Natural History, Hydrology and Water Quality of Enchanted Lake – Kaelepulu Pond

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ABSTRACT

The Kaelepulu watershed once incorporated all of the present day Kawainui (7,175 acres) and Kaelepulu (3,450 acres) watersheds. With only one natural outlet, large storm events would commonly cause flooding across the low elevation sand dune separating the waterbodies from Kailua Bay. In response to the growth of Kailua Town across the sand dune, the USACE constructed the Oneawa Canal (1952) to drain the marsh to the west end of Kailua Bay, and in 1966 completed building the Kawainui Levee. The levee protected Kailua Town from flooding but also separated Kaelepulu Stream from its primary water source of 10 to 15 cubic feet per second. Also in the late 1960s, the 190-acre Kaelepulu Pond, surrounded by an additional 90 acres of marsh, was dredged and filled around its perimeter to create the urban community of Enchanted Lake. This resulted in the 100-acre pond that we see now. The Enchanted Lake Residents Association (ELRA) purchased 89 acres of the pond from Bishop Estate and has managed it since 1989. The City and County of Honolulu (City) owns all of the storm drains leading into the lake and the main channels of the Kaelepulu Stream, and Kawainui Stream. These water bodies receive storm drain flow from most of Kailua and channel this flow to the Kaelepulu Stream mouth at the east end of Kailua Bay.

The area of the Kawainui and Kaelepulu streams, pond, and wetlands totals about 142 acres currently. The estuary has a maximum depth of 9.5 feet (at 1.5 ft LMLLW) and a volume of 30 million cubic feet (MCF), with the Kaelepulu stream containing 3 MCF, the Kawainui Stream containing 1 MCF, with the balance contained in the pond. A rise or fall of the 142 acre surface by 2 inches requires 1 MCF of water exchange.

The pond and streams are brackish, receiving flow both from rainfall/runoff and from ocean flow, and are more correctly termed to be an estuary. Rainfall averages 41-inches per year varying seasonally from a 1.5-inch per month in the summer to 6-inches per month in the winter. Runoff typically results in a rise in lake elevation about three times the rainfall amount, although intense or large storms may result in a 1:4 rise ratio. Because evaporative losses from the system total about 7.5-inches per month, water levels in the lake typically fall during months that do not have at least 2.5 inches of rainfall.

The City opens the mouth of the stream at Kailua Beach six to ten times per year to promote circulation and minimize flood threat from water impounded by the beach sand berm. Water surface elevations higher than 3.3 ft LMLLW result in the stream overflowing to adjacent residential areas. The number of days the stream remains open to tidal flow is directly dependent upon the height of the stream, the depth (not width) of the initial opening, and the length of time of the initial outflow until the rising tide flows back into the stream. The presence of high surf on the beach also appears to shorten the period of time the stream is open by increasing the quantity of sand pushed into the channel by wave action. The quantity of water exchange from the ocean is typically several times larger than the quantity of water entering the system from rainfall runoff. In most estuaries this salinity difference promotes mixing and maximizes exchange with the ocean. However, the Kaelepulu Stream has a shallow area that blocks the flow of salt water to the pond and greatly decreases the circulation efficiency.

During rainfall events, runoff enters the estuary through 55 City storm drains and canals. The quality of the water entering the system is a function of the size and present land use of the sub-watershed serviced by each drain. The greatest contribution of sediment turbidity (cloudiness) and nutrients is from construction projects with open soil, particularly if these bare graded lands are on steep hill slopes. Turbid water entering the pond from construction sites will drop half (50%) of its sediment load within 100 minutes, but it takes about a week for 90% of the sediment to settle out of the water. During large storm events the brown water entering the Ocean through the stream mouth likely represents only a very small fraction of the sediment and nutrient load entering the pond from the upland pollutant source.

Drainages from City streets and canals also provide pollutant loads to the pond in the form of road gravel, trash, and green-waste and garbage discarded into open, and primarily hardened, channels. The 5.75 miles of City roads in the watershed contribute about 44 cubic meters (57 cu yd) of road gravel and tar residue to the pond each year — the equivalent of 6 large dumpsters of gravel every year.

Following every significant rain and runoff event, the storm drains introduce large quantities of debris to the pond, a portion of which floats on the surface and collects on windward shores of the pond. Floating debris is removed on a monthly basis by the ELRA clean-up crew. Typically about half of the material removed is vegetative matter (primarily tree trimmings and coconuts) and half is floating plastics and cans. Each of the five open channels draining to the pond transports an abundance of yard cuttings and garbage to the pond.

Mangroves have been successfully removed from the Kaelepulu wetland, pond, and stream but these areas are continually re-seeded from mature mangrove colonies along the banks of the upper Kawai Nui Stream. A pending State/City project should soon (2016) remove the large quantity of mangrove along the upper Kawai Nui Stream. The mangroves increase the chance of flooding, overgrow native flora and fauna habitats, provide roosting for non-native birds, and result in water with low dissolved oxygen, low pH, high turbidity, and high tannin content. Permanent removal of the mangroves is seen as a necessary positive management action to protect the estuary ecosystem.

Sewage inflow to the system has been a concern in the past. Prior to completion of the Kailua Waste Water Treatment Plant (1966), secondary treated sewage flowed directly into Kaelepulu Pond. Repair and re-lining of the community sewers in the early 2000s is believed to have sealed leaky pipes that may have contributed to groundwater pollution. A sewage pump station located on the bank of Kaelepulu Pond discharged raw sewerage to the pond numerous times in the 1990s and early 2000s during heavy rainstorm events when stormwater entering the sanitary sewer system overwhelmed the capacity of the pumping system. City improvements to control stormwater inflow to the sanitary sewer system and upgrades to the lift-pump station have limited the overflow to a single occurrence in the past 5 years.

A number of studies conducted over the last three decades by the University of Hawaii, USGS, the City, and the Department of Health have searched unsuccessfully for chemical and sewage pollutants within the estuary system.

The primary challenges facing the estuary are six-fold:

1. Loss of historical flow from the Kawainui headwaters has caused the Kawainui Stream branch of the estuary to become stagnant.
2. Poor coordination of stream mouth openings contributes to the lack of water exchange within the system
3. Overgrowth by mangroves results in poor water quality, displaced native species, and increased flood risk.
4. Ineffective controls of erosion and sediment transport from construction sites, particularly those on hillsides, contribute extremely large quantities of sediments and nutrients to the system.
5. A lack of gross filters on storm drains and storm channels allows large quantities of road gravel, trash, and vegetation trimmings to enter the pond.
6. A buildup of sediments in one portion of the Kaelepulu Stream prevents the effective flow of ocean saltwater all the way into the pond.

The systematic solution to each of the above problems will greatly contribute to the restoration of the Kaelepulu and Kawainui Stream ecosystem, improve water quality, enhance fisheries and increase the level of ecosystem functions and services provided by the estuary to the surrounding community and nearshore waters of Kailua Bay.

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PROLOGUE

This paper has been produced as a means to assemble a wide variety of information concerning the Kaelepulu estuary in Kailua, Oahu, Hawaii to help managers understand how the estuary works, to help make wise stewardship decisions, and to guide others in future investigations of this estuary.

Every natural system is the product of multiple factors working together to produce a unique ecosystem. But some factors in each ecosystem play more important roles than others, and shoulder a disproportionate effect on the way the system functions. To effectively manage a natural system it is important to identify the key factors of control, and understand how they may be manipulated to both avoid ecosystem catastrophes and direct the production of valued ecosystem functions and services to the community.

"Nature to be Commanded Must be Obeyed" (Bacon ~1850)

I first met this estuary over 30 years ago, in 1983 when I helped Mark Brooks gather a dozen gunny sacks of ogo, (*Gracilaria tikvayhae,* the same species that dominates the estuary today*)* to be used as seed stock for an aquaculture venture at Heeia fishpond. The ogo was collected from the shallow wetland end of the lake in patches between the oyster beds that covered half of the substrate, and in the afternoon shadows of the 50-foot tall mangroves that lined the western shore of the pond along Keolu Drive. Like most people in the community, I'd driven past "The Lake" hundreds of times without appreciating the value of the estuary, only decrying the foul odor downwind of the mangroves every summer. In the early 1990s I was approached by Mr. Dixon Yamamoto, who had purchased land along Keolu from Jimmy Lee. Mr. Lee had gotten rid of the mangroves and filled the land (and was cited by the USACE for it), before selling the property to Mr. Yamamoto. But the rotten egg smell attributed to the mangroves persisted, and Mr. Yamamoto was worried it would lower his land value. He need not have worried, as the Japanese economic bubble popped before he could sell his developed lots, and they were eventually sold for only about half of his original asking price. In 1999 I purchased one of the improved but undeveloped lots, built a house, and therein began the persistent journey trying to understand how this estuary works, how to protect it, and what needs to be done to improve it for future generations.

ALOHA

Bob Bourke

1. Historical Context

1.1. Kaelepulu Pond – Pre Human Contact

Pre-historically, the Oahu Koolau caldera collapsed about 1 million years ago leaving the Pali and Koolau escarpments to mark the edge of the caldera. The embayment resulting from the collapse was subject to sea level changes both higher and lower than the present elevation. About 10,000 to 15,000 years ago when the sea level was about 100 feet lower than present, both valleys drained to the sea through a common stream channel, the likely remnant of which can be seen as a river of sand in the middle of Kailua Bay in 80-90 feet of water. 4,000 to 6,000 years ago, when the sea level was near its present stage, waves washed up onto Oahu's shoreline at the mauka edge of both Kaelepulu and Kawainui bays. The bays became isolated from the ocean by sand bar and beach accretion across the embayment mouth that slowly isolated the system from the ocean. Marine bivalve shells are commonly found in shallow excavations in the Kaelepulu wetlands, and beach sands containing shark tooth fragments have been found in deposits 20 feet beneath the surface at the mauka edge of Kawainui Marsh.

1.2. Kaelepulu Pond – Pre-1964

Kaelepulu is the Hawaiian name given both to the wetland pond and to the watershed, including Kawai Nui, that it once drained . The literal translation of Kaelepulu, "the moist darkness" attests to its likely long history as a shallow, probably highly organic, wetland pond. Legend describes the pond as a source for Ama ama, or mullet, which could be caught in the waters and taken by runner to chiefs across the island. The historical presence of mullet within the pond attests to at least some brackish influence to the pond and may explain why, in the early 20th century, sugar plantations preferred obtaining their irrigation water from Kawai Nui – the headwaters of Kaelepulu. The 1883 map by Alexander shows rice being cultivated in the flow from Kawainui to Kaelepulu, but not around the perimeter of the pond, again attesting to its likely brackish nature. In contrast, the artifacts and heiau found around the perimeter of Kawainui and many legends and stories declare that this was an open fresh or brackish water body at the time when the Hawaiians arrived about 1,600 years ago and was maintained as an open fish pond through the reign of King Kamehameha (~1820), becoming covered by vegetation by 1900.

The oldest available nautical map of Kailua shows the mouth of Kaelepulu Stream about 1,000 feet west of its present location adjacent to the "Kailua Tavern" near the present location of Kalapawai Store. Examination of present day aerial photos show the presence of a sand channel through the shallow nearshore reef at that same location (Figure 29). Other original maps of Kailua (#1345 Jackson1884, #1026 Alexander 1884, and #1434 Bishop 1888) show Kaelepulu pond as an open water pond surrounded with a 200-300 foot wide band of wetland. The Alexander map, surveyed in February of 1884, shows an open water area of about 190 acres. All three maps indicate slightly different locations for the stream mouth (although all three show it open to flow) and the presence of multiple oxbow lakes on the Kaelepulu Stream boundary indicating the likely lack of stability of the stream channel.

Pre-1964 photos and maps of the pond depict a black-water pond with an indistinct shoreline of reeds or grasses.   There is no evidence that the pond was actively managed as a fish pond, but rather it was actively maintained as a natural fishery. Hawaii Fish and Game pamphlets from the 1930s describe large flocks of Hawaiian Coots (now an endangered species nesting in the system's wetlands) with the warning that the catch limit of 20 birds per day being was enforced.

In 1921, the Waimanalo Sugar Company began plans to obtain water from Maunawili through a series of ditches and tunnels (Waimanalo Sugar Company annual reports). In 1923, the Waimanalo Sugar Company obtained an 18-year lease of rice fields and water rights from Kaneohe Ranch which allowed them to displace the rice farmers, and use a 175 HP pump to extract 120 MCF to 244 MCF per year from Kawainui Marsh and pump it to an elevation of 180 feet from which it flowed in a series of ditches and tunnels to the Waimanalo Reservoir at an elevation of 160 feet. In 1926 Waimanalo Sugar Company excavated a 1,970-foot long by 15-foot wide ditch within the marsh to improve the flow of water to the pump. This ditch is clearly seen in the 1928 USGS map of Kailua (Figure 4). Combined water extraction from Kawainui Marsh and flow from upper Maunawili to the Waimanalo Sugar fields varied from an annual average of 4 CFS (123 MCF/yr) to 7.7 CFS (244 MCF/yr) between the years of 1926 and 1946. In 1944, a 36" diameter slotted pipe was driven and excavated to a depth of 57 feet in the marsh in an unsuccessful attempt to increase flow rates.   In 1945 and 1946, which were considered to be drought years, the water extraction drained Kawainui Marsh completely dry by June. Pumping stopped in late 1946 when Waimanalo Sugar Company ceased operations. The Maunawili ditch still transfers water from upper Maunawili to the agriculture fields of Waimanalo, but at a much lower rate estimated to vary from 1 to 2 cfs.

Beginning in the 1930s, the USACE was asked to find a solution to the relatively frequent flooding of portions of Kailua from the Kawai Nui Marsh. By 1952, the USACE had completed construction of the Oneawa channel, forming a new outlet from the north-east extent of the marsh to the ocean just beyond the north end of Kailua Beach (Figure 1). The channel appears to have been named as an extension of the Oneawa Stream noted on early maps as the lower extension of the Kapaa Stream. This new outlet lessened, but did not completely stop the incidence of flooding, and by 1966 the USACE had constructed a flood control levee from Kailua Road to the head of the Oneawa channel. In the process of constructing the levee, the bed of Kawainui Stream was enlarged and extended the length of the levee to within a few feet of, but not connected to, the Oneawa channel. The levee blocked all flow (10-16 cfs) from the marsh to Kawai Nui Stream.   The Kawai Nui Stream became a 1.6-mile long channel running behind Kailua Town and fed only by groundwater and City stormwater drains to its junction with the Kaelepulu Stream below Kaelepulu Pond. The average flow to the marsh (as measured from USGS gauges on Manuwili and Kohanaiki Streams is about 9.75 cfs, with a mean flow of about 3 cfs. This does not include any groundwater flow to the marsh. In 1989, on New Year's Eve, the levee overtopped and inundated several hundred homes in the Coconut Grove area of Kailua. Following this event, the USACE raised the levee to its present 13-foot elevation (at station 15:00) and topped it with a 4-foot tall concrete wall.

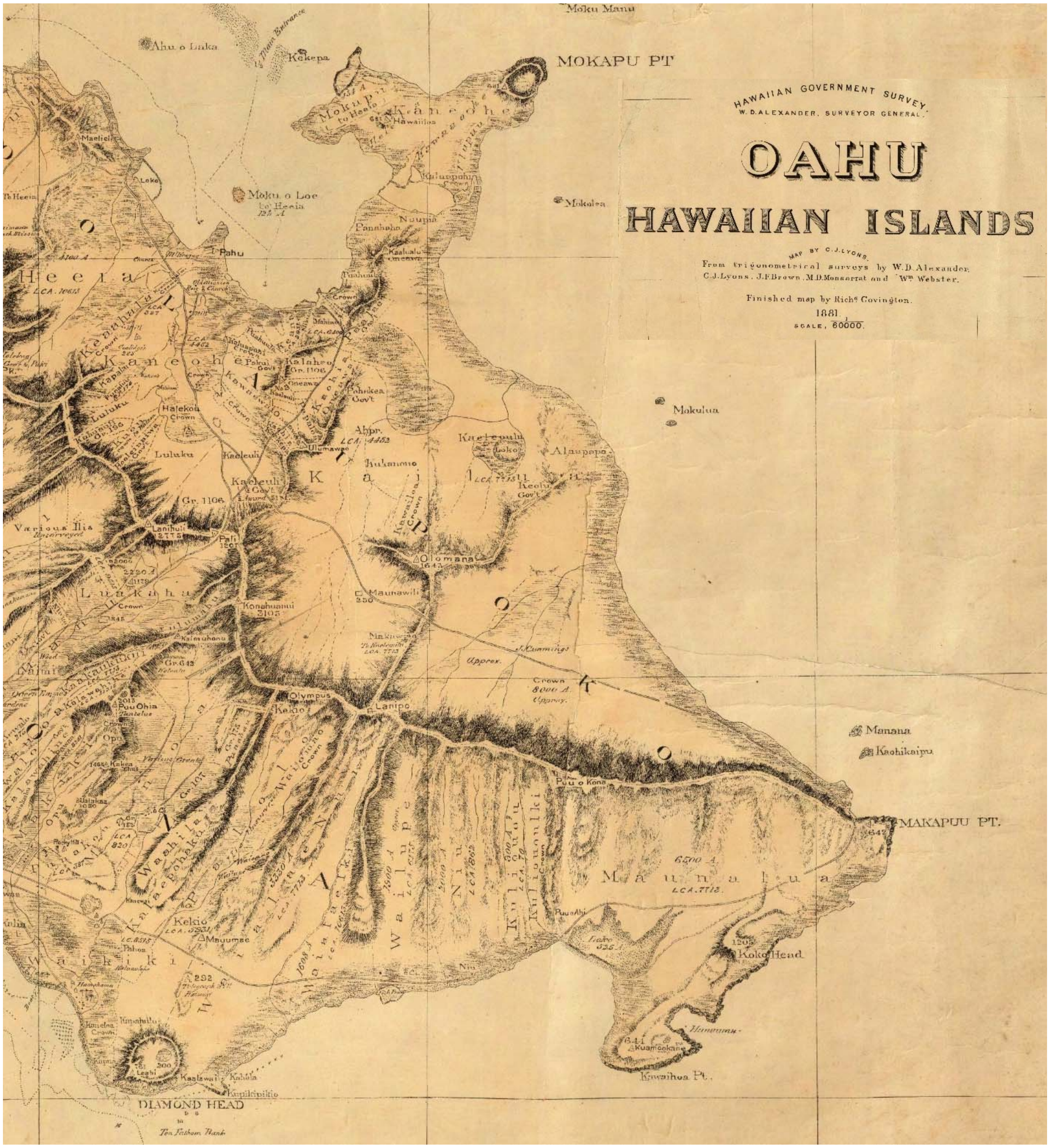


Figure 1. Section of Oahu map of 1881 by Rich Covington showing mouth of Kaelepulu Stream about 1,000 feet west of its present location

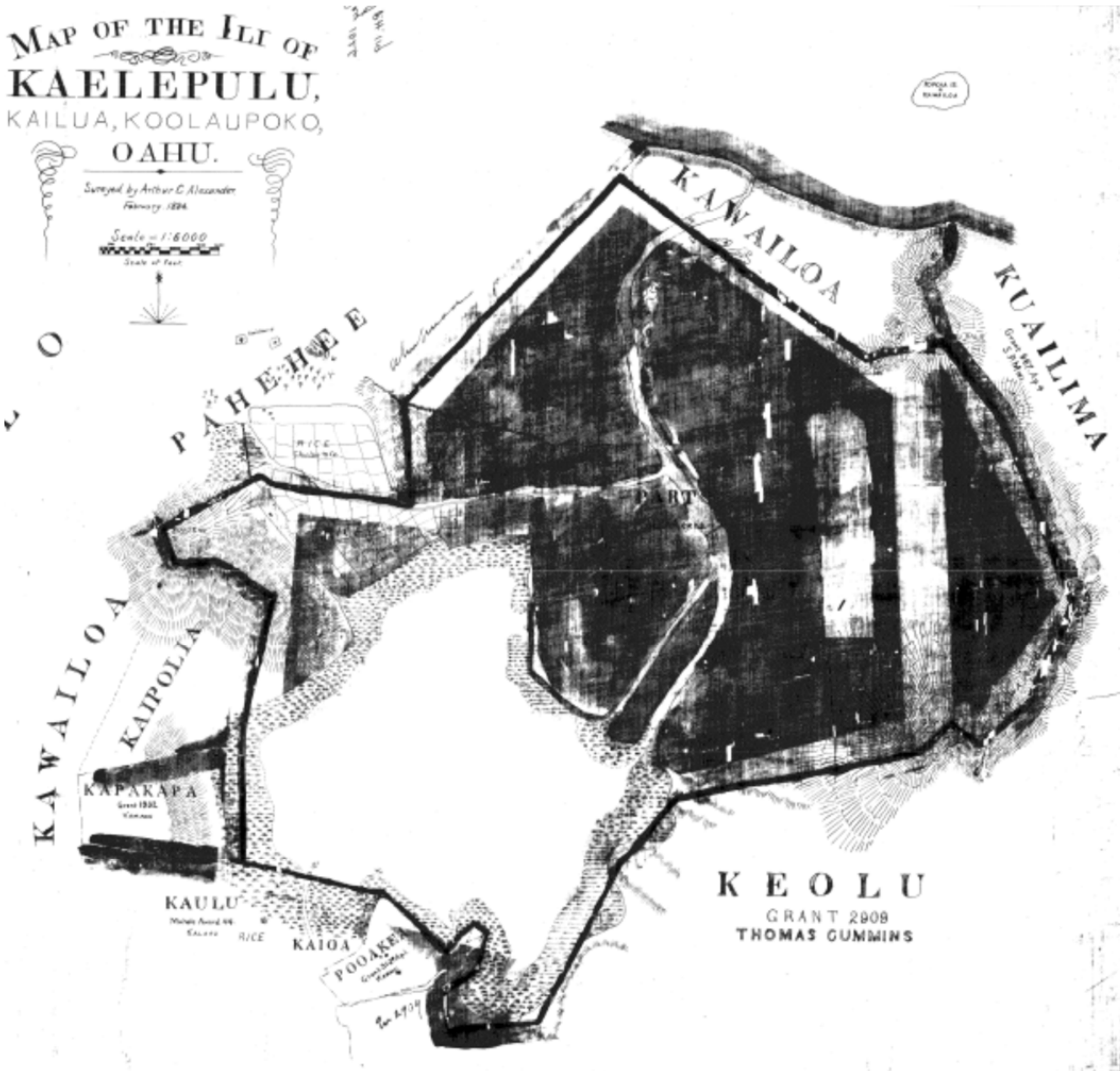
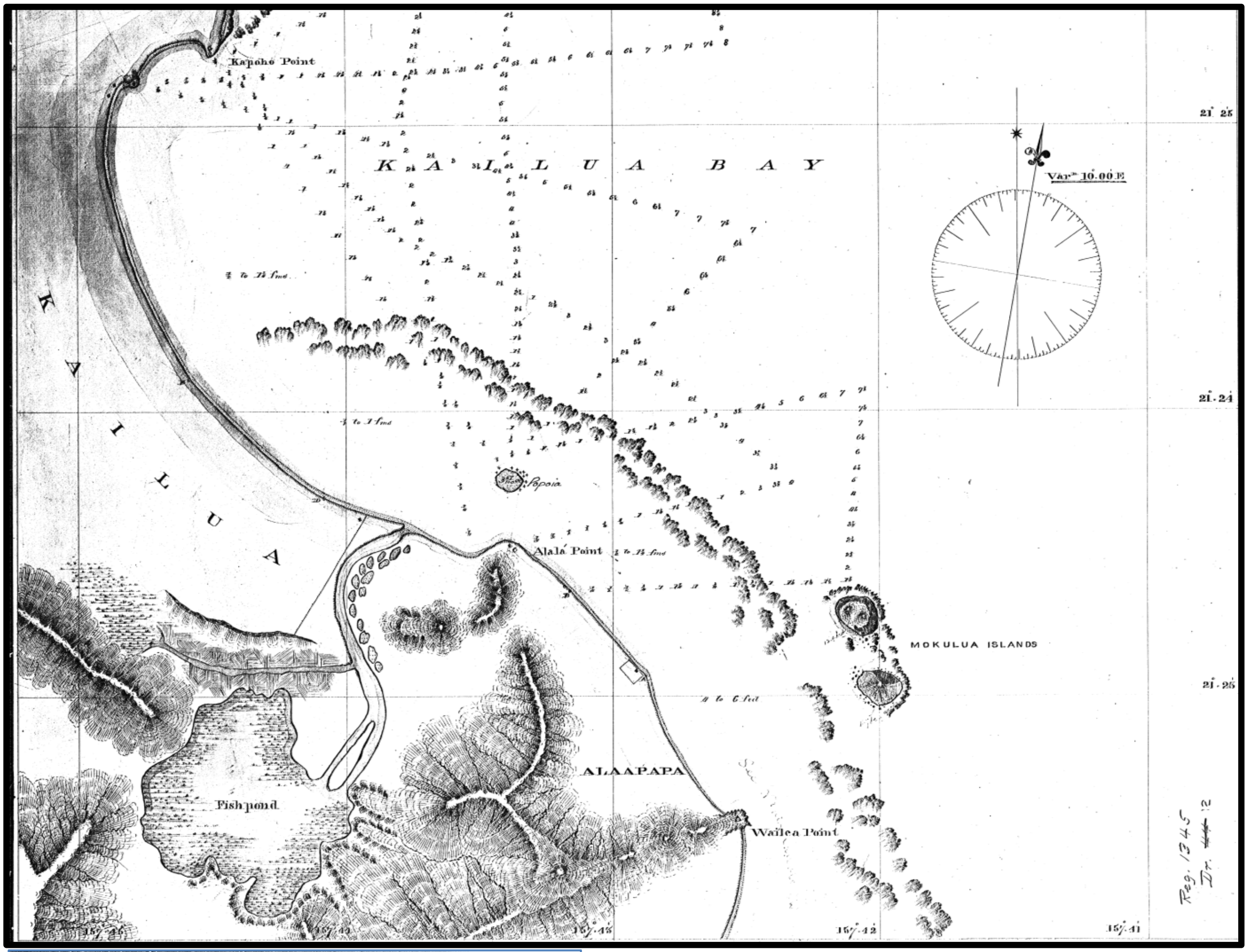


Figure 2. February 1884 map (reg.# 1026) of Kaelepulu by Alexander



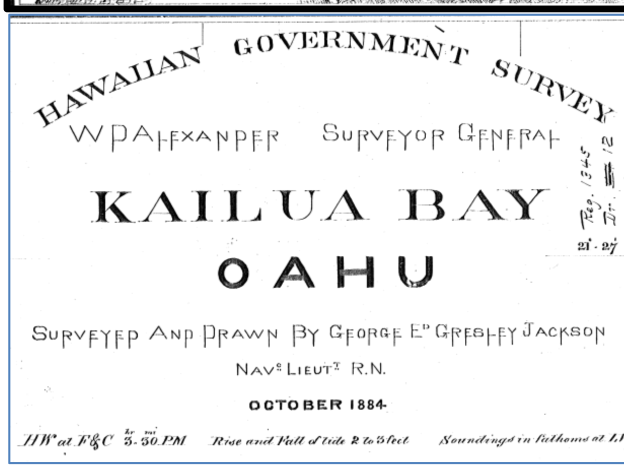


Figure 3. 1884 Map of Kailua by Jackson

Figure 4 Portion of USGS Kailua 1928 map quadrangle showing beginnings of urban growth.

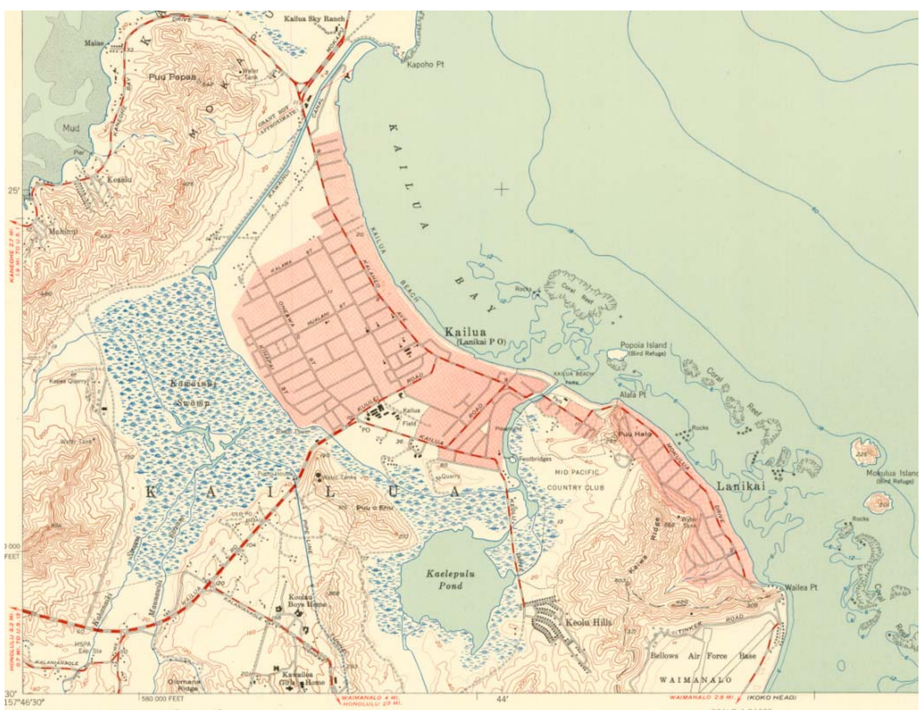


Figure 5 Portion of USGS 1952 Kailua Quadrangle showing completed Oneawa drainage canal.

Between 1952 when the Oneawa canal was completed, and 1966 when the levee was finished, the Kawainui Stream still drained the marsh and the flow to the ocean through the Kaelepulu Stream mouth was significant. Consistent with the oldest maps, statements from Kailua residents prior to 1966 consistently describe the mouth of the Kaelepulu Stream at Kailua Beach as flowing over the sandbar on a regular basis as compared to after the construction of the levee (Figure 29) (Turner, personal communication, Morely, personal communication).

1.3. 1964: The Creation of "Enchanted Lake"

In 1964 the Bishop Estate Trust (now Kamehameha Schools) reached agreement with Lone Star Hawaii developers headed by Joe Pau, Scarfoni, and other partners to develop the lands surrounding Kaelepulu Pond. Mr. Scarfoni was the owner of an 80-foot tall hill in the middle of Kailua. This hill was mined to develop fast lands and a shoreline around the pond. Remnants of the hill are visible in the 1963 aerial photo shown in Figure 6 as the lite unvegetated area just north of Kawainui Stream. The pond was

Figure 6. 1963 aerial photo of Enchanted Lake under construction. Note lack of Kawainui levee and presence of berm across stream exit from pond with heavy silt load entering from Hele Channel inlet (enlarged inset) where the stream channel is still very shallow. USGS: EKM-2CC-246, 1-14-63.

dredged to provide the balance of the fill material. A 1963 USGS aerial photo (No. 4289) shows most of the lake dredged with silt pouring in from the Hele channel and what appears to be a dam preventing flow from the stream back into the newly created lake (Figure 6).

The dredging and filling resulted in a water body of about 100 acres, 89 of which was within the original lease grant from Bishop Estate, and 13 acres at the upper, south, end of the pond was owned by one the original construction partners, Lone Star Developers. The pond is connected to the ocean through a mile-long sea-level channel, Kaelepulu Stream, which is intersected by the Kawainui Stream about halfway to the ocean. The surface area of these two streams is about 33 acres, yielding a total water surface area of about 142 acres to the estuary. As the community was constructed, each successive group of shoreline home lots was brought into the "Enchanted Lake Association" (ELA) for a total of 136 private home owners. An additional 37 home lots abut the Kaelepulu wetland which, as it was outside the initial Bishop Estate properties leased to Lone Star, are not obligatory members of the community association (ELRA) who now own the lake. As part of the development agreement the storm drain system was deeded to the City which was granted a drainage easement for storm water to be "discharged into Kaelepuu Pond, and therefrom to the sea." But as part of the agreement the City is responsible for the upkeep and maintenance of the canal draining the lake to the sea "*including necessary dredging and keep open, all inlets to Kaelepulu Pond and the outlet from said pond*." Bishop Estate owned the water area of the pond until 1989 when they sold it for $1 to the newly re-organized Enchanted Lake Residents Association (ELRA). Bishop Estate also owned the lease hold of the Kukilakila Condominiums (110 units) who were initially incorporated into the ELA membership through their lease requirements. The Kukilakila individual owners are no longer required to be obligatory members of the ELRA.

In 1966, a pumping station began operation adjacent to Enchanted Lake to pump the sewage to the newly constructed Kailua waste water treatment plant. However, rumors of very leaky sewers surrounding the lake persisted until about 2003, when all of the main trunk sewer transfer lines were renovated (lined) or replaced, thereby ensuring no contamination of the pond with groundwater containing sewage from leaky pipes. The sewage pump station is located on an inlet to the pond and can by-pass sewage to the pond in case of pump failure or overwhelming flow due to inflow during intense rainfall events.

Figure 7 Outline of the 1926 Kaelepulu Pond superimposed over present day Enchanted Lake.

After the completion of the home lots on the relatively level lands surrounding the pond, the hillsides were next developed. The majority of the Keolu hillsides to the east of the pond were populated with home lots by the mid 1970s, followed by the development of several hundred homes as part of "The Bluffs" on the hills to the south of the pond beginning in the late 1970s. During the initial grading phase of "The Bluffs" the developer, Lone-Star, used upper margins of the Kaelepulu Pond for stockpile and fill. Along this south-east boundary of the pond mangroves had taken root and formed a mangle with a 150-foot wide swath of 50-foot tall trees extending a quarter mile along Keolu Drive. The mangle was a favored roost for egrets and other birds, but often developed a very strong odor which resulted in numerous complaints.

Figure 8 1998 Aerial of Kaelepulu and Kawainui watersheds.

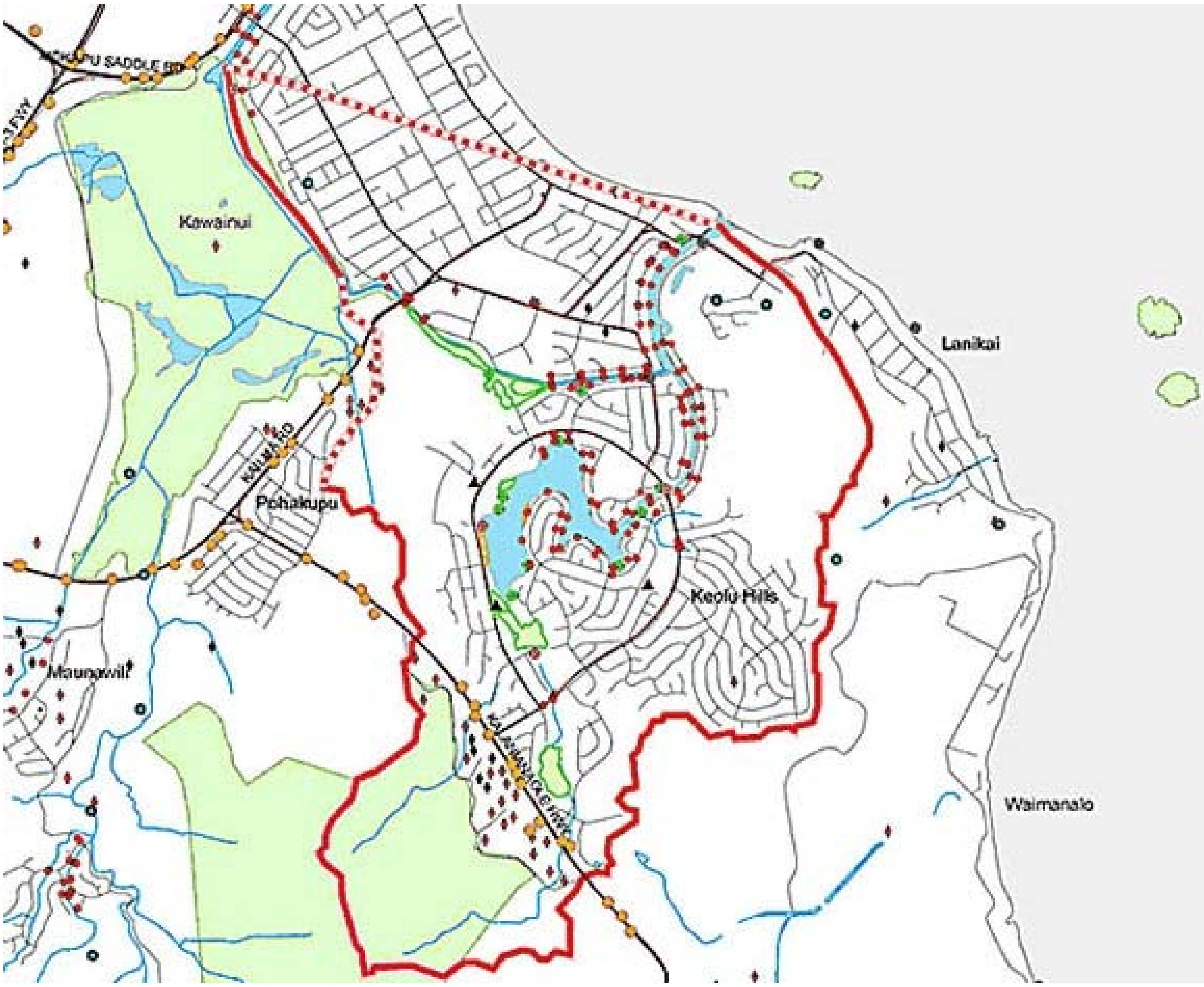


Figure 9 Present day map with Kaelepulu watershed boundary and effluent points from City storm drains.

Lone-Star was cited by the USACE in 1978 for illegally filling this property, and a decade later sold it to one of its partners, James Lee of LECI Corp. Purportedly in response to the community odor problem, Mr. Lee removed the mangroves, constructed a retention wall and filled the land in a 110-foot wide buffer between Keolu Drive and the pond to prevent the mangroves from growing back. The filled land was sold to another developer (D. Yamamoto) who developed 22 residential lots, but not before the USACE again demanded mitigation for the un-permitted fill to about 2-acres of wetland.   As a condition of the consent decree the balance of Mr. Lee's holding (~11 acres of pond and wetland plus 2 acres of "fast" land) was converted to conservation land, with seven bird islands designed (and almost constructed) within the wetland area, and 6 acres of the property designated as a permanent wetland preserve. As the seven constructed bird islands were nearly completed, but not yet stabilized by vegetation, a large storm event struck and reconfigured the multiple islands into one large contiguous island. The property was subsequently sold in 2003 and is now well-managed by the de Vries family who constructed a home on the 2-acres of fast land in 2006.

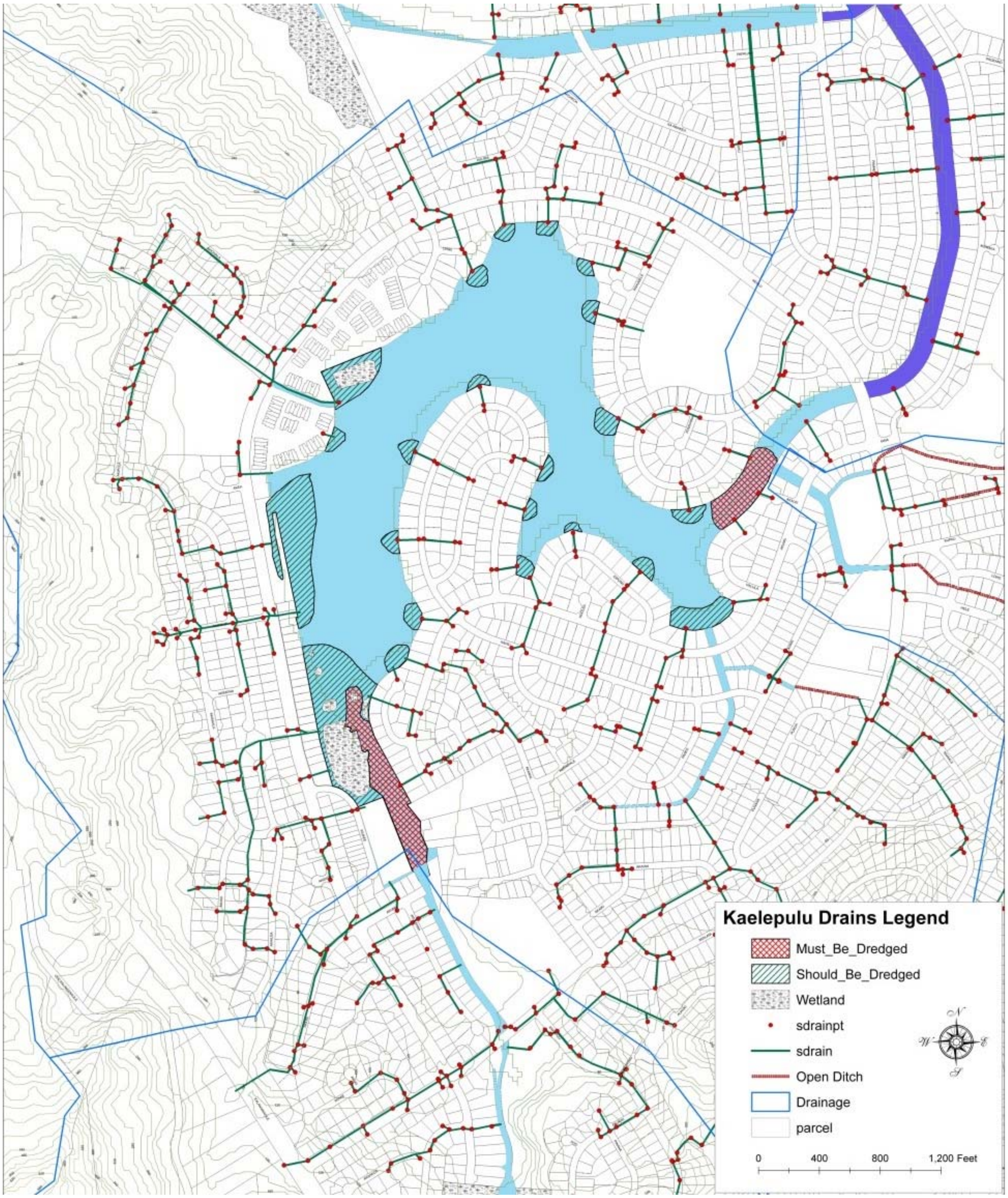


Figure 10 City storm drain map of Kaelepulu Pond showing areas with sediment buildup at mouths of drain outlets.

Development of “The Bluffs” included construction of the Keopu storm control basin on the upper reach of Kaelepulu Stream, at the head of the half-mile long 20-foot wide 10-foot deep box culvert originally constructed as part of the Enchanted Lake development. Also during the 1990s the former fallow lands on the foothills of Mt. Olomana were converted to 2 to 5-acre “gentleman farm” lots in the Norfolk development. Each of the above development phases yielded extremely large sediment loads to the pond as a result of grading practices that lacked adequate erosion control.

At some point, likely prior to 1980 and with some degree of regularity in the 1990s, the City began taking responsibility for opening of the stream mouth through the sand bar at Kailua Beach. The regular openings were in response to flooding that resulted if the sand beach was allowed to build up too high prior to any significant rainfall event. During heavy rainfall events the pond would rise above flood elevation (3.3 ft LMLLW) prior to overtopping the sand berm of Kailua Beach. On many occasions neighborhood residents from the impacted homes would physically dig a trench through the sand dune to help the canal open itself prior to the arrival of the City’s bulldozer. Over the past decade better records have been kept of the opening schedule and methods and since about 2012 the City sporadically began following a suggested opening schedule coordinated with peak monthly tides. Results were much improved when they followed the schedule. The long term practice of moving the sand out of the stream ben and piling it up on the sand dunes (out of the active beach cell) has likely contributed to the documented erosion of this section of beach, even though all of the rest of Kailua Beach has been accreting over the past 80 years.

2. Ecosystem Driving Factors

2.1. Rainfall

The Kaelepulu watershed is located on the windward side of Oahu and is subject to trade wind bourn showers as well as the larger typical central Pacific weather systems and occasional “Kona” storms erupting from the south. The majority of the watershed is separated from the Koolau Mountain ridge and is therefore not typically subject to diurnal orographic rainfall or to the intense rainfall associated with the uplift of the Kona storm systems as they meet this mountain range. The closest official rain gauge (HI24 / OFSH1) is about 1 mile mauka of Kaelepulu Pond at the Olomana fire station. Six-hour accumulated data is available in graphical format on line by month from 2005 to the present (http://www.prh.noaa.gov/hnl/hydro/pages/rra_graphs.php?station=OFSH1). 15-minute data is available (http://www.prh.noaa.gov/hnl/hydro/hydronet/hydronet-data.php) for this site.

Rainfall statistics (Giambelluca et al, 2012 - http://rainfall.geography.hawaii.edu/ and NOAA Rainfall Atlas) indicate that a 24 hour storm with a return period of 10 years has a total rainfall of about 8.7-inches, whereas the average annual 24-hour storm has a total rainfall of about 3.9 inches (Figure 12). Annual rainfall averages 41.2 inches. The annual rainfall is not distributed evenly during the year (Figure 14) and there is a large variance by month between years (Figure 15).

2.2.Runoff Sources and Quantity

The contributing area of the Kaelepulu watershed is about 3,450 acres (Figure 9), or roughly 25-times the water surface area of the estuary. Significant rainfall events (0.5 to 2-inch/24 hours) typically result in an average rise in pond elevation at a ratio of about 1:3. For small rainfall events or for rainfall events without significant antecedent rainfall the rates are often as low as a 1:2 rise. Large or intense rainfall events often display a rain:rise ratio of 1:4. During a single exceptionally intense event, in the presence of significant antecedent rain (12/31/07, measured at 7.9 inches over 6 hours), the rain:rise ratio was about 1:4.5 with the lake surface reaching an elevation of almost 4 ft LMLLW and requiring the fire department to open the sand berm by hand to lower flood waters (Figure 11).

Evaporation in the absence of rainfall results in an average .25-inch elevation drop in the system per day (7.5 inch/month)(Figure 16). Over the 142-acre area of the waterbody, this is equal to an evaporation rate of about 1.4 cubic feet per second (41L/s or 11 gal/sec) During the months of May through September when the average monthly rainfall is not sufficient (less than 2.5 inches per month) to offset the monthly evaporation (7.5-in/mo), the water surface elevation of the pond often falls to near mean sea level (1.2 ft LMLLW). Evaporation below this elevation is much slower than 0.25-inch/day, likely due to the inflow of surrounding groundwater. Evaporation loss rates from the pond have been measured as high as .33-inch per day during dry periods with strong trade winds, and as low as 0.2 inches per day in the presence of humid weather and low wind speeds.

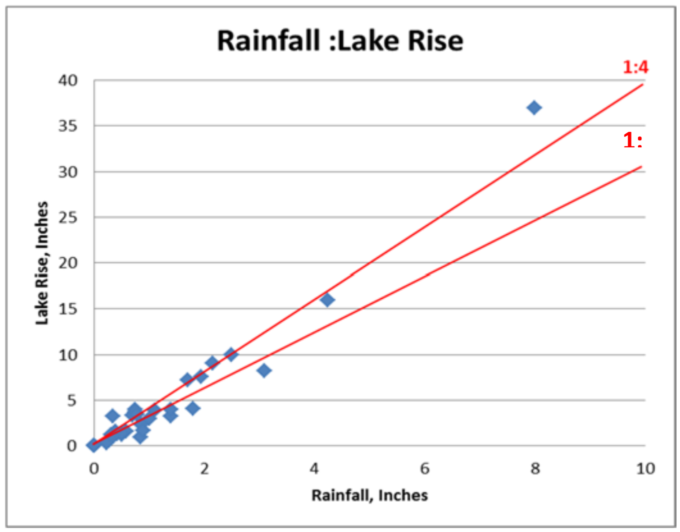


Figure 11. Typical rainfall events result in a rain:rise ratio of about 1:3. In intense, or large rainfall events the rain:rise ratio is often closer to 1:4.

The large majority of flow enters the estuary through the City's storm drain system most of which consists of buried drain pipes emptying directly into the pond. Much of the storm drain system was constructed by the original developer in the 1960s and deeded to the City for operation and maintenance. An agreement between Bishop Estate, the ELA (now ELRA), and the City states that the pond owner grants the City use of the lake in perpetuity as a stormwater effluent easement from its drains into Kaelepulu Pond and from there to the sea. Note, however, that this agreement was made prior to the Federal Clean Water Act, and while the City may have permission to drain storm water into Kaelepulu, they do not have the right to allow these waters to carry pollutant loads into the pond. The agreement does stipulate that the City will maintain and repair, including necessary dredging and keep open, all inlets to Kaelepulu Pond and the outlet from said pond. There are 4 channelized flows and 33 buried culverts (with over 300 inlet points) entering the main body and wetland portion of Kaelepulu Pond (Figure 10) with the balance (55 total) entering the Kawainui and Kaelepulu stream channels.

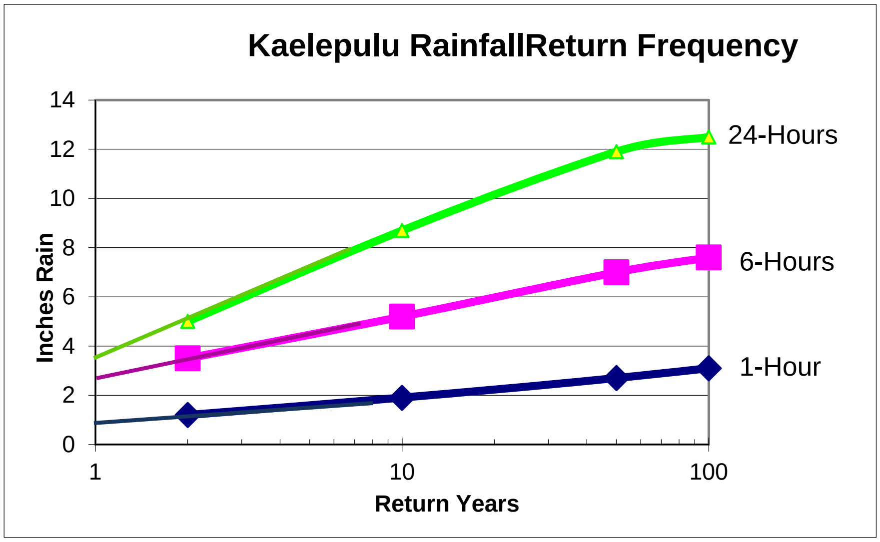
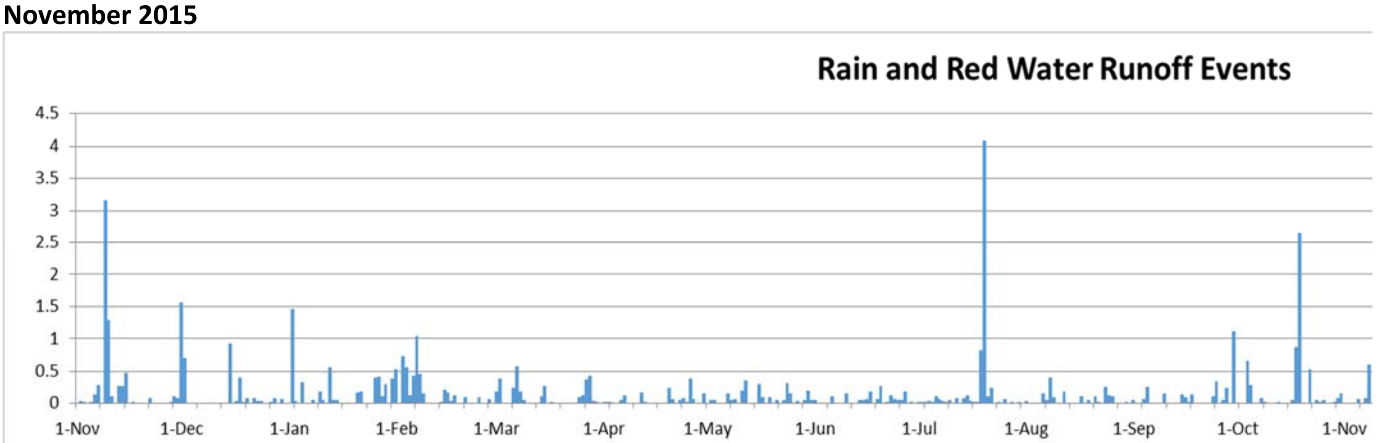


Figure 12 Rainfall long term expected incidence of large storm events at Kaelepulu. Derived from Gaimbelluca et al. 2013

Figure 13 (Below and next page) Daily rainfall at Kaelepulu for 2-year period from November 2013 to November 2015



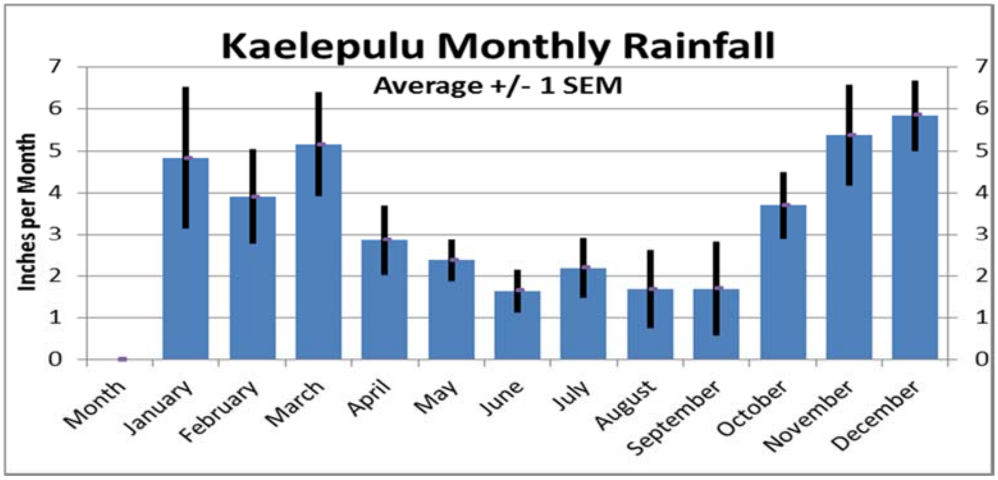


Figure 14 Monthly average rainfall (+/- 1 Standard Error of Mean)

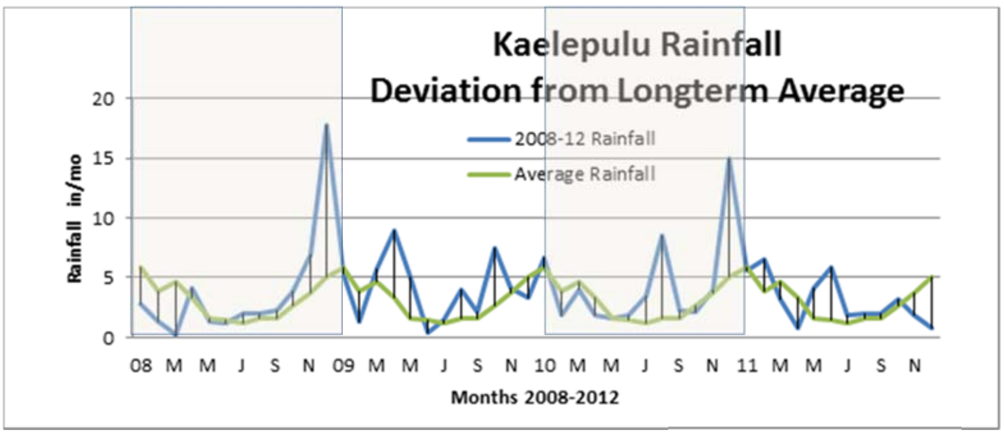
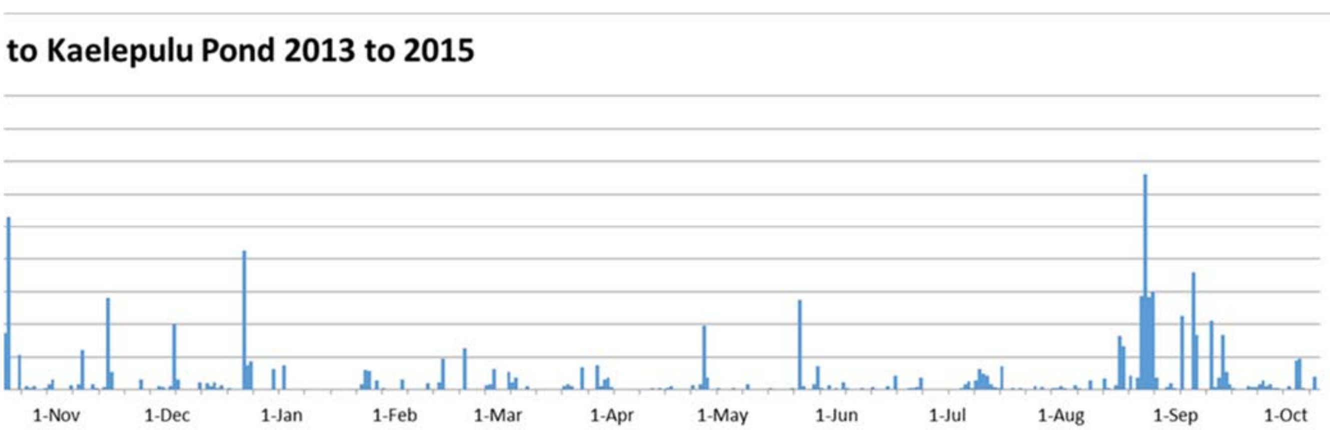


Figure 15 Actual monthly rainfall for 2-year period showing deviation from expected average.).



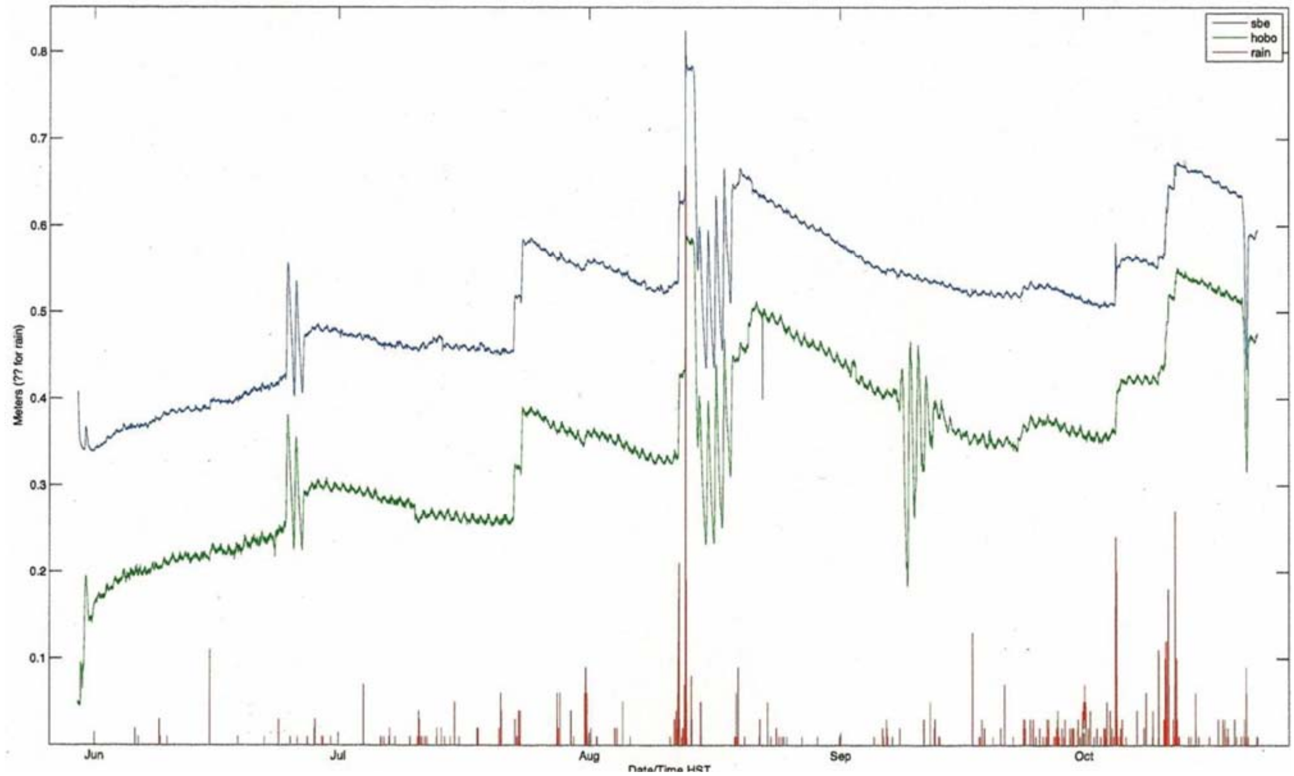


Figure 16 Typical pond water surface elevation patterns associated with rainfall, evaporation, and stream mouth berm opening events as recorded 5/30/09 through 10/22/09. Evaporation rate in the absence of rainfall is about ¼-inch per day (From: Babcock & Tamura, 2010).

2.3.Estuary Bathymetry and Volume

Prior to 2000, no one had measured the depth of the pond. The son of one of the dredge operators remarked that he had been told that the lake had been dredged to a depth of “two to three fathoms” (12-18 feet), which seems reasonable given the equipment used for the operation. Today, at a typical water surface elevation of 1.5-ft LMLLW the maximum depth of the pond is about 9.5 feet. The bottom consists of very fine soft black sediments. As a curiosity I once took a 20-foot length of ¾-inch PVC pipe to test the consistency of the sediments. At most locations that were not near drain outlets, the pipe could very easily be pushed down to the water surface level, indicating at least 10 feet of soft unconsolidated sediments. Near drain outlets, sediments were coarser, often mixed with debris and pipe penetration was typically limited to less than a couple of feet.

During these initial investigations it was noted that many of the storm drain openings appeared to have accumulated sediment and debris, actually forming small vegetated peninsulas fronting some outfalls (Figure 10). One extreme area of shoaling occurs at the mouth of the pond where it enters Kaelepulu Stream and is joined by the City’s Hele drainage channel. At this location the depth of the channel shoals to about 1-foot (@1.5’ LMLLW). Assuming a design depth of 8-feet for this channel, the estimated volume of sediment necessary to fill the channel to these contour lines is approximately 15,000 cubic yards. There are two possible sources for this large quantity of fill partially blocking the mouth of Kaelepulu Stream out of Kaelepulu Pond. As the Hele ditch drains much of the upper hill slopes of the Enchanted Lake community, it is likely that a great deal of sediment entered the lake in the early 1970s as the hillside lots were being developed with little or no erosion or runoff controls (See Figure 6). During the development of Enchanted Lake, the contractor was also said to have constructed a land bridge near this location (also visible in Figure 6) which may not have been completely removed.

The estuary has a volume of about 26.5 Million cubic feet (MCF), at 1.5 ft LMLLW with the Kaelepulu stream containing about 4 MCF, the Kawainui stream containing about 1 MCF, with the balance contained in the pond (Figure 17). A rise or fall of the 142 acre surface by 2-inches requires 1 MCF of water exchange. A 6-inch rise or fall represents about 10% of the volume of the estuary.

For a period of 3 months during the summer of 2015 an experiment was conducted (Oceanit. 2015) in which about 2 CFS flow was restored from Kawainui Marsh over the Levee and into Kawainui Stream. In the absence of rainfall, this flow was shown to be sufficient to more than balance evaporative losses and raise the elevation of the system by about .125 to .25-inch per day. Fresh water entering the upper reach of Kawainui Stream did not displace the salt water within the reach, but spread out on the surface maintaining a surface gradient throughout the entire lower estuary. The report calculated mass balance average monthly flow rates for the system before and after construction of the Kawainui Levee, and after construction of a presumed flow restoration structure allowing 2 CFS to flow from the marsh to the stream (Figure 18)

A NOTE CONCERNING WATER SURFACE ELEVATIONS

Water surface elevation measurements in this document are fixed to a locally established Local apparent Mean Lower Low Water (LMLLW) tide as marked with a tide staff affixed to the Lanikai Pedestrian Bridge. The nearest NOAA tide gauge providing real-time water surface elevation (to MLLW) and deviation from predicted tide is the Mokuoloe Gauge in Kaneohe Bay. We assume that our tides follow the Waimanalo predicted tide pattern with deviations from predicted being the same as that measured at Kaneohe. To determine the elevation a temporary staff gage was established at the Lanikai pedestrian bridge in 2006, and over the course of a year on 10 separate occasions when the stream was open to tidal flow, elevations and times were noted when the water within the stream reached slack tide – when the ocean and the stream were at equal elevations. The “true” elevation at the slack tide was taken to be the predicted elevation for the Waimanalo tide plus the deviation at that time as recorded by the Kaneohe tide gauge. All ten measurements were in agreement to a common base to within 0.1 foot. A second staff gage was established on a pile in the Kaelepulu wetland at this same datum. Since 2006, we have noted that predicted flows associated with tidal elevations have agreed well with our locally established measurement of mean lower low tide. The City affixed a staff gage on a piling of the Lanikai automobile bridge in 2008. The City’s gage elevations are tied to the City’s MSL survey base which was established at Honolulu Harbor and is 0.26 feet higher than our LMLLW. Our LMLLW gauge reads 0.26 feet when the City’s MSL gauge reads 0.0.

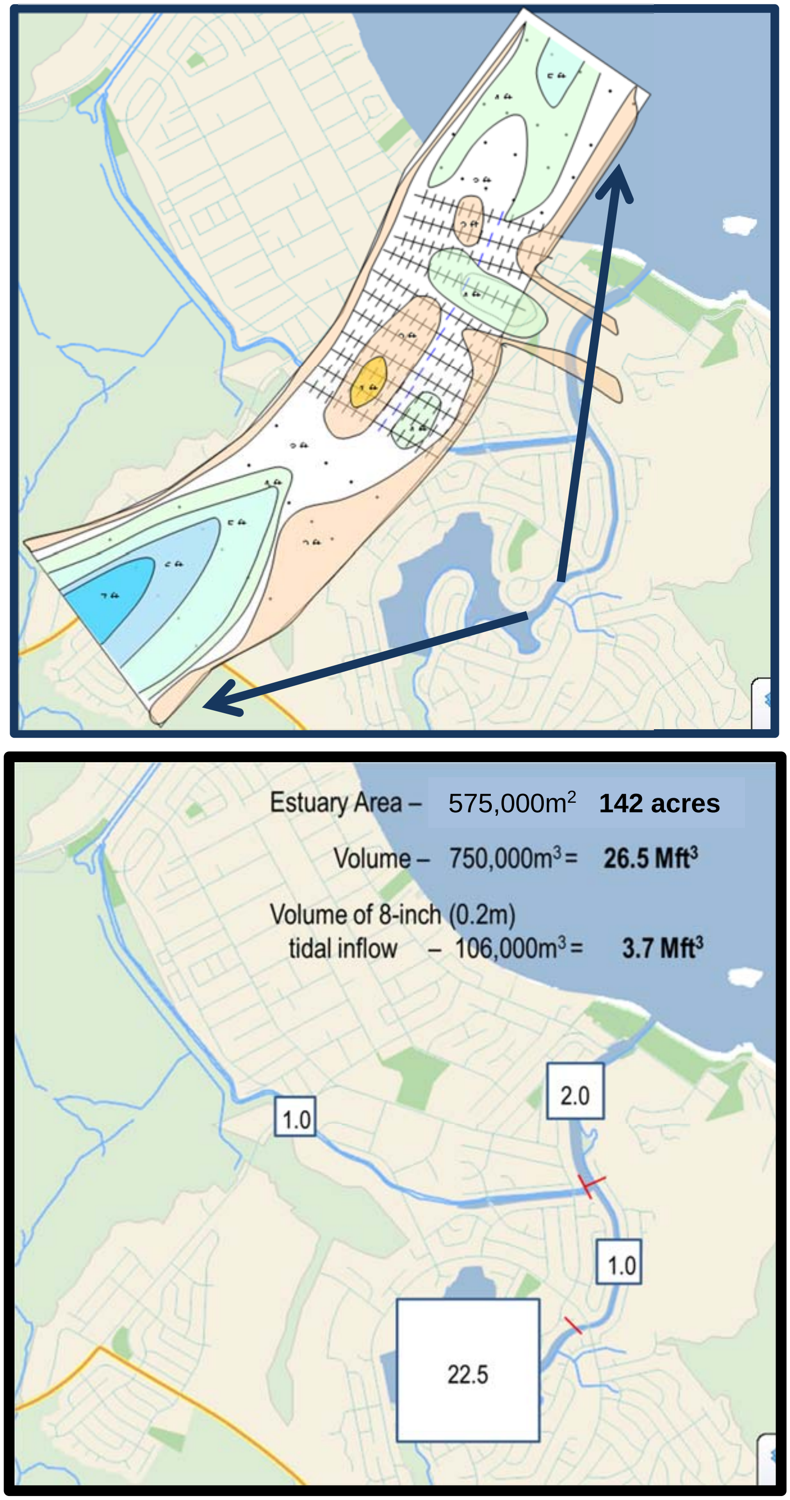


Figure 17. Top: The mouth of Kaelepulu Stream as it exits the pond is shoaled to within a foot of the surface and dramatically impacts circulation between the stream and the pond. Bottom map graphically depicts the estimated relative volume of water in each section of the estuary as represented by cubes with a base as shown

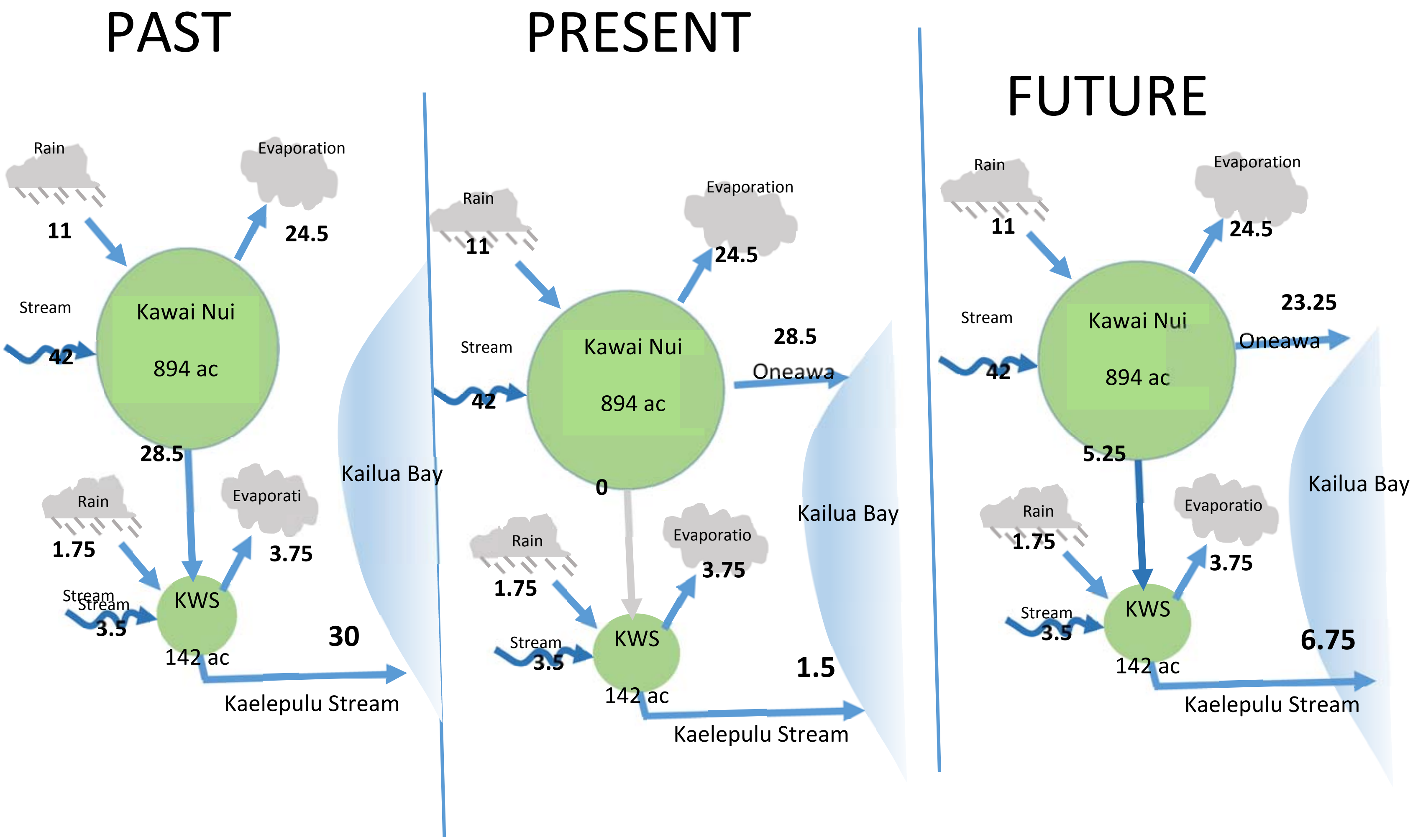


Figure 18 Average monthly mass balance water flow for Kawainui and Kaelepulu Systems before and after construction of the Kawainui Levee, and after proposed flow restoration (From: Oceanit, 2016)

2.4. Water Quality Impacts of Runoff

During rainfall events, each of the City's outfalls to the pond displays different water quality depending upon the size of the area drained and land use activities at the time of the rainfall (Figure 19). The greatest predictor of high turbidity is the presence of construction activities with exposed soils. As the estuary pond will commonly display a salinity of about half sea water (15-18 ppt) the freshwater runoff tends to spread across the top of the denser high salinity waters (Figure 23). If the stream mouth is open at the ocean, this low salinity water is the first to leave the system and can carry significant loads of the finest suspended or dissolved pollutants to the ocean (Figure 20). Estimates of the quantity of sediment entering the pond from any storm drain can be made by measuring the flow volume (cross sectional area times velocity) and the dry weight quantity of sediment suspended in a sample of the water obtained from the flow. In the flow pictured in the upper right photo of Figure 20 the upper reach of Kaelepulu storm drain channel was estimated to be delivering 1 ton of sediment containing 2.5 kg of nitrogen and 0.75 kg phosphorous fertilizer into the pond every 6 minutes. If the stream mouth is closed at the beach, then sediment and pollutant load slowly precipitates out over a period of minutes to several days (Figure 22) and therefore remains in the estuary.

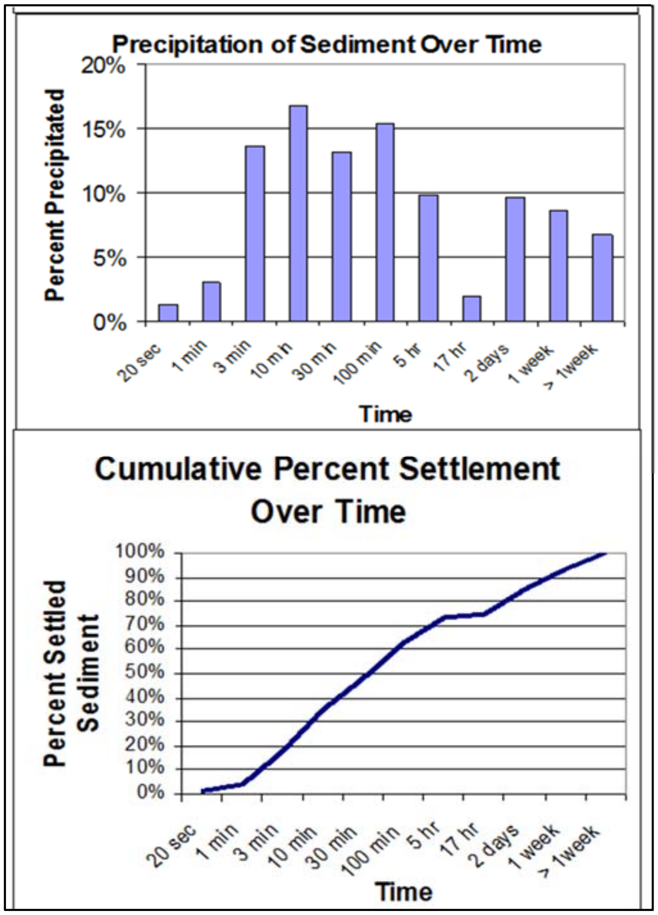
Figure 19 Water quality samples from pond inlets obtained during a single runoff event (3/19/06) distinguish between drainages that have active construction grading projects and those that do not.

The most obvious source of pollutants to the system is sediment in runoff from construction sites with inadequate erosion and runoff controls. The samples depicted in Figure 19 were taken during a single storm event from inlets all around the pond. The inlets influenced by construction sites are obvious. Data from analyses of the above samples is presented in Appendix B.

To better understand the fate of sediments entering the lake through storm drains, a controlled laboratory test was conducted. A highly turbid 2-liter sample of stormwater entering the lake was collected from a City storm drain that was receiving runoff from a large hillside construction site. The sample was kept agitated until it was poured into a 50-cm deep funnel cone with a valve at the bottom. At various intervals, the valve was opened to remove that portion of the sediments which had settled to the bottom. These sediments were then individually dried and weighed. Roughly 25% of the sediments settled within 10 minutes and half had settled after about an hour. However it required two days for an additional 25% (75% total) to settle, and after one week, 10% of the settleable solids still remained in solution. These results are graphically displayed in Figure 22. From a practical perspective this means that even if the stream mouth is open during a heavy storm event that at least 50% of all sediments entering the lake, settles within the lake. It is likely that well in excess of 90% of solids entering the lake remain there.

Figure 20 Construction activities (A) have the greatest impact upon delivery of sediment and nutrient turbidity to the pond (B) and into the ocean (C) when the stream mouth is open.

Figure 21 Poorly implemented BMPs at construction sites (A) or intentional by-passing of required BMPs (B) result in significant plumes of turbid water entering the pond (C) and deposition of fine mud throughout the estuary (D). The high iron content of the soil colors the pond bright orange for several days following major rainfall events when land is being graded in the watershed.



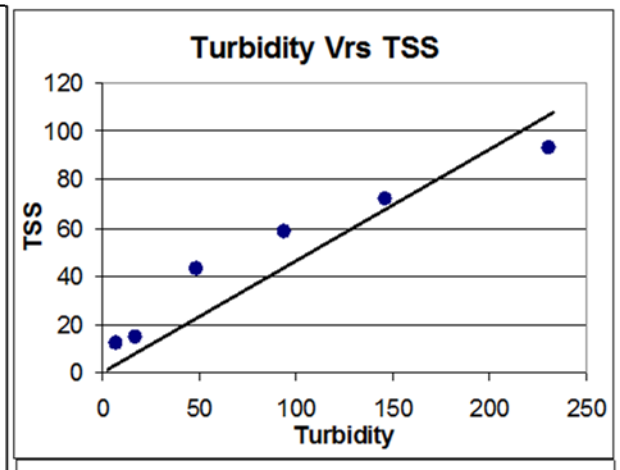
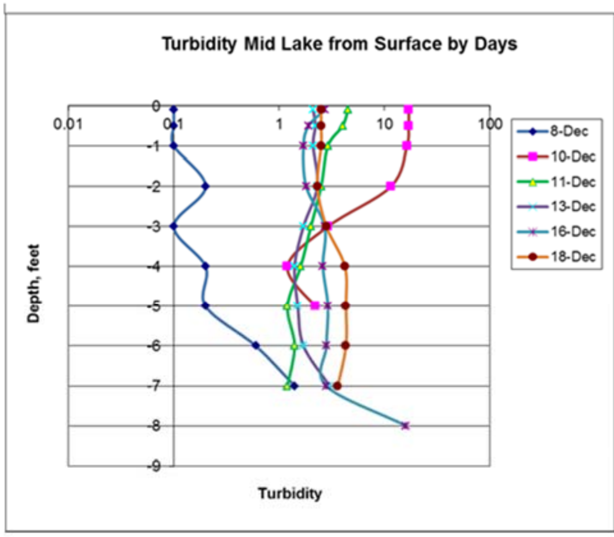


Figure 22. Laboratory results showing the relationship between turbidity and total suspended sediments over time in a water sample. Two graphs on the left depict results of a laboratory test and display the length of time required for erosive sediments to precipitate out of a 50 cm (20-inch) water column. Above graph is from one event taken at increasing distances from the storm water outfall to the opposite side of the pond.

The most visible sign of pollutant loads to the pond is the turbidity caused by suspended sediment load. The relationship between turbidity and sediment load from a construction site is shown in the top right graphic of Figure 22. The most common source of these sediments has been from grading activities on construction sites. As a first estimate the quantity of sediment as measured in milligrams per liter (mg/L) is half the turbidity NTU reading. The graphic (Figure 22) shows the relationship between turbidity and TSS as measured in a set of samples from a single storm event, adjacent to the plume inlet drain (230 NTU) to the opposite side of the pond (15 NTU).



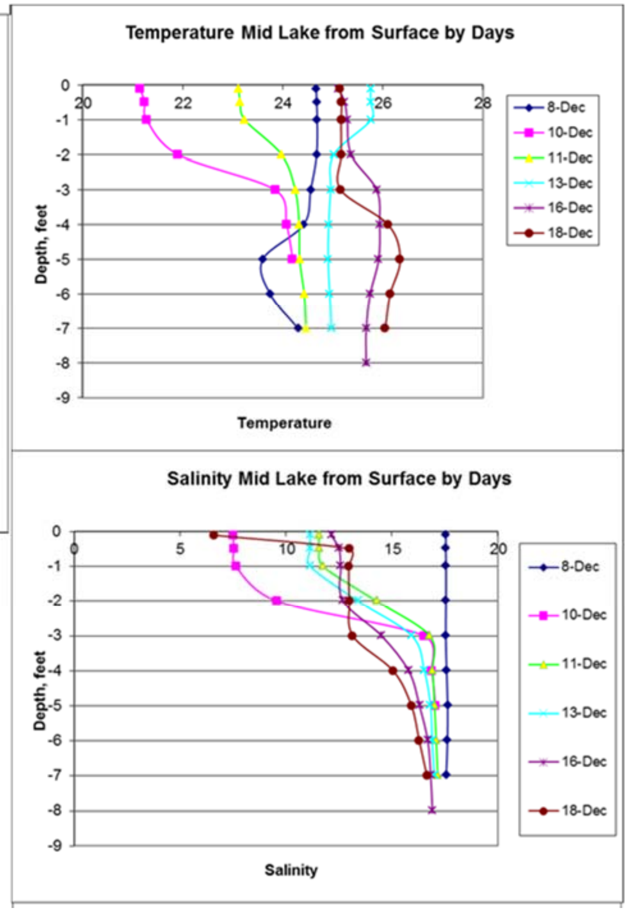


Figure 23. Turbidity, temperature and salinity cross section data from mid-lake taken one day prior and on several days following a large runoff event associated with hillside construction runoff from above the lake.

Following a rainfall runoff event, the estuary displays distinct stratification that slowly mixes over a period of several days to weeks depending upon the magnitude of wind waves. Just prior to and following a significant rainfall event (12- 9-2010) water quality profiles of temperature, salinity and turbidity were measured near the center of the lake (Figure 23). The graphics clearly show a well mixed un-stratified waterbody on Dec. 10, transformed by storm water inflow to produce a 2-foot thick layer of low salinity, low temperature, high turbidity (11-17 NTU) water on the top of the estuary. Profiles taken over the course of the following week show the stratification slowly dissipating through mixing but resulting in a generally more turbid pond. Typically the turbidity in the pond following a runoff event involves sequential blooms of phytoplankton and zooplankton over a period of one to several weeks. Note that while the salinity profile appears to take one to two weeks to become un-stratified, the sediment carried in with the fresh water lens as measured by turbidity, disappears within about a day. This is consistent with the laboratory results that show a 75% reduction in TSS within 24 hours (Figure 23).

During one very large rainfall event (9-inches on 12/19/10) the water surface of the 142 acre estuary rose from 1.73 feet to 3.4 feet LMLLW before the sand berm was over-topped and the water began to flow to the ocean (Figure 24). A YSI water quality data sonde on the Lanikai Bridge at the mouth of Kaelepulu Stream recorded a turbidity of about 80 NTU as the estuary fell to an elevation of 0.9 feet (Figure 24**Error! Reference source not found.**). 2.5 feet of water drop across the 142 acre estuary represents about 5.59 x10^9 liters of water. If a turbidity of 80 ntu is equal to a TSS of 40 mg/l (Figure 22) then a first order calculation would suggest that about 22 metric tons of sediment was carried to Kailua Bay during the first period of stream outflow following this storm.

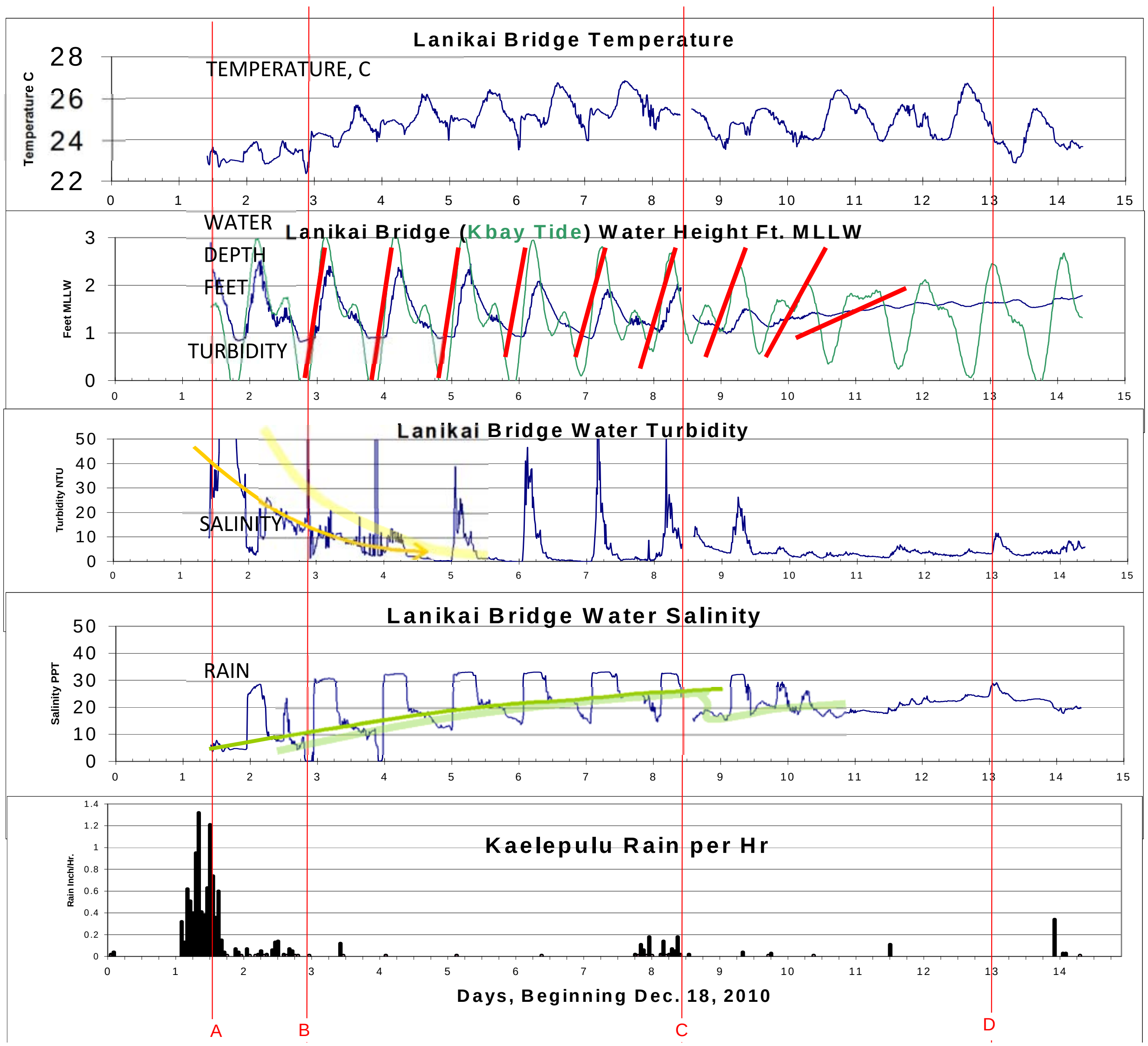


Figure 24. Dynamics of water quality during stream opening following December 18, 2010, 9-inch rainfall event as measured at Lanikai Bridge using a YSI water quality sonde.

In Figure 24 temperature fluctuates with both diurnal and tidal cycles. Water level in stream (blue=stream, green=ocean tide) breached the sand berm and fell to meet high tide (A), then began responding directly to tidal flow through a broad (100ft) opening to the ocean. The rate at which sand re-fills and eventually stops flow is mirrored by the inflow rate as shown by the red lines. Turbidity of the outflowing water was initially 80 NTU and then fell on subsequent tide flows to background levels within about 3 days. Spikes in turbidity during tidal inflow are attributed to entrained bubbles and particulates entrained up by breaking waves. Salinity of inflowing water is always near 33 ppt, whereas the salinity of the outflowing water gradually increases over time as the outflowing surface water becomes mixed with the inflowing salt water. The lower graphic shows rainfall during the period of measurement.

The magnitude of sediment that is carried to Kaelepulu Pond as a result of inadequate sediment and runoff controls at construction sites cannot be overemphasized. The difficulty arises because when the sediment is in transit, it is difficult to quantify, and when it is in the pond it is dispersed and out of view. Contractors, when confronted with evidence of a plume in the pond inevitably transition through several standard responses:

- Oh, no, we didn't have any significant runoff from our site. Must be from somewhere else. [Response: Would you like to look at this series of photos showing the runoff coming from your site?]
- You can't say all of that sediment is from our construction site. [Response: Yes, we can. Would you like to see the photos we took in adjacent drainages with clear runoff during the storm?]
- Well, it's really not all that much sediment. [Response: We have taken samples and made runoff volume calculations and can estimate the total quantity as about X tons.]
- No way that's accurate.   Besides, everyone knows that lake has been polluted forever, so big deal?

At this point the dialogue diverges differing between the socially responsible and the socially irresponsible contractors, with one dialogue leading to erosion control upgrades and cooperation, the other leading towards legal action.

In the runoff event displayed in Figure 24 we estimate that 22 tons of sediment were washed into Kailua Bay, but we know from sediment settlement calculations (Figure 22) that it is likely that upwards of 90% of the sediment (200 tons) remained in the pond and stream channels. When construction sites have large quantities of land open and inadequately protected from erosion, the quantity of material that is transported to the lake and from there to Kailua Beach over the period of several storms can be highly significant.

In the spring of 2004, a lot owner was conducting filling and grading of a steep parcel. The main drain from the parcel empties at the back of the "wetland" property owned by the de Vries family, who had been in the process of excavating the drainage easement between the end of the drain pipe and the Kaelepulu Stream. The two photos (Figure 25) show the result of a single 4-inch rainfall event that transported and deposited the estimated (8x30x120 ft) 1,000 cubic yards of sand gravel and rock into the excavation. Note that all of the fines, which typically represent at least half of the total quantity, were all washed into the stream and wetland.

Figure 25. Before (left) and after(right) sediment from a City storm drain filled this swale during a single storm. The staff is a 16-foot survey rod.

2.5.Keopa Flood Control Basin

The Keopa flood control basin (TMK 42004048) was constructed (1971-1972?) as part of the Kailua Bluffs development in the early 1970s and the dam deeded to the City for maintenance. The structure intercepts most of the runoff from the upper portion of the watershed and conveys it into Kaelepulu Pond through a concrete lined Kaelepulu Stream (Figure 20, upper right). In a very large (100 year 6 hour) storm the basin may receive runoff as high as 2,322 cfs (almost half of the total flow to Kaelepulu Pond) but limits the outflow to only 397 cfs (ParEn, 1993). In even larger storms when inflow may be as high as 3,665 cfs, the structure will overflow, but still limit the discharge to “only” 2,560 cfs. Although the dam is owned and maintained by the City, the actual basin is privately owned. Within the basin and about 100-feet back from the inner dam- face is a dirt mound (access easement) that is raised two or three feet above the basin floor and running across the width of the basin. This mound serves as an internal retention basin and likely was very effective as a silting basin to capture sediments during runoff events. Unfortunately, a lack of maintenance (this is within the privately owned section of the property) has allowed the formation of two erosional gullies through the mount which negates the effectiveness of this structure to capture sediment. This portion of the basin is also listed as a wetland on the City’s GIS map site, which would greatly complicate the permit process to make repairs to this berm. With minimal alterations to the internal configuration of the Keopa Basin, this structure could be greatly improved to act as an effective sedimentation basin for the watershed.

Figure 26. Top: Looking down the inside dam face as muddy water pours through the two erosional channels cut through the internal raised berm. Bottom: Inside the basin looking at the back of the dam face with the muddy water flowing into the two flow control structures beneath the dam.

2.6.City Streets as a Source of Physical Pollutants to Lake

Many of the inlets into the pond are fronted by a shallow area of built up sediment. When digging in these areas one often comes across deposits of fine gravel similar to the type used in asphalt. When Keolu Drive was re-surfaced in 2010, measurements of the eroded street surface were made prior to re-surfacing. One square meter of road surface was found to have eroded at least 3 liters of material of which 325 cc's of sand and gravel still remained. Given that there are 5.75 miles of City roadways in the watershed, the total area of all roads (assumed average width of 53 ft) is about 150,000 square meters and the total eroded material is about 450 cubic meters of material. This is equal to about 588 cubic yards, or 60 ten-yard dump trucks. Assuming this erosion took place over a period of 15 years yields an annual erosion rate from City Roads of about 39 yd^3/year.

Road surfaces are often considered to be sources of heavy metals like Chromium, Lead, and Cadmium due primarily from automobile engine and brake wear. Samples of gravel from the lake below a storm drain after a big storm, another of fresh (hot!) asphalt, and the third sample of 325 cc vacuumed from the road surface all tested at below detection limits for arsenic, cadmium, chromium, lead, mercury, selenium and silver.

Figure 27 Testing for quantity and quality of material eroded from City road surfaces.

2.7.Stream Mouth Openings and Ocean Exchange

2.7.1. Why the stream mouth needs to be manually opened

The necessity for the City to artificially open the stream mouth likely began shortly following completion of the initial Kawainui Levee in 1966 which deprived Kaelepulu Stream of the flow volume necessary to push sand out of the stream mouth across the beach and into the ocean. Clearing of the stream mouth using heavy equipment often involved merely pushing the sand up and out of the stream to either side, or out into the ocean, although there are persistent rumors that sand may also have been trucked off to other locations such as City golf course sand traps and Waikiki beach. Present day permit requirements stemming from the Clean Water Act prevent the City from pushing the sand into the ocean (as the stream would naturally do) and decree that the sand must be placed above the high water mark. In the 1960s there was little or no dune formation on the beach fronting the stream mouth with residents able to see the horizon and the ocean from Kawailoa Road. Today the sand dunes are 10-15 feet high on both sides of the stream channel. Kailua Beach has historically been accreting sand, growing seaward at a rate of about 1 foot per year – except for the section of beach adjacent to the Kaelepulu Stream mouth which has undergone historical erosion (see UH Coastal Geology, 2016)

Figure 28 The City uses heavy equipment to open the stream mouth about nine times per year.

Figure 29 1963 aerial (USGS EKM-2CC-246) dated 1-14-63 prior to construction of Kawainui Levee. Note stream flowing across sand beach (a), and wide sand beach continuous around Aala Point and into Lanikai (b). Location of historic stream mouth channel (~1850 nautical chart) can be seen ~1,000 feet to the west (c).

The stream must be manually opened because the lack of head-water flow resulting from construction of the Kawainui Levee has not left sufficient natural flow to keep the channel open across the dynamic sand beach. Prior to construction of the levee, the average monthly flow through the stream mouth was about 30 MCF, but since the levee was constructed the flow has only been about 1.5 MCF per month (Figure 18). The channel that evolved to carry 30 MCF is now only carrying about 5% of its average flow. This lower flow rate is not sufficient to offset the quantity of surf-suspended sand that builds up in and quickly closes the channel.

2.7.2. Three functions of stream mouth openings

Artificial opening of the stream mouth serves three essential functions: 1) it decreases flood threat to the community, 2) promotes exchange between Kaelepulu and the ocean and improved water quality in the estuary, and 3) supports fishery resources dependent upon estuary exchange (specifically mullet, and awa that must spend part of their lifecycle in brackish water).

The Park Engineering study (1993) estimated that a 100-year storm would generate flood elevations in the lower Kaelepulu stream of about 3.8 feet MSL (~4.1 ft LMLLW) and that this flood elevation would inundate the ground floors of several house lots located along Wanaao and Kawailoa Roads. More recent observation sets a flood inundation level of 3.3 feet LMLLW based upon bank overflow immediately upstream of the Lanikai Bridge at this elevation. If the sand berm at Kailua Beach is kept lower than 3.3 feet LMLLW then it will overtop and erode away before a flood elevation can be reached.

The secondary reason to breach the sand berm on a regular basis is to improve circulation and exchange within the stream, estuary, and associated wetlands. In summer months when evaporation exceeds inflow, exchange with the ocean at high tide is the only mechanism that will keep the wetlands wet, and prevent odoriferous mud flats from being exposed. Seawater inflow during a stream mouth opening can exchange much more water through the estuary than even very large storms. A 1-year rainfall event of 4.5 inches will raise the elevation of the estuary by 1 to 1.5 feet representing about a third of the entire estuary volume. But if the stream mouth is kept open through eight days at two tide cycles per day (such as occurred February, 2015, Figure 32), the accumulated volume of seawater inflow is 5.5-feet which exceeds the volume of the entire estuary. Of course, much of this water is merely mixed and then flows out on the next outgoing tide (Figure 24) but the effect is still quite positive.

The positive impact of estuary exchange upon local nearshore fisheries is an often overlooked impact of stream mouth openings. In addition to acting as a filter, preventing most of the land-based sediments and nutrients from reaching the nearshore coral reef habitats, the estuary also acts to transform these same nutrients into biological material of importance to the broader aquatic ecosystem. Following a runoff event nutrients are quickly absorbed by fast-growing phytoplankton and macro-algae in the pond. Visible blooms of phytoplankton often begin within days after runoff events or ocean exchange events, and are quickly followed by blooms of zooplankton (primarily copepods and rotifers) feeding off of the phytoplankton. These zooplankton are the primary feed for many larval fish and invertebrates. Larvae of ocean fish that find their way in through the stream mouth (kaku, papio, ama’ama, awa, lae, aholehole, and others) find plentiful food within the estuary. When the estuary is in the midst of a zooplankton bloom and the stream mouth is opened to flow, the feast of copepods and rotifers broadcast out into the bay definitely supports the broader community of larval fish in the bay.

2.7.3. Hydrologic influences that impact stream opening effectiveness

When the stream mouth is open to the ocean at the beach, low salinity water from the surface of the stream flows out to sea whenever the stream water surface elevation is higher than the ocean. The rate of flow is determined by the size of the channel and the hydraulic gradient (head difference) between the stream and the ocean. The effluent plume from the stream spreads out on the surface of the nearshore waters and is transported either to the left (west) towards the center of the beach, or to the right (east) towards the boat ramp and Lanikai by nearshore currents. On the rising tide the water flowing into the estuary commonly has a salinity of 33-35 ppt – essentially full strength sea water. As it flows into the stream this salt water tends to sink beneath the lower salinity water in the estuary and flow upstream as a classic estuary salt wedge. However, the progress of the salt wedge is blocked at the entrance to the pond by the shallow shoaled channel adjacent to the City's Hele drainage channel (Figure 31). As this flow is blocked, the Kaelepulu stream channel tends to fill up with higher salinity water, pushing the low salinity water back up and into the body of the pond. This submerged berm in the stream channel greatly reduces the efficiency of water exchange and circulation within the body of the pond (Figure 33).

The impact of this submerged berm upon water circulation is demonstrated in Figure 31. The figure shows salinity cross sections through the Kawainui (top) and Kaelepulu (bottom) branches of the estuary. The top pair of cross sections represents a period of time without significant rainfall to the well mixed estuary. In the middle figure the stream mouth has been opened allowing ocean water (red) to flood into and across the floor of the estuary. Note how the water of high salinity is stopped by the submerged berm and does not enter the main portion of the pond. In the lower pair of cross sections, the stream mouth is closed at the beach, but rainfall has lowered the salinity of the surface waters and depressed the salt wedge in the estuary.

As the denser seawater slowly fills the fresh and brackish water stream channels, it eventually overtops the submerged berm at the mouth of Kaelepulu Pond and then falls into the bottom pond basin. The volume of the streams (at 1.5 ft elevation) is roughly 4 MCF. Assuming the stream channels need to be half full of dense sea water to overtop the submerged berm and flow into the main body of the pond, this would be a volume of 2 MCF, or equal to about a 4-inch (0.33 ft, 10 cm) rise in water surface elevation from a tidal inflow. Any inflow events less than 4-inches are not likely to effectively pump sea water into the body of the pond.

During periods when the stream mouth is open to flow, channel erosion and widening occurs if the water flow speed exceeds about 3 feet per second. At speeds above about 5 feet per second there is significant fluidization of the sand bed and very rapid erosion and channel widening occur. The rate at which the channel closes itself is dependent upon the size of the initial opening at the end of the initial draw down, the size of waves generating suspended sand particles in the stream mouth surf zone, and the height of the incoming tides governing flow speed through the channel. Flow speeds less than about 3 ft/sec allow suspended sand to precipitate and fill the channel. Experience has demonstrated that the

Figure 30. October 2014 the City responded to a high water surface in the pond and an impending rainstorm to conduct an "emergency" opening of the stream mouth. Flow established in a 1-foot deep 15 foot wide channel completed at 16:15 developed into a 30-foot wide 3 foot deep channel in about an hour and fifteen minutes. Within minutes of the last photo the cameraman had to abandon his location as the bank was eroding from beneath his feet.

best time for the City to open the stream channel is on a low low falling tide several days prior to the highest tides of the month. If done properly, this maximizes the initial water head and duration of outflow and allows the outflowing water to erode a channel of significant width and depth. This wide and deep channel then stays open on subsequent inflow events if the inflow velocity remains near or above 3 feet per second across the sand bar. The eroded sand stays in the Kailua Bay system and is eventually re-deposited on the beach. The series of photos in Figure 30 show an initial 15-foot wide, 1 foot deep channel created by the City's bulldozer widening to a 30 foot wide 3 foot deep channel in about an hour and fifteen minutes. A half hour after the final photo the channel was 50 feet wide. The City had attempted to open the stream four hours prior (10 am) and were not successful because of a high tide. Timing openings with the tide is very important.

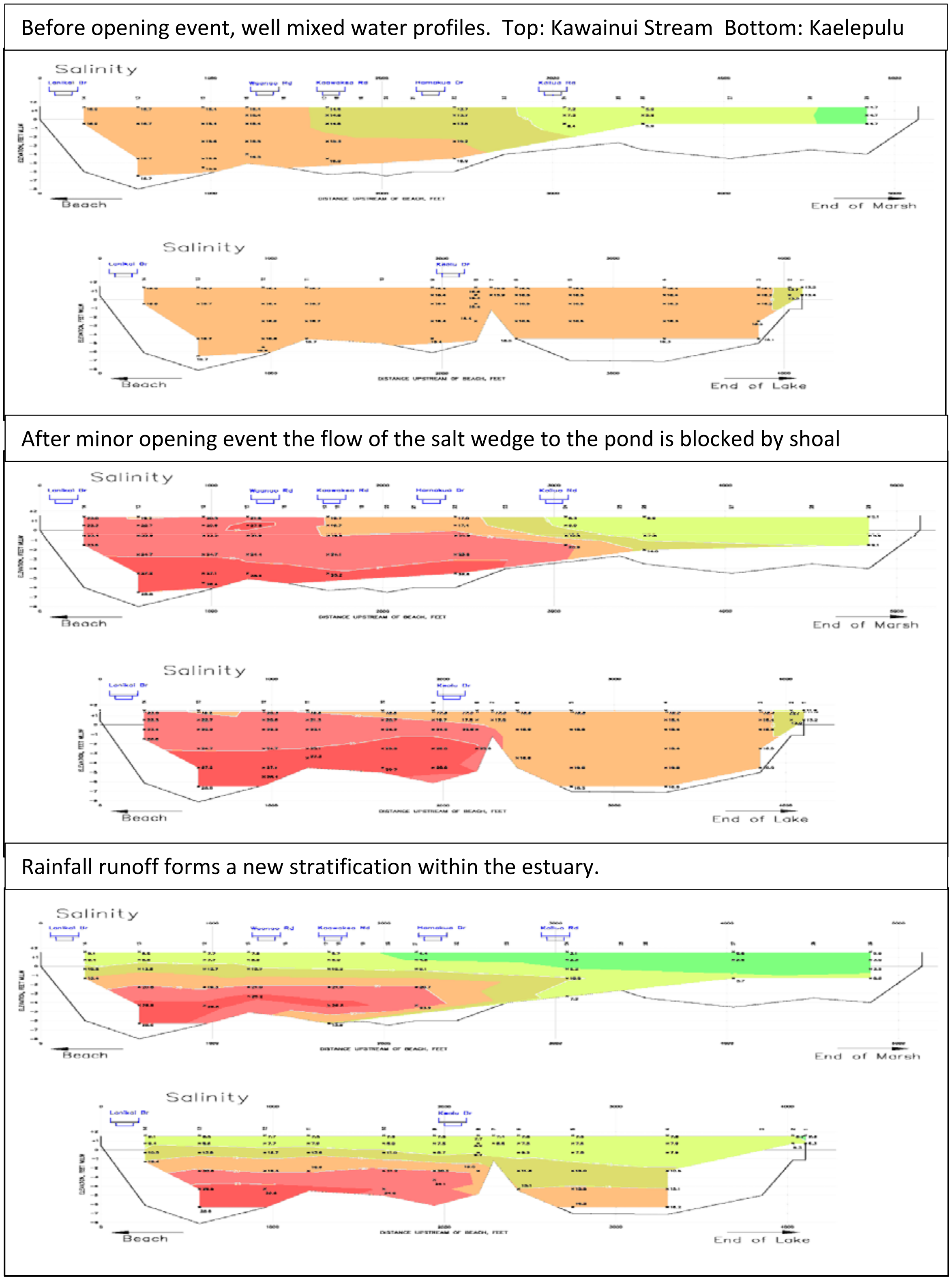


Figure 31 Water quality cross sections of Kawainui (top, each pair) and Kaelepulu (bottom of each pair) before (top) and after stream mouth opening (middle), followed by inflow from rainfall (bottom).

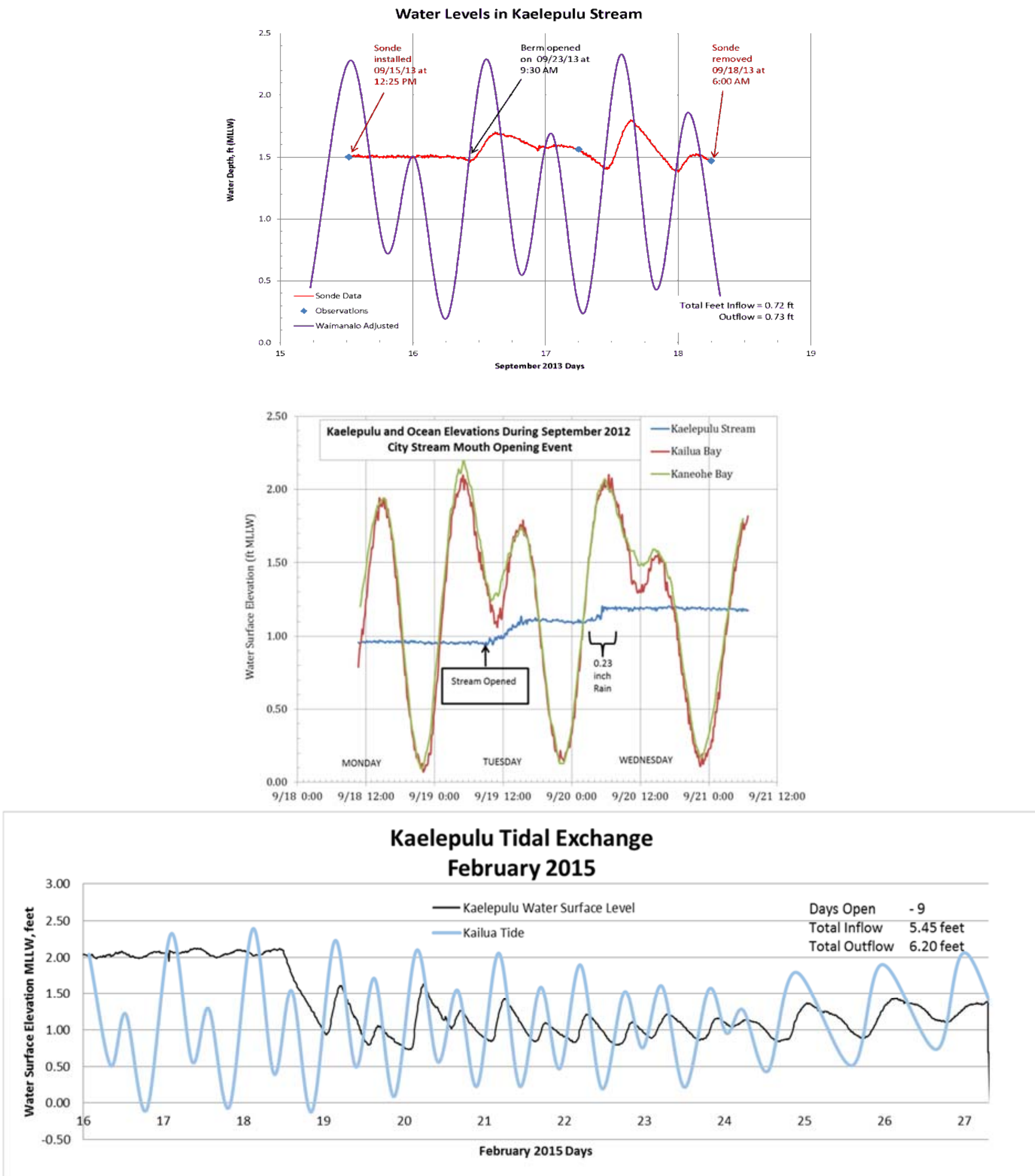


Figure 32. Stream mouth openings initiated by City heavy equipment operators vary greatly in the quantity of resulting exchange. Openings made with only a short outflow period until the incoming tide (top) or those openings made when the sea level were higher than the stream (middle) were not effective. Openings that produce greater exchange are the result of a high initial water surface elevation, high amplitude tides, and the timing of the openings to produce a long period of initial draw down. It is presumed that the long period of initial drawdown served to erode a larger channel through the beach which then requires more time to close over several tidal cycles.

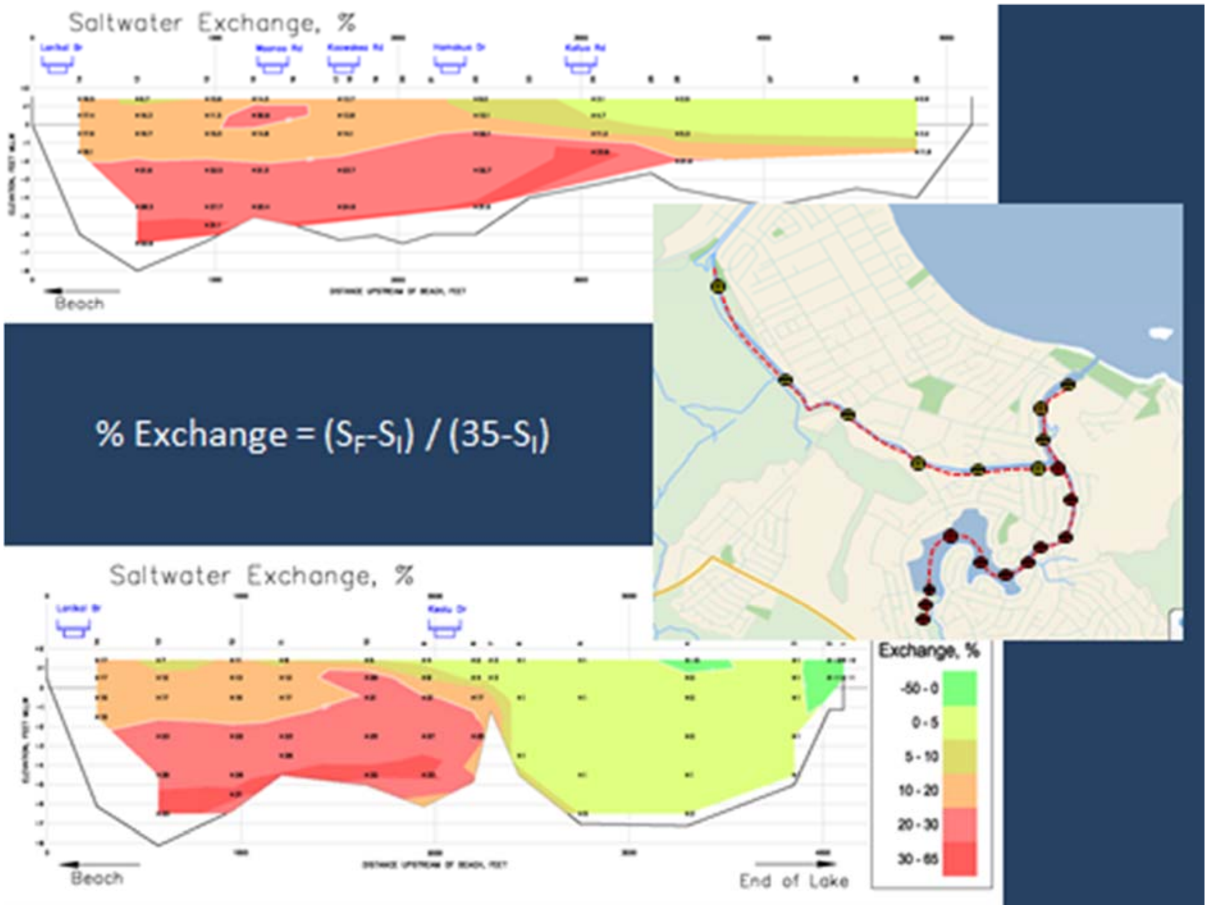


Figure 33 Results of percent exchange calculations, based upon salinity changes following one stream mouth opening event. As expected the greatest exchange occurs nearest the stream mouth, however it is also evident that the shallow area in Kaelepulu Stream (lower graphic) is a significant block to effective water exchange. Removal of this obstruction by dredging will allow the inflowing salt water to penetrate all the way into the body of the pond, greatly improving total circulation.

2.8.Mangrove Removal from Kaelepulu Pond and Stream

Beginning in 2000, work began towards the removal of the many hundreds of seedling mangroves beginning to grow in the shallows of the Kaelepulu Wetland. The area had been cleared of mangrove during construction of the mitigation wetland and adjacent homes but was rapidly being re-seeded from adjacent mature mangle within the pond. The seedlings were the result of two major (and numerous minor) mangle patches in the pond covering an area of about 2.5 acres. In 2003 the ELRA received a 319-grant from the Department of Health to remove mangrove from the pond. The bulk of the money was spent to hire two separate companies to physically remove the two large mangle forests from the pond. As the largest mangle was growing on the last remaining undeveloped shoreline, still owned by Kamehameha Schools, they also contributed to the cost of the removal, and have since maintained their 2-acre wetland parcel free of mangroves. Over a period of about two years volunteer work crews removed the balance of mangrove growth around the perimeter of the pond and re-trimmed the thousands of seedlings that sprouted from the remnant roots of the removed mangle.

In 2008 the ELRA and Kailua Canoe Club were joint recipients of a grant from the Hawaii Community Foundation and Kaneohe Ranch to clear mangroves from the mile-long Kaelepulu Stream between the lake and the ocean, and from the lower 1/3rd mile length of Kawainui Stream above its junction with Kaelepulu. Upon completion of this task, the canoe club was awarded a new racing canoe valued at about $20,000 (Figure 35).

Figure 34. Mangrove removal from Kaelepulu and Kawainui Streams by the Kailua Canoe Club earned them a new racing canoe from the Kaneohe Ranch Foundation

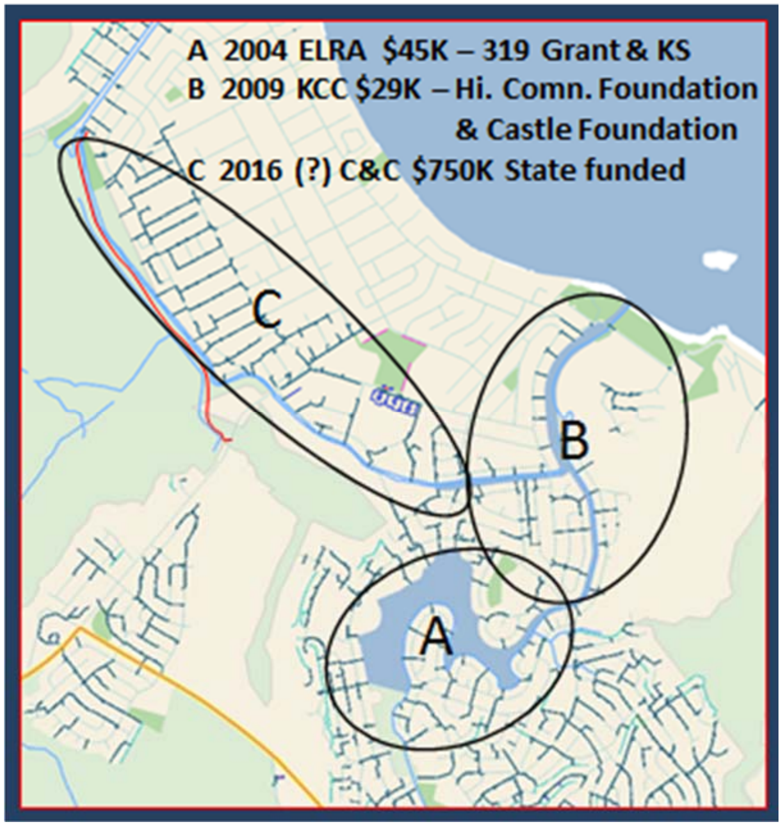
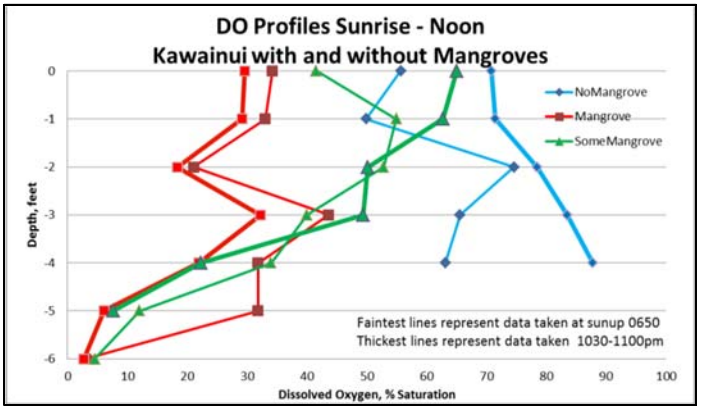


Figure 35 Mangrove removal efforts in the pond, the lower reaches of Kaelepulu and Kawainui Streams have been conducted with grant funds and a good deal of community effort. Removal of the large mangle in the upper Kawainui reach is pending funding from the State and City and is anticipated to be completed in 2016.

In 2010 as the Kailua Canoe Club removal of mangrove in the lower Kaelepulu was being completed, it became clear that the very large stands of mature mangrove clogging the upper Kawainui Stream were rapidly reseeding the estuary and were much too large to be removed through community effort. During the following State Legislature session $750,000 in State funding was obtained to pass through to the City to allow them to remove the mangrove. This action is still pending (as of 12/15).

The adverse impact of mangrove upon water quality is clear. The impact upon dissolved oxygen and pH was demonstrated along a short reach of Kawainui Stream where the stream transitions from open water, to a section recently (2 years) cleared of mangrove, to a section completely overgrown with mangrove. Depth profiles of dissolved oxygen and pH taken in the early morning and again at noon show the persistence of low oxygen and pH within the mangle. The poor water quality in the area recently cleared of mangrove is attributed to the persistence of the roots and trunk systems that remain below water for several years following removal of the aerial portion of the plant. In addition, the mangle shades and crowds out native flora and fauna and provides roosts for non-native birds, in particular large flocks of cattle egrets. Fecal material deposited within the mangrove fuels anaerobic conditions and a number of these non-native birds prey upon endangered native water birds dependent upon adjacent wetlands.



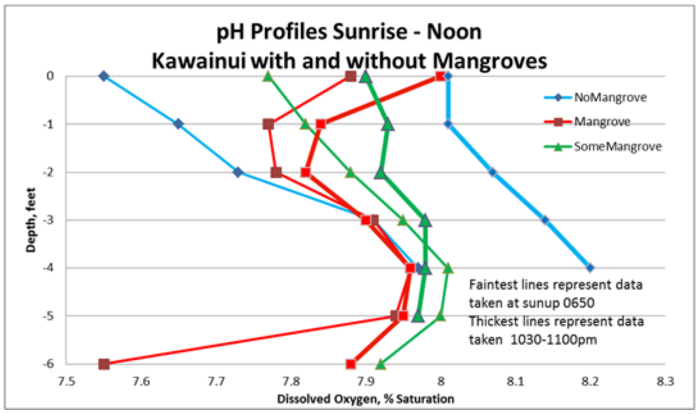


Figure 36 Dissolved oxygen and pH profiles obtained in Kawainui channel at dawn and again at noon at three locations 1) in the midst of mature mangrove growth, 2) in an area where mangrove had been removed two-years prior, and 3) in an area with no mangroves. These graphics depict the adverse impact of mangroves upon dissolved oxygen and pH. Consistent with similar results obtained in Pearl Harbor, the ability of mangroves to adversely impact oxygen and pH water quality exists long after their removal, likely due to the presence of the massive root systems which are not typically removed when the trees are cut.

3. Fisheries

The pond supports populations, in rough order of prevalence, of tilapia, gobies, milkfish, mullet, barracuda, papio, and lae. The papio (*Caranx ignobilis*) is a recent addition, first noted in the late summer of 2013 as small (4-6”) juveniles, and presently (9/2016) as larger (12-20””) sub-adults. The milkfish (Awa, *Chanos chanos*) occur in schools of 10’s to a few hundred sub-adults (12-24”) grazing on the macro-algae beds of Gracilaria (Figure 38) in shallow water. When the stream mouth is open, these Awa awa are targeted by throw-net fishermen near Lanikai Bridge. Barracuda are plentiful in the lake and are avidly sought by fishermen, most of whom release their catch. Sizes typically range from 24-39”, but individuals approaching 72” have been reported (and personally seen by the author). The large barracuda in Figure 38 were all killed by a low oxygen event associated with overgrowth of macro-algae in the pond. The macro algae growth was likely stimulated by the inflow of sediments and associated nutrients from an upslope development grading project.

Figure 37 Recreational fishing, often catch and release, is popular in Kaelepulu Pond

Figure 38 Large barracuda are common the in pond, these died due to an algae bloom. Awa awa schools feed almost exclusively on the macro *algae Gracilaria tikvayahe* as seen in the right hand photo.

Figure 39. The use of gill nets is prohibited in the ELRA and Kaelepulu Wetland portions of the estuary. The 10-pound Awa in the top photo provides a good rationale for this prohibition. Samoan crabs can reach sizable dimensions in the estuary. Since 2014, papio have been becoming more prevalent in the pond.

Gobies (o'opu akupa, *Eleotris sandwicensis)* are abundant, but not often observed in the pond. They are commonly caught by net in the shallows. On one occasion, during what appeared to be an algae bloom low-oxygen event, thousands of gobies were seen at the surface and many hundreds died (11-25-05).

Nutrients entering the system from the surrounding watershed coupled with the inflow of ocean water fuels the growth of phytoplankton and zooplankton which, if they don't result in low-oxygen fish die-offs, fuel the growth and reproduction of an impressive crop of fish within the pond. The crowds of pole fishermen, throw-netters, and (illegal) gill netters that vie with each other for the fish leaving the pond on every stream mouth opening are testament to the vitality of the fishery.

4. Conclusion and Recommendations

The Kailua Waterways, consisting of the truncated branch of the Kawainui Stream, the Hamakua Wetlands, the Kaelepulu Stream, Kaelepulu Pond, and Kaelepulu Wetland, are a much modified but vibrant ecosystem innervating the town of Kailua. Over a period of a little more than a century, both Kaelepulu and Kawainui transitioned from bountiful open water fish ponds, to irrigation sources for taro, rice, and sugar farmers, and by the mid-twentieth century into swamps choked with alien vegetation acting as receptors for sewage. Subsequent "improvements" to these systems literally cut the watershed in half by construction of the Kawainui levee, and then cut the area of Kaelepulu Pond in half by filling the perimeter of the pond for home lots. Yet, both systems retain ecosystems that support recreation, wildlife and fisheries. With the advent of the Clean Water Act and recognition of the value these systems bring to the broader community, a number of studies and projects have pointed the way for the restoration of these ecosystems.

The primary challenges facing the Kaelepulu estuary are six-fold:

1) restoring partial flow to the Kawainui Stream,
2) maximizing ocean exchange through the stream mouth,
3) ridding the estuary of invasive mangroves,
4) effecting control over sediment loads from construction sites,
5) improving penetration of the salt wedge circulation into the main pond and
6) retrofitting the City storm drains to prevent introduction of gross pollutants into the pond.

Loss of historical flow from the 6,200 acres of the Kawainui watershed has caused the Kawainui Stream branch of the estuary to become stagnant. Prior to 1966 when the levee was constructed, this stream carried an average of 28.5 MCF per month to the Kaelepulu Stream and out into Kailua Bay. Under present conditions, unless there is active rainfall and runoff, the flow is essentially zero. The trial restoration of 2 CFS (~5.25 MCF/mo) (Oceanit, 2016) demonstrated the positive ecological impact of this flow restoration and the absence of any measurable increase to flood threat.

The City has periodically opened the Kaelepulu Stream mouth through the sand berm at Kailua Beach because, according to its drainage agreement with the pond owner, it is responsible for maintaining the drainage of Kaelepulu Pond to the sea and because it is a good flood threat minimization measure to keep the top of the berm lower than the flood elevation. Observations made of numerous opening events show a broad range of both effort and effectiveness of the openings. The most effective openings tend to be a few days before peak tides (new or full moon), a few hours after high tide when the level of the ocean drops below the level of the stream. This allows both a long period of outflow and the highest hydraulic gradient as the ocean falls to its low-low tide. Narrow deep openings are more effective than wide shallow openings.

Mangroves have proven to have very negative impacts upon nearshore ecosystems in Hawaii. Removal of mangroves from the Kaelepulu portion of the estuary resulted in marked improvement to ecosystem quality and decreases in the incidence of malodorous events. It is critical that ALL of the mangroves are removed from the system to eliminate the constant source of re-seeding from existing mature trees.

Silt loads from construction sites with open grading have been highly significant sources of pollution to the system over the past two decades. The nitrogen and phosphorus carried in 10 pounds of top soil is sufficient to grow over 100 pounds of algae in the pond. Most construction sites have only minimal BMPs designated in their permits, and most do not even follow these. Even when BMPs are followed, however, there is still a very significant (many tons) of sediment that often makes its way off the construction site into City storm drains and into the estuary. The Keopu flood control basin used to act as an effective silt trap but has been allowed to degrade to a point where it no longer serves this function. It is not right that the owners of the pond must pay for the inability of contractors to control their sediment loads. If the City cannot find a way to force contractors to keep sediments on their construction sites, then it is likely that this issue will be raised on future federal NPDES permit applications.

Because of the shallowing of the Kaelepulu stream near Hele Channel and its junction with the pond body, the dense salt water entering from the ocean does not typically flow all the way into the pond, but mixes within the canal and flows out again on subsequent outgoing tides. This shallow spot has likely been in existence since 1963. Removal of this shallow sill by dredging will allow the inflowing water to enter and fall to the bottom of the main pond, with less saline surface water draining out to the ocean on subsequent outgoing tides. This would both greatly improve the actual exchange and increase the salinity of the pond – likely to the point where it will again support oyster growth to improve water quality and more robust fisheries.

In the final analyses, most of the water entering the system does so through the City storm water drain system, which operates under the Federal non-point source discharge elimination system permit and is subject to Federal Clean Water Act and State Department of Health water quality regulations. While much of the pollutants originate from non-City sources (with the exception of road surfaces), the City is still responsible for the pollution loads that come out of the end of the pipe into the estuary. The State began a total maximum daily load (TMDL) study of Kaelepulu in 2003, and funded a number of studies up through 2010 but has never completed the process. The City conducted a storm water BMP study (AECom, 2008) and then rejected the key BMP recommendations of the report to filter gross pollutants from several of the major open channels entering the system. Completion of the State TMDL will very likely put pressure on the City to upgrade its drainage system.

The systematic solution to each of the above problems will greatly contribute to the restoration of the Kaelepulu and Kawainui Stream ecosystem, improve water quality, enhance fisheries and increase the level of ecosystem functions and services provided to the surrounding community and nearshore waters of Kailua Bay.

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Appendix A
Summary of Previous Studies

4.1. Park Engineering Flood Study 1992

Park Engineering completed a flood study in 1992, three years following the 1989 flood event that overtopped the Kawainui flood levee. The study concluded that the Kaelepulu Pond acted as a flood detention basin with a flood elevation of 3.8 ft MSL impacting homes in low lying areas nearest the shoreline. The presence of mangrove along the channels was noted to decrease the flood flow capacity of both the Kaelepulu and Kawainui streams and had resulted in significant shallowing of the Kawainui Branch. The only shallow portion of the Kaelepulu branch was the submerged berm at the entrance to Kaelepulu Pond.

As part of the preparation for proposed dredging of the Kawainui Stream behind Kailua AECOs in 1991 sampled five surface water stations between Kailua Bridge and the Kaawakea Bridge in the Kawainui Stream adjacent to Hamakua Wetland as part of an environmental assessment involving development of these lands for housing. One set of samples was during dry weather and the other following rain events.

4.2. University of Hawaii – Water quality & Bacteriology, Fujioka et al.

A series of studies were conducted by the University of Hawaii in the early 1990s in response to public outcry concerning potential pollution of Kailua Bay from the Kailua Waste Water Treatment Facility ocean outfall. These studies include works by Anuna and Fujioka, 1993; Roll and Fujioka, 1993; Moravcik and Heitz, 1993; Krock and Fujioka, 1993, and Fujioka, Wu, and Fujioka, 1993) Conclusions of these studies where they touched upon Kaelepulu Stream include:

- Recreational water quality standards in Kailua Bay are exceeded when Kaelepulu Stream is open to flow.
- Kaelepulu Stream salinity is subject to ocean water inflow and should be considered as an estuary, not a stream system.
- Water quality standards for streams were always exceeded in the Kaelepulu Stream and Pond.
- The primary source of indicator bacteria were sewage discharges and duck feces, with lesser input from source waters, soil and storm drain runoff.
- Nutrient loading was suspected in the Hele ditch, in the Kawainui Stream, and in the pond adjacent to the City sewage pump station on Akumu Street.

4.3. University of Hawaii TMDL Studies Tamaru & Babcock

The Department of Health allocated funds to UH for the performance of several studies including

- Kaelepulu TMDL Scoping Study, 2005 in which previous reports are reviewed and an overall analyses of the watershed conducted to better understand the scope of work necessary to be completed to achieve a TMDL
- Kaelepulu TMDL Sampling and Analyses Plan (Draft,2005; Final 2009).
- Kaelepulu TMDL Progress Report, 2011.
- Kaelepulu TMDL Water Quality Monitoring Report. 2012 A compilation of over a year of monthly sampling events, rainfall monitoring and water surface elevation measurements from sites spread across the entire water body. Report was rejected by DOH for alleged mis-handling of sample quality control. The data was obtained from the authors and used to create the graphics in Appendix C
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4.4.Kailua Bay Advisory Task Force – KBAC – 2003 Draft Kailua Waterways Improvement Plan

4.5.Kailua Bay Advisory Task Force - KBAC – 2007 Koolaupoko Watershed Restoration Action Strategy.

KBAC funded.

4.6.University of Hawaii PCB study – 2003

Funded by KBAC, the University of Hawaii was tasked to describe the bathymetry and currents within Kaelepulu Pond, and to investigate the potential buildup of PCB contaminants in fish within the estuary. A single bathymetry cross section was conducted through the pond and salinity profiles conducted along the transect identified both the shallow sill at the pond entrance as well as its effect in blocking the salt wedge penetration into the pond. Sufficient quantities and sizes of fish were not able to be captured to conduct most of the tissue studies planned. PCB analyses conducted on the limited samples obtained (1 barracuda) showed levels of PCBs in the fish tissue with extremely low concentrations – about the same as can be detected in butter obtained from any grocery store. The UH report, purporting to have documented the presence of contaminated fish within the estuary, was reviewed and rejected by the State Department of Health (DOH).

4.7.DOH Legislative Report 2006-2008

The State DOH listed the Kailua Waterways (Kaelepulu + Kawainui Stream) as "water quality limited segments" in 2002 and began the TMDL study in 2004. This report authored by D. Penn reviewed the findings of the first several years of effort by the DOH and provides a good summary of the challenges involved.

4.8.TEC sediment cores – for City drainage study.

The City conducted a planning study of the watershed to determine the best approach for management of effluent through the drain system into the pond and associated streams (AECom, 2008). This study identified the four channelized drains to the pond as likely candidates for the installation of physical best management practice devices. A follow-up study is being conducted to better understand runoff and pollutant loading characteristics of the storm sewer system and to develop plans for physical BMPs

4.9.USGS Sewage Tracer Study – 2006 Bill Hunt

Hunt, 2006 with the USGS on contract to the State DOH as part of the TMDL program collected a series of samples at 41 stations throughout the watershed and measured 71 trace contaminants typically linked to sewage contamination. As part of the investigation, water quality nutrient sampling was also conducted at seven stations along the Kaelepulu Stream, eight stations along the Kawainui Stream, eight stations within the main body of Kaelepulu Pond and four stations within the Kaelepulu wetland. The only contaminant detected above laboratory analyses detection limits was caffeine, at three locations as depicted in Figure 40

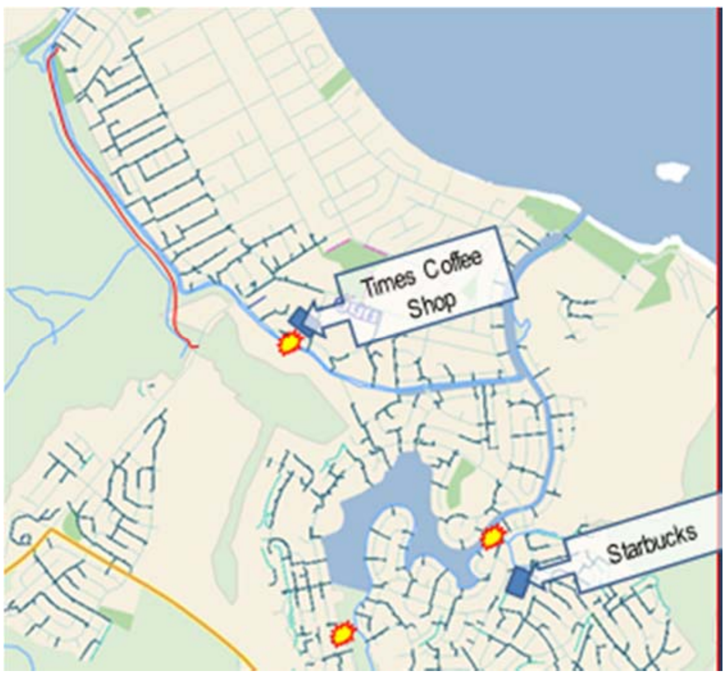


Figure 40 Sample sites where caffeine was detected in surface waters, with overlay of local coffee houses.

4.10. Kailua Waterways. Report to the 24th State of Hawaii Legislature (2008).

A very thorough, but highly biased, report authored by Dr. Penn as (then) the head of the State of Hawaii DOH TMDL program. The 2006 legislature, perceiving a lack of progress on the TMDL study of the watershed initiated in 2002, the 2006 requested summarizing information from previous reports and studies related to the Kailua waterways (Kawainui Stream, Kaelepulu Stream and Pond). The report incorrectly assumes that Kaelepulu is a pollutant source (not as an estuary ecosystem) and focuses upon the multiple potential sources of pollutants to the system and theoretical ways to control these pollutant sources. The report then goes into great detail concerning the State water quality standards, the types of systems to which these apply, and how the Kailua Waterways do not meet these standards.

One of the recommendations of the report is to evaluate the possibility of restoring flow from Kawainui Marsh to Kawainui Stream.

4.11. Summary of Previous Water Quality Nutrient Studies

Previous investigations of water quality within the Kailua Waterways have been conducted by

- Hunt, in 2006 as part of the USGS study funded by the DOH TMDL program

Location Sorted Data from USGS 2008

	System	Descriptor	site_no	sample_dt	sample_tm	p00095 Conductivity	mg/L Ammonia N	p00608 Ammonia N	Ammonia NH4	p71846 Ammonia NH4	mg/L N03+NO2 as N	p00631 N03+NO2 as N	mg/L Phosphorus PO4	p00660 Phosphorus PO4	mg/L Phosphorus p	p00671 Phosphorus p
Kaelepulu Below Junction						31425	0.105	<0.1	0.12	0.11	0.008	0.008	0.015	0.015	0.005	
	Kaelepulu Stream	at Lanikai bridge	212300157440914	7/24/2008	14:00	32100	0.12	< 0.240			0.008	< 0.016	0.016	E 0.016	0.005	E 0.005
	Kaelepulu Stream	End of golf course above Lanikai Br	212300157440928	7/24/2008	13:50	30800	0.088	E 0.088	0.11	E 0.11	0.008	< 0.016	0.015	E 0.015	0.005	E 0.005
	Kaelepulu Stream	Mid golf course	212300157440913	7/24/2008	13:42	31900	0.12	< 0.240			0.008	< 0.016	0.015	E 0.015	0.005	E 0.005
	Kaelepulu Stream	at golf island	212300157440927	7/24/2008	13:31	30900	0.091	E 0.091	0.12	E 0.12	0.008	< 0.016	0.013	E 0.013	0.004	E 0.004
Kaelepulu Above Junction						29867	0.093	<0.1	0.14	0.11	0.009	<0.016	0.013	0.015	0.004	
	Kaelepulu Stream	Just above Kawainui St junction	212300157440926	7/24/2008	13:22	29500	0.05	< 0.100			0.011	E 0.011	0.014	E 0.014	0.005	E 0.005
	Kaelepulu Stream	500 feet above Kawainui Junction	212300157440912	7/24/2008	13:16	30100	0.12	< 0.240			0.008	< 0.016	0.013	E 0.013	0.004	E 0.004
	Kaelepulu Stream	Near Golf Course Side channel	212300157440925	7/24/2008	13:09	30000	0.108	0.108	0.14	0.14	0.008	< 0.016	0.011	E 0.011	0.004	E 0.004
Lower Kawainui Stream						24450	0.364	0.364	0.468	0.468	0.033	0.034	0.073	0.015	0.024	0.024
	Kawainui Stream	Below Kaawakea Br	212300157440924	7/24/2008	12:46	28400	0.146	0.146	0.19	0.19	0.048	0.048	0.025	0.025	0.008	0.008
	Kawainui Stream	below Hamakua Bridge - mangroves	212300157440904	7/24/2008	12:00	27000	0.329	0.329	0.42	0.42	0.067	0.067	0.049	0.049	0.016	0.016
	Kawainui Stream	Hamakua Wetland	212300157440923	7/24/2008	11:46	23700	0.427	0.427	0.55	0.55	0.008	E 0.008	0.053	0.053	0.017	0.017
	Kawainui Stream	above Kailua Bridge	212300157440903	7/24/2008	11:25	18700	0.553	0.553	0.71	0.71	0.008	< 0.016	0.165	0.165	0.054	0.054
Upper Kawainui Stream						17025	0.355	0.355	0.455	0.455	0.0083	<0.016	0.084	0.015	0.027	0.027
	Kawainui Stream	1/3 way above Kailua Bridge to Kaha	212300157440911	7/24/2008	11:02	16800	0.423	0.423	0.54	0.54	0.009	E 0.009	0.092	0.092	0.030	0.030
	Kawainui Stream	Above Kailua Br. 1/2 way to Kaha	212300157440922	7/24/2008	10:50	16900	0.415	0.415	0.53	0.53	0.008	< 0.016	0.084	0.084	0.027	0.027
	Kawainui Stream	Below Kaha park at side channel	212300157440921	7/24/2008	10:34	16700	0.334	0.334	0.43	0.43	0.008	< 0.016	0.081	0.081	0.026	0.026
	Kawainui Stream	at Kaha Park 1st side channel	212300157440902	7/24/2008	10:20	17700	0.248	0.248	0.32	0.32	0.008	< 0.016	0.078	0.078	0.025	0.025
Main Pond Body						36663	0.053	<0.1	0.08	0.08	0.008	<0.016	0.032	0.032	0.010	0.010
	Pond	KS Lot lagoon	212300157440907	7/28/2008	10:45	37600	0.05	< 0.100			0.008	< 0.016	0.070	0.070	0.023	0.023
	Pond	North west near Clemmer's	212300157440917	7/28/2008	12:15	36900	0.05	< 0.100			0.008	< 0.016	0.019	0.019	0.006	0.006
	Pond	East side - edge of wetland	212300157440930	7/28/2008	11:45	36800	0.062	E 0.062	0.08	E 0.08	0.008	< 0.016	0.026	0.026	0.009	0.009
	Pond	md pond - off KS lot below wetland	212300157440931	7/28/2008	11:30	36500	0.05	< 0.100			0.008	< 0.016	0.027	0.027	0.009	0.009
	Pond	Kukilakila Pennensula end	212300157440932	7/28/2008	12:30	36000	0.065	E 0.065	0.08	E 0.08	0.008	< 0.016	0.028	0.028	0.009	0.009
	Pond	Bevar's house shoreline	212300157440933	7/28/2008	11:55	36300	0.05	< 0.100			0.008	< 0.016	0.031	0.031	0.010	0.010
	Pond	North shore	212300157440936	7/28/2008	12:10	36400	0.05	< 0.100			0.008	< 0.016	0.023	0.023	0.007	0.007
	Pond	North west shore	212300157440934	7/28/2008	12:25	36800	0.05	< 0.100			0.008	< 0.016	0.032	0.032	0.010	0.010
Inlets to Pond						17750	0.358	0.358	0.460	0.460	0.015	<0.016	0.337	0.337	0.11	0.11
	Pond Inlet	Keopa Channel by Kaelepulu Elem	212300157440901	7/24/2008	10:30	17000	0.475	0.475	0.61	0.61	0.009	E 0.009	0.43	0.43	0.140	0.140
	Pond Inlet to wetland	Kaelepulu Stream mouth at wetland	212300157440905	7/28/2008	9:30	18500	0.241	0.241	0.31	0.31	0.02	0.02	0.244	0.244	0.080	0.080
Pond wetland						26775	0.105	0.105	0.135	0.19	0.0143	<0.016	0.091	0.091	0.030	0.030
	Pond Wetland	Channel on west side	212300157440906	7/28/2008	9:48	13600	0.185	0.185	0.24	0.24	0.033	0.033	0.216	0.216	0.070	0.070
	Pond Wetland	West side - edge of open water	212300157440915	7/28/2008	10:30	32500	0.057	0.057	0.07	E 0.07	0.008	< 0.016	0.039	0.039	0.013	0.013
	Pond Wetland	East Side - edge of open water	212300157440916	7/28/2008	11:40	30300	0.111	0.111	0.14	0.14	0.008	< 0.016	0.059	0.059	0.019	0.019
	Pond Wetland	Center - edge of open water	212300157440929	7/28/2008	10:20	30700	0.068	0.068	0.09	E 0.09	0.008	< 0.016	0.05	0.05	0.016	0.016
Untested (?) Samples																
	Pond	Northshore - Kellys'	212300157440918													
	Pond	Junction with exit channel	212300157440919													
	Kaelepulu Stream	Below Keolu Br	212300157440920													
	Pond	Center main lake	212300157440937													
	Pond	East shore	212300157440938													
	Pond	Center off Mike's	212300157440939													
	Pond	East Lake - across from Maosi's	212300157440940													
	Pond Inlet	by kukilakila boatramp	212300157440941													
	Pond	Kemo's cove	212300157440908													
	Pond Inlet	Channel to Maosi's cove	212300157440909													
	Pond Inlet	Dead Dog Creek by shallows	212300157440910													

#	P00095	- Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
#	P00608	- Ammonia, water, filtered, milligrams per liter as nitrogen
#	P00631	- Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen
#	P00660	- Orthophosphate, water, filtered, milligrams per liter
#	P00671	- Orthophosphate, water, filtered, milligrams per liter as phosphorus

- Tamaru, in 2009-2010 as part of the State DOH's TMDL program for Kaelepulu compiled monthly samples from over 40 surface water stations spread throughout the estuary.

Attachment III: 2005 Fish Kill in Kaelepulu Pond
Kaelepulu Pond Fish Kill

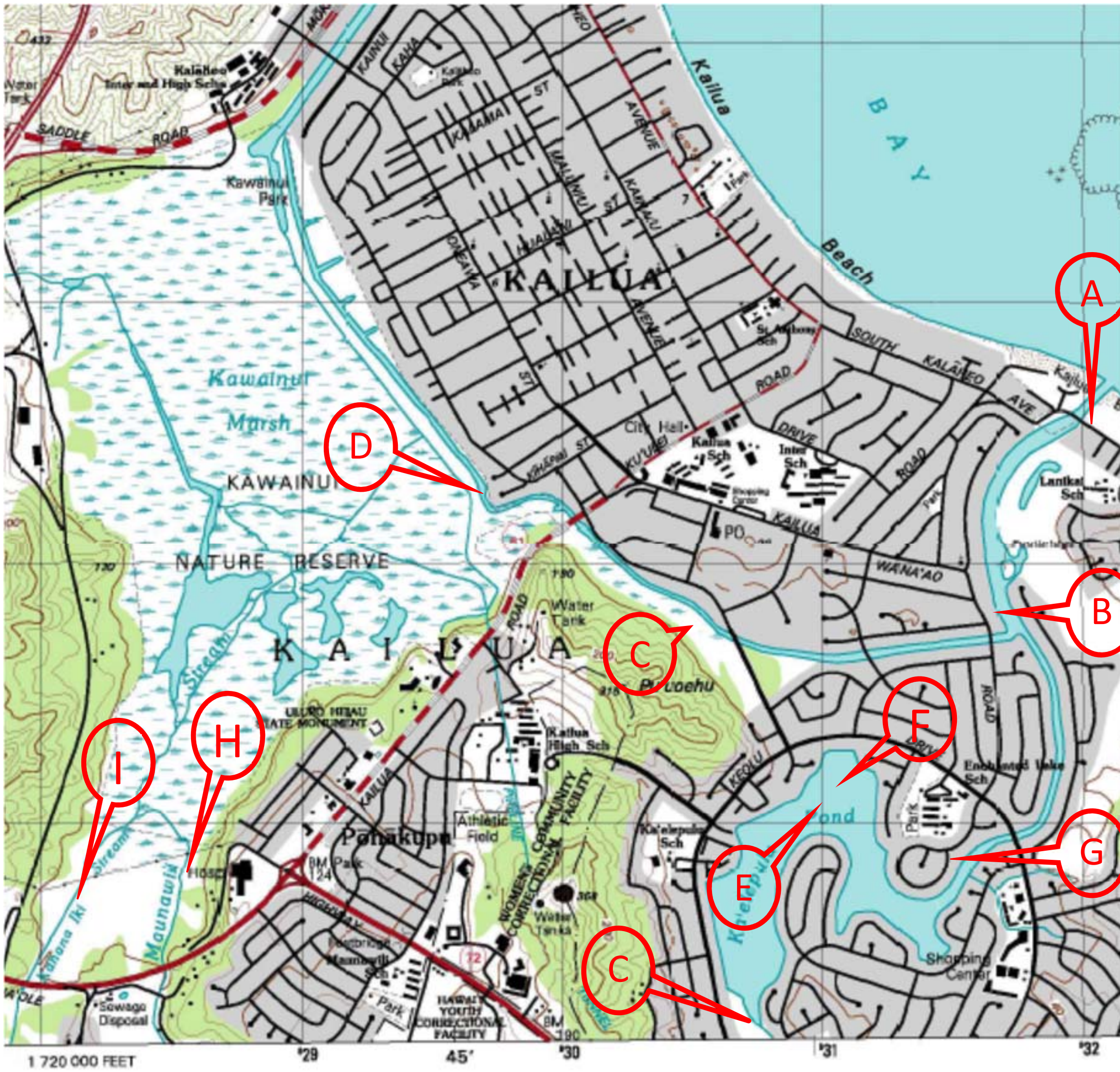
During the night of November 23 and morning of the 24th, 2005 a fish die-off occurred in Kaelepulu Pond. The die off involved several thousand native gobies (S. hawaiiensis), 4-5 inches in length, at least a hundred pufferfish (A hispidus), and an equal number of tilipia, with a few large samoan crabs, and a few large awa (C chanos) and other miscellaneous species also succumbing. The presumptive cause of the die off is low dissolved oxygen. The majority of the large populations of mullet, baraccuda, and awa in the pond survived. The die off was preceded by a large planktonic algae bloom (species unknown), followed by several days of cloudy weather with little or no breeze. A relatively heavy rainfall in the early morning of the 24th (0.86") increased the elevation of the pond by 2 $^{1}/_{3}$ " and may have minimized the impact by delivering oxygenated water to the pond.

On Saturday November 12 a brown discoloration was noted in the water near the Kukilikila condominiums. The colored water had a definite edge and perimeter extending half way out into the pond apparently centered on the Kukilakila outlet. At the time the observer attributed the discoloration to an inflow of turbid water – although there had been sunny calm skies for the preceding week and no rainfall.

On Sunday the 13th the discolored water was very apparent across the entire lake and formed discolored "fingers" extending along the surface. At several locations the surface was noted to have a white to green slimy appearance and was initially thought to be the result of a latex paint spill. A sample was taken on the 14th and examined by the DOH HEER office (Mike Cripps) on the 15th and determined to be of organic microscopic plankton origin.

On Wednesday November 17, C&C maintenance personnel used heavy equipment to open the sand berm at Kailua Beach connecting the pond and canal system to the ocean. No change in lake elevation was noted.

RELATIONSHIP TO OTHER WATERSHED PROJECTS



A. Regular muliwai opening of Kaelepulu Stream at Kailua Beach
B. Mangrove removal from estuary by ELRA and Kailua Canoe Club
C. Wetland restoration for improved bird habitat, Kawainui, Hamakua, Kaelepulu .
D. Kawainui Stream Flow Restoration from Kawainui Marsh
E. State Total Maximum Daily Load study of Kaelepulu
F. City Drainage Improvement Study and Implementation Report
G. Dredging of blocked segment of Kaelepulu channel for improved circulation.
H. Kawainui Bird Pond Construction
I. State Stream Bank and Wetland Restoration

B. Mangrove removal from estuary by ELRA and Kailua Canoe Club

B-1 Kaelepulu Pond Mangrove Control.
2002-2004 - Complete
Cost: $44,000 ($20,000 State DOH 319 funds, $24,000 match from ELRA and Kamehameha Schools)

Mangrove in Hawaii is an alien invasive species that ruins native ecosystems and leads to poor water quality. In 2002 the DOH awarded a 319-grant to the ELRA to assist with the removal of large stands of mangroves within Kaelepulu Pond. Today there are no mangroves in the pond and regular maintenance continues to eliminate young sprouts that come into the system as seedlings.

B-2 Control of Mangrove in the Lower Kawainui and Kaelepulu Streams.
2011-2012 – Complete
Cost $89,666 (HCF: $14,000, Match from ELRA & KCC: $48,666, Castle Foundation: $25,000)

In 2011 the Hawaii Community Foundation and Harold Castle Foundation awarded ELRA and the Kailua Canoe Club a grant to eliminate mangroves from the lower reaches of the Kawainui Stream and the Kaelepulu Stream between the beach and the pond. This effort was initiated on the coat-tails of a City funded (~$150K) effort two years prior to cut the large mangroves from this same body of water. Experience has shown that a single cutting of large mangrove is not effective at long-term control because of the thousands of seedlings that sprout within the tangled mat of cut mangrove roots. Today this project is about 90% complete

C. Upper watershed restoration for improved bird habitat

C-1 Kawainui Marsh Bird Pond Creation
2003-2011 Planning and Permitting, complete.
2012 (summer) Contracted Construction
Cost:$5,000,000. (Cost share between State DLNR /USACE)

Thirteen ponds are to be constructed in two groupings on either side of the Manawili Stream just below Castle Hospital with a total water surface of 8 acres. The ponds are to be fed from rainfall and shallow wells. At an elevation of 10 to 22 feet, it is not anticipated that the Kawainui Stream flow restoration project, at an elevation of about 6 feet, will have any adverse impact on the operation of the bird ponds.

C-2 Kawainui Marsh Natural Area Wetland Enhancement

2010-present.
Cost $939,000 Cost share between DLNR/Federal NRCS & FFWS

About 30-acres of overgrown brush and invasive plants are being cleared from the lower reach of the Kahaniki Stream in Kawainui Marsh near the junction of the Quary Road with the Pali Highway. The project will expose the stream, wetland flats, and natural small ponds for use as native waterbird habitat. At an elevation of 10 to 30-feet, this project is above the elevation that may be impact by water withdrawal from the other side of Kawainui Marsh at an elevation of about 6 feet, or by manipulations of the stream mouth at an elevation of 0-2 feet.

C-3 Hamakua Marsh Restoration
2005-2008 Complete
Cost $ 500,000 DLNR with partial funding from NRCS. $1.2Million scheduled for purchase.

The DLNR cleared overgrown cattle pasture in a wetland area adjacent to the Kawainui Stream where is flows behind downtown Kailua. The land is at an elevation of 2 to 3 feet and is managed as habitat for Hawaiian Stilts, Coots, and Gallinules. An increase in water elevation, particularly during the summer months, would be seen as a benefit to this site, inundating more of the flat ex-pasture land to create more habitat for Hawaiian Stilts.

C-4 Kaelepulu Wetlands
1994-present
Cost – Privately Funded

In 1994 as a result of regulatory action by the USACE approximately 5.8 acres at the Diamond Head/Mauka end of Kaelepulu Pond are designated as preservation land to be managed as a wetland bird preserve. The wetland, now under different private ownership, is being very successfully managed as nesting and foraging habitat for Hawaiian Stilts, Coots, and Gallinules. The wetland managers believe that regular stream openings to the ocean are essential to the health and success of the wetland. The additional seawater flow helps control predators (bullfrog) and invasive vegetation and lowers the threat of high water flood events that drown the eggs and chicks of the endangered native waterbirds. Regular interchange of lake water with the ocean also minimizes the conditions that cause fish die-offs which in turn causes deadly avian botulism.

D. Kawainui Stream Flow Restoration from Kawainui Marsh

2012 – ongoing
Cost $248,000 (Funded Engineering Study & EA) $1,000,000 (Construction estimate) State of Hawaii

The State is embarking on an engineering study and environmental assessment to examine the feasibility and potential impact of restoring flow from the Kawainui Marsh to the Kawainui

Stream over (through, around, under) the Kawainui flood control levee. An experimental phase (Summer 2012) will siphon water from the marsh to the stream to test for any adverse impacts of the water transfer. The concept is to allow the system to slowly raise over a period of a month to an elevation of about 2.0-feet. This is about 0.5 feet above the present average stream elevation. The additional flow would improve water quality and allow for sufficient hydraulic head to augment the monthly mechanical opening of the stream mouth by City crews. Observations of multiple stream mouth openings have shown that this additional 0.5 foot of head can have a pronounced positive effect on the opening of the stream mouth during a falling tide.

E. State Total Maximum Daily Load study of Kaelepulu and Kailua Waterways

2004- Present. Cost $94,000 (to date) for studies of water quality.

The EPA has mandated that studies be conducted to determine the pollutant sources and pollutant loads to water bodies that do not meet water quality standards. Once the pollutant loads are understood, then methods are devised to control these sources and bring the water body back to within water quality standards. The DOH has funded studies by the UH and the USGS to investigate pollutant loads within the Kaelepulu Wetland, Pond, and Stream, and the Kawainui Stream.

F. City Drainage Improvement Study and Implementation Report

F-1 Enchanted Lake Stormwater Drain Assessment

The City has conducted a survey of all drainage ways entering Kaelepulu Pond to assess their condition and their likely role in transmitting pollutants to the system. Areas requiring repairs were identified and the drainages that were likely contributing significant loads to the system were identified. Preliminary concepts to control pollutant loads from these drainages have been developed.

F-2 Enchanted Lake Stormwater Drainage System Modifications

Design Phase: 2012 - ?

The City has hired a consultant to develop preliminary plans and cost estimates for the control of pollutants from selected drains within the watershed.

G. Dredging of blocked segment of Kaelepulu channel for improved circulation.

Future Project: Cost Estimate: $1,000,000

The 1993 Flood Capacity Study of the Kailua Waterways by Park Engineering concluded that the channels were not in need of dredging to accommodate flood flows, except in one location just outside the bounds of their official survey at the mouth of Enchanted Lake (Kaelepulu Pond). At this location they identified a 100-yard length of channel that was much shallower than the balance of the stream and could interfere with the flow of water from the lake into the channel under extreme storm events. However, this blockage was within the bounds of the Enchanted Lake Residents Association property.

The source of the sediment blocking the channel is from a side channel draining the commercial and residential areas of Enchanted Lake, as well as portions of the Mid-Pac Golf club. It is likely that the bulk of the sedimentation occurred prior to 1980 associated with the massive hillside residential community development in the absence of effective erosion control. Trash and green waste typical of residential drains continues to collect at this site following heavy rainfall events, but the actual sediment load from this drainage is low. The shoal inhibits boat traffic and (more importantly) greatly limits the exchange of water with the ocean. Saltwater entering from the ocean is denser than fresh water and cannot get up and over this hump in the stream bottom. The result is that effective salt water flushing is limited to the stream bed only. This lack of effective change has had, and will continue to have, adverse impacts on water quality in the pond. The ELRA is in the process of obtaining a permit through the USACE for dredge removal of the approximately 5,000 cubic yards of material that constitute this shoal. The ELRA would welcome any assistance from government agencies to remove this blockage that would help to restore water exchange and greatly improve water quality within the system.

Quotes from long-time Kailua Residents

Harry Morley, Wanaao Street, Kailua

11/7/2007 (via email)

In 1961 the Camps Dairy was still in operation where Daiei & Safeway are located, all the around the Kaneohe side of Enchanted Lke..during heavy rains the smell was enough to make us gag…and often did as high school students. At that time the high school was operating down in Kailua where the Intermediate school is. Anyway, the outflow during heavy rains was more polluted at that time due to the treatment plant near Keolu and the runoff from the dairy operations.

At the same time, there was no real dike across Kawainui Marsh…and the coconut grove area just flooded until the Mokapu canal could handle the load.

Cindy Turner DeVries.

2016 verbal

Growing up in Kailua in the 60's we lived at a number of different homes along both Kailua and Lanikai beaches. The stream at the Lanikai Bridge was almost always flowing, with at least a small channel that you could jump across flowing over the sand bar at the beach. I suppose it may have closed sometimes during the summer, but I always remember it flowing and being jealous of all the other kids who got to jump off the bridge into the deep stream, 'cause my parents wouldn't let me do that.