

# Waikiki Beach, Oahu, Hawaii: History of its transformation from a natural to an urban shore

By

Robert L. Wiegel

*Professor Emeritus*

*Department of Civil & Environmental Engineering.*

*University of California*

*Berkeley, CA 94720-1718*

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## ABSTRACT

Waikiki, in Honolulu, Hawaii is a narrow beach that has been modified extensively. This history from a coastal engineering perspective is of the shore between Kewalo Basin and the Elks Club near Diamond Head. The beach and reef are exposed to waves from the south, with good surfing sites. A century ago, most of the shore was a narrow, thin ribbon of carbonate sand lying between wetlands, mudflats, duck ponds, fishponds, and a gently sloping fringing reef a few thousand feet wide. Not much sand was in the beach or the thin patches of sand on the reef. Several small streams flowed into the sea. The first encroachment onto the beach with buildings and other works occurred in the 1880s and 1890s — a few homes, several bath-houses, and small hotels, some built partly on piles. Seawalls, groins, and several piers were constructed. The Natatorium was built from shore 200 feet onto the reef in 1927. The Ala Wai Canal and Ala Wai Yacht Harbor were also constructed. Of great importance was the removal of many truckloads of sand from the premises of Queen Lili'uokalani circa 1909, and the dredging of sand, coral rubble, and rock from the reef for fill of portions of the wetlands at Fort DeRussy in 1909. A

dredge was used to clear a channel through the reef to the shoreline, and then parallel to the shore. In 1913, additional dredging was done to permit a 69-ton coast artillery gun to be brought by barge to the reservation. Channels, basins, and ponds have been dredged in the reef for several purposes; they front about one-half of the shore. These have caused changes in wave and current action, and in the transport and deposition of sand and silt. Much of the sand now on the beach segments between Diamond Head and Ala Moana Beach Park has been brought from other locations in Hawaii for beach fill, or for constructing a beach by placing sand on top of a base made of crushed coral rock dredged from the nearshore. Also, sand was dredged in 2000 and in 2006 from small deposits on the reef, pumped to shore at Kuhio Beach, and distributed along the section of beach which is protected by a shore-parallel breakwater (crib wall), elevation about MLLW, and groins connected to shore. Since Duke Kahanamoku's comments in the 1930s, guidelines governing beach nourishment have been to preserve the breakers for surfing, provide a sand blanket to cover the in-shore coral, and stabilize a dry beach for sunbathing.

**W**aikiki is a beach of world renown in Honolulu, Hawaii on the leeward side of the semi-tropical high island of Oahu (Figure 1). The beach is narrow, composed of a thin layer of carbonate sand, several miles long, and fronted by a gently sloping fringing coral reef a few thousand feet wide. The beach faces southwest, toward the bight of Mamala Bay. With its mild climate and warm ocean water, Waikiki is favorable for outdoor activities all year, including sunbathing, swimming, surfing, outrigger canoeing, and snorkeling. The beach, reef, and sea are popular with residents and with visitors.

Waikiki has been extensively changed from a nearly natural shore to an intensively used urban beach during the past century. "Waikiki Beach originally was a barrier beach between Ala Wai-Moiliili

### ADDITIONAL KEYWORDS:

Ala Wai Canal, beach construction, beach erosion, beach nourishment, beach rehabilitation, carbonate sand, dredging, fill, fishponds, Fort DeRussy, groins, marina, mosquito control, Natatorium, reef, sand pumping, seawalls, shoreline boundary, surfing, wetlands.

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duckponds and swamps and the ocean" (Moberly *et al.* 1963). Waikiki bears little resemblance to what it was in the 1880s and 1890s, or even in the 1910s and 1920s. Compare what can be seen in recent and historic photographs (Figures

1, 2, and 3). Historic photos may be found in the collections of the Bishop Museum Archives, the U.S. Army Museum of Hawaii, and in several books (Brown 1985; Hibbard and Franzen 1986; Grant 1996). Coastal works and other events related to this transformation are listed in the "Chronology of Significant Coastal Events at Waikiki, 1825-2007" (updated from Wiegel 2002; 2005), which is appended to this paper.

This paper is an abbreviation of a report by the author (Wiegel 2002), with some updates. The report was based on information from more than 200 references, many photographs, maps and charts, writing to and talking with people, and personal knowledge. The report identifies coastal engineering data, where they can be obtained, and presents examples of data. It is in several parts: anthropogenic and natural



**Figure 1. Waikiki Beach,, Oahu, Hawaii. Aerial photo, 24 January 1998; between Ala Wai Yacht Harbor (left) and Sans Souci (Kaimana) Beach (right). (By R.L. Wiegel, #8878.)**

events at Waikiki and their effects on shore and coastal processes; beach erosion control studies; beach restoration and sand sources for beach nourishment and construction; and features of the several sections of the shore and beach; beach and reef sand (including details of carbonate sand formation and transformation), waves, tides, currents (including rip currents), bathymetry and profiles. Owing to length limitations, many of the details on sand sources, waves, tides, currents (including rip currents), bathymetry, and beach profiles are not included in this paper. For example, the SHOALS survey of bathymetry made in August 2000 (USACE Mobile District 2002) is not included.

#### **PLACE NAMES OF WAIKIKI BEACH AND CONTIGUOUS SHORE**

“Waikiki Beach” originally referred to the beach between Fort DeRussy and the northwest end of the causeway leading from the city to Kapiolani Park, the “Diamond Head side” (Engineering Committee on Waikiki Beach Improvement 1927; Appendix 1 of USACE Honolulu District 1950). This causeway was part of Waikiki Road, which was renamed Kalakaua Avenue in 1905 (Hibbard and

Franzen 1986). For coastal engineering reasons, the original Waikiki Beach and the contiguous shore at both sides is considered here. This includes Kewalo Basin and its entrance channel on the “Ewa side,” and San Souci (Kaimana), Outrigger Canoe Club, and Elks Club Beach at the “Diamond Head side.” This is the same region written about in “The Waikiki Beach Story,” an article in *Shore & Beach* by Wachter (1958), then Superintendent of Public Works and chairman of the Board of Harbor Commissioners, Territory of Hawaii. A history of the place names is in the book *Beaches of O’ahu* by Clark (1977).

Names and locations of the several sections are given in Figure 4. A few beach names at the “Diamond Head side” of Waikiki Beach in USACE reports to Congress (U.S. Congress 1953; 1963) differ from those given in Wachter (1958), and Clark (1977).

Queen’s Surf Beach is located on Figure 4 between the Queen’s Surf storm drain/groin and the Natatorium. It is shown in parentheses, as the name is used on some maps (U.S. Congress 1965; Clark 1977; Gerritsen 1978; Edward K. Noda & Associates Inc. 1991), but not

on others. Clark (1977) says this beach is part of Kapi’olani Regional Park, at the western side of the Park Beach Center, and is named after a restaurant-nightclub which was there from 1946 until it was demolished in 1971; it was in a converted oceanfront mansion. It was named after the famous Waikiki surfing break, Queen’s Surf. However, this surf site is off Kuhio Beach (Walker 1974; Edward K. Noda & Associates 1991); the name of the surfing break off Queen’s Surf Beach is Publics. Wachter (1958), in the caption of an aerial photo of the site and in the text of his paper, refers to the segment between the groin and the Natatorium as Kapiolani Park Beach, which he called “Waikiki’s newest beach.” The AAA map of Honolulu (2006) shows the entire shore between the Kapahulu storm drain/groin and the Natatorium as Kapiolani Beach Park, and the U.S. Geological Survey map labels it Kapi’olani Park Beach; no segment is labeled Queen’s Surf Beach.

Figure 1 is a 1998 aerial photo of most of the extended Waikiki Beach. The section between Ala Wai Yacht Harbor is on the left, and Sans Souci (Kaimana) Beach is on the right. Figure 5 is a photo look-



ing toward Diamond Head. The Royal Hawaiian-Moana Hotels Beach is in the foreground, and Kuhio Beach, with the crib wall breakwater (known as the “slippery wall,” Clark 1977) at top center. Figure 6 is a 1986 oblique aerial photo from offshore Diamond Head, with the Elks Club, Outrigger Canoe Club Beach, and Sans Souci (Kaimana) beaches near the bottom right of the photo; the Natatorium and Kapiolani Park Beach/Queen’s Surf Beach at the center; and Kuhio Beach Park at top left.

Figure 7 is an aerial photo from 1999 of Magic Island (Aina Moana) at the left, Ala Wai Canal entrance channel and Ala Wai Yacht Harbor at left center, Duke Kahanamoku Beach and Lagoon and Fort DeRussy Beach at top right and center right. Figure 8 is an aerial photo from 1998 of Kewalo Basin at the left side, Ala Moana Beach Park and dredged channel in front of the beach at the center, and the west side of Magic Island (Aina Moana) at the top right.

Waikiki hosts several shorefront parks. These include Kewalo Basin State Park, Ala Moana Beach Park, Magic Island (Aina Moana State Recreation Area), Fort DeRussy Beach Park, Kuhio Beach Park, and Kapiolani Park Beach.

### CARBONATE SAND

Waikiki beaches are narrow, as can be seen in the photographs. What is not apparent is that the sand cover is thin and shallow — the limestone bedrock under the sand is probably at about -2 feet MLLW. Several reports mention that seawalls at Waikiki were built on a coral foundation with the coral bed close to low water (e.g., Engineering Association of Hawaii 1927; Crane 1972; Noda 1991). Professor Ralph Moberly of the University of Hawaii (1968; 2001) estimated the quantity of sand on Waikiki Beach in 1968 to be about 70,000 cubic meters (92,000 cubic yards). This was in the reach from the San Souci area (Kapua Channel) to the seawall west of the Royal Hawaiian Hotel. Shallow patches of sand only a few feet thick are on the reef flat. As part of an ecological survey of the reef in the early 1970s, the type of bottom was classified as sand, rubble, limestone, live coral, etc. (Chave *et al.* 1973). It was estimated that 36% of the bottom inside the reef crest (approximately the 1-fathom depth contour), and 39% outside, were sand substrate. There is not much sand on the beach or reef. However, hard bottom shoals on the reef flat are important for surfing.

The native sand on the beach and reef

was created and transformed on the reef by biochemical, bioerosion, and mechanical processes (e.g. Moberly *et al.* 1965; Stearns 1938; USACE 1950; U.S. Congress 1953; Gerritsen 1978). Details may be found in Wiegel (2002). Moberly *et al.* (1965) say: “It is rather a misnomer to speak of ‘coral sand’ as coral is a poor fifth in general order” of sand components in Hawaii’s carbonate beaches. Native sand on Waikiki Beach and most other Oahu beaches is carbonate, with constituents in the order of abundance being: foraminifera, mollusks, red algae, echinoids, corals, and *Halimeda* (e.g., Moberly *et al.* 1965). There does not appear to be sand in the Waikiki Beach littoral system from the local streams, except for a trivial amount (U.S. Congress 1953; Gerritsen 1978).

Analyses of four samples of sand from the intertidal zone of the beach in Waikiki (exact locations not given) in July 2000 had a different order of abundance than given above (Hampton *et al.* 2002), with coral and coralline algae being the most abundant. However, much of the sand in recent years on Waikiki Beach and its extension through Ala Moana Beach Park, has been brought from other locations on Oahu and Molokai - for beach nourishment, and for beach construction,

**Figure 2.**  
**Waikiki, Oahu,**  
**Hawaii. Aerial**  
**photo, 9**  
**September 1920,**  
**looking**  
**landward over**  
**shore; taro**  
**patches, rice**  
**paddies.**  
**Apuakehau**  
**Stream mouth**  
**(almost closed**  
**by beach sand),**  
**Moana Hotel**  
**and pier in**  
**center. (U.S.**  
**Army Museum**  
**of Hawaii,**  
**USAMH No.**  
**1716.)**



where sand is placed on top of a base made of crushed coral rock dredged from the nearshore (Wiegel 2002). Examples of beach nourishment may be seen at Kuhio Beach and Kapiolani Park/Queen's Surf Beach. Examples of constructed beaches are at Ala Moana Beach and Fort DeRussy Beach. In 1970, legislation was passed making it illegal to mine sand from beaches in the state of Hawaii after 1975 (Campbell and Moberly 1978).

When Horton (1948) inspected the Waikiki Beach area prior to the major beach fills, he noted the sand grains were mostly cream colored and light tan. Close inspections of the sand made by the author walking on the beach in recent years, found that the sand appeared to be similar in color.

### **FRINGING REEF — SURFING AND OUTRIGGER CANOEING**

The sport of surfing, or surf-riding, was revived and became popular in the early 1900s. Modern surfing essentially started at Waikiki. Locations of the surfing sites at Waikiki are shown in Figure 9. Surfboards became long and heavy, with the modern lighter and more maneuverable boards being developed about fifty years later. The legendary great Olympic athlete Duke Kahanamoku introduced the 10-foot long surfboard in about 1910. The Outrigger Canoe Club was established in 1908 (Grant 1996), and the clubhouse/boat house built at the edge of the beach at the mouth of the Apuakehau Stream just west of the

Moana Hotel. It housed several hundred upright surfboard lockers filled with boards of all sizes and colors (Blake 1955, in Dixon 1966). It closed when the club moved to its new building near Kaimana (Sans Souci) Beach at the end of 1963 (Clark 1977).

Jack London visited Waikiki in 1900, where he learned to surf. He described vividly how he learned, the dangers associated with surfing, and his enjoyment of what he called "a Royal sport" in his book *The Cruise of the Snark* (1911, as reproduced in Blake 1966).

A detailed presentation of technical information about surfing is in the extensive report by James R. ("Kimo") Walker: *Recreational Surf Parameters* (1974). One of Walker's observations is that the majority of "surf shoals" (where waves transform and break) in Hawaii are "comprised of coral, basalt, and beach rock, which remain essentially stable under wave attack; while sand shoals may shift with changing wave conditions." Details of two of the popular surfing sites on the reef at Waikiki are given, one is Queen's off Kuhio Beach; both are at coral bottom shoals that remain stable. As mentioned elsewhere, in planning and implementing beach restoration, modification, and nourishment, it is necessary to preserve the surfing breaks.

### **STREAMS FLOWED TO THE SEA AT WAIKIKI**

A century ago, most of the shore was a narrow ribbon of carbonate sand be-

tween wetlands and the wide fringing reef, and there were mud flats where Ala Moana Beach Park was constructed. The subsurface geology of this coastal plain is a complicated mix of horizons/lenses of lagoonal deposits, marsh deposits, sand and coralline debris, coral ledges, alluvium, cemented sand, cinder, clinker, tuff, and basalt (Ferrall 1976; Noda 1994). Several streams flowed into the sea, as shown on the 1907 map by Dove (Figure 10). An aerial photo taken in 1920 (Figure 2) shows Apuakehau Stream at the center left (almost closed), and the Moana Hotel and pier. Rice paddies, taro patches, duck ponds, and fish ponds can be seen in this photo and in historic photos in the Bishop Museum. Several are reproduced in the book by Hibbard and Franzen (1986).

One of the historic photos of streams at the beach is shown in Figure 3a looking inland from the mouth of Ku'ekaunahi Stream in 1886, at what is now Kuhio Beach. An old postcard, circa 1912, shows the Apuakehau Stream to the left of the Moana Hotel and pier (Figure 3b) Note that the stream mouth is closed.

Several streams are shown entering the sea on Bishop's (1881) modified map of Waikiki (1881, 1888, 1922, 1952): the Pi'inaio at the west side of where Fort DeRussy is now; the Apuakehau between what is now the locations of the Moana and Royal Hawaiian Hotels; and the Ku'ekaunahi (labeled "Hamohamo Stream" on Dove's map) at Kuhio Beach. Note that on Bishop's map the Hawaiian

words “muliwai,” which means estuary, and “loko,” which means fish pond are used. A copy of this map may be found in Wiegel (2002), but is not reproduced herein (a modified version is in Hibbard and Franzen 1986).

In addition to fresh water flow onto the reef, during heavy rainfall and flooding events the streams transported large amounts of silt and clay to the shore. The *Pacific Commercial Advertiser* (May 1913) quotes G.H. Buttolph of the Outrigger Canoe Club:

“...during each freshet in Moana Valley or higher in the hills the flood waters are carried in torrents down the stream, bringing debris and mud in much quantity (sic, and) the beach is fouled and uninviting. The surf for some distance on each side of the mouth of the stream is generally muddy and uninviting to bathers.... Last Sunday I went to the beach with some tourist friends...and found the water as thick as mud. It was disagreeable to look at, and certainly an offensive place for swimming.”

A similar comment was made by Kinau Wilder (1978) in her book *Wilders of Waikiki*; her family home was on the beachfront. Wiegel (2002) contains a copy of an aerial photo in color taken by the author about a week after an extreme rainfall event showing the turbid water



**Figure 3a (above).** Ku'eikaunahi Stream, looking inland from mouth, 1886. (A. Mitchell, Bishop Museum, Neg. No. CP 56428.)

**Figure 3b (below).** Historic postcard, circa 1912, Apuakehau Stream to left of Moana Hotel and pier; note stream mouth closed. (Island Curio Co., Jas. Steiner, Honolulu.)

on the reef a few miles east of Diamond Head, also illustrating this phenomenon.

It was suggested that Apuakehau Stream be diverted into the lagoon in Kapiolani Park, and then into the sea through a sluice gate (*Pacific Commercial Advertiser* May 1913). In 1914 it was recommended that “one of the streams be blocked, and then, from the end of the other, a pipe be run out well beyond the reef...” (*Honolulu Star Bulletin* 1914). Neither of these projects were imple-

mented. Rather, the Ala Wai Canal, draining, wetlands reclamation and mosquito control projects were completed in the 1920s.

#### **ENCROACHMENT AND SAND REMOVAL**

Vegetation grows rapidly in this climate, and the bare sand beach was naturally narrow. The beach was encroached upon by people building homes, other structures, and landscaping, Figure 11. The postcard photo (circa 1910) shown

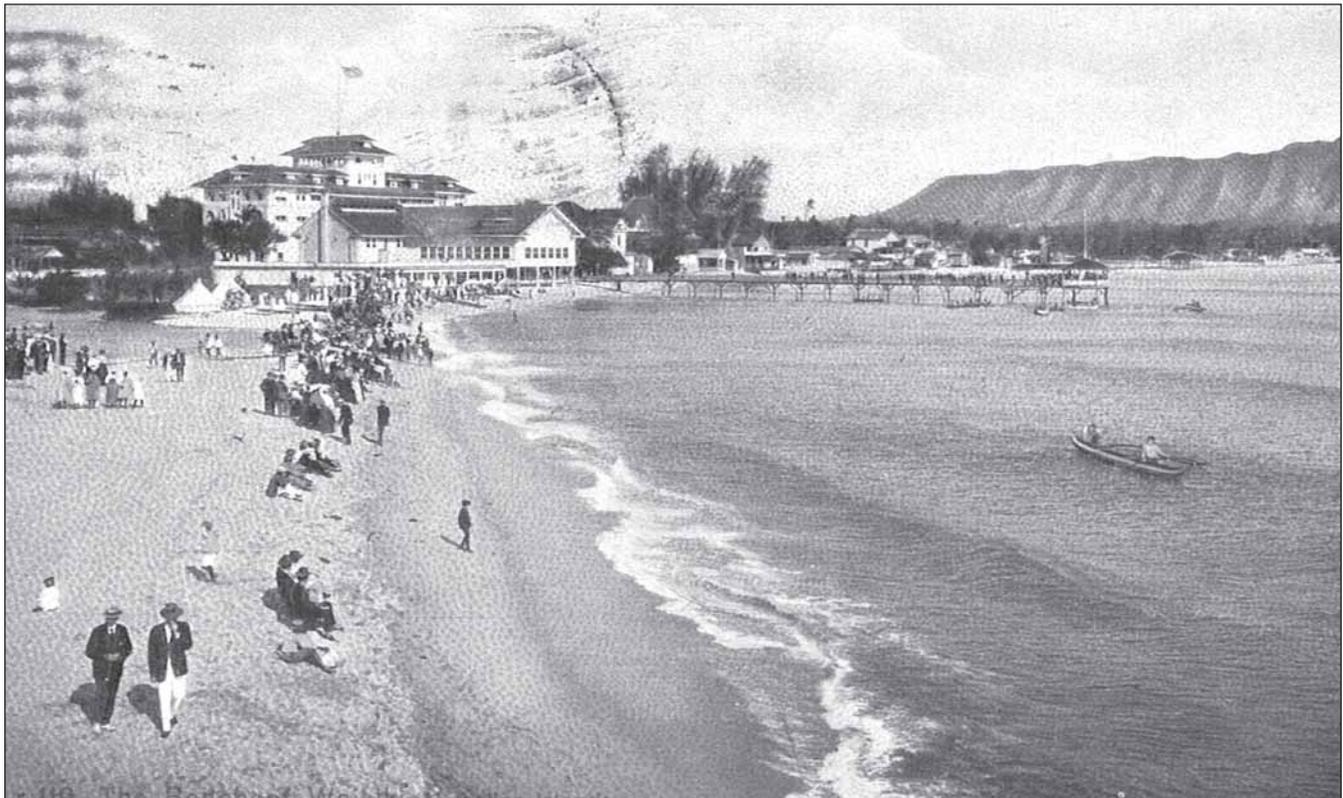
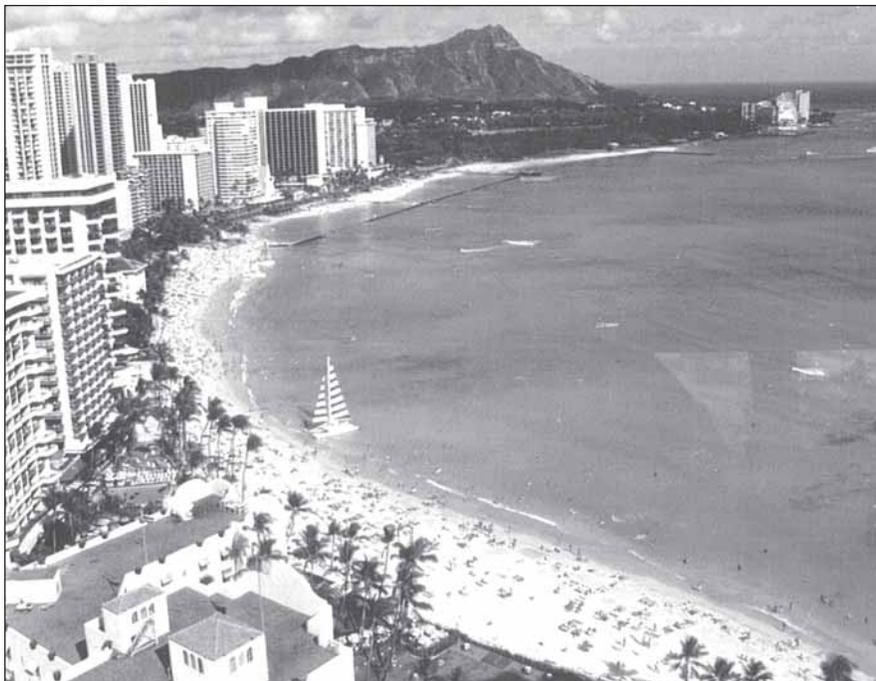




Figure 4. Map of Waikiki, Oahu, Hawaii; names of sectors added to USGS topographic map, edited 1983 (adapted from U.S. Geological Survey).

Figure 5. Royal Hawaiian and Moana Hotels Beach, with Kuhio Beach at top center; 24 June 1986. (By R.L. Wiegel, #5894.)



in Figure 12, is of the Seaside Hotel (opened in 1906), its lawn and seawall, and a narrow beach. This was at the site of the present Royal Hawaiian Hotel. Historic photos of buildings and seawalls are in the Bishop Museum Photo Collection, and in the books by Hibbard and Franzen (1986), Brown (1985), and Grant (1996).

Owing to encroachment, much of the beach at Waikiki disappeared from view under structures and landscaping, with some excavated for foundation preparation (e.g. at the Royal Hawaiian Hotel and at the present Outrigger Canoe Club building).

As mentioned in a previous section, there is a mix of geologic horizons/lenses in the Waikiki area. Major problems occurred during the construction of the Royal Hawaiian Hotel. A large part of the building started to sink into the swampy soil, and a significant redesign and construction modification was required, doubling the cost of the hotel (Cohen 1999; Peralta, 2002).

Large quantities of sand were removed many years ago from Waikiki. In 1910 the *Pacific Commercial Advertiser* reported on a meeting of the Hawaii Promotion Committee — the article's headline was:

“Spoiling the Waikiki Beach. How Honolulu’s World-famous Bathing Resort is Being Ruined. Heavy Removal of Sand.”

According to the article:

“...thousands of loads of sand removed from the Waikiki Beach stretches have caused the present deplorable condition of the bathing beaches.... Much of the enormous amount of sand was removed from the premises of Queen Liliuokalani. In addition ... the federal government is also removing large quantities of sand to be used for construction purposes. The removal of sand should be stopped. The accumulations of centuries and the contour of the beach formed in centuries was being marred by the sand removals of the present day.... A letter will be written to Major Winslow, Corps of Engineers, U.S.A., and to the Liliuokalani Estate, asking them if they could not get sand elsewhere than on the beach frontages.”

At a later date, owing in part to encroachment onto the beach and removal

of sand, it was decided to bring sand to the shore from other areas for beach nourishment. Projects where this was done are described subsequently. For possible future work, offshore sources of sand have been investigated (Casciano and Palmer 1969; Moberly Jr. and Campbell 1969, revised 1972; Moberly Jr., Campbell, and Coulbourn 1975; Edward K. Noda and Associates, Inc. June 1991; Sullivan and Bodge 2000).

### DREDGED CHANNELS AND BASINS IN THE REEF

Channels, basins, and ponds have been dredged in the reef for reasons including to obtain fill material, for navigation, for small craft harbors, and for swimming and sea bathing. About one-half of the shore between Kewalo Basin on the northwest (“Ewa”) side, and the Elks Club near Diamond Head is fronted by about a dozen of them. Several of these dredged areas can be seen in aerial photos. In Figure 13 are Kewalo Basin and its entrance channel through the reef, and the Ala Moana Beach Park, with its shore-parallel channel, and the entrance through the reef along the west side of Magic Island (Aina Moana); see also Figures 7 and 8. Figure 7 shows the entrance channel to the Ala Wai Yacht Harbor and Ala Wai Canal, the Ala Wai Yacht Harbor, and Duke Kahanamoku Beach. A navigation channel was dredged in the 1950s through the reef for the Hilton Hawaiian Village Hotel catamaran dock basin. The connecting channel between Fort DeRussy and Halekulani Channel, and the Halekulani Channel through the reef can be seen in aerial photos of Figures 1 and 14. Part of the connecting channel can be seen in an aerial photograph, Figure 15. The shore-parallel dredged channel between the Kewalo Basin and the Ala Wai Yacht Harbor can be seen in a 1930 oblique aerial photo, Figure 16. Other aerial photos are instructive, although not reproduced here. An example is a 16 February 1949 photo that shows the channel in front of the Ala Moana Park before the beach was constructed, and the Ala Moana Yacht Harbor and canal before the entrance was dredged through the reef (Bishop Museum Photo Collection, No. c.p. 126,191). A chart in Horton’s paper (1948) shows this channel dredged to a depth of 12 feet.

Dredged basins and channels for harbors and navigation are easy to see in



**Figure 6. Waikiki Beach; aerial photo from offshore Diamond Head, 16 January 1986: Elks Club and Outrigger Canoe Club (at bottom of photo), Sans Souci (Kaimana) Beach, Natatorium, Kapiolani Park, Queen’s Surf Beach, and Kuhio Beach (top). (By R.L. Wiegel, #5581.)**

aerial photos. But what about smaller works such as the removal of coral to make sea-bathing more comfortable? A 1910 article in the *Pacific Commercial Advertiser*, reports that Mr. Campbell, Superintendent of Public Works, said: “... as far as the removal of coral is concerned, he believed funds would be forthcoming to prosecute the work. ... A swim in the beach at present is a decided disappointment, owing to the sharp clumps of coral which tear bathers’ feet....He believed that the matter was of such public interest that the public would backup any effort to free the bathing places from coral.” Moberly *et al.* (1963) wrote: “the center area of reef off the [sic, beach] hotels and Kuhio Beach had been largely cleared of coral heads for the convenience of swimmers.”

Dredged features such as these affect coastal forcings and processes: waves,

currents, and sand transport and distribution. Little quantitative information is available about the details of their actions and effects.

In the following section dredging on the reef done for Fort DeRussy is described, including a channel through the reef. Figure 17 is a copy of part of the chart North Pacific Ocean, Sandwich Islands, Southside of Oahu, U.S. Navy Hydrographic Office, No. 867, (1880; hydrographic surveys in 1840, 1873 & 1875). Note that Kapua Entrance is shown, but no channel is shown in the vicinity of where Fort DeRussy was subsequently built.

### FORT DERUSSY DREDGING AND CONSTRUCTION

The main construction of Fort DeRussy in the Kalia area of Waikiki was between 1909 and 1911, and the placement of the first of two 14-inch coast ar-



**Figure 7. Magic Island (Aina Moana), Ala Wai Canal entrance channel, Ala Wai Yacht Harbor, Duke Kahanamoku Beach and Lagoon, Fort DeRussy Beach. Aerial photo, 30 January 1999. (By R.L. Wiegel, #9523.)**

tillery guns was in 1913. This is described by Dorrance in *The Coast Defense Study Group Journal* (1998; 1999) and in Hibbard and Franzen (1986). Dorrance (1998) says:

“On November 12, 1908, Headquarters and Company A, First Battalion of Engineers, arrived under the command of Maj. E. Eveleth Winslow.... Winslow soon had a hydraulic dredge on site that blasted through the offshore reef, dredged a channel to the shoreline, and deposited the dredged bottom sand and coral within the reservation. By the end of 1910 the dredge’s

work was done and construction of fortifications could begin.”

A suction dredge was used to obtain material for fill from the reef in front of the reservation. It was pumped through a pipe to the site (Thompson 1985).

Thompson also states (1985):

“In preparation for the arrival of the 69-ton guns, a deep channel was dredged through the reef in front of Fort DeRussy so the cannon could be barged from Honolulu to as close to the battery as possible.”

Dorrance (1999) says:

“Delivery of the 69-ton guns ... was another matter. ... [sic, the ship] Lurline was directed to Pearl Harbor, where a heavy duty floating crane was located. ... On August 2, 1913...the navy crane off-loaded the gun onto a barge... Three days later the gun-bearing barge was towed to Waikiki Beach where it was pushed through the reef and aground in front of Battery Randolph’s parapet. ...The channel [sic, that was previously] dredged for bottom sand and fill was deepened and widened for this operation.”



**Figure 8. Kewalo Basin, Ala Moana Beach Park, Magic Island (Aina Moana); aerial photo, 19 January 1988. Note dredged channel in front of the man-made beach. (By R.L. Wiegel, #6354.)**

The *Pacific Commercial Advertiser* (6 August 1913) reported (underlining for emphasis):

“At an early hour yesterday morning, the barge bearing the gun was taken in tow by Young Brothers’ launch Huki which drew the unwieldy craft up the coast to the Hau Tree channel through which it picked its way to that running parallel to Fort DeRussy...”

The dredged area in front of Fort DeRussy, and the dredged connection to the Hau Tree channel (now known as the Halekulani sand channel) are depicted in a sketch map by Moberly Jr. (1968). A portion of the same area can be seen in a 1999 aerial photo, Figure 14, and in a 1919 aerial photo, Figure 15. A comment in *Hawaii’s Shoreline* (State of Hawaii, Dept. Planning and Economic Development 1964) is: “An old seldom used boat channel offshore from the Halekulani Hotel is filled with sand twenty feet deep and extending beyond the reef.” [As an aside, refer to Figure 17; this bathymetric chart of 1880 does not show an entrance through the reef at this location.]

Figure 16 is an oblique aerial photo (28 July 1938) which shows several dredged channels. Fort DeRussy is at the lower left, Ala Wai Yacht Harbor in the center, and Ala Moana Beach Park and Kewalo Basin at the upper left. A channel between Fort DeRussy and the Ala Wai Yacht Harbor can be seen. The channel was not deep all the way, being less than six feet at the west end of Fort DeRussy [See bathymetry on map dated 15 May 1950 of Waikiki Beach, Oahu, Hawaii; date of survey August-November 1948; Plate 1 of the USACE Honolulu District report (1950) and U.S. Congress (1953).] This channel was probably dredged subsequent to the original Fort DeRussy work.

In her book *Wilders of Waikiki*, Kinau Wilder (1978) says:

“There was a raft, which the Waikiki residents had paid for, just offshore near our house. ...And then the army brought in an eighteen (sic 14) inch gun to Fort de Russey (sic, DeRussy), right next to the old Lewers place which is now the famous Halekulani Hotel. ...They brought it by barge ... In order to reach the emplacement, it was necessary to break through the reef just beyond the spot where our raft floated. This com-

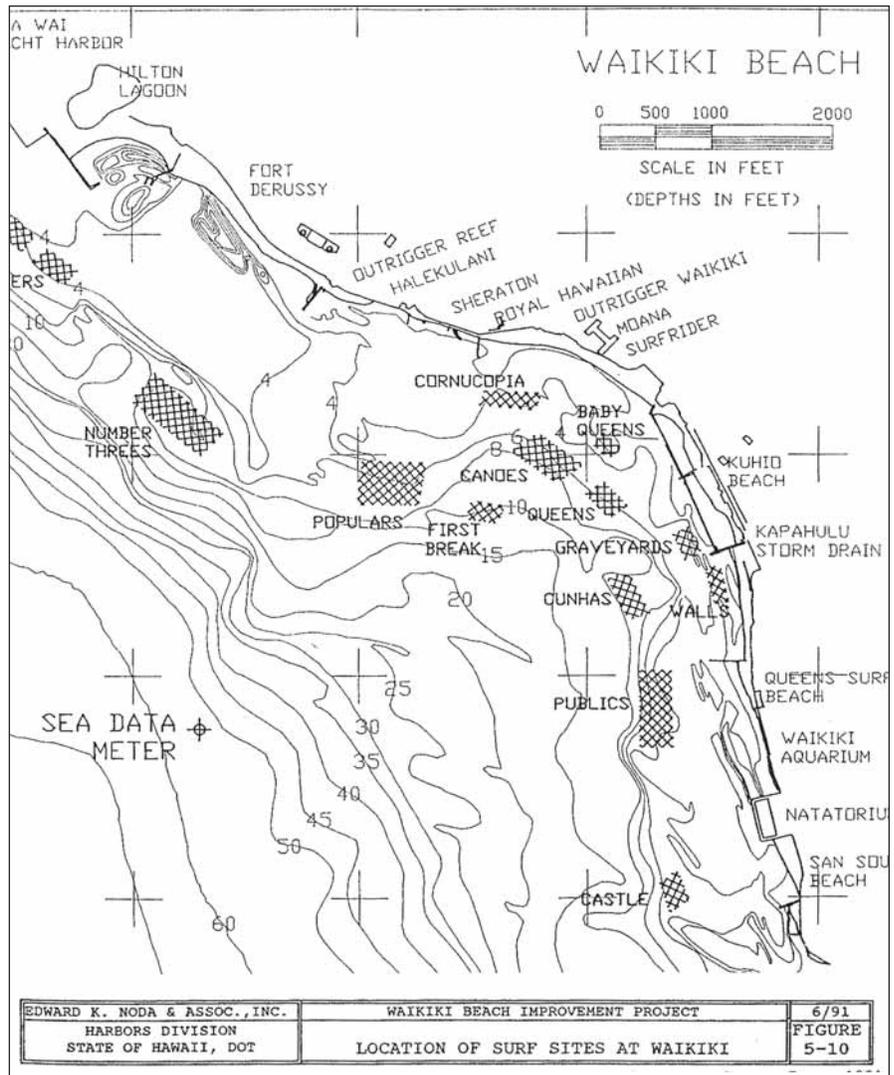


Figure 9. Locations of surf sites at Waikiki. (From Edward K. Noda & Associates Inc., July 1991.)

pletely changed the pattern of the currents. The beach at Waikiki was never the same. Instead of the reef holding the sands of the beach and preventing them from being carried out by the changing tides, the sand was swept through the hole in the reef, never to return. What had been a glorious beach -- which no other beach on earth could touch -- was nothing. Property owners lost anywhere from ten to thirty feet of their ocean frontage. Everyone was forced to put up seawalls to keep from losing their houses as well. Instead of running from the grass right on out to the ocean, we had to go down slippery steps to a miserable little strip of sand which, during certain months, was non-existent. At times I could jump from our seawall right into the water.” [Note: The Sheraton Waikiki Hotel was built in 1971 on the site of the Wilder property.]

Owing to erosion at Fort DeRussy, in 1914 a plan was developed, and a decision made, to construct a seawall (USACE, Chief of Engineers, 3 letters, 11 March 1914, 2 May 1914, 5 June 1914; 1st Ind., (3) by U.S. Engineer Office, Honolulu 15 April 1914, 19 May 1914, 23 June 1914). In 1916 the Corps of Engineers constructed a long seawall on the coral reef where there was no sand (Engineering Association of Hawaii 1927). The seawall can be seen in the photograph circa 1916, Figure 18. Note the sea water inland of the wall. Shortly thereafter this area was filled with about 26,000 cubic yards coral rock and rubble dredged from the reef (USACE, Honolulu, Hawaii, District Engineer Officer 19 September 1916). An additional 134,000 cubic yards were dredged for the fill of duck ponds in the reservation. Note a diving tower, and a swimming pier in the

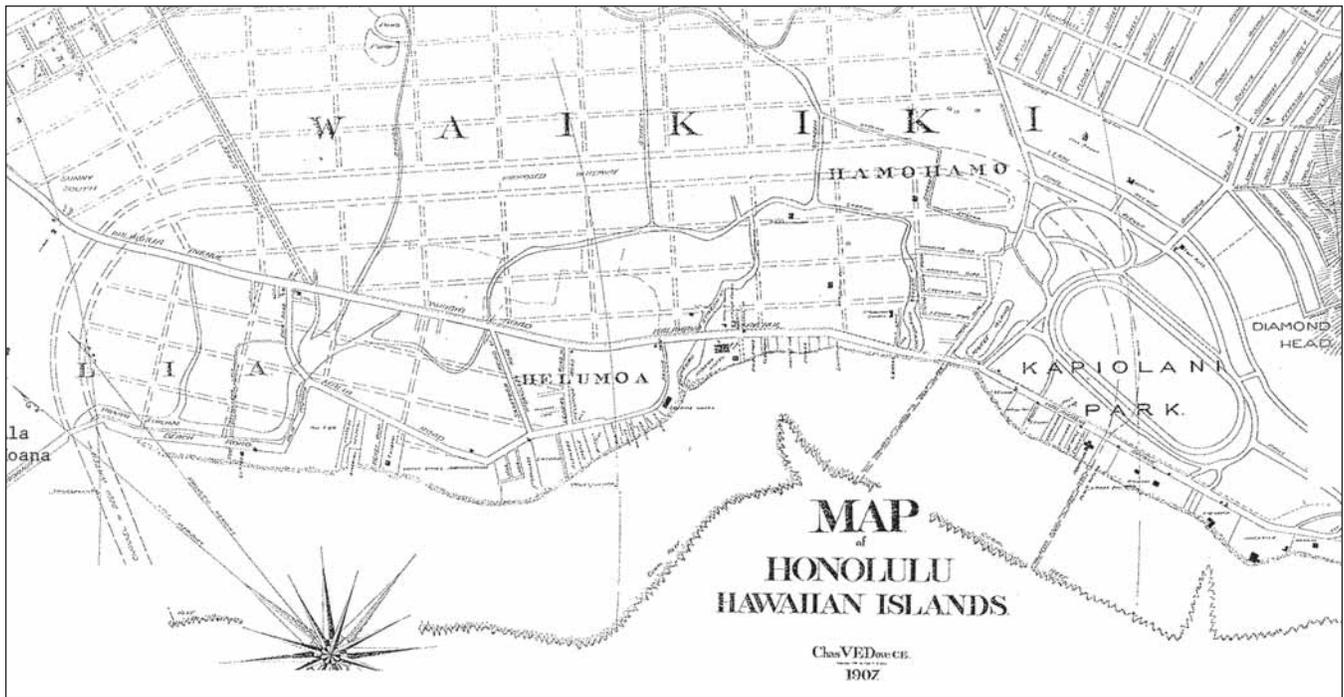


Figure 10. 1907 Map of Waikiki (Chas. V.E. Dove).

aerial photos of Figures 15 (1919) and 19 (1932). The channel had become a swimming basin.

At a later date, a beach was constructed seaward of the seawall. This will be described subsequently.

There is almost no beach along the shore in front of the Halekulani-Sheraton Waikiki Hotels. This is probably a long-term effect of the dredging. Note the lack of beach in the 2 November 1932 aerial photo, Figure 19. Little sand can be seen in recent photographs such as Figure 1 and Figure 14, or in many earlier photos. In Figure 1, Fort DeRussy beach is near the left, and the Halekulani-Sheraton Waikiki section at the left center.

#### ALA WAI CANAL; DRAINING, WETLANDS RECLAMATION, AND MOSQUITO CONTROL

The location of Ala Wai Canal is shown on the map of Figure 4. Note the “dog-leg” section to the ocean at the top center.

The Ala Wai Canal, draining, wetlands reclamation, and mosquito control project was constructed in 1921-1924; it was widened at a later date to obtain more fill material (Gonzalez, Jr. 1971; Hibbard and Franzen 1986; Edward K. Noda and Associates Inc. October 1992). The canal, a total length of about two miles, was dredged and the material used to fill rice paddies, taro patches and fishponds. It

connects with the reef’s waters a little westerly of Fort DeRussy. This tidal canal is a partially mixed, moderately stratified estuary (Gonzalez Jr. 1971). One consequence of the project was that streams no longer flowed into the ocean at several locations, with their fresh water and sediments. Instead, the streams flow into the canal. It is a sediment trap, with the amount of siltation ranging from 8,000 to 10,000 cubic yards per year (e.g. Edward K. Noda and Associates Inc. October 1992). Maintenance dredging was done in 1966, in 1978, and in 2002 (e.g., Blakeman 2002). The canal’s waters are a source of pollutants to the Waikiki shore and the reef’s waters (Grigg 1995; 1996; Mamala Bay Study Commission April 1996; Summer 1996). This project must have had major effects on the reef and beach. It is still a source of pollutants during heavy rainfall events, and long-term planning is being done in regard to the “100 year flood” (Gonser 2004; *Honolulu Advertiser* editorial 2004; Cooper 2006).

#### TSUNAMIS — EMPHASIZING DRAWDOWN

Anthropogenic actions at Waikiki, and effects of stream flooding have been mentioned. [Others, such as hurricane-generated and other severe wave events (e.g., Grigg, 1995) are described in Wiegel (2002); see also, Hwang (2005).] But what about other natural events? Substantial effects to reefs and shores

may also be caused by great natural events such as major tsunamis, hurricanes (tropical cyclones), and floods. In this section tsunamis are discussed (Iida, Cox and Pararas-Carayannis 1967; Pararas-Carayannis and Calebaugh 1977).

Owing to its location relative to the sources of tsunamis in the Pacific Ocean, and the wide fringing reef protecting the shore, run-up of tsunami waves has been relatively low at Waikiki Beach compared with some locations in the Hawaiian Islands, such as Hilo. This has been studied by Professor Doak C. Cox, of the University of Hawaii, and by others. Houston, Carver, and Markle (1977) made an investigation of tsunamis in the Hawaiian Islands, and developed frequency of occurrence curves for run-up elevations (flooding) along the shore, using a hybrid finite element numerical model and historical data. They estimated the elevation of maximum tsunami wave crest above mean sea level 200 feet shoreward of the coastline. Information is given by Hwang (2005) on utilizing wave, flood, and inland zones in overall hazard mitigation mapping by FEMA, Flood Insurance and Mitigation Administration. This includes consideration of tsunamis. Hwang (2005) states that for Oahu and other islands, tsunami inundation boundaries have been computed for most of the shoreline. He refers to Fletcher III, Grossman *et al.* (2002) for Waikiki.



**Figure 11. Aerial photo, circa 1940, looking toward Diamond Head; Royal Hawaiian-Moana Hotels Beach (curved groin near bottom); Kuhio Beach; “crib wall” breakwater; seawall along section of Kalakaua Ave.; Natatorium in distance at top right. (By Anon.)**

In this paper, tsunami wave drawdown is emphasized, rather than run-up. Little is known about this, as on the reef there are no equivalents of the “swash marks, lines of debris, trash left hanging from trees and buildings,” etc. used in determining the highest run-up of tsunami waves. How can maximum drawdown be determined? The damage cannot be assessed as reliably as can damage on land. There were eyewitness accounts of the 1 April 1946 tsunami (generated in the Aleutian Islands) -- the waves struck Hawaii during daylight hours — and the 23 May 1960 tsunami (generated off Chile) -- although the waves arrived in the middle of the night. For the 1 April 1946 tsunami, Shepard, MacDonald, and Cox (1950) say:

“At Diamond Head the water rose as high as 12 feet but came in very gently. ... At the eastern end of Waikiki Beach, 1.5 miles northwest of Diamond Head, the water flooded over the sea wall and attained a height of about 9 feet. All along the south side of Oahu the reefs were laid bare between waves....”

**Figure 12. Seaside Hotel, seawall, beach, circa 1910; postcard (Anon., 1910).**



A Honolulu newspaper quotes Timothy Lyons, of Diamond Head Road, an “amazed witness”:

“At about 6:50 (sic, a.m.), the ocean was sucked almost dry clear out to the reef. I could see nothing but coral and

rock on the floor of the ocean. Then it started coming in....”

During the 23 May 1960 tsunami a flash photo taken by Jack Titchen (1960) shows the reef bottom bared at the catamaran loading pier of the Hilton Hawai-



**Figure 13. Ala Moana Reef, Kewalo Basin, Ala Moana Beach Park, Magic Island (Aina Moana), Ala Wai Yacht Harbor/Canal entrance; dredged channels, aerial photo. (From Gerritsen, March 1981, p. 215.)**

ian Village [in the *Honolulu Star-Bulletin* 23 May 1960]. A 1963 Coast & Geodetic Survey chart (USC&GS Chart 4132, 10th Ed. June 3/63) shows a pier, dock, and a small basin in the reef at the end of the pier, with a note “being dredged to 5 ft.” A chart in Chave *et al.* (1973) of the reef bathymetry shows a depth of about 10 feet at the catamaran basin.

Another item in the *Honolulu Star-Bulletin* (23 May 1960) says that at Kuhio Beach:

“Between waves, foolhardy persons were able to run out on the reef and pick up fish.”

And, in the newspaper’s “Police Log”:

“1:16 (sic a.m.) — at Kuhio Beach, water is splashing over the sea wall; 1:28 — water that has withdrawn at Kuhio Beach is now rising; 1:37 — Ala Wai Canal at Ala Moana is down 11 feet; 1:40 — sand and reef is exposed 100 feet beyond Waikiki hotels...”

George S. Kanahale (1996), in his book on the history of Waikiki, quotes

an observation about a tsunami in the late 1860s by Harriet N. Deming in her unpublished manuscript. Her home was on the beach next to Kamehameha V’s property. The tsunami probably occurred in 1868 (see catalogs of tsunamis in Hawaii by Iida, Cox and Pararas-Carayannis 1968; and by Pararas-Carayannis and Calebaugh 1977). Deming recalled the “tidal wave” with the “tide so low that the bed of the ocean was uncovered all the way out to the reef, with rocks and seaweed glistening in the sunlight... “and then the “sea came flooding in, rising higher and higher, not stopping at the edge of the beach, but rushing up on the long slope until the waves were lapping at our veranda foundation ... In a few minutes the waters again receded ... leaving the ocean bed bare. Three times was this movement repeated...”

A considerable drawdown was likely to have occurred at Waikiki during the tsunami from Chile of 7 November 1837. This is based on the fact that water was observed to have receded to 2.4 meters below normal tide in Honolulu Harbor, leaving it partly dry (Pararas-Carayannis and Calebaugh 1977).

The author made a search of the technical literature for information about tsunamis on reefs, but found little. It is probable that considerable quantities of sand, silt, broken coral and shell were washed off the reef by the hydraulic flows of these tsunamis, and lost from the littoral system.

#### **EXTENSIVELY MODIFIED URBAN SHORE**

Waikiki is an extensively modified urbanized waterfront, intensively used, and vital to the economics of Hawaii. According to a study by the State of Hawaii Department of Business, Economic Development & Tourism (2003): “Waikiki remains the flagship of the state’s tourism industry...with 45% of all visitor units.” Its visitor industry supports 8% of the Gross State Product. “Directly and indirectly, the small, one-square mile area of Waikiki can be associated with supporting about 11% of all civilian jobs in the state and 12% of state and local tax revenue.”

Many works and events are listed in the *Chronology of Significant Coastal Events at Waikiki, 1825-2007*, an appendix at the end of this paper (update of Wiegel 2002; 2005). Small-craft harbors

have been developed, with basins and navigation channels dredged in the reef. Many seawalls have been constructed. Eighty-one structures along the shore were listed in a 1950 report (USACE, Honolulu District 1950); seawalls, groins, piers, storm drains. This list was updated, with the status of each structure given, in a University of Hawaii report by Crane (1972). Several of the structures can be seen in a 1932 aerial photo, Figure 19; the reach between the Royal Hawaiian Hotel and the Ala Wai Canal entrance. Additional data on structures are in reports by Gerritsen (1978), and by Edward K. Noda and Associates, Inc. (July 1991). Narrow beaches have been widened with carbonate sand, mostly brought from other parts of Oahu or Molokai (USACE, Honolulu District 1963; U.S. Congress 1965; Moberly *et al.* 1965; 1975). Several beaches have been constructed of coral rubble and crushed coral base, with the material dredged from the reef — topped with carbonate sand brought by truck (Campbell and Moberly 1978; Thompson 1985). Structures have been built to try to hold the sand on the shore. Beach erosion control studies, and beach restoration recommendations are available in several reports (e.g., Engineering Association of Hawaii 1927; U.S. Army, Corps of Engineers, Honolulu District 1950 and 1963; U.S. Congress 1953 and 1965; Gerritsen 1978; Edward K. Noda and Associates Inc. 1999, as given in Bodge 2000; Bodge 2000).

*The guidelines were — preserve the breakers for surfing, provide a sand blanket to cover the inshore coral, and stabilize a dry beach for sunbathing.* (O'Brien 1938, as given in Thompson 1985).

Another comment by O'Brien as a result of his investigation of Waikiki Beach for the USACE Beach Erosion Board in 1938, given by Thompson (1985) is:

"...Although he talked to people who had known Waikiki for many years, (sic, O'Brien) was still uncertain whether the beach had eroded. He was not sure if the beach had actually been lost or if the many structures there covered the original beach... Seawalls had been built along most of the beach and the local opinion blamed them for the erosion. O'Brien wondered though if they weren't the consequence rather than the cause."



**Figure 14.** Halekulani, Sheraton Waikiki, Royal Hawaiian (and long curved groin), Moana Surfrider, Moana Hotels; Halekulani "sand channel" at left; aerial photo, cloudy, 30 January 1999. (By R.L. Wiegel, #9524.)

**Figure 15.** Vertical aerial photo of Fort DeRussy, 21 November 1919; narrow channel dredged in reef connecting to dredged channel in front of new beach. Note diving tower at left. (U.S. Army Museum of Hawaii, USAMH No. 2078.)



From a study of reports, newspaper articles, photographs, personal knowledge, and a review of other situations, the author concludes (Wiegel 2002) that most, if not all, of the seawalls at Waikiki Beach have been built as part of, or because of, encroachment on the shore, mining of sand and removal of "coral," and/or erosion/recession caused by other anthropogenic and natural actions.

Information on the several reaches of shore follows.

**Natatorium; and Sans Souci (Kaimana), Outrigger Canoe Club and Elks Club Beaches.** These can be seen in the aerial photograph, Figure 6.

The War Memorial Natatorium was completed in 1927, at the site of the old W.G. Irwin home (Hibbard and Franzen 1988). An 1886 photo (Bishop Museum,

Neg. No. CP 126,423) shows this and the adjacent Mitchell house at the edge of, or on, a narrow beach. The Irwin home location is shown on the 1907 Dove Map, Figure 10. The Natatorium is about 375 feet long, and extends into the ocean about 200 feet (U.S. Congress 1953; Gerritsen 1978). It is a salt water swimming pool, and the depth of water varies with the tide. It is the subject of political controversy (demolition or major restoration), and its status is still being debated.

The reach between the War Memorial Natatorium and the Elks Club is about 1,000 feet (U.S. Congress 1965). The beaches are small, but larger than in the past. The present Outrigger Canoe Club building was built here in 1963. Clark (1977) says sand excavated as part of the construction of the new buildings was



**Figure 16. Oblique aerial photo of Fort DeRussy, Ala Wai Yacht Harbor, Ala Moana Beach Park, 28 July 1938, Dredged channels parallel to shore are evident. (U.S. Army Museum of Hawaii, USAMH No. 2789.)**

placed on the beach. Two 1962 photographs by Alex William Photography show coarse sand and carbonate pebbles and cobbles. [These photos are in Wiegel (2002); from the Outrigger Canoe Club Historical Committee archives.] About 1,660 cubic yards of coral fill and 6,000 cubic yards of sand, 2½ feet thick, were placed to a maximum elevation of 7 feet near the seawall (U.S. Congress 1965). The Outrigger Canoe Club constructed a rubblemound groin in front of the Colony Surf apartment building. Crane (1972) refers to it as the Colony Surf groin, built in 1963; length 190 feet, width 10 feet, elevation between 8.1 and 3.7 feet.

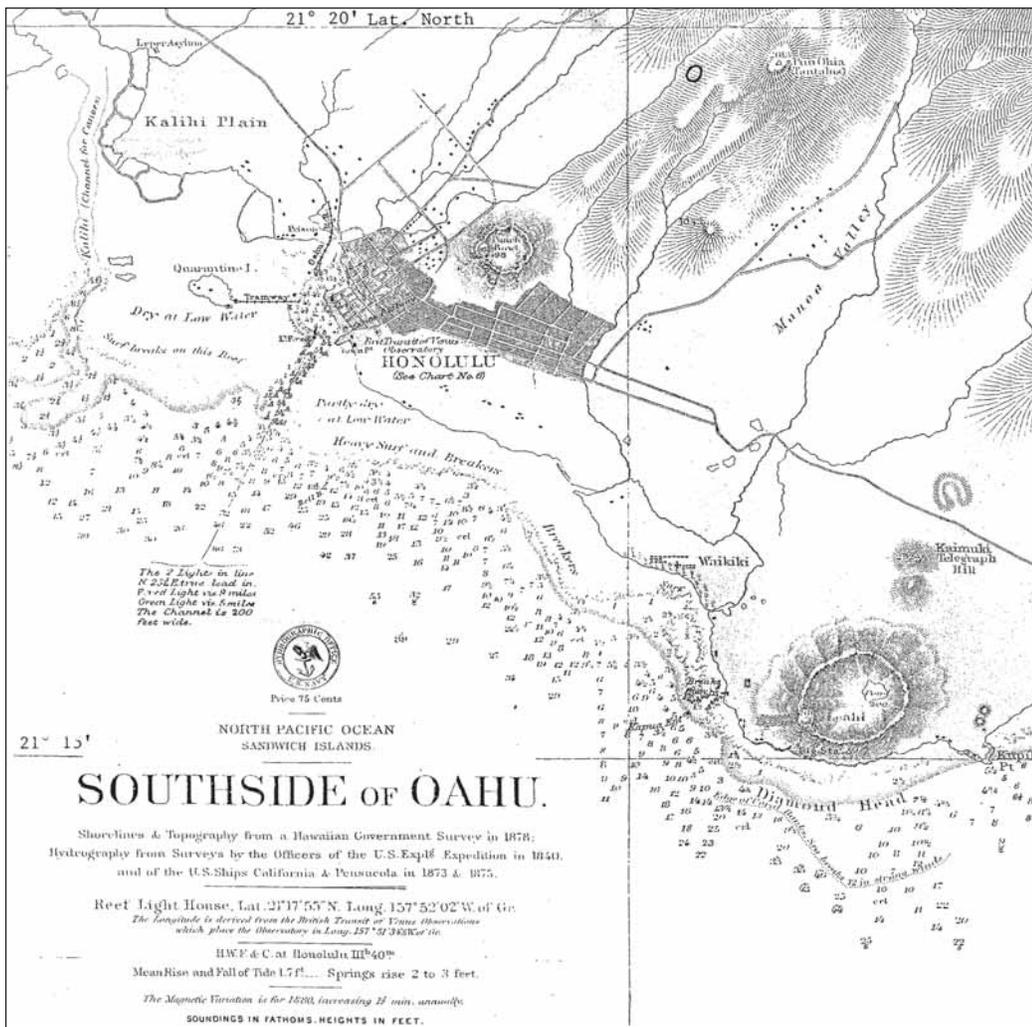
[As an aside, when the author visited Sans Souci Beach on 6 February 2002, sand was observed being moved by use of a front-end loader from where it had accumulated at the east side of the Natorium, to the southeast end of the beach from where it eroded; a photo of this work is in Wiegel (2002).]

The original Sans Souci Hotel was located here, probably at the site of the present Kaimana Beach Hotel. A 1902 photo (Bishop Museum Neg. 2322), taken from the original pier at Sans Souci shows a one-story small structure on concrete piles, extending over the water, and no beach. Two photos circa 1910 of the McInerny property (in Hibbard and Franzen) show a seawall along part of the property and thick vegetation on the Diamond Head side extending to the ocean's edge.

The Outrigger Canoe Club and the Elks Club are on the site of the former James B. Castle home, which was built in 1899 at Kalehuawehe Point on the site of the earlier Park Beach Hotel (Grant 1996). A photo of the Castle mansion (by Hedemann, in Bishop Museum, Neg. No. 78098) shows the seaward part built over water on piles, with seawalls along the front on both sides; and no visible sand beach.

The Outrigger Canoe Club dredged an access channel 4½ feet deep (U.S. Congress 1965). AECOS Inc. (1979) says it provides access from the canoe club's anchorage to the Kapua Entrance.

Kapua Entrance is a natural channel through the reef that extends nearly to shore here. It is shown on the 1880 chart of the U.S. Navy Hydrographic Office, Figure 17. [Historic note. The first submarine communication cable between San Francisco and Honolulu was brought ashore through the Kapua Entrance (Channel) on 28 December 1902; Clark (1977) says remnants of the old submarine cable can still be found in this channel.] On 23 June 2002, Orville T. Magoon observed the bottom in this channel, using a face mask. He took underwater photos, and one of them showed two cables (2" to 3" in diameter) on the "dead" coral rubble or hard bottom, but the cables were buried at some places. Copies of several of his photos are in



**Figure 17. Southside of Oahu, Sandwich Islands, North Pacific Ocean, 1880. (U.S. Navy Hydrographic Office, No. 867; hydrography from survey in 1840, 1873 and 1875; courtesy Survey Division, State of Hawaii.)**

Wiegel (2002); additional photos are in Magoon (Sept. 2002). He commented that the bottom appeared to be hard, with some rounded cobbles, and some fine sand. He said that very little coral was growing in the channel, but that there was an increasing growth on the reef to the east.

**Kuhio Beach and Kapiolani Park Beach/Queen's Surf Beachs.** In the center of Waikiki are Kuhio Beach Park; and Queen's Surf Beach/Kapiolani Park Beach east of them. Photos of these beaches are in Figures 1, 5, and 6. As mentioned previously, a stream once flowed to the shore here; and much sand was removed from the Kuhio Beach area circa 1910. A 130-foot-long timber pier on piles was built here prior to 1890, and removed in 1934; it was known as Queen Lili'uokalani pier and also as Kuhio pier (Crane 1972).

These are Reaches E, F, and G (1,450, 1,050 and 1,240 feet in length) in the Waikiki Beach area measurements of Edward K. Noda and Associates Inc.

(July 1991). Beach areas obtained from vertical aerial photographs between 1952 and 1990 are presented in Table 1, and beach widths in 1952 and 1990 are in Table 2. The beach sand was brought here from other areas of Oahu. The author is not sure of the total amount of sand that has been placed, as there are discrepancies in the published data.

Loss of sand during storms, and waves breaking over the seawall in 1937, led to action at Kuhio Beach in 1938 (Horton 1948; USACE, Honolulu District 1950; U.S. Congress 1953). 7,000 cubic yards of sand were placed on the beach in 1939 to widen it to 150 feet. A shore-parallel breakwater 650 feet long was built about 200 feet offshore, with the crest at about MLLW. Shore return structures were built at each end of the breakwater to help retain the sand. This is known as the "crib wall." Coral patches between the breakwater and the shore were cleared by a dragline excavator. This project and the road-retaining seawall along Kalakaua Avenue can be seen in the center of Fig-

ure 11, an aerial photo circa 1940. Note the absence of a dry sand beach in front of part of the seawall. Before-and-after photos of the beach in 1939 are in Figures 20a and 20b. These Beach Erosion Board photos are in Horton (1948), together with a photo taken in December 1947.

When Horton made his inspection of Kuhio Beach in December 1947, he noted there had "been a considerable loss of sand fill from the beach in the 8 years since its artificial placement. The results are considered satisfactory, however..."

In March 1951 an additional 107,000 cubic yards of sand was brought by truck and placed along this section and a little easterly of it (Wachter 1958). The 355-foot-long Kapahulu storm drain was built, 19 feet wide, top elevation 8.5 feet (Crane 1972), which functions as a groin. In 1953 the breakwater was extended about 750 feet easterly to the storm drain; it is shore-parallel, seaward of the Kalakaua Avenue seawall (U.S. Congress 1953; Wachter 1958). Sand was brought



**Figure 18. Looking along “new” seawall at Fort DeRussy, toward Diamond Head, circa 1916. Note seawater inland of seawall. (U.S. Army Museum of Hawaii, USAMH No. 4582.)**

to widen the beach along the seawall (quantity unavailable). A swimming area was dredged between the beach and the breakwater. [Note. The breakwater, storm drain, and groins enclosed the beach; but sand is still transported out. According to Edward K. Noda and Associates Inc. (July 1991): “The increased water level within the basin due to wave overtopping causes strong outflows through the openings, scouring deep holes and loss of sand from this enclosed beach system.”]

The project included placing sand along Queen’s Surf Beach (quantity unavailable).

An aerial photo in Grant (1996; Baker-

VanDyke Collection) shows the then newly constructed Kapahula storm drain/groin, and the recent sand fill of Kuhio/Queen’s Surf Beaches. The southerly (“Diamond Head side”) Kuhio Beach breakwater was not completed. [This photo was probably taken between July 1951 and July 1953.] Sand was brought from the Bellows Airfield dunes, eastern shore of Oahu, and placed on the beach (U.S. Congress 1963). Note that for Reach F, Kapahulu Drain-Queen’s Surf Groin, Edward K. Noda and Associates Inc. (July 1991; reproduced here in Table 2) list the beach area as 75,400 square feet in the 1952 aerial photo; and 120,800 square feet in the 1990 aerial photo.

In 1966, a model study was made in a wave tank at the University of Hawaii to investigate several proposed changes for Kuhio Beach (Palmer and Kartha 1966).

In 1972-1973 and in 1975 remedial work was done at Kuhio Beach. Plan view drawings are in Figures 21a and 21b (from Gerritsen 1978). This included modification of the crib wall, and adding sand. Gerritsen (p. 29) says that 12,000 cubic yards of sand were placed in 1972-1973; and that 9,500 cubic yards of sand were added in 1975.

A study of the Kapahulu storm drain water was made by Fujioka and Morens (1994). They concluded that while there was no immediate health risk during

**Figure 19. Oblique aerial photo, looking from west boundary of Royal Hawaiian Hotel to Fort DeRussy, Cassidy’s Point, and Ala Wai Canal entrance (at upper left), 2 November 1932. (U.S. Army Museum of Hawaii, USAMH No. 2788.)**





**Figure 20a. Kuhio Beach, 20 May 1939, prior to construction of crib wall breakwater and placement of sand fill. (Courtesy USACE Beach Erosion Board.)**

storm water discharge at the drain, “prudence states that it is not a good decision to allow a storm drain to discharge so close to a swimming area.” A State of Hawaii report (Dept. Land and Natural Resources 2005) says Fujioka and Morens “recommend that the water within Kuhio Beach should have better circulation and that the storm drain water discharge be relocated by extension or by changing the walls and jetties.”

One source of sand for beach fill is offshore. A demonstration project for Kuhio Beach was made in February 2000 (Edward K. Noda and Associates Inc. 2000; Anon. June 2001). About 1,400 cubic yards of sand were dredged from thin deposits (two to four feet thick) in shallow water on the reef, about 1,100 seaward of the breakwater. It was pumped through an eight-inch pipeline along the bottom to Kuhio Beach, and deposited on the beach.

A summary of the actions taken at Kuhio Beach through 2004 was prepared by the Hawaii Department of Land and Natural Resources (DLNR) (January 2005). [Proposed T-head stabilizing headlands, for future replacement of the existing shore-parallel breakwater shown in this report (see also Bodge 2000), have not been implemented.] In the DLNR report they say that: “...today major segments of the beach have little to no sand at high tide and few will disagree that overall, the beach here is in a degraded state.” A study was made of currents at the site to help assess sediment transport pathways at and near Kuhio Beach, using fluorescent dye in the nearshore waters of Kuhio Beach (Eversole 2004).

A larger small scale demonstration project was planned (Hawaii DLNR 2005), to dredge, pump through a pipe, place on Kuhio Beach, and distribute/grade sand from a deposit on the reef flat,

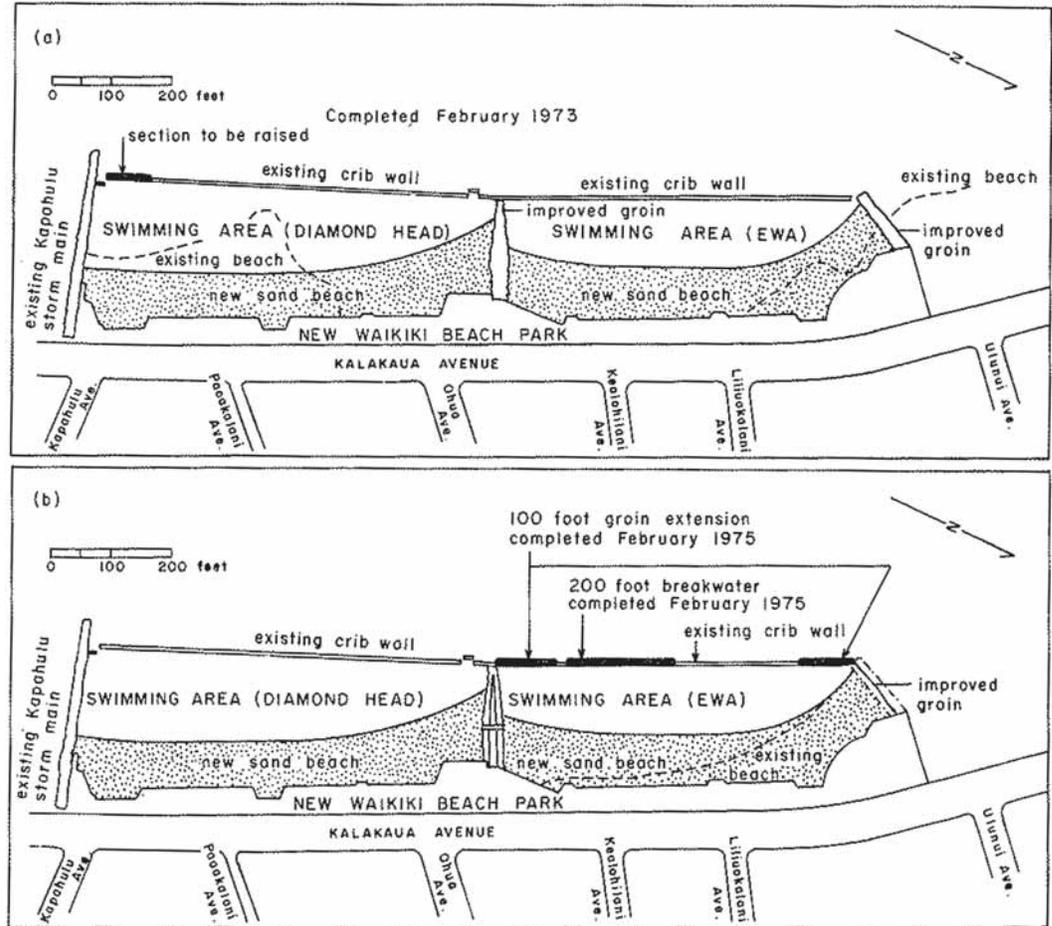
about 2,000 feet offshore. It was scheduled for January-February 2005, but was delayed until October 2005, and delayed again until December 2006 (e.g., *Honolulu Advertiser* staff 2006). Dredging and pumping sand of this project, the Kuhio Beach Nourishment Project, was started on 4 December 2006, and the project completed on 5 January 2007. An estimated total of about 9,000 cubic yards of sand was pumped. The contractor was the American Marine Corporation. Details of the project are available from the Web site of the Office of Conservation and Coastal Lands, State of Hawaii, Dept. Land and Natural Resources (December 2006-January 2007), including color photos before, during and after, at <http://www.hawaii.gov/dlnr/occl/waikiki.php>.

This state project was estimated to cost \$475,000 (*Honolulu Advertiser* staff 2006). The author visited the completed project on 24 January 2007 with Dolan



**Figure 20b. Kuhio Beach, 1939, after construction of crib wall breakwater and placement of sand fill. (Courtesy USACE Beach Erosion Board.)**

Figure 21 a,b. Kuhio Beach improvement plans: (a) 1973 and (b) 1975. (From Gerritsen, 1978, p. 29.)



Eversole (University of Hawaii Sea Grant College Program and Hawaii DLNR). It appeared to be successful, and many people were on the wider beach. An article about the project by Eversole and Lemmo (2007) is in "Coastal Voice," the newsletter of the ASBPA.

The 1,050-foot-long section between the Kapahulu storm drain/groin and the Queen's Surf storm drain/groin is relatively wide. Long, wide storm drains/groins are at each end. Widths and areas are given in Tables 1 and 2, Reach G. The sand was brought to the site from other areas of Oahu.

In 1956-1957, beach work was expanded easterly through Kapiolani Park Beach, the reach between the Queen's Surf storm drain/groin and the Natatorium, about 1,200 feet. The 370-foot-long Queen's Surf storm drain/groin was built in 1956, 15 feet wide, top elevation 4.4 to 6.6 feet (Crane 1972). 32,000 to 35,000 cubic yards of sand were brought to the site and placed on top of a coral base (Wachter 1958). A shore-parallel offshore swimming area was dredged, and the bottom covered with sand. This

beach can be seen in an aerial photo in Wachter (1958), with the caption "Waikiki's Newest Beach." Edward K. Noda and Associates Inc. (July 1991) say that, "Prior to artificial nourishment, there was no dry beach along this reach north of the Natatorium. The 1958 photo shows the beach initially constructed with a fairly uniform width over its entire length, including a groin at the north end to stabilize the reach."

The bathymetry of the swimming channel is shown in Figure 22; this is from a report on the measurement of currents by Professor Gerritsen (1978). [Note. The ebb and flood current patterns are shown on this figure.] At present there is almost no dry sand beach; when the author visited the site on 24 January 2007, it looked like the photo of 6 February 2002, in Wiegel (2002). [Note. The author has not been able to find anything about the large shore-parallel pipeline that can be seen in this photo. Also, Queen's Surf Beach is shown on Figure 22, as used by the USACE, but as mentioned herein the author previously (Wiegel 2002) used this name for the

reach between the two long storm drains/groins.] The lack of a sand beach is probably because of the swimming channel. However, details of the interactions are unknown.

The Waikiki Aquarium is a little northwest of the Natatorium, near the shore; Figure 22. A substantial quantity of sea water is used in the aquarium (AECOS Inc. 1979). It is obtained from a well drilled in the 1950s, just landward of the seawall, and from directly offshore (water about 10 feet deep) through an intake pipe. Sea water is discharged by means of a pipeline running along the same trench as the intake pipe. Details are in Wiegel (2002), from the Aquarium staff via Magoon (31 May 2002).

**Royal Hawaiian-Moana Hotels Beach** can be seen in the photos of Figures 1, 5, and 11. This 1,660-foot-long beach is between the long curved groin at the west side of the Royal Hawaiian Hotel, and the sandbag rubble-mound groin at the westerly end of Kuhio Beach. The beach sand along this slightly concave shore appears to be held by the long curved groin, Figures 1, 11, and 14.

Edward K. Noda and Associates Inc. (1991) give beach toe line data they measured from 15 vertical aerial photographs, 1952-1990, in figures and tables. Their summaries of data on beach areas and average beach widths are given here in Tables 1 and 2. For the Royal Hawaiian-Moana Hotels Beach, they say:

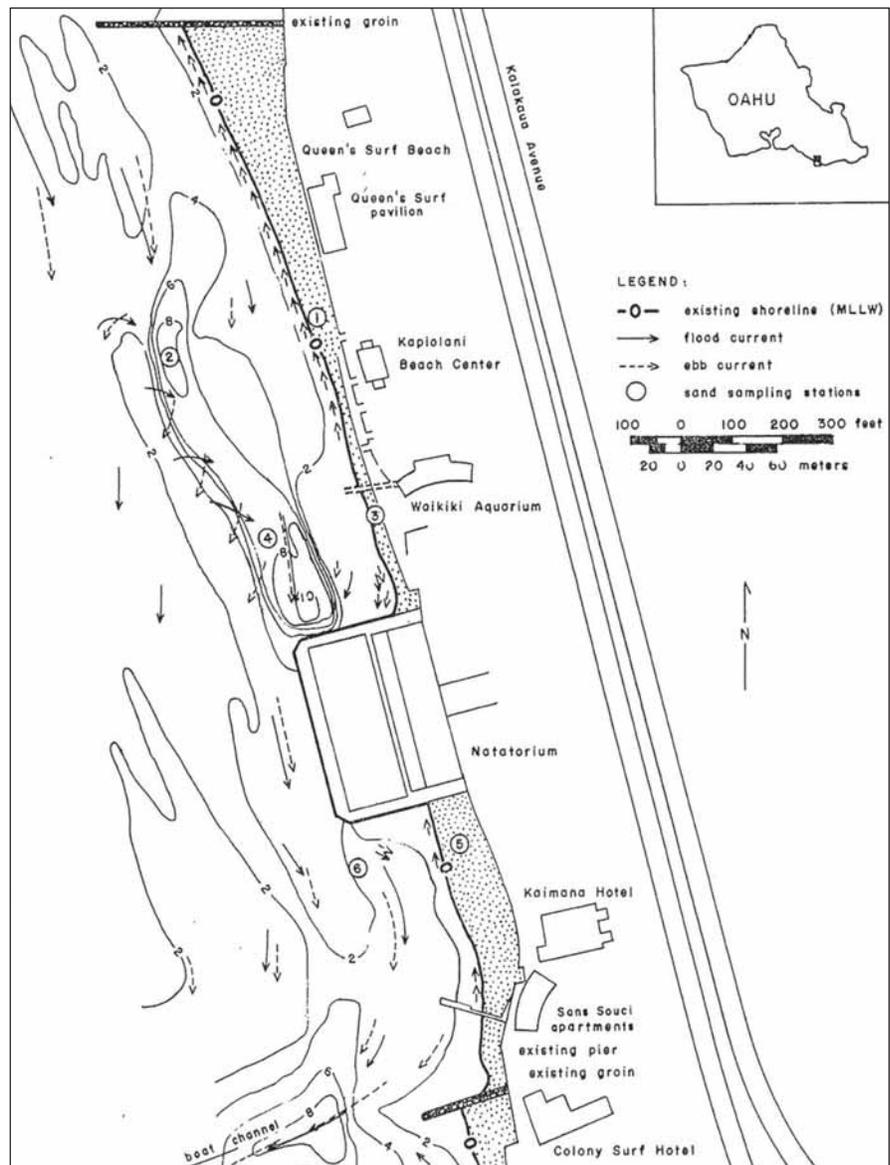
“...a crescent-shaped beach...This reach has shown a long-term trend of increasing average beach width from a minimum of about 70 feet in 1952 to a maximum of about 160 feet in 1982. Present (sic 1991) width is about 125 feet. This beach area has probably gained additional beach sand from transport out of the Kuhio Beach area.”

The center area of reef off these hotels and Kuhio Beach “...has been largely cleared of coral heads for the convenience of swimmers. Sand lies in large patches that seem to shift their position very little, according to older aerial photographs.” (Moberly Jr., Cox *et al.* 1963)

The Moana Hotel opened in March 1901 (Cohen 2000); it is at the site of the W.C. Peabody home which was just east of the Long Branch Bathhouse. Historic photographs, circa 1902-1925, show the hotel dining room extended over the beach almost to the sea’s edge, supported by piles; see Figure 3b. The concrete wings were built in 1917-1918. The 21-story Surfriider on the west side of the Moana opened in 1969. A 240-foot-long timber pier on piles (Peacock Pier; subsequently renamed Moana Pier) was built in about 1890 (perhaps rebuilt in 1901?), Figure 2. It was taken down in 1931 (Crane 1972). The original Outrigger Canoe Club building/boat house and additions were west of the Moana Hotel. Apuakehau Stream flowed into ocean between these buildings; the stream mouth was closed at times, as in the photo of Figure 3b.

The Royal Hawaiian Hotel (the “Pink Palace”) was built in 1925-1926 (Grant 1996; Peralta 2002). It is at the site of the former Seaside Hotel; which is shown in the old postcard of Figure 12. A long groin was built when the hotel was constructed. It was lengthened to 368 feet in 1930, and raised in elevation at an unknown date (Crane 1972); this groin can be seen in Figure 11.

**Halekulani-Sheraton Waikiki Hotels Section.** This 1,480-foot-long reach



**Figure 22. Ebb and flood current patterns around the Natatorium, and bathymetry; Queen’s Surf Beach/Kapiolani Park Beach, and Sans Souci (Kaimana) Beach. (From Gerritsen, 1978, p. 45.)**

of shore was formerly known as Gray’s Beach (Clark 1977). It is between two long groins; the curved groin at the boundary of the Royal Hawaiian Hotel, and the Fort DeRussy storm drain/groin (box culvert) at the “Ewa” side. There is almost no dry sand beach along this slightly convex shore, Figures 1 and 14; nor at the bottom right of the 1932 aerial photo, Figure 19. According to Moberly Jr., Cox *et al.* (1963): “West of the groin at the west end of the Royal Hawaiian Hotel the beach is very narrow, if it is present at all. The reef offshore has few sandy areas, but a moderately large channel filled with sand to a thickness greater than 20 feet does cross the reef offshore from the Halekulani Hotel.” The author has mentioned previously herein a prob-

able reason for the lack of a sand beach here.

Additional data about the sand in the Halekulani sand channel are in Casciano and Palmer (1970); Kerr (1970) as reported in Gerritsen (1973; 1978); Edward K. Noda and Associates Inc. (June 1991); Hampton *et al.* (2002).

Groins were built in this reach, which can be seen in the 1932 aerial photo, Figure 19. When Crane inspected them in 1972, all but one had completely deteriorated or were buried, or nothing remained. The short “YWCA groin” was in reasonable condition, owing to repairs; it is a short distance east of the Fort DeRussy storm drain/groin. A long box culvert/groin at the easterly end of Fort



**Figure 23. Aerial photo looking toward Diamond Head, 1946; Cassidy's Point, lower left and Fort DeRussy, 1946. Note dredged channel in front of Fort DeRussy. (From Isaacs, 1946.)**

DeRussy can be seen on the right side of the aerial photo, Figure 7.

In 1929 an experiment was made to pump sand from the reef flat to the beach here, using a centrifugal pump and a pipeline about 600 feet long (Crane 1972). The experiment worked, but was discontinued as the equipment was not of sufficient size to be efficient.

**Fort DeRussy Beach.** An aerial photo looking toward Diamond Head from offshore Cassidy's Point shows Fort DeRussy in 1946, Figure 23. Compare this with the 1999 aerial photo, Figure 7.

The early work at Fort DeRussy has been described in a previous section. In 1957 "one severe storm caused the beach to virtually disappear" (USACE, Honolulu District 5 May 1975). A postcard of an aerial photo of Fort DeRussy, circa 1967 (Dexter Press), shows four groins with evidence of alongshore transport of sand towards "Diamond Head." According to Crane (1972) the groins were removed in 1970. In 1969 a beach construction project was authorized, which was done in 1970. This beach was built in front of the seawall. An aerial photo of the work underway is in Figure 24. The box culvert and groin, which was

built in 1917 at the easterly boundary, can be seen at the top center. The beach, about 1,800 feet long, was made with about 82,000 cubic yards of dredged coral material and concrete debris. Unwashed crushed coral sand was used to cover the fill (Thompson 1985). During construction Waikiki was subject to high winds and waves by a storm on 13-14 January 1970; but there was no damage to the beach or to construction equipment (Yoshimoto 1970).

According to AECOS Inc. (1979), in 1971 a thick layer of silt formed over the shallow reef flat off Fort DeRussy after the crushed coral had been placed on the beach.

In Thompson's book (1985) on the history of the Corps of Engineers in the Pacific, he says the "pulverized coral that had been laid down in the 1960s had compacted into a hard surface, more like an airfield than a beach."

Tune (1975) said:

"In the early 1970s the Corps' spent more than \$1,000 a month to scruff up (sic, scarify) the coral three times a week...the machine looks like a tractor with a giant comb dragging at the rear." Later, the cost increased to \$1,500 a month.

In 1976, a two-foot layer of quality sand was placed on top of the beach (Thompson 1985). Beach maintenance was done in 1981, in 1987, and again in 1994 (following Hurricane Iniki) (USACE, Honolulu District 28 February 1975; 5 May 1975; 23 May 1975; 2 June 1975; 1987; 1993).

A concrete box culvert/groin is between Fort DeRussy and the former YWCA (site of the present Waikiki Shore Apartments); at the easterly ("Diamond Head") boundary of the military reservation. The culvert runs along a 10-foot-wide easement. According to Crane (1972) the concrete storm drain, which was originally built in 1917, was lengthened from 70 feet to 300 feet in 1969, and a rubble-mound/stone-face groin 160 feet long was built against the westerly side of it in 1969. The date 1969 is in error, as owing to a delay, the rubble-mound groin was not completed until July 1971; the crest elevation is +7 feet above MLLW (USACE, Honolulu District 25 Jan. 1972).

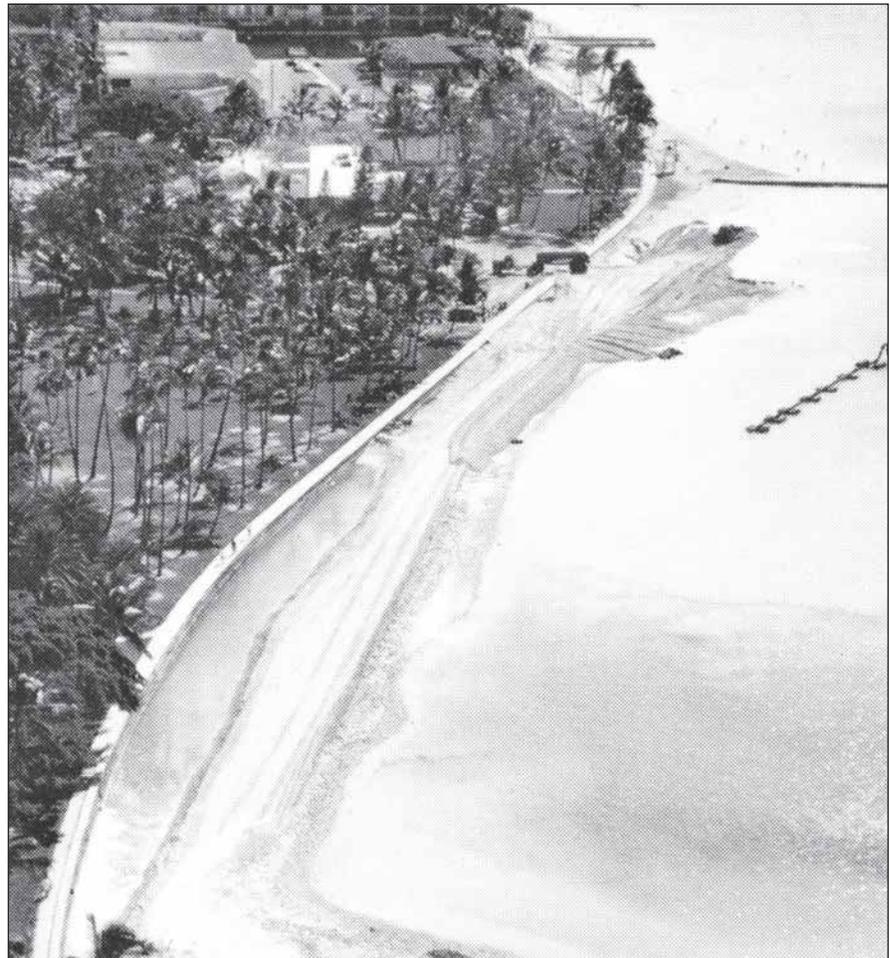
**Duke Kahanamoku Beach and Lagoon; Hilton (originally Kaiser) Hawaiian Village.** This 1,000-foot-long concave shaped beach and lagoon are be-

tween Fort DeRussy and the Ala Wai Yacht Harbor and Canal, Figures 1 and 7. They were constructed in 1956, with a 150-foot wide sandy beach and a 7-foot deep, 150-foot wide swimming basin (U.S. Congress 1965; USACE, Pacific Ocean Division 1971; Edward K. Noda and Associates, Inc. July 1991). The beach and lagoon were manmade, a dredging and sand filling joint venture of the Board of Harbor Commissioners and Henry J. Kaiser (Clark 1977).

The lagoon was made by placing sand around the then open water areas, completely enclosing it (Edward K. Noda and Associates Inc. July 1991). Water was pumped from the lagoon into the Ala Wai Yacht Harbor; and water flowed from the ocean into the lagoon through two 36-inch diameter pipes. This provided circulation of the lagoon's water. At present (2006/2007) the Hilton Hawaiian Village Lagoon Restoration project is under way. This is a project of the Hilton Hotels Corp., by an agreement with the city and county of Honolulu (Eversole April 2007; Dingeman 2007). It includes restoration of water quality in the lagoon. Several wells have been installed to obtain clean sea water (and no marine organisms) from the ground water, rather than directly from the ocean as it was originally; about 15,000 gallons of salt water per minute, a water turnover of about five times per day. Storm water flows into the lagoon have been eliminated. A geotextile barrier was placed on the existing mud bottom of the lagoon, and a layer of clean sand was placed on top of the barrier and beach; 33,000 tons of sand.

The catamaran dock basin and narrow navigation channel to the ocean were dredged in the reef (Kaiser-Burns Development Corp. 1950s; USACE, Honolulu District 5 May 1975). A map by Kaiser-Burns Development Corp., dated 31 May 1960, in the USACE, Honolulu District files shows soundings taken in the basin in 1956, just after completion of the dredging. The navigation channel is shown on a map dated 20 July 1959 (Kaiser-Burns Development Corp. undated, but probably 1959).

The beach is protected by a narrow curved portion of reef between the two basins that was not dredged; it was left to function as a submerged breakwater. In 1963 a groin/breakwater was built at



**Figure 24. Fort DeRussy Beach; restoring sand beach, 1970 aerial photo; box culvert/groin near top (From Thompson, 1985, p. 259.)**

the west end of the beach and a long culvert/groin at the east end (USACE, Honolulu District 5 May 1975).

Sand was added to the beach berm in 1958. In 1966, a third sand fill of 2,500 cubic yards was placed on the berm (Yoshimoto 1970).

This beach was constructed at the site of the former Niualu Hotel, which was established in 1926 at the location of the Pierpont Hotel, Hummel's Court, Cassidy's Court, and Cressaty's Court (e.g., Grant 1996). A point and a pier are shown on the 5 May 1927 USC&GS Chart 4132; and the point can be seen at the upper left of the 1932 aerial photo, Figure 19, adjacent to Fort DeRussy, and at the lower left of the 1946 aerial photo, Figure 23. In the Engineering Committee on Waikiki Beach Improvement report (Engineering Association of Hawaii 1927), it is said:

“The effects of a groyne are evident at Cassidy's Point, where by gradual extensions of a barrier built of rock, palm

leaves, trash and sand bags, the high water line was advanced 300 feet beyond the original high water line. This reclaimed land is now enclosed by a sea wall and occupied....The barrier was so constructed that the sand accumulated on the Waikiki side only.”

[See also U.S. Congress (1953).] A 1920 photo of this point, seawall, walkway, and short observation pier are in Grant (1996).

**Ala Wai Yacht Harbor** was constructed in increments, beginning in 1935 with a basin dredged in the reef at the mouth of the Ala Wai Canal (USACE, Pacific Ocean Division 1971). Prior to this, small craft were moored in the Ala Wai Canal, with access being a shore-parallel navigation channel which had been dredged in the reef between it and Kewalo Basin in 1928. Aerial photos are shown in Figures 1, 7, and 16. A chart in Horton (1948) shows this channel with a notation “dredged to 12 feet.” In 1952, an entrance channel was dredged directly across the reef to the ocean (Wachter

**Table 1. Waikiki Beach areas, 1952-1990 (square feet).**

(From Edward K. Noda and Associates Inc., July 1991, p. 6).

Month/year	Reach A 1100 LF	Reach B 1700 LF	Reach C 1450 LF	Reach D 1670 LF	Reach E 1450 LF	Reach F 1050 LF	Reach G 1240 LF	Reach H 630 LF	Total 10,290LF
9/52	0	63,100	27,100	120,200	126,600	75,400	0	12,900	425,300
1/58	171,400	56,600	69,400	131,500	141,700	93,800	105,400	?	769,800+
1/66	202,400	68,700	50,300	184,500	117,200	64,700	65,500	24,800	778,000
?/69	200,900	154,400	70,200	158,700	89,400	77,100	67,100	?	817,800+
11/70	200,400	259,700	62,600	147,600	100,400	82,400	68,800	39,800	961,700
1/72	210,500	271,100	79,300	160,800	105,200	82,300	69,500	28,400	1,007,000
3/75	167,700	225,200	60,000	158,500	130,300	75,300	45,200	25,300	887,600
12/76	215,400	288,500	71,400	206,600	151,600	98,900	58,400	40,300	1,131,100
10/78	201,300	254,500	59,100	193,200	130,800	85,100	38,300	43,800	1,006,100
12/82	227,800	267,400	70,700	269,200	161,400	138,400	47,500	59,000	1,241,200
9/83	223,500	216,200	?	217,600	116,400	132,200	39,700	49,600	995,300+
8/87	200,200	230,100	?	217,600	?	?	?	?	
2/88	207,100	232,600	63,700	221,200	136,500	110,100	39,000	55,700	1,066,000
5/89	?	264,400	83,700	224,500	129,800	119,000	34,000	?	
7/90	193,200	192,200	46,200	209,800	110,700	120,800	31,100	53,600	957,500
<b>NET AREA 1952-1990</b>	<b>193,200 GAIN</b>	<b>129,100 GAIN</b>	<b>19,200 GAIN</b>	<b>89,500 GAIN</b>	<b>15,900 LOSS</b>	<b>45,400 GAIN</b>	<b>31,100 GAIN</b>	<b>40,600 GAIN</b>	<b>532,200 GAIN</b>

REACH A: Ala Wai Harbor-Hilton Pier  
 REACH B: Hilton Pier-DeRussy Groin  
 REACH C: DeRussy Groin-Royal Hawaiian Groin  
 REACH D: Royal Hawaiian Groin-Kuhio Beach

REACH E: Kuhio Beach (within crib walls)  
 REACH F: Kapahulu Drain-Queens Surf Groin  
 REACH G: Queens Surf Groin-Natatorium  
 REACH H: Natatorium-Colony Surf Groin

1958). A hydraulic model study was made of the Ala Wai Yacht Harbor, Magic Island (Aina Moana) complex, Ala Moana Beach Park and Kewalo Basin at the USACE Waterways Experiment Station (Brasfield and Chatham 1967). Improvements were made subsequently by the state of Hawaii (USACE, Pacific Ocean Division 1971; 1975). Recent aerial photos (1998, 1999) are in Figures 1 and 7.

**Ala Moana Beach Park and Magic Island (Aina Moana).** Historic maps and charts, and a topographic map based on 1909-1913 surveys show this region to be coastal wetlands at that time. Prior to 1920 it was known as Kalia (Campbell and Moberly 1978). Ala Moana Park was developed on a swamp and the Honolulu garbage dump (Wachter 1958, Clark 1977). William M. Wachter, Superintendent of Public Works, T.H., made the following statement in his article in *Shore & Beach* (1958):

“The heart of Waikiki is land created by the filling of swamps, marshes, and

duck ponds. Ala Moana Park, Waikiki’s most popular weekend play spot, rests on fill covering an old garbage dump.”

A 2-foot-deep coral fill was placed along the Ala Moana Park seawall in 1934, with a topping of sand. It was not wide owing to the shore-parallel navigation channel that had been dredged in the reef in 1928; see top left of the 1938 aerial photo of Figure 16.

In 1954-1955, reef rubble was dredged and used to fill the old channel, to form a platform on which a 4,000-foot-long beach was constructed; 490,000 cubic yards. 54,455 cubic yards of sand were placed on top, brought from Keawaula Beach (also known as Yokohama Beach), at the northwest corner of Oahu. A new channel for swimming was dredged in the reef seaward of it. Between 1955 and 1976 the beach eroded, and in 1976, about 30,000 cubic yards of sand were brought from a fossil beach ridge (sand dunes) at Mokuleia on the north coast of Oahu, and placed on the beach (Campbell and Moberly 1978).

An aerial photograph of the reach, circa 1981, is shown in Figure 13 (from Gerritsen 1981).

Magic Island (Aina Moana) is a peninsula, not an island; see the aerial photos of Figures 7 and 13. It is between the Ala Wai Canal and Yacht Harbor, and the Ala Moana Beach Park. Substantial changes were made from the more extensive original plan for the Ala Moana Reef (Belt, Collins & Associates Ltd. 1961). It was constructed of fill placed on 30 acres of the reef flat, and completed in 1964 (Belt 1963; Nance and Hirota 1974). Most of the fill came from the coral dredged from a future boat slip outboard of the Ala Wai Yacht Harbor. Two small beaches were made with sand brought from another part of Oahu and from Molokai. Both beaches can be seen in Figures 7 and 13, and a narrow channel parallel to the new western shoreline which was dredged across the reef. Detached breakwaters were constructed to protect the “outer beach.”

[As an aside, the light-draft harbor

**Table 2. Summary comparison of Waikiki Beach areas and average beach width 1952 and 1990.**

(From Edward K. Noda and Associates Inc., July 1991, p.10.)

SECTION OF BEACH	BEACH AREA (SQ.FT.)		AVG. BEACH WIDTH (FT.)		CHANGE (+/-) AREA (SF) WIDTH (FT)
	1952	1990	1952	1990	
REACH A: Ala Wai Harbor-Hilton Pier	0	193,200	0	175	+193,200 +175
REACH B: Hilton Pier-DeRussy Groin	63,100	192,200	37	113	+129,100 +76
REACH C: DeRussy Groin-Royal Hawaiian Groin	27,100	46,200	19	32	+19,200 +13
REACH D: Royal Hawaiian Groin-Kuhlo Beach	120,200	209,800	72	126	+89,500 +54
REACH E: Kuhlo Beach (within crib walls)	126,600	110,700	87	76	-15,900 -11
REACH F: Kapahulu Drain-Queens Surf Groin	75,400	120,800	72	115	+45,400 +43
REACH G: Queens Surf Groin-Natatorium	0	31,100	0	25	+31,100 +25
REACH H: Natatorium-Colony Surf Groin	12,900	53,600	21	85	+40,600 +64
<b>TOTAL REACH A-H (10,290 LF)</b>	<b>425,300</b>	<b>957,500</b>	<b>41</b>	<b>93</b>	<b>+532,200 +52</b>

Kewalo Basin was constructed in 1945. It is at the site of the small basin which is shown on U.S. Coast & Geodetic Survey Chart 4132, May 5, 1927. The present berthing basin was dredged in the reef, and a navigation (entrance) channel dredged across the reef (USACE, Pacific Ocean Division 1971).]

**BEACH WIDTH AND AREA CHANGES; MEASUREMENTS FROM VERTICAL AERIAL PHOTOS**

Shoreline changes were investigated by Edward K. Noda and Associates Inc. (July 1991). The data are in their report *Coastal Processes and Conceptual Design Considerations for Waikiki Beach Improvement*. Detailed data from 15 vertical aerial photographs are in several figures and a large insert in their report. Their summaries of beach areas and average beach widths are reproduced herein as Tables 1 and 2.

One of the reviewers referred to a later study, of which the author was not aware. This work, by Miller and Fletcher (2003), includes data from aerial photos (1951, 1970, 1975, 1985, 1992, 1999, 2001) and

a series of twenty-two cross-shore beach profiles surveyed in 2000-2002.

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## APPENDIX:

### Chronology of significant coastal events at Waikiki, 1825-2007

1825. Waiatite (Waikiki) depicted on the chart "Sandwich Islands. South Coast of Woahoo and Honoruru Harbour," surveyed by Lieut. C.R. Malden, R.N., Hydrographic Office of the Admiralty, Great Britain; first printed 1841; corrections, 1857.
- 1837, 7 November. Tsunami (source, Chile).
1866. King Kamehameha V oceanfront house at Waikiki.
1868. Tsunami. Reef bared at Waikiki.
1877. Kapiolani Park opened; Waikiki Road to its entrance.
- 1880, circa. Bridge/ causeway built (across Ku'ekaunaki Stream mouth), at entrance to Kapiolani Park; at edge of ocean.
1880. North Pacific Ocean, Sandwich Islands, Southside of Oahu, chart by U.S. Navy Hydrographic Office; extensive updates April 1891, July 1892.
1881. Long Branch Baths built on beach, at the water's edge.
- 1881, 1888. Map of Waikiki, S.E. Bishop.
1890. Seawall (highway retaining wall) 390-foot long built to protect Waikiki Road (renamed Kalakaua Avenue in 1905) - replaced part of bridge and causeway near entrance to Kapiolani Park.
- 1890, circa. Pier built at Queen Liliuokalani's beach property.
1890. W.C. Peacock pier built (later called Moana Hotel pier).
- 1895, circa. Waikiki Villa built, encroached on beach berm; part built on piles over beach face.
1897. Map of Waikiki, M.D. Monsarrat.
1898. Sans Souci Hotel opened. Partly on piles over water.
1899. James B. Castle home built, partly on piles; seawall.
- 1900, prior to. 867-foot long highway retaining wall (seawall) built along Waikiki Road (renamed Kalakaua Avenue 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).
1904. Original aquarium opened.
1905. Waikiki Road renamed Kalakaua Avenue.
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.
1907. "Public Baths" built on shorefront, partly on piles, in Kapiolani Park; coral removed from offshore, and bottom deepened.
1907. Map of Honolulu, with details of Waikiki, by Chas. V.E. Dove.
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 nearshore sea-bathing areas.
- 1909, circa. Great quantities of sand removed from premises of Queen Liliuokalani, and Fort DeRussy.
1909. Channel probably dredged though reef, to get dredge to Fort DeRussy site.
1909. Fort DeRussy; seawall constructed.
- 1909-1910. Dredging of reef flat for fill of wetlands, in construction of Fort DeRussy.
- 1910, 9 August. Hawaiian Dredging Co. completed its contract to fill in fishponds opposite Fort DeRussy.
- 1909-1913. U.S. Army Engineer survey of Waikiki etc., USGS topographic map of 1917.
- 1909-1914, and other. Apuakehau Stream flooded on occasions, with large quantities of silt and debris transported to shore. Proposals made to divert 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.
1913. Beach eroded in vicinity of Fort DeRussy, in front of Wilder's home, and nearby.
- 1913-1914. Seawalls constructed after beach eroded, between Fort DeRussy and site of future Sheraton Hotel; see below.
1914. Seawall 290 feet long built, probably on Wilder's property.
- 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.
1916. Additional 1150 feet of seawall built at Fort DeRussy seaward of the shore; total length of seawalls probably now 1,775 feet. Area landward of new seawall filled with dredged material, 26,343 cu. yds.
1916. Material dredged from offshore for filling old duck ponds in Fort DeRussy (1,118,656 sq. ft. area, requiring 134,642 cu. yds.).
1916. Seawall 210 feet long built in front of what is now (2002) the Elks Club.
1916. Seawall 208 feet long built in front of what is now (2002) the New Otani Kaimana Beach Hotel.
1917. Fort DeRussy. Concrete box culvert/groin 70-foot long built at "Diamond Head" boundary.
1919. Pan Pacific Association Committee's report on Waikiki Beach problems.
- 1919, prior to, also 1920. Several seawalls built along most (all?) of Kapiolani Park.
1920. Map of Honolulu, Territory of Hawaii, with details of Waikiki, by M.D. Monsarrat.
- 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. Kewalo Basin wharf built and channel dredged in reef.
- 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.
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.
1927. More fill placed in Fort DeRussy.
1927. Engineering Association of Hawaii, Committee on Waikiki Beach Improvement study and report.
1927. The Natatorium built, 375 feet long, extending 200 feet onto reef.
1928. Kewalo Basin - Ala Wai Canal shore-parallel navigation channel dredged in reef.
1929. YWCA groin built, 110 feet long.
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.
1934. Ala Moana Park. Coral fill, topped with sand placed along the entire length of seawall, just landward of the shore-parallel boat (navigation) channel.
1935. Ala Wai Yacht Harbor (original) constructed by dredging in the reef.
1937. Severe wave action; beach eroded, seawalls overtopped.
1938. Kuhio Beach. 700-foot-long shore-parallel breakwater (crest at about MLLW) constructed; known as the "crib wall."
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.
1945. Kewalo Basin enlarged; berthing basin and entrance channel dredged in reef.
- 1946, 1 April. Tsunami (source, Aleutian Islands) caused reef to be "bared" during wave drawdowns; seawalls overtopped during runups.
1951. 110,000 cubic yards of sand imported and placed along shore between the Breakers (about 1,000 feet southeasterly of the Kapahulu storm drain/groin) and the "crib wall" northwesterly of Ohua Avenue.
1951. Ala Wai Entrance navigation channel dredged through reef to deep water.
1951. Kapahulu storm drain/groin built; 355 feet long, 19 feet wide, top +8.5 feet above MLLW. An extension of an earlier drain.
1951. Seawall ("terrace wall") built southeasterly from Kapahulu storm drain/groin, 425 feet long.
- 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 (see above).
- 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).
- 1954-1955. Ala Moana Beach Park. Reef rubble dredged to fill old navigation channel, 490,000 cubic yards; 54,000 cubic yards of sand placed on top for a beach, brought from Yokohama Beach.
- 1954-1955. Ala Moana Beach Park. New swimming channel dredged in reef, parallel to new beach along entire reach, extending from 400 to 500 feet offshore.
1955. Present aquarium built.
1956. Duke Kahanamoku Beach and Lagoon constructed on reef flat, with a 150-foot wide, 7-foot deep, swimming area offshore the beach. A strip of shallow reef left in place while dredged on both side, between the structures at both ends (see below).
1956. Duke Kahanamoku Beach. A long groin built to hold western end, and a long storm drain/groin built to hold eastern end of beach fill.
1956. Pier and dock built from end of the storm drain/groin at the eastern end of Duke Kahanamoku Beach, and basin - 5 to -8 feet below MLLW dredged for large catamaran. [Narrow channel probably dredged through reef from basin to deep water]
- 1956-1957. Queen's Surf Beach groin/storm drain built, 360 feet long.
1957. Kapiolani Park Beach. Between 32,000 and 35,000 cubic yards of sand placed on coral base.
1957. Kapiolani Park Beach. Shore-parallel swimming basin dredged in reef and covered with sandy bottom, just northwesterly of The Natatorium.
- 1957, 9 March. Tsunami (source, Aleutian Trench).
1958. Catamaran pier extended at Kaiser Hawaiian Village (Kahanamoku Beach), and basin deepened to -12 feet below MLLW; probably.
1959. Kuhio Beach. 18,757 cubic yards of sand fill placed.
1959. Hurricane Dot
- 1960, 23 May. Tsunami (source, Chile) caused reef to be "bared" during wave drawdowns; seawalls overtopped during run-ups.
- 1960s. Fort DeRussy. Pulverized coral placed as a beach, which became "more like an airfield than a beach."
- 1962-1964. Magic Island (actually a peninsula) constructed on 30 acres of reef flat. Two beaches made, the "inner beach" and the "outer beach." Detached rubble mound breakers built seaward of the "outer beach" to protect it and to provide a swimming basin.
- 1962-1964. Narrow channel dredged parallel to northwest side of Magic Island, through most of reef.
- 1962-1964. Stone seawall built along "Diamond Head" side of Magic Island and the Ala Wai entrance channel to hold fill.
1963. Outrigger Canoe Club (new - at Sans Souci/Kaimana Beach), 1,660 cubic yards of coral fill and 6,000 cubic yards of sand from foundation excavation placed on beach.
1963. Connecting channel 4½ feet deep dredged in reef, new Outrigger Canoe Club.
1963. A 75-foot-long rubble mound spur jetty built at right angle to the stone seawall along the Ala Wai entrance channel.
1963. Groin, 190-feet long, built a little "Ewa" of the new Outrigger Canoe Club.
1963. Bagged concrete groin at northwest end of Kuhio Beach extended.
- 1964, 24 March. Tsunami (source, Alaska).
1966. Maintenance dredging of silt from Ala Wai Canal.
1968. Kuhio Beach. Sand bag groin at western end of beach extended.
- 1969-1972. Groin built in front of Elks Club.
- 1968-1970. Fort DeRussy. Beach 1,800 feet long constructed in front of seawall; 82,000 cubic yards of coral material dredged from reef (U.S. Navy's stockpile) and concrete debris as base; unwashed crushed coral sand used to cover the fill.
1970. Storm drain box culvert extended in length from 150 to 418 feet. At eastern ("Diamond Head") boundary of Fort DeRussy.
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 and (?) Queen's Surf Beach sand fill of 82,500 cubic yards (quantity not certain).
1972. Highway retaining seawall (Kalakaua Avenue) removed.
1972. Beachwalk park begun, a "linear park" between Kalakaua Avenue and Kuhio and Queen's Surf Beaches.
1975. Kuhio Beach. 9,500 cubic yards of sand placed.
1976. Fort DeRussy. Layer of sand 2 feet thick placed over the beach.
1976. Ala Moana Beach Park. 30,000 cubic yards of sand placed on eroded beach.
1978. Maintenance dredging silt from Ala Wai canal.
1981. Beach restoration (maintenance), Fort DeRussy.
1982. Hurricane Iwa.
1982. Sans Souci pier destroyed as a result of Hurricane Iwa.
1987. Beach restoration (maintenance), Fort DeRussy.
1991. Queen's Surf Beach. Sidewalk improvements made following alignment near the 1952 beach backshore line, reducing beach area.
1992. Hurricane Iniki. Waves inundated seaward edge of Ala Moana Beach Park.
1994. Beach restoration (maintenance), Fort DeRussy, and Hawaiian Village (Duke Kahanamoku Beach).
2000. Kuhio Beach. 1,400 cubic yards of sand dredged from thin pocket in reef offshore and pumped through a pipeline to the beach.
2000. SHOALS bathymetry survey of Waikiki, and other shallow water coastal regions of Hawaii, made jointly by the U.S. Army Corps of Engineers and U.S. Navy.
2002. Sand moved by front-end loader in Feb. from west end of Kaimana Beach (where it accumulated) to east end (from where it had eroded).
- 2002, 22 August-8 October 2003. Maintenance dredging of silt (and trash and debris) from Ala Wai Canal (185,801 cubic yards).
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.
- 2006, 3 October. Exploring idea to create a new lagoon-type beach next to the Waikiki Aquarium; by Hawaii State Dept. Land and Natural Resources.
- 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 cubic yards of sand dredged and pumped to beach; grading completed.
- 2006-2007. Hawaiian Village Lagoon Restoration project

## REFERENCES

- AECOS Inc., *O'ahu Coral Reef Inventory. Part B - Sectional Map Descriptions*, prepared for the U.S. Army Corps of Engineers, Pacific Ocean Division, v.07/79, 1979 of 1981?, 552 pp.
- Anon., "Army Engineers Look into Widening Waikiki Beach," *Maui News*, 3 June 2001.
- Anon., "The History of Today, Jan. 17, 1917. Beach Boulevard is Proposed by James Wakefield," refers to Jan. 17, 1917 *Pacific Commercial Advertiser, Honolulu Advertiser*, 17 January 2006, p. B1.
- Anon., "The History of Today, August 9; 1910," Pacific Commercial Advertiser report on fill of fishponds opposite Fort DeRussy in Waikiki, *Honolulu Advertiser*, 9 August 2006, one short paragraph.
- Belt, Collins & Associates, Ltd., and Harland Bartholomew and Associates, *The Comprehensive Plan, Ala Moana Reef*, prepared for Hawaii Department of Land and Natural Resources, Honolulu, HI, 1961.
- Belt, Robert M., "New Land Worth \$23 Million for Honolulu," *Civil Engineering*, Vol. 33, No. 9, September 1963, pp 60-62.
- Bishop, S.E., *Waikiki Survey and Map, 1881*; map reconstructed by S.E. Bishop, January 1881, copied from Registered Map No. 1398 by Jos. Iao, Oct. 1922 with additions and alterations from Government Survey Records; traced by Herman K. Aki, August 1952. One sheet.
- Blake, Tom, "Modern Surf-riding," In *Men and Waves: A Treasury of Surfing* by Peter L. Dixon, Coward-McCann Inc., New York, 1966, pp 42-57.
- Blakeman, Karen, "Ala Wai Dredging Moves to Next Phase," *Honolulu Advertiser*, 4 November 2002
- Bodge, Kevin R., "Engineering Design for Beach Nourishment," *National Beach Preservation Conference (NBPC 2000) Abstracts*, American Shore & Beach Preservation Association annual conference, Kaanapali, Maui, Hawaii, 6-10 August 2000, a four-page expanded abstract.
- Brasfeild, C.W., and C.E. Chatham, Jr., *Magic Island Complex, Including Kewalo Basin and Ala Wai Boat Harbor, Honolulu, Hawaii; Hydraulic Model Investigation*, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Tech. Rept. No. 2-767, April 1967, 139 pp.
- Brown, DeSoto, *Aloha Waikiki. 100 Years of Pictures from Hawaii's Most Famous Beach*, Editors Limited, Honolulu, HI, 1985, 96 pp.
- Buttolph, G.H., a quotation in *Pacific Commercial Advertiser*, May 24, 1913.
- Campbell, Superintendent of Public Works, a quotation in *Pacific Commercial Advertiser*, April 25, 1910.
- Campbell, J. Frisbee, and Ralph Moberly, *Ala Moana Beach Erosion; Monitoring and Recommendations*, Univ. Hawaii, Hawaii Inst. Geophysics, Honolulu, HI, Rept. HIG-78-10, Nov. 1978, 21 pp.
- Casciano, Frederick M., and Robert Q. Palmer, *Potential of Offshore Sand as an Exploitable Resource in Hawaii*, Univ. Hawaii, Dept. Ocean Engineering, Sea Grant 69-4, December 1969, 32 pp.
- Chave, Keith W., Robert J. Tait, John S. Stimson, and Edith H. Chave, *Waikiki Beach Erosion Project: Marine Environment Study. Final Report*, prepared for U.S. Army Corps of Engineers, Univ. Hawaii, Hawaii Inst Geophysics, Honolulu, HI, HIG-73-12, Jan. 1973, 67 pp.
- Clark, John R.K., *The Beaches of O'ahu*, University Press of Hawaii, Honolulu, HI, 1977, 193 pp.
- Cohen, Stan, *The Pink Palace. Royal Hawaiian, Waikiki*, Pictorial Histories Publications Co., Inc., Missoula, Montana, 7th printing, July 1999, 100 pp.
- Cohen, Stan, *The First Lady of Waikiki. A Pictorial History of the Sheraton Moana Surfider*, Pictorial Histories Publishing Co., Inc., Missoula, Montana, 2nd printing, February 2000, 86 pp.
- Committee of the Pan Pacific Association, *Report to the Board of Harbor Commissioners on the Waikiki Problem*, Honolulu, T.H., 1919.
- Cooper, Jeanne, *San Francisco Chronicle*, 9 April 2006, p. F2.
- Crane, J.K., *History of the Marine Structures on Waikiki Beach and Their Effects Upon the Beach*, unpublished report of the Dept. of Ocean Engineering, Univ. Hawaii, Honolulu, Nov. 1972, 69 pp, 8 plates.
- Deming, Harriet N., a quotation in book by George S. Kanahele, 1996, from her unpublished manuscript.
- Dingeman, Robbie, "Hilton Lagoon Revived. Pond Named for Kahanamoku Restored, to Open Next Month," *Honolulu Advertiser*, 17 October 2007, pp C1 and C4.
- Dixon, Peter L., *Men and Waves: A Treasury of Surfing*, Coward-McCann, Inc., New York, 1966, 250 pp.
- Dorrance, William H., "Fort DeRussy," *The Coast Defense Study Group Journal*, Vol. 12, Issue 1, Feb. 1998.
- Dorrance, William H., "Fort DeRussy," *The Coast Defense Study Group Journal*, Vol. 13, Issue 4, November 1999.
- Dove, Chas. V.E., *Map of Honolulu, Hawaiian Islands, 1907*, one sheet.
- Edward K. Noda and Associates Inc., *Sand Source Investigations for Waikiki Beach Fill. Waikiki Beach Improvement Project*, prepared for Hawaii Dept. Transportation, Harbors Division, Rept. No. EKN-1201-R-5-1, June 1991, 23 pp and appendices.
- Edward K. Noda and Associates, Inc., *Coastal Processes and Conceptual Design Considerations for Waikiki Beach Improvements*, prepared for State Hawaii, Dept. Transportation, Harbors Division, Rept. No. EKN-1201-R-5-1, July 1991, 56 pp, four appendices, and one exhibit.
- Edward K. Noda and Associates Inc., *Ala Wai Canal Improvements, Honolulu, Hawaii. Feasibility Report*, prepared for Hawaii Dept. Land and Natural Resources, Division of Water and Land Development, Rept. R-89a, October 1992.
- Edward K. Noda and Associates Inc., *Ala Wai Canal Improvement Project. Test Boring and Monitoring Well Program, Ala Wai Golf Course, Honolulu, Hawaii*, prepared for Hawaii Dept. Land and Natural Resources, Div., Water and Land Development, Rept. R-89e, 6 July 1994, boring logs, and five figures.
- Edward K. Noda and Associates Inc., *Kuhio Beach Improvements. Small Scale Sand Pumping Design Effort, Kuhio Beach, Waikiki, Oahu, Hawaii. After-Action Report*, prepared for Hawaii, Dept. Land and Natural Resources, Land Division, Engineering Branch, 19 April 2000, 16 pp and 5 appendices.
- Engineering Association of Hawaii, *Report of the Engineering Committee on Waikiki Beach Improvement Experiments Conducted at Waikiki Beach During the Summer, Fall, and Winter of 1926*, (Richard Quinn, Committee Chairman, Honolulu, Hawaii, Feb. 11, 1927, 9 pp. This is reproduced as Appendix 1 of USACE Honolulu District (1950).
- Eversole, Dolan, *Results from Current Study Research, September 2004, Nearshore Kuhio Beach, Oahu*, State of Hawaii, Dept. Land and Natural Resources, Office of Conservation and Coastal Lands, seven-page print-out, 18 November 2004. <http://www.hawaii.gov/dlnr/occl/files/waikiki/results.pdf>
- Eversole, Dolan, and Sam Lemmo, "Offshore Sand Recycling on Waikiki Beach," "Coastal Voice," American Shore & Beach Preservation Association, February 2007, pp 6-7.
- Eversole, Dolan, *Information Regarding the Hilton Lagoon Restoration Project at Duke Kahanamoku Beach, Waikiki, Oahu*, Letter to Robert L. Wiegel, from Hawaii Dept. Land Natural Resources, Office of Conservation and Coastal Lands, Honolulu, HI, 20 April 2007, 2 pp and attachment.
- Ferrall, Charles C. Jr., *Subsurface Geology of Waikiki, Moiliili and Kakaako with Engineering Applications*, M.S. thesis, Geology and Geophysics, Univ. Hawaii, August 1976, 168 pp and 5 plates.
- Fletcher, Charles H., III, Eric E. Grossman, Bruce M. Richmond, and Ann E. Gibbs, *Atlas of Natural Hazards in the Hawaiian Coastal Zone*, U.S. Dept. Interior, U.S. Geological Survey, Univ. Hawaii, Hawaii Office of Planning, National Oceanic and Atmospheric Administration, Geological Investigations Series I-2761, 2002, 182 pp.
- Fujioka, J.R. and M.D. Morens, *Assessing the Impact of the Kapahulu Storm Drain System on the Quality of Water at Kuhio Beach and the Health of the Swimmers Using the Beach*, Project Completion Report prepared for Hawaii Dept. Health, Water Resources Center, Univ. Hawaii at Manoa, March 1994.
- Gerritsen, Frans, "Hawaiian Beaches," *Proc. Thirteenth Coastal Engineering Conference*, July 10-14, 1972, Vancouver, B.C., Canada, ASCE, 1973, Vol. II, pp 1257-1276.
- Gerritsen, Franciscus, *Beach and Surf Parameters in Hawaii*, Univ. Hawaii Sea Grant College Program, Rept. UNIHI-SEAGRANT-TR-78-02, June 1978, 178 pp.
- Gerritsen, Franciscus, "Wave Attenuation and Wave Set-up on a Coastal Reef," *Proc. Seventeenth Coastal Engineering Conference*, March 23-28, 1980, Sydney, Australia, ASCE, Vol. I, 1981, pp 444-461.
- Gerritsen, Franciscus, *Wave Attenuation and Setup*

- on a Coastal Reef, Univ. Hawaii, Sea Grant Cooperative Report, UNIHI-SEAGRANT-CR-81-05, March 1981, 416 pp.
- Gonser, James, "Ala Wai Flood Potential Assessed," *Honolulu Advertiser*, 30 June 2004, pp B1 and B6.
- Gonzalez, F.I., Jr., *Descriptive Study of the Physical Oceanography of the Ala Wai Canal*, Univ. Hawaii, Hawaii Inst. Geophysics, Honolulu, HI, Rept. HIG 71-7, 1971, 176 pp.
- Grant, Glen, *Waikiki Yesteryear*, Mutual Publishing, Honolulu, HI, 1996, 92 pp.
- Grigg, R.W., "Coral Reefs in an Urban Embayment in Hawaii: A Complex Case History Controlled by Natural and Anthropogenic Stress," *Coral Reefs*, Vol. 14, No. 4, 1995, pp 253-266.
- Grigg, R.W., "Impact of Point and Non-point Source Pollution on Coral Reef Ecosystems in Mamala Bay," Project MB-9 (30 May 1995), *Mamala Bay Study Final Report*, Vol. II, April 1996, 40 pp.
- Hampton, M.A., C.H. Fletcher III, J.H. Barry, and S.J. Lemmo, "The Halekulani Sand Channel and Makua Shelf Sediments: Are They a Sand Resource for Replenishing Waikiki's Beaches," *Carbonate Beaches 2000*. First International Symposium on Carbonate Sand Beaches, Key Largo, Florida, ASCE, 2002, pp 67-81.
- Hawaii Dept. of Business, Economic Development & Tourism, *The Economic Contribution of Waikiki*, dbedt e-reports, May 2003, 7 pp.
- Hawaii Dept. Land and Natural Resources, *Kuhio Beach Improvements - Facts on Beach History and Engineering Design*, January 2005, 9 pp.
- Hawaii Dept. Land and Natural Resources, Office of Conservation and Coastal Lands, "Waikiki Small-scale Sand Pumping Project," *Kuhio Beach Replenishment Plan*, 5-page printout, 27 May 2005. <http://www.hawaii.gov/dlnr/occl/waikiki/php>.
- Hawaii Dept. of Land and Natural Resources, Office of Conservation and Coastal Lands, "Waikiki Beach Nourishment: A Demonstration of Offshore Sand Recycling," *Sand Bypassing Project at Kuhio Beach*, 4 December 2006 - 5 January 2007. <http://www.hawaii.gov/dlnr/occl/waikiki.php>.
- Hawaii Dept. Planning and Economic Development, *Hawaii's Shoreline*, 1964, 134 pp. There are two appendices to this, Univ. Hawaii, Hawaii Inst. Geophysics reports, Honolulu, listed separately under authors' names.
- Hibbard, Don, and David Franzen, *The View from Diamond Head. Royal Resident to Urban Resort*, Editions Limited, Honolulu, HI, 1986, 221 pp and notes.
- Honolulu Advertiser*, editorial, 14 June 2004.
- Honolulu Advertiser* staff, "Waikiki Sand Plan Waiting Out Waves," *Honolulu Advertiser*, 24 November 2006. <http://thehonoluluadvertiser.com/article/2006/Nov/24/ln/FP6112403>.
- Honolulu Advertiser* Staff, "Waikiki's Beach Gets an Assist," *Honolulu Advertiser*, 28 November 2006, pp B1 and B4.
- Honolulu Star Bulletin*, "Plans to Dam Stream at Outrigger Club," 25 September 1914.
- Honolulu Star Bulletin*, several articles on the Chile tsunami of 23 May, 1960, 23 May 1960.
- Horton, Donald F., "An Engineer Looks at Waikiki Beach," *The Bulletin of the Beach Erosion Board*, USACE, BEB, Vol. 2, No. 2, 1 April 1948, pp 1-7.
- Houston, James R., Robert D. Carver, Dennis G. Markle, *Tsunami-wave Elevation Frequency of Occurrence for the Hawaiian Islands*, U.S. Army Corps of Engineers, Waterways Experiment Station, Hydraulics Laboratory, Tech. Rept. H-77-16, August 1977, 63 pp and 44 plates.
- Hwang, Dennis, *Beach Changes on Oahu as Revealed by Aerial Photographs*, Univ. Hawaii, Hawaii Institute of Geophysics, and UH College Sea Grant Program, Cooperative Report UNIHI-SEAGRANT-CR-81-07, July 1981, 146 pp.
- Hwang, Dennis J., *Hawaii Coastal Hazard Mitigation Guidebook*, Hawaii Dept. of Business, Economic Development & Tourism, Office of Planning, Hawaii Coastal Zone Management Program, January 2005, 216 pp.
- Iida, Kumizi, Doak C. Cox, and George Pararas-Carayannis, *Preliminary Catalog of Tsunamis Occurring in the Pacific Ocean*, Univ. Hawaii, Hawaii Inst. Geophysics, Honolulu, HI, Rept. HIG-67-10, August 1967, 131 sheets (264 pp, unnumbered).
- Isaacs, John D., *Field Report on the Tsunami of April 1, 1946*, a report of the Univ. of California Subgroup of the Oceanographic Section of Joint Task Force One, Univ. California at Berkeley, College of Engineering, Rept. HE-116-216, 3 May 1946, various pagination, mostly photographs. In UCB Water Resources Center Archives.
- Kaiser-Burns Development Corporation, *Proposed Dredging and Catamaran Pier - Application by Kaiser-Burns Development Corp., Hawaiian Village Hotel*, a one-page plan (8-1/2"x11"), 31 May 1960.
- Kanahale, George S., *Waikiki 100 B.C. to 1900 A.D. An Untold Story*, The Queen Emma Foundation, Honolulu, HI, Univ. of Hawaii Press, 1995, 185 pp 1996.
- Kern, David E., *A Study of Sand Movement in the Halekulani Sand Channel off Waikiki, Hawaii*, Plan-B paper, Dept. Ocean Engineering, Univ. Hawaii, Honolulu, HI, 1970.
- London, Jack, "A Royal Sport," from the *Cruise of the Snark*, (1911), as reproduced in *Men and Waves: A Treasury of Surfing* by Peter L. Dixon, Coward-McCann, Inc., New York, 1966, pp 31-41.
- Lyons, Timothy, quotation in a Honolulu newspaper, April 1946; in report by Isaacs (1946), with the name of the newspaper missing.
- Magoon, Orville T., personal communication regarding Waikiki Beach, draft letter to R.L. Wiegel, 24 August 2001, 7 pp.
- Magoon, Orville T., personal communication, *Memorandum for the Record; Re Honolulu Aquarium (at Waikiki) Sea Water Supply*, 31 May 2002, 1 p.
- Magoon, Orville T., personal communication, letter to R.L. Wiegel, 4 September 2002, 1 p., 4 pp appendix, many underwater color photographs, Kapua Entrance channel and Hanauma Bay channel, HI.
- Mamala Bay Study Commission, *Mamala Bay Study Final Report*, (the commission was a component of the Hawaii Community Foundation, Honolulu, HI), April 1996, five volumes (including appendices), various pagination.
- Mamala Bay Study Commission, *Mamala Bay Study Newsletter*, No. 4, Summer 1996, 12 pp (the commission was a component of the Hawaii community Foundation, Honolulu, HI).
- Miller, Tara, and Charles H. Fletcher, "Waikiki: Historical Analysis of an Engineered Shoreline," *Journal of Coastal Research*, Vol. 19, No. 4, Fall 2003, pp 1026-1043.
- Moberly, Ralph, Jr., with sections by Doak C. Cox, Theodore Chamberlain, Floyd W. McCoy, Jr., and J.F. Campbell, *Coastal Geology of Hawaii, Hawaii's Shoreline Appendix 1*, Univ. Hawaii, Hawaii Inst. of Geophysics, HIG Rept. No. 41, Nov. 1963, 216 pp.
- Moberly, Ralph, Jr., David Baver, Jr., and Anne Morrison, "Source and Variation of Hawaiian Littoral Sand," *Jour. Sedimentary Petrology*, Vol. 35, No. 3, Sept. 1965, pp 589-598.
- Moberly, Ralph, Jr., "Loss of Hawaiian Littoral Sand," *Jour. Sedimentary Petrology*, Vol. 38, No. 1, March 1968, pp 17-34.
- Moberly, Ralph, Jr., J.F. Campbell, W.R. Coulbourn, *Offshore and Other Sand Resources for Oahu, Hawaii*, Univ. Hawaii, Hawaii Institute of Geophysics, Rept., Honolulu, HIG-75-10, 1975, 36 pp.
- Moberly, Ralph, Jr., Dept. Geology and Geophysics, Univ. Hawaii, Honolulu, *Letters to Robert L. Wiegel*, 17 October 2001 and 11 November 2001, one page each.
- Nance, Thomas F., and Paul M. Hirota, "Magic Island -- Ten Years After," *Shore and Beach*, Vol. 42, No. 2, Oct. 1974, pp 19-22.
- O'Brien, Morrour P., 1938, quotation in Thompson, 1958.
- Pacific Commercial Advertiser*, "Spoiling the Waikiki Beach. How Honolulu's World-famous Bathing Resort is Being Ruined. Heavy Removal of Sand," April 25, 1910.
- Pacific Commercial Advertiser*, "Seek Aid for Improving Beach. Outrigger Club Would Divert Stream and Install Sunken Garden," May 24, 1913.
- Pacific Commercial Advertiser*, "Big Gun's Muzzle Trained on Oahu. Barge Bearing Giant Cannon Successfully Beached Before Fort De Russy," by Anon., August 6, 1913.
- Palmer, Robert Q., and T.D. Krishna Kartha, *The Kuhio Beach Model*, Univ. Hawaii, Look Laboratory of Oceanographic Engineering, Tech. Rept. No. 22, Dec. 1966, 10 pp and 17 figures.
- Pararas-Carayannis, George, and Jeffrey P. Calebaugh, *Catalog of Tsunamis in Hawaii. Revised 1977*, U.S. Dept. Commerce, NOAA, Environmental Data Service, Rept. SE-4, March 1977, 78 pp.
- Peralta, Dominic, "In the Pink. Celebrating 75 Colorful Years of Royal Hawaiian History," *Hana Hou!*, Magazine of Hawaiian Airlines, Vol. 5, No. 1, February/March 2002, pp 49-52.
- Shepard, F.P., G.A. McDonald, and D.C. Cox, "The Tsunami of April 1, 1946," *Bulletin of the Scripps Institution of Oceanography*, Univ. California, La Jolla, CA, Vol. 5, No.

- 6, 1950, pp 391-528, plates 6-33, 21 figures in text.
- Stearns, Harold T., *Geologic Map and Guide of the Island of Oahu, Hawaii* (with a chapter on mineral resources), Hawaii Div. Hydrography, Bulletin 2, August 1939, 75 pp, map.
- Sullivan, Scott, and Kevin Bodge, "Hawaii Pilot Beach Restoration Project Coastal Investigation," *The National Beach Preservation Conference (NBPC 2000). Abstracts*, American Shore & Beach Preservation Association annual conference, Kaanapali, Maui, Hawaii, 6-10 August 2000, a four-page expanded abstract.
- Thompson, Erwin N., *Pacific Ocean Engineers. History of the U.S. Army Corps of Engineers in the Pacific, 1905-1980*, Pacific Ocean Division, U.S. Army Corps of Engineers, Honolulu, Hawaii, March 1985, 460 pp.
- Titchen, Jack, "Photos at the Catamaran Loading Pier at Hawaiian Village Hotel During Tsunami, 23 May 1960," *The Honolulu Star-Bulletin*, 23 May 1960.
- Tune, Jerry, "Ground Coral Beach. A Hard Lesson at DeRussy," *Star Bulletin*, Honolulu, HI, 25 Jan. 1975, p. 2.
- U.S. Army, Corps of Engineers, Chief of Engineers, *Letter to District Engineer Officer, U.S. Engineer Office, Honolulu, H.I.*, 11 March 1914, 1 page. 1st Ind., from District Engineer Officer, Honolulu, to the Chief of Engineers, 15 April 1914, one page.
- U.S. Army, Corps of Engineers, Chief of Engineers, *Letter to District Engineer Officer, U.S. Engineer Office, Honolulu, Hawaii*, 2 May 1914, one page. 1st Ind., from District Engineer Officer, Honolulu, to the Chief of Engineers, 19 May 1914, one page.
- U.S. Army, Corps of Engineers, Chief of Engineers, *Letter to District Engineer Officer, Honolulu, H.I.*, 5 June 1914. 1st Ind. from U.S. Engineer Office, Honolulu, to Chief of Engineers, 23 June 1914, one page.
- U.S. Army, Corps of Engineers, Honolulu, Hawaii, *Letter to Chief of Engineers*, 19 September 1916, one page.
- U.S. Army, Corps of Engineers, Honolulu District, *Report of Cooperative Study for Beach Erosion Control at Waikiki Beach, Honolulu, Island of Oahu, T.H.*, 1950, 53 pp, seven appendices, 16 plates, seven exhibits.
- U.S. Army, Corps of Engineers, Honolulu District, *Cooperative Beach Erosion Study, Waikiki Beach, Oahu, Hawaii*, 9 August 1963, 26 pp, four tables, two plates, one attachment, four appendices .
- U.S. Army, Corps of Engineers, Honolulu District, *Information on Fort DeRussy Beach*, two-page attachment and three sketches to a letter to U.S. Senator Daniel K. Inouye, from Col. F. M. Pender, District Engineer, 18 February 1975, one page.
- U.S. Army, Corps of Engineers, Honolulu District, *Environmental Assessment, Fort DeRussy Beach Project, Beach Widening Remedial Action*, Colonel F. M. Pender, District Engineer, 5 May 1975, 5 pp.
- U.S. Army Corps, of Engineers, Honolulu District, *Notice of Start of Beach Improvements at Fort DeRussy Beach, Oahu, Hawaii*, 1-page and plan, and "Advanced Notice to Bidders," 23 May 1975. And "Change," by Chief of Engineering Division, 2 June 1975, one page.
- U.S. Army, Corps of Engineers, Honolulu District, *Environmental Assessment for Fort DeRussy Beach Restoration, Waikiki, Oahu, Hawaii*, July 1987, 22 pp, one appendix, and seven attachments.
- U.S. Army, Corps of Engineers, Honolulu District, *Environmental Assessment for Fort Derussy Beach Restoration, Waikiki, Oahu, Hawaii*, December 1993, 19 pp, one appendix.
- U.S. Army, Corps of Engineers, Mobile District, *Oahu, Hawaiian Islands, Waikiki, Color Contour Plot*, SHOALS Bathymetry Survey of August 2000, three sheets, September 2002 and 18 October 2002.
- U.S. Army, Corps of Engineers, Pacific Ocean Division, *Hawaii Regional Inventory of the National Shoreline Study*, August 1971, 110 pp.
- U.S. Army, Corps of Engineers, Pacific Ocean Division, *Hawaii Water Resources Development*, January 1975, 64 pp.
- U.S. Congress, *Waikiki Beach, Island of Oahu, T.H., Beach Erosion Control Study*, letter from the Secretary of the Army transmitting a letter from the Chief of Engineers, United States Army, dated 23 January 1953, submitting a report, together with accompanying papers and an illustration, on a cooperative beach erosion control study of Waikiki Beach, Island of Oahu. T.H., prepared under the provision of Section 2 of the River and Harbors Act approved on 3 July 1930, as amended and supplemented. 83rd Congress, 1st session, House Document No. 227, 3 August 1953, 55 pp and one plate (Plan of Improvement), U.S. Government Printing Office, Washington, D.C.
- U.S. Congress, *Waikiki Beach, Oahu, Hawaii, Beach Erosion Control Study*, letter from the Secretary of the Army transmitting a letter from the Chief of Engineers, Department of the Army, dated 4 June 1964, submitting a report, together with accompanying papers and illustrations, on a cooperative erosion control study of Waikiki Beach, Oahu, Hawaii, authorized by the River and Harbor Act approved 3 July 1930, as amended and supplemented. 89th Congress, 1st session, 8 March 1965, 55 pp and two plates (General Plan), U.S. Government Printing Office, Washington, D.C.
- U.S. Navy Hydrographic Office, *North Pacific Ocean, Sandwich Islands, Southside of Oahu*, chart, 1880, with extensive corrections, April 1891 and July 1892, one sheet.
- Wachter, William M., "The Waikiki Beach Story," *Shore and Beach*, Vol. 26, No. 1, April 1958, pp 21-24.
- Walker, James R., *Recreational Surf Parameters*, Univ. Hawaii, James K.K. Look Laboratory of Oceanographic Engineering, Tech. Rept. No. 73-30, Feb. 1974, 311 pp and five appendices.
- Wiegel, Robert L., *Waikiki, Oahu, Hawaii -- An Urban Beach. Its History from a Coastal Engineering Perspective*, Univ. California, Berkeley, CA, Hyd. Engrg. Lab., UCB/HEL 2002-1, 15 November 2002, 181 pp.
- Wiegel, Robert L., "Waikiki, Oahu, Hawaii -- An Urban Beach. Chronology of Significant Events, 1825-2005," *Coastal Observations, Shore & Beach*, Vol. 73, No. 4, Fall 2005, pp 30-32.
- Wilder, Kinau, *Wilders of Waikiki*, Topgallant Pub. Co., Ltd., Honolulu, HI, 1978, 280 pp, ill., facsimis.
- Yoshimoto, Charles Y., "High Wind and Waves of 13-14 Jan. 70 (Waikiki Beach)," *Memo for Record*, U.S. Army Corps of Engineers, Honolulu District, 26 January 1970, two pages.