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Summary of the Water Quality Research from Kahaluʻu Bay, Hawaiʻi Island: Tidal Flows, Recreation Water Indicator Bacteria, and Nutrient Fluxes

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The Kahaluʻu Bay Education Center (a program of The Kohala Center) actively strives to inform visitors and the community about the protection and conservation of the bay's marine ecosystem. A group of committed volunteers and staff provide daily, on-site educational programs. Similarly, they have collected scientific data about the bay for over a decade. This trove of data is priceless. It tells us much about the interaction of the ocean with the adjacent urban lands. Except for the marine waters of Kaloko Honokōhau National Historical Park, no other maritime site in Kona has been studied so thoroughly and for so long.

The data from Kahaluʻu Bay gave rise to three technical research reports. They are:

I. Tidal Influence on Temperature and Salinity
II. Elevated Kahalu'u Bay Enterococci Associated with Large Tidal Flux
III. Kahaluʻu Bay Nutrient Trends 2009 to 2019

The purpose of this summary is to provide an easy-to-understand synopsis of the three technical reports to enable the community to "see below sea level" so that we may be better informed of the best stewardship of our nearshore waters.

I. Tidal and Ground Water Influence on Bay Waters

The mountains above Kailua Kona are blessed with abundant rainfall. Some sites get over 70 inches of rain per year. Yet there are no rivers or streams. On the Hilo side of the island, there are over 200 streams. So, in Kona, where does all that water go? It percolates quickly through the fractured lava rock and forms a fresh groundwater lens that floats upon the seawater that permeates the island. From there, fresh groundwater flows toward the shore. It includes a nearshore subterranean estuary (STE). In the estuary, groundwater and seawater mix under the forces of tidal action. Four times a day, the tides rise and fall. During the Spring Tides, massive tidal fluxes of over two feet push and pull on the estuary with great force.

Groundwater eventually discharges along the coast as a cold mixture of fresh water and recirculated seawater. For those that swim in the ocean, encountering cold spots is inevitable. For snorkelers, these surface cold spots can have hazy visibility. This is a refraction caused by the incomplete mixing of seawater and groundwater. The fresher water is less dense and floats on the ocean surface in many locations.

[1] Applied Life Sciences LLC, and Waiwai Ola Ohana
[2] The Kahaluʻu Bay Education Center, The Kohala Center

In the Kahaluʻu Bay shore area, there are pronounced discrete locations where water flows can be seen, and the coolness is perceived. In other places, the brackish water is more diffuse. And yet, in some offshore sites, the cold brackish water emerges from the floor of the ocean. Most of all, water that does not evaporate flows into the sea one way or another. Water is almost a perfect solvent. A high number of things dissolve in it even though it may remain crystal clear. In the kitchen, we can dissolve a lot of salt or sugar in a glass of water without changing its appearance.

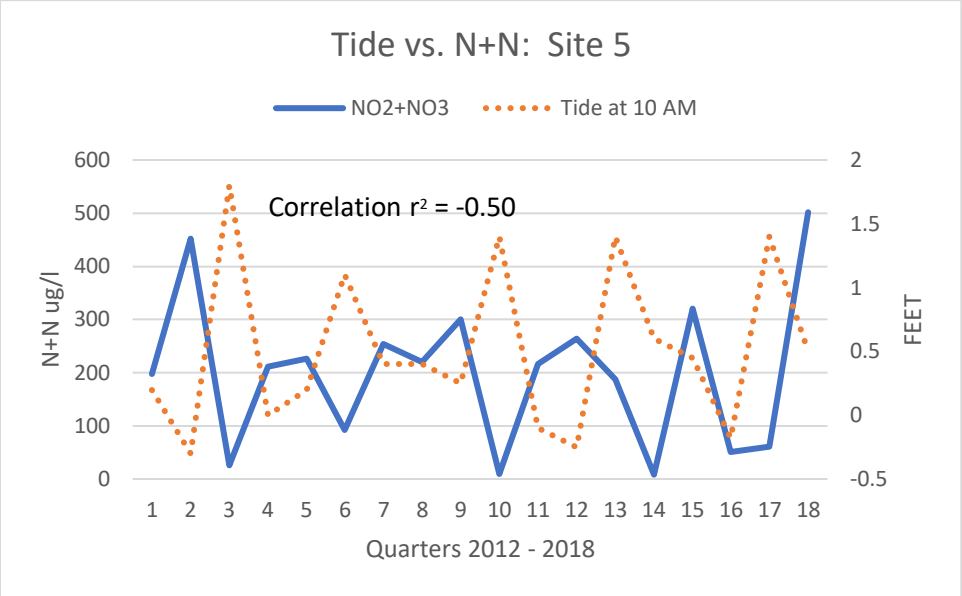
Figure 1. Kahaluʻu Bay Shoreline Sample Sites

Statistical Distribution of Salinity 2017
Low tide, 29.36 Orange vs. High Tide 32.26 ppt Green

This site map of the bay shows where water samples are collected. Site one is where water flow at low tide can be seen. At low tide, the salinities at site 1 differed from the others. At high tide, the salinity of sites 1 - 4 was different from 5. This shows that water inflow can be very localized. We know that lava tubes and fractured rock can provide such a discrete conveyance.

Similarly, it should not be too hard to imagine how the flow of the tides can influence the temperature of the nearshore water. Ocean water is warmer and more saline. Thus, a good high tide will render the nearshore water warmer and saltier. At a very low tide, the converse is also true.

Figure 2. The Influence of Tides on Nitrogen Concentration.



At low tide, groundwater flows increase, and salinity and temperature decrease quite dramatically. This suggests the volume of water flowing into the bay is massive. As shown in Figure 2., over a 4.5-year period, there is an inverse relationship between the tide level and the concentration of Nitrogen (N) measured as Nitrate and Nitrite. The effect is simply seawater, that is lower in Nitrogen is diluting the higher N groundwater Nitrogen content. Thus, it is critical that tidal effects be accounted for in any monitoring of marine nitrogen. Accounting for groundwater Nitrogen concentrations flowing into near shore waters is a requirement of Hawai‘i Administrative Rules when conducting water tests.[3]

UH researchers using some advanced chemistry with Radon isotopes, estimate for each mile of the Kona Coastline between one to three million gallons of groundwater flow into the sea per mile of coastline per day. On the Hilo side, the flow of water from the land can be seen in rivers and streams. On the Kona side, it is unseen but still vast in many submarine groundwater discharges.

One way we can see this flow is to use cameras that see temperature, called infra-red (IR). This IR photo was taken of a submarine groundwater discharge, just north of the Kona Airport. The cold, fresh water (shown by the cooler colors in the image) extends over 200 yards out to sea.

[3] Hawai‘i Administrative Rules §11-54-6(B)

Figure 3. Thermal Image of a Prominent Submarine Groundwater Discharge. Adapted from Johnson (2008)

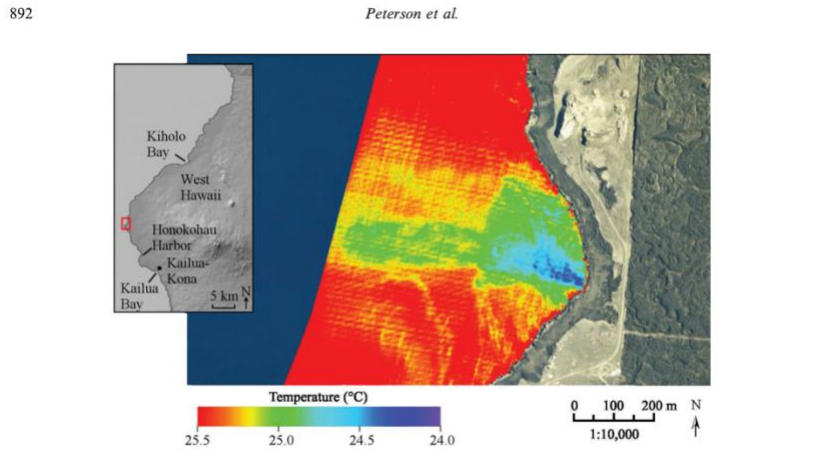
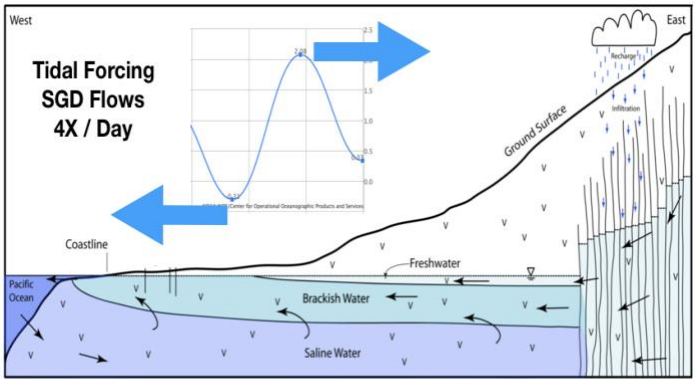


Fig. 2. Example of aerial TIR image of a buoyant SGD West Hawaii SGD plume, located north of Kailua-Kona in the vicinity of Kona International Airport, Makako Bay (19°44′09″N, 156°03′11″W). Note the marked cool surface water temperature of the plume relative to ambient ocean water. Image from Johnson (2008).

This collective and massive flow of groundwater into the sea is part of our island water cycle, and it has been flowing this way long before the Hawaiians came to inhabit the island. Now that the shore area is urbanized or otherwise altered in the last century; what is flowing in this water now is of great interest and concern.

The take-home story in this section is that groundwater flows dramatically alter the nearshore ocean and it's easily detected and measured with simple instruments like a thermometer or salinity meter. This will take on greater significance in Part III.

Figure 4. The Tidal Forces that Drive the Subterranean Estuary (STE) on the Kona Shore.



Adapted from Johanesson 2017

The greater Kona area is underlain by a complex network of fissures and crevasses filled with saline waters. Anchialine Ponds are a common feature of this geology, yet rather unique to Kona, Hawaii. The term, Subterranean Estuary (STE) more aptly describes these structures (Bishop 2015). Monitoring wells tracked by NELHA[4] as far as one mile inland provide evidence of seawater intrusion and water levels consistent with tidal action (Peterson 2009). This fact is largely unrecognized by the state as well as the community. The implications are profound. Marine waters of the Kona Coast communicate with ground water well inland and vice versa. Nonetheless, wastewater discharges to land in this region are likely to be impacting the waters of the coast and circumventing requirements for the regulation of such waste discharges to the waters of the United States.[5]

[4] NELHA CEMP Report https://nelha.hawaii.gov/resources/library/nelha-lab-reports/

[5] *Cty. of Maui v. Haw. Wildlife Fund*, 140 S. Ct. 1462, 1476 (Apr. 23, 2020)

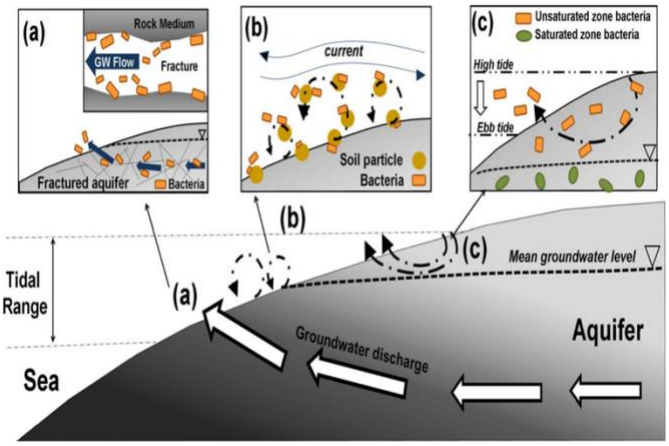
II. Influence of Tides on the Recreation Safety Bacterial Water Quality Indicator

When the local news recently (Jan 8, 2019) reported several beaches on Oahu were closed due to elevated Enterococci (ENT) indicator bacteria, and Kahalu'u Bay was "Posted" by the Health Department of Hawai'i, at about the same time. These events raised curiosity. There had been no significant rain events on the islands, and no sewer spills to cause health department warnings. Instead, the warnings arose for beaches widely separated geographically and simply because the levels of ENT were elevated above the regulatory threshold.

The State Department of Health monitors the indicator bacteria Enterococci (ENT). The official belief was that ENT was a useful marker for fecal contamination. A lot of science has shown that it is not a valid indicator, nonetheless, it is still the official test (Boehm 2009). This ENT monitoring data is part of the Kahalu'u Bay collection. When the Bay was posted as contaminated in January, it generated posed a question. We were having colossal Spring Tides at the time. Could the tides have something to do with the bacteria levels? The bottom line is indeed they do. But how?

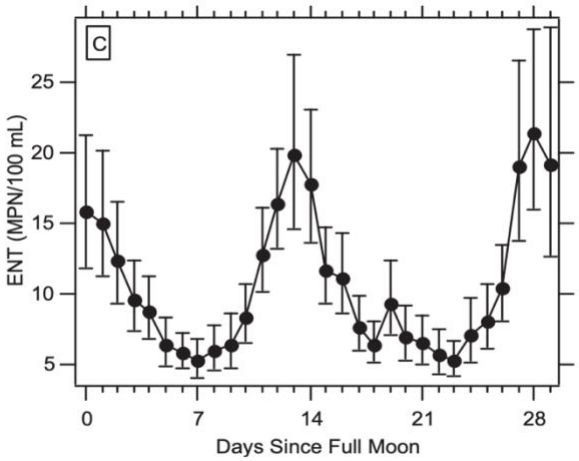
The ENT bacteria are common to land and water sources even where there is no fecal matter at all. They grow in wet places like culverts, compost piles, drainpipes, and wetlands. From there they flow into the sea, and they make a home there too. They can be found floating in the seawater, and that is where the state measures them. But more critically, they live and grow in wet beach sand above and below water level. Many times, more ENT can be found in the beach sand than in the water above.

Figure 5. How Tidal Circulation at the Shore Conveys Indicator Bacteria to the Water Column (Lee 2017)



A super high tide followed by a minus low tide and allows for a huge water outflow from the STE. The water flows above and through the sand dispersing ENT up into the water column where the ENT can be detected and counted. When the ENT count is high, beaches get warning signs and may be closed.

Figure 6. Lunar – Tidal Influence on Marine Water Enterococci (Boehm 2005)



This graph shows the ENT count and the moon cycle. Fourteen days after a full moon are the astronomical Spring Tides and associated rise in the ENT. This tidal force literally stirs things up.

There remains a distinct possibility that elevated ENT counts are often an artifact of the tide cycle at the time of sampling. This bias likely triggers official warnings where there is no apparent health risk events like sewage spills or flooding.

However, given that the region near Kahalu‘u Bay is not served by sewer and most homes have utilized cesspits for decades, sewage components may be conveyed to the ocean by groundwater. Microbiologists have documented the presence of human virus in seawater when the ENT is low or absent. The need for a better risk indicator is great. Stable chemical indicators of sewage such as Sucralose (Bennett 2021) and an MRI diagnostic marker (Johannesson 2017) show promise in wastewater tracking research conducted in Hawaii Island.

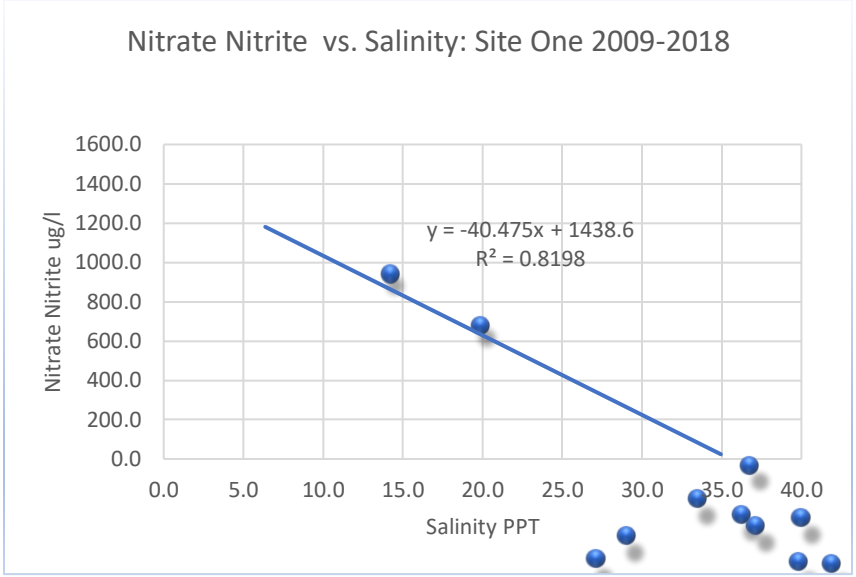
The real good news about the safety of recreation water in Hawaii is the sun. The intense midday UV sunlight penetrates clear water and kills microbes in a matter of hours. We shall see, however, in the next section, clear ocean water is less common these days.

III. The Nutrients Nitrogen and Phosphorus in Nearshore Groundwater[6]

It is well established that brackish groundwater flowing in discrete and diffuse STE is abundant in the nutrient’s nitrogen and phosphorus. According to University of Hawai‘i researchers, wherever there is cold STE water flows, elevated nutrients are present (Johnson 2008). These flows result in thousands of pounds of the nutrients being conveyed daily to the nearshore waters. Tropical water ecosystems are naturally low in nutrients (De Goeij 2013), and yet corals have adaptations to these conditions. Unfortunately, decades of human derived nutrients in the ocean nourish algal biomass expansion to the detriment of the corals.

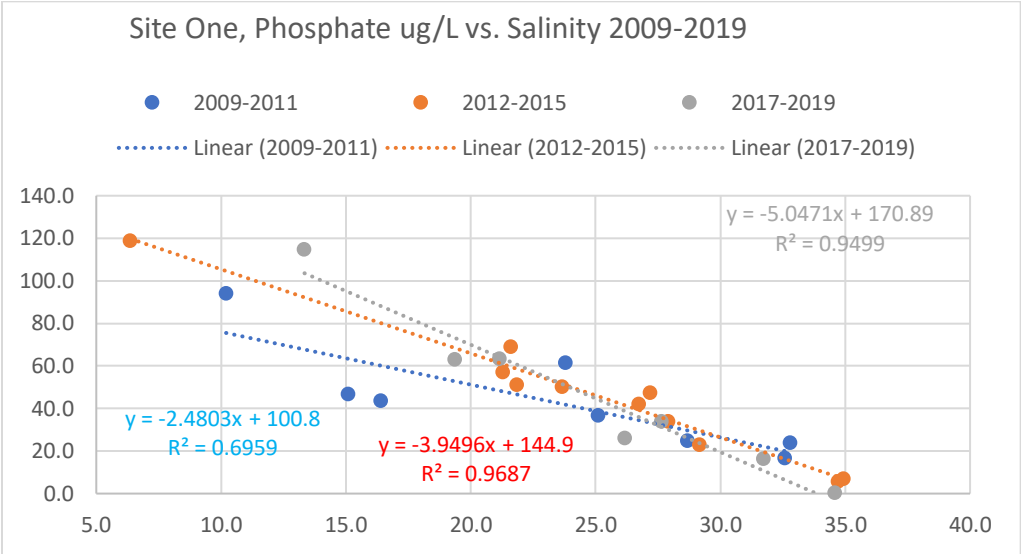
[6] All nutrient analysis performed by the certified laboratory at NELHA

Figure 7. Nitrate-Nitrite Relationship to Salinity



This graph looks complicated, but it's not. Let's interpret. The line says, when sea water is saltier there is less N in it. Conversely, the fresher the water the higher N is there. Taken over 10 years in many locations in the bay and from other Kona Coast sites, this pattern is very consistent. Simply, it means the elevated N source is from the land and groundwater and not from the sea.

Figure 8. Phosphate Relationship to Salinity



This chart looks even more complicated, but it is just three sets of years P plotted against salinity. It shows a very similar relationship as the N chart. Yet here we are looking at a ten-year period in three phases. It answers the question, are things changing over time? For both N and P there is no evidence of a time trend. The nutrient concentrations in groundwater are staying about the same.

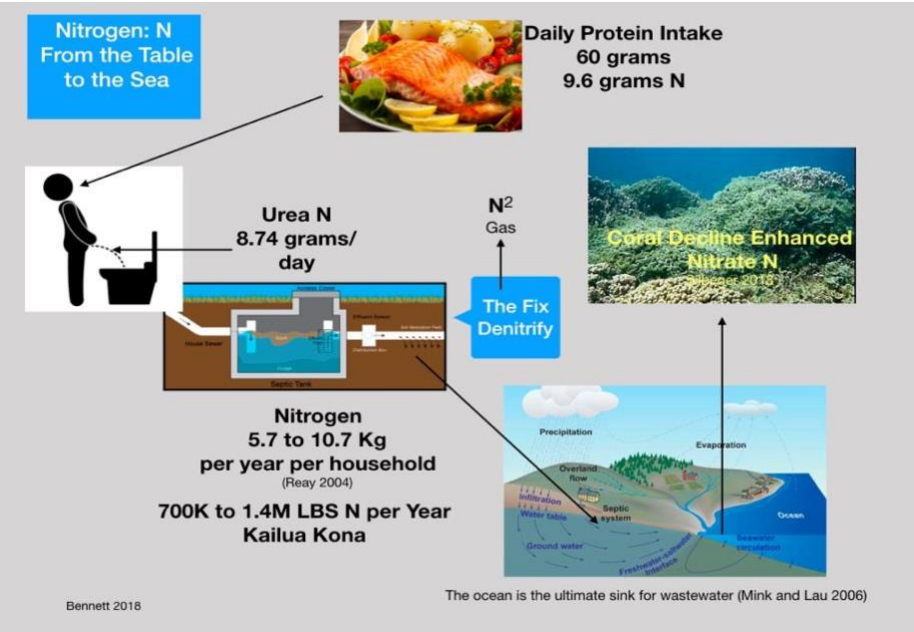
Just as for salinity and temperature in the first report, tidal action dilutes the groundwater and hence the N concentration (Fig. 2). Thus, if one was trying to say there is no problem or a lessor problem, the sample would be collected at the highest tide to get the lowest N level.
In all future work, we must account for the tidal effect on nutrient concentration in nearshore waters.

A very large mass of the nutrients, N, and P, flow into the ocean for almost the entire Kona Coastline. Some have conveniently wanted to say the N and the P are natural, meaning this system was here before humans. While it is true, the mass of nutrients was far, far less as there was little importation of nutrients other than through fish consumption.

Given that, what is the reason for the large mass of nutrients? We are! A lot of research on this island and others shows very clearly that the N and P are from human activity. We say the elevated nutrients are anthropogenic, or human-associated. This includes the fertilizers imported and dispersed in landscape and agriculture. Yet the largest single source is the human diet and the nutrients we excrete daily.

For example, protein-rich foods contain much more N than starchy foods and vegetables. The proteins get absorbed and ultimately broken down and the nitrogen is excreted in the urine as urea. Leave urine in the bowl for a day and the bacteria break it down and form ammonia with its distinctive odor. In the environment, bacteria convert ammonia to nitrate. It is the same nitrate found in a bag of lawn fertilizer.

Figure 9. A Simple Mass Balance for Human Dietary Nitrogen Marine Impact



Each household, on average, contributes about 21 pounds of N per home per year. Add up all the homes in Kailua Kona and a year, and we can produce around a million pounds of N that flow into cesspits, septic systems, and treatment plants. No matter which one is used, most of the N ends up in the groundwater and the sea.

This fertilizer in the sea has the same effect as it does on your lawn. Instead of grass growing, the microscopic green plant microbes called phytoplankton grow and in high numbers make the

water shades of cloudy green. This growth absorbs sunlight making the natural UV disinfection of seawater less effective. Ecosystem research from Kaneohe Bay demonstrates that wastewater N in the bay has an additive effect with increased temperature to cause greater coral bleaching (Tanaka 2013).

Figure 10. Nitrogen Mass Dependent on Ground Water Flow Volume

Lastly, it is not sufficient just to know the concentration of the nutrient flowing into the bay as it tells us nothing of the mass or pounds in the flow. Thus, we must know or estimate the volume of the flow so that we can calculate the mass of nutrients delivered to the sea from the STE.

The blue arrows represent the same nutrient yet at very different flow volumes. The total mass of N, reaching the bay and impacting the ecosystem is very different. Where currents move and mix these nutrients to the open ocean, adverse impacts are less likely. However, in protected embayments like Kahaluʻu, the transport and mixing is much less and the impact on the local ecosystem is more significant.

Think of it this way. A little soy sauce on food gives it just the right salt taste, but add a quarter cup of soy sauce on food and it becomes horribly salty. The salt in the soy is at the same concentration; there was simply more salt.

In the bay, we cannot alter the volume of water flowing in, just like we cannot stop a river. So, we need to employ the tools that reduce the concentration of N and P discharged to groundwater.

The people of Long Island NY, Cape Cod MA, and coastal Florida have severely polluted their estuaries from Septic Systems. The environmental and economic consequences are monumental. The residents put their collective shoulders to the wheel and financed solutions research. That research demonstrated a simple technique that removes the nutrients in human wastewater by over 90%. The states are implementing the "Layer Cake-Nitrogen Reducing Biosystem leach field. Kona can do this too. The consequences of "kicking the can down the road" will be dire. Sustainable Hawaiʻi must be our goal.

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For over 35 years, Dr. Bennett has worked in the environmental science field where the land meets the water. From Tomales Bay CA. to New South Wales Australia to the Big Island wherever there are people and oceans there are huge challenges. A resident of Kona since 1999, he serves as Na Mako O Ke Kai (eyes of the sea) for the Kona Coast Waterkeeper Waiwai Ola Ohana.

Acknowledgments
Special appreciation goes out to Cindi Punihaole Kennedy, the founding director of The Kohala Center's Kahaluʻu Bay Education Center, and Marine Stewardship and Education Specialist Kathleen Clark. Together with many volunteers, they have collected high-quality data since 2009. The data is the basis of the three reports and this summary. Also extending appreciation to the former UH researcher James. M. Bishop for his assistance in understanding the hydrology of Hawaiʻi Island and the review of the manuscripts.

List of Abbreviations

ENT	Enterococci (a genus of bacteria)
IR	Infra-red
MPN	Most Probable Number (method for estimating bacteria concentration)
N	The element Nitrogen
N+N	Nitrate plus Nitrite
NELHA	Natural Energy Laboratory Hawaii Authority
NO2	Nitrite
NO3	Nitrate
P	The element Phosphorus
STE	Subterranean Estuary
UV	Ultra-violet
µg/l	Microgram per Liter

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