transport.

The original beach design featured a 1V:7.5H slope, a crest elevation of +2 m, and a toe elevation of −1 m. The beach slope and crest elevation were predicted to reach an equilibrium profile similar to the pre-nourished beach (Environmental Assessment, 2010). Beach width was expected to reduce by half approximately 10 years following initial replenishment. Hinging on the success of this first phase of nourishment, a second phase was planned that included sand placement of an additional 9000 $m^3$. These two project phases were designed to maintain beach width for 20 years following the initial replenishment.

The sand used for nourishment was recovered from offshore sand deposits using a submersible Toyo DB75B slurry pump. The pump was suspended from an 80-ton capacity crawler crane that was stationed on a barge from which sand was pumped through an 8-inch pipeline to an onshore dewatering basin (Fig. 1). Mined sand was composed of carbonate and reported as having the same grain size distribution, texture, and similar color as the existing beach sand. The sand source had a median diameter of 0.34 mm with no coarse material, minimal fines and was composed of calcareous skeletal fragments of corals, coralline algae, mollusks, echinoids and foraminifera.

The original project design proposed the use of a pneumatic conveyance system to transport sand from the dewatering basin to placement locations. However, inadequate transport speeds of the conveyance system necessitated an alternative approach to distribute sand along the project length. Grading and sediment transport was ultimately accomplished using an 18 metric ton DK6 Dozer, and several CAT 725 dump trucks weighing over 45 metric ton when fully loaded.

Various forms of evidence suggest that the truck haul method of sediment conveyance caused compaction of nourished sands. Project engineers reported a 10% compaction factor based on sediment compaction tests designed to replicate the sand placement method (Sullivan, unpublished results). The DLNR attributed a 0.3–1 m hardened berm that formed along the seaward edge of the haul route as the product

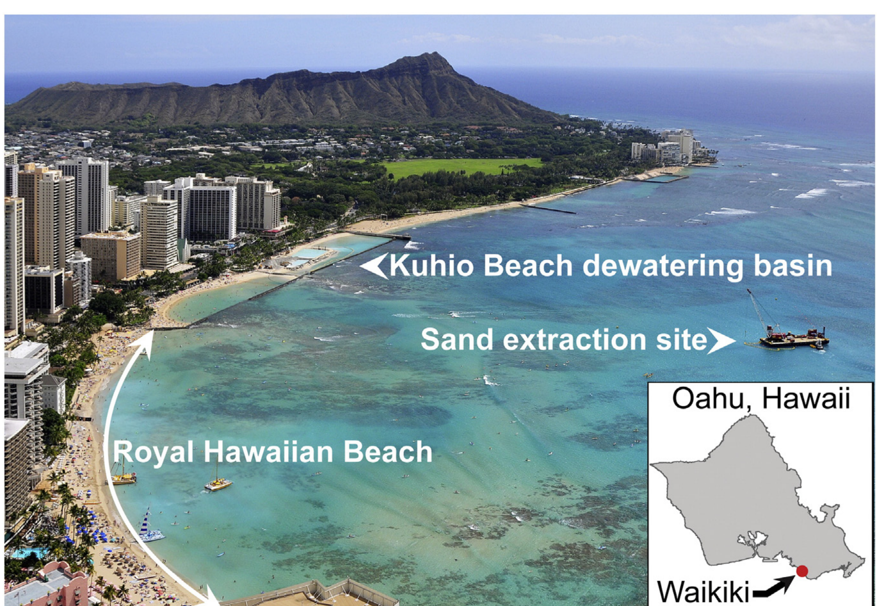


**Fig. 1.** Aerial image of Royal Hawaiian Beach and Kuhio Beach, which are respective locations of the 2012 nourishment project and dewatering basin. Image shows beach condition immediately prior to sand placement. West is towards the bottom of the figure.