PUAKŌ

Monitoring Plan for Assessing Impacts of Wastewater Treatment Upgrade Project

measuring the success of wastewater upgrades

October 31, 2016

Table of Contents

Updated: *September 2017*

Puakō Wastewater Upgrade Monitoring Plan Quick Reference Summary

CORAL REEF ALLIANCE

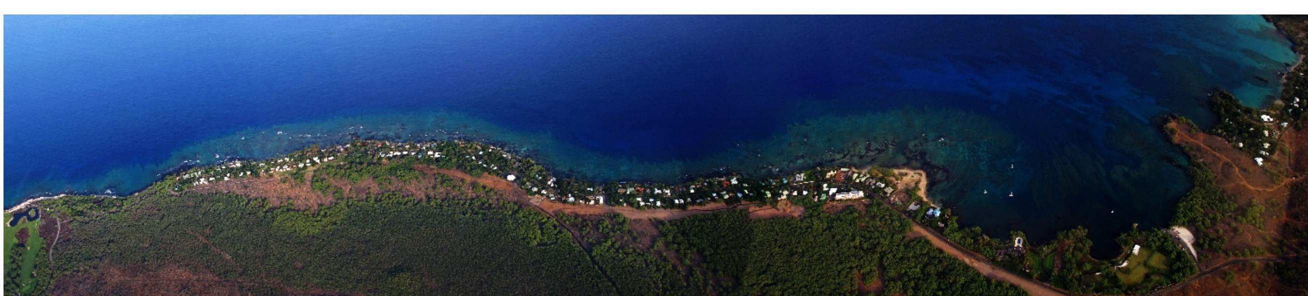
The Coral Reef Alliance is an international non-profit organization that unites communities to save coral reefs

11 informed planners with connections to Puakō through fishing, business, governance, research, management, and education participated in a 3-day workshop at the NELHA Gateway Center to evaluate measures for wastewater upgrades.

How will we measure success?

- **Clean Water**
- **Pono Practice**
- **Coral Health**
- **Human Health**
- **Community Pride**
- **Property Value**
- **Knowledge & Awareness**

Puakō's coral reef is a cultural treasure that has sustained this coastal community for hundreds of years. Independent scientists have confirmed that wastewater is present at Puakō's shoreline where it impacts coral health and may contribute to bacterial infection. Efforts are underway to reduce sewage in Puakō waters.



Contact: More information at coral.org/puako/
Erica Perez at cwfrpuako@coral.org

Acronyms and Abbreviations

ATU – Aerobic Treatment Unit
CI – Conservation International
CFU - Colony-forming unit (CFU)
CORAL – Coral Reef Alliance
DAR – Division of Aquatic Resources
USEPA – United States Environmental Protection Agency
GF/F – Glass fiber filter, 0.7 µm
gpd – Gallons per day – unit of flow
HDOH – Hawaii Department of Health
HIHWNMS – Hawaiian Islands Humpback Whale National Marine Sanctuary
HIMB – Hawaiʻi Institute of Marine Biology
IDEXX – Manufacturer of analyzer for *Enterococcus* spp quantification.
IRMS – Isotope Ratio Mass Spectrometer
MRSA - Methicillin-resistant *Staphylococcus aureus*
msw – meters of seawater – unit of depth
µM – micro mols
NOAA – National Oceanic and Atmospheric Administration
PacIOOS – Pacific Islands Ocean Observing System
PCA – Puakō Community Association
PI – Principal Investigator
ppm – parts per million
ppt – parts per thousand
PR – public relations
SKCP – South Kohala Coastal Partnership
Staph - *Staphylococcus*
TKC – The Kohala Center
TN – Total Nitrogen
TNC – The Nature Conservancy
TP – Total Phosphorous
UH – University of Hawaiʻi at Manoa
UHH – University of Hawaiʻi at Hilo
USCRTF – United States Coral Reef Task Force
USGS – United States Geological Survey
USD – United States Dollar(s) ($)
WWTP – Wastewater Treatment Plant

Acknowledgements

CORAL would like to acknowledge the generosity of the participants of the workshop who gave their time to develop this plan and reviewed several versions of this document. We would also like to thank Chad Wiggins for his assistance in leading the facilitation of the planning workshop and for developing this plan. We would also like to acknowledge the generous funding from the National Fish and Wildlife Foundation, The Atherton Family Foundation and The Keith Campbell Foundation for their generous support of this project.

Context

Located within Lalamilo, South Kohala, Hawai‘i, is the village of Puakō. Lalamilo ahupua‘a runs from the agricultural lands of Waimea, down gulches carved by now ephemeral streams, through ancient Mauna Kea lava flows before reaching Puakō's village atop Mauna Loa's 1,500-3,000 year old Pu‘u Hinai flow.

> **Puakō's prayer…**
> "O Kū‘ula,
> Keep me safe from harm from the sea…,
> O Hina,
> Keep me safe from harm from the land…"[1]

Puakō likely derives its name from a Hawaiian woman who made her home there long ago. Many stories and legends have been told about the piety, skillful exploits, and adventures of Puakō and her husband, a skillful and intrepid fisherman, that illustrate the lifestyle of residents here prior to European contact.[1] By some accounts, the fisherman is known as Lalamilo, the counterpart of Puakō, who extends himself to care for her, just as Lalamilo ahupua‘a, after progressing down slope in a consistent manner, notably extends along the coast to include Puakō within. There is much wisdom in these stories that depict the native peoples of Puakō as independent and skilled at fishing. Ancient Puakō is known as a place of marine abundance, especially for he'e, or octopus.[2]

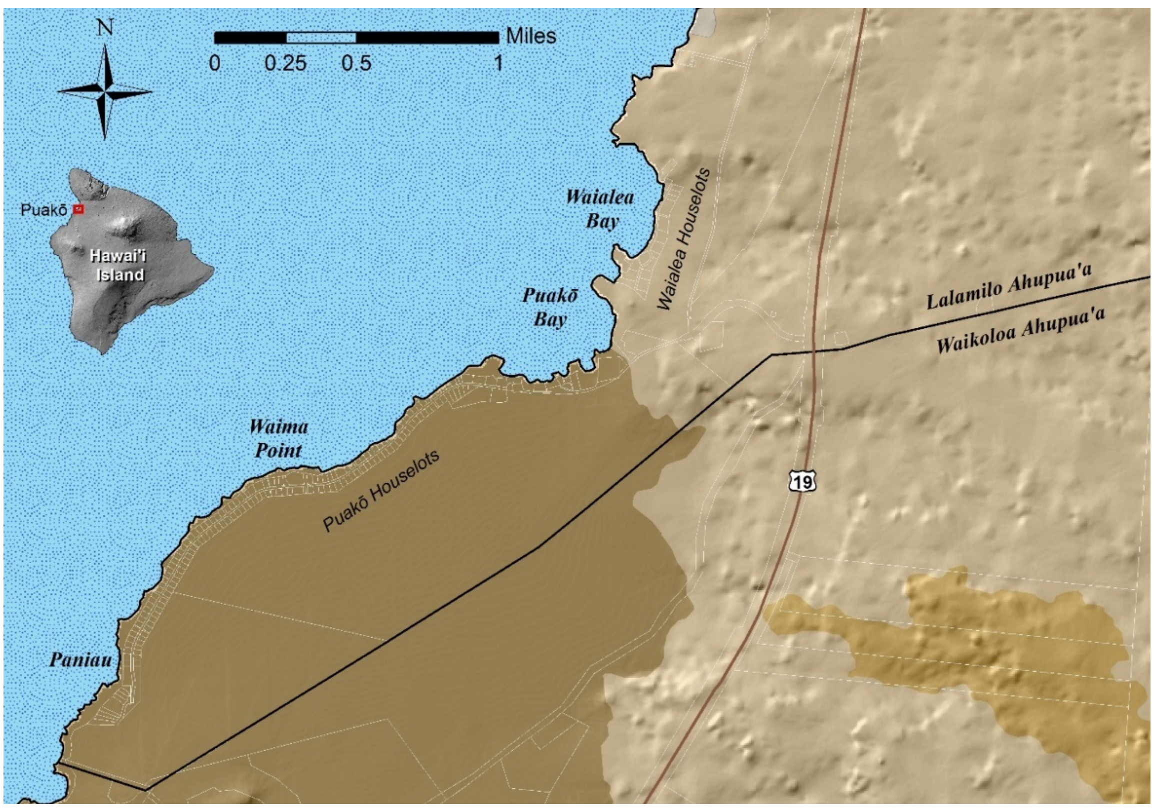
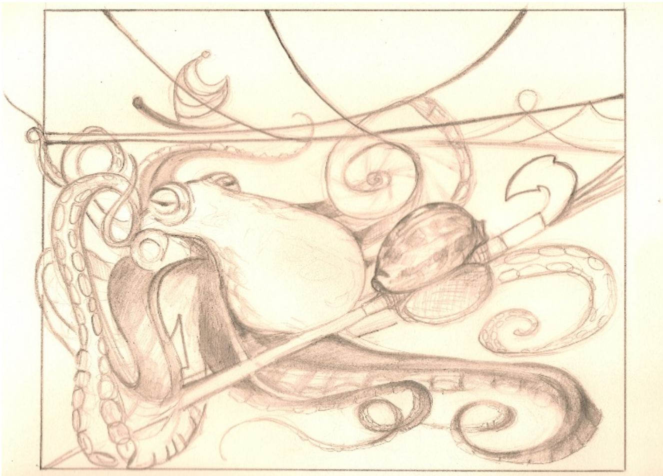


Figure 1. Puakō and Waialea Houselots, both located in Lalamilo ahupua‘a, are geologically distinct. Puakō's foundation is 1,500-3,000 y.o. Mauna Loa lava, while Waialea sits upon 64,000-300,000 y.o. Mauna Kea flows.

---

[1] Pūku'i, Mary Kawena. *The Cowry Shell.* Hawai'i Island Legends – Pīkoi, Pele and Other. Kamehameha Schools Press. Honolulu. 1996. Retold by Caroline Curtis. Illustrated by Don Robinson.
[2] Next Page: Puakō he'e by Jonatha Giddens



This independence and marine resource abundance helps explain why the people of Puakō were spared from the disease that coincided with early European contact that ravaged ports and centers of commerce including Kawaihae just five miles away.

When Hokuloa Church was constructed of stone and coral mortar in 1860 under the leadership of Reverend Lorenzo Lyons, it was a spectacular sight. Today, it is a reminder of Puakō's history during a time of great change - of the diverse community that came together to live here.

Kūpuna accounts indicate that streams, fed by mauka forest rains, once ran just north of Puakō, but today, surface water that reaches the ocean is not often present in the South Kohala region – rather groundwater provides for the kiawe forest mauka of Puakō and serves to meet the freshwater needs of residents.

When the first lots in Puakō were auctioned off in 1962, the Queen Ka`ahumanu Highway had not yet been constructed. The harbor at Kawaihae was less than a decade old. No paved road connected the Puakō lots, and electricity was not available. Life in Puakō was off the grid and not for the faint of heart. Tales of fortunes lost to marauding rats and fires characterize a hard scrabble community where tenacity was required and comfort not assured. Though few early residents remain today, their valuable knowledge about this time in Puakō's recent history lives on in some of their neighbors and books such as *Puakō, An Affectionate History*.

In the 1990s, Puakō became an attractive place to escape the hustle and bustle of city life, to relax and retire in a peaceful and remarkable place. Puakō's current residents have embraced this special community and made their home here sheltered from the sea by the spectacular reef and from the land by a thick forest, protected just as Puakō desired in her prayer so long ago. Puakō's is a long uninterrupted history of residence, and today's community values the ability to live and visit this special place at the boundary between land and sea.

Wailea or Waialea?

Just north of Puakō, lies the bay known to the kama 'āina (ancestral peoples) of Kohala as "Wailea Bay." Kūpuna (elders) indicate names for each portion of the sandy bay here from Pulehu at the North End to Wailea at the South. Maps and signs also record Waialea as the name for this area, and both are used today to denote this peaceful and scenic place with a special community of its own.

Challenge

Unlike more recent coastal developments in West Hawai‘i, Puakō is not a master planned community designed around central infrastructure. Instead, Puakō grew organically via shacks that were built on both sides of the winding overgrown Puakō Beach Road. For nearly 30 years, this resettled fishing village became an outpost for the adventurous and intrepid who were willing to tame the land to build their future along the shore of a thriving fringing coral reef – provided they knew the place existed. Lacking better options, for decades, pits have been excavated for disposal of residents' and visitors' wastewater. Then as now, many holes dug in Puakō hit brackish water within the first few centimeters or meters demonstrating the clear connection between cesspools and groundwater, a connection that is likely to increase with rising sea levels.

Because Puakō grew gradually over time of necessity, there was never a concerted effort to construct the necessary infrastructure to manage the waste generated by her residents and visitors, so cesspools, simple covered holes in the ground, continued to be a suitable method for wastewater disposal until the creation of new cesspools was prohibited in the 1990s.

Since the time of Puakō's establishment as a modern coastal community, several attempts to improve wastewater infrastructure have been initiated. The County of Hawai‘i convened an engineering report for a sewer at Puakō in 1967, but did not pursue facility construction. In the 1990s, a plan to pump effluent to the neighboring Mauna Lani Resort was proposed, but never approved. This proposal continues to inform possible solutions for replacing Puakō cesspools. In 2008, a connection to the Mauna Lani wastewater treatment facility at Kalahuipua‘a Lagoons was recommended in the South Kohala Community Development Plan, which became a county ordinance following signature by Mayor Harry Kim on November 20, 2008. Concurrently, the Kapoho Wastewater Feasibility study evaluated alternatives for replacing coastal cesspools in East Hawai‘i. In 2009, TNC hired a contractor familiar with the Kapoho process and study to lead an investigation of alternatives for Puakō and provided this report to the Puakō Community Association and, later, CORAL. Notably, none of these plans or studies were implemented, indicating the need for a more focused and intensive project.

In 2014, the Puakō Community Association solicited help from CORAL to lead a process to upgrade cesspools in Puakō as soon as possible. In 2015, a Preliminary Engineering Report contracted by CORAL recommended construction of a wastewater treatment facility in the vicinity of Puakō to maximize health and environmental benefits. To implement this recommendation, community and government level support is required.

Today, Puakō is known as a place with valuable homes and properties, although a few beach shacks and humble houses remain. However, Puakō retains the atmosphere of a true small town community. The support of this community is a vital component to ensuring success for the process to upgrade wastewater technology. Understanding the impact of actions at Puakō is vital in informing and building community support locally and across Hawai‘i.

Opportunity

Today, based on records from Hawai‘i County and the Office of Planning, and research conducted by TNC and CORAL contractors, up to 68 cesspools and over 70 septic systems persist in Puakō. The remaining homes utilize aerobic treatment units (ATUs) for wastewater disposal. Wastewater technology has improved significantly since the modern community of Puakō was established, and a 2016 Hawaii State tax credit of $10,000 for upgrades of coastal cesspools makes wastewater upgrades less of a financial burden for property owners. Wastewater Treatment Plant (WTP) technology has advanced to scalable facilities appropriate for communities the size of Puakō, and research has demonstrated the impact of inadequate technology (cesspools, septic tanks) on the beaches and coastal reefs at Puakō. Lawmakers, permitting agencies, and residents understand the need to take action and want to support solutions to do so in the most efficient and least burdensome way possible.

The scientific research is summarized in the next section. Yet, even with the documented environmental impacts and available solutions, implementing a wastewater treatment upgrade solution that works for the entire community is not easy. Decades of delays in the design, permitting, construction, and operation of wastewater upgrades in Puakō demonstrate the magnitude of the challenge this community faces if it is to ensure that the current and future residents of Puakō can continue to enjoy these coral reefs and beaches.

Evidence

Historic Research

The proximity of the reef to homes and roads, the marine life, and the supportive local community have all contributed to making Puakō one of the most studied nearshore areas on Hawai‘i Island. Puakō has a long history of providing new information to inform coastal and marine management, and studies have been underway looking at corals and fishes in Puakō since the 1970’s. Here are some highlights:

- In 1974, Dr. Richard Brock and Dr. Julie Brock mapped north Kona coral reefs and described Puakō Bay’s as a shallow finger coral dominated reef in 3 m of water. Today, Puakō Bay is full of sediment that has accumulated in this sheltered area following flood events and modern studies show that this area is extremely susceptible to post bleaching coral mortality, demonstrating over 90% coral death at a single monitoring site from 2015-2016 (TNC unpublished data).
- In 1982, Dr. Hayes and a research team from the Hawai‘i Cooperative Fishery Research

Unit (HCFRU) demonstrated that lay gill nets were impacting the fishery. This informed the establishment of the Puakō Fishery Management Area, which prohibits all nets except throw nets in Puakō. Compliance with these rules is high (TNC Unpublished data), and fish targeted by net fisheries alone have benefited (Williams et al., 2009).

- In 2008, the Puakō Community Association contracted Aecos Laboratory to conduct a water quality study designed to evaluate the coastal waters of Puakō to identify areas of concern, if any, for nutrients associated with human activities. This study was terminated before sufficient data for evaluation could be collected.
- In 2009, Jonatha Giddens, then a student at UH Hilo, determined that only 7% of fishermen in Puakō reside there, while most travel from as far away as Hilo (29%), Honokaʻa (18%), and Kohala (10%). Surgeonfish took less than one hour to catch while jacks took up took up to 12 hours to catch, on average.
- In 2010, Megan Lamson with Mehana Consulting looked at data collected by Puakō resident volunteer James Heacock since 2006 and found that 94.5% of the 23,482 individuals observed at Paniau were engaged in recreational use rather than fishing

Overall, this information constitutes a large body of evidence for the characterization and condition of Puakō's coral reef, fish population, coastal use, and landings to inform future comparisons.

Perhaps the most striking finding when looking at this historic data was that coral cover declined from approximately 80% in the mid-1970's to 32% in 2010 (Minton 2012). This is consistent with coral declines reported by Hawaii's Division of Aquatic Resources (Walsh et al. 2013).

Recent Research

More recently, science in Puakō paints an even bleaker picture of coral loss - following the 2015 mass coral bleaching event - with sites declining by 55-99% from 2014-2015 (Dr. Courtney Couch, unpublished). This event was triggered by unusually warm water that persisted in west Hawaiʻi for 18 consecutive weeks. This type of thermal stress event is expected to occur with increasing regularity in the coming decades (van Hooidonk et al. 2013). This massive impact has caused some to question whether coral reef ecosystems can persist into the future.

The best international science demonstrates that coral reefs can recover even from catastrophic bleaching events, but a major factor in recovery is the reduction or elimination of existing local stressors. By addressing impacts from wastewater nutrients in Puakō, one of the key components of coral health can be improved, enhancing the resilience of Puakō's reef.

In 2012, based on community concerns about potential impacts of cesspools on Puakō's coral reef, researchers from Cornell University worked with the Puakō Community Association (PCA) to design a preliminary study to examine the presence of wastewater indicators along the shoreline at Puakō and Wailea Bay. his study found elevated levels of the fecal indicator bacteria *Enterococcus* in Puakō (Yoshioka et al. 2016).

A research collaboration between UHH, TNC, and the HIMB, with financial support from NOAA and the Puakō Community Association has continued to investigate sources of sewage contamination and its effects on Puako's reefs. Using a combination of dye tracer releases, measurements of sewage indicators (fecal indicator bacteria (FIB), nutrient concentrations, $\delta^{15}N$ in macroalgae), this collaborative found that sewage from cesspools was detected at the shoreline in as little as nine hours, and shoreline nutrient concentrations were two times higher than those in upland groundwater. Nutrient concentrations and FIB abundance were highly spatially variable, but were elevated in shoreline areas and declined seaward, confirming the presence of land-based inputs. $\delta^{15}N$ macroalgal values and presence of human-specific gut bacteria confirmed the presence of chronic sewage and when combining all variables, they identified sewage 'hot spots' in Puakō. Nutrient concentration was also the strongest environmental predictor of coral health, with higher prevalence and severity of growth anomalies in regions with elevated nitrate concentrations. This collaborative is currently pooling data to generate maps and reports, to communicate the presence of sewage indicators along the shoreline, beaches, tidepools, and reefs of Puakō. Teams from these institutions are preparing relevant data for publication, and these studies represent an important baseline against which to measure future conditions.

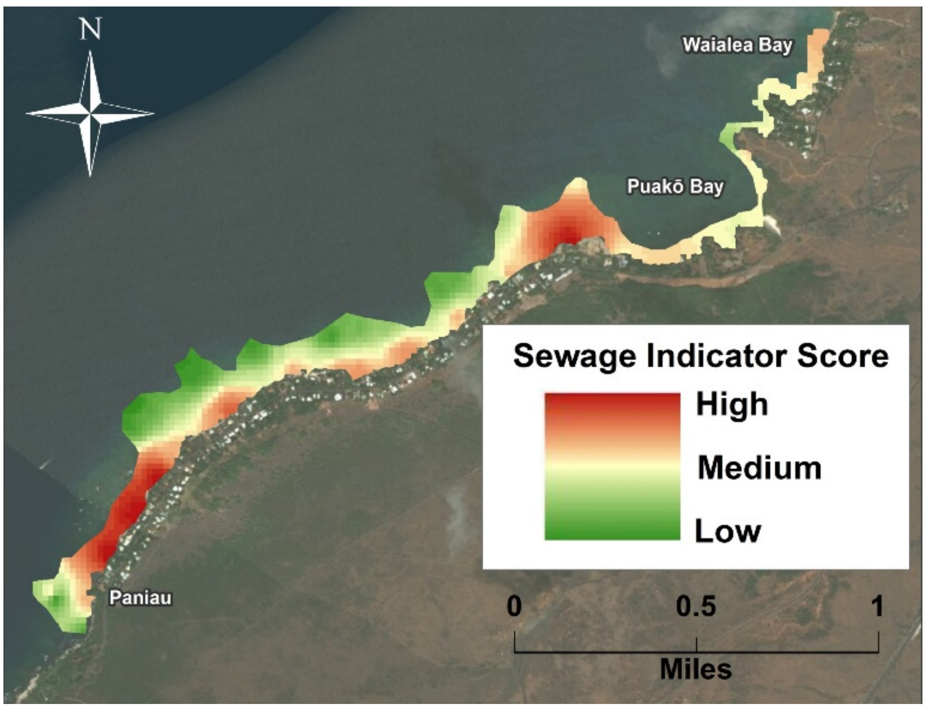


Figure 2. Sewage indicator score map for Puako. Score was derived from stable nitrogen isotopes in seaweed, fecal indicator bacteria, and nutrient concentrations (data from UHH, TNC and Cornell University). These three metrics are indicators of wastewater. By combining wastewater indicators into a single score, it is easier to visualize likely locations of wastewater pollution, or hot spots, along the Puakō shoreline.

This collaboration combines the resources of each organization to improve management of Puakō's coral reef. By combining multiple sewage indicators from independently collected datasets, a 'sewage indicator score' was developed. This study provides an important management tool for visualizing the extent of sewage pollution in Hawai'i's nearshore waters and provides a baseline to gauge the efficacy of sewage treatment remediation (Fig. 1). Preliminary maps depicting this information were shared with the Puakō community in attendance at the Puakō

Homeowner's Association Annual meetings and results have been used to refine data collection.

Given the preponderance of evidence from Puakō, demonstrating coral declines and linking coral reef health to wastewater indicators, one might justifiably ask why any additional effort to design and implement monitoring plans to evaluate the impact of wastewater upgrades is needed. After all, as one Puakō researcher quipped, "*How many scientists does it take to change a lightbulb?*"

The need for science demonstrating changes in response to management action ensures that resources are effectively allocated, that actions are successful, or indicates the need to adapt strategies to accomplish goals – the next section will focus on measuring success.

Monitoring Plan Rationale

A great deal of effort has been allocated to measurements at Puakō, and those measurements have documented the connection between coral health and wastewater indicators. This information provides the scientific justification for wastewater upgrades at Puakō. Yet, all of the measurement to date constitutes baseline conditions against which changes should be evaluated to determine the extent to which upgrades demonstrate tangible benefits to people and natural systems. If measurements do not continue during and subsequent to wastewater upgrades, the assumption of benefit cannot be tested or quantified. This would be a missed opportunity to learn from Puakō's example on how other coastal communities in Hawai'i can improve their wastewater systems. Without understanding the benefits of eliminating cesspools, the opportunity to improve the efficiency and effectiveness of replacement will be lost. The ability to adapt based on what is learned will not be realized.

The process of refining measurements with the result of improving the outcomes for Puakō and beyond, fueled the project team to collaboratively develop a monitoring plan to guide Puakō research.

Although measurement is a vital component of adaptive management, it is often overlooked. Because it is so important, 28 agencies and non-profit organizations support the Conservation Measures Partnership (CMP), a cooperative effort to improve the practice of developing and implementing measurements to ensure projects are accomplishing their objectives.

On Measurement

"…I have been struck again and again by how important measurement is to improving the human condition. ***You can achieve amazing progress if you set a clear goal and find a measure that will drive progress toward that goal-in a feedback loop …*** *This may seem pretty basic, but it is amazing to me how often it is not done and how hard it is to get right."*

- Bill Gates

Without measures, it is impossible to understand if projects are on track or if the goals for which projects were designed are being accomplished. At the request of CORAL, the Puakō Monitoring workshop focused on status measures. Status measurement is intended to track the results to the systems that are influenced by project success – in this case the oceanographic, social, ecological, cultural, and economic systems that are currently impacted by inadequate and outdated wastewater treatment at Puakō.

Planning Process

Figure 3. The adaptive management cycle of the Conservation Measure Partnership Open Standards for the practice of conservation consists of several steps from conceptualizing and designing projects, to implementing and measuring, to sharing and adapting based on what is learned. This document is focused on step 2 of the process, specifically Monitoring Plan Development.

While many management planning processes that include monitoring plan development exist, the Open Standards for the Practice of Conservation is an adaptive planning process with a proven track record of success in hundreds of projects across the globe. The Open Standards have been used to plan at the scale of villages, species, and entire ocean basins and the ability to ensure participation and collaboration throughout the planning process is a hallmark of the processes that utilize these Standards as their foundation.

This Open Standards process aligns well with previous work at Puakō, as the Open Standards were used to draft a Puakō Conservation Action Plan (CAP) in 2008 that identified sewage pollution as a priority threat to Puakō's coral reef and visitors to the area which led to creation of the following objective: *Reduce sewage discharge in nearshore waters by 50% by 2017.*

The Puakō CAP sewage discharge strategy provides an example of how the Open Standards can be used to identify priorities. Actualizing this clear objective was considered achievable in 2009 when the plan was completed, but it must be evaluated now, in 2016, based on progress toward the 50% reduction identified. In an adaptive framework, the strategy conceived during the initial plan must be modified to reflect a deeper understanding of the system and acknowledgement of the functional influences that determine success. Now that the pollution reduction objectives have been updated for Puakō and clear measures developed to evaluate success, tracking progress is a vital component of the adaptive management process. Knowing these values requires measurement.

In August 2016, TNC and CORAL co-facilitated a three-day workshop to develop a monitoring plan to evaluate conditions at Puakō, following wastewater treatment improvements. Representatives from research institutions, regulatory entities, management agencies, local and international non-profit organizations participated in the planning process to develop and provide input on goals and objectives, indicators, and methods of evaluation. This monitoring plan is intended to be used to strengthen research partnerships, identify resources, and justify support for investment in measuring the impact of Puakō's wastewater upgrade process.

It was the objective of CORAL to identify both research and citizen science methods of evaluation for social, ecological, economic, and cultural indicators and, in some cases, opportunities to engage community members in research science as volunteers.

Figure 4. Monitoring Plan Participatory Workshop Process Summary August 2016.

Participants

Table 1. Puakō Monitoring Planning Workshop Participants

Name	Affiliation	Acronym
Bill Walsh, PhD	Kona Division of Aquatic Resources	DAR
Courtney Couch, PhD	Hawai'i Institute of Marine Biology	HIMB
Cynthia Punihaole	The Kohala Center	TKC
Jos Hill	Coral Reef Alliance	CORAL
Justin Logan	AQUA Engineers	AQUA
Kim Falinski, PhD	The Nature Conservancy of Hawai'i	TNC
Lani Watson	NOAA Habitat Blueprint	NOAA
Lindsey Kramer	Kona Division of Aquatic Resources	DAR
Lydia Smith	Kona Division of Aquatic Resources	DAR
Robin Pulkinnen	USDA Rural Development	USDA
Tracy Wiegner, PhD	University of Hawai'i at Hilo	UHH
Bert Weeks	Facilitator, The Nature Conservancy	
Chad Wiggins	Facilitator, The Nature Conservancy	
Cherie Kauahi	Facilitator, Coral Reef Alliance	
Erica Perez	Facilitator, Coral Reef Alliance	
Kanoe Steward	Facilitator, The Nature Conservancy	
Nakoa Goo	Facilitator, The Nature Conservancy	

Table 1. Planning participants who contributed to the 3 day planning workshop 8-10 August 2016. Affiliation is group individual represents. Participants are in blue boxes and Facilitators in green.

Participants were invited by project leads from CORAL to ensure strong knowledge of methods of evaluation for wastewater impacts and wastewater engineering, as well as experience coordinating citizen science programs with water quality components.

Review Process

To orient participants to the project, CORAL staff provided a process overview of the steps and milestones necessary to implement the preferred alternatives for wastewater upgrades at Puakō, and answered questions about key stages of the process. The team was asked to focus on developing content based on the successful completion of each process. *More information about the upgrade processes presented can be found at the Clean Water for Reefs in Puakō website (coral.org/puako).*

Identify Alternatives

Immediately prior to the workshop, the decision was made to plan for four possible scenarios at Puakō to ensure contingencies if conditions change and a different approach is required. The four scenarios evaluated by participants were:

1. **Onsite Treatment Facility**: Construction of infrastructure and a wastewater treatment facility adjacent to Puakō to receive, treat, and utilize residential wastewater for crop irrigation. This is the preferred alternative identified in the Preliminary Engineering Report (PER) and CORAL's project advisory board.
2. **Kalahuipua'a Lagoons**: Construction of infrastructure to connect Puakō house lots to the Mauna Lani Resort Development treatment plant upslope of Puakō. This is the secondary alternative identified in the PER. This alternative had the second most support of CORAL's project advisory board.
3. **100% ATU:** Conversion of 100% of Puakō house lots to aerobic treatment units as the best case scenario for individual wastewater treatment options.
4. **35% ATU:** Conversion of 35% of Puakō house lots to aerobic treatment units as the worst case scenario for individual wastewater treatment options.

Information about the first three scenarios can be found in the Preliminary Engineering Report.

If complete treatment and re-use of wastewater effluent is assured through either the onsite wastewater treatment facility or Kalahuipua'a Lagoons option, the environmental outcomes will be similar.

Some participants expressed concerns about the ability for Kalahuipua'a Lagoons to utilize an injection well to dispose of excess effluent. Although the intent of the operators of Kalahuipua'a Lagoons is not to inject effluent, information obtained and included in the PER could not rule this potential disposal method. In Hawai'i, wastewater from injected effluent has been detected in coastal waters and reef algal tissue (Smith and Smith 2006; Derse et al. 2007; Dailer et al. 2010; Dailer et al. 2012; Dailer et al. 2013; Glenn et al. 2013; Wiegner et al. 2016). Emergent wastewater from injection wells has been connected to economic (Cesar and van Buekering 2004) and ecological impacts in Maui (Dailer et al. 2010). Despite this possible risk, in order to proceed with developing a monitoring plan for Puakō upgrades, participants assumed that no effluent injection would occur and designed monitoring methods with controls to identify effluent if injection were to occur.

The 100% ATU scenario relies on voluntary cesspool and septic system upgrades and perpetual annual maintenance for every Puakō residence. This scenario assumes that ATUs with the highest level of wastewater treatment would be installed and maintained by all homeowners.

Scenario four was considered a minimum cost scenario, based on resources currently available. Because it represents a modest improvement from current conditions, it was evaluated to consider the impact that could be expected if the other scenarios are not viable.

For planning purposes, scenario one is the simplest to evaluate based on the fewest assumptions, scenario two contains some risk under certain conditions, scenarios three and four represent a minimum and maximum range of impacts from ATU conversion with actual quantities likely to fall within this range.

Develop Objectives

Objectives are specific measurable statements focused on threat abatement or improvement of positive attributes of a health system. Workshop participants developed one or more objectives focused on ecological, cultural, economic, and social outcomes following the successful completion of a wastewater treatment upgrade process. These objectives were used to inform and develop indicators to establish measurable foundation for evaluating success at Puakō.

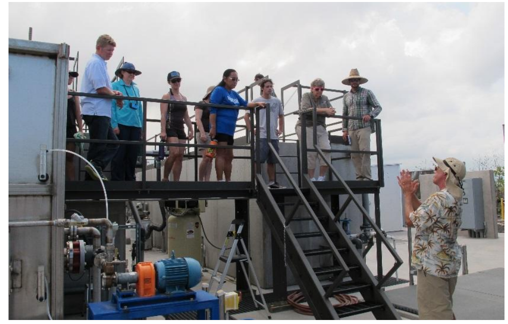
The specificity of each objective varied based on the group's knowledge and expertise. In many cases quantities were assigned for expected changes following upgrades.

In the case of the nutrient reduction objective, Total Nitrogen (TN) and Phosphorous (TP) concentration had been recently quantified by UHH researchers in upland wells and along at Puakō's shoreline. This research suggested that Puako homes contribute 50% to the shoreline nutrient concentrations, with the remaining amount from upslope groundwater (Wiegner et al. unpublished data). If all homes no longer had onsite wastewater treatment systems (cesspools, septic tanks, ATUs), a 50% reduction in shoreline nutrient concentrations could be expected. This would therefore meet the criteria for a realistic objective based on the best available data.

In the instance of property value, quantities were not available to the group to consider specific benefits, so a trend was considered sufficient. It was expected that property value would increase for residences that upgraded cesspools, which represent a liability to new owners.

Although they differ in precision, both approaches are valid, and either can determine the extent to which project success is translated into measurable cultural, socio-economic, and ecological benefits. Throughout implementation of this monitoring plan, it is recommended that specific measurable objectives be developed for remaining priority metrics once sufficient baseline data exists to inform them.

WWTP Site Visit



Field trips are a useful way to re-energize participants in multi-day workshops and inspire new ideas. Participants visited the recently completed 70,000 gpd treatment plant at Kohanaiki. The plant's operator, Dave Thomas, explained the components that process residential and beach park effluent to R1 water for surface irrigation and reuse. Participants observed the tanks, filters, and operations of a functioning facility and asked questions to inform Puakō's monitoring plan.

Refine Objectives

Following the field trip, participants returned to the meeting room to revisit the previous day's objectives as a group and identified opportunities to further refine them. By evaluating content together, the group reached consensus on multiple objectives, as represented in the monitoring plan objectives table. The table is sorted by priority as described in the next two sections.

Develop Indicators

Using these objectives as a guide, participants then specified indicators to measure progress. Two breakout groups formed, one focused on research-driven and the other on citizen science-driven measurement.

Considerations for developing indicators focused on the best way to evaluate progress toward objectives. For some indicators, this involved developing a new indicator, but for many, it involved understanding how other management-driven research in Puakō and elsewhere in Hawaiʻi could inform measurement at Puakō. The group recognized that a great deal of relevant work on ecological indicators had been done recently by the United States Coral Reef Task Force Watershed Partnership Initiative and indicators within the Priority Ecosystem Indicators document developed by the Watershed Working Group Metrics Subcommittee (Holst et al. 2016) were used when appropriate. Participants identified multiple priority indicators beyond those recommended for watershed assessments.

After populating viable indicators for each goal and objective, the groups reconvened to share their work and ask clarifying questions before summarizing the second workshop day.

Rank Indicators

On the third planning day, workshop participants acknowledged that measuring every indicator prioritized indicators by ranking their ***constituency***, ***partnership***, and ***sufficiency***.

Constituency – How much will key decision-makers or community leaders care about or be motivated by the indicator?

Partnership – How much external partner support exists or is likely to develop to support measurement of the indicator?

Sufficiency – How much of an understanding of the impact of the project does the indicator, alone, provide?

In plenary, the priority of each of the initial indicators developed was ranked relative to its counterparts. Socio-economic and eco-cultural indicators were ranked separately. These three rankings were averaged to generate indicator ranks.

Develop Measures

Prioritized indicators were used in break-out groups to identify metrics and methods for measurement. Because perspectives on research can vary between institutions and researchers, there was some debate in these groups, particularly pertaining to sampling design criteria such as scope and frequency. There was also consensus on the benefits of aligning with existing protocols for water quality that have been successfully implemented previously in Puakō or comparable areas.

All monitoring methods were derived based on the assumption of project success as measured by the initiation of operations of upgraded wastewater treatment technology at Puakō.

For each priority indicator, break-out groups debated and agreed upon design for a suitable measurement plan that would be able to evaluate progress toward objectives. The role of volunteer citizen scientists in participating in measurement was evaluated for each indicator and specified as applicable. Group reconvened to share and clarify measures at the conclusion of this activity.

The following was identified for each indicator:

Principal investigator – Who will be primarily responsible for leading/coordinating monitoring? Individuals and organizations were suggested based on prior experience and relevant reputation.

Method – What specific technique(s) will be used for monitoring? Knowledge of relevant monitoring methods considered and adapted for this project.

Scope – Over what geographic area will monitoring occur? At how many sites? Will a control site be needed? If so, where will it be located? Knowledge of relevant monitoring scope considered and adapted for this project.

Sampling Design – When will monitoring begin? How long will monitoring continue following successful completion of upgrades? How often will monitoring occur? Prior experience demonstrating impact of management action or activities used to inform sampling initiation, frequency, and continuation.

Cost – Based on the above, how much will monitoring cost per year? Total? Publicly available budgets for similar work and numbers from prior experience used to estimate cost of monitoring. Unless otherwise specified, costs include salary, fringe, supplies, transportation, contracts for service/analysis, and meeting expenses.

Identify Gaps

Adaptive management is dynamic. Projects utilize different stages of the planning process throughout the span of development and implementation. No plan for a novel project can be truly final as there is always room to refine actions and evaluation based on new knowledge and evidence.

The final step of the participatory planning workshop was for the group to identify knowledge gaps. The group specified gaps for which information likely exists, but was not present in the accumulated expertise of workshop participants. To address these gaps, the group identified specific items warranting post-workshop follow up and individuals committed to obtaining information to contribute to the monitoring plan. Much of that information has been directly incorporated into this document. Identified gaps for which no source of information was currently known, but that will directly influence the success of evaluation (e.g. the date of completion for wastewater treatment upgrades around which to develop before-after-control-impact monitoring). For these gaps, ensuring clear and effective partner communication as the project progresses is vital, and the group agreed to maintain communication to increase the likelihood that gaps will be addressed.

The 3-day process to develop a monitoring plan for Puakō engaged the participation of many topical experts and the outcome is based on the best available information at the time of its development. This information is captured in the tables that follow.

Planning Analogue

We all have experience with monitoring planning concepts, even though we might not think of it that way. One way to understand this framework for monitoring plan development is to make an analogy to medical terms used during a check-up.

If our doctor tells us to **lower our blood pressure before our next annual check-up**, we can consider the correlation to planning terms to illustrate their meaning.

Objective – What must we do by when?
Medical correlation – ***Doctor's orders*** "Lower your blood pressure in 12 months."

Measure – What does objective target?
Medical correlation – ***Circulation***

Indicator – What will we measure?
Medical correlation – ***Blood pressure***

Metric – What constitutes a measurement?
Medical correlation – ***Pressure in millimeters of Mercury*** *(mm Hg)*

Method – How is the measurement derived?
Medical correlation – ***Numbers on blood pressure cuff gauge recorded by trained health care provided at start of annual check-up and compared to previous year.***

Puakō Monitoring Plan

Objectives

Table 2. Objectives for Puakō Wastewater Upgrades				
Measure	***Onsite Treatment Facility***	***Kalahuipua'a Lagoon***	***100% best treatment ATU***	***~35% best treatment ATU***
Nutrients	50% ↓ Nutrient (3yr)	50% ↓ Nutrient (3yr)	25% ↓ Nutrient (3yr)	10% ↓ Nutrient (3yr)
Engagement	↑Program Participation (3yr)	↑Program Participation (3yr)	↑Program Participation (3yr)	↕ program participation
Bacteria	100%↓ Fecal indictor bacteria (3yr)	100%↓ Fecal indicator bacteria (3yr)	100%↓ Fecal indicator bacteria (3yr)	25%↓ Fecal indicator bacteria (3yr)
Ocean Use	↑Ocean resource use (3yr)	↑Ocean resource use (3yr)	↑Ocean resource use (3yr)	↕ Ocean resource use (3yr)
Nitrogen 15	N15 @ 4ppm (3yr)	N15 @ 4ppm (3yr)	N15 @ 5.5ppm (3yr)	N15 @ 7ppm (3yr)
Awareness	↑ Public awareness about wastewater human health issues (3yr)	↑ Public awareness about wastewater human health issues (3yr)	↑ Public awareness about wastewater human health issues (3yr)	↕ Public awareness about wastewater human health issues (3yr)
Ocean Health	↑Perception of ocean health (3yr)	↑Perception of ocean health (3yr)	↑Perception of ocean health (3yr)	↕ Perception of ocean health (3yr)
Algal Abundance and Interaction	↓ Algal proliferation and coral interaction (3yr)	↓ Algal proliferation and coral interaction (3yr)	↓ Algal proliferation and coral interaction (3yr)	↓ Algal proliferation and coral interaction (3yr)
Property Value	↑Home Value (3yr)	↑Home Value (3yr)	↑Home Value (3yr)	↕Home Value (3yr)
Coral Cover	↑Coral cover (10yr)	↑ Coral cover (10 yr)	↑ Coral cover (10 yr)	↕ Coral cover (10yr)

Continued on next page

Table 2. Objectives for Puakō Wastewater Upgrades (cont'd)				
Measure	***Onsite Treatment Facility***	***Kalahuipua'a Lagoon***	***100% best design ATU***	***~35% best design ATU***
Human Health	↓Human Health Issues (Staph, MRSA) (1yr)	↓Human Health Issues (Staph, MRSA) (1yr)	↓Human Health Issues (Staph, MRSA) (1yr)	↕Human Health Issues (Staph, MRSA) (1yr)
Coral Size	↑Coral recruit density and colony size for target species (7yrs)	↑Coral recruit density and colony size for target species (7yrs)	↑Coral recruit density and colony size for target species (7yrs)	↕Coral recruit density and colony size for target species (7yrs)
Vacation Rentals	↑Vacation Rentals (3yr)	↑Vacation Rentals (3yr)	↑Vacation Rentals (3yr)	↕Vacation Rentals (3yr)
Media	↑Positive press coverage (3yr)	↑Positive press coverage (3yr)	↑Positive press coverage (3yr)	↑Positive press coverage (3yr)
Community Pride	↑Community Pride (3yr)	↑Community Pride (3yr)	↑Community Pride (3yr)	↓Community Pride (3yr)
Cultural Practice	↑Pono Ocean Use (3yr)	↑Pono Ocean Use (3yr)	↑Pono Ocean Use (3yr)	↕ Pono ocean use (3yr)

Table 2 summarizes the objectives derived through the workshop in ranked order based on the criteria described in the Rank Indicators section of this document for each of 4 possible scenarios. The measure column is a one word summary of the focus of each objective. Arrow directions indicate increase, decrease, or no change in the measure. The expected timeframe to meet the objective is in parenthesis.

Objectives were developed for the expected outcome of each scenario (Table 2). Measures represent a short summary of objective type. The next sections refine measures into indicators and metrics. More information on the indicator types derived from the Table 2 objectives is provided below.

Nutrients: Coral reef ecosystems are very efficient at cycling nutrients, but are limited in their ability to process elevated nutrient inputs. This latter attribute provides a competitive advantage to opportunistic algae that utilize elevated nutrients to overgrow corals, shifting reefs from a coral-dominated to an algal-dominated system (Hughes 1994; Hughes et al. 1999; Work et al. 2008; Bruno et al. 2009). Wastewater has high nutrient concentrations, and it is well documented that coastal environments polluted with wastewater have elevated nutrient concentrations (Knee et al. 2008, Street et al. 2008, Nelson et al. 2015). Reductions in wastewater effluent reaching the coast are likely to reduce nutrient concentrations in coastal and marine waters. This change is likely to be observed within 3 years of upgrade completion.

Engagement: Engaged communities take ownership of the issues that affect their lifestyle and livelihoods and demonstrate leadership in processes to improve conditions. Existing programs to empower and activate citizens at Puakō include Makai Watch, ReefTeach, and Keep Puakō Beautiful. A new citizen science program designed around measures of success for Puakō has been developed to provide additional engagement opportunities. By tracking attendance at these events as well as community meetings and trainings over time, changes in community engagement can be evaluated. This change is likely to be observed within 3 years of upgrade completion.

Bacteria, a.k.a. Fecal Indicator Bacteria (FIB): Certain bacteria are used as indicators of wastewater pollution at beaches and coastal waters and have been correlated with risks to human health (Myers et al. 2014). Wastewater from homes is a contributor to elevated FIB concentrations. FIB concentrations will likely decline as wastewater reaching coastal waters is reduced or eliminated. This change is likely to be observed within 3 years of upgrade completion.

Ocean Use: The perception that Puakō is polluted may be keeping some people from swimming, diving, and recreating there. By monitoring changes in ocean use over time, the extent to which improvements to wastewater treatment influences the behavior of Puakō residents and visitors can be evaluated. Notably, if this objective is met without ensuring use is well managed, an unanticipated impact could result. Therefore, it must be carefully monitored to inform management. This change is likely to be observed within 3 years of upgrade completion.

Nitrogen 15 ($\delta^{15}N$): The ratio of stable nitrogen in algal tissue is a well-established method used to identify sources of coastal nitrogen pollution. Wastewater has a high ratio of ^{15}N to ^{14}N demonstrating a positive $\delta^{15}N$ value compared to other nitrogen sources such as fertilizers, plants, soils, ocean water. Algal $\delta^{15}N$ measurements have been used in Hawaii to document nearshore sewage pollution (Smith and Smith 2006; Derse et al. 2007; Dailer et al. 2010; Dailer et al. 2012; Dailer et al. 2013; Wiegner et al. 2016). $\delta^{15}N$ values in algal tissues should decrease predictably with reductions in wastewater reaching the shoreline. This change is likely to be observed within 3 years of upgrade completion.

Awareness: The extent to which Puakō residents and concerned parties are aware of the link between wastewater and human health is informed by the amount and type of information provided through targeted communications. Community support is vital to continued project success. Changes in awareness are likely to occur throughout the process of wastewater treatment upgrades at Puakō as resident and visitor engagement increases. This change is likely to be observed within 3 years of upgrade completion.

Ocean Health: Perceptions of ocean health often precede quantitative ecological demonstrations of changes in ocean health. A belief that the ocean is healthy both supports the rationale for long term support of upgrades and provides a leading indicator for communicating changes as a result of action. This change is likely to be observed within 3 years of upgrade completion.

Algal Abundance and Interaction: Elevated nutrients associated with wastewater provide a competitive advantage to algae, which can overgrow and kill coral and prevent resettlement of coral larvae. Measuring algal cover is a well-established method of evaluating benthic habitat quality (Hill and Wilkinson 2004). Algal interaction with coral is a more recent measure used to evaluate stressed coral colonies before mortality occurs (Couch et al. 2014). By combining algal height and benthic cover measurement, a more complete understanding of algal competition emerges (Flower et al. 2016). This change is likely to be observed within 3 years of upgrade completion.

Property Value: Wastewater treatment infrastructure, or lack thereof, affects the property value of coastal homes. Current laws restricting renovation of properties with cesspools represent a liability for homeowners that may become the responsibility of new owners. By tracking the change in home values over time, the accrual of economic benefits to homeowners can be quantified to demonstrate the impact of action on the local economy. This change is likely to be observed within 3 years of upgrade completion.

Coral Cover: Coral cover represents the amount of live coral present on a reef and is a legacy indicator of coral reef habitat quality (Hill and Wilkinson 2004). The amount of wastewater nutrients on the reef influences live coral cover. Reductions in wastewater present are likely to improve conditions for coral growth and survival. Because coral is slow growing, this objective is likely to be observed within 10 years of upgrade completion.

Human Health: Understanding the impact of coastal wastewater on people is vital. It is likely that changes in the number of bacterial nfections will change with changes in wastewater on beaches and in nearshore waters. Obtaining these data is a challenge, however, this change is likely to be observed within 1 year of upgrade completion.

Coral Size: A range of sizes from young recruits to large mature coral colonies is a desirable outcome for a healthy reef to ensure habitat is suitable for its perpetuation. Recent studies demonstrating that this indicator is important for recovery (Jackson et al. 2014), water quality (Cooper et al. 2009), and resilience (McClanahan et al. 2012) warrant continued evaluation of size frequency distribution at Puakō. This indicator may respond before improvements in coral cover are observed with changes observed within 7 years of upgrade completion.

Vacation Rentals: Both coastal water quality and the perception thereof likely influence the decisions of visitors to Hawaiʻi when renting properties. Puakō has a number of locally managed vacation rentals, and changes in the desirability of these properties to visitors will demonstrate the extent to which changes in perception and water quality measurements impact visitor behavior. This change is likely to be observed within 3 years of upgrade completion.

Media: Media is considered press coverage in print, television, radio, and online fora. This objective depends on effective press engagement. Changes in the number of positive media stories for Puakō over the course of and subsequent to upgrade completion are likely to be observed within 3 years of completion.

Community Pride: A proud community demonstrates resilience and cohesion in the face of adversity. The amount of wastewater present at the shoreline is likely to impact community pride. Change is likely to be observed within 3 years of upgrade completion.

Cultural Practice: Described by workshop participants as pono ocean use, or use that "is respectful of the traditional Hawaiian practices and that maintains the resource for the future." Puakō's cultural practice include gathering food at the shoreline for consumption, sharing, and sale. Sharing is a particularly important part of pono fishing in Hawaiʻi and constitutes a significant portion of catch allocation based on interviews with fishers in Puakō (UHH Giddens 2009). Fishing catch and effort can be useful metrics to evaluate resource condition and utilization (Friedlander and Parrish 1991; Friedlander et al. 2013). Pono practice is likely to change as wastewater present in coastal areas changes. This change is likely to be observed within 3 years of upgrade completion.

SCENARIO NOTE

Objective development was subsequently utilized to develop priority indicators to inform a monitoring plan – the purpose of this document. The objectives table demonstrates that objectives will vary somewhat between the four potential implementation scenarios because different scenarios will have different wastewater reduction outcomes. Based on the assessment of workshop participants and the Puakō Clean Water for Reefs Advisory Group, the Onsite Treatment Facility and Kalahuipuaʻa Lagoons scenario, if properly managed and maintained, will have similar outcomes. A potential unknown regarding the Kalahuipuaʻa Lagoons scenario is summarized in the Identify Alternatives section of this document.

The 100% Best Technology ATU scenario is likely to generate positive outcomes for many of the measures, but current technology is not likely to reduce nutrients as quickly or effectively as the first two scenarios which will influence multiple measures (e.g. Algal Abundance, Coral Cover, and Coral Size). Best Technology is important. For instance, if chlorine tablets are used to eliminate pathogens to reach the Fecal Indicator Bacteria objective, chlorinated water that reaches coastal areas is likely to negatively impact marine life further eroding ecological objectives. Best Technology must include well-designed leach fields that cannot seep into coastal or groundwater and ultraviolet (UV) disinfection.

The 35% ATU scenario likely provides the smallest amount in improvement in environmental, socio-economical, and cultural benefits. Because it constitutes a subset of households able to acquire wastewater treatment upgrades (~70 homes), it will likely impact community cohesion. Workshop participants were concerned that, rather than improving conditions, it is conceivable that an incomplete transition could further divide the Puakō community by perpetuating different classes of homeowners.

Similar methods of evaluation are considered for each scenario, but the outcomes will be different depending upon what decision-makers capable of charting and navigating the course for Puakō wastewater upgrades decide.

Indicators

Table 3. Indicators	
Measure	**Indicator**
Nutrients	At minimum, **Total Dissolved Nitrogen (TDN) and Total Dissolved Phosphorous (TDP)[1,3] concentration (µM);** IDEALLY would also include nitrate + nitrite, ammonium, phosphate, and silica[3]
Engagement	Number of people who attend community meetings and activities[3], participate in community groups[3], and/or are willing to be community leaders
Bacteria	Enterococcus and Clostridium colony forming units (CFUs)[2,3]
Ocean Use	Number of ocean users observed at priority areas[3]
Nitrogen 15	Nitrogen 15 isotope concentration in algal tissue[3] in parts per million (ppm)
Awareness	Ranked priority of wastewater treatment issue among other issues of potential concern
Algal Abundance and Interaction	% cover of algal mats[1,3] and density of algal mats **AND** frequency and severity of coral/algal interactions[1,3]
Ocean Health	Perception Ocean and Human Health
Property Value	Assessed market value of homes in Puakō relative to comparable areas in United States Dollars (USD)[3]
Coral Cover	% live coral cover[1,3]
Human Health	# of pathogenic ocean health-related issues/yr.
Coral Size	Hard coral colony size structure (size/frequency distribution) for *P. lobata and P. meandrina* (cm)[1,3]
Vacation Rentals	Number of rentals over time[3]
Media	Number of positive articles published[3]
Community Pride	Perception of pride in community
Cultural Practice	# of fishers/day and gear types[3] **AND** number of fish caught per member of family
[1] aligns with USCRTF Watershed Partnership Initiative Priority Ecosystem Indicators [2]aligns with US EPA and HDOH Water Quality Indicators [3]aligns with existing Puakō dataset	

Table 3 depicts indicators to evaluate objectives. Indicators represent the general metric that will be used to evaluate progress toward objectives Metrics are included for some indicators to provide clarity.

Indicators represent what measurements are important throughout the wastewater upgrade process. Repeated measures of indicators can track changes over time. Most of these indicators will need to assessed before, during, and after upgrades to evaluate success.

Ranked Indicators

Table 4. Ranked Indicators		
Socio-Economic	Rank	Ecological and Cultural
Community Engagement (CE)	1	Nutrient Concentration (NC)
Ocean Use Levels (OU)	2	Fecal Indicator Bacteria Counts (BC)
Awareness of Wastewater Issue (AW)	3	Nitrogen 15 Concentration (N15)
Perception of Ocean Health (OH)	4	Algae - Abundance and Cover (AC)
Property Value (PV)	5	Algae - Interaction w/ Coral (AI)
Vacation Rentals (VR)	6	Percent Hard Coral Cover (PC)
Pathogenic Ocean Health Cases (PA)	7	Hard Coral Size Frequency Distribution (CS)
Community Pride (CP)	8	Fishing Catch, Effort, and Sharing (FC)

Table 4 shows the ranked indicators (and 2-letter code designator) derived through group consensus based on the criteria of constituency, partnership, and sufficiency as defined in the process section of this document.

Derivation of ranked indicators increases plan efficiency by establishing clear priorities for evaluation of project success. As described in the Ranked Indicators section of this document, socio-economic indicators were ranked relative to other socio-economic indicators and eco-cultural indicators were ranked relative to other eco-cultural indicators leading to dual priority indicators for each rank. Indicator priority can inform resource allocation for monitoring.

In some cases, measurement can occur at the same time for multiple indicators. Both Coral and Algal Cover, for instance, can be determined from a single quadrat or photograph, and therefore there is an economy of scale for the combined indicators which was not considered during ranking.

Conversely, some indicators may require additional metrics not considered during the workshops. For instance, the Citizen Science water quality monitoring methods include additional properties of water beyond nutrient and bacteria concentrations such as turbidity, temperature, salinity, dissolved Oxygen, and acidity. These indicators were not considered during the workshop, but are required by the Department of Health and the Environmental Protection Agency for accredited citizen science programs. Therefore, although they are not ranked priorities, they may be necessary to conduct monitoring under this plan.

Ranked indicators were assessed based on the extent to which community members can collect and manage data generating professional research and citizen science methods as reported in the next section.

Monitoring Methods

All monitoring methods were derived based on the assumption of project success as measured by the initiation of operations of upgraded wastewater technology at Puakō. Unless otherwise specified, before and after timelines are centered on the onset of operations[3] (e.g. 2 years before – 3 years after). Unless otherwise specified, data will be stored in a database or spreadsheet developed by the PI, analyzed to demonstrate spatial and temporal trends, and shared as appropriate to communicate results, inform further research, or adapt implementation. Data sharing and communication may require agreements not considered in the budgets and timelines herein. The methods in this document are not comprehensive or exclusive – they are designed to effectively demonstrate change, should it occur.

Each method description contains the following information for the assessed indicator:

- *Existing data* may represent extant complementary or comparable datasets, and represents an efficiency in data collection and/or an indication of why specific methods can enhance rigor.
- *Design* is a detailed description of monitoring methods.
- *Annual Cost* is an informed estimate of the actual cost of monitoring.

In some cases, *additional recommendations* are included for consideration.

Professional Research Science Monitoring

Although volunteers may be able to support professional evaluation in some instances, professional research science methods are led by experienced, accredited professionals who are directly involved in monitoring (Table 5).

Nutrient Concentration (NC) is a measure of nutrient concentrations present in water samples. Excess nutrients may harm coral reefs by providing a competitive advantage to macroalgae, inhibiting coral larvae settlement, fueling harmful algal blooms, and altering coral reproduction. TDN and TDP are measures of the total concentration of all the dissolved forms of Nitrogen and Phosphorous present in a sample, and are used by engineers, regulators, and scientists to characterize water quality. Methods for sampling TDN and TDP adhere to Priority Ecosystem Indicators identified by the USCRTF Watershed Working Group Metrics Subcommittee to ensure comparability with USEPA National Coastal Condition Assessment data.

Existing Data: Nutrient data at Puakō, Wailea, and adjacent resorts (Mauna Kea, Hapuna Prince, Fairmont Orchid, Mauna Lani) currently exist from studies by Cornell University (2013), and

[3] The iterative scenario for partial ATU replacement is not tied to a fixed date of infrastructure completion and monitoring should be initiated as soon as a determination is made that partial ATU upgrades are the most viable scenario.

ongoing studies by UHH and TNC (2014- present), and Seattle Aquarium (2017) TDN and TDP. Appendix B is a report from UHH on 2017 monitoring.

Design: Bimonthly sampling at 8 sites to begin 2 years prior and continue for 3 years subsequent to implementation.

Surface and benthic (0.5 m above reef) samples collected at low tide at stations with previously established high and low levels of sewage indicators using acid cleaned, triple-sample rinsed polyethylene bottles (250 mL - 1 L) or 60 mL plastic syringes. Samples can either be filtered in the field or laboratory into plastic centrifuge tubes (15-60 mL) through muffled (500 C for 6 h) 25- or 4-mm GFF. Whether samples are filtered in the field or laboratory, samples need to be immediately chilled during transport. All filtered samples should be stored frozen until analysis. Samples should be analyzed within three months of collection. TDN (DL 5.0 µmol L^{-1}, ASTM D5176) will be analyzed by high-temperature combustion, followed by chemiluminescent detection of nitric oxide (Sharp et al. 2002). TDP (DL 0.5 µmol L^{-1}, USGS I-4650-03) will be analyzed via autoanalyzer (e.g. Pulse TechniconTM II) using standard methods.

Annual Cost: $20,000 without control site; $27,000 with control site. Personnel cost for researcher and student technicians, transportation, supplies (e.g. filters, vials), and lab analysis fees (https://hilo.hawaii.edu/~analab/). Sampling can occur in conjunction with FIB and/or N15 sampling if applicable.

Additional Recommendation: Resources permitting, it is recommended that additional nutrient data be collected in conjunction with sampling to provide a fuller understanding of coastal water quality. Specifically, dissolved inorganic nutrients are assimilated by reef organisms providing a direct link between water quality and coral reef condition. Methods for collecting dissolved inorganic nutrient samples is the same as described above for TDP. The only thing that differs is the analytical method used for detection. Standard autoanalyer methods will be used for NO_3^- + NO_2^- [Detection Limit (DL) 0.07 µmol L^{-1}, USEPA 353.4)], NH_4^+ (DL 0.36 µmol L^{-1}, USEPA 349), PO_4^{3-} (DL 0.03 µmol L^{-1}, USEPA 365.5), and H_4SiO_4 (DL 1.0 µmol L^{-1}, USEPA 366). Nutrient analyses will be conducted at the Analytical Laboratory at the UHH.

Ocean Use (OU) is a measure of the number of people engaged in activities at the shoreline and in the water. Changes in ocean use in response to measured or perceived changes water quality can be used to evaluate project success.

Existing Data: Daily ocean use data for Paniau and Puakō Access 152 date back to 2007.

Design: Observations will be made daily at all priority coastal access sites in Puakō/Wailea by one or more individuals trained in replicable coastal use sampling protocols (Lamson 2010) according to a randomized time schedule. For each priority beach access site, surveyors will use a standard datasheet to record environmental conditions and the number and type of ocean activities using predetermined categories such as hiking, camping, sunbathing, wading, diving, snorkeling, and spearfishing. Counts will be snapshots of activity collected immediately upon reaching survey points. Surveyors or coordinator will enter data into a database. Data will be evaluated annually.

Annual Cost: $15,000. Cost includes a contract for part time coordinator to conduct survey training, support, data management, analysis and reporting. Does not include contract administration cost.

Fecal Indicator Bacteria Concentrations (FIB) are standard indicators used by HDOH and USEPA to determine the safety of coastal areas for swimmers and beachgoers. *Enterococcus* spp. (Ent.) and *Clostridium perfringens* (Clos.) are standard FIB for harmful viruses, bacteria, and protozoa associated with wastewater. Soils, seaweeds, plants, and other animals are non-wastewater sources of Ent. that can confound the interpretation of Ent. concentrations relative to sewage pollution (Byappanahalli et al. 2012). Additionally, Ent. can multiply in seawater to a concentration above initial pollution levels. Hence, HDOH uses Clos. as a secondary FIB. Clos. is present in large numbers in human and animal feces. It is an anaerobic bacterium that does not multiply in oxic seawater, and is spores can persist in the environment after a sewage spill. A scale has been developed to characterize Clos. concentrations relative to the sewage pollution type: non-point source (i.e., cesspool, septic tanks) and point source (sewage treatment plant) (Fung et al. 2007).

Existing Data: Currently, HDOH samples one station at Puako regularly. TNC, Cornell University, and Seattle Aquarium have Ent. data for multiple areas of Puakō and Wailea Bay, and adjacent resorts (Mauna Kea, Hapuna Prince, Fairmont Orchid, Mauna Lani). UHH has Clos. data for their stations at these locations.

Design: Bimonthly triplicate sampling at 8 sites to begin 2 years prior and continue for 3 years subsequent to implementation.

Shoreline surface and benthic (0.5m above the benthos) water samples will be collected in 1-L sterile polypropylene[4] bottles, triple rinsed in sample water prior to collection, in the morning at the same stations where nutrient samples are collected. FIB samples must be stored on ice during transport to the laboratory and processed within 6 hours of collection. Ent. will be analyzed using the Enterolert MPN method (IDEXX Laboratories, Inc.). Clos. will be quantified using membrane filtration (Bisson and Cabelli 1979). A high number of replicate samples is needed due to the high environmental variability of this parameter.

Annual Cost: $6,000 with volunteer support; $8,000 without volunteer support. Cost includes student/technician salary, fringe, sampling and lab processing supplies, and transportation. Sampling can occur in conjunction with NC and/or N15 sampling if applicable.

[4] autoclavable

Awareness of Wastewater Issue (AW) is a measure of the perception that wastewater is an important issue for the community. Perception is often a leading indicator and changes thereto can be measured prior to the documentation of significant differences in ecological indicators.

Existing Data: None.

Design: Surveys administered before and after upgrade completion. A survey instrument will need to be developed and the community polled using one or more of the following methods – mail survey, phone survey, focus group survey. By administering surveys to a representative sample of the Puakō community before and after implementation, changes in awareness can be documented and these perceptions incorporated into communications strategies. The survey instrument will be designed by social science researchers and administered by trained individuals to ensure accurate results.

Annual Cost: Unknown cost of survey design/polling/focus groups/analysis. $300 for printing costs. Survey can occur in conjunction with OH and/or CP as applicable.

Nitrogen 15 in Algae (N15) is **t**he ratio of stable nitrogen isotopes in algal tissues and a well-established method used to identify sources of coastal nitrogen pollution. Wastewater has a high ratio of ^{15}N to ^{14}N. The isotopic composition of macroalgal tissues reflects the isotopic composition of the N they consumed because these plants minimally discriminate between ^{14}N and ^{15}N during uptake (Costanzo et al. 2005). Therefore, wastewater has a very positive $\delta^{15}N$ value compared to other nitrogen sources, like fertilizers, N_2-fixing plants, and soils. For instance, treated sewage has $\delta^{15}N\text{-}NO_3^-$ values ranging from +10‰ to more than +20‰, while fertilizers produced from atmospheric N_2 range from 0‰ to +3‰; soil N ranges from +2‰ to +5; and atmospheric N_2's value is 0‰ (Wiegner et al. 2016). Hence, $\delta^{15}N$ algae measurements have been used in Hawaii to document nearshore sewage pollution, both from sewage injection wells and cesspools (Smith and Smith 2006; Dailer et al. 2010; Wiegner et al. 2016).

Existing Data: $\delta^{15}N$ algal samples have been collected at Puakō, by UHH, Cornell University, and Puakō community volunteers.

Design: Bimonthly sampling at 8 sites to begin 2 years prior and continue for 3 years subsequent to implementation.

Predominant macroalgae will be collected at all stations and analyzed for $\delta^{15}N$. Approximately a palm-full of tissue will be placed in plastic baggies with water from the station, and transported to a laboratory in a cooler on ice for processing and analysis. Prior to drying the samples , a subsample of the algal tissue will be taken and and preserved as a voucher specimen. Specimens will be identified to species or the nearest taxonomic level.

Subsamples will be dried in aluminum weight boats at 60° C until a constant weight is achieved. Dried algal tissue samples will be ground and homogenized using Wiglebug, and ~2 mg of macroalgal tissue folded in 4x6 mm tin capsules for stable isotope analysis. $\delta^{15}N$ analysis will be conducted using an isotope ratio mass spectrometer (IRMS). Data will be reported relative to $\delta^{15}N$ of internationally accepted standards using the notation: $\delta^{15}N = R_{sample}-R_{std}/R_{std} \times 1000$, where R = ratio of ^{15}N:^{14}N in the sample or standard (std).

$\delta^{15}N$ values in the macroalgal tissues will be compared to $\delta^{15}N$ values from all potential N sources (sewage, fertilizers, up-mountain groundwater, Kiawe) to coastal waters at Pūako to determine whether sewage N is being assimilated by the macroalgae.

Annual Cost: $2,000 with volunteer support; $3,300 without volunteer support. Cost for sample collection and analysis includes: student/technician salary, fringe, sampling supplies, vehicle rental and fuel, and analytical fees for analyses (https://hilo.hawaii.edu/~analab/, see price list). Sampling can occur in conjunction with NC and/or FIB sampling if applicable.

Perception of Ocean Health (OH) changes will likely precede measurable changes in ocean health. Derivation of this indicator will be facilitated by a participatory survey instrument developed to evaluate how the health of the ocean is perceived as well as the relationship between this perception and the perception of human health.

Existing Data: None

Design: Ocean health perception will be evaluated by a survey administered before and after infrastructure upgrades (and perhaps during) and/or via focus group(s). The target sample group will be the Puakō community and the survey will be developed to quantify the perception of ocean health and its link to human health at Puakō.

Annual Cost: Unknown. Dependent upon survey instrument and sampling design. Costs include personnel, field supplies, and transportation for data collection, analysis, and reporting. This survey may be combined with OA and/or CP monitoring.

Algae – Abundance and Cover (AC) is the amount of algae present on the reef. Reef algae is directly linked to elevated nutrients, and related to herbivore population.

Existing Data: DAR Kona has algal cover data at a single site in Puakō since 2000 and 25 other comparable sites in West Hawai‘i; TNC and UHH have data on algal percent cover at 12-16 stations at Puakō, Wailea, and Mauna Lani, as well as a characterization of the entire Puakō reef from previous fish and coral baseline studies and similar data at 20 comparable sites in N. Kona-S. Kohala. No data yet exists on algal height in Puakō.

Design: Bi-annual surveys of eight stations (2-4 m depth) paired with parallel to NC, FIB, and N15 sites to begin 2 years prior and continue for 3 years subsequent to implementation.

Calibrated scientific divers will deploy 25-m transects at a fixed point for each survey and take photographs of the bottom at a standard height at every meter (n=25). Photos will be analyzed using Coral Point Count with Excel extensions (CPCe) or similar software. Algae will be identified to the lowest possible taxon at randomly generated points within each photograph to yield a percent cover. To analyze turf algae height/thickness, a power analysis will determine the sampling effort prior to surveys. Height will be measured with a ruler at predetermined sites along each transect. Algal biomass will be calculated as the product of percent cover and height (Steneck et al 2014).

Annual Cost: $17,500. Cost includes personnel, field supplies, and transportation for data collection, analysis and reporting. Surveys can occur in conjunction with AI, PC, and/or CS monitoring if applicable, although more time will be required to evaluate AI and CS.

Algae Interaction with Coral (AI) is a more sophisticated evaluation technique that can identify sub-lethal impacts of algae on corals using coral health monitoring techniques. Several types of algal overgrowth may occur on stressed coral colonies that will not be detected in algal or coral cover data. Data collection for this indicator requires specialized observer training and more time *in situ*.

Existing Data: TNC has data on algal coral interactions at 12 stations in Puakō and Mauna Lani, and 19 additional sites in the region including multiple transects at Pelekane Bay and Kīholo-Ka‘ūpūlehu.

Design: Bi-annual surveys at eight stations at 2-4 m depth parallel to NC, FIB, and N15 sites to begin 2 years prior and continue for 3 years subsequent to implementation.

Calibrated scientific dive surveyors will record the prevalence of algal interactions that occur within $1m^2$ quadrats at each meter of a 25-m transect line, identifying and recording the general type of algae and species of coral affected at each occurrence.

Annual Cost: $5,500 combined with AC - $23,000 stand alone. Cost includes personnel, field supplies, and transportation for data collection, analysis, and reporting. Surveys can occur in conjunction with AC, PC, and/or CS monitoring if applicable - more time will be required to evaluate CS.

Percent Hard Coral Cover (PC) is an indicator that has declined in Puakō over the last 40 years. It represents a legacy indicator of coral reef condition in Hawai‘i due to the large amount of spatial and temporal data available for comparison. By measuring the percentage of live hard coral cover in a location over time, conclusions about the survival and growth of hard coral can be approximated. The ease of data collection, combined with its utility, make this an important indicator despite the amount of time necessary for slow-growing hard corals to respond to changes in environmental conditions (several years to decades). Improvements in hard coral habitat are a primary goal of this initiative, so extending monitoring for this indicator to at least eight (and preferably ten) years is justifiable.

Existing Data: DAR Kona has coral cover data at a single site in Puakō since 2000 and 25 other comparable sites in West Hawai‘i; TNC. TNC has coral cover data in Puakō dating back to 2009 and at over 30 comparable sites. UHH, UH, and private contractors have been collecting coral cover data in Puakō since 1973.

Design: Bi-annual surveys of eight stations (2-4 m depth) paired with parallel NC, FIB, and N15 sites to begin 2 years prior and continue for 10 years subsequent to implementation.

Calibrated scientific divers will deploy 25-m transects at a fixed point for each survey and take photographs of the bottom at a standard height at every meter (n=25). Photos will be analyzed using Coral Point Count with Excel extensions (CPCe) or similar software.[5]

Hard coral will be identified to the lowest possible taxon at randomly generated points within each photograph to yield a percent cover. By tracking hard coral cover over time, longer term changes in benthic community structure will be evaluated.

Annual Cost: $1,500 combined with AC - $17,500 stand alone. Cost includes personnel, field supplies, and transportation for data collection, analysis, and reporting. Surveys can occur in conjunction with AC, AI, and/or CS monitoring if applicable – more time will be required to evaluate AI and CS. Note that surveys could occur less frequently after the initial period of intense data collection (through year 3), with annual rather than bi-annual surveys adequately demonstrating long term trends.

Pathogenic Ocean Health Cases (PA) may be indicative of changes associated with wastewater treatment upgrades, but proved to be the most challenging indicator to evaluate by monitoring planners for a variety of reasons. Valid concerns ranged from the legal and institutional sensitivity of personal health information to the practicality of training hospital staff to take on non-critical tasks. Along with confounding influences to shared data such as individual susceptibility, non-wastewater related occurrence of pathogens in the environment or on individuals, accuracy of subjects' recollection, and the geographic precision associated with pinpointing the source of infections that may take several days to manifest, it this indicator is daunting to measure[6]. However, because it focuses on human health, the importance of this indicator to community and decision-makers warranted its inclusion.

Existing Data: None available for Puakō.

Design: Therefore, the determined method for gathering these data in Puakō is to conduct a field survey of beachgoers and homeowners. This survey will be designed to document past occurrences of waterborne infections respondents associate with Puakō. Surveys will be

[5] Field methods identical to AC and can be conducted simultaneously.

[6] Although UHH researchers have provided training to Hilo Hospital's infectious disease nurse and designed a survey to quantify MRSA cases geographically, the lack of a single medical facility likely to service Puakō beachgoers pre-empts utilizing this methodology.

conducted at least once before and once after implementation is complete – ideally annually - to track trends. The homeowner survey can be administered by CORAL staff or a community coordinator. The beach intercept survey can be administered by an undergraduate student or community volunteer. Data will be entered by students and analyzed by researchers.

Annual Cost: $1,000 for a student led Senior Thesis project - $2,500 for a volunteer supported professional research project. Cost includes personnel, field supplies, and transportation for data collection, analysis, and reporting.

Hard Coral Size Frequency Distribution (CS) is a robust indicator of the trajectory of coral reef ecosystems and enhances the ability to document and justify action to address coral reef impacts prior to coral mortality. This indicator is a pro-active complementary measure that indicates changes prior to percent hard coral cover (PC). A diverse representation of hard coral species at various sizes is indicative of a coral community that is well positioned for future survival and that is more likely to be resilient to stochastic events than ecosystems where one of more size classes are underrepresented.

Existing Data: TNC has data on this indicator for 12 stations at Puakō and Mauna Lani since 2013, as well as additional sites at Puakō, Pelekane, Kīholo, and Ka'ūpūlehu since 2011 and 20 comparable reef locations in N.Kona and S. Kohala inclusive of those areas in 2015.

Design: Annual monitoring of eight stations (2-4 m depth) paired with parallel NC, FIB, and N15 sites to begin 2 years prior and continue for 10 years following implementation.

Calibrated scientific dive surveyors using standard data sheets will record the species and size of all hard coral colonies to the nearest 5 cm, ensuring that small (<5cm) recruiting coral colonies are recorded within four 1-m^2 quadrats along a transect line.

Annual Cost: $1,500 if combined with AI surveys - $19,000 for a stand-alone project. Cost includes personnel, field supplies, and transportation for data collection, analysis, and reporting. Surveys can occur in conjunction with AC, AI, and/or PC monitoring if applicable – more time will be required to evaluate AI.

Community Pride (CP) is an indicator of cohesion and success for community-based initiatives. In the context of Puakō, community members feel as though it is their responsibility to care for the place they are privileged to live. The Hawaiian concept of kuleana is a traditional representation of this value, which can be evaluated to see how operations are affecting residents. By embracing kuleana and taking action, community pride can drive positive change in Puakō and beyond.

Existing data: None.

Design: After its attributes are defined by social scientists, community pride will be evaluated by a survey administered before, during, and after operations begin and/or focus groups. The sample group will be the Puakō community and the survey will be developed to quantify the perception of ocean health and its link to human health at Puakō.

Annual Cost: Unknown. Dependent upon social science survey design. Cost must include personnel, field supplies, and transportation for data collection, analysis, and reporting. This survey may be combined with the OA, OH and/or AW survey instruments.

Positive Press (PP) is an indicator of the attention Puakō receives from the media. Newspaper articles have highlighted the challenges Puakō faces with wastewater and tracking the content of future articles to quantify positive messages related to community and ocean health will both promote the success of Puakō and provide a measure thereof.

Existing data: CORAL's media team has compiled Puakō articles and stories.

Design: Articles will be tracked before, during, and after operations. Efforts will be made to share results with print and television media to influence article content. Comparing the number of positive articles over time will demonstrate the benefit of upgrades and spread the message of success.

Annual Cost: $1,500. Includes staff time to compile and analyze media data.

Fishing Catch, Effort, and Sharing (FC) are indicators of resource utilization and provisioning that relate to marine life health and abundance. If these activities are pono,[7] harvest is self-regulated to ensure abundant resources for others. Evaluating changes in pono practice in Puakō over time will provide insight into the positive impact that a united community taking action to improve ocean health has on the type of harvest activities that occur.

Existing data: TNC contracted a UHH Master's student to conduct a 12-month creel survey in 2008-2009 that could constitute a baseline against which to measure change (Giddens, 2009).

Design: Two rounds immediately before and 3-5 years following operations are recommended. Sampling design will consist of observations of and interviews with fishers at Puakō based on a randomly stratified schedule over a 12-month period. Fishing gear type, start, and end time will quantify effort. Catch will be evaluated by measuring fish caught by willing fishers. During interviews, fishers will be asked for information about their point of origin, catch disposition, and knowledge of pono practice relevant to Puakō. Due to data sensitivity of detailed landings information, it will be shared with the Puakō community prior to sharing externally.

Annual Cost: $40,000 with full time volunteer support - $110,000 stand-alone. Includes staff time to provide training, conduct surveys, compile, and analyze data, supplies, transportation, and incentives for survey participants.

[7] as defined during the planning workshop – see Cultural Practice

Monitoring Methods Table – Professional Research Science

Table 5. Professional Research Science Puakō Measures Monitoring Plan Development Table						
Code	**Indicator**	**PI/Lead**	**Method/Design**	**Scope**	**Frequency**	**Annual Cost**
NC	TN and TP	UHH TNC	Autoanalyzers using EPA and USGS Methods 2 years before - 3 years after operations begin*	8 Sites @ Puakō/Wailea shoreline and ML Wells (alternative 2 requires shoreline control site)	bi-monthly	$20,000 - $27,000[1]
OU	# ppl using ocean and how	PCA, TNC	Randomized coastal use survey at priority access sites documents # ppl engaged in activities	Puakō/Wailea shoreline access sites	Daily	$15,000
BC	CFU's	UHH	Sampling 2yr before - 3 yr after* IDEXX Analyzer - *Enterococcus;* Membrane - *Clostridium*	8 Sites @ Puakō/Wailea shoreline - 3 samples per site	bi-monthly	$6,000[2] - $8,000
AW	Ranked priority of wastewater issue	TNC PRFirm CORAL	Survey at Puakō meeting(s) to derive ranked priority of issues of concern + Focus groups	Puakō/Wailea community meetings and events	annual	$300 plus survey design, polling, focus groups, analysis
N15	Nitrogen 15 concentration in algal tissues	UHH	Sample algae from coastal sites and use IRMS to calculate concentration 2yr pre-3yr post*	8 Sites @ Puakō/Wailea shoreline - 3 samples per site	bi-monthly	$2,000[2] - $3,300
OH	Awareness of Ocean Health	TNC PRFirm CORAL	Survey at Puakō meeting(s) to derive ocean health perception + Focus groups	Puakō/Wailea community meetings and events	annual	combine w AW at little cost
AC	Algae % cover and height	TNC HIMB	$1m^2$ photoquadrats every meter along fixed 25m transects; algal height measured along transect 2yr pre-3yr post*	8 sites @ Puakō/Wailea adjacent to WQ sites (2-4 msw)	bi-annually	$17,500
AI	Algal coral interaction	TNC HIMB	record coral algal interactions w/in $1m^2$ quadrats every meter along ixed 10m transects 2yr pre-3yr post*	8 sites @ Puakō/Wailea adjacent to WQ sites (2-4 msw)	bi-annually	$5,500[3]-$23,000

Table 5. Professional Research Science Puakō Measures Monitoring Plan Development Table cont'd						
Code	**Indicator**	**PI/Lead**	**Method/Design**	**Scope**	**Frequency**	**Annual Cost**
PC	Hard Coral % Cover	TNC HIMB	$1m^2$ photoquadrats every meter along fixed 25m transects; 2yr pre-8yr post*	8 sites @ Puakō/Wailea adjacent to WQ sites (2-4 msw)	bi-annually	$1,500[3]-$17,500
PA	# of Pathogenic ocean health cases at Puakō	UHH	Compare MRSA infections at Puakō 2yr pre-3yr post*	Puakō/Wailea Bay	annual	$1,000[4] - $2,500[5]
CS	Hard Coral Size/Frequency	TNC	4 x $1m^2$ quadrats along 10-25m transect 2yr pre-3yr post*	Puakō/Wailea Bay	annual	$1,500[6] - $19,000
CP	Perception of Community Pride	UH CORAL	Survey administered prior to and after operations to track change in pride	Puakō/Wailea Bay	annual	combine w/ AW at little cost
PP	Positive Press	CORAL	Track number of positive articles about Puakō over time prior to and after operations	Puakō/Wailea Bay	annual	$1,500
FC	Fishing catch, effort, and sharing	TNC CI	Randomized interview survey of fishers at Puakō to derive catch, effort, disposition, and demographic data before/after	Puakō/Wailea Bay	10days/mo. X 24 months	40,000[2] - $70,000

[1]Cost of adding control site for Kalahuipuaʻa Lagoons scenario
[2]Cost if volunteer support available
[3]Cost combined with AC or PC monitoring
[4]Cost of senior thesis student beach intercept interview survey
[5]Cost of professional researcher led volunteer data collection survey
[6]Cost of combined with AI
*infrastructure upgrade completion except partial ATU

Table 5 represents the social and ecological research science monitoring methods for evaluation of project success. Research science denotes science conducted by professional researchers. Code refers to Table 4 where indicators were summarized by two letter codes. Indicator is the type of measurement to be conducted. Method/Design includes the timeline of measurement and survey instrument. Scope is the geography over which measurement will occur. Frequency is the period of measurement. Annual cost is a cost based on actual numbers provided during the workshop based on previous budgets.

Citizen Science Monitoring

Citizen science volunteers are engaged community members with time and interest to support data collection and management. Programs throughout Hawaiʻi demonstrate that residents and ocean goers are not only able to support data collection, but trained volunteers are capable of collecting data that meets rigorous research and regulatory standards. Not only can residents and practitioners who know their place intimately support researchers to identify sensitive areas, impacts, and seasonal trends, but they can carry research results back into the communities they represent, reaching groups and individuals who may not read reports and scientific articles.

For the following indicators, citizen scientists provide a higher level of support, including quality assured field data collection and sampling, transportation, data entry, analysis, evaluation, reporting, and communication. With proper design and implementation, citizen science methods can reduce project costs, ensure community participation, improve communication between scientists and residents, and build local capacity for taking action.

Community Engagement (CE) is an indicator of community participation. An engaged community participates actively in governance, planning, decision-making, and communicating results. Because community support is vital to the success of wastewater upgrades at Puakō, it is both a leading and a trailing indicator; community engagement must be increased for the project to succeed (leading), and the increase in community engagement subsequent to the project is a demonstration of success (trailing). A simple proxy for community engagement is participation in community meetings. The Puakō Community Association (PCA) Board of Directors hosts a community meeting annually and invites the entire community to join. Attendance is recorded on sign-in sheets.

Existing Data: Puakō annual meeting attendance is tracked by the Puakō Community Association via sign-in sheets.

Design: Comparing meeting attendance before, during, and after wastewater upgrades become operational will give an indication of the level of engagement of the Puakō community. The existence of this data and a mechanism for its continued collection means that this indicator will require the fewest resources to track.

Annual Cost: N/A. A request from CORAL to the Puakō Community Association for annual meeting attendance will fulfill the data necessary to monitor this indicator.

Nutrient Concentration (NC) sampling can be conducted by well-trained and supported citizen scientists following the Hui O Ka Wai Ola Quality Assurance Project Plan. Collaborators at The Nature Conservancy, Maui Nui Marine Resource Council (MNMRC), West Maui Ridge to Reef Initiative, and UH Maui College formed Hui o Ka Wai Ola, which trains and organizes citizen scientists to collect quality assured data. Using this framework and that of the National Water Quality Monitoring Council, Puakō citizen scientists can provide quality assured data to support

Hawai‘i Department of Health (HDOH) regulatory compliance.

Existing Data: CORAL conducted training on citizen science collected nutrient data in Puakō in July 2017. Similar programs that engage community members in collecting actionable samples are underway in Maui and Oahu.

Design: Methods will align with the Hui O Ka Wai Ola Quality Assurance Project Plan (QAPP) and include monthly and post-storm sampling at 6 stations (3 in Puakō and 3 outside) two years prior to the sewage treatment upgrade project implementation, and 3 years after operations begin. At least two stations will be located at hot spots for groundwater and wastewater indicators based on TNC and UHH research, and a third at a relatively comparable geographic distance from the hot spot sites. Three adjacent sites will be selected at relatively comparable distances from one another.

Water samples will be collected in triple-rinsed 125 mL bottles at the 0.1m depth.

Samples can either be filtered in the field or laboratory into plastic centrifuge tubes (15-60 mL) through muffled (500 C for 6 h) 25- or 4-mm GFF. Whether samples are filtered in the field or laboratory, samples need to be immediately chilled during transport. All filtered samples should be stored frozen until analysis within 28 days of collection.

If the UHH lab is used for processing, TDN (DL 5.0 µmol L^{-1}, ASTM D5176) will be analyzed by high-temperature combustion, followed by chemiluminescent detection of nitric oxide (Sharp et al. 2002). TDP (DL 0.5 µmol L^{-1}, USGS I-4650-03) will be analyzed via autoanalyzer (e.g. Pulse TechniconTM II) using standard methods.

Annual Cost: $20,000 plus NGO support includes compensation for training from qualified researchers, consistent support from project leads, supplies and equipment, meeting costs, and sample analysis. Sampling can be combined with BC.

Additional Recommendation: Including measurements of temperature, salinity, dissolved oxygen (DO), acidity (pH), and turbidity is desirable. These metrics can be measured in situ during nutrient sampling using the following methods. Seawater will be collected at 0.1 m below the water surface in a triple-rinsed bucket or similar collection device. Instantaneous temperature, salinity, dissolved oxygen (DO), pH, and turbidity measurements are made at the monitoring sites by the monitoring teams using hand-held instruments (e.g. Hach 40QD multiparameter portable and Hach 2100Q turbidimeter). The estimated one-time cost of measuring these additional data is $15,000 for additional training and supplies, if combined with NC sampling.

Fecal Indicator Bacteria Counts (BC) sampling can be conducted for Ent. by well-trained and supported citizen scientists. Whether in addition to, or in lieu of, research scientist led sampling, programs that engage community members in collecting actionable samples are underway in Maui and Oahu, and can meet both scientific and social goals.

Existing Data: CORAL conducted training on citizen science bacteria counts in Puakō in July 2017. Similar programs that engage community members in collecting actionable samples are underway in Maui and Oahu.

Design: Methods will align with the Hui O Ka Wai Ola Quality Assurance Project Plan (QAPP) and include monthly and post-storm sampling at 6 stations (3 in Puakō and 3 outside) two years prior to the sewage treatment upgrade project implementation, and 3 years after operations begin. At least two stations will be located at hot spots for groundwater and wastewater indicators based on TNC and UHH research, and a third at a relatively comparable geographic distance from the hot spot sites. Three adjacent sites will be selected at relatively comparable distances from one another.

At each station, sample water will be collected by placing sterile bags (e.g. Sterile Whirl-Paks Nasco B01489WA) under water, filling, and sealing. FIB samples must be stored on ice during transport to the laboratory and processed within 6 hours of collection. If UHH lab is used, Ent. will be analyzed using the Enterolert MPN method (IDEXX Laboratories, Inc.).

Annual Cost: $8,000 plus NGO support includes compensation for training from qualified researchers, consistent support from project leads, supplies and equipment, meeting costs, and sample analysis. Sampling can be combined with NC.

Property Value (PV) is expected to increase once wastewater upgrades are complete. Cesspools represent a liability when buying or selling a home as any modifications requiring permitting will require upgrades to a sealed tank individual wastewater treatment system such as an ATU at homeowner expense. As the perception of ocean health increases, property values may increase beyond the cash value of infrastructure upgrades.

Existing Data: Home values are recorded for all real estate transactions representing an existing dataset that could be utilized for comparisons over time in Puakō, Wailea, and other coastal communities in Hawaiʻi.

Design: Analyze property value data for changes in home values in Puakō, Wailea, and adjacent subdivisions (e.g. Mauna Kea, Mauna Lani) to begin 3 years prior and continue for 3 years subsequent to implementation. Compare to other communities where cesspools are present such as Wai Opae to illustrate the extent to which upgrades alter home values, providing a useful metric for the economic benefit of wastewater upgrades and helping to build support from additional sectors. Some compensation for time and support from project leads will be required.

Annual Cost: Unknown. Includes staff time or contract to conduct research.

Vacation Rentals (VR) may respond to changes in the perception of ocean health at Puakō, providing an economic incentive to increase support for wastewater upgrades in Hawaiʻi. Unmanaged increases in coastal utilization may not be desirable, but, if increased numbers of visitors are well managed, the constituency for conservation action will be strengthened.

Existing Data: Several companies manage vacation rentals in Puakō. Company records can be used to track changes over time.

Design: Work with vacation rental companies to track rental rates two years prior and three years after operations begin. Annual analysis based on inter-annual variation will be sufficient to demonstrate change.

Annual Cost: Unknown. Includes staff time or contract to conduct research.

Hard Coral Cover and Algae Cover (PC) are complementary indicators of coral reef condition in Hawaiʻi. A large amount of spatial and temporal data available for comparison. By measuring the percentage of live hard coral and algae cover in a location over time, conclusions about the stability, survival, and growth of hard coral can be derived. The ease of data collection, combined with its utility, make this an important indicator despite the amount of time necessary for slow-growing hard corals to respond to changes in environmental conditions (several years to decades). Improvements in hard coral habitat are a primary goal of this initiative, so extending monitoring for this indicator to at least eight (and preferably ten) years is justifiable.

Existing Data: DAR Kona has coral cover data at a single site in Puakō since 2000 and 25 other comparable sites in West Hawaiʻi; TNC. TNC has coral cover data in Puakō dating back to 2009 and at over 30 comparable sites. UHH, UH, and private contractors have been collecting coral cover data in Puakō since 1973.

Design: Annual surveys of 20 randomly generated stations (2-4 m depth) to begin 2 years prior and continue for 8 years subsequent to implementation.

Trained community members will establish 20 fixed sites and take photos a standard distance from the bottom. Photos will be analyzed using Coral Point Count with Excel extensions (CPCe) or similar software.

Hard coral and algae will be identified to the lowest possible taxon at randomly generated points within each photograph to yield a percent cover. By tracking hard coral and algal cover over time, longer term changes in benthic community structure will be evaluated.

Annual Cost: ~$5,000. Includes staff time for training, data entry, analysis, and reporting.

Unranked Indicators

Dye Tracer Concentrations (DT) are used to document underground connections between homes and nearby water bodies. Studies conducted by the UHH demonstrate a direct connection between current wastewater disposal technology (cesspools, septic tanks, and malfunctioning ATU's) and coastal waters at Puakō. As an indicator of success in reducing wastewater contributed to the coastal system, dye tracer concentrations are readily understandable. Based on the ranking criteria, they were not included in the top indicators derived during the workshop. They are included in this report because an out-of-the-box idea was conceived to demonstrate the magnitude of the problem at

Puakō to build support for action.

Existing Data: Individual cesspools, septic tanks, and ATU's have been tested by UHH researchers. This method differs from previous studies in that quantitative data on dye concentrations over a multi-hour/day range will not be necessary.

Design: Prior to operations, fluorescein dye distributed to all Puakō homeowners during training sessions. On a predetermined low-tide morning at a standard time, dye added to cesspools, septic systems, and ATU tanks directly, if possible, or flushed down the toilet. Homeowners and volunteers document time for dye to reach shoreline at their property. During visible peak, aerial images taken to demonstrate the presence and persistence of dye in coastal waters and shared with homeowners and decision-makers to build support for wastewater upgrades. Can be repeated subsequent to upgrades.

Annual Cost: $222,200. Includes staff time for training, photography contract, and dye for 202 homes.

Monitoring Methods Table – Citizen Science

	Table 6. Puakō Citizen Science Monitoring Plan Development Table					
Obj.	**Indicator**	**PI/Lead**	**Method/Design**	**Scope**	**Frequency**	**Annual Cost**
CE	Meeting Attendance	PCA CORAL	Compare sign-in attendance over time before and after operations begin	Puakō/Wailea community meetings and events	variable	"free :)"
NC	TDN and TDP	TKC CORAL TNC	Autoanalyzers using EPA and HI-DOH Methods 2yr pre-3yr post*	3 sites @Puakō - (2 hotspots) N/S/Mid 3 sites @ Mauna Lani - N/S/Mid	monthly & post-storm	$20,000 + NGO staff
BC	Enterococcus CFU's	UH TNC Srfrdr	Sampling 2yr pre-3yr post* IDEXX Analyzer - Enterococcus	3 sites @Puakō - (2hotspots) N/S/Mid 3 sites @ Mauna Lani - N/S/Mid	monthly & post-storm	$10,200 + NGO staff support
PV	Property Value (USD)	CORAL Realtors	Normalized real estate value at Puakō v. comparable communities 2 yr before-3y after	Puakō and adjacent coastal communities	annual	time to conduct assessment
VR	Vacation Rental Occupancy	CORAL	Compare Vacation Rental occupancy rates 2yr pre- 3yr post operation	Puakō and adjacent communities	annual	time to conduct assessment
PC	Hard Coral Cover and Algae Cover	TNC HIMB	20 1mX1m fixed photoquadrats annually 2yr before - 8yr after	20 sites @ Puakō/Wailea randomly selected 2-4fsw	annual	~$5,000
	* to begin immediately under ATU scenarios					

Table 6 represents the citizen science monitoring methods for evaluation of project success. Code refers to Table 4 where indicators were summarized by two letter codes. Indicator is the type of measurement to be conducted. Method/Design includes the timeline of measurement and survey instrument. Scope is the geography over which measurement will occur. Frequency is the period of measurement. Annual cost is a cost based on actual numbers provided during the workshop based on previous budgets.

Conclusion

Beyond outlining methods of measurement, the intent of this document is to ensure that conservation action is accompanied by honest evaluation to improve future outcomes. The authors and workshop participants hope it will further erode barriers to participatory science in support of the actions that are necessary to ensure coral reefs persist. The role of the scientific methods in this document is to evaluate action.

What works and what doesn't work? Based on what we learn, what do we do differently or more?

Puakō has been the focus of scientific studies, trainings, and education and outreach programs since the 1970's. Initial studies were focused on exploration and characterization of the remarkable coral reef. Later, studies focused on management-driven research to address observed impacts to that reef, resulting in establishment of the Puakō Fisheries Management Area by Hawai'i Administrative Rule in 1985.

The knowable causes of decline at Puakō include, but are not limited to, impacts on coral health from wastewater leaching from coastal cesspools, septic tanks, and broken ATUs. Wastewater from Puakō is impacting beaches and coastal waters at Puakō. Because risks and resource declines have been effectively demonstrated, solutions must be accelerated to address them.

More science, without bold action, will likely continue to tell the tale of decline at Puakō.

As this document conveys, a variety of indicators are warranted to evaluate the economic, ecological, and socio-cultural impact of wastewater solutions at Puakō. Ensuring that these impacts are monitored and shared will inform future community-driven infrastructure projects with expected environmental benefits. Monitoring will require investments of time and resources. Fortunately, partners are already bringing these resources to Puakō through programs, grants, and donations. These external resources enable the Puakō community to focus on action without compromising evaluation. Evaluating action by applied science in a management context at Puakō encapsulates the spirit of efforts underway throughout Hawai'i to take care of the places we love – to solve problems.

The leadership that Puakō demonstrates in tackling the challenge of upgrading outdated wastewater treatment technology is an example of what committed and dedicated citizens can do to provide tangible benefits to public resources. The scientists and researchers engaged in the process of planning for monitoring the impact of Puakō's action applaud the Puakō community and the committed supporters in academia, natural resource management, regulatory compliance and permitting, engineering, contracting, construction, real estate, education, technology, communications, and beyond who will move this project forward.

Together, we can change the fate of Puakō's reef and community – to change our behavior consciously so that Puakō remains a place of discovery, rejuvenation, and inspiration where people do not merely dwell but truly live.

The volunteer supported research community is ready to write the story of Puakō's action

so that all can understand the impact of wastewater treatment upgrades in Hawai‘i.

For more information about this plan, or to find out about volunteer opportunities, contact cwfrpuako@coral.org

References

Bisson J.W. and Cabelli V.J. 1979. Membrane filter enumeration method for *Clostridium perfringens*. Appl. Environ. Microbiol. 37:55-66.

Bruno J.F., Sweatman H., Precht W.F., Selig E.R., and Schutte V.G.W. 2009. Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. Ecology 90(6): 1478–1484.

Byappanahalli M.N., Nevers M.B., Korajkic A., Staley Z.R., and Harwood V.J.L. 2012. Enterococci in the environment. Microbiology and Molecular Biolology Reviews 76:685-706.

Cesar H.S. and Van Beukering P. 2004. Economic valuation of the coral reefs of Hawai'i. Pacific Science, 58(2), pp.231-242.

Cooper T.F., Gilmour J.P., and Fabricius K.E. 2009. Bioindicators of changes in water quality on coral reefs:

review and recommendations for monitoring programmes. Coral Reefs 28: 589-606.

Couch C.S., Garriques J.D., Barnett C., Preskitt L, Cotton S, Giddens J, and Walsh W. 2014. Spatial and temporal patterns of coral health and disease along leeward Hawai‘i Island. Coral Reefs 33(3):693-704. DOI 10.1007/s00338-014-1174-x.

Costanzo S.D., Udy J., Longstaff B., and Jones A. 2005. Using nitrogen stable isotope ratios of macroalgae to determine the effectiveness of sewage upgrades: changes in the extent of sewage plumes over four years in Moreton Bay, Australia. Marine Pollution Bulletin 51: 212-217.

Dailer M.L., Knox R.S., Smith, J.E., Napier, M., and Smith, C.E. 2010. Using δ^{15}N values in algal tissue to map locations and potential sources of anthropogenic nutrient inputs on the island of Maui, Hawai‘i, USA. Marine Pollution Bulletin 60: 655-671.

Dailer M.L., Ramey H.L., Saephan S., Smith, C.M. 2012. Algal δ^{15}N values detect a wastewater effluent plume in nearshore and offshore surface waters and three-dimensionally model the plume across a coral reef on Maui, Hawai‘i , USA. Marine Pollution Bulletin 64: 207-213.

Dailer, M., Smith C., and Glenn C. 2013. Preventing the introduction and spread of nutrient driven algal blooms and coral reef degradation in West Hawai‘i. Final project report for Hawai‘i Coral Reef Initiative Research Program.

Derse, E. et al. 2007. Identifying sources of nitrogen to Hanalei Bay, Kauai, utilizing the nitrogen isotopes signatures of macroalgae. Environmental Science and Technology 41: 5217-5223.

Flower, J, Ortiz, JC, Chollett, I, Abdullah, S, Castro-Sanguino, C, Hock, K, Lam, V, Mumby, PJ. 2016. Interpreting coral reef monitoring data: A guide for improved management decisions. Ecological Indicators 72(2017): 848-869.

Friedlander A.M. and Parrish J.D. 1997. Fisheries harvest and standing stock in a Hawaiian Bay. Fisheries Research 32(1): 33-50.

Friedlander A.M., Shackeroff J.M.., and Kittinger J.N., 2013. Customary marine resource knowledge and use in contemporary Hawai'i. Pac. Sci. 67, 441–460.

Fung D.Y.C., Fujioka R., Vijayavel K., Sato D., and Bishop D. 2007. Evaluation of Fung double tube test for Clostridium perfringens and Easyphage test for F-specific RNA coliphages as rapid screening tests for fecal contamination in recreational waters of Hawai'i. Journal of Rapid Methods and Automation in Microbiology 15: 217-229.

Giddens, J.L. 2009. Final analysis of 12 month pakini (creel) survey at Puakō. Unpublished report for Puakō Community Association.

Glenn C., Whitter R.B., Dailer M.L., Dulaiova H., El-Kadi A.I., Fackrell J., Kelly J.L., and Waters C.A. 2012. Lahaina groundwater tracer study, Lahaina, Maui. Final report to HDOH, US EPA, and US Army Engineer and Research Development Center.

Hill J. and Wilkinson C. 2004. Methods for ecological monitoring of coral reefs: a resource for managers. Australian Institute for Marine Science. 117pp.

Hughes T.P. 1994. Catastrophes, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef. *Science* **265**(5178): 1547-1551.

Hughes T.P., Szmant A.M., Steneck R., Carpenter R., and Miller S. 1999. Algal blooms on coral reefs: what are the causes? Limnology and Oceanography 44(6): 1583–1586.

Jackson J.B.C., Donovan M.K., Cramer K.L. and Lam V.V. (Editors). 2014. *Status and trends of Caribbean Coral Reefs: 1970-2012.* Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland. 304pp.

Knee K., Layton B., and Street J. 2008. Sources of nutrients and fecal indicator bacteria to nearshore water on the north shore of Kaua'i (Hawai'i USA). Estuaries and Coasts 31:607-622.

Lamson M (2010). Coastal human-use report for Puakō, Hawai'i. Report prepared for The Nature Conservancy Hawai'i. Request Report.

McClanahan T.R., Donner S.D., Maynard J.A., MacNeil M.A., Graham N.A.J., Maina J., Baker A.C., Alemu J.B., Berger, M., Campbell S.J., Darling E.S., Eakin C.M., Heron S.F., Jupiter S.D., Lundquist C.J., McLeod E., Mumby P.J., Paddack M.J., Selig E.R., and van Woesik R. 2012. Prioritizing key resilience indicators to support coral reef monitoring in a changing climate. PLoS ONE 7(8): e42884. Doi:10.1371/journal.pone.0042884.

Minton, D, Conklin, E, Weiant, P, Wiggins, C. 2012. *40 Years of Decline on Puako's Coral Reefs — A Review of Historical and Current Data (1970–2010)*. The Nature Conservancy. Request Report.

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2014, Fecal indicator bacteria (ver. 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, section 7.1, May 2014, accessed 29 December 2017 from http://pubs.water.usgs.gov/twri9A/.

Nelson C., Donahue M., Dulaiova H., Goldberg S., La Valle F., Lubarsky K., Miyano J., Richardson C., Silbiger N., and Thomas F. 2015. Fluorescent dissolved organic matter as a multivariate biogeochemical tracer of submarine groundwater discharge in coral reef ecosystems. Mar Chem 177:232-243.

Rice S.H., Bradley P., Slay H., Wiltse W., Polhemus D., Storlazzi C., Montgomery T., Sturm P., Viqueira R., Callender T., Curtis M., and Dean J. 2015. United States Coral Reef Task Force Watershed Partnership Initiative: Programmatic Checklist. Washington, DC. 6pp.

Rice S.H., Bradley P., Slay H., Wiltse W., Polhemus D., Storlazzi C., Montgomery T., Sturm P., Viqueira R., Callender T., Curtis M., and Dean J. 2016. United States Coral Reef Task Force Watershed Partnership Initiative: Priority Ecosystem Indicators. Washington, DC. 56pp.

Sharp J.H., Carlson, C.A., Peltzer, E.T., Castle-Ward, D.M., Savidge, K.B., and Rinker, K.R.. 2002. Final dissolved organic carbon broad community intercalibration and preliminary use of DOC reference materials. Marine Chemistry 77: 239-253.

Smith C.M. and J.E. Smith. 2006. Algal blooms in North Kihei: an assessment of patterns and processes relating nutrient dynamics to algal abundance. City and County of Maui Report.

Steneck R.S., Arnold S.N., and Mumby, P.J. 2014. Experiment mimics fishing on parrotfish: insights on coral reef recovery and alternative attractors. *Marine Ecology Progress Series*, *506*, 115-127.

van Hooidonk R, Maynard J, Manzello D, Planes S. 2013. Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology, doi: 10.1111/gcb.12394.

Walsh, W., R. Sparks, C. Barnett, C. Couch, S. Cotton, D. White, K. Stone, E. Conklin. 2013. Long-term monitoring of coral reefs of the Main Hawaiian Islands Final Report. 2009 NOAA CRCP. State of Hawai‘i Monitoring Report. NA06NOS4260113.

Williams I.D., Walsh W.J., Claisse J.T., Tissot B.N., and Stamoulis K.A. 2009. Impacts of a Hawaiian marine protected area network on the abundance and fishery sustainability of the yellow tang, Zebrasoma flavescens. Biol. Conserv 142: 1066–1073.

Wiegner T.N., Mokiao-Lee A., and Johnson E.E. 2016. Identifying nitrogen sources to thermal tide pools in Kapoho, Hawai'i, U.S.A, using a multi- stable isotope approach. Mar Pollut Bull 103:63-71

Work T.M., Aeby G.S., and Maragos J.E. 2008. Phase Shift from a Coral to a Corallimorph-Dominated Reef Associated with a Shipwreck on Palmyra Atoll. PLoS ONE 3(8):e2989. doi:10.1371/journal.pone.0002989.

Yoshioka, R, Kim, C, Tracy, A, Most, R, Harvell C. 2016. Linking sewage pollution and water quality to spatial patterns of Porites lobata growth anomalies in Puakō, Hawaiʻi. Marine Pollution Bulletin 104: 313-321

.

Appendices

Appendix A: Workshop Agenda

Agenda Puakō Wastewater Upgrade Measures Workshop

Workshop Objective – Collaboratively develop priority measures and monitoring plan before, during, and up to 10 years after cesspool replacement in Puakō.

Monday, August 8 – Process Discussion and Ecological Benefit of Alternatives

8:30 Arrive and Settle-In – Coffee, Tea, and Continental breakfast

9:00 **Introductions**

9:15 **Workshop Overview**
- Group Expectations and Ground Rules
- Meeting Objectives and Approach
- Measures Terminology

9:30 **Puakō Clean Water for Reefs Overview**
- Process Timeline
- Collaboration and Working Group
- Key Process Steps - Preferred Option

10:00 ***Break***

Puakō Improvement Process Discussion
- Key Process Steps - Additional Options
- Unintended consequences
- Contingencies and adaptation

Benefits of Alternatives
- Objectives Presentation
- Breakout groups derive goals objectives: Ecological, Socio-Cultural, Economic

12:30 ***Lunch***

1:30 **Finish Developing Objectives**
- Measures from Objectives

3:30 ***Break***

3:45 **Report Back**

4:30 **Prep for Next Day**

- Tomorrow's agenda
- Feedback on today
- Packing list of field trip (Closed-toe shoes, sunscreen, hat, sunglasses, snorkel gear, towel, water bottle (water refill will be available), showers are available)

5:00 **Day One Concludes**

6:30 **PAU Hana dinner**

Tuesday, August 9, 2016 – Target & Threat Status Measures

8:30 *Coffee, Tea & Light Refreshments – please come early so we can start on time*

9:00 **Welcome to New Attendees**

9:15 **Quick Review & Prep for Today**

9:30 **Depart for Kohanaiki Wastewater Treatment Facility Tour/Snorkel**

12:30 ***Lunch Off Site***

1:30 **Measures from Objectives**

- Refresher and Example

2:00 **Status Measures**

- Breakout groups

3:00 **Report Back on Measures**

3:15 ***Break***

3:30 **Finalizing Priority Measures**

- What is required? What aligns with agency methods? What data exists?

4:30 **Prep for Next Day**

5:00 **End of Second Measures Day**

Wednesday, August 10 – Finalize Measures, Results Chains, and Develop Monitoring Plan

8:30 Arrive and Settle-In – Coffee, Tea, and Continental breakfast

9:00 **Welcome to New Attendees**

9:15 **Quick Review and Prep for Today**

9:45 **Monitoring Methods from Measures**

10:30 **Consensus on Monitoring Methods**

11:15 ***Break***

11:30 **Monitoring Plan Overview**

11:45 **Monitoring Plan Development**

- Breakout Group for Citizen and Research Science
- PI, Lead, Frequency, Cost, Location

12:30 ***Lunch***

1:30 **Report Back on Monitoring Plan and Discussion**

2:30 **Complete Process Chart w/ Monitoring Milestones**

3:15 ***Break***

3:30 **Data Use and Sharing**

4:30 **Group Next Steps and Commitments**

4:45 **Meeting Evaluation**

5:00 **Pau**

Puakō Measures Workshop August 8-10, 2016 Confirmed Participants	
Name	Affiliation
Jos Hill	Coral Reef Alliance
Courtney Couch	Hawai‘i Institute of Marine Biology/The Nature Conservancy
Lani Watson	NOAA Habitat Blueprint
Tracy Wiegner	UHH Marine Science
Cindi Punihaole	The Kohala Center/Kahalu’u Bay Education Center
Robin Pulkkinen	USDA Rural Development
Kim Falinski	The Nature Conservancy
Lindsey Kramer	Hawai‘i Division of Aquatic Resources
Bill Walsh	Hawai‘i Division of Aquatic Resources
Lydia Smith	Hawai‘i Division of Aquatic Resources
Courtney Couch	UH Manoa
Justin Logan	AQUA Engineering
Pelika Andrade	UH SeaGrant

Puakō Monitoring Planners at the NELHA gateway center in Kailua-Kona

Front row from left: Dr. Courtney Couch, Dr. Tracy Wiegner, Jos Hill, Robin Pulkinnen, Cindy Punihaole, Lydia Smith, Erica Perez, Dr. Kim Falinski. Back row from left: Nakoa Goo, Justin Dennis, Bert Weeks, Lani Watson, Chad Wiggins. Not pictured: Cherie Kauahi, Dr. Bill Walsh, Lindsey Kramer, Kanoe Steward.

> "Plans are of little importance, but planning is essential."
> -Winston Churchill

Appendix B: University of Hawaiʻi at Hilo Report to NFWF and CORAL

NFWF Progress Report September 2017 to Coral Reef Alliance
Project title: Local Engagement for Conservation Solutions: Measuring the Impact of Management Action in South Kohala, Hawaiʻi Island
Written and edited by: Tracy Wiegner, Courtney Couch, Leilani Abaya, and Julia Stuart
Project co-Principal Investigators: Jim Beets and Steve Colbert
Plan: Monitoring will be conducted between Spring 2017 and Spring 2018 with 3 water quality samplings and 1 benthic survey per year along the Puakō – Mauna Lani coast on Hawaiʻi Island to establish baseline water quality and benthic conditions prior to a sewage pollution remediation project at Puakō.

Work completed to date: Prior to sampling, the proposed sampling design was reexamined, and the Principal Investigators decided that a modified before-after-control-impact (BACI) design was best for assessing the success of a future sewage pollution remediation project at Puakō. Using this BACI design, shoreline and offshore benthic stations were selected with input from University of Hawaiʻi at Hilo (UHH) and The Nature Conservancy (TNC).

Several of the selected stations were UHH or TNC long-term monitoring ones. The number of stations proposed to be sampled changed due to the higher number of stations needed to statistically detect change in benthic communities, and the financial and time constraints of collecting water samples at all stations. The final design included 10 paired, priority shoreline and offshore benthic stations (20 stations total) for water quality sampling and benthic surveys (Fig. 1, red circles; Table 1, gray highlight, priority #1). Six of the priority stations were considered to be in areas of high sewage impact according to a sewage pollution scoring system developed in a prior project (Abaya et al. in revision), two were in medium and low sewage impact areas, respectively, and the remaining two stations were located at resorts south of Puakō. These latter two priority stations are considered "reference" stations as the resorts have a sewage treatment plant and its effluent is used for irrigation of a sod and tree farm. It is unlikely that sewage treatment at these resorts and any resulting coastal inputs of sewage will change in the foreseeable future. Lastly, benthic surveys were conducted at five "additional" stations (Fig. 1, yellow circles; Table 1, white highlight, priority #2), one station surveyed was in the high sewage impacted area, two in the low sewage impacted area, and the last two in the "reference" area.

At the priority stations (shoreline and offshore benthic), water samples were collected and analyzed for fecal indicator bacteria (*Enterococcus* spp., *Clostridium perfringens*), nutrients (NO_3^-+NO_2^-, NH_4^+, PO_4^{3-}, H_4SiO_4, TDN, TDP), salinity, pH, and turbidity. Seaweed samples were also collected at these locations and analyzed for stable isotopes of nitrogen ($\delta^{15}N$). Samples were collected in the morning at low-tide. Water quality and seaweed samples were analyzed at the UHH Analytical Laboratory using standard procedures. To date, two water quality surveys have been completed (May – July 2017, September 2017). All samples have been submitted to the UHH Analytical Laboratory, and most have been analyzed, except for the most recent sampling. The last trip for water quality sampling at the priority sites is planned for January 2018.

In June 2017, benthic surveys were conducted at priority and additional stations (Fig. 1, Table 1). These stations were located at the edge of the bench and/or at 3-5 m water depth. The priority offshore benthic stations were located parallel to its paired shoreline station (Table 1).

At each benthic station, a 10-m transect line was placed on the benthos running parallel to shore. To quantify % coral and algal cover, 1-m^2 photo-quadrats were conducted along the transect lines. These photo-quadrats will be analyzed for benthic cover (% coral and algal cover) using Coral Point Count with Excel extensions (CPCe). Algae and coral will be identified to the lowest possible taxon at randomly generated points within each photograph to yield a percent cover. Additionally, all corals within a half meter on both sides of the transect line were surveyed, and species and the presence of direct coral-algal competition were recorded, for a total survey area of 10-m^2 at each station. For colonies with direct coral-algal competition, the algal species was identified to the lowest possible taxon. These data are currently being entered and will provide information on the % of the coral community at each station experiencing direct coral-algal competition. Algal height was also measured every 20 cm down the transect line with a ruler. These measurements in conjunction with % algal cover data from the photo-quadrats will be used to calculate benthic algal biomass. In the first and last 2 m of each transect line, the maximum coral colony diameter was measured to the nearest 5 cm for colonies larger than 5 cm, and to the nearest 1 cm for colonies smaller than 5 cm, for a total of 4, 1-m^2 quadrats/transect. These data will provide the population size structure of various coral taxa and coral recruit density.

Figure 1. Stations selected for baseline monitoring at Puakō, Hawai‘i. At priority stations (red) water quality sampling and benthic survey were conducted. At “additional” stations (yellow, priority 2), only benthic surveys were conducted. Shoreline and offshore benthic stations were selected from long-term monitoring ones from University of Hawai‘i at Hilo (UHH) and The Nature Conservancy (TNC). Details regarding the stations used for this project can be found in Table 1.

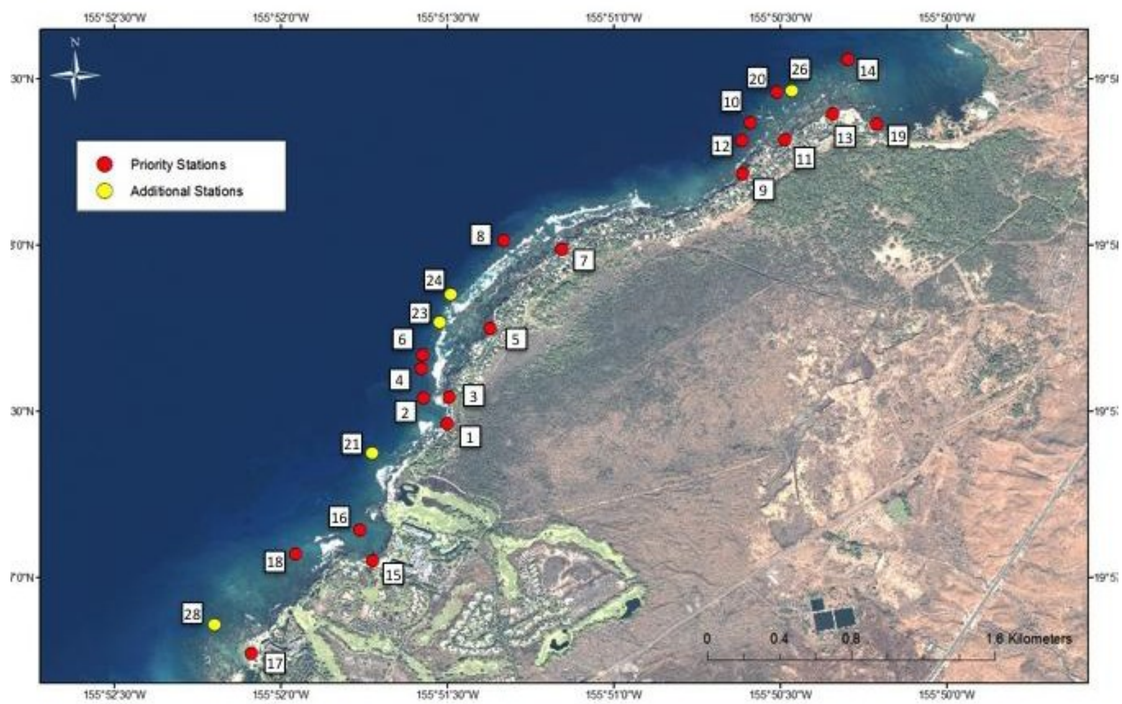


Table 1. Locations of stations selected for baseline monitoring at Puakō, Hawai‘i. (Project Station). Shoreline and offshore benthic stations were selected from long-term monitoring ones from University of Hawai‘i at Hilo (UHH) and The Nature Conservancy (TNC) (Organization). Previous station codes used by these organizations are listed under Organization Station. Priority shoreline and offshore benthic stations (Sampling Priority 1), where water quality sampling and benthic surveys took placed, are shaded in gray. Paired priority shoreline (odd #) and offshore benthic (even #) stations are located next to one another in the table and share the same shade of gray. Additional stations (Sampling Priority 2), where only benthic surveys were conducted, are in white. Sewage pollution scores were determined from Abaya et al. in revision.

Project Station	Organization	Organization Station	Latitude (°N)	Longitude (°W)	Station Location	Sampling Priority	Sewage Pollution Score
1	UHH	1	19.957700	-155.858310	Shoreline	1	Low
2	TNC	10	19.958996	-155.859515	Offshore	1	Low
3	UHH	2	19.959050	-155.858220	Shoreline	1	High
4	TNC	16	19.960471	-155.859635	Offshore	1	High
5	UHH	4	19.962500	-155.856190	Shoreline	1	High
6	TNC	17	19.961155	-155.859550	Offshore	1	High
7	UHH	7	19.966450	-155.852600	Shoreline	1	High
8	TNC	28	19.966876	-155.855487	Offshore	1	High
9	UHH	11	19.970250	-155.843520	Shoreline	1	High
10	TNC	30	19.972818	-155.843143	Offshore	1	High
11	UHH	12	19.971950	-155.841430	Shoreline	1	Medium
12	TNC	4	19.971907	-155.843577	Offshore	1	Medium
13	UHH	13	19.973250	-155.839020	Shoreline	1	High
14	TNC	39	19.975990	-155.838270	Offshore	1	High
15	UHH	Fairmont Lagoon	19.950850	-155.862060	Shoreline	1	Reference
16	TNC	13	19.952381	-155.862703	Offshore	1	Reference
17	UHH	Mauna Lani	19.946180	-155.868120	Shoreline	1	Reference
18	TNC	14	19.951196	-155.865926	Offshore	1	Reference
19	UHH	14	19.972750	-155.836850	Shoreline	1	High
20	TNC	25	19.974327	-155.841821	Offshore	1	High
21	TNC	21	19.956230	-155.862080	Offshore	2	Reference
23	TNC	23	19.962799	-155.858703	Offshore	2	Low
24	TNC	24	19.964210	-155.858140	Offshore	2	Low
26	TNC	26	19.974420	-155.841080	Offshore	2	High
28	TNC	28	19.947630	-155.869980	Offshore	2	Reference

References:

Abaya, L.M., T.N. Wiegner, S. Colbert, J. Beets, K.M. Carlson, K.L. Kramer, R. Most, and C. Couch.A multi-indicator approach for identifying shoreline sewage pollution hotspots adjacent to coral reefs. In revision with Marine Pollution Bulletin, submitted April 2017, revising September 2017.

Personnel:

Students trained (undergraduatea, graduateb): 11

Water quality (6): Adel Sharifa, Tyler Gerkena, Amy Olsena, Byrant Tongaa, Melia Takakusagia, Carey Demapana 4 SCUBA divers (5): Julia Stuarta (lead diver), Jenna Budkeb , Rosie Leea ,Keelee Martina , and Devon Aguiarb

Boat drivers (3): Matt Connelly, Steve Kennedy, and Jim Beets

Technicians (2): Leilani Abaya and Jazmine Panelo

Mahalo to the additional support provided by UHH Marine Science Department, UHH Analytical Laboratory (https://hilo.hawaii.edu/~analab/), and several UHH internship programs: PIPES https://hilo.hawaii.edu/uhintern/), SHARP (http://www.uhhilo-sharp.org/), and NSF EPSCoR Ike Wai (https://www.hawaii.edu/epscor/).