Investigating an Impaired Estuary
ʻIke One o Kaʻelepulu
Knowledge from the sands of Kaʻelepulu

Capstone
for the degree of
Master's of Science
Plan C in
Natural Resources and Environmental Management
by Derek Esibill
Advisory Committee
Yin-Phan Tsang, Ph.D.
Craig Nelson, Ph.D.
Kirsten Oleson, Ph.D.

Abstract:

Estuaries are highly productive spaces that transform nutrients into biological products and have been heavily used and modified by people. While it is known that tropical estuaries are areas of high productivity, generally 10 to 15 times greater than coastal plain estuaries, little is known about the functionality of these systems. Changes in human population dynamics and demographics have shifted land use and cultural values. Wetlands and flood plains have been developed and waterways modified without an understanding of estuarine functionality. Kaʻelepulu Estuary on Oʻahu's eastern shore was once a highly productive area. Housing development in the area rerouted natural stream flow to prevent flooding resulting in an accreted sand berm at the stream mouth and 0.54 km^2 (134-acre) area of stagnant water. Nutrient cycling has been disrupted, dissolved oxygen crashes resulting in fish die offs contribute to pathogenic bacterial growth. The estuary now needs to be managed by periodic dredging of the sand berm to prevent street runoff flooding nearby houses and introduce oceanic water. Residents are concerned for both the health of the estuary and the pollution risk to Kailua Bay when the berm is open.

This investigaton explored the impact of current estuary management and its impact to the adjacent popular beach by testing the following hypotheses: If the berm is open and the estuary has exchange with the ocean, then the water quality in the estuary will improve and there will be negligible impact to the water quality along Kailua beach. Rainfall will increase nutrient and enterococci concentrations in the stream mouth and inland sections of the estuary. Longer berm openings will correlate with greater oceanic exchange and therefore an increase in salinity at the stream mouth section post berm closure. Lastly, if community engages in the research process, then greater awareness of and attitudes towards stewardship of place will be garnered. The Watershed Investigations Education Research and Design (WIRED) outreach program has been studying the area for several years engaging local students, community members, and the environmental firm, Oceanit. This investigation engaged WIRED's students and their school teachers to use the same well-established Department of Health protocols at thirteen sample locations distributed along the beach and estuary. Principal component analysis determined salinity, as the primary parameter to assess changes in estuarine biogeochemistry. It appears that the opening of the berm does not significantly contribute to poor water quality along the beach, especially when addressing the differences in water quality threshold limits based on freshwater input. Opening events appeared improve increase in the estuary and the duration of estuarine and coastal water exchange appears to be a factor. Runoff inferred by rain fall appears to contribute to increases enterococci and chlorophyll-a, to a lesser extent. Community participation helps to elicit more informed and engaged residents to steward this impaired system.

Acknowledgements:
I would like to thank Bob Bourke for introducing me to the estuary in a way that has piqued my curiosity and inspired me to help make it a better place. He plays a significant role in guiding me as to the issues the estuary faces and some of the methodologies to both investigate and address those issues. I have been blessed with incredible support from my wife and children, coworkers, and friends. I also want to thank my advisory committee; Yin-Phan Tsang, for taking a leap of faith in taking me on as her student and keeping me on a timeline to ensure success; Craig Nelson for his constant and consistent support of the WIRED program and keeping me in check with what I really can accomplish and what is overboard; Kirsten Oleson, for pushing me to enter the program and statistical advice. Thank you to the Graduate Committee for rebooting the NREM Master’s Plan C and having confidence in me as a test subject. Most importantly, I would like to thank the students and their teachers and Ed Noh, Director of Kaʻōhao School, who simply said ‘yes’. Each were essential in the success of this project.

Table of Contents:

Introduction:

Estuaries are generally defined as semi-enclosed coastal bodies of water that extend from the ocean upstream to the effective limit of tidal influence, within which sea water is significantly diluted with freshwater from inland sources (Bianchi, 2013). Situated at the interface between the land and the ocean, they are highly productive spaces that house a multitude of habitats, including critical nursery habitats for many off-shore species. They are a place where the coupling of physics, ecology, and biogeochemistry occurs at many spatial scales (Geyer et al., 2000), making them biogeochemical hotspots and areas of high primary production. These transitional areas have intense fluctuations of environmental conditions that influence a multitude of species and their lifecycles (Villanueva, 2015). Tropical estuaries are areas of high productivity, generally 10 to 15 times greater than coastal plain estuaries (Villanueva, 2015 Duarte, 1995); however, little is known about the functionality of these productive systems.

Compared with watersheds on continents, Hawaiʻi's watersheds are short and well-defined. These small sizes, along with seep topography, more than likely enable localized weather phenomena, such as wind strength and direction and localized rain events to have a much more significant impact on the dynamics of the systems' biogeochemistry, as the residence time of accumulated nutrients is relatively short (Ostrander, 2007). Understanding that humans modify and manage landscapes to meet their needs where ever they settle, these relatively small watersheds allows for landscape level management. Traditional Hawaiian land divisions, known as ahupuaʻa, frequenlty encompassed an entire watershed, inclusive of estuaries. Landscapes were modified and managed in way to minimize waste and harm to the environment, as not doing so was believed to "anger the gods" (Keala et al., 2007). This landscape level ecosystem management was a necessary strategy to support the pre-contact population of the Hawaiian Islands that according to the Pew Research Center, may have approached 1 million (Goo, 2015).

Changes in human population dynamics and demographics, have been accompanied by shifts in land and cultural values. Land once valued for food production and sustainable living, became more valued for providing housing. Consequently, development boomed. To bolster those booms, land managers modified waterways, wetlands, and estuaries, and even built on flood plains (Swain and Huxel, 1971). These areas continue to be modified without an understanding of how they naturally function. As a result, habitats and ecosystems that we know very little about have and continue to be destroyed, causing a cascade of effects at all trophic levels.

Kaʻelepulu Estuary located on Oʻahu's eastern shore is one such place. Translated to "moist blackness" Kaʻelepulu was once a highly productive area. The name more than likely attests to its history as a shallow, organic rich, brackish estuary and wetland pond (Bourke, 2016). The area provided food for the residents of Kailua, and in turn the residents kept the area well maintained, as described in 1939 by the Bishop Museum's Mary Kawena Pukui and Kenneth Emory, along with Kealohanui Alona, reported in the Kailua Historical Society's 2009 publication (Kailua, 2009). They noted that the people of the area kept the pond clean and that "fat mullet, were found there along with much limu kalawai (*Spirogyra spp*)." "The fish [awa (*Chanos chanos)*, āhole (*Kuhlia sandvicensis*), and ʻoʻopu] there [Kaelepulu Pond] were tender and always fat." "Makaloa (*Cyperus laevigatus*) also grew there and was used to a certain extent."

The presence of such organisms would indicate a funtional estuarine system. Infrequently did those folks purchase food at the store, given the abundant harvest from their environment.

During this time period, the entirety of the Kailua watershed discharged to Kailua Bay through the Kaʻelepulu stream. The perennial streams of Maunawili, Kahaniki, and Kapaa drained into Kawainui, at one point the second largest fishpond in Hawaiʻi. From Kawainui water flowed East into what is now called Hamakua, then to Kaʻelepulu and from Kaʻelepulu to the southern part of Kailua Bay. The perennial stream, Waioniki, flowed into the most inland section of Kaʻelepulu Pond (Figure 1) (Kailua, 2009). Estuary discharge scoured the naturally accreting sand at the stream mouth, keeping it open to oceanic interaction (Drigot, 1982). Only rarely, during the dry summer months did water flow lessen to the extent it could not keep up with the natural accretion of longshore transported sands, and the stream mouth would close. On the occasions when this happened, children would dig pathways reconnecting the steam and estuary with the bay, then play in the running water.

In the late 1940's and early 1950's people moved closer to the beach and the housing development "Coconut Grove" was constructed along the Kailua Beach sandy flats, a flood plain. In the early 1950's a flooding event prompted the U.S. Army Corps of Engineers (USACE) construction of the Oneawa Canal. The Canal provided another drainage point at the North End of Kailua Bay. The area flooded again in the 1960's prompting the construction of a levee separating Kawainui from Kaʻelepulu. Finally in the 1993, due to another flooding event, the levee was constructed 1.2m higher and the perennial streams of Maunawili, Kahanaʻiki, and Kapaʻa were now completely disconnected from Kaʻelepulu Pond and estuary (Figure 2) (Hall, 1998) and all drainage diverted to the north end of Kailua bay (Drigot, 1992).

Meanwhile, the Kaʻelepulu pond and estuary were undergoing their own changes brought upon by housing developments. In the 1960, the Lone Star Developers began construction on the 'Enchanted Lake' housing development. The pond was dredged to an average depth of roughly 2m (6.5 feet) and the dredge spoils, along with earth from the nearby Keolu Hills development, were used to create "fast land" upon which houses were built. The fast lands reduced the pond size from ~0.73 km^2 to ~0.4 km^2 (180 acres to 100 acres). To aid in Enchanted Lake construction, a sill was created to allow for the evacuation of water from the Kaʻelepulu pond, when construction was complete the sill was partially removed allowing water to return to the pond (Bourke, 2016). As of May 2020, the remnant sill is still present, with plans to remove it in the near future (Figure 3). During this time period water was diverted from Kailua to support the sugar cane industry in the adjacent town of Waimanalo (Hall, 1998), the Waioniki stream lost its perennial flow and was channelized to prevent flooding in the Keolu Hills housing development. It is now a drainage culvert into Kaʻelepulu Pond.

The events described above changed waterflow throughout the Kaʻelepulu Estuary, and split the Kailua watershed in two, the Kawainui and Kaʻelepulu complexes (Figure 4). Kawainui receives all perennial streams input. Kaʻelepulu, isolated from natural stream flow, received the majority of storm drains and street runoff (Figure 5). This lack of stream flow has caused sand to accrete at the stream mouth blocking oceanic exchange, critical for proper estuarine functionality, and has resulted in a 575,000 m^2 area of stagnant water. Nutrient cycling has been disrupted. Abrupt crashes in dissolved oxygen concentrations result in fish die offs that contribute to pathogenic bacterial growth, including fecal coliforms like enterococci (Tamaru and Babcock, 2011). The lack of salt water wedge further reduces estuarine functionality. Kaʻelepulu now can pose a human health risk, making people sick from the place that once fed them. Households along the impaired estuary are at risk of flooding due to the sand berm accreting to a height that does not allow for water to drain into the ocean. To prevent flooding, the sand berm needs to be periodically opened by heavy machinery (Figure 6.) The Kailua community has noticed when the berm is open, water in the estuary appears to be of better quality. Others complain of 'severe and drastic' negative impacts on the water quality along the adjacent internationally popular beach during these opening events.

Motivation:

In 2005, the Ramsar Commission recognized the Kawainui and Kaʻelepulu complexes as wetlands of international importance. As a home to some of the largest populations of endangered Hawaiian water birds and a habitat for many endemic flora and fauna, society has an obligation to understand and restore estuarine functionality.

Many environmental concerns throughout the world are only addressed by research through federal and international agencies, big business who are required to conduct environmental impact studies, and universities. This does not need to be the case. Local environmental issues create special opportunities for community members to participate in the cultural and scientific understanding as well as the preservation and restoration of their environment. According to McKinley et al. 2016, Cadiz 2017, "Community-based monitoring (CBM) and citizen science can play an important role in integrating knowledge systems, improving conservation science, and enhancing natural resource management."

Involving local school students in the research process can both increase students' interest in and attitudes towards STEM subjects, as well as create future environmental stewards. Low test scores and case studies with teachers in science and math at Hawaiʻi secondary schools demonstrate a glaring need to engage Hawaiʻi students in meaningful watershed educational experiences (McKinley et al., 2016). Many students are disconnected from their place and not aware of the environmental issues potentially have a direct impact on their food & water security, and over-all sense of well-being. Evidence has shown involving students in programs that (1) build connections to place through the identification of local environmental issues and (2) utilize approaches that integrate western science with traditional Hawaiian cultural wisdom knowledge increases student engagement for learning, understanding of scientific principles, and environmental stewardship (McKinley et. al., 2016, Manoa, 2016, Luft e.t al., 2008, Kanaʻiaupui et. al., 2005)

The project presented here engaged the Kailua community in the research process, embracing our responsibility to steward the area to meet the needs of both human and natural systems. This study's goal was to gain a greater understanding of the functioning of the impaired Kaʻelepulu estuary by addressing the following questions:

- How does the sand berm that frequently disconnects the Kaʻelepulu Estuary from Kailua Bay impact the water quality in the estuary?
- When open, how does the water quality of the estuary impact the water quality along the adjacent Kailua Beach?
- Is storm water as inferred by rainfall a factor in water quality?
- Is the duration of the berm opening a factor in water quality?
- Is the duration of the berm opening a factor in water quality?
- Can the use of citizen science and participatory research garner greater stewardship of this impaired system and greater STEM aptitudes in student?

These questions lead to the development of the following hypotheses:

1. When there is a connection to the ocean, the stream mouth and back sections of the estuary will experience increases in salinity and dissolved oxygen and decreases in nutrient loads and chlorophyll-a.
2. When the berm is open, there will be little impact on salinity, dissolved oxygen, nutrient loads, and enterococci as compared to Hawaii Department of Health acceptable levels as per Hawaiʻi Administrative Rules chapter 11-54 on coastal waters along Kailua Beach.
3. Rainfall will increase nutrient and enterococci concentrations in the stream mouth of the estuary (SME) and inland sections of the estuary.
4. Longer berm openings will correlate with greater oceanic exchange and therefore an increase in salinity at the stream mouth section post berm closure.
5. The use of citizen science and participatory research will create a more aware and conscientious community that is more engaged in the stewardship of this impaired system

Methods:

<u>Water Quality:</u>

Understanding that estuaries have a salinity gradient, the Kaʻelepulu estuary should be no different. To investigate the dynamics of this complex system, the Kaʻelepulu estuary was broken into four sections based on salinity groupings from most to least saline (Figures 7 and 8).

- Coastal, five sites along Kailua beach, bordering either side of the stream mouth
- Mouth, the point where the stream meets the Kailua Bay
- Stream mouth of the estuary (SME), three sites from Kailua Bay to 350m inland
- Back of Estuary, five sites ranging evenly from 1230m to 5000m inland

The focus of the study was around the coastal and stream mouth of the estuary sections. Water Quality samples were collected between 11/01/2018 and 01/05/2020 on 18 separate occasions. It is important to note that not every site was sampled every time, due to schedule constraints by both the school groups involved, the principal investigator, and equipment failure. Eight of those days the berm was open and 10 the berm was closed. It was intended for measurements to be taken just prior to an opening event, 1 day after the opening, 1 day before the natural closure of the berm from accreted sand, and several days after closure. Samples were collected, as best as practical, during an outgoing (ebb) tide with the thought that the ebb tide would best reflects changes to both the estuary and the ocean.

Surveys were conducted using guidance from the State of Hawaiʻi's Department of Health Clean Water Branch Chapter 11-54 Hawaiʻi Administrative Rules using YSI proDSS sondes taking measurements of temperature, dissolved oxygen (DO% saturation), conductivity, salinity, pH, and turbidity at water depths of 5, 30, 60, 90, 120, 180cm, and bottom as regulated by water depth. Water samples (1000 mL) were collected targeting a depth of 30cm using 1000 mL acid washed HDPE collection bottles. Where necessary, a 1.5 L horizontally deployed Niskin Bottle was used for water capture, then decanted into a 1000 mL collection bottle. Water samples were taken directly from collection bottles to be tested for the presence of enterococci, using IDEXX Enterolert methodology (Eckner,1998). Remaining water was filtered through 0.7µm glass fiber filters (Whatman 1825-047). Filter samples were analyzed at the SOEST Laboratory for Analytical Biogeochemistry (S-LAB) for chlorophyll-a using a Turner Designs 10AU Benchtop and Field Fluorometer. Filtrates were analyzed at the S-LAB for nutrients using a SEAL Analytical AA3 HR Nutrient Autoanalyzer using standard EPA protocols (Equipment). In tandum, students assessed nutrient loads using LaMotte colorimetric nutrient analysis kits assessed nitrite, nitrate, ammonia, total nitrogen (TN), and phosphate. The difference in sensitivity between the two different techniques (i.e. SEAL vs. LaMotte analytical equipment) was discussed and quickly deemed the LaMotte kits should be used only for educational purposes in order to inform students on the processes of colorimetric analysis and to assess relative changed in nutrient concentrations.

Enterococci was chosen as a bioindicator of water quality because they are a pathogenic group of organisms that thrive in both salt and fresh water. These fecal coliforms are found in mammalian (human) and some bird feces, making them a good indicator of sewage contamination and the likelihood of the presence of other more virulent pathogens. These organisms are commonly used by departments of health across the United States as water quality indicators. IDEXX is a preferred methodology because it does not require the manipulation of and prevents contact with these pathogens, making it a very safe method of quantifying enterococci abundance. This methodology required culturing to take place within a 6-hour window beginning at time of collection keeping sample water at ambient temperature. Due to that constraint, it was not possible to assess enterococci levels each sampling event.

All data were entered into Google Sheets and can be accessed here: https://bit.ly/3bqNDaf. Raw data was then entered into JMP 15.0.0 for statistical analysis with a confidence level of 95%. Measurements that did not have a normal distribution were log transformed to obtain as close to normal distribution as possible. Enterococci (CFU) and rainfall (cm) had 1 added to eliminate a zero value in data processing. Logarithmically transformed data was then visualized through a principal component analysis (PCA) (Water Quality Results Figure1). PCA facilitated the grouping of sites into sections, that also correlated with geographical location. Drivers were determined by measurement parameters with absolute load values greater than 0.65 (Water Quality Results Table 1).

Identified drivers were then plotted against salinity linear regression and t-test analyses were performed on the identified drivers at the Beach and SME, testing the impact of the presence or absence of the sand berm Linear regression models were also performed to assess the correlation between rainfall and enterococci, Chlorophyll-a, and Nitrite+Nitrate in the Coastal, SME and Mouth sections. Site "End Golf" was individually tested to investigate highly localized changes in the aforementioned parameters (Water Quality Results Figure 16).

The Hawaiʻi Department of Health (DOH) Clean Water Branch Amendment and Compilation of Chapter 11-54 Hawaiʻi Administrative Rules adopted on November 15, 2014 served as the guiding document to determine a baseline for water quality. Water quality standards vary as to the season and type of water bodie being assessed, for the purposed of this project Open Coastal Class A Waters and Estuaries were the water body types applied and compared. Open coastal waters are defined as marine waters bounded by the 183 m depth contour and the shoreline, these guidelines were applied to sites along Kailua Beach. Water quality parameters along open coastal waters have different water quality value thresholds during "Dry" and "Wet" conditions. "Wet" conditions are allowed to have higher nutrient and chlorophyll concentrations than "Dry" conditions. "Wet" criteria apply when the open coastal waters receive more than 11,356 m^3/day of fresh water discharge per shoreline mile. "Dry" criteria apply when the open coastal waters receive less than 11,356 m^3/day of fresh water discharge per shoreline mile. During times when the berm is not present (i.e., open), discharge rates typically exceed 1,000,000m^3/day, and "wet" conditions are applied to the analysis. On the other hand, when the berm is closed there is less than 11,000 m^3 of discharge and "dry" conditions are applied. Because there are different acceptable value thresholds for "Wet" and "Dry" conditions, ratios were calculated by dividing the measured nutrient and chlorophyll-a data by the conditional threshold (i.e. measured value /DOH Limit). Any ratio above 1 would indicate the waters were impaired, according to DOH guidelines. This ratio was inputted into JMP to analyze the difference, and then liner regression analysis and T-testing was performed.

Water Quantity:

According to Oceanit 2016, the volume of the Kaʻelepulu Estuary at an average elevation of 0.46 m above mean lower low water is roughly 849,505 m^3, as the estuary is closed to the ocean most of the time. This can be assumed as the base volume, and any changes in pond elevation can be attributed to either rain input or oceanic input from a berm opening. Effective estuarine/coastal exchange for the purpose of this study occur when there is a net input or output of 170,000 m^3 or 25% of the resident volume. Change in storage is the amount of water that enters and exits the system, not necessarily how well mixed that water is. The 25% value was determined using data from the Kaʻelepulu Stream Restoration Experiment (Oceanit 2016).

Estuarine elevation was determined by measuring water height using staff gauges at the Lanikai Bridge installed by the city and county of Honolulu set to 0.079 m below Mean Lower Low Water (MLLW) and a staff gauge at the back of the estuary, in the Kaʻelepulu Wetland, calibrated to MLLW. Each time measurements were taken at both locations. Any differences between the two heights would be due to a bolus of water, either from a large rain event, wind-blown, or oceanic exchange. In the event of that occurrence, estuarine elevation was determined as an average of the two heights. Because of the presence of nearly vertical banks in the estuary, not slopes as typically found elsewhere, the surface area of the system is assumed to be constant when estimating the water volume in the estuary. Oceanit 2016 assessed the surface area using ESRI GIS tools to be 142 acers (≈574,654m^2), using Google Earth, I was able to assess the surface area to be approximately 575,440 m^2 (≈142 acers). Therefore, any change in estuarine elevation multiplied by the surface area would result in an adequate approximation of the volume of water input or output.

On 12/18/2019 a pressure sensor, on loan from Dr. Brian Glazer’s Lab at University of Hawaiʻi at Mānoa’s School of Earth Ocean Science and Technology (SOEST) was in the Kaʻelepulu Stream at Lanikai Bridge, it was able to record the 12/24/2019 to 12/31/2019 opening event. During that time there were two other, much less significant opening events, one on 01/10/2020 and the other on 01/12/2020 (Water Quantity Results Figure 4). Initial Volume of water in the estuary was obtained from the elevation readings at calibrated staff gauges at Lanikai Bridge and Kaʻelepulu Wetland. This was then compared with Moku o Loʻe Tidal datum from NOAA. The pressure sensor was deployed at the Lanikai bridge at a depth of 0.905m from the surface, this equates -0.1262 m mean lower low water (MLLW), by applying the 0.0792 m difference between the City and County of Honolulu Staff Gauge and MLLW (Oceanit, 2016) and empirically obtained through observation, see below:

Lanikai Bridge Staff gauge	0.6996m	C&C datum
C&C datum is	-0.0792m	Below MLLW
Estuary elevation is	0.7788m	MLLW
Sensor depth is	0.905m	From surface
Sensor depth is	-0.1262m	MLLW

Pressure data in kPa were logged for one month and the units were converted from kPa to meters using a salt water conversion value of 10.05 kPa/m for salt water obtained from BlueRobotics, and following Glazer Lab protocols uses for their deployments. After converting kPa to meters, I forced the depth indicated on the sensor to the actual depth of the sensor related to MLLW (-.1262 m), this value of 10.380 m was then applied to relate all pressure sensor data to MLLW. See below:

Initial estuary elevation MLLW	=	Bridge Staff gauge	+	0.0792 m MLLW correction
0.7788m MLLW	=	0.6996 m	+	0.0792 m MLLW correction
Sensor depth MLLLW (measured)	=	sensor from surface	–	initial estuary elevation
-0.1262 m MLLW	=	0.905 m	–	0.7788 m MLLW
Conversion factor	=	Sensor kPa/10.05 kPa/m	–	sensor depth MLLW measured
10.38 m MLLW	=	10.254 kPa/10.05 kPa/m	–	-0.1262 m MLLW

The sensor data was then compared to the verified tidal datum from the station at Moku o Loʻe (Water Quantity Results Figures 4 & 5).

The volume of oceanic exchange was assessed by comparing tidal datum to pressure sensor, rain and evapotranspiration data (Water Quantity Results Figure 6). During times when pressure sensor data correlated with tidal datum from visual observation, it was determined there was oceanic exchange. The volume of water exchanged was calculated by summing the observed tidal range for each tidal cycle and multiplying by the surface area.

$$\text{Volume Exchange} = \Sigma\big((High - Low) * surface\ area\big)$$

When compared with the initial volume of the estuary a percent water exchange could be determined (Water Quantity Results Table 1).

Vertical profiles were used to determine the extent of the exchange, assuming that salinity is a conservative factor (Oceanit 2016) their values appear to be a strong indicator of the transport of oceanic water into the system and can be used to measure the proportion of water exchanges. Following protocols used by Oceanit 2016,

$$\%\ \text{Exchange} = (S_F - S_I) / (S_O - S_I),$$

where S_F is the salinity of the sample, S_I is the salinity of that sample site prior the sampling event, and S_O is the average salinity of Kailua Bay. Sample site salinity will be assessed by taking the mean salinity of the water column and the aforementioned depths. It is understood that this is not a true measure of the percent exchange because of dilution problems, however, it is a reasonable approximation. The percent salinity change was run against the number of days open in a linear regression, after log transforming the data. Percent salinity change was also run against total tidal range (i.e. $\Sigma(High - Low)$), log transformed, to investigate the possibility tidal range was a contributing factor.

Rain data were obtained from two rain gauges, one at Olomana Fire Station, maintained by the National Oceanic and Atmospheric Administration (NOAA) Weather Forecast Office Honolulu, HI. The other was a Davis Vantage Pro2 Plus GroWeather wireless stationed at the Kaʻelepulu Wetland at the back of the Estuary directly next to the staff gauge used to measure estuarine elevation. The gauge is owned, maintained, and regularly calibrated by Hugo Devries. Evaporation data was obtained from this instrument, using Modified Penman Equation as implemented by CIMIS (California Irrigation Management Information System) including Net Radiation calculation (California).

Citizen Science and Participatory Research:

Grounded in findings that cultivating more informed citizens fosters commitment to local environments and the community (Greenlaw et.al.,2009), this project heavily relied on the involvement of the Kailua community in the measuring water level, collection of water samples, the processing of those samples, and involvement in the research process as part of school curriculum. Using the Pacific American Foundation's Watershed Investigations, Research, Education, and Design (WIRED) Program local 6th through 12th grade students were trained and utilized as field technicians. Specifically, 6th grade students from Kaʻōhau Public Charter School did the lion's share of the water sampling and YSI vertical water column profiling. Student scientists were supervised by WIRED staff and trained teachers to ensure reliable data documentation, water sample collection, and sample processing. YSI data were transcribed onto preprinted data sheets and screenshots of the device taken.

Participant outcomes regarding gains in knowledge and skills relating to natural sciences, community resilience, individual interactions and impacts with nature, and science, technology, engineering, and math (STEM) interests were assessed through pre- and post-WIRED Program participation survey (Appendix A). The survey was designed to measure those changes by using response shifts on a Likert Scale (Likert, 1932). It was also designed to safeguard participant identities and was therefore deemed non-human subject by the University of Hawaiʻi's Internal Review Board protocol number 2020-00029 (Appendix B). Participant outcomes were also assessed by looking at the number of participant; the number of times they have engaged in WIRED activities and lessons;, the number of teachers trained; the number of teachers who reported gains in knowledge, skills, and abilities regarding conducting and integrating environmental research into classroom practices; the number of lessons developed that bridge in and out of school experiences and learning; and the number of student projects developed that directly use data gathered through WIRED experiences. It is important to note that not all WIRED activities, lessons, and student participants were directly involved in the Kaʻelepulu Estuary Investigation. They were, however, engaged in related activities and lessons in the immediate vicinity of the participants' school. The COVID-19 pandemic prevented adequate post evaluative surveys to be conducted and therefore could not be used in final assessment of participant outcomes.

Results and Discussion:

Water Quality

Principal component analysis (Figure 10) indicates that component 1 explains 41.6% of the variation in water quality. The parameters that make up component 1 are listed in order of greatest to least influence in Table 1. Likewise, principal component 2 is responsible for 27.5% of the variation in water quality. Table 2 illustrates the eigenvalue of each component, displaying the significance of each component, and provided guidance to focus on principal components 1 and 2. Parameters with absolute loading values greater than 0.65 (highlighted in blue, Table 1) were identified as drivers of water body relationships and used to group sites based on water quality parameters rather than geographical location alone. According to loadings in Table 1, salinity had the greatest influence on grouping sites into sections. The other changes in water biogeochemistry appeared to follow a salinity gradient from the most inland section of the estuary to the coast in all parameters, $P<0.0015$. This does not mean salinity is the cause of the changes, merely there is a relationship between biogeochemical changes and changes in salinity. Figure 11 illustrated how wetlands and estuaries are places of transormation and high productivity and increases in Dissolved Oxygen (DO) $p>0.0001$, and decreases in Chlorophyll-a, Nitrite+Nitrate (N+N) $p>0.0001$, enterococci $p>0.0001$, Total Nitrogen (TN) $p>0.0001$, and Total Phosphate (TP) $p=0.0002$ may correlate with changes in salinity (Figure 11).

Figure 12 demonstrates a gradual increase in salinity from Inland Kaʻelepulu Estuary to Kailua Bay. It is also shown that with the presence of a sand berm there is no measurable communication between the waters of the Estuary and the Bay. As freshwater enters the ocean, it does result in a change in water salinity, demonstrated in Figure 12. Generally speaking, nutrients increase and chlorophyll increase with the addition of freshwater when the berm is open (Figure 13). This is not unexpected, rather the contrary, as evidence by the change in Department of Health Clean Water Branch Administrative Rule having a sliding scale on acceptable levels of nutrients based on the amount of freshwater input. Change in water conditions does not necessarily equal harm to the environment, our native fresh water fish rely on being able to detect those changes so they can return to the streams from the sea as they progress through their lifecycle.

The sand berm is usually dredged opened to prevent homes from being flooded. Upon initial opened water drains from the estuary into Kailua Bay. The inland section of the estuary is comprised of shallow water estuary and wetlands environments. As indicated in Figure 4, those inland water are nutrient rich and oxygen poor. They also have high enterococcus levels, which may be explained by the populations of endemic water birds. As water moves from the stream mouth section into the bay, it appears to be replaced with further inland water, drawing hypoxic, nutrient rich waters towards the stream mouth (Figure 13).

To address the 1st, Figure 14 demonstrated that when the berm is dredged open and there is connection to the oceanic waters, salinity in the SME section does significantly increase P=0.0028, as well as Total Phosphorus P=0.0010. However, there no other significant changes that can be explained in the SME or inland sections of the estuary can be explained by the opening or natural closure of the berm. The salinity change is more than likely explained by the influx of salt water as the tide rises. Phosphate increases may be explained by sediment transport that occurs by the flow of water while the berm is open and/or transported from inland sources.

Regarding the impact of estuarine waters to coastal waters, Figure 14 illustrated that while there are significant differences directly at the stream mouth in salinity P=0.0050, N+N p=0.0476, TN p=0.0013, TP p= 0.0034, there was no significant difference in water quality along the coastal section. Significant salinity changes at the mouth were expected when there was connection to the estuary, as estuarine waters demonstrated to be less saline than coastal waters (Figure 12).

When applying a ratio to standardize DOH specified “Wet” and “Dry” conditions, it was found that only immediately seaward of the stream at site “Mouth” had a significant difference in TN p=0.0209, and TP p=0.0032 (Figure 15). This further supported the second hypothesis, when there was connection between the estuary and the bay, estuarine waters did not significantly negatively impact Kailua Bay. Interestingly, the parameters of Chlorophyll-a, N+N, and TN, had a decreased ratio, when the berm was open.

Any ratio greater than 1 indicated impaired waters, according to DOH guidelines, independent of berm status (i.e. open or closed). Figure 6 demonstrated that coastal waters along Kailua Beach appear to be impaired during both “Wet” and “Dry” conditions and the presence or absence of the berm (i.e. open or closed), regarding the parameters of N+N and Chlorophyll-a.

Site “Mouth” appeared to show impaired waters regarding the parameters of TN and TP attributed to the opening of the berm.

As for examining hypothesis 3, the impact of runoff as inferred by rainfall, there appeared to be a correlation between enterococci and rainfall in all sections. Site “End Golf”, located at the most inland section of the SME, appeared to have the strongest correlation (R^2=0.544 and P=0.0232). The relationship between enterococci and rainfall at “End Golf” may be due to a transportation of enterococci from inland sources being concentrated in this location. Incoming tide and outflow of the estuary may create a “choke point” here, while the other sites in the SME section may be diluted with ocean water. Additionally, it may be due to sediment transportation by flowing stream water, but if that were the case, the site “Mouth” should have experienced a stronger correlation, as there appeared to be more motion of sediments at that site. Chlorophyll-a also appeared to have a correlation with rainfall at all sites with the strongest being throughout the SME (R^2=0.323 and P=0.0047) and the “Mouth” (R^2=0.354 and P=0.0414). This may be explained by the transportation of plant material from inland sources by rain water flowing seaward. There did not appear to be any correlations at any of the sites and sections that attribute increases in N+N attributed to rainfall (Figure 16).

Water Quantity:
Water quality needs to be discussed with the quantity of water moving through a system. Addressing hypothesis 4, longer berm openings would correlate with greater oceanic exchange, was much more complicated than initially thought because of the complexities regarding the hydrodynamics of the Kaʻelepulu estuarine system. From November 1, 2018 to February 29, 2020, total rainfall exceeded total evapotranspiration (ET), however 10 of the 16 months ET exceeded rainfall (Water Quantity Results Figure 17). While not surprising through the “Dry” season months, it was surprising for wet months January, March, and April of 2019 as well as February of 2020.

Aside from rainfall, the other input of water into this system is sea water through the ocean, when the berm is dredged open. The average estuary elevation over the time period between February 08, 2019 and March 18, 2020 was determined to be 0.6013 m above MLLW, 0.14 m above Oceanit 2016, and an initial estuarine volume of 1,034,594 m^3 of water. It was initially thought that estuarine volume and exchange could be assessed by using staff gauge, rainfall, and evapotranspiration data, at time of sampling. While I was able to assess rainfall and evapotranspiration, assessing estuarine elevation soley reliant on staff gauge data at sampling times proved to be ineffective. The data gaps surrounding the quantity of water exiting and entering the estuary could not be accurately determined.

Dredging only took place at times that coincided with significant rain events, rainfall exceeding 50 mm in 24 hours. The dredging seemed to be dependent on weather forecasts predicting significant rain events, and solely for the purposes of flood control, not habitat improvement. This is evident as to the times of berm openings, as highlighted in Water Quantity Results Figure 18. It was initially presumed that amount of water exchange during opening events could be estimated by taking measurements at the staff gauges at both Lanikai Bridge and the Kaʻelepulu

Wetland at the time of sampling. This was found not to be the case and more frequent measurements were needed.

The pressure sensor placed at the Lanikai Bridge did provide accurate data to calculate amount of oceanic exchange during the December 24, 2019 to January 2,2020 opening event (Water Quantity Results Table 3). It was found that over the 9-Day period of the December 2019 opening event there was a total volume exchange of roughly 1.5 million m^3 of water (396 million gallons), 150% of the total estuarine volume, visualized in Figure 18. When overlaying tidal cycle data onto estuarine elevation, it became apparent that while the berm was present changes in estuarine elevation did not coincide with or appear to be influenced by oceanic tidal cycles. However, when the berm is dredged open, estuarine elevation changes appear to reflect tidal cycles, (periods not highlighted in blue, Figure 18). Because the diurnal fluctuation appeared to reflect evapotranspiration and not following the tidal cycle or its magnitude. However, when the berm is dredged open (period highlighted in blue box in Figure 2), estuarine elevation changes appear to reflect tidal cycles, indicating a more natural estuarine functionality (Figure 18.)

The timing of when the berm is dredged open appears to influence the duration of the opening. The December 24, 2019 opening occurred at about 23:00 UTC (13:00 HST), during the top of the high tide prior to a spring low tide, a six-hour falling tidal period. By opening the berm at this time estuarine waters were able to scour the narrow dredged opening deeper and wider for roughly 6 hours before the rising tide brought sands back into the stream mouth, beginning the natural process of berm closure. The tidal cycles over the next 9 days continued sediment transport both into and out of the stream mouth. As estuarine elevation decreased, the scouring force keeping the berm open decreased allowing sediment at the stream mouth to slowly accreted until the sand berm fully formed, prohibiting interaction between estuarine and coastal water (Figure 18). Two other opening events occurred, one on 1/10/2020 and the other on 1/12/2020. These opening times did not coincide with a falling tide, rather a rising tide. Natural sediment transport brought sand back into the stream mouth, the berm accreted blocking connection between the estuary and coastal waters a few hours after opening. All closures appear to have coincided with an incoming tide (flood tide) (Figure 18).

When investigating the amount of water the estuary received in rainfall over the period of study, November, 2018 through February, 2020, according to the Kaʻelepulu Wetland rain gauge, total rainfall was 5522.7 mm and evaporation estimated by the Davis GroWeather Station at Kaʻelepulu Wetland was 1497.7 mm. However, December of 2019 had an anomalous rainfall of 4542.8 mm, accounting for 82% of the rain for the entire observational period. The overall water budget for the Kaʻelepulu Estuary over the month between December 18th, 2019 and January 17th, 2020 can be visualized (Water Quantity Figure 20), it indicated a net loss of 24.2mm from the 500mm baseline (Water Quantity Results Table 4). While this may seem like a small amount, when applied over the entirety of Kaʻelepulu Estuary, 575,000 m^2, the result is a loss of 13,800 m^3 of water. This loss indicates there may be a general decreasing trend in the amount of water in Kaʻelepulu Estuary, which is also supported by Lanikai Bridge and Kaʻelepulu Wetland staff gauge data over the course of this investigation.

In the hypothesis 4, longer berm openings would correlate with greater oceanic exchange and therefore an increase in water quality in the SME and inland estuary as indicated by an increase in salinity at the stream mouth section post berm closure. For Hypothesis 4, percent change in salinity was assessed and a linear regression was run to assess correlation between days open and salinity change R^2=0.804 and p=0.29 (Water Quantity Results Figure 20). The regression model running percent salinity change against tidal range indicated R^2=0.317 and p=0.6193. Despite only three points (openings) assessed, it is likely that the amount of time open is the greatest driver of salinity change but also influenced by total tidal range. With only three sound data points, the data is scanty and further examination may be warranted in subsequent investigations. It was thought that the volume of water exchanged might be estimated based on percent salinity change per days open, perhaps future investigations adding to this data set may elucidate that possibility.

Citizen Science and Participatory Research:

In this study effort, citizen science and participatory research can indeed be used to garner greater stewardship of the Kaʻelepulu System. The extent of that stewardship and its depth are however unclear. The educational outcomes in Table 5 demonstrate the effectiveness of the WIRED Program on student learning and teacher professional development. For evaluative purposes, the project was heavily reliant on the use of pre- and post-survey data to elucidate a shift in student ideas, values. Unfortunately, due to the COVID-19 induced school closures, most of the post evaluative surveys could not be administered making statistical analysis impossible. Pre-survey data indicated that:

- 75% spend significant time interacting with their natural environment
- 70% felt science to be interesting
- 65% felt they could make a positive impact on their local environment
- 40% spent time in the streams and coastal waters
- 35% felt familiar with the watershed they reside in
- 15% engaged in community work
- 8% had experience using scientific equipment
- 4% felt they had engaged in research

It was interesting to see the gaps and disconnects between seeing science as interesting (70%) and doing science (4%-8%). Additionally it was interesting to see that while participants felt like they could positively impact their environment (65%), much fewer (15%) actually engaged in restoration efforts. While many students (75%) spend time interacting with their natural environment, interactions with marine and aquatic ecosystems was less (40%) despite this is an island community.

WIRED activities and lessons targeted those gaps. Post survey data would have been very useful in assessing the efficacy of closing those gaps. Despite the missing post-survey data, in conversations with students, teachers, parents, and community members it was apparent the excitement for doing science and understanding place was generated. Because students were offered the opportunity to explore their watersheds following the pathways water takes, students were able to make connections regarding the functioning of the watersheds. The extensive use of full day “field trips” enabled students to travel through their watershed. That coupled with visual bioassessments, water quality surveys, and for some, coastal (coral reef) survey, participants were able to concretely understand the connection from upland to ocean and why healthy watersheds are important. Students were able to successfully identify issues within their watershed, and identify personal actions they and their families can take to improve water quality. This program brought relevance to why science is important. Specifically, students in the Ahupuaʻa Kailua were able to identify the issues that the Kaʻelepulu Estuary is facing, how those issues impact both natural and human systems and actions they can take to improve water quality in the waters they recreate and harvest food from. Results of this participatory outcomes Figures 1, 2, 3, 4, and 5 demonstrate a representative sample of students making connections regarding their watershed.

On a social emotional level, students whom did not previously connect with science, or feel science was something they were “good at”, gained a new perspective on both the fields of environmental and marine science and themselves.

> *“As the first member of my family to graduate High School, this program gave me the confidence to get a college education.”*

is a quote from a WIRED student who was deeply moved by experiences engaging in the research process and working alongside graduate students and researchers with whom the student was able to identify with. As a result of this student’s work ethic in the field, the student was afforded an opportunity to intern in a biogeochemical lab. Another WIRED student, first in the family to go to college, was offered a substantial scholarship along with a job in the university’s genomics lab, as a direct result of the experiences gained in the Program, opening up and changing the career ambitions of this individual.

WIRED offered the ability for K-12 students and their teachers to interact with research equipment typically only used by research level institutions and agencies. That exposure to research tools gave students the “feel” that they were doing actual science, and in fact they were. By using those tools, properly calibrated and maintained, the data students were able to generate became usable to other researchers, and in fact has been. Students were also afforded the opportunity and ability to analyze samples in laboratory environments, outside of their school. This increased student safety, added to data fidelity, and boosted confidence in student’s ability to actually “do science”, especially important for marginalized students whom are typically “turned off by science”. Results section educational outcomes Figures 5 through 9 highlight students running nutrient analytics using LaMotte colorimetric kits and using a confocal microscope to measure coral tissue thickness that will be compared water quality in a burgeoning project assessing the impact of biocultural restoration on water quality. Figures 7 and 9 show parts of the teacher professional development in which they were shown the techniques for extracting DNA from the microbes found in sediments in the Kaʻelepulu Estuary and how to sequence targeting the 16s region using Oxford Nanopore’s Minion 3rd generation sequencer. They were also given the tools and resources to bring this activity to their classrooms.

Conclusions:

Kailua Bay and the Kaʻelepulu Estuary are areas that are important to both natural and human systems. Landscape modification in the 20th and early part of the 21st centuries seem to have altered the biogeochemistry of those areas, degrading the ecosystems from both natural and human system perspectives. According to the Department of Health Clean Water Branch standards, the water quality in both areas is impaired regardless of the presence or absence of the sand berm that disconnects the two waterways. That being said, data indicates that when the berm is absent and there is interaction between the two bodies of water salinity in the stream mouth section of the estuary rises significantly. Many estuarine organisms are dependent on a higher saline environment, especially in that section of the estuary. There was not a rise in dissolved oxygen in the SME and inland sections of the estuary, as expected, rather a slight decrease. This decrease in the SME section is most likely explained by the introduction of hypoxic inland waters. Likewise, findings suggest when there is connection between the two bodies, there is no significant change in water quality. Yes, Kailua Bay looks, smells, and tastes different when there is an outflow of estuarine waters, but different does not equate to poor water quality. That fact is recognized by the Hawaiʻi Department of Health and reflected in their administrative rule regarding water quality. As stated earlier those differences are essential for many endemic estuarine and freshwater species.

Water cycling through the estuary is spotty and inconsistent at best (i.e. Babcock, 2004; Tamaru and Babcock, 2011; Bourke, 2016). Freshwater input is driven by inconsistent rain events causing street run off that vary in both duration and amount. Also inconsistent are the openings of the berm, allowing for the introduction of oceanic water. Cyclical changes in estuarine water volume and chemistry are necessary for proper estuarine habitat functionality (Perissinotto, 2013). Regular openings of the berm may reduce the impacts of “first flush”, the discharge of long period standing eutrophic water, inclusive of storm water runoff. Those openings would be most effective when correlate with tidal cycles during a “Spring Tide”. Opening at the top of a high tide prior to the ebb of a roughly 6-hour or greater duration appears to promote scouring of the narrowly cut channel through the berm. The scouring seems to deepen and widen the channel, improving duration of estuarine/oceanic exchange.

There does appear to be a correlation between rainfall and enterococcus throughout three of the four sections, specifically, SME, Mouth, and Coastal. The strongest correlation at the site “End Golf” the most inland site within the SME section. Although lesser, there did appear to be a correlation between rainfall and Chlorophyll-a in those same areas. While there did not appear to be a correlation between nutrient concentrations and rainfall, there appears to be sufficient evidence to support the hypothesis regarding rainfall. With this in mind, there are no storm water mitigation infrastructures on the storm drains that feed the entirety of freshwater input to the Kaʻelepulu Estuary. Adding the storm water infrastructure will more than likely lead to improvements in the water quality and biogeochemistry of this system.

This project relied heavily on community participation to address the need to understand how the Kaʻelepulu estuarine system functions. The majority of the water samples collected and measurements taken were collected by students, participants in WIRED program. Involving the community in this project allowed for a much larger data set to be garnered, to some extent it may be thought of crowd sourcing data, with lots of oversight. Involving students to that extent provided its own challenges as well, especially as data collection revolved around nature’s schedule rather than a school bell schedule. One hundred and eight of those students were 6th graders from Kaʻōhao Public Charter School, led by their teacher Parker Sawyer. Many of the challenges surrounding student involvement were overcome largely due to the flexibility of Mr. Sawyer, his co-teacher Holly Kemsley, and the staff of Kaʻōhao School. Due to their facilitation, each of those students were directly involved in the taking and handling of water samples, equipment, and the interpretation of the data generated. They (students and teachers) became part of the research process, became more familiar with this estuarine system, and gained college and career exposure. Through a deeper developed understanding of the Kaʻelepulu system, a deeper sense of responsibility to care for it manifested. The class was engaged in projects that communicated issues with system and practices that will contribute to better water quality in Kaʻelepulu to Kailua residents and beyond.

As a part of a Ramsar wetland of international importance and home to endangered water fowl that depend on consistent water cycling, it is the obligation of the community, including myself, to better steward this impaired system

Works cited:

22% Proficient: Hawaii DoE Test Scores Reach Level of Alabama, Mississippi. (2012, May 10). Retrieved October 20, 2016, from http://www.hawaiifreepress.com/ArticlesMain/tabid/56/ID/6724/22-Proficient-Hawaii-DoE-Test-Scores-Reach-Level-of-Alabama-Mississippi.aspx

AECOS, 1992. Water quality and biological studies of Kawai Nui Stream relative to the Kailua Gateway Project. AECOS No. 664: 31 p. April 1992.

Allen, James A. "Mangroves as Alien Species: The Case of Hawaii." *Global Ecology and Biogeography Letters* 7.1 (1998): 61. Web.

Babcock, R. (2004). *Scoping Report Kaelepulu Stream Total Maximum Daily Loads*. Honolulu, HI: Engineering Solutions Inc and Kennedy/Jenks Consultants.

Bianchi, T. S. (2013) Estuaries: Where the River Meets the Sea. *Nature Education Knowledge* 4(4):12

Bourke, R.E, (2016) Natural History, Hydrology and Water Quality of Enchanted Lake – Kaelepulu Pond, unpublished manuscript

Cadiz, E. A. (2017). *PILINA — MĀLAMA — ʻĀINA MOMONA A COMMUNITY-DRIVEN MONITORING PROGRAM TO UNDERSTAND HEALTH AND WELL-BEING OF PEOPLE AND PLACE IN HĀʻENA, KAUAʻI.*(Unpublished master's thesis). University of Hawaiʻi at Mānoa.

California, S. of. (n.d.). Retrieved from https://cimis.water.ca.gov/Resources.aspx

Cox, E.F. & Jokiel, P.L. (1996) *An environmental study of Nuupia Ponds Wildlife Management Area, Marine Corps Base Hawaii, Kaneohe Bay*. Final Report.

Datums - NOAA Tides & Currents. (n.d.). Retrieved from https://tidesandcurrents.noaa.gov/datums.html?id=1612340

Drigot, Diane C. Ho'ona'auao no Kawai Nui: Educating about Kawai Nui: a multimedia educational guide. Honolulu: Environmental Center, University of Hawaii, 1982.

Eckner, K. F. (1998). Comparison of membrane filtration and multiple-tube fermentation by the Colilert and Enterolert methods for detection of waterborne coliform bacteria, Escherichia coli, and enterococci used in drinking and bathing water quality monitoring in southern Sweden. *Appl. Environ. Microbiol.*, *64*(8), 3079-3083.

Elbert, S. H., & Pūkui, M. K. (1986). *Hawaiian Dictionary: Hawaiian-English; English-Hawaiian*. Honolulu: Univ. of Hawaii Press.

Equipment. (n.d.). Retrieved from http://www.soest.hawaii.edu/S-LAB/equipment/slab_autoanalyzer.htm

Estuarine Science. (n.d.). Retrieved January 19, 2019, from http://omp.gso.uri.edu/ompweb/doee/science/descript/whats.htm

Frazier, A. G., and Giambelluca, T. W. (2017), Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. *Int. J. Climatol.*, 37(5), 2522–2531. doi: 10.1002/joc.4862

Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y.-L. Chen, P.-S. Chu, J.K. Eischeid, and D.M. Delparte, 2013: Online Rainfall Atlas of Hawaiʻi. *Bull. Amer. Meteor. Soc.* 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1.

Geyer, W. R. *et al*. Interaction between physical processes and ecosystem structure: a comparative approach. In *Estuarine Science: A Synthetic Approach to Research and Practice*. Ed. Hobbie, J. E., (Washington, D.C.: Island Press 2000). 177-206.

Giant Landslides of the Hawaiian Islands. (n.d.). Retrieved October 3, 2013 from https://hilo.hawaii.edu/~kenhon/GEOL205/Landslides2/default.htm

Greenlaw, S., Knowlden, S., Landis, C., & Talucci, T. (2009). Biocultural Restoration in an Urban Watershed

Goo, S. K. (2015). After 200 years, Native Hawaiians make a comeback. Retrieved August 08, 2016, from http://www.pewresearch.org/fact-tank/2015/04/06/native-hawaiian-population/

Hall, W. Thomas. The History of Kailua, Hawaii. Kailua, Hawaii: Dolphin Printing & Pub. 1998.

Kailua: In the wisps of the Malanai breeze = Kailua i ke oho o ka Malanai. (2009). Kailua, Hawaiʻi: Kailua Historical Society.

Kanaʻiaupui, S.K., N. Malone, and K. Ishsibashi. (2005). Ka huakaʻi: 2005 *Native Hawaiian educational assessment.* Honolulu, HI: Kamehameha Schools. Pauahi Publications

Keala, Graydon "Buddy", James R. Hollyer, and Luisa Castro. *Loko I'a: A Manual on Hawaiian Fishpond Restoration and Management*. Working paper. College of Tropical Agriculture and Human Resoruces, University of Hawaii. Honolulu: U of Hawaii, 2007. Print

Kelly, M. A. (1979). Kawainui Fishpond Historical Report. (tDAR id: 358796).

Likert, R. (1932). A Technique for the Measurement of Attitudes. *Archives of Psychology*, 140, 1–55.

Luft, J., Bell, R. L., & Gess-Newsome, J. (2008). Science as inquiry in the secondary setting. Arlington, VA: National Science Teachers Association. doi:10.1111/j.1475-682X.2008.00238.x

Mānoa's Racial and Ethnic Diversity Profile (Rep.). (2016, March 1). Retrieved February 1, 2019, from Office of Student Equity, Excellence & Diversity website: http://www.hawaii.edu/diversity/wp-content/uploads/2016/09/Manoa-Diversity-Profile_Mar30-2016.pdf

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C. Evans, D.M., French, R.A., Parrish, J.K., Phillips, T.B. and Ryan, S.F. (2016). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*.

NOAA: C-CAP Land Cover Atlas. (n.d.). Retrieved from https://coast.noaa.gov/ccapatlas/

Norcross, Z. M., Fletcher, C. H., & Merrifield, M. (2002). Annual and interannual changes on a reef-fringed pocket beach: Kailua Bay, Hawaii. *Marine Geology,190*(3-4), 553-580. doi:10.1016/s0025-3227(02)00481-4

Oceanit Laboratories, Inc. (2016). *KAWAI NUI MARSH FLOW RESTORATION PROJECT SIPHON FLOW RESTORATION EXPERIMENT REPORT* (pp. 15-57, Rep.). Honolulu, HI: Oceanit Laboratories.

Oliveira, A., & Baptista, A. M. (1997). Diagnostic modeling of residence times in estuaries. *Water Resources Research,33*(8), 1935-1946. doi:10.1029/97wr00653

Ostrander, C. E., Mcmanus, M. A., Decarlo, E. H., & Mackenzie, F. T. (2007). Temporal and Spatial Variability of Freshwater Plumes in a Semienclosed Estuarine–Bay System. *Estuaries and Coasts, 31*(1), 192-203. doi:10.1007/s12237-007-9001-z

Perissinotto, R. (2013). Ecology and Conservation of Estuarine Ecosystems: Lake St Lucia as a Global Model. (pp. 323–331). https://doi.org/10.1017/CBO9781139095723

Pizzini, E. L., Shepardson, D.P., and Abell, S. K. (1991). The inquiry level of junior high activities: Implementations to science teaching. *Journal of Research in Science Teaching, 28(2)*, 111-121.

Swain, L.A. and C.J. Huxel. 1971. Relation of drainage problems to high ground water levels, Coconut Grove area, O'ahu, Hawai'i. U.S. Geological Survey, Honolulu.

Tamaru, C. and R. Babcock, 2011. Water quality data collected from the Kailua Waterways in support of a Total Maximum Daily Load study conducted for the State Department of Health.

Top 5 Beaches on Oahu. (n.d.). Retrieved from https://www.hawaii.com/oahu/beaches/top-5-beaches/

US Department of Commerce, & NOAA. (n.d.). Honolulu, HI. Retrieved January 21, 2019, from http://www.prh.noaa.gov/hnl/hydro/pages/rra_graphs.php?station=OFSH1&mo=122018

Villanueva, M. C. (2015). Contrasting tropical estuarine ecosystem functioning and stability: A comparative study. *Estuarine, Coastal and Shelf Science, 155*, 89-103. doi:10.1016/j.ecss.2014.12.044

Water Quality Standards, Hawaiʻi Department of Health Clean Water Branch, Title 11, Chapter 54 §11-54-1 et. seq. November 15, 2014

Figures and Tables:

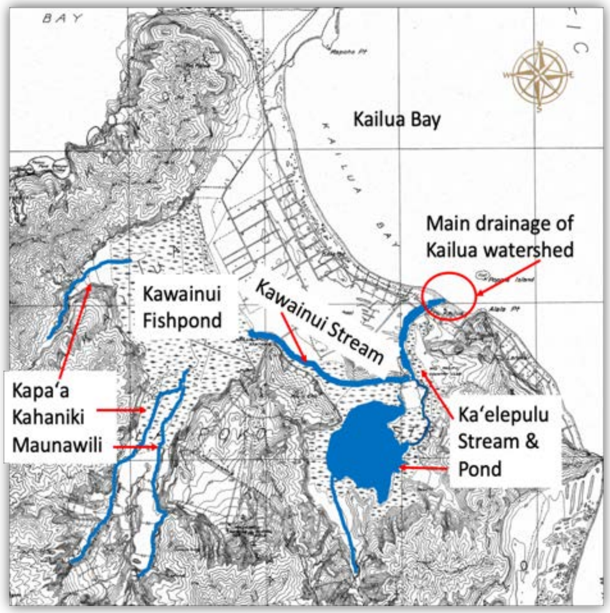


Figure 1: Circa 1928 Kailua and its waterways, note how all water drained from Kaelepulu Stream and the size of the Ka'elepulu Pond.

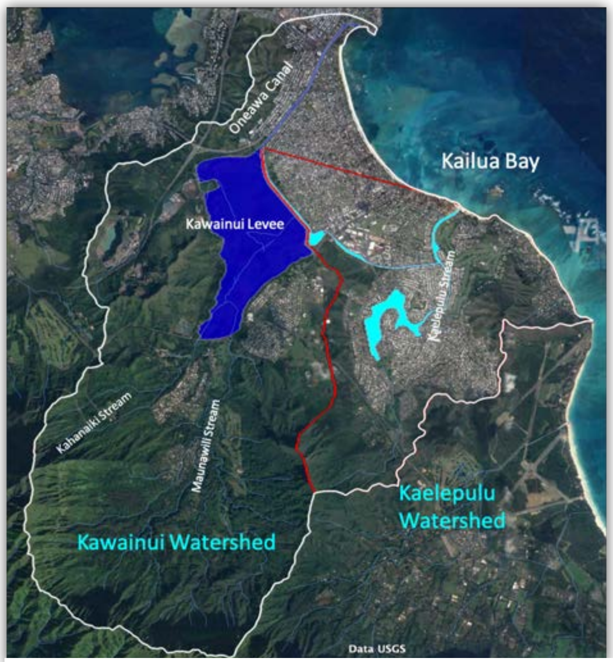


Figure 2: Present day Kailua watershed, drainage has been altered to the North through the Oneawa Canal. Levee constructed preventing Kawainui waters from entering Ka'elepulu.

Figure 3: The dredging of Kaelepulu Pond, creation of fast land for houses and the construction of a submerged sill, restricting flow between the pond and the estuary. Credit Bourke, 2016

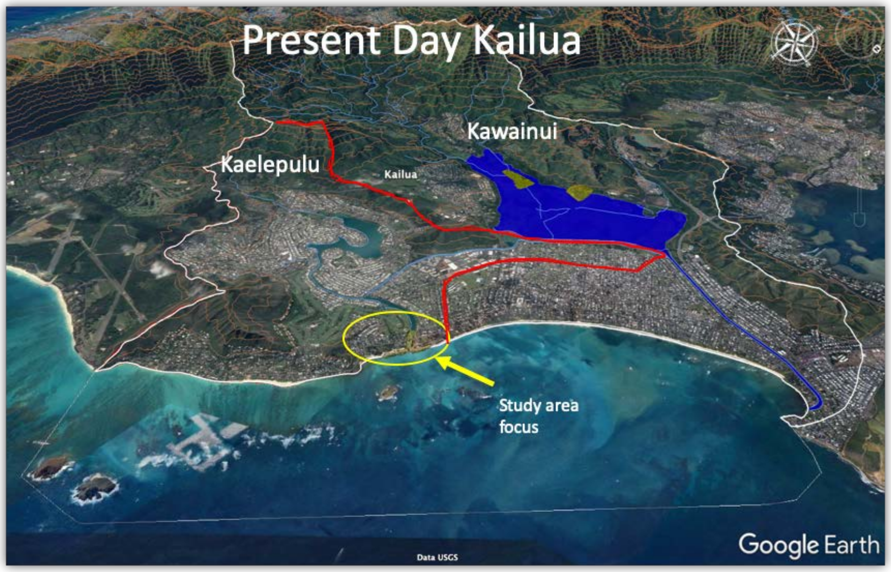


Figure 4: Present Day Kailua, the watershed has been split into two watersheds, Ka‘elepulu and Kawainui. The red line highlights the human created boundaries. The yellow circle denotes the area of focus for this investigation.

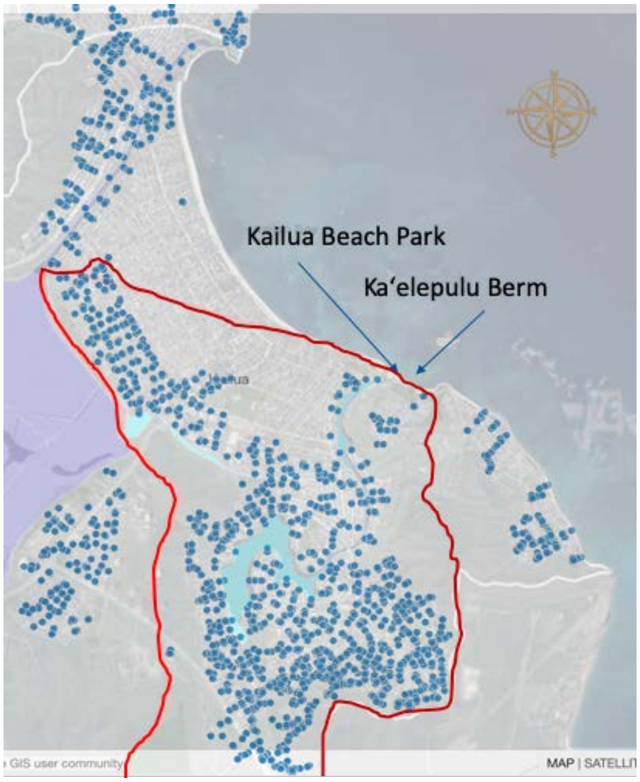


Figure 5: Map of Kailua with storm drain layer added represented by blue dots, ~80% drain into the Ka‘elepulu estuary bound in red. This is the only freshwater source for the area.

Figure 6: To establish connection between Kailua Bay and Kaelepulu Estuary, heavy equipment is needed to move the naturally accreting sand. Photo Credit Bob Bourke, 2016

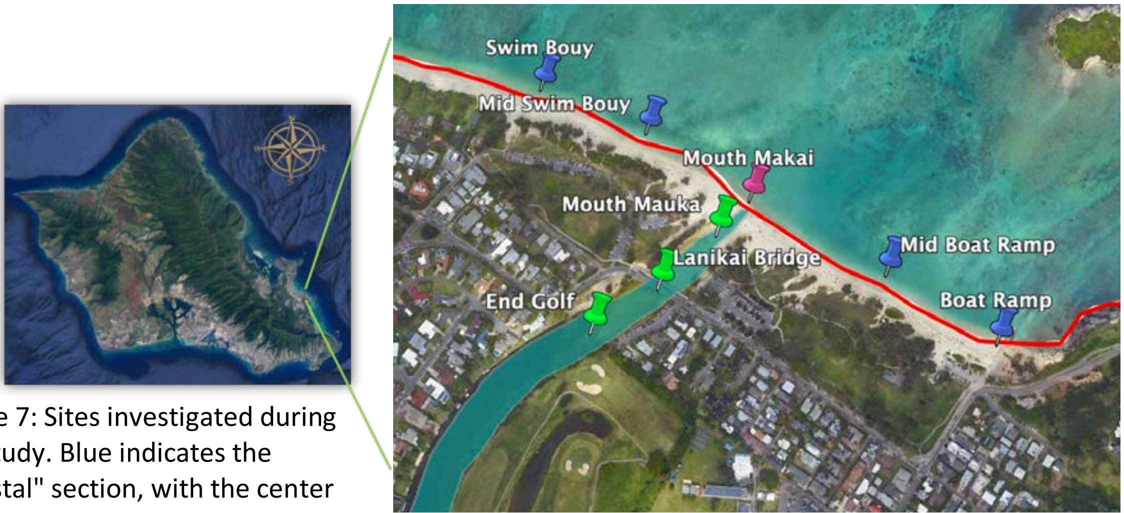


Figure 7: Sites investigated during the study. Blue indicates the "Coastal" section, with the center magenta site as “Mouth” and green indicates the stream mouth of estuary (SME) section.

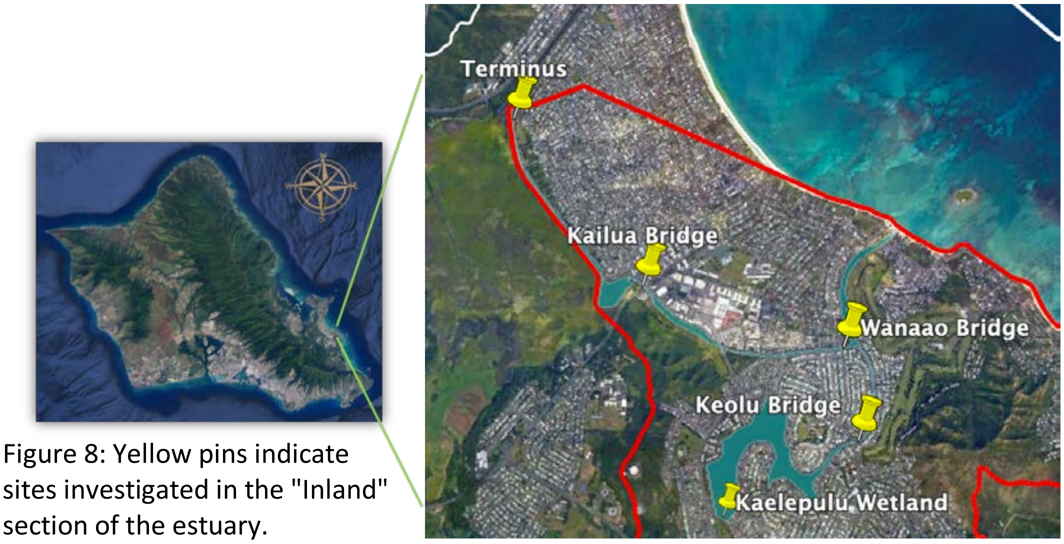


Figure 8: Yellow pins indicate sites investigated in the "Inland" section of the estuary.

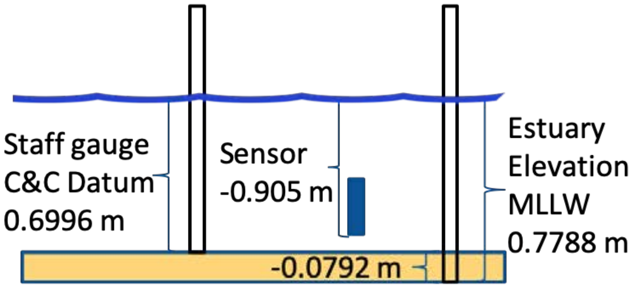


Figure 9: Sensor depth is adjusted to mean lower low water MLLW data using by first converting staff gauge measurements to MLLW elevation, then applying the actual depth of the sensor.

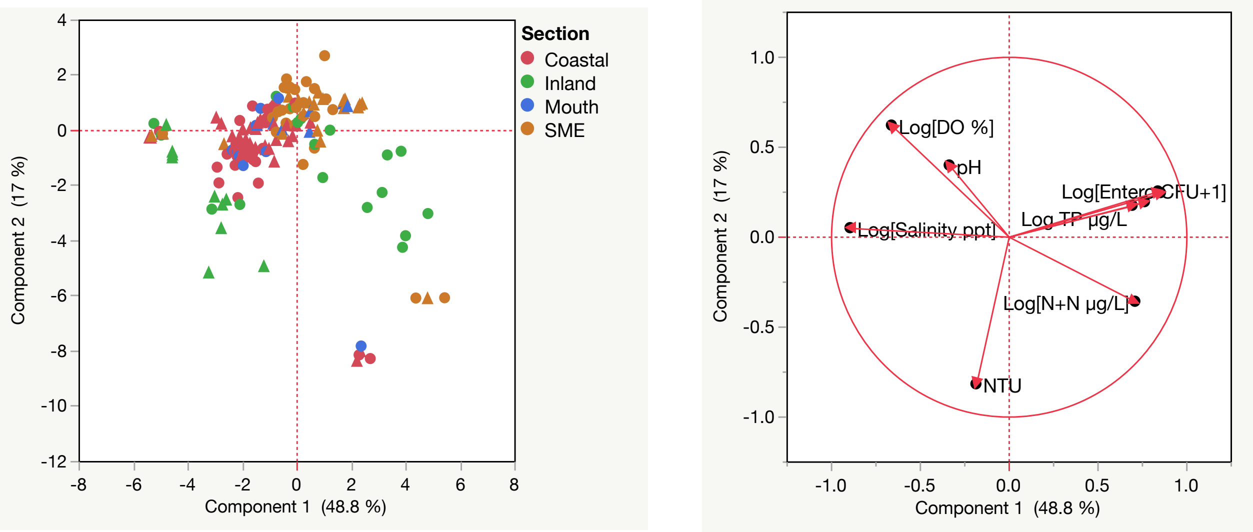
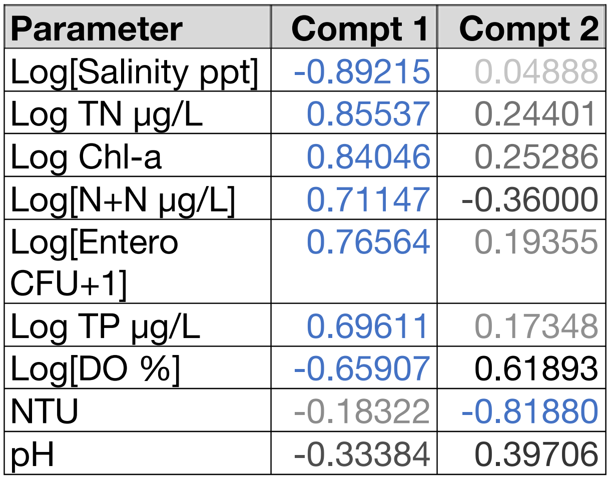


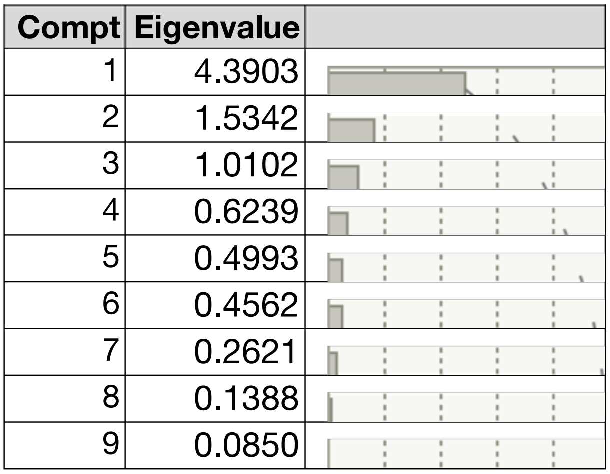
Figure 10: Principal components 1 and 2 together explained 65.8% of the variation in water quality. Parameters with loading matrix absolute values higher than 0.65 were looked at as principal component drivers to be drilled into and further analyzed. It is a linear combination of the variables in an orthogonal relation. Color coded sections, grouped together by the analysis, are more closely related. The arrows in the right pannel are correspond with the loading values in Table 1, indicated salinity was the primary parameter in determining relationships.

Table 1: Loading values of water quality parameters. Parameters with absolute values greater than 0.65 were further drilled into.



Parameter	Compt 1	Compt 2
Log[Salinity ppt]	-0.89215	0.04888
Log TN µg/L	0.85537	0.24401
Log Chl-a	0.84046	0.25286
Log[N+N µg/L]	0.71147	-0.36000
Log[Entero CFU+1]	0.76564	0.19355
Log TP µg/L	0.69611	0.17348
Log[DO %]	-0.65907	0.61893
NTU	-0.18322	-0.81880
pH	-0.33384	0.39706

Table 2: Eigenvalues indicating the influence of each principal component.



Compt	Eigenvalue	
1	4.3903	
2	1.5342	
3	1.0102	
4	0.6239	
5	0.4993	
6	0.4562	
7	0.2621	
8	0.1388	
9	0.0850	

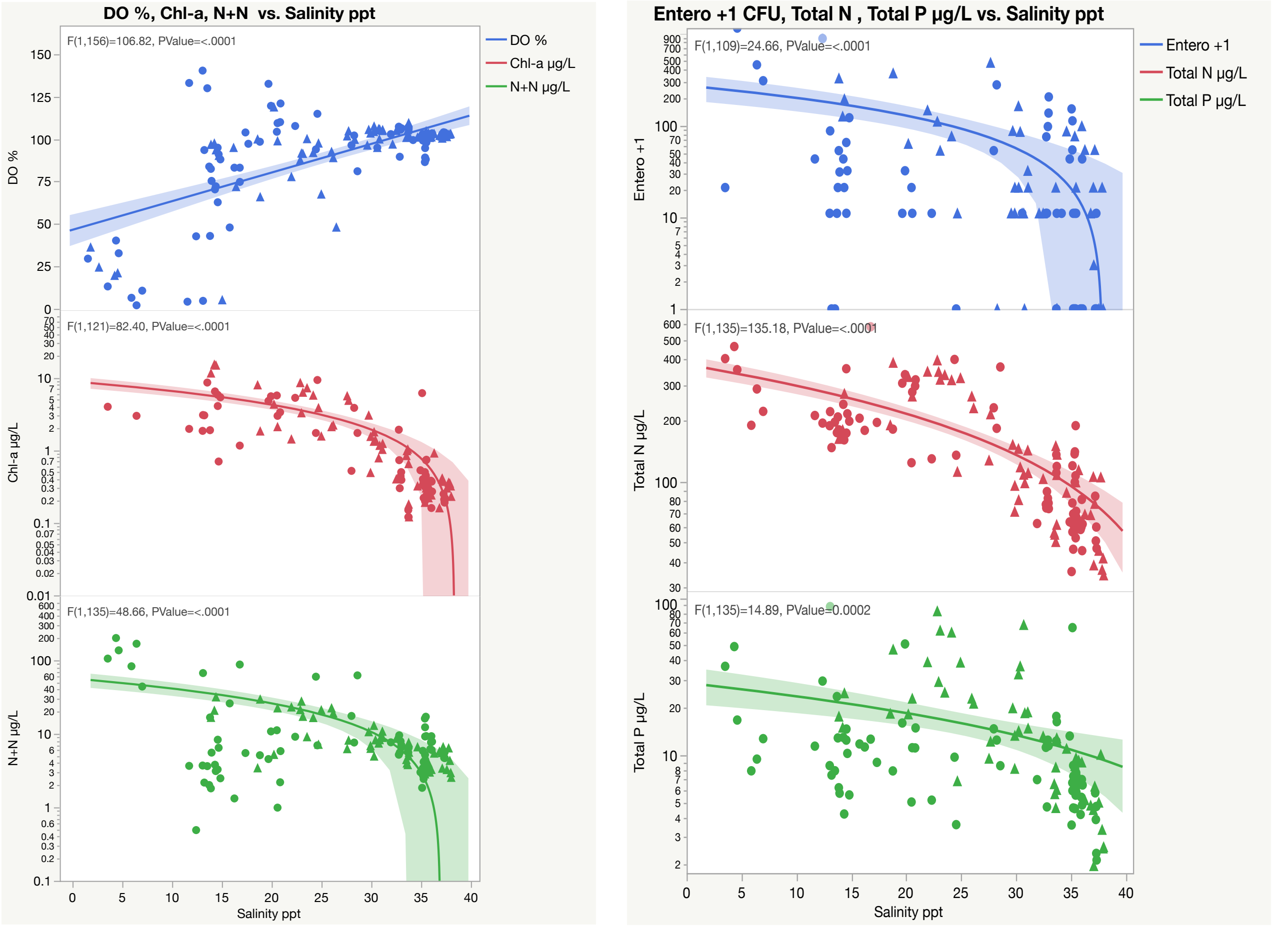


Figure 11: changes in DO% and log transformed Chlorophyll, Nitrite+Nitrate, enterococci, Total Nitrogen and Total Phosphorus as a response to freshwater input. Salinity increases to the right on the x axis.

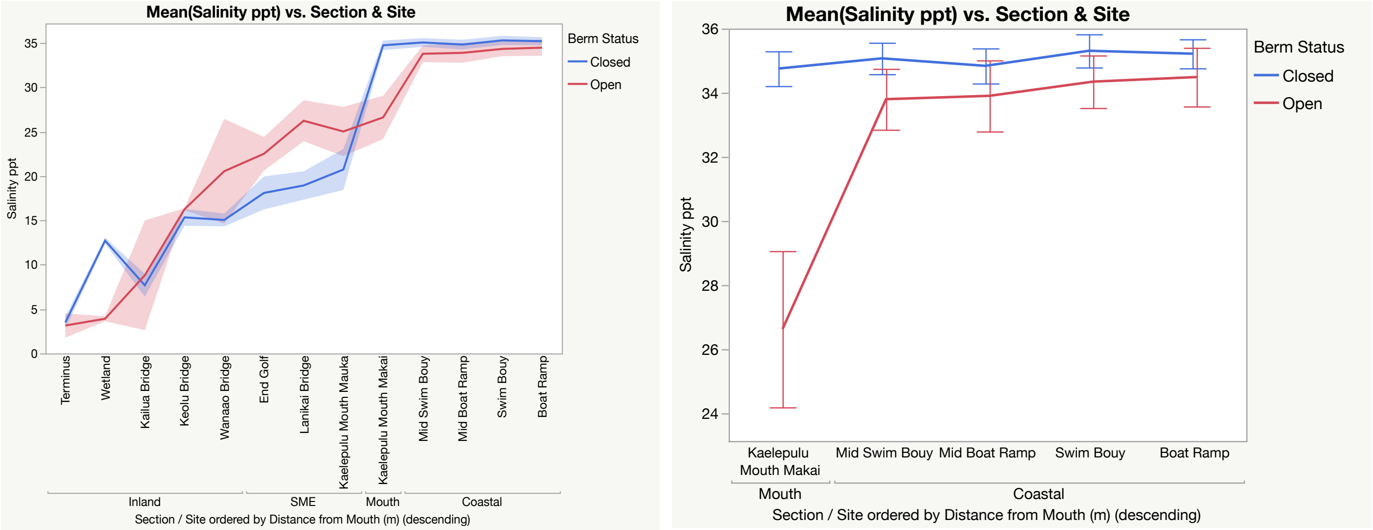
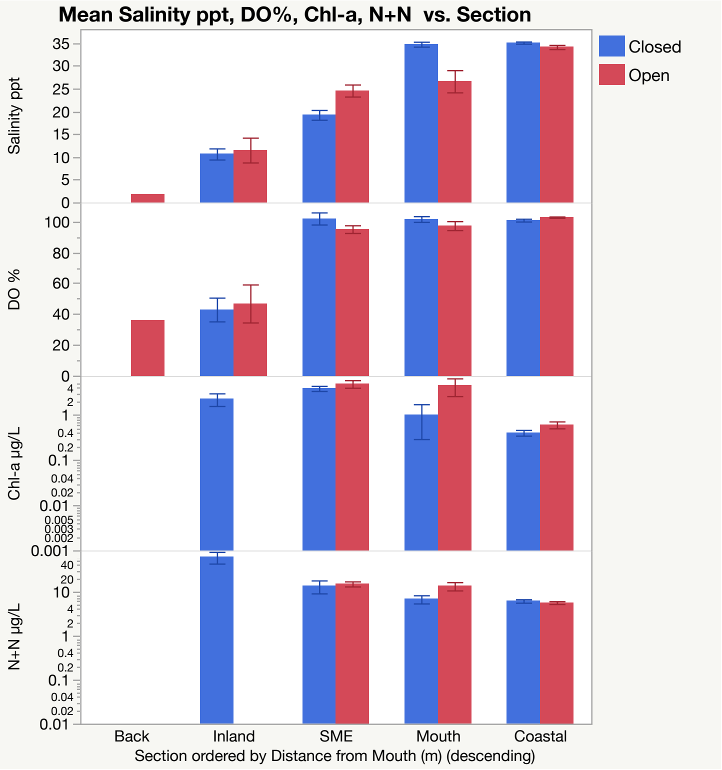


Figure 12: Salinity changes from inland to coastal, when the berm is closed there appears to be no communication between the estuary and coastal waters. Standard error is applied in shading left and whisker bars right.



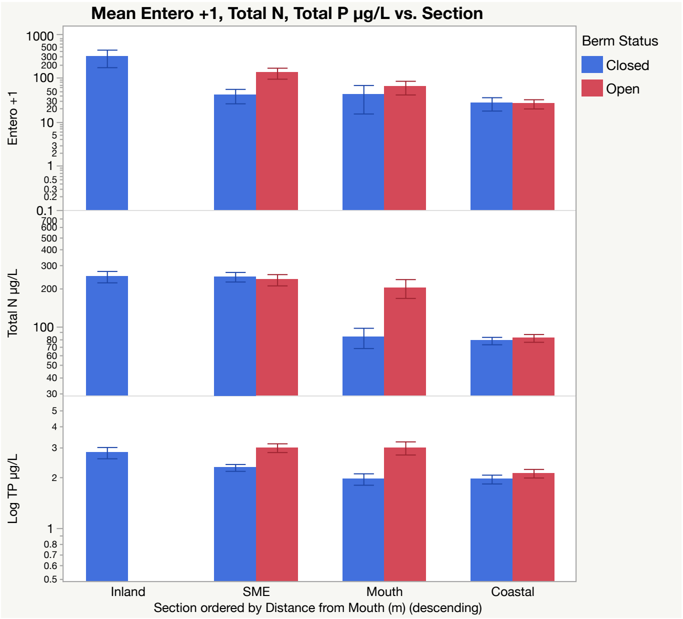


Figure 13: Changes in Dissolved Oxygen, Chlorophyll-a, Enterococcus, Nitrite+Nitrate, Total Nitrogen, and Total Phosphorus at different sections in the Estuary, as a response to opening the berm. Log scale for nutrients, chlorophyll, and enterococcus.

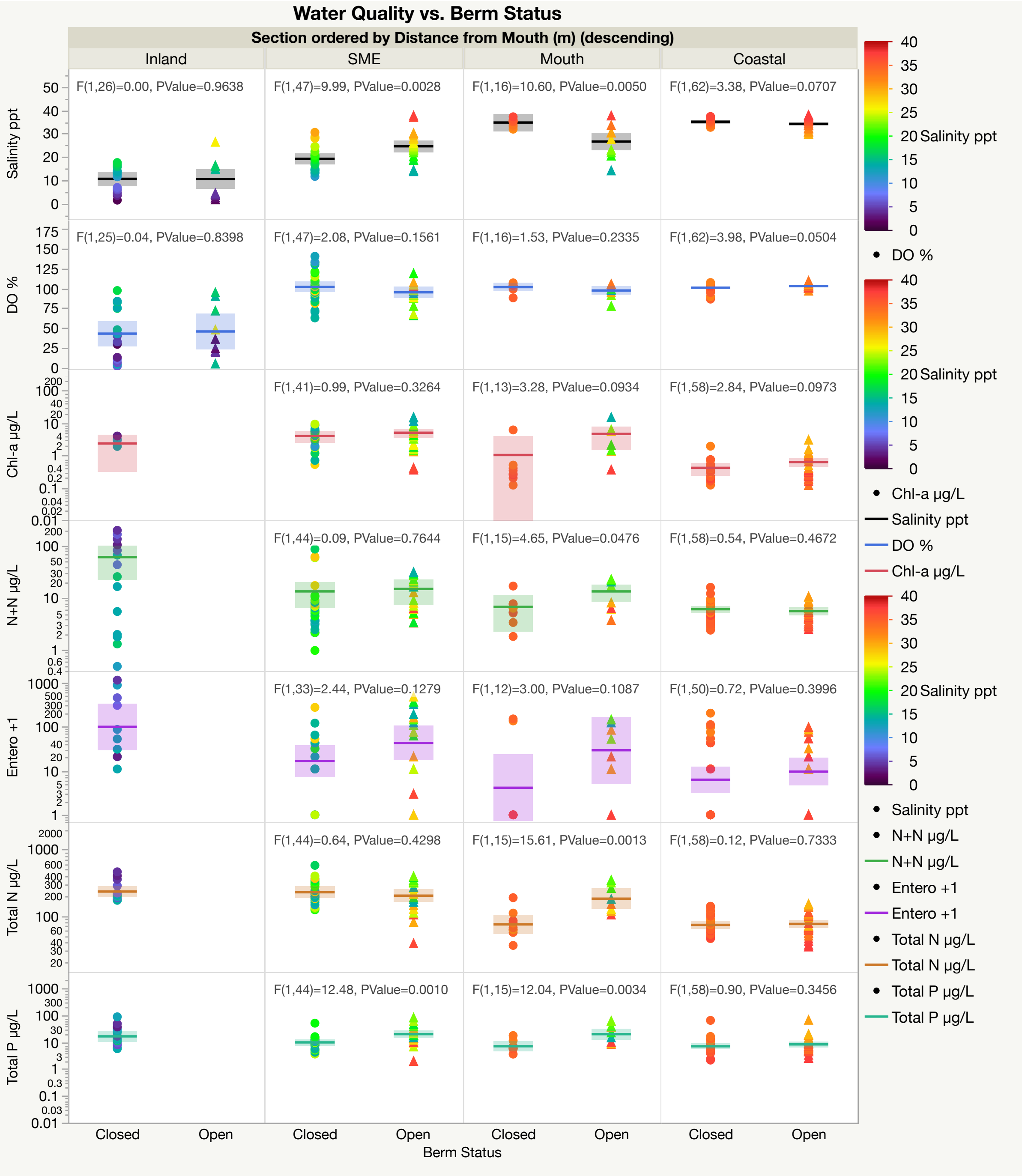


Figure 14: Changed in water quality parameters as driven by the presence or absence of the sand berm. Salinity gradients are colored. Note the lack of significant change in all parameters at the coastal section.

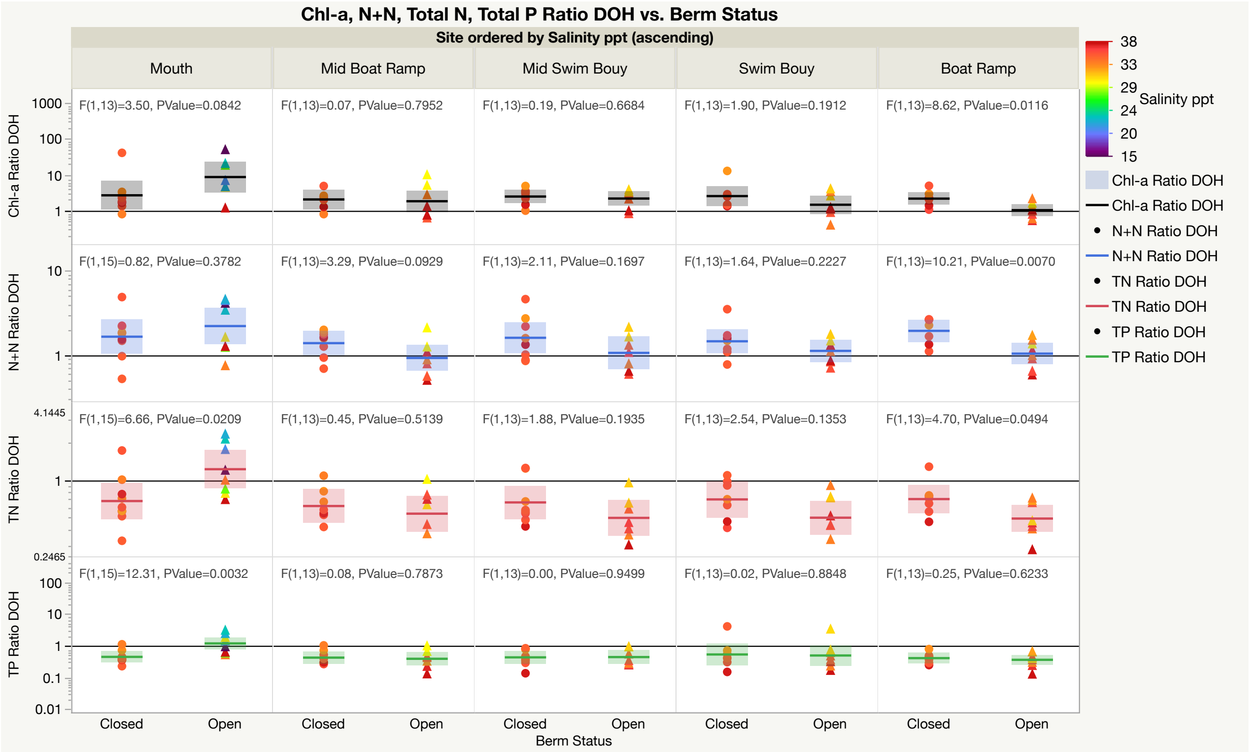


Figure 15: T-Test berm open vs. closed assessing Chlorophyll-a and Nutrients when ratio standardizing "Wet" and "Dry" conditions along the coastal waters and immediately seaward of the stream mouth is applied. There appear to be increase of Total Phosphate and Total Nitrogen explained by the presence or absence of the berm directly seaward of the stream mouth, those differences do not appear elsewhere. Values that are above 1, indicated by the line aligning with the y axis, are considered impaired by Department of Health guidelines.

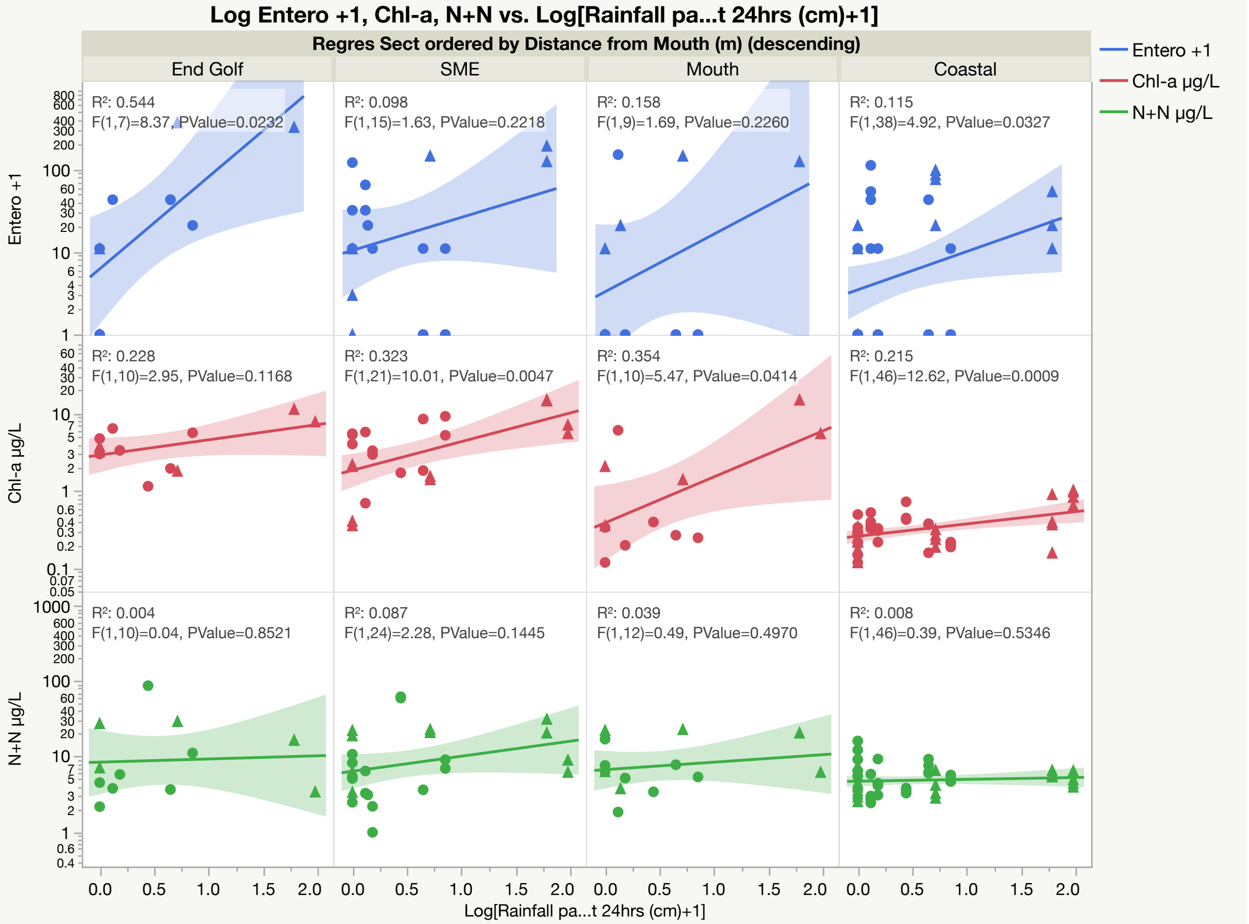


Figure 16: Linear Regression assessing the relationship between enterococci, Chlorophyll-a, Nitrite+Nitrate to rainfall. There appeared to be a correlation between rainfall and both enterococci and Chlorophyll-a along all sections, the strongest was regarding enterococci at the site "End Golf". There did not appear to be a correlation regarding Nitrite+Nitrate.

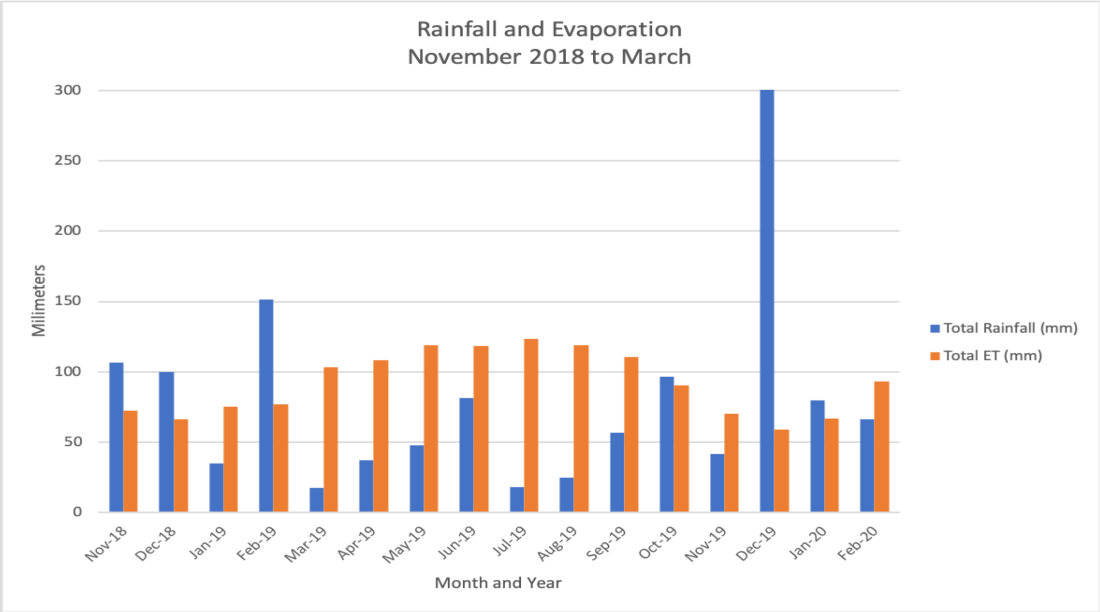


Figure 17: Rainfall and evapotranspiraton over the study period as measured at the Kaelepulu Wetland Gauge in mm as a 4 km^2 representation of the 14.8 km^2 Ka‘elepulu Estuary encatchement area.

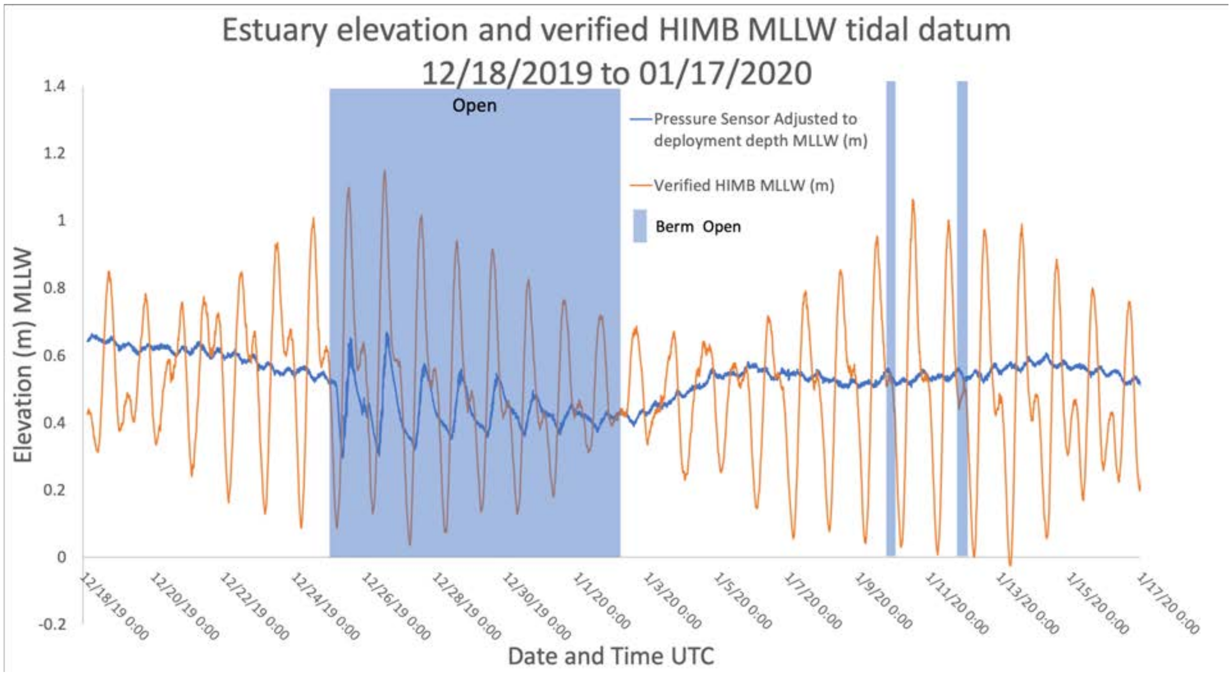


Figure 18: Kailua Bay tidal cycle as measured from the NOAA tide gauge at Moku o Loʻe overlaid on Kaʻelepulu Estuarine elevation in meters related to Mean Lower Low Water, blue sections indicate open berm. It is to be noted the open period between 12/24/2019 and 1/02/2020 began on an outgoing tide, promoting scouring at the stream mouth and may contribute to the length of the open period. The other two less significant open periods were opened as the tide was rising and possibly pushed sand back into the stream mouth, closing it to the bay shortly after opening. It is also to be noted how estuarine elevation during 2/24/2019 and 1/02/2020 period mimicked tidal cycles, while the other two did not.

Table 3: Water volume and percent of total estuarine water volume exchange between Kaʻelepulu Estuary and Kailua Bay during the opening event from 12/24/2019 to 01/02/2020

Total ebb (m)	Total flood (m)	Total elevation change (m)	Total volume exchange (m^3)	Net volume exchange (m^3)	Percent exchange
-1.391	1.301	2.692	1548151.74	-51092.04	150

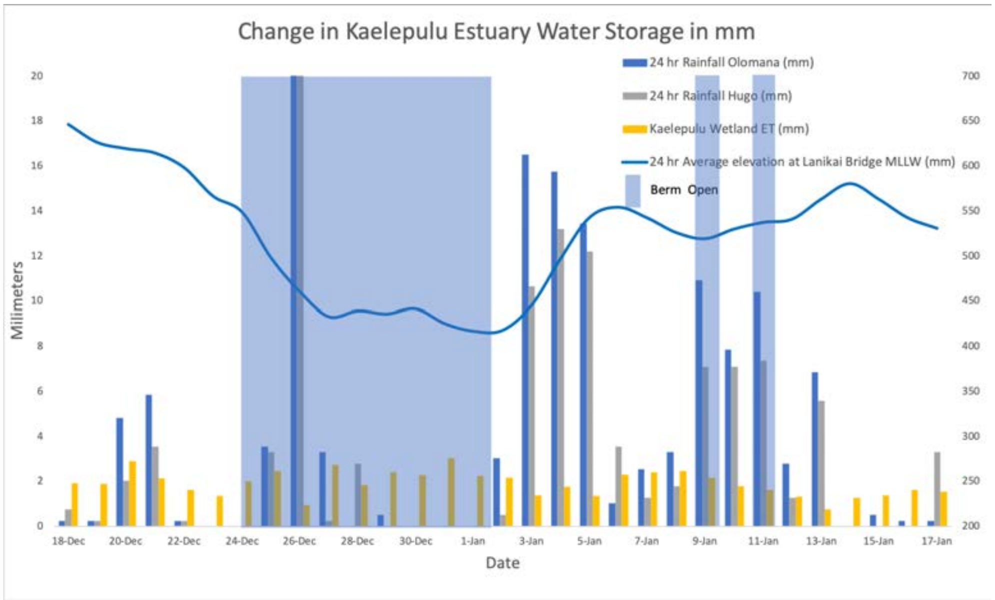


Figure 19: Change in Ka‘elepulu Estuary water storage in mm from 12/17/2019 to 1/18/2020. The blue line is the daily average estuarine elevation in mm related to mean lower low water (MLLW). The orange bars represent loss through evapotranspiration, the gray and dark blue bars are precipitation as measured from Olomana fire station and Ka‘elepulu Wetland gauges. The light blue sections indicate berm open periods.

Table 4: Water budget for Ka‘elepulu Estuary between 12/18/2020 and 1/17/2020 in mm

∆S =	P +	ET+E +	Estuary - Bay Exchange
-24.23 =	163.83	-59.11	-128.96

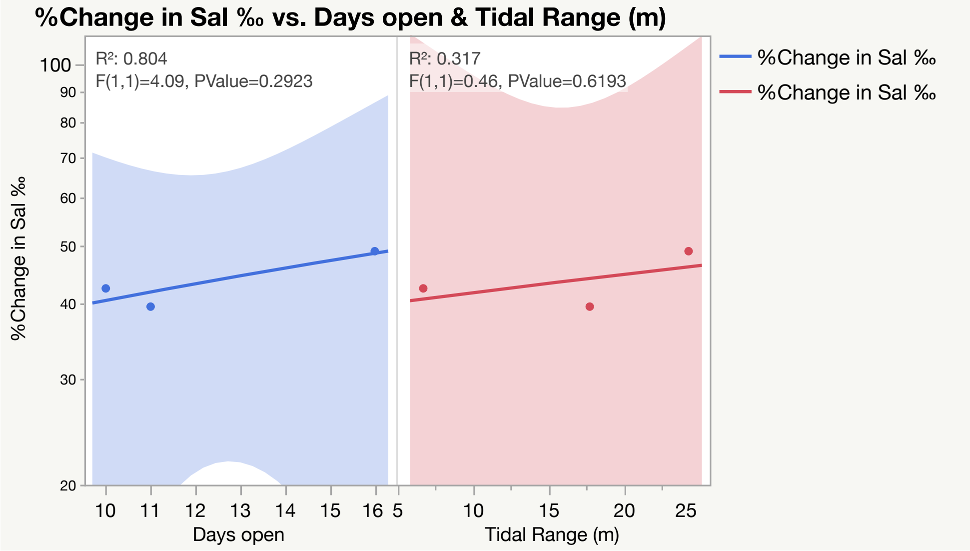


Figure 20: Linear regression looked at the percent change in the average salinity at the stream mouth of estuary (SME) section against days the berm was open and there was oceanic exchange. The right panel compared that salinity percent change against tidal range, values log transformed. While data indicated there might be a relationship, only three exchange events might be inconclusive and warrant further study in subsequent investigations.

Table 5: Educational Outcomes

Objective Performance Measures	Goal	Achieved To-date (1/1/19 – 03/31/20)		Comments
		Number	% of Goal	
# students (grades 6-12) participating	500	517	103 %	The number of students in the classes of the participating teachers.
# and % of student participants who report qualitative gains in their knowledge of earth sciences, community resilience, and environmental education	100 %	83 pre-program surveys complete. Post survey could not be administered.		Participants surveyed to assess growth in knowledge and confidence regarding the science inquiry process, new skills gained re: collecting water samples, analyzing water samples, graphing collected lab and field data.
# and % of student participants who report qualitative gains in favorable attitudes towards and expressed interest in STEM disciplines	100 %	83 pre-program surveys complete. Post survey could not be administered.		Participants surveyed to assess changes in favorable attitudes towards STEM and STEM disciplines through field, lab, classwork and conversation.
# of teachers trained in watershed investigations	10	29	290 %	Teachers have participated in workshops as well as in field trip training.
# and % of teachers who report qualitative gains in knowledge, skills, and abilities	10	21	210 %	Instrument: personal conversation
# of undergraduate and graduate students participating	10	15	150 %	Undergraduate students have been assisted by 6th grade WIRED students in conducting stream surveys
Lessons Bridging in and out of school activities	6	6	100 %	Lessons have been implemented regarding water quality, invasive species control, forestry, and coral reef health.
Inquiry Projects presented	100	48	48%	Because many projects were produced by teams, to date, 85 students have presented projects. COVID-19 is providing a challenge to meet this.
Publications using student gathered data	1	1	100 %	WIRED data and student experiences was used by Dr. Rebecca Prescott at the Astrobiology Science Conference (AbSciCon) 2019

Figure 21: Students using YSI ProDSS to vertically sample Kaʻelepulu Stream at Lanikai Bridge

Figure 22: Students observing wildlife at Kaelepulu Wetland and making connections to water quality

Figure 23: A-ha moment regarding water flow and stream impacts

Figure 24: Students engaged in stewardship alongside DOFAW

Figure 25: Students using LaMotte kits to quantify nutrients in samples at WCC

Figures 26 & 27: Student using confocal microscope at HIMB to assess coral tissue for thickness and chlorophyll concentration

Figure 28: Teachers learing how to engage in third generation DNA sequencing

Figure 29: Teacher from Kailua Inter loads a flow cell for DNA sequencing

Appendix A: Participant Survey

The following items ask you to respond to statements about your knowledge, attitudes, and behavior before involvement in the WIRED Program. (https://goo.gl/forms/H6aQGHXWHVctop2V2)

How many time have you engage in WIRED Program activities ?		**1**	2	3	4	**5+**
Have you ever		**Never**				**Frequently**
1	Talked with friends or family about environmental issues?					
2	Participated in environmental research?					
3	Snorkeled on a coral reef?					
4	Gone hiking?					
5	Gone fishing?					
6	Explored streams?					
7	Explored my watershed (ahupaʻa)?					
8	Engaged in stewardship activities or community workdays?					
9	Used special science equipment (microscope, probes/sensors, etc.)?					
10	Gone birdwatching?					
How comforatable are you with		**Not at all**				**I'm great at this**
1	Identify positive human impacts to my ahupaʻa?					
2	Identify negative human impacts to my ahupuʻa?					
3	Identifying invasive plants?					
4	Identifying native and/or introduced non-invasive plants?					
5	Identifying invasive animals?					
6	Identifying native and/or introduced non-invasive animals?					
7	Describing the place you live in terms of both human and natur					
8	Explaining what an estuary is?					
9	Explaining what a watershed (ahupuaʻa) is?					
10	Participating in field research regarding the watershed (Ahupuaʻa) I live in?					
I agree with the following statements		**Disagree**				**Agree**
1	I think science is intersting.					
2	Indigenous Ecological Knowledge is a form of scie					
3	Scientists have a chance to make a difference in the world.					
4	Scientists spend most of their time working by themselves.					
5	Scientists have other interests, not just science.					
6	There are many careers in science, not just scientists.					
7	The media (TV, Movies, etc.) makes science seem cool.					
8	Scientists have to go to school for many years					

Demographic Information

1 **I am (circle the one that best fits you)**

Middle school student (6th - 8th)

High School Student

Undergraduate

Graduate Student

Community Member

Kūpuna

Other Please write in ______________________

2 **If you are a K-12 student, where do you go to school? And skip to 7.**

____

3 **If you are an undergraduate student, where do you attend? And skip to 7.**

____

4 **If you are a graduate student, where do you attend? And skip to 7.**

____

5 **If you are a community member, where do you call home? And skip to 7.**

____

6 **If you are a Kūpuna, where do you call home?**

____

7 **Ethnically, I identify with (mark all that apply)**

☐ White
☐ Hispanic or Latino
☐ African-American
☐ Asian
☐ Hawaiian
☐ Pacific Islander
☐ Native American
☐ Persian-American
Other:____________

8 **Racially, I am**

☐ White
☐ Hispanic or Latino
☐ African-American
☐ Asian
☐ Hawaiian
☐ Pacific Islander
☐ Native American
☐ Persian-American
Other:____________

9 **I idendify as**

Male		Neutral		Female
☐	☐	☐	☐	☐

UNIVERSITY of HAWAIʻI®
MĀNOA

Office of Research Compliance
Human Studies Program

DATE:	March 04, 2020
TO:	Tsang, Yin, PhD
	Oleson, Kirsten, University of Hawaii at Manoa, Natural Resources and Environmental Management, Esibill, Derek, Master□s Plan C, University of Hawaii at Manoa, Natural Resources and Environmental Management, CTAHR - Hawaii County
FROM:	Rivera, Victoria, Dir, Ofc of Rsch Compliance, Social&Behav Exempt
PROTOCOL TITLE:	Watershed Investigations Research Education and Design
FUNDING SOURCE:	NOAA BWET
PROTOCOL NUMBER:	2020-00029
APPROVAL DATE:	March 20, 2020

NOT HUMAN SUBJECTS RESEARCH DETERMINATION

The above referenced study, and your participation as a principal investigator, was reviewed and determined to be Not Human Subjects Research (NHSR). As such, your activity falls outside the parameters of IRB review. You may conduct your study, without additional obligation to the IRB, as described in your application.

The NHSR Determination is based upon the following Federally provided definitions:

"Research" is defined by these regulations as " a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge."

The regulations define a **"Human Subject"** as "a living individual about whom an investigator (whether professional or student) conducting research obtains data through intervention or interaction with the individual, or identifiable private information."

All Human Subjects Research must be submitted to the IRB. If your study changes in such a way that it becomes Human Subjects Research please contact the Research Compliance office immediately for the appropriate course of action.

Please contact this office if you have any questions or require assistance.

UH Human Studies Program, Office of Research Compliance
Office of the Vice President for Research and Innovation, University of Hawai'i, System
2425 Campus Road, Sinclair 10, Honolulu HI 96822
Phone: 808.956.5007 • Email: uhirb@hawaii.edu
https://www.hawaii.edu/researchcompliance/human-studies
An Equal Opportunity & Affirmative Action Institution

UAS Orthomosaics of Ka‘elepulu Stream mouth

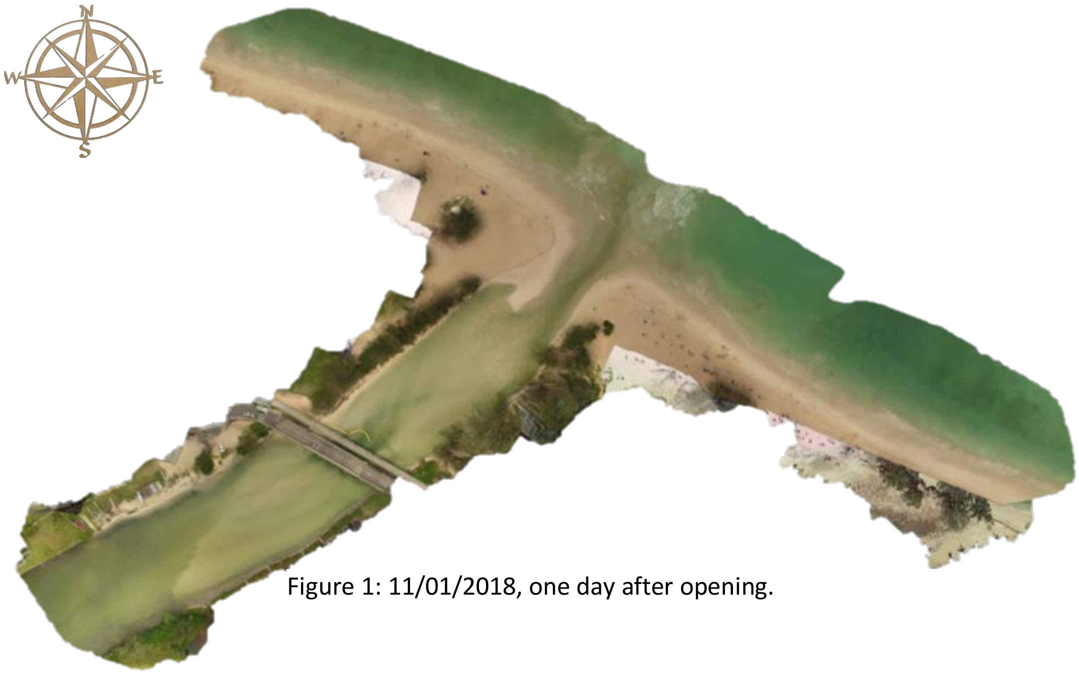


Figure 1: 11/01/2018, one day after opening.

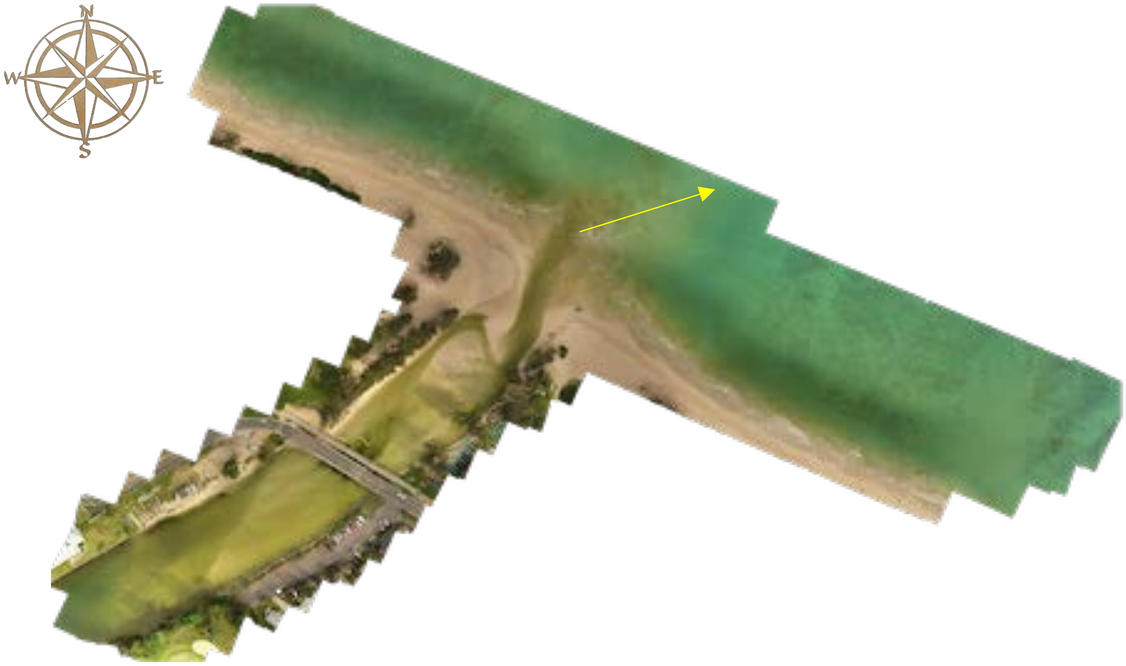


Figure 2: 11/06/2019 7-days after opening. Sediments appear to be transported to the East as indicated by the arrows

Figure 3: 02/19/19, 5 days after berm opening. Striations are bulldozer tracks. Sediment appear to be transported to the Northeast as indicated by the arrow.

Figure 4: 03/15/2020 4 hours after berm opening. Sediments appear to be transported to the Northeast as indicated by the arrow.