DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS, HONOLULU DISTRICT
230 OTAKE STREET, BUILDING 230
FORT SHAFTER, HAWAII 96858-5440

February 13, 2023

Civil Works Branch
Programs and Project Management Division

Office of the Mayor
County of Hawaii
25 Aupuni Street
Hilo, HI 96720

Dear Mayor Roth:

The Honolulu District, U.S. Army Corps of Engineers (USACE) is pleased to transmit to you a final hardcopy of the Hilo Bay Watershed Planning Assistance to States Report dated February 2023. In April 2020, former County of Hawaii Mayor, Harry Kim met with our staff to discuss the County's vision for long term water resource management and economic development within the Hilo Bay Watershed. The Corps and the County entered into a cost-shared partnership agreement on November 2020, under the Planning Assistance to States (PAS) program, as authorized under Section 22 of the Water Resources Development Act of 1974, as amended (42 U.S.C. §1962d-16). Last April we met with you and your staff to present the study findings and recommendations.

This letter transmits the final Hilo Bay Watershed Planning Assistance to States Report. You will also receive an electronic copy of the final PAS report for your use and reference. Please contact me if you would like to schedule a follow-up meeting to further discuss the results of the report and begin discussing USACE ability to assist the County with implementation of the recommendations.

Should you have any questions or comments, please contact my Deputy, Mr. Benjamin E. Reder, at 808-835-4203 or BenjaminE.Reder@usace.army.mil. Thank you for your cooperation.

Sincerely,

Rhiannon Kucharski

Rhiannon L. Kucharski, MPIA, WRCP
Chief, Civil and Public Works Branch

Enclosure

Enclosure

US Army Corps of
Engineers
Honolulu District

County of Hawaii
Planning Department

Hilo Bay Watershed
Planning Assistance to States

February 2023

EXECUTIVE SUMMARY

On April 29, 2020, the Honolulu District, U.S. Army Corps of Engineers' (Corps) Civil and Public Works Branch met with the County of Hawaii (County) Planning Department and, then Mayor, Harry Kim to discuss the County's vision for long term water resource management and economic development within the Hilo Bay Watershed. The Corps and the County entered into a cost-shared partnership agreement on November 6, 2020, under the Planning Assistance to States (PAS) program, as authorized under Section 22 of the Water Resources Development Act of 1974, as amended (42 U.S.C. §1962d-16). Under this agreement, the Corps would provide technical assistance to the County related to the management of water resources in the Hilo Bay watershed.

The objective of this PAS study is to investigate the problem of water quality impairment in Hilo Bay and identify possible solutions. The first phase of the study involved a scientific literature review to establish the state of the current knowledge base and account for efforts that have already been undertaken towards implementing water quality solutions. The second phase of the study formulated specific measures to address the sources of water quality impairment, mitigate their impacts, or to advance the existing knowledge base in areas that are lacking information.

Past studies and discussions with community stakeholders indicate that the pollutants causing water quality impairment in Hilo Bay are primarily terrigenous sediments and nitrogenous compounds, and secondarily, heavy metals such as arsenic that are present, but appear to be neutralized. The main pathways for pollutants entering the bay are via natural surface drainage e.g. Wailuku and Wailoa Rivers and stormwater discharge across land. Due to the coarsely porous basalt landforms surrounding Hilo Watershed, groundwater discharge may also convey pollutants to Hilo bay, to an unknown degree.

High levels of nitrates and phosphates cause eutrophication, making waterways uninhabitable for aquatic flora and fauna. Previous research by the Corps indicates that the Hilo breakwater, designed to protect Hilo Harbor by reducing wave energy, consequently, increases residence time of pollutants in Hilo Bay, further contributing to water quality impairment. It is important to note that studies evaluating potential for modification to the breakwater indicated that the magnitude of effects to water quality from inputs of pollutants is significantly greater than poor circulation. In other words, as a matter of priority, the initial effort should focus on watershed management to reduce the conveyance of pollutants into Hilo Bay, followed by detailed analysis to identify the level of circulation necessary and measures to implement.

The PAS study team identified several measures, both structural and non-structural, both in Hilo Bay and across the entire watershed study area, that could address the County's concern of impaired water quality in Hilo Bay. Structural measures were considered solely based on feasibility of implementation and general effectiveness; no concept design or detailed cost estimates were developed. Non-structural measures include regulatory and policy recommendations, future research recommendations to address critical knowledge gaps, and *in situ* projects such as bioremediation and aquaculture applications. The measures were evaluated to ensure they meet the study

objective and using The Water Resources Council's National Evaluation Criteria: completeness, effectiveness, efficiency, and acceptability (see). In total, four (4) structural and eleven (11) non-structural measures were examined and qualitatively prioritized based on the evaluation criteria. A common goal among stakeholders and reiterated in this report, is the need to address pollutants at their source, as opposed to in the bay.

The recommendations of the study are as follows: address the lack of data and knowledge via non-structural measures by 1) analyzing water quality and sediments accumulated in Hilo Bay to comprehensively identify pollutants of concern and 2) identifying pollutant sources through flood mapping the entire watershed and conducting a shear-stress analysis to identify erosion hot spots. Once this critical information has been collected, a watershed management plan could provide all stakeholders with a roadmap of efforts and avenues of coordination among all concerned parties.

This report is not meant to provide a specific plan or outline projects to address the water quality issues within Hilo Bay, nor is it a comprehensive examination of all potential water quality measures. Rather, it examines the most promising water management measures, with their associated pros and cons, and provides information to be used by federal, state, county, and other stakeholders, in determining the best course of future collaborative action. It also identifies research areas with critical knowledge gaps and addresses how future research can help bridge those gaps.

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Hilo Bay Watershed Planning Assistance to States Report

1. Study Authority

Section 22 of the Water Resources Development Act (WRDA) of 1974, as amended (42 U.S.C. 1962d-16, Public Law 93-251), authorizes the Secretary of the Army to provide technical assistance related to the management of state water resources.

2. Study Purpose

The purpose of this Planning Assistance to States (PAS) study is for the U.S. Army Corps of Engineers (Corps, USACE) to provide technical assistance to, and at the request of, the County of Hawaii (County) Planning Department for the long-term management of water resources development in the vicinity of Hilo Bay, Hilo, Hawaii in accordance with the State of Hawaii Ocean Resource Management Plan published March 2020. This report documents the results of this PAS study.

3. Location of Project

Hilo Bay constitutes the eastern most extent of the town of Hilo, the largest city in the County. This report focuses on the Hilo Bay Watershed, extending from the base of Mauna Kea and Mauna Loa volcanoes (Figure 1). For the purposes of this report, the Hilo Bay watershed study area is comprised of the Wailuku River and Wailoa River watersheds.

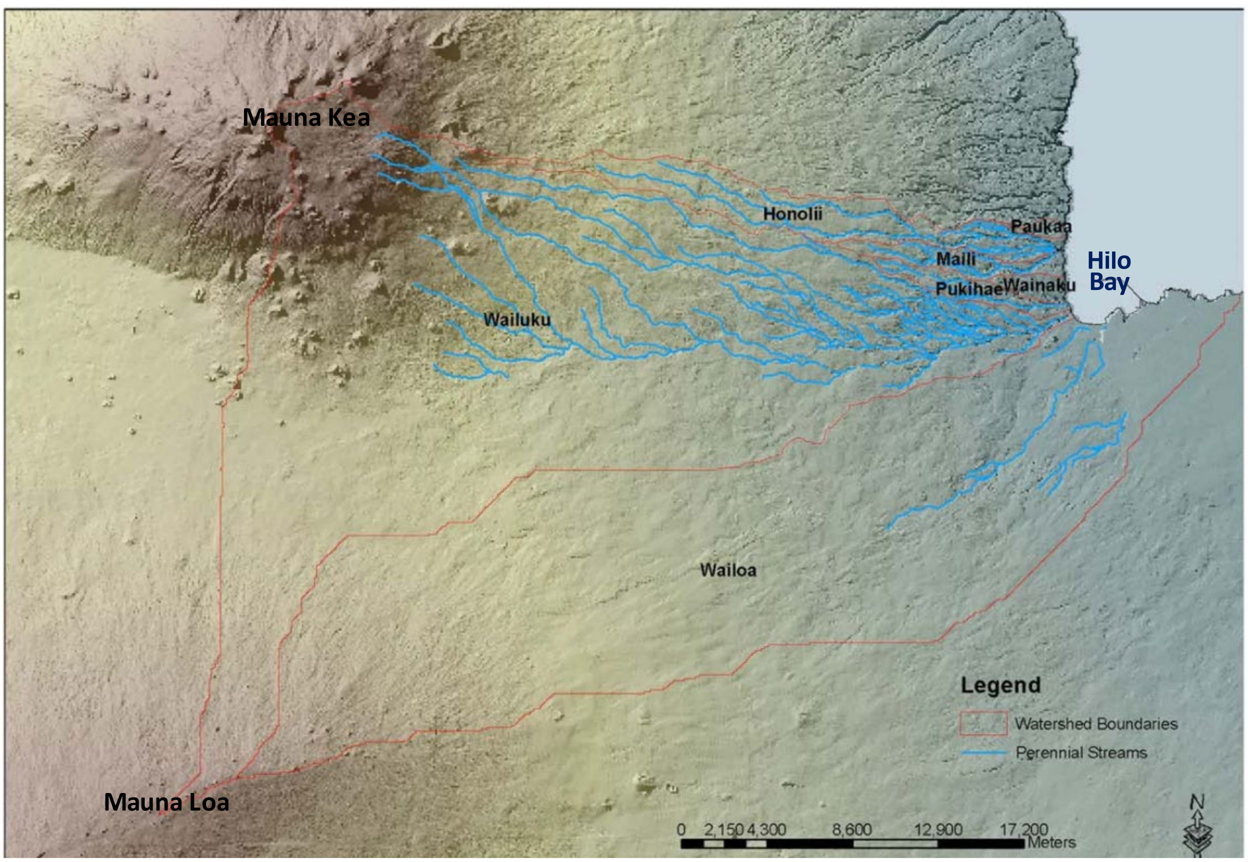

Figure 1 Hilo Bay Watershed (source: Hilo Bay Watershed-Based Restoration Plan, 2005)

The Wailuku River Watershed (Division of Aquatic Resources (DAR) Watershed Code 82060) area is 252.2 square miles, with maximum elevation of 12,779 feet above sea level and featuring the 28.0-mile perennial Wailuku River. To the immediate south, the Wailoa River Watershed (DAR Watershed Code 82061) drains a 98.6 square mile area, with maximum elevation of 9,724 feet above sea level and features 25.2-miles of ephemeral streambed, the Waiakea and Alenaio Streams, which empty into Waiakea Pond. Both the Wailuku River and Wailoa River watersheds terminate in Hilo Bay. These surface waters are tributaries to a navigable water and are waters of the U.S. as regulated under the Clean Water Act.

For the purposes of the study, these watersheds were divided into three segments based on geographic area for implementation: the upper watershed (or whole watershed), the lower watershed, and within Hilo Bay. The division between upper and lower watersheds were made based on elevation profiles of the streams and the proximity to Hilo Town.

4. Prior Studies, Reports, and References

Numerous reports, studies, papers, and articles referencing the study area have been prepared by federal, state and local agencies, as well as other stakeholder groups and academic institutions over the past several decades. The following, selected references served as the basis for preparation of this report. Additional references are provided in the References section of this report. The study team strived to reference the best available scientific information representative of the watershed however, the references are not all-inclusive of all published documents regarding the study area.

In 1963, the public health service conducted a dye tracer study to investigate the flushing and mixing patterns within Hilo Bay (Public Health Service, 1963). The study concluded that the observed diffusion patterns were caused by the littoral currents, the tidal currents, the currents induced by freshwater runoff, and the locally generated wind-driven currents.

In 1973, the Neighbor Island Consultants performed a study collecting data from July 17 to August 21, 1972, which indicated the existence of two cells (Eastern and Western) with different circulation patterns in the surface layers of the bay(Neighbor Island Consultants, 1973). The Eastern cell circulates clockwise with the tide, and the Western cell circulates counterclockwise, mainly from freshwater runoff out of the Wailuku River. The net transport of the entire system is seaward, and the salinity found in the deeper waters indicates replenishment from ocean waters.

In 1980, a study performed by M&E Pacific, Inc. investigated the circulation patterns within Hilo Bay by deploying drogues and current meters (M&E Pacific, Inc. 1980). The drogues were deployed at three depths across three cross sections, and the current meters were placed in two locations to capture the temporal variations in the bottom current. The study found a two-layer salinity stratified circulation pattern caused by the large amounts of freshwater entering the harbor from the groundwater and surface flows. These waters are less dense and float atop the denser seawater, thus forming a well-defined surface layer with little mixing. Also, found was a temporal variation which operates as a function of the rate of surface runoff, where the wet season has a dominant outward flow of fresh water (i.e., the surface layer), and the dry season has a less defined and thinner surface layer with a weak offshore gradient of salinity. Overall, the general circulation pattern is a net water transport out of the bay by the surface layer and a net water transport into the bay by the sub-surface layer.

In 2005, the University of Hawaii (UH) Manoa and the Hilo Bay Watershed Advisory Group (WAG) used U.S. Environmental Protection Agency (USEPA) Section 319 funds to investigate the source of watershed impairment in Hilo Bay and develop a watershed-based restoration plan (Silvius et al. 2005). UH Manoa and Hilo Bay WAG found that there was insufficient data to successfully identify sources of pollution. The report identified key threats to water quality in the watershed including, but not limited to: erosion and urban flooding due to high rainfall; young geology and inappropriate urbanization in flood zones; conservation area flooding and erosion; a lack of appropriate county level regulations especially in grubbing and grading areas; a lack of enforcement for existing state and county regulations; a general lack of awareness among the general public, local and county officials, and the state government regarding the water quality issues and best management practices; the continued impacts of sugar cane industrial agriculture; the impacts of the Hilo breakwater on bay circulation; incomplete wastewater systems; pervasive use of cesspools and lava tube dumping; and invasive plant and animal species. The study also found that land-based sources of pollution and sediments drain into Hilo Bay along multiple paths, including surface water drainage, stormwater runoff, and ground water infiltration. The plan recommended a range of best management practices that included monitoring and data collection efforts necessary to accurately identify and address pollutants throughout the watershed. The plan also recommended USACE investigate potential benefits to water quality from modification of the breakwater in Hilo Bay. This report heavily informed future USACE work as well as this PAS study.

In 2009, USACE conducted the Hilo Bay Water Circulation and Water Quality Study together with the County of Hawaii and UH Hilo Marine Science Dept. As recommended in the 2005 UH Manoa and Hilo Bay WAG study, the County requested USACE provided technical assistance under the PAS program to evaluate the feasibility of modifying the breakwater in order to increase water circulation within the bay. The breakwater was designed to minimize the effects of wave action on navigation within Hilo Bay, especially Hilo Harbor, which resulted in secondary impacts to water circulation and exacerbated already poor water quality conditions. Because the breakwater plays a critical role in protecting the federal navigation channel, the study also examined how any proposed modifications would affect navigation operations and safety. Based on mathematical modeling, little impact to water quality was predicted across the proposed alternatives, while navigational effects ranged from minor to significant in terms of unacceptable increases in wave energy. The study recommended redirecting focus towards stopping conveyance of pollutants into Hilo Bay.

In 2016, USACE conducted a planning study to investigate problems negatively affecting harbor operations, transportation, and commerce, including inadequate turning basin dimensions and high wave energy. The planning study goals were to improve the navigation and operational efficiency of the harbor, improve its safe use, and increase the maximum allowable size for vessels calling at Hilo Harbor. Modeling completed for the study indicated that adding a spur at the end of the existing breakwater would reduce wave energy in the harbor, the turning basin, and the Pier #1 and Pier #2 areas. The spur achieved the greatest reduction in wave energy because of how it was controlling waves coming through the entrance channel. However, due to the high cost of the modifications (approximately $145M in 2014 dollars), the project was determined to be not economically justified.

5. Existing Conditions

Since the late 1970's, Hilo Bay waters have failed to meet state water quality standards, and Hilo Bay was formally designated an impaired waterbody by the USEPA in 1998 (Koch, 2004). Nevertheless, Hilo Bay is an important wildlife and fishery area and contains one of the longest and most-accessible, yet least-used sandy beaches on the Island of Hawaii (Hawaii Island Journal, 2004). In addition to the already low utilization rate of Hilo Bay, only 10% of Hilo Bay beachgoers, swims there (USEPA, 2002), due to the persistent water quality issues and perceptions.

The Hilo Bay watersheds have one of the highest precipitation rates in the Hawaiian Islands, ranging up to 610 centimeters or 240 inches annually in the upper reaches (Juvik & Juvik 1998), which in turn means that the Hilo Bay estuary has more freshwater entering it than any other estuary in the state (Wiegner & Mead 2009). The primary surface water conveyance is the Wailuku River and Waiakea Stream. The Wailuku River is the largest perennial river in the state (with an average daily flow of 1 million cubic meters) and is the largest source of surface waters in the bay. Additionally, the Waiakea Stream is a groundwater-fed, flood-control channel that discharges into Waiakea Pond prior to entering Hilo Bay via the Wailoa River. Waiakea Pond is the single largest source of groundwater that ends up in Hilo Bay (M & E Pacific 1980). It is estimated that 1.8 million cubic meters of groundwater enters the Bay from Waiakea Pond, daily (M & E Pacific 1980). The Wailuku River passes primarily through agricultural land and forest preserves before reaching the bay. The Wailoa River watershed also passes through mostly undeveloped land in the upper reach, but is primarily urbanized in the lower reach.

The distinctly different sources and characteristics of the Waiakea and Wailoa watersheds results in very different contaminant profiles. The Waiakea Stream and Waiakea Pond are polluted with arsenic as a result of dumping of arsenic trioxide into the pond and river by a canec manufacturing plant from 1932 to 1963 (Kelly, Nakamura, and Barrere 1981). Arsenic concentrations in the sediments of Hilo Bay area have been sampled as high as 6,370 ppm, which is approximately 34 times higher than anywhere else in the state (Department of Health 1978) and were recently found to be 138 times higher than the national background level of arsenic in soil (Peard & Brewer, 2019). Nitrate and nitrite levels are also 5 times higher in the Waiakea Stream than in the Wailuku River (Wiegner & Mead 2009). Conversely, soil erosion during storm events can cause high levels of suspended solids in the Wailuku River plume, up to 10 times higher than in the Wailoa plume (Economy & Wiegner 2019). The lower salinity and increased volume of suspended solids from the Wailuku River combine with the nitrogen nutrient load from the Waiakea Stream to provide very hospitable climates for eutrophication following storm events. Chlorophyll hotspots have been observed in the middle of the bay following storm events as well (Badlowski 2021). It can take up to five days for conditions to return to baseline after a storm event (Wiegner & Mead 2009). Recent research efforts from the University of Hawaii have attempted to address the critical lack of knowledge, but results have been slow to develop, as this kind of research can be time- and labor-intensive and funding tends to be on a competitive basis from external sources.

Another reason water quality monitoring and research efforts have faced difficulty is the fact that the primary marker for detecting presence of fecal indicator bacteria (FIB) is *Enterococcus,* which is naturally present in the tropical soils of Hawaii and readily multiplies tropical conditions (Winfield & Groisman 2003). This limits the applicability of water quality research done in other parts of the world to conditions in Hawaii, as high concentrations of *Enterococcus* do not necessarily equate to a human fecal bacteria source. Better and more accurate methods have been developed to address this issue, most notably using a second FIB marker, *C. perfringens* (Fujioka et al. 2015), but many impairments towards a comprehensive understanding of FIB patterns in Hawaii waters remain. FIB levels can significantly vary with time, from seasonally down to hourly, and this variability can lead to large errors (>40%) in beach water condition advisories (Kim & Grant 2004). Advisories that are issued too late pose great risk to community health, and beach closures that are unnecessarily prolonged even after conditions have returned to acceptable water quality standards negatively impact recreation, tourism, and the local economy. Despite the importance of correctly issuing beach advisories, studies on FIB patterns and predictive models have been hindered by the need for time- and labor-intensive sampling methods (Weisz 2014).

While evidence indicates the majority of increases in *Enterococcus* levels during storm events are from soil erosion and not sewage leakage (Wiegner 2013), presence of human fecal bacteria was positively confirmed (Lyon-Colbert 2018). It is unclear whether the source of the confirmed human fecal bacteria is from on-site sewage disposal systems (OSDS) entering the groundwater (which would indicate that the immediate region surrounding Hilo is the primary culprit) or whether it is possibly entering the bay with stormwater runoff (indicating an issue further upstream). In either case, cesspools are a substantial source of sewage pollution, especially in rural areas, and Hawaii uses cesspools more widely than any other state (USEPA 2013). The most recent comprehensive study of the issue found that there are over 58,000 cesspools on Hawaii Island alone, nearly double previous estimates, and the Hilo region is a particularly egregious offender (Whittier & El-Kadi 2014). Although the Hawaii state legislature outlawed new cesspools several years ago and mandated that all cesspools be converted to septic tank systems or better by 2050, there remains widespread acceptance of the practice (Halladay 2003). Conversion may be cost prohibitive for some homeowners. The magnitude of cesspool impacts is still unknown, but it is critically important to determine the extent of the issue, especially in Hilo Bay.

Sewage pollution can directly contribute to coral disease (Vega Thurber et al. 2014; Yoshioka et al. 2016), and *Serratia marcescens* introduced from sewage runoff caused an 85% decline in coral cover in affected areas of the Caribbean Sea (Sutherland & Ritchie 2004). As Hilo Bay is surrounded by the fragile Blonde Reef, negative impacts of wastewater introduction into the bay have the potential to be catastrophic. Elevated nutrients from sewage pollution alter coral growth and calcification rates, species distribution and abundance, and coral community diversity (Pastorok and Bilyard, 1985; Reopanichkul et al., 2009, Prouty et al., 2017), increasing susceptibility and decreasing resilience to global climate change effects such as global warming and ocean acidification.

Finally, an issue that receives heightened public attention with regards to Hilo Bay water quality is the presence of the Hilo breakwater. Construction of the 10,080-foot-long Hilo breakwater was completed in 1930 to protect the Hilo Harbor, attenuating wave energy into the bay. Consequently, the breakwater significantly alters the natural circulation in the bay and dampens the wave energy on its leeward side that would normally prevent fresh and salt water from settling into layers. This lack of mixing allows a freshwater layer to extend several kilometers into the bay (Dudley & Hallacher 1991), which is significant, as low salinity is an important factor correlated with increased FIB growth. However, a recent water quality study conducted on the other side of Hawaii island near another high-risk community, Puako, also showed elevated levels of FIB near the shore (Abaya 2018) despite no breakwater and deeper water near the shore. Additionally, ongoing research at the University of Hawaii – Hilo suggests that FIB may be entering the waters outside of the breakwater near Keaukaha through natural shoreline springs. When coupled with the fact that the exact relationship between circulation and water quality has still not been definitively established (Wiegner & Mead 2009), the available evidence indicates that only removing or otherwise modifying the breakwater to improve circulation will not by itself solve the problem of poor water quality in Hilo Bay stemming from land-based pollutant sources. All in all, the nature and extent of the contamination in Hilo Bay, its sources and impacts, and what can be done to address them are all still poorly understood.

6. Expected Future Conditions

The resident population in Hilo is expected to grow nearly 30% by the year 2040. It is also expected to remain the largest city within the county, as most of the total growth in the county is predicted to be dispersed among many smaller communities. It is also forecast to remain the largest employment center in the county, with roughly one third of all jobs in Hawaii County.

While the population and housing growth is forecast to be modest compared to the rest of the state, any growth at all has the potential to add to current water quality issues unless it is properly managed. Compounding this problem, Hilo’s geographically limited Wastewater Treatment Plant (HWWTP) is also in a state of disrepair and not able to operate at anywhere near its intended design capacity. Local officials say it could cost up to $100 million to bring the HWWTP to a state of good repair and that no other alternative would be available if it failed (Hawaii News Now, 2022). OSDS runoff already contributes heavily to the current water quality issues, and new housing units in the area will likely have OSDS, which are anticipated to have a large impact on future conditions. Without a coordinated and comprehensive mitigation effort, the current water quality issues persisting in Hilo Bay will likely get worse.

7. Problems, Objectives, Opportunities

The study was divided into two phases. Phase I was a literature search to document existing conditions and identify data gaps. Phase I informed Phase II, formulation of measures to address water quality issues in Hilo Bay. The first step in formulating solutions is to identify the problems and opportunities followed by defining the objectives and considerations that will guide solving those problems and achieving those opportunities.

Problems

Based on discussions with the County, water quality impairment in Hilo Bay limits the long-term economic and social development of water resources in and around Hilo, Hawaii. Previous watershed studies have concluded that the landside portion of the Hilo Bay Watershed significantly and negatively affects the water quality in Hilo Bay (Silvius et al 2005; Wiegner et al, 2013). The pollution and contaminants in Hilo Bay are inextricably linked to the two main catchment basins that drain into the bay, the Wailuku and Wailoa River watersheds. Both river watersheds flow into Hilo Bay and are the main conveyances for pollutant transport. While the rivers are the main contributing factors, direct runoff and groundwater were not dismissed as factors to water quality conditions.

While the Hilo breakwater effectively protects maritime navigation and infrastructure of Hilo Harbor through wave attenuation, it also has impacted the natural circulation currents within and out of the bay. Reduced circulation can increase residence time of pollutants in the bay and exacerbate the impaired water quality issues. Impaired water quality and the perception of impaired water quality deters use of Hilo Bay by the local community for recreational and economic purposes.

Opportunities

Addressing the sources of water quality impairment will improve water quality and facilitate long-term development of Hilo Bay for use by the local community. Improving water quality in Hilo Bay would improve community health and well-being as well as ecological benefits of improved marine and riverine habitat throughout the Hilo Bay watershed which could increase opportunity for aquaculture, waterfront commerce recreational and commercial fishing, ocean recreation, including improved water and beach access for local residents and visitors, and lastly improved resilience to climate change and sea level rise.

Objectives

The primary objective of the study is to develop a comprehensive list of both structural and non-structural measures intended to improve water quality in Hilo Bay, contributing to long-term water resource and economic viability of the Hilo Bay Watershed. This study also aims to identify data gaps that prevent successful implementation of any proposed water management measures.

Planning Considerations

There are several factors to consider when developing possible solutions for addressing the issue of water quality in Hilo Bay. Hilo Harbor is the primary commercial port for the County of Hawaii and Hilo Bay is used by both commercial and recreational vessels; any solution must consider the potential adverse impact or obstruction to safe navigation within the bay. Hilo Bay provides shelter to a diverse marine ecosystem; implementation of any measure must consider potential adverse impacts to coral reef and other ecologically sensitive marine resources protected by state and/or federal law. The quiescent Hilo Bay provides safe access to ocean waters; any solution must consider public access to Hilo Bay from the shoreline out to the ocean to maintain cultural use and practice such as fishing, canoeing and surfing. The ocean are shoreline are dynamic environments; any solution must consider potential for adverse impacts to sediment transport including shoreline erosion and accretion, consistent with local policy and regulation e.g., Hawaii's moratorium on new seawalls. Solutions at the watershed scale can be vast and widespread in order to be successful; any solution to improving Hilo Bay water quality must consider construction, implementation, operations and maintenance costs to be supported by the budgets of potential local sponsors, so that selected recommendations can be implemented.

Cultural Considerations

In consideration of the Native Hawaiian culture, USACE approach to watershed studies is consistent with the traditional *ahupuaa* (watershed) concept. *Ahupuaa* was historically integral to Native Hawaiian culture, lifestyle and identity. It remains integral to this day and should inform natural resource management and planning into the future.

The *ahupuaa* extends from mountain to ocean or *mauka* to *makai*. Hawaii's streams and rivers form a lifeline joining the land and sea by an inseparable bond. The complex interconnectivity of *mauka* to *makai* as a single system, an *ahupuaa*, must form the context under which future watershed planning efforts are developed, to be successful. Since the arrival of humans to the Hawaiian Islands, Hawaii's incredibly unique ecosystems have and continue to succumb to the external anthropogenic forces of deforestation, urbanization and other activities that introduce manmade threats to the natural environment (DLNR-DAR, 2020).

The Hawaiian cultural "renaissance" that began in the 1970s and continues today is the impetus for increasing interest in cultural, biocultural and ecological restoration throughout the islands.

> *"The task is ongoing, and the idea arises now that in the next phase of the Hawaiian Renaissance, a goal should be to demonstrate that Hawaiians were, and can again be, masterful ecologists, naturalists, landscape engineers, and resource managers. Surviving an era of conscious suppression, during which both Hawaiian ecosystems and Hawaiian culture were gravely damaged, we enter a phase of rebuilding, recovery, and reestablishment of the relationships that originally resulted in a*

millennium of sustainable co-existence of people and nature" (Gon, et. al.,2019).

Globally, Hawaiian practices and values centered in sustainability are being praised and even considered to give insight to how large populations can survive harmoniously in their environment.

These practices are firmly rooted in the traditional Native Hawaiian concept of *malama aina*, literally, care for the land, which establishes a stewardship and wields a relationship between humans and the land where humans are the caretakers of the land, which sustains human life. This innate and inherent responsibility creates the foundation for ancient Hawaiian land management. As stated in Senator Kenneth Brown's speech on the Senate Floor of the Hawaii State Capitol,

"All of man's acts in Hawaii must be dominated by the spirit of "Malama". The Pukui-Elbert Hawaiian Dictionary defines "Malama" thus: "To take care of, care for, preserve; to keep or observe, as a taboo; to conduct, as a service; to serve, honor, as God; care, preservation, support; fidelity, loyalty; custodian, caretaker." Because he knows so many ways to destroy his natural environment, Man must now become its custodian and caretaker for his own sake. He must exercise malama, because if he starts selling parts of his natural environment abroad for creature comforts, he will lose it all, and be unable to survive here. If he uses up his landscapes, mountains, valley and vistas, or if he degrades his air and waters, he will destroy the beauty and hence the spirit of Hawai`i, and in so doing, his own spirit. Malama is thus an imperative. It is applicable to our entire lives in Hawaii." (Brown, 1973).

8. Stakeholders

The study team coordinated throughout the study, from its inception to development and execution of the study scope, with the County. At key points throughout the study, the study team sought input from key local stakeholders, as described below.

Agency Stakeholders

County of Hawaii

The County Planning Department provided primary input on the scope and direction of the study, confirming the results of the Phase I effort and informing development of solutions in the Phase II effort. The problems and opportunities identified in Section 7, above align with the County's desire to improve water quality of Hilo Bay to improve long-term water resource management and development of the Hilo Bay watershed.

USACE also met with the County Parks Department to better understand recreational considerations in Hilo Bay. According to the Parks Department, recreational use of Hilo Bay includes, but is not limited to, canoe paddling, kayaking, stand up paddle boarding, swimming, commercial and recreational fishing and sailing. However, public use of Hilo Bay is reduced due to the perception of impaired water quality ranging from murky water, sand fleas and oil/petroleum sheen. The County also highlighted the need to investigate local dredged material management to ensure open access to clean sandy beaches bordering Hilo Bay.

State of Hawaii, Department of Transportation, Harbors Division

The Department of Transportation as represented by the Harbors Division (DOT Harbors) served as a key stakeholder in the investigation of water circulation in the bay. Any investigations involving the breakwater and especially modifications to the breakwater, are coordinated with and at the request of DOT Harbors, to ensure safe and continued navigation in Hilo Bay.

Community Stakeholders

Waiwai Ola Waterkeepers Hawaiian Islands

The Waterkeeper Alliance is a global movement to protect water resources, currently uniting more than 350 Waterkeeper Organizations in 47 countries worldwide. Waiwai Ola Waterkeepers Hawaiian Islands is a local nonprofit organization, with three individual Waterkeeper chapters: Kona Coast, Oahu, and Hilo Bay. Conversations with Waterkeepers Hawaii were very useful in understanding existing water quality improvement efforts and how those efforts could be accelerated with support from governmental organizations and USACE. In particular, Waterkeepers Hawaii was a significant resource for information on bioremediation current efforts and future possibilities. Waterkeepers Hawaii emphasized the need to better understand sources of land-based pollutants and reducing or eliminating such sources to prevent water quality impairment; any solutions in Hilo Bay are viewed as “Band-Aid fixes” that treat the symptoms and not the source.

University of Hawaii - Hilo

In-depth discussions were held with UH faculty who are involved with previous and ongoing water quality research. In particular, conversations with Dr. Wiegner regarding her work on pollution conveyance factors in the Hilo watershed were especially informative. Dr. Wiegner was able to show that the Wailuku River is the largest source of sediment and nitrogen pollution in the bay. However, Dr. Wiegner stressed that she was unable to ascertain the specific sources of these pollutants and that more work would need to be done to address the knowledge gap.

Additional conversations with Dr. Colbert regarding heavy metal pollutants within the sediment layer at the bottom of Hilo Bay were also helpful in addressing associated water management measures. Dr. Colbert pointed out that poor data quality and data collection issues in the Hilo Bay region could seriously affect the effectiveness of potential study alternatives, as sources of serious contamination could go unaddressed. Dr. Colbert recommended a comprehensive water quality analysis in Hilo Bay with an emphasis on identifying and evaluating impacts of contaminated sediments on water quality.

Finally, Dr. Haws provided her expertise in regard to bioremediation and aquaculture alternatives and potential issues surrounding their implementation. Dr. Haws recommended flood mapping of the Hilo Watershed to better understand stormwater and sheetflow inputs of pollutants into Hilo Bay.

9. Management Measures

Upon identification of the study problems, objectives, opportunities, and considerations in Section 7 above and with input from the stakeholders identified in Section 8, above, USACE formulated potential management measures that would address the identified problems and meet the study objectives. Common structural and nonstructural water quality control measures along with potential environmental impacts and concerns related to their implementation are discussed below. Although development of concept-level designs and quantitative cost estimates for these items were beyond the scope of this study, parametric design, construction, and maintenance costs are qualitatively described below based on existing information. For ease of comparison, these measures have been divided into their main geographic area of impact and proposed area for implementation.

Measures Proposed for Implementation in the Upper Watershed or Across the Whole Watershed

This group includes 5 recommendations. While none of these items will directly improve the water quality within Hilo Bay, they will all have significant secondary effects and will provide vital information for any future decision-making or project justifications. Because of their relatively low costs and the importance of the information they will provide, these projects are all recommended to be prioritized.

Flood Mapping

The Hilo Bay Watershed encompasses an area of about 470 square miles and is the largest in the state. The watershed includes the Town of Hilo, which is the county seat. Much of the area surrounding Hilo has already been mapped as part of FEMA's Flood Insurance Program, but the remainder of the watershed has not. The figure below shows some of the floodplain areas in Hilo (Figure 2). FEMA studies typically map only the 1% and 0.2% Annual Exceedance Probability flood events. While large in magnitude, these events occur infrequently. This flood mapping recommendation would focus primarily on those events that occur more frequently, such as the 4%, 10%, 20%, and 50% AEP events. These more common events are generally not as damaging to structures, but they contribute more to soil erosion and transport from the watershed into Hilo Bay because of their frequency. Identifying areas at risk from these events would identify and help to prioritize areas for further study. If flood prone areas across the watershed are not identified, there is a risk of missing areas that are susceptible to the erosion that contributes to pollution to Hilo Bay, which would affect the goals of the current study.

The effort will require Hydrologic and Hydraulic modeling to properly identify the areas of concern. The budget estimate for flood mapping ranges from $50,000 to $200,000, depending on the availability of data and the amount of modeling required. The existing FEMA floodplains could serve as a foundation, but FEMA funding for mapping is beyond the control of the study team, so alternative funding sources should be examined.

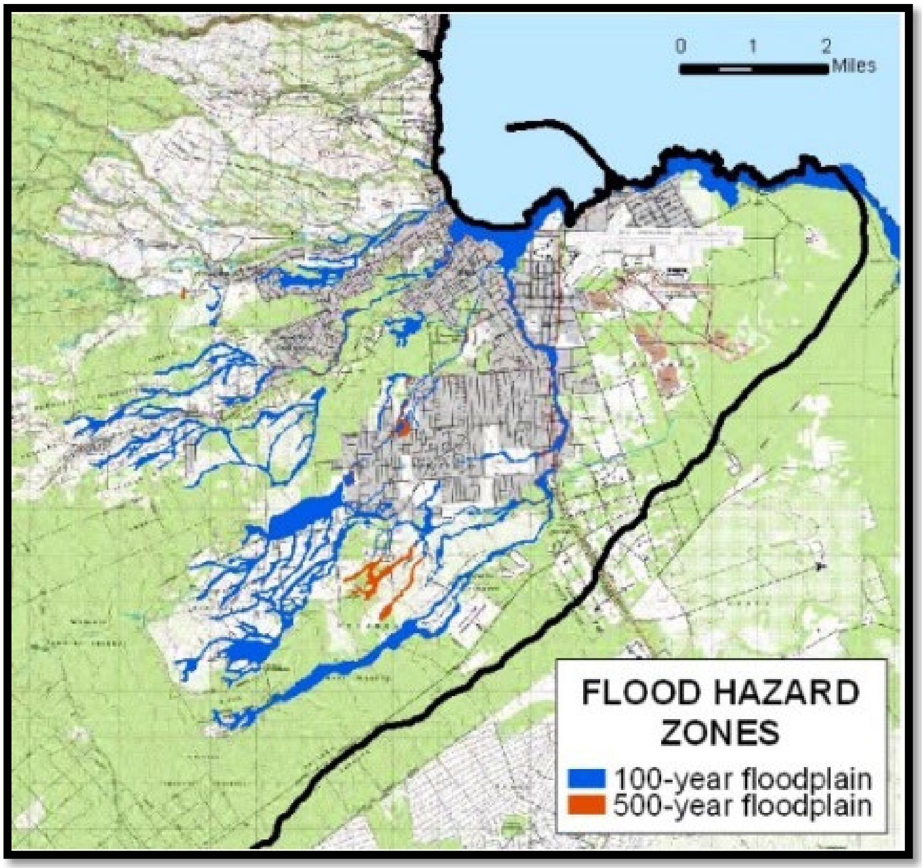

Figure 2 FEMA Flood hazard zones in the Hilo Bay Watershed

Watershed Management Plan

Section 729 of WRDA 1986 authorizes USACE to develop watershed plans that are multi-purpose and multi-objective in scope in cooperation with federal, state, and local government entities. The study team recommends the county or state pursue an investigation of water resources development in the Hilo Watershed and address water quality improvement beyond the scope of this effort and at the watershed level.

Under a Watershed Management Study, USACE would collaborate with the local sponsor, stakeholders, the public, and other federal and local resource agencies to identify a shared vision, identify problems and objectives in order to identify strategies, recommendations, and priorities for implementation at the watershed level. The study effort should leverage the whole of government including USACE, USEPA, Department of the Interior, U.S. Department of Agriculture, Department of Commerce, State Department of Land and Natural Resources, State Department of Health, State Office of Planning, the Commission on Water Resource Management and other collaborating agencies' technical expertise to build upon the foundations established in this report. In addition, the watershed management plan could identify potential funding sources and partnership opportunities to achieve the plan goals.

The watershed management plan for Hilo watershed would also provide the basis for additional spinoff studies, projects, and initiatives to improve the ecology, economy, and overall health of the watershed for the Hilo community. The cost to develop the study is relatively low as it does not result in construction projects. Historically, Honolulu District executed these studies in 24 months at a cost of ~$3M, cost shared 50% federal and 50% non-federal.

Shear Stress Analysis and Erosion Study

Sediment erosion from the watershed makes its way into the stream corridor and is transported downstream, where it is eventually deposited in Hilo Bay. These sediment particles often carry pesticides, herbicides, and other chemicals as well as organic matter that are also then transported into the bay. This sediment increases turbidity in the water column, the chemicals adversely affect the water quality, and the organic matter can lower dissolved oxygen for aquatic species, making the water uninhabitable. This recommendation proposes an analysis on the erodibility of the soil structure in the watershed to identify those areas most subject to erosion and develop methods to reduce or eliminate the problems identified. Figure 3 below shows the general erodibility factor of the soil groups in the Hilo Bay watershed (USDA SSURGO Database).

The analysis would determine a more specific erosivity of the soil by comparing such factors as land use, land slope, and agricultural practices to determine the amount of sediment detached from the landscape. Identifying these areas would be the important first step in developing methods to reduce the sediment load into Hilo Bay. Without identifying and reducing the amount of sediment entering the bay, improving the water quality of Hilo Bay will remain a difficult task.

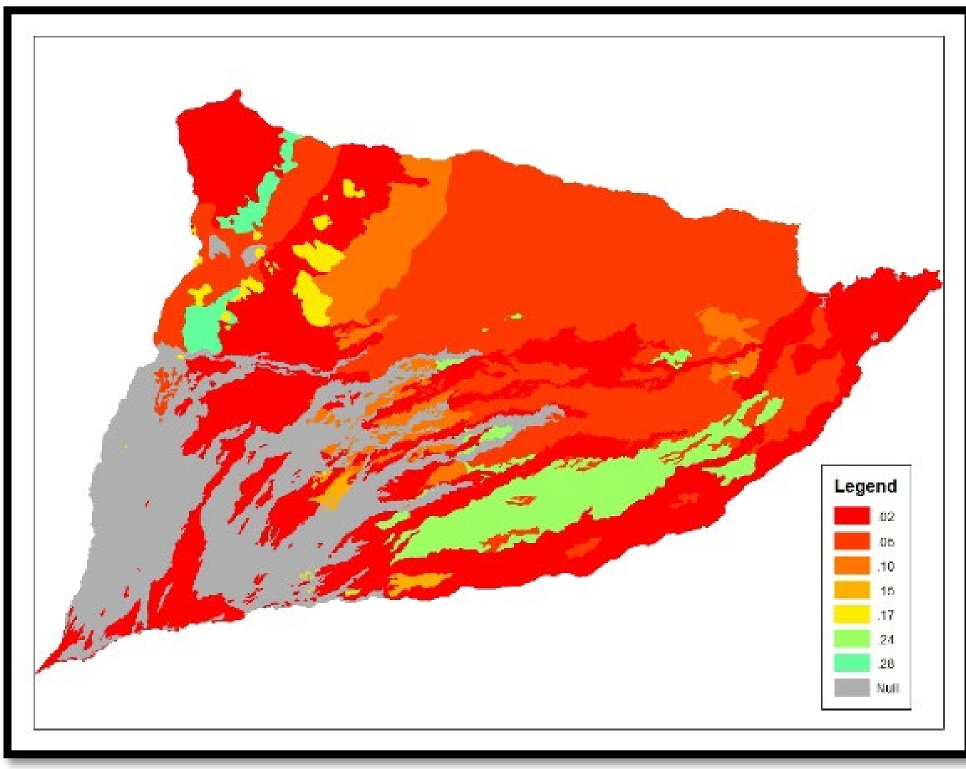

Figure 3 Erodibility factor of the soil groups in the Hilo Bay watershed (USDA, SSURGO)

Modeling of the watershed erosion would identify and quantify the amount of sediment entering the streams, and determine where, when, and how sediments are transported to the ocean. During both processes, measures to reduce the sediment load will be examined. This type of modeling effort ranges in cost from $500,000 to $1 million.

In 2007, the "Pelekane Bay Watershed Sediment Runoff Analysis" study was published (USACE, 2007). This study estimated sediment yield, characterized sediment deposits, and defined critical watershed issues. While not located within the Hilo Bay watershed, this study provides an example of the type of analysis that can be conducted to identify the impacts of land-based pollutants to Hilo Bay.

<u>Local Wastewater Management Plan</u>

The island of Hawaii has more than 58,000 private wastewater systems, in various states of repair (Whittier & El-Kadi 2014). The location of such systems within the Hilo Bay watershed is shown in Figure 4 (Hawaii GIS Portal). There have been numerous studies and research addressing the problem of wastewater intrusion into Hilo Bay. In 2014, the Hawaii State Legislature compiled a report acknowledging the problem these systems pose to nearshore water quality and the health of sensitive coral reefs. This report led to an initial state-wide moratorium on new cesspool constructions and eventually to a 2017 mandate that all cesspools in the State of Hawaii be converted to approved septic tank systems or better by the year 2050.

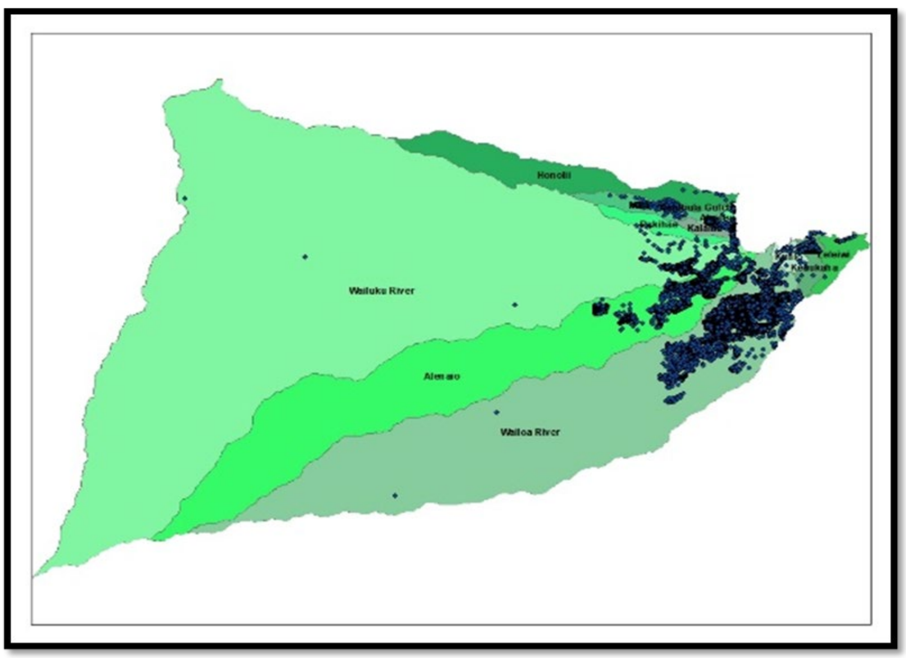

Figure 4 Known locations of private wastewater (Hawaii GIS Portal)

However, the State of Hawaii Department of Health estimates that as many as 50% of all private wastewater systems are unregistered or otherwise illegal, making evaluation of compliance with the 2050 mandate a difficult task (Figure 4). This recommendation proposes to build upon past efforts by the legislature and researchers by developing a comprehensive wastewater management plan to mitigate the adverse effects of the private systems and aid the state in managing the conversion.

Initial efforts by local stakeholders have already begun to identify and prioritize sources of wastewater discharge from these systems. The wastewater management plan would continue the process of source identification, identify current practices that are outdated, develop methodologies for mitigation, and identify sources of funding for implementation of mitigation efforts. The long term goal of the plan would be to reduce or eliminate the discharge of untreated wastewater into Hilo Bay.

This proposal would leverage the support of local government and previous work by local stakeholders to develop a single comprehensive management plan to be used as a blueprint for the remediation effort. In the 2017 report, the initial cost for remediation was estimated at almost $1 billion. This blueprint will also provide targeted prioritization lists to ensure that limited funding can be directed to the highest impact areas first. There is significant work being done by the State of Hawaii as part of the Act 125 and Act 132 programs. Depending on the outcomes of these programs, if a holistic report needs to be developed, it is estimated at $3-$4 Million to develop a complete Wastewater Management Plan. The cost and scope will be refined based on coordination with state and county partners.

Public Outreach/Education

Educating and sharing information with the public is a cost-effective way of engaging and empowering the Hilo community to participate in planning and implementation efforts. Rather than waiting for policy changes that force a beneficial action, successful outreach can lead to immediate implementation and immediate benefit to the watershed. A watershed study in Minnesota concluded that public availability of outreach and education materials would result in community readily engaging in recreational opportunities because of the connection they feel with their local environment. By identifying with the watershed's historic, ecological, and personal significance, people will begin to value this resource and create a culture of water quality stewardship (Ayers Looby, 2014).

From a Native Hawaiian cultural perspective, the importance of understanding watershed dynamics is based not only in scientific and ecological fact, but also serves as the foundation for the Native Hawaiian value of *malama aina*. Production of education and outreach material available to the public centered around *malama aina* could increase community cultural connection to the Hilo Bay watershed and thereby help the community to identify with the cultural significance of improving water quality throughout the watershed. Promoting and establishing a cultural connection between the Hilo community and the Hilo watershed would restore practicing of Hawaiian values centered around environmental stewardship.

Measures Proposed for Implementation in the Lower Watershed

There are two alternatives in the lower watershed, a circulation pump and ecosystem restoration, both in Waiakea Pond, the largest groundwater contributor to Hilo Bay. These alternatives can moderately improve the water quality within the bay, as the Waiakea Stream is the origin of the most nitrate and nitrite contamination in the Bay and empties into Waiakea Pond before discharging into Hilo Bay. Given these projects are likely to be relatively expensive and would require additional upstream measures to reduce nitrate and nitrite levels entering the pond, they are ranked lower in the prioritization list.

Waiakea Pond Circulation Pump System

The Waiakea Pond is a large, estuarine inland waterbody that conveys flows from the Waiakea Stream into Hilo Bay (Figure 5). Due to its surface connection, a major source of pollution into Hilo Bay is outflow of the poor-quality waters from Waiakea Pond (HDOH, 1978; Hallacher et al., 1985; and HDOH, 2005). By improving the water quality within Waiakea Pond, improvements could also be made to the water quality within the bay.

Figure 5 Waiakea Public Fishing Area (green polygon) within Waiakea Pond via DLNR Division of Aquatic Resources

A water pump system designed to pull water from the pond and into the bay would help facilitate recirculation of the pond water and accelerate the flushing of pollutants. Improvements to the water quality within the pond would be expected soon after construction of the water pump system, likely to consist of a pipe extending into the bay that connects to an intake box and pump. The study team notes that a pump system would facilitate conveyance of pollutants from inland waters to the ocean for circulation to the open ocean where pollutant concentrations would be diluted. Improving circulation and flow out of Waiakea Pond would decrease residence time within the pond and facilitate improved water quality. While this measure potentially improves water quality in Waiakea Pond and Stream, it, in essence, transfers the problem downstream to Hilo Bay. Overtime, the output from Waiakea Pond is expected to be of better quality than the status quo.

The construction of the pump system is estimated to cost more than $50 million and would involve moderate effort. The prospective placement of the pump system would be in Waiakea Stream near where the pond meets the harbor. Modeling and other evaluation efforts would be needed to determine the size of the pump needed, as well as the exchange rate and timing with the harbor's tidal levels to help facilitate the exchange of water. Consideration would need to be given to the maintenance and repair requirements of a pump system, as it would likely be prone to biofouling and clogging due to vegetation and debris in the water. An environmental assessment is also recommended to ensure that the introduction of the water pump system has less than significant environmental impact. Because of the costs and efforts involved in constructing such a pump system, prioritization of this alternative would require strong support from local sponsors and communities to be successful.

Waiakea Pond Ecosystem Restoration

The University of Hawaii at Hilo report titled *Water Quality in Hilo Bay, Hawaii, USA, Under Baseflow and Storm Conditions* (Wiegner & Mead, 2009) concluded that of the common pollutants measured in their study, nitrates have the greatest negative impact on Hilo Bay water quality. The highest nitrate concentrations in the Hilo Bay system were measured in the Waiakea Stream and its discharge plume. Arsenic contamination of the pond sediment has also been studied since the 1960s, although a recent bioaccessibility study (Peard & Brewer 2019) concluded that the arsenic is tightly bound to iron in the sediment and does not appear to be entering the food chain.
Waiakea Pond, Waiakea Stream's 25-acre estuary, may be a strategic location to intercept nitrate pollution before it enters Hilo Bay. Restoration, such as wetland and/or estuarine restoration could be designed in a way that maximizes its retention and uptake of nitrates, while increasing its ecological productivity (USEPA 2000). However, comprehensive testing of the estuary sediment may be needed to evaluate whether other contaminants exist that may limit the restoration of Waiakea Pond and determine what native plants and other organisms may be best suited for the restoration project. This measure may possibly require structural elements once the goals and objectives of the restoration effort are further defined and a plan for restoration is formulated.

Successful ecosystem restoration within Waiakea Pond would directly improve water quality factors, both within Waiakea Pond and in Hilo Bay. Ecosystem restoration would provide opportunity to improve fishing and other recreational uses of Waiakea Pond. Restoration of traditional Hawaiian *loi* or taro fields is also a prospective opportunity to perpetuate cultural practices and encourage community engagement.

Addressing and mitigating sources of pollution in the watershed before it is conveyed to Hilo Bay is an effective measure to improving Hilo Bay water quality. Depending upon the scale of the ecosystem restoration efforts, construction costs could range from $5 million to $50 million or higher. This recommendation is anticipated to be environmentally and publicly acceptable, and funding may be available from state agencies with involvement by local non-profit, community or Native Hawaiian organizations. Further analysis of the feasibility of ecosystem restoration is necessary to identify type of ecosystem to restore and restoration goals with adaptive monitoring and management to ensure success.

Under the authority provided by Section 206 of WRDA 1996, the Corps may plan, design and build projects to restore aquatic ecosystems for fish and wildlife. Pursuant to Section 206, USACE provides the first $100,000 of study costs and a non-federal sponsor contributes 50 percent of the cost of the feasibility study after the first $100,000 of expenditures, 35 percent of the cost of design and construction, and 100 percent of the cost of operation and maintenance. Projects must be in the public interest and cost effective and are limited to $10 million in Federal cost.

Measures Proposed for Implementation in Hilo Bay

There are eight alternatives proposed to be sited within Hilo Bay waters: bioremediation via a living-agent aquaculture project, a comprehensive sediment analysis, a comprehensive water quality analysis, dredging of contaminated sediments, development of a local dredged material management plan, modification of the breakwater for better exchange, creation of breakwater gaps, and a breakwater circulation pump system. Similar to the full watershed analyses, the two bay-specific analyses will not improve water quality by themselves, however, they will provide critical information for future decision-making and as such are recommended to be prioritized. The aquaculture project would improve water quality within Hilo Bay, but due to the likely high cost to maintain the project, potential for legal issues and need to combine with other measures that reduce pollutant inputs to optimize its success, aquaculture is graded as only a tentative option. The three structural alternatives would provide the most to control and improve the water quality within Hilo Bay, but they are likely to be very expensive to construct and maintain, which will place strain on county resources. They are also not likely to be received well by the local community and may cause different environmental issues themselves. As such, the structural measures are not recommended for prioritization at this time.

Bioremediation

Bioremediation is broadly defined as the use of living agents to return a contaminated environment back to its original or uncontaminated condition (Li, 2009). Among other agents, oysters and some seaweed species have been documented for their superior ability to improve water quality and clarity by removing pollutants from the water column. Depending on the species and size, oysters can filter up to 50 gallons of water per day, removing sediment, bacteria, heavy metals, polychlorinated biphenyl, oil/petroleum/hydrocarbons, microplastics, and nutrients from the water column (Waterkeepers, 2021). Oysters also remove carbon from the water column to build their shells. Similarly, seaweed can act as a biofilter by removing carbon, nitrogen, and phosphorus during its photosynthesis process, with some performance variability based on species and age of the plant (Roleda and Hurd 2019; Chung, et. al., 2002).

The use of oysters for improved water quality has been widely implemented across the east and southeast coasts of the United States, most notably by the Billion Oyster Project in New York Harbor (Janis, et al. 2016). This project replanted 6.7 billion oysters on 2,200 acres to reduce storm surge impacts, increase biodiversity, improve water quality, and create educational opportunities.

Inspired by the Billion Oyster Project and the results of a 2017 feasibility study from the Department of Land and Natural Resources, Division of Aquatic Resources, Pacific Oysters have been used by various groups, notably, Waiwai Ola Waterkeepers

Figure 6 Oyster Cage placed at Sand Island (Honore, 2019)

Hawaiian Islands, to improve water clarity and quality throughout the State of Hawaii, including Hilo Bay. On Oahu, Oahu Waterkeeper has deployed oyster remediation projects at Joint Base Pearl Harbor-Hickam, Marine Corps Base Hawaii in Kaneohe Bay, the Hawaii Yacht Club and the Waikiki Yacht Club in Ala Wai Harbor, and Honolulu Community College's Marine Education & Training Center near the Honolulu Harbor (Figure 6). To date, the projects currently implemented in Hawaii have successfully demonstrated the use of oysters as a water quality remediation tool (Thompson, 2019). However, there are many aspects that are still being studied, such as the most successful method for implementation, as well as understanding the long-term impacts and improvements caused by the oysters. In a conversation with the Waterkeepers of Hawaii, it was estimated that roughly 2,000 native oysters were successfully planted in Hilo Bay.

The use of seaweed as a biofilter has shown similar promise to oysters, but it is still being investigated. Particularly, a better understanding of species-specific performance characteristics is needed in order to properly include seaweed as a part of an integrated bioremediated system. Currently in Hawaii, research is being conducted on *limu kohu* and other native seaweed species, which will provide insight on using these culturally significant and ecologically optimal seaweed species for bioremediation within Hawaiian waters (McDermid, Martin, Haws 2019).

This alternative will greatly accelerate the ongoing bioremediation efforts in Hilo Bay, including increasing the number of oysters and seaweed plantings, and additional investigation on the performance of the various living agents, with the goal of developing an integrated strategy for larger scale implementation. For example, a 2017 study in Pearl Harbor outplanted 500 oysters contained within 14 cages in shallow waters for about 100 days at a cost of approximately $100,000. Defining water quality improvement goals for Hilo Bay and referencing oyster's ability to filter as many as 50 gallons of ocean water daily, filtering microalgae and phytoplankton out of the water column, a study can be scaled to meet improvement goals.

It is important to note, as Waiwai Ola has clarified, that bioremediation measures in Hilo Bay may provide some resolution, but will not solve all the water quality concerns in the watershed (Thompson, 2019). Reducing land-based pollution input into Hilo Bay is paramount to the success of any bioremediation effort in Hilo Bay. Although oysters and seaweed may become part of an eventual comprehensive watershed management plan for reducing contaminants within Hilo Bay, they are not recommended for highest priority at this time.

Water Quality Analysis

A comprehensive analysis of water quality throughout Hilo Bay will increase the knowledge base upon which measures for remediation are recommended. This information would guide prioritization for addressing the sources of the most harmful or largest volume of pollutants and ensure that the greatest impact is achieved given available funding.

The first step of this analysis would be to coordinate with local education institutions, non-profit organizations, and state and local stakeholders to summarize current water quality study efforts and identify current knowledge gaps to be addressed. Water quality monitoring by the State of Hawaii Department of Health is limited. Deficiencies in existing water quality analyses identified by USACE in Phase I of this study include short duration of monitoring, discrete survey locations spatially across the bay and throughout the water column, and limited chemical and biological analysis over a limited temporal scale.

The proposed water quality analysis would be a long-term effort with a broad array of survey stations both spatially across the bay and watershed and stratified throughout the water column and comprehensively analyzed for full contaminant characterization in order to provide a more robust understanding of water quality concerns within the bay. The results of the analysis would inform next steps for strategic implementation of measures both landside and within the bay to address watershed scale water quality issues.

While the State Department of Health regularly monitors state waters, it is limited in the breadth of analysis in any one location and relies upon community groups to supplement water quality monitoring efforts throughout the State. For example, Hui O Ka Wai Ola is a volunteer-based organization in partnership with Maui Nui Marine Resource Council, The Nature Conservancy, and the West Maui Ridge to Reef Initiative that optimizes the collective efforts of community volunteers from diverse backgrounds to conduct long-term water quality monitoring in West Maui. A similar approach involving community members, researchers, and other volunteers could help to maximize the robustness and success of any implemented comprehensive water quality monitoring survey.

This alternative will not directly improve water quality within Hilo Bay on its own. However, the data generated from this effort are critical in prioritizing future water quality management efforts. Depending upon the scope and scale of the comprehensive water quality monitoring effort, implementation budget for this effort is less than $5 million, and is recommended for prioritization.

Sediment Analysis/Identify Contaminated Sediments

Certain sea and wind conditions may stir up bottom sediments in Hilo Bay and resuspend them and any bound contaminants into the water column (Colbert, 2021). While USACE sampled sediment within the Federal shipping channel of Hilo Harbor at the east side of Hilo Bay in 2014 (Tetra Tech, 2014), little or no sediment chemistry data exists for the rest of Hilo Bay, especially within the discharge fans of the Wailuku and Waiakea Streams. Investigation into the physical and chemical composition of seafloor sediments within Hilo Bay may provide insight into sources of water quality impairment and thus, potential solutions.

This measure proposes a bay-wide bathymetric survey, sub-bottom profile survey, and a sediment analysis to identify shoaling and obtain better understanding of the type, placement, and stratification of sediments and any potential contamination. Local hydrology experts have suggested this analysis could be coupled with a stratified, comprehensive water quality monitoring program to gather enough data to understand whether or not the suspension of contaminated benthic material is cause for concern in Hilo Bay. As these types of programs tend to be labor and time intensive, their inclusion will be heavily dependent upon availability of funding, but should be considered, if feasible.

A complete examination of the sedimentary deposits will also address any potential pollutants within Hilo Bay that have not already been assessed, such as toxic chemicals, decaying organic matter, or fine sedimentation (which remains suspended for longer and requires different management solutions). Knowledge of all potential pollutants within Hilo Bay will be important to ensure that any proposed water quality remediation efforts will be successful. While this alternative will not directly impact water quality in the bay, it will provide critical information for guiding future efforts. Coupled with the water quality analyses, this alternative will provide a comprehensive snapshot of the current state of water contamination issues that need to be addressed within Hilo Bay.

Local Dredged Material Management Plan

The purpose of a dredged material management plan (DMMP) is to ensure that dredging and management of dredged material is conducted in an environmentally acceptable manner. This measure was recommended by the County of Hawaii Department of Parks as a result of observed dredged material handling on the beach at Hilo Bay that was perceived by residents as a source of water quality impairment and a deterrent for recreational use of the shoreline (COH, 2021). A DMMP would investigate various disposal options e.g., ocean disposal, upland disposal, beneficial reuse, etc. and define appropriate dredged material handling and disposal for local dredging efforts. A DMMP is typically completed in two phases: a preliminary assessment and a full DMMP study. The preliminary assessment lays the foundation of the full plan and aids in identifying any knowledge gaps. A preliminary assessment can cost roughly $20,000 or more while the full DMMP study can cost roughly $150,000 or more, depending on the level of investigation required. Under the Planning Assistance to States Program, the Corps could cost share development of the DMMP for the responsible party.

To create a DMMP, an investigation into the dredge history of the area would be completed to understand accumulation rates and dredging frequency, dredge volumes, and dredging costs. By evaluating the historic dredging events and any related survey data, shoaling rates can be calculated, and future dredging requirements can be projected. Other investigations needed to produce a DMMP include identifying the sediment pathways, characterizing the grain size of the sediment, and identifying the presence of any chemicals of concern or hard substrates such as limestone pavement and coral in the area. If contaminants are discovered, it will restrict disposal options. Disposal options for a DMMP typically include renourishment, stockpiling, landfill, or an Ocean Dredged Material Disposal Site (ODMDS).

Generally, the State of Hawaii is very interested in obtaining sand for beach nourishment as sand is a limited resource on the islands and relatively expensive given its scarcity. Hawaii's beach nourishment projects have been relatively small volumes when compared to mainland projects and incurred a higher cubic yard cost (Welp and Maglio, 2014). The State of Hawaii only permits sand with 0 to 5 percent fines to be placed on the beach, and due to the HDOH requirement of "no return water", it is very difficult and expensive to find and place acceptable sand (Welp and Maglio, 2014). No nearshore placement sites exist in or near Hilo Bay, so the disposal options would require a pump ashore option from the dredge (Welp and Maglio, 2014). However, Hilo Harbor and adjacent lands have limited open areas available for a sediment re-handling facility or stockpiling areas. Other potential beneficial reuse opportunities for the dredged material include landfill cover, use at quarry sites, and mixture of dredged material with green waste to make topsoil as part of the county's green waste recycling program (Welp and Maglio, 2014). Salinity content in ocean dredged material limits beneficial reuse options

Once the disposal options have been determined, an economic assessment would need to be completed to compare the rough order of magnitude costs of each disposal option. An investigation of environmental compliance requirements necessary for each disposal option to ensure no adverse effects on the surrounding ecosystems and water quality during both dredging and disposal would be required, as well as ensuring no degradation of the deep ocean environment if an ODMDS is used. After all options have been assessed for both economic feasibility and environmental compliance recommendations for dredge material placement can be determined.

While a DMMP would not directly affect water quality in Hilo Bay, it would instead support future remediation efforts, especially if the Sediment Analysis alternative shows unacceptably high levels of contaminants. While a DMMP is not recommended for prioritization at this time, it would be critical for the success of remediation dredging efforts, should local sponsors choose to pursue that route.

Breakwater Modification: Seawater Exchange System

The construction of the Hilo breakwater eliminated the breaking wave energy and open water transport across the reef, which reduced the exchange rate within the harbor, thus contributing to the decrease in water quality within the bay (M & E Pacific, 1980). A seawater exchange system (SES) could be utilized to improve water quality within Hilo Bay, without affecting the integrity of the breakwater.

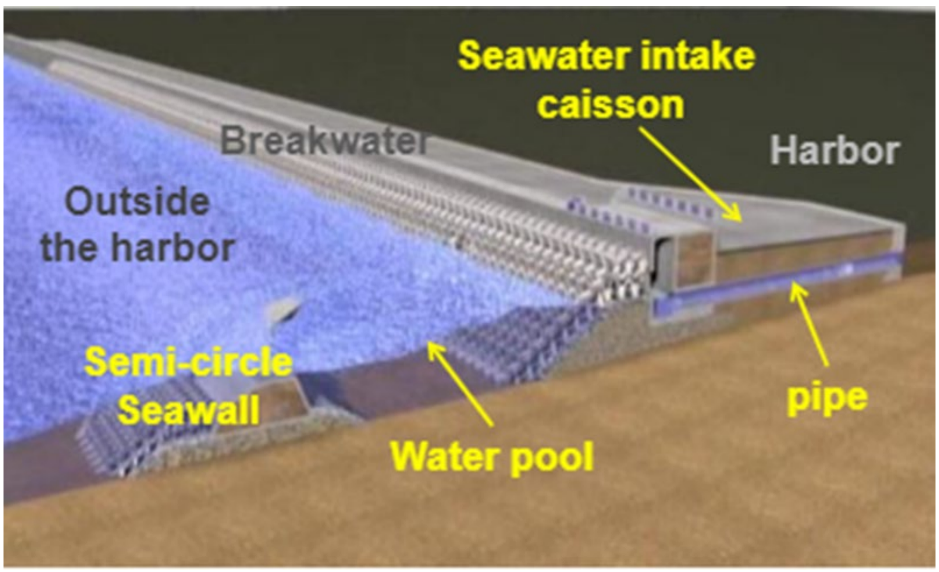

Figure 7 Depiction of the SES at Jumunjin Harbor (Oh et al. 2010)

An example of such a system was implemented in Jumunjin Harbor, South Korea (Oh, et al., 2010, Figure 7). Before the SES was constructed, Jumunjin harbor had poor water quality caused by reduced circulation and pollution inputs which far exceed the natural purification capabilities of the harbor. The SES was established to accelerate the seawater circulation within the harbor and thus improve the overall water quality. The Jumunjin Harbor SES was composed of three seawater intake caissons and a detached semi-circle seawall exterior to the pre-existing breakwater, shown in Figure 6. The SES functions by maintaining a mean seawater level within the water pool slightly higher than that inside the harbor, creating a unidirectional flow of water into the harbor. The system induces currents into the harbor which improves the water quality. Improvements would likely be observed soon after installation.

In Hilo Bay, the construction of the SES would require a large-scale effort at a high cost (>$50 million). Annual inspections and performance of any necessary repairs would be required after construction of the SES. Placement of the SES would likely be along the trunk of the breakwater away from Pier 1 to provide the most exchange of water within the bay. However, placement alternatives would need to be investigated to ensure a maximum exchange of water, while still maintaining stability of the breakwater and the SES.

To modify the existing breakwater with the addition of an SES, a Section 408 approval from the USACE would be required pursuant to Section 14 of the Rivers and Harbors Act of 1899 (33 USC 408) and prior to modifying a Corps project. Additionally, federal and state permits would need to be acquired; and an investigation into the environmental and navigation impacts would also be necessary. Computer modeling of the effects on circulation due to the construction of the SES would be advised as well as examining any other environmental impacts the SES might cause, such as increased salinity in the harbor and the effects of higher volumes of polluted water flowing onto the adjacent Blonde Reef. Potential funding sources for the implementation of an SES would likely be from the State of Hawaii. Federal funding may be available through USACE under Section 1135 of WRDA 1986. Under this authority, USACE may plan, design and build modifications to existing USACE projects, or areas degraded by USACE projects, to restore aquatic habitats for fish and wildlife..

Breakwater Modification: Breakwater Gaps

Alternatives 3 and 5 from the 2009 Hilo Bay Water Circulation and Water Quality Study were determined to be the most viable of the five alternatives proposed in the study (Figure 8; USACE, 2009). However, the wave transformation modeling completed for the study indicated that while it would improve water quality, it would also increase wave energy within the harbor after implementation. Alternative 3 consisted of six detached breakwater segments on the harborside of the existing breakwater, with offset segmented breakwaters constructed to reduce direct wave transmission into the bay. Alternative 5 consisted of notching the existing breakwater to provide a gap in the structure's root with an additional 500-foot offset breakwater constructed on the oceanside to provide wave attenuation.

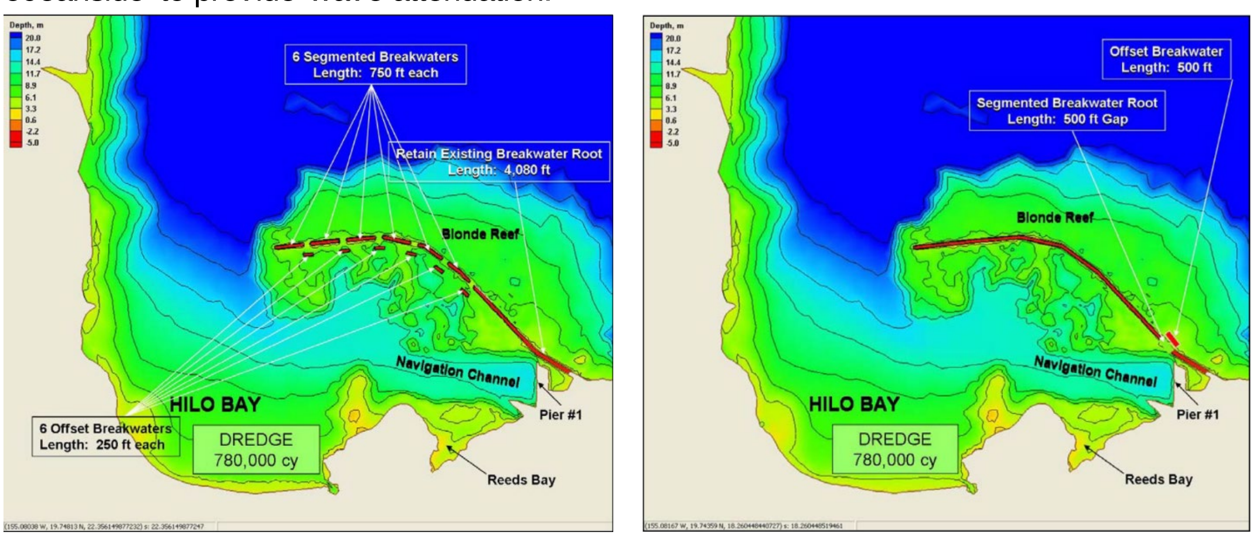

Figure 8 Hilo Breakwater Modification Alternatives from USACE 2009 Hilo Bay Water circulation and Water Quality Study. Alternative 3 (left) and Alternative 5 (right) layout. (USACE, 2009)

The construction of either alternative would be a large-scale effort with a high cost (>$50 million) and would require similar permits to the proposed SES before making changes to the existing federal structure. Introduction of gaps into the breakwater will likely increase maintenance and inspection requirements, as the large flows which can develop within the gaps can affect the long term stability of the structure. These alternatives would need to be evaluated by a coastal engineer to assess the impact of increased wave energy and currents within the harbor. Additionally, impacts to sediment transport rates and patterns can be expected, so a thorough review of existing sediment studies and an evaluation of the predicted impacts along the shoreline due to the increased wave height, current speed, and water levels would be imperative.

Considerations that would be necessary for implementation of either alternative include mitigation actions to prevent economic impacts on navigation due to the increased wave energy and currents. A thorough evaluation of the effects these alternatives would have on the marine environment is also required by federal and local law. Potential funding sources for implementing these alternatives would likely be from the State of Hawaii or the County of Hawaii.

Hilo Bay Circulation Pump System

Circulation pump systems can improve water quality by drawing in higher quality ocean water into the bay, promoting increased circulation within the bay and flushing pollutants. Pump systems generally are composed of a pipe which extends into the ocean and connects an intake box with a motor and pump. This draws the ocean water into the harbor, which then circulates out through existing channels. An example of such a system was implemented in Destin, Florida’s small boat harbor (Figure 9; Destin, 2019). The semi-enclosed harbor experienced nitrogen and phosphorus loading which, during warm temperatures, caused algal blooms, fish kills, cloudy water, and other negative impacts. Upon completion of the pump system, the water quality in the harbor quickly improved.

The construction of a circulation pump in Hilo Bay would be a large-scale effort with a high cost (>$50 million) and would require similar permits to the proposed SES. Annual inspections and performance of routine maintenance and necessary repairs would be required for the lifetime of the system. An investigation would also be necessary to determine feasibility, as given the size of Hilo Bay, multiple pumps could be necessary to produce enough flushing to improve water quality. However, placement options for multiple pump stations would be limited by the need for power and the necessary ease of access due to the frequent maintenance and repairs that a pump system would require.

This recommendation would also require investigation into the navigational impacts from the changes in currents within the harbor induced by the pump systems, as well as identifying if there will be any environmental impacts from the additional saltwater inflow into the harbor. Potential funding sources for the implementation of a circulation pump system would likely be from the State of Hawaii.

Figure 9 Destin Harbor Pump System with concrete enclosure, Florida (getthecoast.com)

Dredge Contaminated Sediments from Hilo Bay

Discussions with various marine biologists in the state indicated that sediment within Hilo Bay may be a sink of accumulated contaminants, providing a persistent source of pollution for the bay, suspended by ocean circulation, wave energy and tidal cycles. As the energy of certain wave, current, and tidal events increase, so does the number of sedimentary layers that are disturbed on the seafloor, compared with normal conditions. High energy events can potentially resuspend contaminated sediments that are deeper in the sediment layers because of this additional power.

Local disturbance patterns of contaminated and potentially contaminated sediments and their resulting impacts on water quality have not been specifically monitored in past, and the presence and extent of any contaminated sediments in Hilo Bay is currently unknown. If certain contaminated sediments are present, their removal would improve water quality within the harbor, while other uncontaminated sediments can be left undisturbed. While chemical and biological laboratory tests of previously dredged sediments from within the Hilo Harbor federal navigation channel indicated that the material was suitable for ocean disposal (not necessarily nearshore beneficial reuse), in coordination with the U.S Environmental Protection Agency and pursuant to Section 102 and 103 of the Marine Protection, Research and Sanctuaries Act (Tetra Tech, 2015), sediments from elsewhere in the bay were not tested and may contain unacceptable levels of contamination.

As stated previously, certain contaminants, such as iron-bound arsenic, should generally be left undisturbed, as they can enter the water supply and cause environmental complications (Stevens Institute of Technology, 2020). Previous studies have indicated elevated levels of inorganic arsenic in the watersheds emptying into Hilo Bay, especially waters coming from Waiakea Pond, but the most recent studies have shown that arsenic levels in plants and animals in the Bay are similar to the rest of the state (Peard & Brewer 2019). It is unclear how dredging contaminated sediments in Waiakea Pond and Hilo Bay would affect the overall local environmental conditions, and because of this concern, this alternative would require that the sedimentary analysis and dredged material management plan be completed in order to determine if such an action is necessary, possible, and feasible. Once a sediment sampling and analysis plan is developed and coordinated with USEPA and the State Department of Health, and sediments suitable for removal are confirmed to be in the bay, further investigation and planning efforts would be needed to determine dredging means and method, any hazardous dredged material handling requirements, and a suitable location for dredged material disposal. Standard environmental evaluations of the impact of dredging on the marine environment, in accordance with federal and local law, would also be required.

The pre-dredge survey work to define the project scope is estimated to cost $2 million. Given the size of Hilo Bay, dredging of the contaminated areas within the bay would be a mid to large-scale effort with a cost of upwards of $17 million. Because the dredging effort would be for remediation, it would not entail the routine maintenance dredging as required by navigational projects. The need for future dredging of contaminated sediments would be on an as-needed basis, and is not anticipated to be necessary at this time. Potential funding sources for this effort would likely be from the State of Hawaii or the County of Hawaii. Because of the dependency on uncompleted studies and analytical work, this alternative is not recommended for prioritization at this time.

Eliminated Measures

USACE proposed the following management measures (Table 1) which, based on internal discussion and discussion with the stakeholders, were eliminated from further consideration. These alternatives were not eliminated based on qualitative factors such as cost or effectiveness, but rather for issues like redundancy or being fully subsumed by another alternative.

Table 1 Eliminated Measures

Eliminated Measure	Rationale
Water Quality Assessment of Waiakea Pond	Incorporated into Ecosystem Restoration of Waiakea Pond alternative
Several wastewater tracking studies	Included in the Wastewater Management Plan alternative
Artificial Reefs	Subsumed into Bioremediation alternative
Wastewater Infrastructure Improvements	Has already been mandated by State of Hawaii, acceleration of the process would require additional study first (Wastewater Management Plan alternative)

Evaluation of Measures

As depicted in Table 2, USACE evaluated each measure qualitatively for completeness, effectiveness, efficiency and acceptability based on best professional judgement within the context of the information gathered for this study and incorporating stakeholder input on this study. The results are described in the preceding descriptions of each measure and summarized in graphic format in the table below. Measures that rank positively per evaluation criteria are color coded green, yellow for neutral and red for negative ranking

Table 2 Qualitative Evaluation of Management Measures

Proposed Management Measure Evaluation																
	Area for Implementation:	Upper/Whole Watershed					Lower Watershed		In Hilo Bay							
	Structural (S) or Non-Structural (N):	N	N	N	N	N	N	S	N	N	N	S	S	S	N	N
Evaluation Factor:	**Alternative:**	Flood Mapping	Watershed Management	Shear Stress Analysis of Stream Corridors	Local Wastewater Management Plan	Public Outreach/ Education	Waiakea Pond Ecosystem Restoration	Waiakea Pond Pump System	Bioremediation (Living Agent Aquaculture)	Sediment Analysis/ Identify Contaminated Sediments	Water Quality Analysis	Seawater Exchange System (Modify Breakwater)	Circulation Pump System	Breakwater Gaps	Dredge Contaminated Sediments from Hilo Bay	Local Dredged Material Mangement Plan
Completeness	Does the measure rely on other factors to directly improve water quality in Hilo Bay? (Red) Yes; (Yellow) Maybe; (Green) No	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	Red	Red	Green	Green	Green	Yellow	Red
Effectiveness	Degree to which water quality in Hilo Bay is improved: (Red) Little to no effect; (Yellow) Minimal to Moderate effect; (Green) Substantial effect	Yellow	Red	Red	Yellow	Red	Yellow	Yellow	Yellow	Red	Red	Green	Green	Green	Red	Red
Effectiveness	Secondary Benefits: (Red) no secondary benefit; (Yellow) 1-3 secondary benefits; (Green) 3+ secondary benefits	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Yellow	Yellow
Efficiency	Cost to construct: (Red) $50+ million; (Yellow) $5-$50 million; (Green) $0-$5 million	Yellow	Green	Yellow	Yellow	Yellow	Red	Red	Yellow	Yellow	Yellow	Red	Red	Red	Red	Green
Efficiency	Operation & Maintenance Cost: (Red) High O&M; (Yellow) Moderate O&M; (Green) Little to no O&M	Green	Green	Green	Green	Green	Red	Red	Red	Green	Green	Red	Red	Red	Green	Green
Acceptability	Environmental Acceptability: (Red) Significant adverse effect; (Yellow) Minimal adverse effect; (Green) No adverse effect/Beneficial	Green	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Green
Acceptability	Other Social Effects (OSE): (Red) Significant adverse effect; (Yellow) Minimal adverse effect; (Green) No adverse effect/Beneficial	Green	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Yellow	Yellow	Red	Yellow	Green
Acceptability	Legal: (Red) Potential significant legal/policy action; (Yellow) Potential minimal legal/policy action; (Green) No legal/policy action	Green	Green	Green	Green	Green	Green	Yellow	Red	Green	Green	Yellow	Red	Yellow	Green	Green

10. USACE Recommendation for Implementation

In discussing this study with various stakeholders, two key themes were repeated. The first was that the best long-term solution for improving water quality in Hilo Bay is to keep contaminants out of bay waters altogether, by dealing with any pollution sources at their origin. The second was that there is a lack of quality data on those point sources of pollution in the watershed, an incomplete understanding of what pollutants are already in bay waters, and many ways in which this missing information could cause unintended spillover effects when implementing potential mitigation efforts. For this reason, the study team's first recommendation is to address the lack of data and knowledge through implementation of the following measures:

1) Conduct comprehensive water quality and sediment layer analyses in Hilo Bay to provide an informed description of the magnitude of the problem and ensure that implementation efforts address all sources of pollution.
2) Identify sediment pollution sources and high priority upstream mitigation efforts via flood mapping the entire watershed and conducting a shear stress analysis of streams, valleys and gulches.
3) Develop a watershed management plan that provides all stakeholders with a roadmap of prioritized strategies, policies (new policies, or revisions to existing policies), programs for local or state agencies and multi-agency partnerships, or federal and non-federal programs or projects (subject to specific authorities, analysis, or decision making processes) including those eligible for USACE federal funding or other federal, state or local funding opportunities.

There are various ways that the Corps can provide further assistance to the State and County of Hawaii in addressing the above recommendations. Section 729 of WRDA 1986, as amended, and other specifically authorized watershed authorities allow USACE to study the water resources needs of river basins and regions of the United States. Section 22 of WRDA 1974 (PL 93-251), as amended, gives USACE authority to provide states, local governments, and some non-Federal entities and Native American Indian tribes assistance in the preparation of comprehensive plans for the development, utilization, and conservation of water and related land resources. This program can encompass many types of studies dealing with water resources issues, including most relevantly: water quality, environmental conservation, wetlands ecosystem restoration, flood damage reduction, coastal zone protection, and harbor planning.

Watershed planning goes beyond project-specific planning towards more comprehensive and strategic evaluations and analyses that include diverse political, geographic, physical, institutional, technical, and stakeholder considerations. Watershed planning addresses identified water resources needs from any source, regardless of agency responsibilities, and provides a shared vision of a desired end state, which in this case is a clean and usable Hilo Bay. Ultimately, watershed studies will inform multiple audiences and decision makers at all levels of government and provide a strategic roadmap to inform future investment decisions by multiple agencies.

This report is not a comprehensive examination of all potential water quality measures, nor does it encompass the exhaustive planning necessary to specify alternatives for implementation. Rather, it is an enumeration of potential measures, along with pros and cons, to be used by federal, state, county, and other stakeholders in determining the best course of action to collectively address the water quality issues in Hilo Bay.

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