**NOAA Coral Reef Conservation Program**
**Final Project Report**

**I. Recipient**: Marine Science Department, University of Hawai‘i at Hilo

**II. Project Title**: Spatial distribution and effects of sewage on Puakō’s (Hawai‘i) coral reefs

**III. Award Number**: NA14NOS4820087

**IV. Award Period**: July 1, 2014 - December 31, 2016 (approved 1-year no cost extension)

**V. Period Covered by this Report**: July 1, 2014 – March 31, 2017

**VI. Report**

**A. *Introduction.*** Hawai‘i’s coral reefs contribute ~$800 million dollars annually to the state’s economy. Unfortunately, these coral reefs are declining as a result of multiple stressors. Sewage from cesspools is one of most devastating stressors in rural areas where reefs are still relatively healthy. Cesspools are used more widely in Hawai‘i than any other state in the U.S., and their discharge of pathogens, nutrients, cleaning chemicals, and hydrocarbons pose a threat to coral reef and human health. Hence, Hawai‘i State’s Coral Reef Strategy, Objective 1, is to reduce key anthropogenic threats to near-shore reefs. Puakō, a coastal community on Hawai‘i Island, is located within one of the two priority sites in the state identified for site-based actions.

While Puakō’s coral reefs are some of the richest in Hawai‘i State, there has been increasing concern about sewage pollution since the 1960s. Hawai‘i’s Division of Aquatic Resources (HDAR) found Puakō’s reefs to be in ‘dire straits’, with coral cover decreasing 35% and turf and macroalgae cover increasing 38% over the last 30 years. The Puakō Community Association (PCA) contacted the University of Hawai‘i at Hilo (UH Hilo) and requested a study to determine whether sewage was entering their coastal waters and impacting their reef. To do this, dye tracer tests, $\delta^{15}N$ macroalgal and fecal indicator bacteria (FIB) measurements, as well as water quality and benthic sampling, surface and benthic water quality mapping, and coral pathogen testing were conducted. With data from UH Hilo’s study, PCA will have scientifically-defensible results that will demonstrate to Hawai‘i County and State the urgency to remove cesspools from their community and to replace them with an improved sewage treatment system. Options under consideration include: 1) building an on-site sewage treatment plant, 2) connecting homes within their community to an existing sewage treatment plant at the Mauna Lani Resort through construction of a sewer line, or 3) replacing their cesspools with aerobic treatment units (ATU). Removal of cesspools will improve water quality at Puakō and help mitigate coral disease, future coral cover loss, and reduce human health hazards.

**B. *Purpose.*** In November 2013, PCA contacted UH Hilo’s Marine Science Department and requested that they conduct a study to determine whether sewage was entering their coastal waters and impacting their reefs. They wanted to document the presence of sewage in their near-shore waters to convince Hawai‘i County and State of the urgency to improve sewage collection and treatment in their community. Data collected by UH Hilo, as part of this study, is providing PCA with baseline data to compare to following any sewage collection and treatment upgrade efforts, and allowing them to evaluate whether those upgrades were effective. PCA would like to be a model community for Hawai‘i Island and State with regards to a community-based initiative to improve near-shore water quality and coral reef health. Hawai‘i State needs examples like Puakō to help convince the public that a cesspool ban is necessary to improve coastal water quality and decrease the health risks to recreational water users. In 2015, Hawai‘i’s Department of Health (HDOH) revised its proposed 2014 cesspool ban and it was signed into legislation. It bans construction of new cesspools and provides a tax credit to homeowners near waterbodies who <u>voluntarily</u> remove their cesspools and replace them with septic tanks, ATU, or connect to an existing sewer line.

In collaboration with PCA, goals and objectives to address their sewage pollution issue were derived. The **<u>Project’s Goals were to</u>**: (1) use chemical and biological approaches to determine if sewage pollution was entering near-shore waters with coral reefs, (2) determine whether the sewage pollution was impacting water quality, and (3) assess whether the sewage pollution was eliciting a community-level response on the reef. The **<u>Project's Objectives were to:</u>** (1) determine the connectivity between domestic onsite sewage disposal systems (OSDS) and adjacent coastal waters through dye tracer tests, (2) evaluate the presence of sewage in near-shore waters through $\delta^{15}N$ measurements in macroalgal tissues and FIB, (3) determine if state water quality standards were exceeded in Puakō waters through FIB measurements, and (4) assess whether there was coral reef community response to sewage through measurements of benthic cover.

**D. *Accomplishments and Results.*** The UH Hilo Marine Science research team has successfully accomplished all tasks outlined in the proposal (Table 1). Additionally, findings have been presented at meetings and conferences, 1-page project summaries for the general public have been generated and circulated, community outreach events have been attended, undergraduate and graduate students have been trained, and a conference session was organized. Below, accomplishments and results for each objective are described

**Table 1.** Completed and remaining tasks for UH Hilo's NOAA Coral Reef Conservation Program project. Checks (√) indicate completed tasks; x's indicate remaining tasks. Project started July 2014. A no cost extension was awarded until December 2016. This table covers tasks completed from July 2014 to March 2017.

| | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 -2015 | | | | | | | | | | | | 2016 - 2017 | |
| **Task** | J - J | F | M | A | M | J | J | A | S | O | N | D | J-J | A-M |
| **1. Community/outreach events/advisory board** | √ | | √ | | | | | √ | | | | √ | √ | √ |
| **2. Planning/preparation** | | | | | | | | | | | | | | |
| -Hire personnel | √ | | | | | | √ | | | | | | | |
| -Order equipment/supplies | √ | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | √ | |
| -Draft work plan/schedule | √ | | | | √ | | | | | | | | | |
| -Permit applications | | | | | √ | | | | | | | | | |
| -GIS site maps | √ | √ | | | √ | | √ | | | | | | | |
| -Database preparation | √ | | | | | | | | | | | | | |
| **3. Personnel training** | | | | | | | | | | | | | | |
| -Equipment use | √ | | | | | | √ | | | | | | | |
| -Water sampling | √ | | | | | | √ | | | | | | | |
| –$\delta^{15}N$ macroalgal assay | √ | | | | | | √ | | | | | | | |
| **4. Initial sampling** | | | | | | | | | | | | | | |
| -Water sampling/mapping | √ | | | | | | | | | | | | | |
| -Macroalgal sampling | √ | | | | | | | | | | | | | |
| –$\delta^{15}N$ macroalgal assay | | √ | √ | | √ | √ | | | | | | | | |
| -Final site selection | √ | | | | √ | | | | | | | | | |
| **5. Project Sampling** | | | | | | | | | | | | | | |
| -Dye trace studies | √ | | | | | | | | | √ | | | | |
| -Water sampling/mapping | √ | | √ | | | | √ | | | | | | | |
| –$\delta^{15}N$ macroalgal assay | | | | | | | √ | | | | | | | |
| -Benthic community structure | | | | | | | √ | | | | | | | |
| **6. Data Analyses** | | | | | | | | | | | | | | |
| -Sample processing | √ | | √ | | | | √ | √ | √ | √ | √ | √ | √ | |
| -Statistical analysis | | | √ | | | | | | √ | √ | √ | √ | √ | √ |
| **7. Reporting** | | | | | | | | | | | | | | |
| -Progress reports | √ | | | | | | | | | | | | √ | √ |
| -Presentations | √ | √ | √ | | √ | | | √ | √ | | | | √ | |
| -Final report | | | | | | | | | | | | | | √ |

**<u>Objective 1:</u>** In order to determine the connectivity of OSDS with near-shore coastal waters at Puakō, groundwater seeps that may be transporting sewage were identified during low tide when groundwater influence is greatest and easiest to detect through measurements of surface water salinity. These data were then used to make a near-shore surface salinity map. This map was used to identify ideal locations for dye tracer tests and sampling stations for Objectives 2 - 4 (Fig. 1). Based on the location of the groundwater seeps, as well as cooperating homeowners, dye tracer tests were completed at four oceanfront homes' OSDS, three were cesspools in the southern portion of Puakō, and one was a fractured ATU (not in use) in the central portion of the community (Fig. 2, black squares). Five stations along the shoreline in front of each home were sampled before and after the dye was added to the OSDS. Samples were analyzed for salinity and fluorescein (a non-toxic fluorescent dye). Fluorescein concentration vs. time data were used to calculate dye travel time, flow rate, and dilution before entering the near-shore waters. Dye was visually observed at the shoreline in front of all four homes. For each test, there was only one spring with dye, which was located on the beach in front of the home, suggesting that the groundwater flow between the OSDS was restricted to specific fractures in the aquifer. At three homes, dye was only observed during low tide and was highly diluted (max. observed dye concentration = 0.02% initial concentration). At the third home, while the same amount of dye was added to the OSDS, the discharge was much less diluted, and dye was visible during low and high tides for several days, as it was trapped in an area with little water circulation (Fig. 3, inset). The dye from these springs dispersed over an area between 0.25 to 4 $m^2$. Initial detection of fluorescein at the shoreline ranged from 0.4 to 9.3 days after release, and it continued to flow out during low tide over the next several days (Fig. 3). Three homes had comparable flow rates between 4 to 14 m/day; the OSDS at one home had a remarkably faster flow rate, where dye in the groundwater traveled 76 m/day. Based on dilution of the dye, the maximum fraction of sewage in the freshwater at the shoreline varied from <0.02 to 0.14%, depending on how much mixing occurred before shoreline discharge.

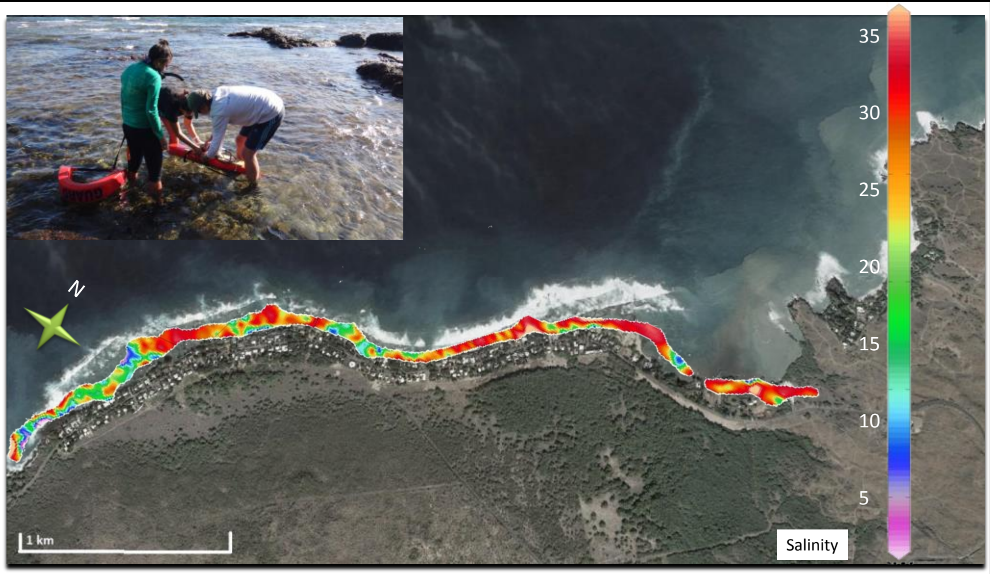



**Figure 1.** Map of surface salinity along the Puakō shoreline (June 2014). The map was created using a YSI 6600 sondes and GPS. Shown in the picture is Dr. Steve Colbert with two of the three summer interns (NSF REU program at UH-Hilo) at the beginning of the surface salinity mapping effort.

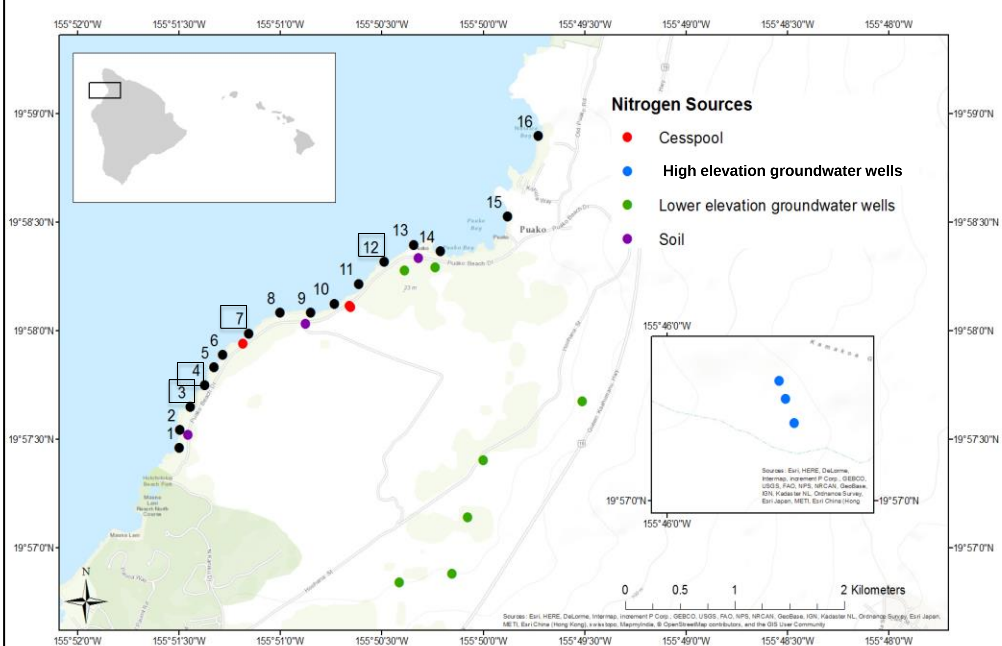



**Figure 2.** Locations of dye tracer tests (open squares), nitrate source sampling (red, blue, green, and purple circles), and shoreline water and algae collections (black circles) along the Puakō coastline, Hawai‘i, USA.

**Objective 2:** Three different approaches were used to evaluate the presence of sewage in near-shore surface and benthic waters. First, groundwater and shoreline waters were sampled and analyzed for nutrient concentrations and $\delta^{15}N$-$NO_3^-$ (*Upland well measurements* section). Second, macroalgal tissues and nearshore waters were collected along the shoreline for $\delta^{15}N$ and FIB analyses, respectively (*Shoreline measurements* section); FIB data are discussed in Objective 3's results. Finally, macroalgal tissues were deployed in surface

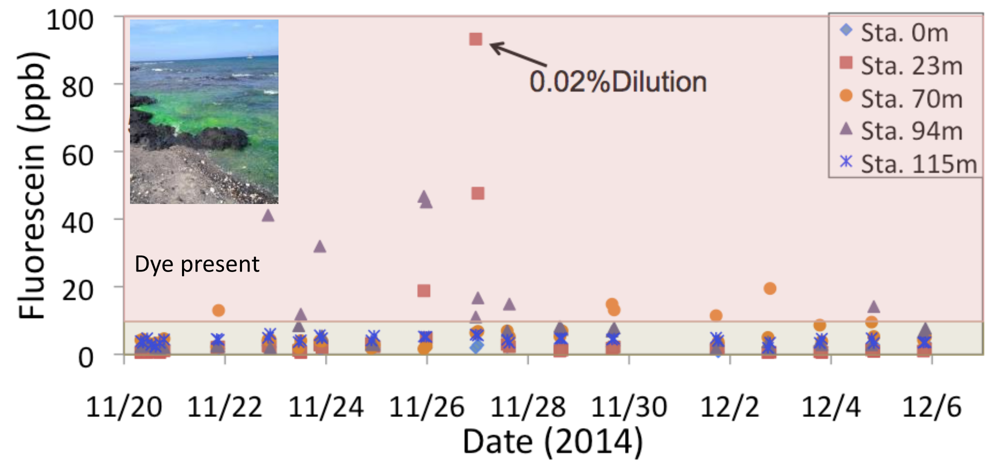



**Figure 3.** Time series of fluorescein dye concentration in near-shore waters of Puakō following dye injection into a cesspool (20 Nov 2014). Background fluorescence levels are indicated by the gray-shaded area. The concentration of the dye injected was 500 ppm. Dye was detected within three days of the initial release and continued to be detected for five more days (pink-shaded area). The dye was only detected at two sampling locations in front of the home and only observed during low tides. Inset picture is from dye tracer study conducted in November 2015. Here, the dye reached the shoreline in nine hours and persisted in nearshore waters for several days, unlike what was observed during the other three dye tracer tests.

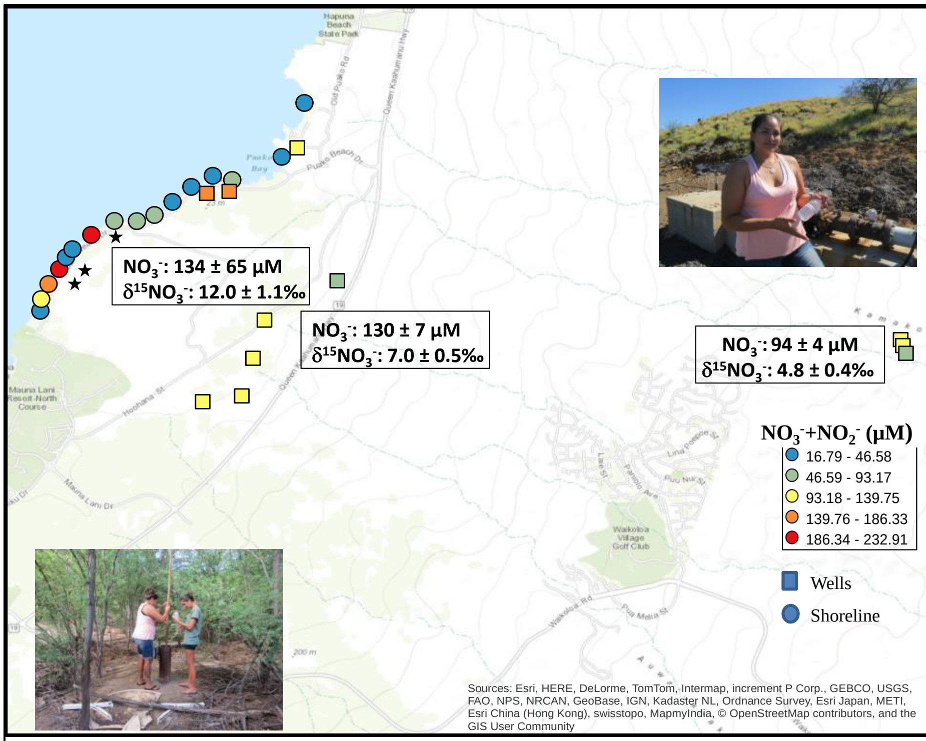



**Figure 4.** Nitrate + nitrite ($NO_3^-$+$NO_2^-$) concentrations (µM) and $\delta^{15}$N-$NO_3^-$ (‰) in up-mountain groundwater and shoreline coastal waters. Shoreline waters at some locations have concentrations ~70- 120 µM higher than up-mountain groundwater.

and benthic cages and analyzed for $\delta^{15}$N, with concurrent nutrient and FIB water measurements at cage stations (*Cage deployment* section).

*Upland well measurements*—During January 2015, upland groundwater samples were collected from drinking (high elevation, n = 3) and irrigation (low elevation, n = 7) wells within the Puakō watershed (Fig. 2, blue and green circles). Samples were analyzed for nutrient concentrations and $\delta^{15}$N-$NO_3^-$. These samples were taken as part of the N source $\delta^{15}$N-$NO_3^-$ determination effort (*see Shoreline measurements* below). Water samples were also collected at 16 shoreline stations for nutrient analyses as part of the *Shoreline measurements* described below. $\delta^{15}$N-$NO_3^-$ was quantified only once at three shoreline stations (3, 4, and 7), as they were suspected of being contaminated with sewage pollution.

$NO_3^-$ + $NO_2^-$ concentrations were ~ 40 µM lower in high elevation wells compared to the low elevation wells (Fig. 4). In contrast, $PO_4^{3-}$ and $NH_4^+$ concentrations were similar between high and low elevation wells (Table 2). $NO_3^-$ + $NO_2^-$ concentrations increased ~70 to 120 µM from the high elevation groundwater wells to the shoreline stations. Comparable increases in $PO_4^{3-}$ and $NH_4^+$ concentrations were not observed.

**Table 2.** Average ± SE of $\delta^{15}$N - $NO_3^-$ (‰) and $NO_3^-$ + $NO_2^-$, $PO_4^{3-}$, and $NH_4^+$ concentrations (µM) of N sources collected in the Puakō watershed. (n = sample size)

| N Source | n | $\delta^{15}$N in $NO_3^-$ | $NO_3^-$ + $NO_2^-$ | $NH_4^+$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|
| Cesspools | 3 | 10.45 ± 0.58 | 20.76 ± 10.50 | 6370.00 ± 806.16 | 378.58 ± 16.59 |
| Soil | 3 | 2.13 ± 2.37 | 6366.67 ± 3682.45 | 594.52 ± 93.24 | 193.56 ± 141.56 |
| Ocean | 2 | 3.02 ± 0.79 | 1.43 ± 0.07 | 2.53 ± 0.55 | 0.11 ± 0.05 |
| High elevation groundwater wells | 3 | 4.76 ± 0.43 | 93.87 ± 4.35 | 4.84 ± 1.43 | 2.48 ± 0.19 |
| Low elevation groundwater wells | 7 | 7.03 ± 0.50 | 130.09 ± 6.69 | 4.82 ± 1.19 | 2.47 ± 0.54 |
| Shoreline | 3 | 11.95 ± 1.13 | 133.93 ± 64.68 | n/a | n/a |

$\delta^{15}N\text{-}NO_3^-$ became increasing enriched downslope from the high elevation groundwater wells to the shoreline stations (Table 2). Additionally, nutrient concentrations ($NO_3^- + NO_2^-$, TDN, $PO_4^{3-}$, TDP, and $H_4SiO_4$) significantly differed among shoreline stations ($p < 0.001$; Table 3). $NH_4^+$ concentrations were similar across all shoreline stations.

**Table 3.** Average ± SE and [range] of $NO_3^- + NO_2^-$, $NH_4^+$, TDN, $PO_4^{3-}$, TDP, $H_4SiO_4$ concentrations (μM), and salinity for shoreline stations at Puakō. Superscript letters indicate significant groupings from One-way ANOVA and post-hoc Tukey's test. α = 0.05; n = 4.

| Station | $NO_3^- + NO_2^-$ | $NH_4^+$ | TDN | $PO_4^{3-}$ | TDP | $H_4SiO_4$ | Salinity |
|---|---|---|---|---|---|---|---|
| 1 | $27.87 \pm 4.09^{b-e}$ [18.10-36.79] | $20.83 \pm 0.15$ [0.78-1.23] | $41.4 \pm 6.8^{c-f}$ [24.6-57.5] | $0.44 \pm 0.04^{fg}$ [0.33-0.51] | $0.70 \pm 0.12^{fg}$ [0.51-1.04] | $132.61 \pm 22.80^{a-c}$ [86.85-195.35] | $27.58 \pm 1.44^{a-c}$ [23.63-30.37] |
| 2 | $149.94 \pm 12.79^{ab}$ [129.62-187.09] | $0.49 \pm 0.11$ [0.18-0.72] | $158.7 \pm 12.8^{ab}$ [139.2-194.6] | $2.24 \pm 0.24^{a-d}$ [1.62-2.73] | $2.86 \pm 0.26^{a-e}$ [2.21-3.45] | $580.91 \pm 154.78^{ab}$ [187.35-875.96] | $7.12 \pm 0.61^{e}$ [5.77-8.70] |
| 3 | $137.12 \pm 35.39^{a-c}$ [36.22-190.37] | $1.95 \pm 0.30$ [1.04-2.29] | $153.6 \pm 39.4^{a-c}$ [41.2-217.1] | $3.81 \pm 0.92^{ab}$ [1.34-5.37] | $4.28 \pm 0.72^{ab}$ [2.42-5.09] | $376.56 \pm 124.15^{a-c}$ [112.21-646.18] | $16.26 \pm 3.96^{b-e}$ [9.50-25.73] |
| 4 | $196.05 \pm 28.14^{a}$ [125.66-263.07] | $1.34 \pm 0.05$ [1.24-1.47] | $221.3 \pm 26.0^{a}$ [153.2-267.1] | $7.42 \pm 1.11^{a}$ [4.12-9.0] | $8.25 \pm 1.36^{a}$ [4.45-10.84] | $501.07 \pm 113.17^{ab}$ [172.26-683.13] | $15.25 \pm 2.30^{c-e}$ [9.10-20.20] |
| 5 | $46.92 \pm 8.73^{a-e}$ [23.44-65.52] | $1.32 \pm 0.16$ [0.86-1.57] | $70.2 \pm 11.8^{a-f}$ [41.5-86.7] | $1.34 \pm 0.17^{b-f}$ [0.90-1.71] | $1.74 \pm 0.28^{b-f}$ [0.90-2.13] | $179.13 \pm 40.75^{a-c}$ [85.38-278.15] | $24.98 \pm 2.35^{a-d}$ [19.70-31.07] |
| 6 | $26.78 \pm 11.48^{de}$ [2.50-54.16] | $1.22 \pm 0.10$ [1.03-1.46] | $43.7 \pm 15.9^{d-f}$ [22.5-86.4] | $0.66 \pm 0.21^{e-g}$ [0.25-1.17] | $0.85 \pm 0.22^{fg}$ [0.25-1.26] | $95.35 \pm 42.89^{c}$ [21.60-219.16] | $30.77 \pm 2.31^{a}$ [24.53-35.53] |
| 7 | $134.56 \pm 54.94^{a-d}$ [42.27-285.74] | $1.69 \pm 0.65$ [0.46-2.90] | $130.5 \pm 42.7^{a-d}$ [52.5-240.8] | $3.08 \pm 0.44^{a-c}$ [2.12-3.83] | $3.41 \pm 0.50^{a-c}$ [2.19-4.51] | $446.70 \pm 132.37^{ab}$ [164.00-803.60] | $21.98 \pm 0.97^{a-d}$ [19.87-24.03] |
| 8 | $39.15 \pm 14.53^{c-e}$ [0.99-67.10] | $2.40 \pm 0.97$ [0.53-5.07] | $59.0 \pm 18.5^{b-f}$ [12.3-98.5] | $0.70 \pm 0.23^{e-g}$ [0.52-1.07] | $1.01 \pm 0.21^{e-g}$ [0.56-1.55] | $252.83 \pm 83.24^{a-c}$ [31.05-416.30] | $20.60 \pm 4.90^{a-d}$ [14.10-35.17] |
| 9 | $69.74 \pm 9.06^{a-e}$ [47.81-91.92] | $1.00 \pm 0.33$ [0.89-1.77] | $85.2 \pm 7.3^{a-e}$ [73.6-105.4] | $1.37 \pm 0.13^{b-f}$ [1.15-1.73] | $1.80 \pm 0.17^{b-f}$ [1.48-2.30] | $341.87 \pm 89.74^{a-c}$ [219.17-608.54] | $15.28 \pm 2.31^{cd}$ [8.53-18.53] |
| 10 | $56.72 \pm 17.48^{a-e}$ [11.59-94.94] | $0.95 \pm 0.27$ [0.47-1.51] | $73.1 \pm 19.0^{b-f}$ [19.7-106.1] | $1.14 \pm 0.31^{c-g}$ [0.34-1.84] | $1.48 \pm 0.16^{b-f}$ [1.18-1.84] | $354.04 \pm 75.56^{a-c}$ [129.10-444.74] | $15.03 \pm 3.60^{de}$ [4.90-21.90] |
| 11 | $16.52 \pm 1.21^{de}$ [14.08-18.73] | $0.96 \pm 0.30$ [0.18-1.45] | $29 \pm 3.9^{ef}$ [23.2-40.5] | $0.49 \pm 0.04^{e-g}$ [0.40-0.58] | $0.76 \pm 0.22^{fg}$ [0.25-1.33] | $108.26 \pm 26.71^{bc}$ [52.94-172.90] | $28.30 \pm 0.93^{ab}$ [26.07-30.60] |
| 12 | $35.80 \pm 4.37^{a-e}$ [25.62-46.59] | $1.34 \pm 0.25$ [0.78-1.88] | $46.4 \pm 4.7^{b-f}$ [34.2-55.6] | $0.99 \pm 0.11^{c-g}$ [0.40-1.31] | $1.26 \pm 0.29^{c-g}$ [0.91-2.11] | $259.66 \pm 104.79^{a-c}$ [111.52-567.91] | $24.50 \pm 0.96^{a-d}$ [22.57-27.13] |
| 13 | $34.89 \pm 4.73^{a-e}$ [22.54-44.18] | $1.21 \pm 0.19$ [0.73-1.56] | $48.5 \pm 6.7^{b-f}$ [34.5-66.9] | $1.64 \pm 0.28^{b-e}$ [0.91-2.29] | $1.89 \pm 0.17^{b-f}$ [1.66-2.38] | $207.44 \pm 23.43^{a-c}$ [166.70-267.48] | $23.96 \pm 2.00^{a-d}$ [19.90-28.27] |
| 14 | $89.08 \pm 5.48^{a-d}$ [75.93-101.22] | $1.15 \pm 0.29$ [0.64-1.54] | $100.9 \pm 6.9^{a-d}$ [83.7-117.1] | $2.61 \pm 0.17^{a-c}$ [2.22-2.98] | $2.91 \pm 0.27^{a-d}$ [2.35-3.61] | $651.66 \pm 173.89^{a}$ [358.62-1017.63] | $6.43 \pm 0.63^{e}$ [5.33-8.07] |
| 15 | $13.37 \pm 2.80^{e}$ [5.73-19.24] | $1.07 \pm 0.17$ [0.75-1.44] | $21.6 \pm 2.6^{f}$ [14.8-27.4] | $0.39 \pm 0.09^{g}$ [0.16-0.55] | $0.57 \pm 0.21^{g}$ [0.25-1.12] | $120.33 \pm 24.28^{a-c}$ [52.40-157.86] | $29.94 \pm 0.70^{a}$ [28.67-31.27] |
| 16 | $38.53 \pm 7.17^{a-e}$ [17.35-47.44] | $0.63 \pm 0.31$ [0.18-1.51] | $45.8 \pm 4.1^{c-f}$ [33.8-51.7] | $0.81 \pm 0.13^{d-g}$ [0.45-1.09] | $1.14 \pm 0.30^{d-g}$ [0.60-1.99] | $322.79 \pm 86.47^{a-c}$ [141.63-552.47] | $17.13 \pm 3.44^{b-e}$ [7.94-24.53] |

Comparison of $NO_3^- + NO_2^-$ concentration data from high and low elevation groundwater wells with nearshore coastal waters indicate that there is some source between these two locations adding $NO_3^- + NO_2^-$ to the water (Fig. 4). The observation that $NO_3^- + NO_2^-$ concentrations increased from low elevation wells (Mauna Lani Resort just above Puakō and Puakō on the mountain-side of the street) to the nearshore waters suggests that leakage from OSDS is a likely source. Enrichment of $\delta^{15}N\text{-}NO_3^-$ from the low elevation groundwater wells to the shoreline further suggest OSDS leakage is the source, as shoreline values were within range reported for sewage (Table 2). Results from our dye tracer tests confirm that OSDS are the source, as dye was detected at in front of the homes with the highest $NO_3^- + NO_2^-$ concentrations and most enriched $\delta^{15}N\text{-}NO_3^-$ values.

Additionally, the change in the $\delta^{15}N\text{-}NO_3^-$ from the high to low elevation groundwater wells suggests a change in $NO_3^-$ source from forest soil to sewage (Table 2). It is possible that sewage is contaminating the low elevation groundwater as an upslope development (Waikoloa Village) has over 4,800 people whose homes have OSDS (U.S. Census Bureau 2000). Additionally, $NO_3^-$ concentrations increased ~40 μM from the high to low elevation groundwater wells (Table 2).

*Shoreline measurements* –$\delta^{15}N$ measurements in near-shore macroalgal tissues were used to identify locations with sewage pollution along the Puakō coastline. Sixteen stations were identified as sampling locations based on the surface salinity map (Figs. 1 and 2, black circles). At each station, the macroalgal community was characterized, and the most predominant species were collected and analyzed for $\delta^{15}N$ (species included: *Ulva fasciata*, *Cladophora* spp., and *Gelidiella acerosa*). For this study, a pilot collection at six stations occurred during July 2014, four full sampling efforts occurred in November 2014, and March, June, and July 2015, and sampling at five stations (algal cage deployment shoreline stations) continued monthly from September 2015 through February 2016. In September 2015, several new stations south and north of Puakō were sampled to address concerns of residents that resorts in these areas might be contributing to their local pollution problem.

In January, February, and June 2015, potential N sources (sewage, fertilizers, up-mountain groundwater, soil under Kiawe trees, ocean water) were sampled and analyzed for $\delta^{15}N\text{-}NO_3^-$ (Fig. 2, blue, green, red, purple circles). $\delta^{15}N$ fertilizer values from another study on Hawai‘i Island were used in our study (Wiegner et al.

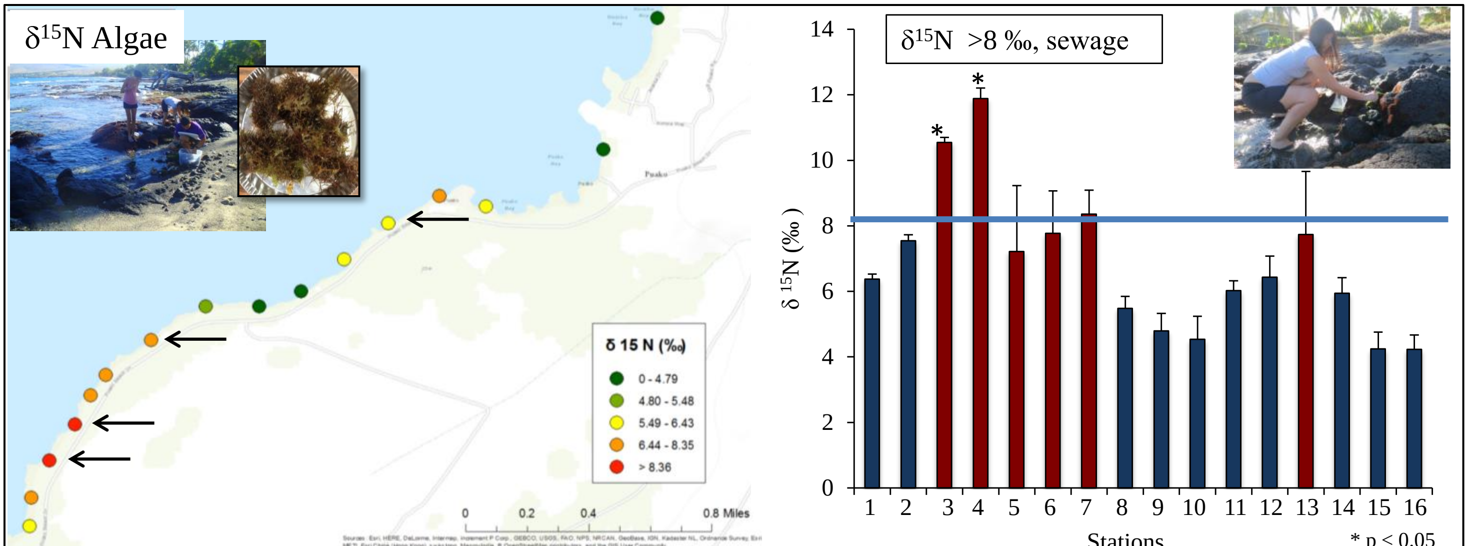



**Figure 5.** Average $\delta^{15}$ N of macroalgal tissues along the Puakō shoreline (November 2014, and March, June, July 2015). Values >8 ‰ are indicative of sewage pollution (light blue line). Arrows indicate location of dye tracer tests.

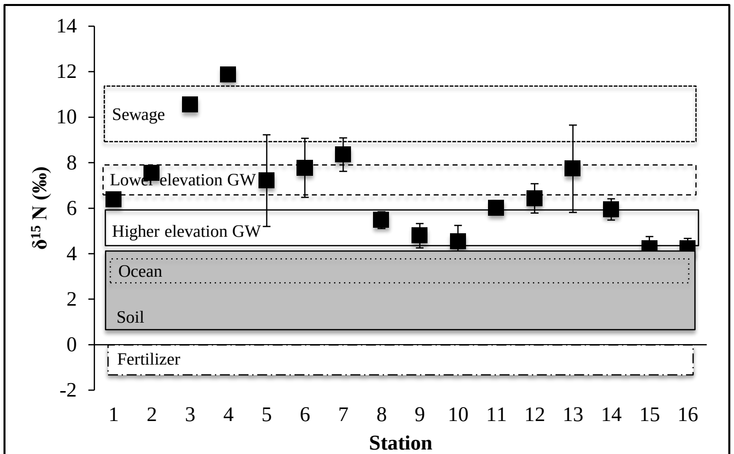



**Figure 6.** Average ± SE $\delta^{15}$ N (‰) of macroalgae found at 16 stations in Puakō. Background areas represent (average ± SE) $\delta^{15}$ $NO_3^-$ of the N sources (fertilizer, soil, ocean, high elevation groundwater wells, low elevation groundwater wells, and sewage; Table ) measured as part of this study. Fertilizer values are from previous sewage study on Hawai‘i Island (Wiegner et al. 2016).

2016). Additionally, in September 2015, shoreline water samples were collected and analyzed at three of the 16 stations (stations 3, 4, and 7) where sewage was thought to be most concentrated for $\delta^{15}N\text{-}NO_3^-$ analyses. N source values were compared to those in the macroalgal tissues and at water at the three shoreline stations to help identify sources of N pollution at Puakō.

The $\delta^{15}N$ macroalgal tissue values ranged from 4.23 to 11.88‰ across all 16 shoreline stations and significantly differed among them ($p<0.0001$), with stations 3 and 4 being the most enriched (Fig. 5). Overall, six of the 16 stations fell within the sewage $\delta^{15}N\text{-}NO_3^-$ range, including stations 3 and 4, as well as 5, 6, 7, and 13 (Fig. 6, encompassing SE of source averages). The remaining stations fell within the high and low elevation groundwater ranges (Fig. 6). These results suggest that Stations 3 and 4 are two sewage pollution hotspots. However, past studies have found that macroalgae assimilate N more rapidly under low $NO_3^-$ concentrations (Fujita 1985), and that $\delta^{15}N$ in macroalgal tissue can be underestimated by up to 6‰ in waters with high $NO_3^-$ concentrations (>10 µM) (Swart et al. 2014). All of the stations had $NO_3^- + NO_2^-$ concentrations exceeding 10 µM, suggesting that the $\delta^{15}N$ macroalgal values may be underestimated. If this is the case, then all 16 stations fall within the sewage range. From these measurements, sewage pollution appears to be widespread along the Puakō shoreline with some areas having more concentrated pollution (Fig. 5).

Similar patterns were not observed in front of the resorts; $\delta^{15}N$ macroalgal ranged from $\delta^{15}N$ -1.0 to +0.1‰, the range reported for fertilizers (shown on Fig. 6).

*Cage deployments*— To determine the spatial extent of sewage pollution offshore, as well as possible inputs from benthic seeps that could directly impact the coral reefs, water was sampled for FIB and nutrients. Additionally, the native green macroalga, *Ulva fasciata*, was deployed during bioassays for $\delta^{15}N$ analysis at five stations (Fig. 7). These stations encompassed three zones (shoreline, bench, and slope) and two depths (surface and benthic) (Fig. 7). Benthic zones were chosen based on physiography features. The bench zone was ~7 m deep, and ~196 m from the shoreline. The slope one was


**Figure 7.** Location of water sample collection (for FIB and nutrients) and algal cage deployments (for $\delta^{15}N$ in *U. fasciata*). Water and macroalgal samples were taken at three zones (shoreline, bench, deep) in Puakō to determine the spatial extent of sewage pollution in surface and benthic waters offshore. Pictures of algal cage deployment design are shown in lower right corner of figure.

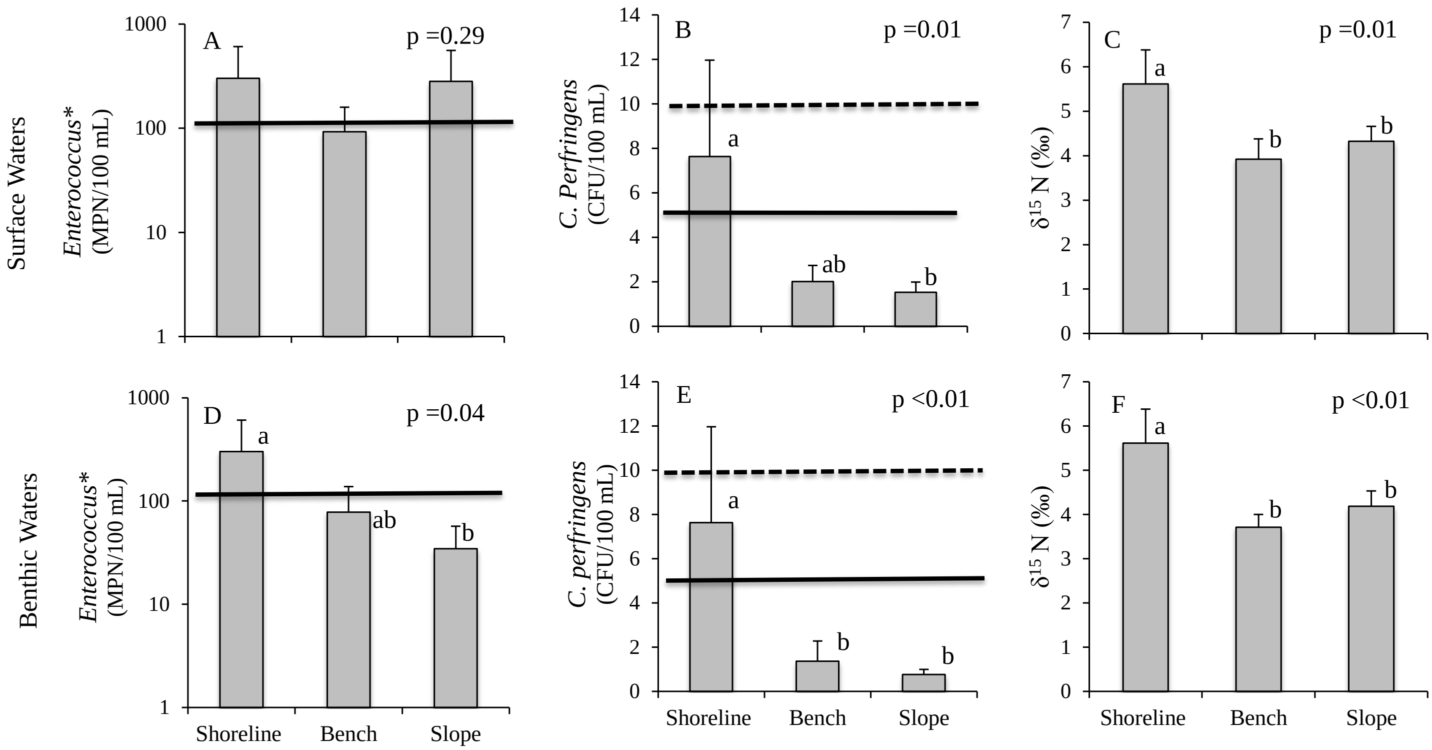



**Figure 8.** Average ± SE of sewage parameters (A, D) *Enterococcus* (*log scale), (B, E) *C. perfringens, and* (C, F) $\delta^{15}N$ in *U. fasciata* collected within three zones (shoreline, bench, slope) in both surface and benthic waters in Puakō. Black lines represent the HDOH single sample maximum for *Enterococcus* (104 CFU/100 mL) and Fujioka's recommendation (1997) for *C. perfringens* in marine recreational waters (5 CFU/100mL). Dashed lines represent non-point source sewage contamination level of 10 CFU/100 mL for *C. perfringens* (Fung et al. 2007) Results from GLM and Tukey's test are shown, with different letters indicating significant differences ($\alpha$ =0.05). FIB n =10. Sample size varied for $\delta^{15}N$ in *U. fasciata* in both surface waters (shoreline, n =9; bench, n =6; slope, n =10) and benthic waters (shoreline, n =9; bench, n =8; slope, n =10).

~15 m in depth, and ~267 m from the shoreline. The bench and slope zones were ~65 m apart. Collection of water samples and algal cage deployments were conducted in June and July 2015. There was one sample collection and cage deployment per month. Additionally, wild algae from the benthos were also collected for $\delta^{15}N$ analyses at all algal cage deployment stations. Public flyers describing the experiment with pictures of the buoys demarcating the deployment locations were placed around Puakō during the cage deployments (*see* Appendix A).

*Enterococcus* counts were similar among surface water zones, but significantly differed among benthic zones ($p = 0.04$; Fig. 8A,D). The greatest differences in the benthos were detected between shoreline and slope zones, which were almost an order of magnitude different. In contrast, *C. perfringens* significantly differed among surface ($p = 0.01$) and benthic ($p < 0.01$) zones (Fig. 8 B,E). In surface waters, the largest differences were detected between shoreline and slope zones (Fig. 8B). Shoreline *C. perfringens* counts were also significantly higher compared to benthic bench and slope waters (Fig. 8E). Nutrient concentrations ($NO_3^- + NO_2^-$, $NH_4^+$, TDN, $PO_4^{3-}$, TDP, and $H_4SiO_4$) were highest on the shoreline in both surface ($p < 0.02$) and benthic ($p < 0.01$) waters (Table 4). Nutrient concentrations among zones in surface and benthic waters were similar between bench and slope zones. Salinity also varied among zones in both surface ($p<0.01$) and benthic waters ($p<0.01$), with the shoreline having the freshest (lowest) values (Table 4). $\delta^{15}N$ in *U. fasciata* significantly varied in surface ($p = 0.01$) and benthic zones ($p<0.01$) (Fig. 8C,F). Shoreline values were the highest, followed by slope, and bench. Both $\delta^{15}N$ for surface and benthic *U. fasciata* samples fell within the $\delta^{15}N - NO_3^-$ range for soil, seawater, and low elevation groundwater at all zones (Fig. 9).

**Table 4.** Average ± SE and [range] of nutrient concentrations (µM) and salinity for surface and benthic water samples among zones (shoreline, bench, slope) in Puakō. A GLM was used and superscript letters indicate grouping from post hoc Tukey's test. $\alpha = 0.05$; n = 10.

| Zone | $NO_3^- + NO_2^-$ | $NH_4^+$ | TDN | $PO_4^{3-}$ | TDP | $H_4SiO_4$ | Salinity |
|---|---|---|---|---|---|---|---|
| Shoreline | $66.87 \pm 11.47^a$ [11.59 – 139.72] | $1.52 \pm 0.16^a$ [0.18 – 3.05] | $72.9 \pm 11.4^a$ [21.1 – 120.6] | $1.67 \pm 0.22^a$ [0.47 – 2.56] | $1.98 \pm 0.22^a$ [0.70 – 3.25] | $439.18 \pm 74.06^a$ [153.57 – 616.73] | $18.52 \pm 3.08^a$ [3.78 – 29.63] |
| Surface | | | | | | | |
| Bench | $1.43 \pm 0.26^b$ [0.83 – 1.84] | $0.57 \pm 0.14^b$ [0.18 – 1.56] | $9.8 \pm 0.5^b$ [7.9 – 11.7] | $0.14 \pm 0.03^b$ [0.02 – 0.27] | $0.64 \pm 0.13^b$ [0.25 – 1.23] | $7.34 \pm 3.07^b$ [1.31 – 20.92] | $33.26 \pm 1.11^b$ [29.95 – 34.47] |
| Slope | $1.23 \pm 0.18^b$ [0.40 – 2.14] | $0.38 \pm 0.11^b$ [0.18 – 1.06] | $9.4 \pm 0.6^b$ [6.5 – 13.0] | $0.12 \pm 0.02^b$ [0.02 – 0.24] | $0.59 \pm 0.11^b$ [0.25 – 0.96] | $5.00 \pm 1.42^b$ [1.21 – 11.10] | $34.24 \pm 0.41^b$ [33.75 – 34.62] |
| Benthic | | | | | | | |
| Bench | $1.10 \pm 0.13^b$ [0.53 – 2.06] | $0.50 \pm 0.12^b$ [0.18 – 1.23] | $9.5 \pm 0.6^b$ [7.2 – 12.9] | $0.18 \pm 0.05^b$ [0.02 – 0.49] | $0.58 \pm 0.11^b$ [0.25 – 0.94] | $2.16 \pm 0.78^b$ [0.83 – 5.49] | $33.55 \pm 0.95^b$ [31.03 – 35.0] |
| Slope | $1.57 \pm 0.51^b$ [1.10 – 6.09] | $1.10 \pm 0.53^{ab}$ [0.18 – 5.58] | $8.8 \pm 0.7^b$ [7.0 – 13.3] | $0.24 \pm 0.11^b$ [0.02 – 1.13] | $0.94 \pm 0.29^b$ [0.25 – 3.25] | $0.65 \pm 0.11^b$ [0.55 – 0.99] | $34.46 \pm 0.30^b$ [34.22 – 34. 85] |

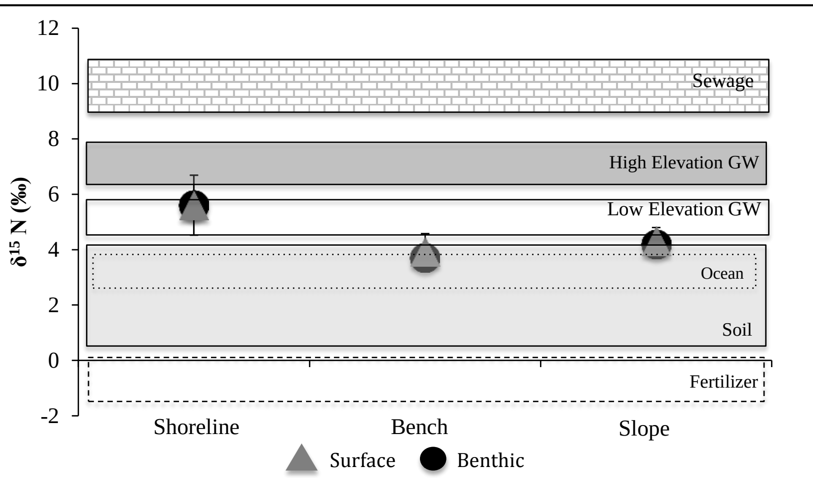



**Figure 9.** Average ± SE $\delta^{15}N$ (‰) of *U. fasciata* deployed within three benthic zones (shoreline, bench, slope) in Puakō. Background areas represent average ± SE of $\delta^{15}N - NO_3^-$ of the N sources and fertilizer from another study on Hawai'i Island (Wiegner et al. 2016). Surface samples are represented by grey triangles and benthic samples by black circles.

Averages of sewage indicators: *Enterococcus*, *C. perfringens*, nutrient concentrations ($NO_3^- + NO_2^-$, $NH_4^+$, TDN, $PO_4^{3-}$, and TDP), and $\delta^{15}N$ in *U. fasciata* were similar among water depths. $H_4SiO_4$ concentrations did vary, with the greatest differences detected between surface waters at the bench and benthic waters at the slope ($p < 0.01$). Salinity was similar between surface and benthic waters.

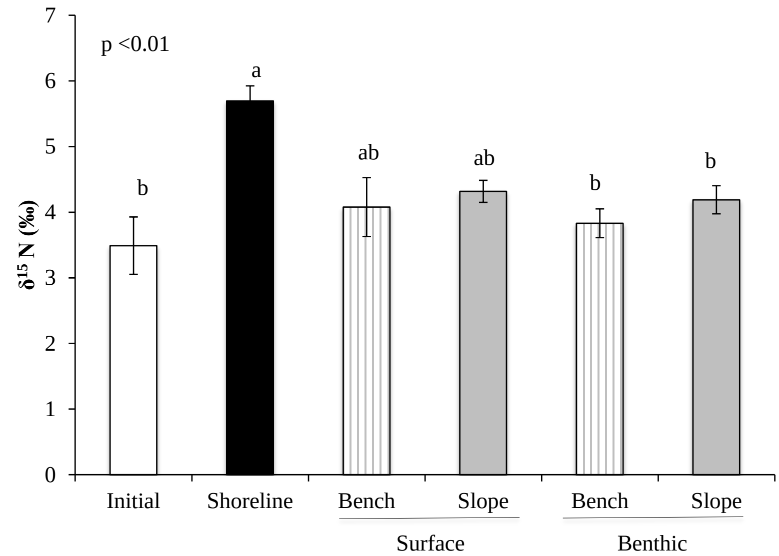



**Figure 10.** Average ± SE δ$^{15}$ N (‰) of *U. fasciata* pre-(initial) and post-deployments within three benthic zones (shoreline, bench, slope) and two depths (surface and benthic) in Puakō. GLM was used and shared lettering indicates no significant differences in Tukey's post hoc test. Sample size varied (initial, n =11; shoreline, n =5; surface bench, n =4; surface slope, n =5; benthic bench, n =5; benthic slope, n =5). α =0.05.

Pre- and post-deployment δ$^{15}$N *U. fasciata* values differed (p <0.01), with the greatest differences occurring at the shoreline (Fig. 10). Within the slope zone, surface and benthic waters showed smaller differences in pre- and post-deployment δ$^{15}$N, followed by the bench zone in surface and benthic waters.

δ $^{15}$N in benthic wild macroalgae and deployed cages were similar to one another, but differed from both wild and caged at the shoreline. Bench zone δ $^{15}$N in wild algae ranged from -0.57 to +4.02‰ (average ±SE; +2.90‰ ± 1.96), whereas caged bench zone *U. fasciata* ranged from +3.23 to +4.27‰, (+3.83‰ ± 0.49). In the slope zone, δ$^{15}$N in wild algae ranged from +3.48 to +8.92‰ (+6.09‰ ± 2.31) and deployed *U. fasciata* ranged from +3.50 to +4.78‰ (+4.19‰ ± 0.48). Wild shoreline algae ranged from +5.07 to +10.18‰

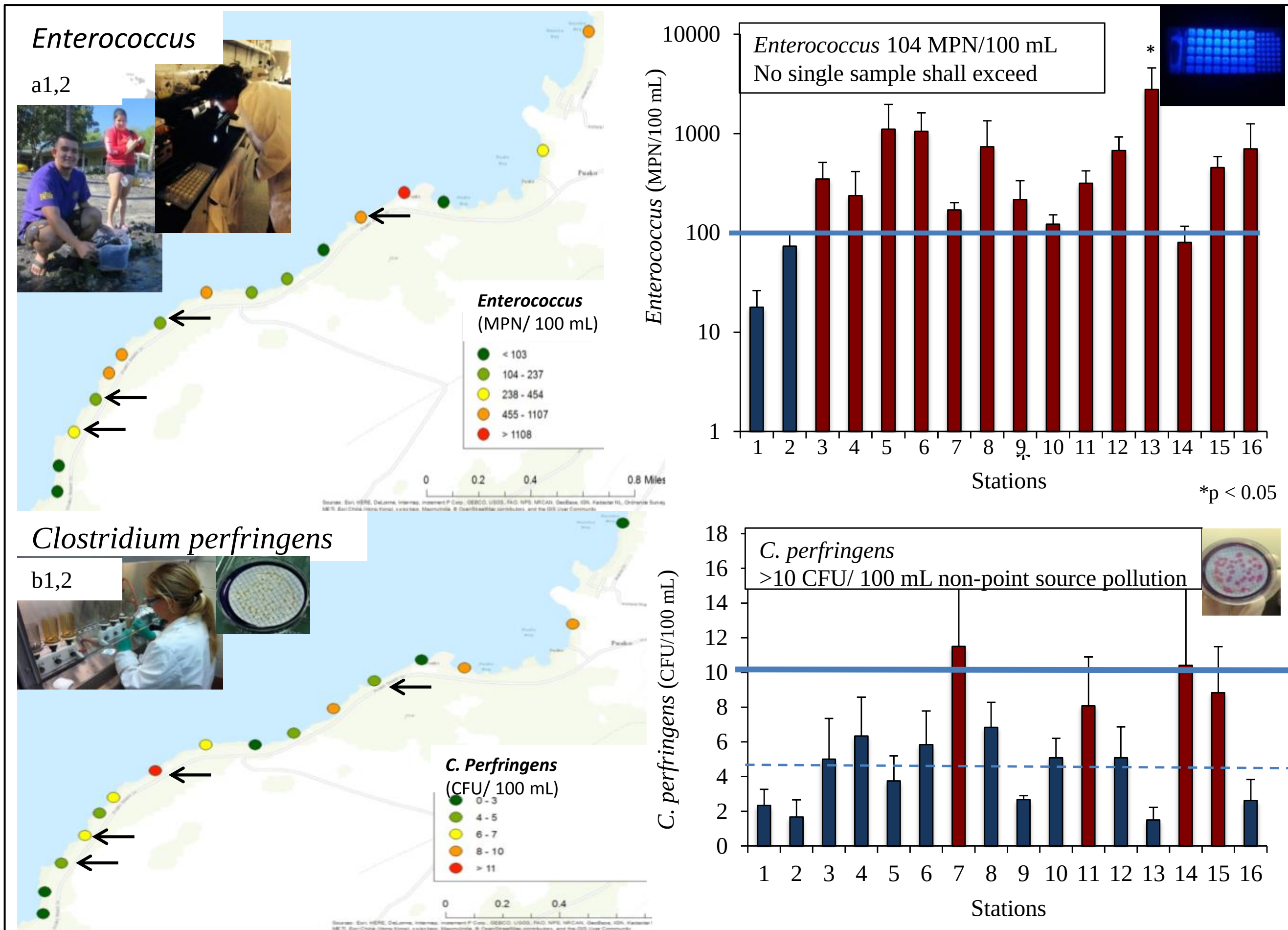



**Figure 11.** Average (±SE) *Enterococcus* (a1,2) and *Clostridium perfringens* (b1,2) values along the Puakō shoreline from November 2014 to July 2015 (n= 4). Red bars indicate values that are above established or recommended standards to HDOH (light blue lines). For *Enterococcus*, no single sample shall exceed 104 MPN/100 mL. For *C. perfringens*, the recommended standard for recreational water is 5 CFU/100 mL (solid line; Fujioka et al. 1997) and 10-100 CFU/100 mL is considered to be indicative of non-point sewage pollution (dashed line; Fung et al. 2007). Arrows are indicative of dye tracer tests.

(+7.75‰ ± 1.25) and caged *U. fasciata* ranged from +3.37 to +7.27‰ (+5.61‰ ± 1.08). The highest shoreline $\delta^{15}N$ values in both wild and caged macroalgae were observed at station 2.

Sewage indicators (FIB, $\delta^{15}N$ macroalgae, nutrients) were highest along the shoreline compared to values offshore in surface and benthic waters in both the bench and slope zones. These results suggest that sewage pollution is concentrated along the shoreline, and that low offshore values reflect smaller direct sewage inputs through benthic seeps or dilution of nearshore inputs.

**Objective 3:** To determine if state water quality standards are exceeded in Puakō's near-shore environment for FIB (*Enterococcus* and *C. perfringens*), water samples were collected at 16 shoreline stations (Fig. 2, black circles). Values for these parameters were compared to state water quality standards to determine if state benchmarks were exceeded. Pilot sampling occurred at six stations during July 2014, four full shoreline samplings occurred November 2014, March, June, and July 2015, and five stations from September 2015 to February 2016. During November 2014, July 2015, and July 2016 samples were also collected for *Bacteroides* analysis. *Bacteriodes* are the most numerous bacteria in the human gut and there are molecular probes to

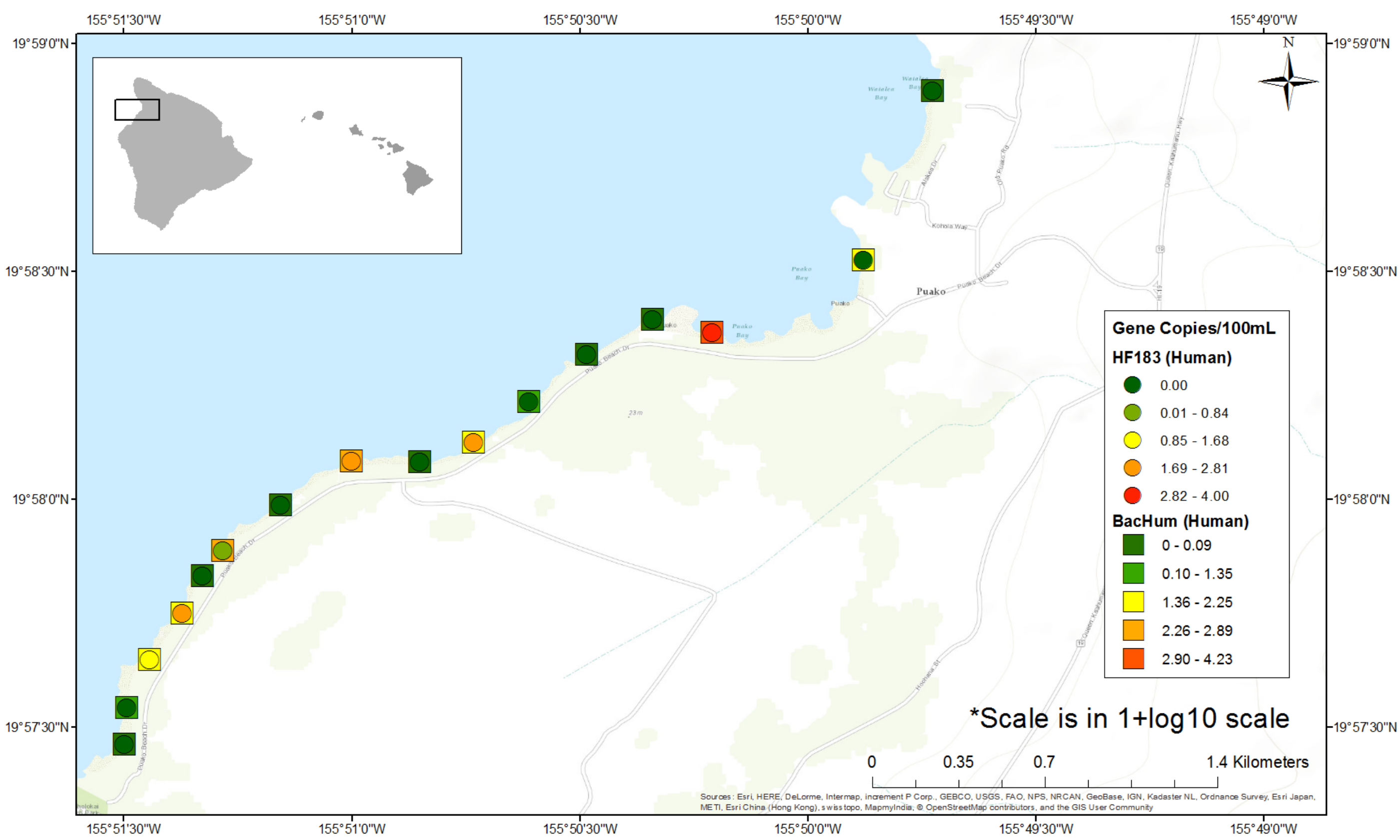



**Figure 12.** Human-associated *Bacteroides* in nearshore waters along the Puakō coastline (November 2014, July 2015, and July 2016). Two molecular markers were used to detect these bacteria (HF183 and BacHum). Data were log transformed (log 10 (x +1)).

identify those specifically from humans. Dr. Craig Nelson from UH Mānoa, Center for Microbial Oceanography (C-MORE), School of Ocean and Environmental Sciences and Technology (SOEST) analyzed these samples using the BacHum-UCD and HF183 markers.

Our results indicate that FIB levels are quite variable and often higher than the HDOH standards at several stations (Fig. 11). For *Enterococcus*, 14 of the 16 stations had average values that were higher than the HDOH single sample maximum recreational water quality standard (no single sample shall exceed 104 MPN/100 mL; Fig. 11a). Eleven of the 16 stations also had *C. perfringens* values higher than the recommended standard to HDOH of 5 CFU/100 mL (Fig. 11b; Fujioka et al. 1997). Four of the stations also had values of 10 CFU/100 mL or higher which is indicative of non-point source sewage pollution (Fung et al. 2007). Overall, 11 of the 16 stations had *Enterococcus* and *C. perfringens* values that were both higher than established or recommended HDOH standards (Fig. 11). Lastly, one of the stations with high *C. perfringens* values was also one of the locations where a dye tracer test was conducted (Station 7); these results confirm that the high bacteria levels were from sewage pollution (Figs. 2 and 11). Eight stations (3, 4, 6, 8, 10, 11, 14, and 15) had positive hits for human *Bacteriodes* markers, two of which were dye tracer test locations (Fig. 12).

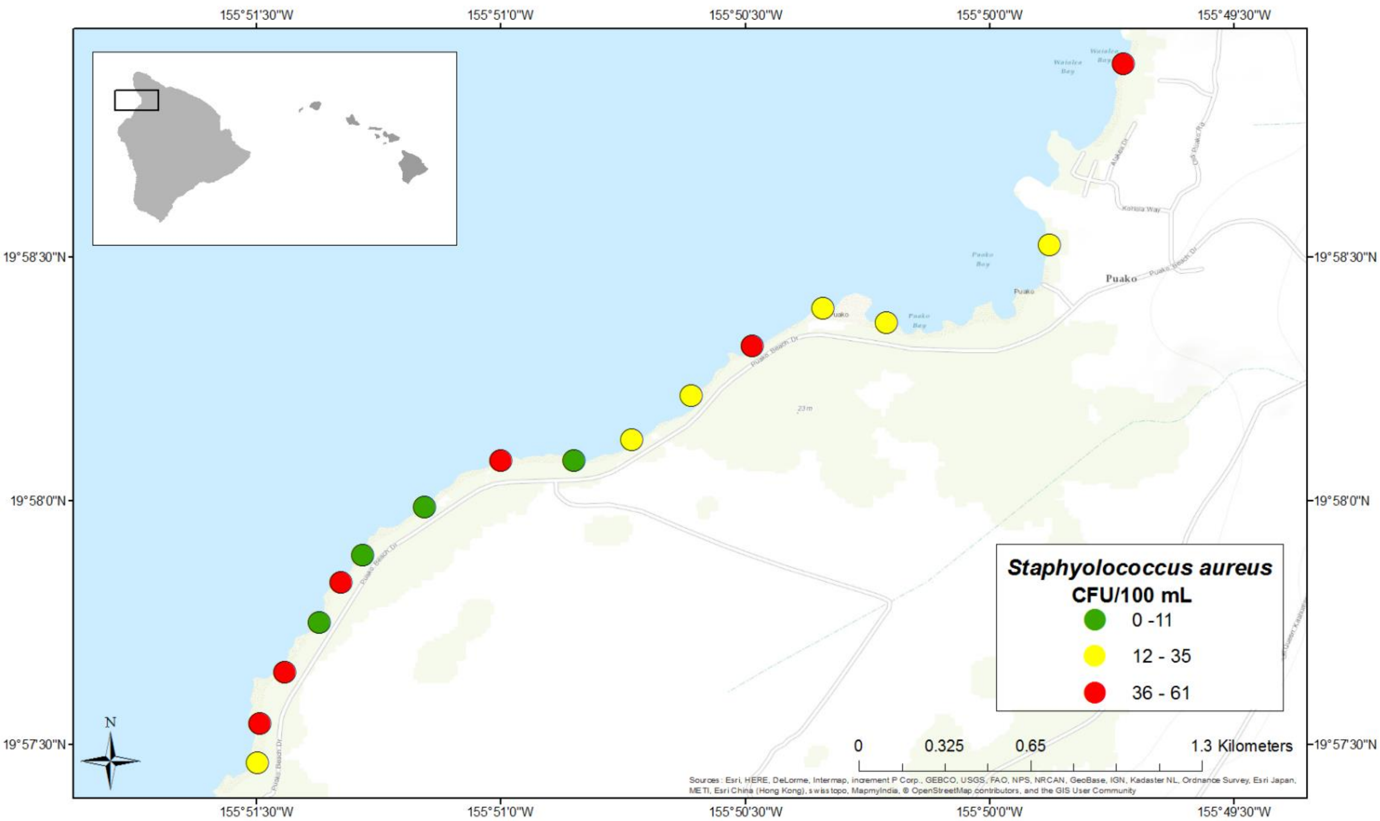



**Figure 13.** *Staphylococcus aureus* counts in nearshore waters along the Puakō coastline (June 2015). There are no HDOH standards for *S. aureus* in recreational waters; however, it has been recommended that counts be lower than 100 CFU/ 100 mL in recreational waters (Shenawy 2005).

In June 2015, shoreline water samples were also collected for *Staphylococcus aureus* analysis at the 16 stations (Fig. 13); sampling at five of these stations continued from September 2015 to February 2016. *S. aureus* is a human pathogen that can be found in sewage. It often causes skin infections that are thought to be acquired during recreational water use. Two stations had values greater than 100 CFU/ 100 mL, which has been recommended as a standard for recreational waters (Shenawy 2005). Presently, there are no HDOH *S. aureus* water quality standards.

**Objective 4**: To assess the benthic community responses to sewage inputs at Puakō, shoreline stations and the two

**Table 5**. Summary of benthic cover at 16 shoreline stations along the Puakō shoreline. Values are presented as (%) cover. Eight major categories were summarized: basalt, coral, crustose coralline algae (CCA), turf, macroalgae, limestone, sand, and invertebrates.

| Station | Basalt | Coral | CCA | Turf | Macroalgae | Limestone | Sand | Invertebrates |
|---|---|---|---|---|---|---|---|---|
| 1 | 51.5% | 0.0% | 0.0% | 39.5% | 0.0% | 0.0% | 9.0% | 0.0% |
| 2 | 10.7% | 26.8% | 2.8% | 52.2% | 0.0% | 2.0% | 5.0% | 0.5% |
| 3 | 87.5% | 0.0% | 0.0% | 7.0% | 0.0% | 4.0% | 1.5% | 0.0% |
| 4 | 38.0% | 0.0% | 0.0% | 52.5% | 0.0% | 0.0% | 9.5% | 0.0% |
| 5 | 11.0% | 0.0% | 0.0% | 72.0% | 0.0% | 1.5% | 15.5% | 0.0% |
| 6 | 12.7% | 7.8% | 11.0% | 64.8% | 0.0% | 1.0% | 2.7% | 0.0% |
| 7 | 18.2% | 23.3% | 10.5% | 40.8% | 0.0% | 0.5% | 6.5% | 0.2% |
| 8 | 27.0% | 0.0% | 0.0% | 41.0% | 0.0% | 11.0% | 21.0% | 0.0% |
| 9 | 8.3% | 19.7% | 8.3% | 61.5% | 0.0% | 2.2% | 0.0% | 0.0% |
| 10 | 23.5% | 0.0% | 0.0% | 70.5% | 0.0% | 6.0% | 0.0% | 0.0% |
| 11 | 4.8% | 16.3% | 18.7% | 59.5% | 0.0% | 0.5% | 0.0% | 0.2% |
| 12 | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 13 | 23.0% | 0.0% | 0.0% | 77.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 14 | 16.5% | 0.0% | 0.0% | 79.0% | 0.0% | 0.0% | 4.5% | 0.0% |
| 15 | 26.5% | 0.0% | 0.0% | 73.5% | 0.0% | 0.0% | 0.0% | 0.0% |
| 16 | 21.0% | 0.0% | 0.0% | 78.0% | 0.0% | 0.0% | 1.0% | 0.0% |

primary coastal benthic environments (basalt bench and coral-dominated fore-reef slope) were surveyed using standardized techniques during the two algal cage deployments in June and July 2015. Data from these surveys have been summarized (Tables 5 and 6). The majority of the shoreline stations were dominated by turf and basalt (Table 5). Benthic cover at the bench and slope stations consisted of turf, coral, and crustose coralline algae, with turf comprising the greatest percentage at the bench and coral at the slope (Table 6).

**Table 6**. Summary of benthic cover at deployments stations onshore at the two primary coastal benthic environments (bench and slope) in Puakō. Values are presented as (%) cover. Eight major categories were summarized: basalt, coral, crustose coralline algae (CCA), turf, macroalgae, limestone, sand, and invertebrates.

| Station | Basalt | Coral | CCA | Turf | Macroalgae | Limestone | Sand | Invertebrates |
|---|---|---|---|---|---|---|---|---|
| **2** | | | | | | | | |
| Shoreline | 32.0% | 0.0% | 0.0% | 61.5% | 0.0% | 6.0% | 0.5% | 0.0% |
| Bench | 0.0% | 35.5% | 0.0% | 63.0% | 0.0% | 0.0% | 0.0% | 1.5% |
| Slope | 0.0% | 45.0% | 8.5% | 32.0% | 0.0% | 0.0% | 14.5% | 0.0% |
| **6** | | | | | | | | |
| Shoreline | 38.0% | 0.0% | 0.0% | 54.0% | 0.0% | 3.0% | 5.0% | 0.0% |
| Bench | 0.0% | 1.0% | 20.0% | 79.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Slope | 0.0% | 22.5% | 13.0% | 61.5% | 0.0% | 0.0% | 3.0% | 0.0% |
| **7** | | | | | | | | |
| Shoreline | 54.5% | 0.0% | 0.0% | 44.5% | 0.0% | 0.5% | 0.5% | 0.0% |
| Bench | 0.0% | 26.0% | 16.5% | 37.5% | 0.0% | 1.0% | 19.0% | 0.0% |
| Slope | 0.0% | 44.0% | 15.0% | 40.5% | 0.0% | 0.0% | 0.0% | 0.5% |
| **9** | | | | | | | | |
| Shoreline | 25.0% | 0.0% | 0.0% | 75.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Bench | 0.0% | 16.0% | 13.0% | 64.5% | 0.0% | 6.5% | 0.0% | 0.0% |
| Slope | 0.0% | 43.0% | 12.0% | 45.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| **11** | | | | | | | | |
| Shoreline | 14.5% | 0.0% | 6.5% | 77.5% | 0.0% | 1.5% | 0.0% | 0.0% |
| Bench | 0.0% | 12.0% | 20.0% | 67.5% | 0.0% | 0.0% | 0.0% | 0.5% |
| Slope | 0.0% | 37.0% | 29.5% | 33.5% | 0.0% | 0.0% | 0.0% | 0.0% |

Sampling for coral pathogens (*Serratia marcescens* and *Vibrio* spp.) occurred from September 2015 to February 2016 at five shoreline locations, and coincided with $\delta^{15}N$ macroalgal tissue, FIB, and nutrient sample collection. Both pathogens were detected in the nearshore waters of Puakō.

**Development of a novel "Sewage Pollution Score":** As this study and others have shown, sewage indicators can provide conflicting information on the intensity and location of sewage pollution. In this study, for example, *Enterococcus* concentrations were highly variable among shoreline stations, with some exceeding HDOH standards, and station 13 having the highest concentrations (Fig. 11a). In contrast, *C. perfringens* concentrations were similar among shoreline stations, but averages for stations 7, 11, 14, and 15 were in the non-point source sewage pollution range (Fig. 11b; Fung et al. 2007). Additionally, $\delta^{15}N$ in macroalgal tissue were found to be highly variable along the shoreline, with six stations (3, 4, 5, 6, and 13) falling within the range of our sewage source value (Figs. 5 and 6, Table 2). Previous studies have confronted similar issues with their sewage indicator data (Shibata et al. 2004; Yoshioka et al. 2016). Hence, we developed a sewage pollution score using sewage indicators to more holistically assess sewage pollution in coastal waters. This score was developed in collaboration with The Nature Conservancy (TNC). Water quality scores and indices have been used successfully in the past to assess water quality conditions for both humans and ecosystems (Zambrano et al. 2009; Wang et al 2015).

Our scoring system used sewage indicators (FIB, $\delta^{15}N$ macroalgae, and nutrients) and was applied to shoreline and offshore surface and benthic waters at Puakō. The scoring system had three levels for each indicator: level 1 = low, level 2 = medium, and level 3 = high. Levels for each indicator were based on established standards or literature information (Table 7). Specifically, the scoring system used HDOH's single sample maximum for *Enterococcus* concentrations in marine waters (HDOH 2014), the Fung/Fujioka *C. perfringens* scale for sewage pollution (Fung et al. 2007), $\delta^{15}N$ values in macroalgal tissue for different N sources (*reviewed in* Wiegner et al.

**Table 7**. Parameters (FIB = CFU/100 mL, $\delta^{15}N$ = ‰, and nutrients = µM) used to evaluate water quality along the Puakō coastline, as well as offshore surface and benthic waters. Sewage parameters were ranked (low = 1, medium = 2, high = 3), multiplied by a weight factor, and summed for a final sewage pollution score. * "Medium" nutrient concentration ranks exceed HDOH standards for open coastal waters wet criteria.

| Sewage Parameter | Weight Factor | Low (1) | Medium (2)* | High (3) | Reference |
|---|---|---|---|---|---|
| *C. perfringens* | 3 | 0 – 10 | 11 - 100 | 101 – 505+ | Fung et al. 2007 |
| $\delta^{15}N$ in macroalgae | 3 | +2 - +7 | -5 - +1.9 | +7 - +20 | Wiegner et al. 2016 |
| *Enterococcus* | 2 | 0 - 35 | 36 - 104 | 105+ | HDOH 2014 |
| $NO_3^- + NO_2^-$ | 1 | 0 – 0.4 | 0.5 – 1 | 1.1 – 1.8+ | HDOH 2014 |
| $NH_4^+$ | 1 | 0 – 0.25 | 0.26 – 0.61 | 0.61 – 1.07+ | HDOH 2014 |
| TDP | 1 | 0 – 0.7 | 0.8 – 1.3 | 1.4 – 1.9+ | HDOH 2014 |

2016), and HDOH's water quality standards for nutrient concentrations in open coastal waters ($NO_3^-$ + $NO_2^-$, $NH_4^+$, TDP) (HDOH 2014) (Table 7). Nutrient concentration standards for the wet criteria were used because the freshwater inputs along the Puakō shoreline ranged from 2083-2730 L $m^{-1}$ $h^{-1}$ (Paytan et al. 2006), an order of magnitude larger than the baseline for the wet criteria (>294 L $m^{-1}$ $h^{-1}$). Two dissolved inorganic forms of N were chosen for the score system rather than TDN because the latter contains DON and there are no well-established patterns with this constituent for sewage pollution. TDP was used as the phosphorous water quality parameter since HDOH has no $PO_4^{3-}$ water quality standard for open coastal waters (HDOH 2014). It should also be noted that a 'medium' score in nutrient concentrations exceeds HDOH standards for open coastal waters wet criteria.

Once each indicator was assigned a level (1-3) based on its measured value and our scoring system (Table 7), its level was multiplied by a weight factor (1-3), with the most reliable sewage indicators having the greatest weight. The greatest weight (weight = 3) was given to *C. perfringens* and $\delta^{15}N$ in macroalgal tissue, because these indicators are more specific to sewage pollution, more integrative measurements of environmental conditions, and do not fluctuate as much as *Enterococcus* and nutrient concentrations (Fung et al 2007; Dailer et al. 2010; Viau et al. 2011; Yoshioka et al. 2016). *Enterococcus* received a medium weight (weight =2) as HDOH uses this FIB to assess marine recreational water safety specifically for sewage pollution, but not the highest weight because concentrations fluctuate over short time scales (min to h) and have other sources, like soils, in tropical areas (Hardina & Fujioka 1991; Byappanahalli & Fujioka 1998; Byappanahalli & Fujioka 2004). Nutrient concentrations received the lowest weight (weight = 1) since sewage pollution is known to increase nutrient concentrations, but nutrients can also come from other sources within the watershed and concentrations can vary over short time scales (Lapointe et al. 1990; David et al. 2013; Nelson et al. 2015). The equation for deriving the overall sewage pollution score for each station was: (*C. perfringens* level x 3) + ($\delta^{15}N$ macroalgae level x 3) + (*Enterococcus* level x 2) + ($NO_3^-$+$NO_2^-$ level x 1) + ($NH_4^+$ level x 1) + (TDP level x 1). Sewage pollution score categories were: 'low' = 11-15, 'medium' = 16-20, and 'high' = 21-30.

The shoreline stations with highest pollution sewage scores were station 7 (score =30) and 4 (30) (Fig. 14a). Note, that based on dye tracer tests, these two stations are known locations of OSDS leakage. Station 3 (score = 27), another location of known OSDS leakage, had the third highest pollution score. Overall, 13 stations fell in the high category, two were medium, and one was low (Fig. 14a). These results confirm of the effectiveness of our score in identifying sewage pollution hotspots.

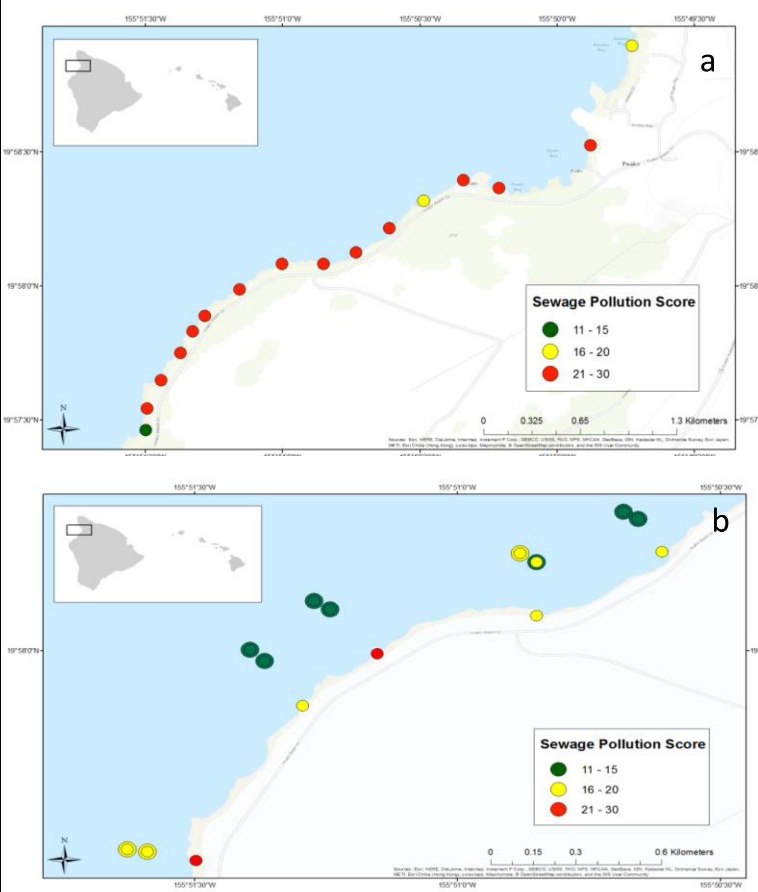



**Figure 14.** Sewage pollution scores for the (a) shoreline and (b) algal cage deployment studies at Puakō. The score is based on standards and literature values for sewage indicators (FIB, $\delta^{15}$ N in macroalgae, and nutrients). Sewage pollution score represents the following catergories: Low = 11 - 15; Medium = 16 - 20; High = 21 - 30.

During the algal cage deployments, shoreline stations had the overall highest scores (medium and high), with stations 2 and 7 being the highest (Fig. 14b). As noted above, station 7 was a dye tracer test location (Fig.

2). Offshore transport or direct sewage discharge onto the reef through benthic seeps was localized, as stations 2 and 9 offshore surface and benthic waters only had medium sewage pollution scores (Fig. 14b). Most offshore stations fell in the low sewage pollution score category (Fig. 14b).

The sewage pollution score is an integrated approach that accurately identified sewage hotspots along the Puakō coastline. At these locations, it is critical for homes to remove their cesspools and employ better sewage treatment technology. These maps also provide information to the community on areas where community members may want to limit water exposure during recreational activities until sewage treatment is improved.

**E. *Outreach*.** The UH Hilo Marine Science research team was involved in 25 outreach and advisory board events from July 2014 to January 2017 (Table 8). They met with PCA 10 times. In June 2014, UH Hilo met PCA to inform them of the funding of the proposal, review the objectives of the project, and introduce the research team. In August 2014, the team met with them during a NOAA CRCP site visit. UH Hilo also attended seven community association meetings: November 2014, January, April, August 2015, and January, April, and October 2016. At the November 2014 meeting, Dr. Wiegner gave a presentation and handed out a 1-page informational sheet on this project and its results to date (Fig. 15). In January 2015, UH Hilo attended PCA's meeting to answer any questions regarding this project, and how its results support the 'Puakō Sewage Disposal Upgrade Project' led by the Coral Reef Alliance. An updated 1-page information sheet was circulated at this meeting (*see* Appendix B). In April 2015, Drs. Wiegner and Beets attended a community meeting where the engineering firm (Aqua Engineering) contracted by Coral Reef Alliance for a sewage treatment upgrade feasibility study was introduced to the community. In August 2015, Dr. Wiegner attended a community meeting where Aqua Engineering presented results and recommendations from their preliminary feasibility study. In January 2016, Dr. Colbert gave a presentation at the annual PCA meeting summarizing results from UH Hilo's and TNC's efforts at Puakō; this presentation, as well as a 1-page handout that was distributed (*see* Appendix C), were a joint effort between the two research groups. In April 2016, Dr. Wiegner attended a PCA meeting with NOAA officials to discuss research in NOAA's Habitat Blue Print area (which includes Puakō). In October 2016, Dr. Wiegner attended a PCA meeting with the new director of HDAR to discuss ways in which HDAR could support the 'Puakō Sewage Disposal Upgrade Project' led by the Coral Reef Alliance. Additionally, Drs. Wiegner, Colbert, and Beets are members of the Coral Reef Alliance's Advisory Board for the 'Puakō Sewage Disposal Upgrade Project'; they met with the

**Table 8.** Outreach during UH Hilo's NOAA Coral Reef Conservation Program project from July 2014 to January 2017.

| Organization | Number of events (year) |
|---|---|
| Puakō Community Association | 10 (2014 = 3; 2015 = 3; 2016 = 3; 2017 =1) |
| Coral Reef Alliance's 'Puakō Sewage Disposal Upgrade Project' Advisory Board | 7 (2014 = 1; 2015 =2 ; |
| South Kohala Conservation Action Plan Advisory Board | 4 (2016 = 4) |
| Hawai'i Theatre for Youth "The Story of Water and Hawai'i" performance – Water Hero appearance | 1 (2016) |
| NOAA BWET water quality lectures | 2 (2015 = 1; 2016 = 1) |
| "Flushing Our Future" workshop panelist – ASLO 2017 Conference | 1 (2017) |

**Figure 15.** Meeting with the Puakō Community Association (PCA) in November 2014. From left to right, (front row): Sierra Tobiason (UH Sea Grant), Tracy Wiegner (UH-Hilo), Erica Perez (Coral Reef Alliance), Kaile`a Carlson (UH-Hilo), Leilani Abaya (UH-Hilo), Wes Crile (Coral Reef Alliance), (back row) Steve Colbert (UH-Hilo), and Jim Beets (UH-Hilo). Photo is from the Coral Reef Alliance letter included in the PCA January 2015 newsletter.

board in October 2014, August and December 2015, November 2016, and January 2017. Dr. Wiegner also attended a two-day workshop in August 2016 held by the Coral Reef Alliance to develop a 10-year monitoring plan for Puakō. Drs. Wiegner and Colbert also served as panelist at a recent forum held by the Coral Reef Alliance to address PCA's questions regarding options for cesspool removal (Fig. 16). At this meeting, a 1-page handout summarizing results from UH Hilo and TNC was distributed (*see* Appendix D). Data from UH Hilo's CRCP project were also submitted in written testimony to the HDOH in support of their proposed cesspool ban in September 2014 and included in a letter to Hawai'i's Governor encouraging him to sign the ban on new cesspool construction in the state (March 11, 2016) (*see* Appendix E).

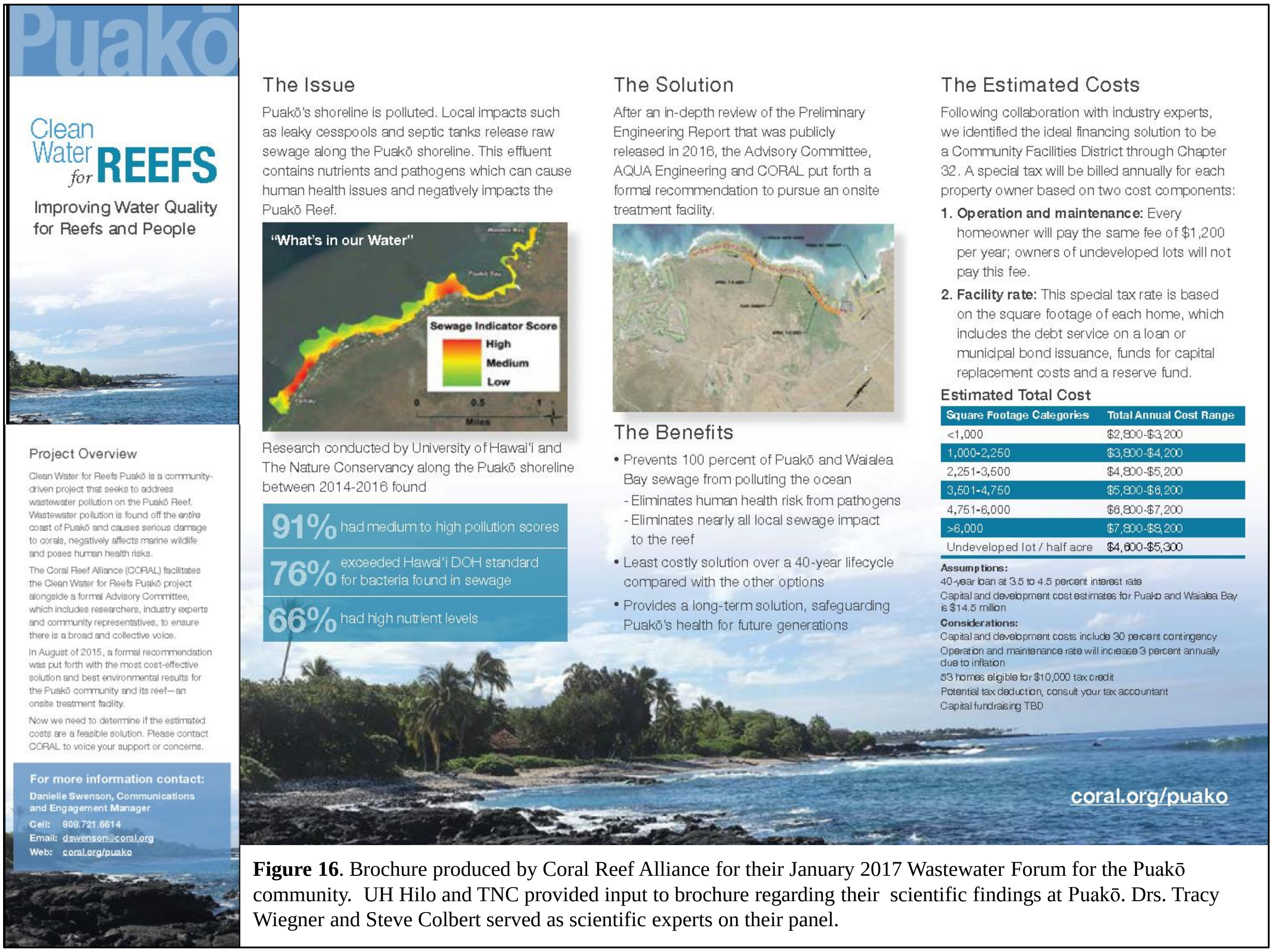



**Figure 16**. Brochure produced by Coral Reef Alliance for their January 2017 Wastewater Forum for the Puakō community. UH Hilo and TNC provided input to brochure regarding their scientific findings at Puakō. Drs. Tracy Wiegner and Steve Colbert served as scientific experts on their panel.

Drs. Wiegner and Colbert are also members of the South Kohala Conservation Action Plan Marine Advisory Board, and attended four meetings in 2016 (March, June, August, and December). In October 2016, Dr. Wiegner was also a "Water Hero" in the Hawai'i Theatre for Youth's performance of "The Story of Water and Hawai'i" at the UH Hilo Performing Arts Center where she spoke about sewage pollution on Hawai'i Island to local K-12 students (Fig. 17). Dr. Wiegner has also given two online lectures (January and November 2016) to Hawai'i State public school teachers (6-12 grade) regarding water pollution in Hawai'i State as part of the NOAA BWET "OPIHI" project at UH Mānoa led by Dr. Kanesa Seraphin Duncan, Education Director for University of Hawai'i Sea Grant College. In February 2017, Dr. Wiegner was a panelist for a town hall event entitled "Flushing Our Future" at the Association for the Sciences of Limnology and Oceanography (ASLO) Conference in Honolulu, HI. This event was organized by Dr. Craig Nelson from UH Mānoa's C-MORE program and Dr. Daniele Spirandelli from UH Mānoa's Department of Urban and Regional Planning.

**HTY Embarks on Statewide Tour with H20: THE STORY OF WATER AND HAWAII**

by BWW News Desk Sep. 20, 2016

Honolulu Theatre for Youth will tour its 2015-16 season finale *H20, THE STORY OF WATER AND HAWAII* to Maui County, Kauai and the Big Island in October and November. This sweeping musical by the HTY company will immerse both school and public audiences in a celebration of our islands' most precious resource. Show dates, times and locations are:

The extraordinary musical floods the senses as HTY's cast of "Water Warriors" (alternately scientists, activists and rock stars) explores the cultural, historical, environmental and physical properties of water through song, humor and interactive story telling. **At the close of each performance, different "Water Heroes" from the surrounding community will take the stage and share their knowledge on an aspect of water in the islands.**

Big Island - Hilo
UH Hilo Performing Arts Center
Public Performance Friday, October 21, 7 p.m.
Tickets $10 all seats all ages, available via www.htyweb.org, (808) 839-9885 ext. 720, or at the door.
(School performances Oct. 19, 20, 21)

**Figure 17.** October 2016, Hawai`i Theatre for Youth performed at the UH Hilo Performing Arts Center and Dr. Tracy Wiegner was their **"Water Hero"** during one of their Hawai`i Island school group performances. She talked about sewage pollution on Hawai`i Island.

**F. *Student Training*.** This project has trained 12 undergraduates and one graduate student to date with a variety of funding sources (Figs. 18 and 20, Table 9, *see* Appendix F). Between summer 2014 and 2016, eight interns (2014: Evelyn Braun, Maile Aiwohi, Ricky Tabandera; 2015: Bryan Tonga, Devon Aguiar, Jazmine Panelo; 2016 Saria Sultan and Christopher Thompson) from the UH Hilo Pacific Internship Program for Exploring Science (PIPES, funded by the National Science Foundation [NSF]) worked with Drs. Wiegner and Colbert. Both years, the students conducted field and laboratory work, wrote final reports, and presented their findings at a student symposium. In 2014, their results served as pilot data for this project. They helped identify groundwater seep locations (Fig. 1), work out the logistics for macroalgal and water quality sampling, processing, and analyses, as well as conduct the first dye tracer test. In 2015, the interns' projects were designed to collect data for portions of the larger project. During the 2014-2015 academic year, two undergraduates (Cherie Kauahi and Devon Aguiar), supported by UH Mānoa's C-MORE program (NSF funded), assisted Dr. Colbert on his dye tracer tests and Dr. Wiegner on her *Enterococcus* sampling. Another undergraduate (Carrie Soo Hoo) completed her senior thesis with Dr. Wiegner examining the $\delta^{15}N$ distribution in coastline macroalgae. She received funding for her project from UH Hilo's Science, Technology, Engineering, and Math (STEM) Honor's program (NSF funded) and Sigma Xi. Another undergraduate (Serina Kiili) received a U.S. Environmental Protection Agency (USEPA) Greater Research Opportunities (GRO) fellowship to examine sewage pathogens affecting coral health. During the 2015-2016 academic year, two undergraduates (Devon Aguiar and Jazmine Panelo), supported by UH Mānoa's C-MORE program, assisted Dr. Wiegner on her *Enterococcus* and *S. aureus* sampling. Ms. Panelo's and Kiili's senior thesis projects focused on *S. aureus* and coral pathogens, respectively. Fall 2016, Carey Demapan joined the research

**Table 9.** Organizations that have provided student (undergraduate and graduate) support during UH Hilo's NOAA Coral Reef Conservation Program project from July 2014 to January 2017.

| Organization | Number of students supported |
|---|---|
| Puakō Community Association | 1 graduate student |
| UH Hilo PIPES (NSF REU) | 8 undergraduate summer interns |
| UH Mānoa C-MORE (NSF) | 3 undergraduate trainees |
| USEPA GRO | 1 undergraduate fellow |
| UH Hilo STEM Honors Program (NSF) | 1 undergraduate senior |
| Sigma Xi | 1 undergraduate |
| 'Ike Wai (NSF EPSCoR) | 1 undergraduate |
| ASLO Minority Program (ASLOMP) | 3 student travel grants (2 graduate, 1 undergraduate) |
| UH Hilo Marine Science Department | 3 undergraduate senior theses; 12 undergraduate interns |
| Ecological Society of America (ESA) | 1 undergraduate travel grant |

**Figure 18.** UH-Hilo PIPES 2014 summer interns. From left to right: Ricky Tabandera (UH-Hilo), Maile Aiwohi (UH-Hilo), and Evelyn Braun (UH-Mānoa).

team as an ‘Ike Wai scholar supported through the UH system NSF EPSCoR grant. Lastly, Leilani Abaya, a graduate student enrolled in the Tropical Conservation Biology and Environmental Science (TCBES) Master’s program at UH Hilo, defended her research proposal in February 2015 and thesis in April 2016. Her thesis was submitted to UH Hilo Library August 2016 (*see* Appendix G).

***G. Products.*** **Sixty products** have resulted from this project (*see* Appendices A–J). These include: reports, manuscripts (*see* Appendix G), student theses (*see* Appendix G), presentations (*see* Appendix F), posters (*see* Appendix B), 1-page information sheets (*see* Appendix F), newspaper/ magazine/ online articles (*see* Appendix D), videos, testimony (*see* Appendix E), and a conference session (Table 10). Reports have been submitted to NOAA’s CRCP (biannual) and HDAR (algal cage deployment permit report). Dr. Wiegner has given eight presentations on this project to date – The Hawai‘i Ecosystem Meeting (July 2014, Hilo, HI), HDOH, Clean Drinking Water Branch, Inter-government Water Conference (INVITED, August 2014, Kona, HI), PCA meeting (November 2014), NOAA CRCP/HDAR meeting (April 2015, Honolulu, HI), NOAA Mokupāpapa Discovery Center (INVITED, May 2015, Hilo, HI), UH Hilo (Public lecture, September 2015, jointly with Dr. Colbert; Fig. 19), International Coral Reef Symposium (ICRS, June 2016, Honolulu, HI), and at the 2017 ASLO Conference (Honolulu, HI). Dr. Colbert has presented twice on this project – a poster at the Hawai‘i Conservation Conference (HCC, Hilo, HI, August 2015) and a presentation at the annual PCA meeting (January 2016). Rebecca Most from TNC also presented results from this project in a joint talk at the ICRS. Dr. Courtney Couch from TNC and UH Mānoa’s Hawai‘i Institute of Marine Biology (HIMB) will be presenting results from this project in a joint talk at HCC in July 2017. Fifteen undergraduate student presentations have been given at the UH Hilo PIPES Summer Internship Symposium, the UH Hilo Marine Science Department Senior Thesis Symposium, and the UH Hilo STEM Honors Program Symposium. Three undergraduate posters and one oral presentation were given at the annual C-MORE symposium (2 posters May 2015, one poster and one presentation May 2016). August 2016, Ms. Panelo presented findings from her undergraduate senior thesis at the Ecological Society of America (ESA) Annual Meeting (Fort Lauderdale, FL). Ms. Panelo received a travel grant through this society. She and Ms. Sultan will also be presenting their results at the 2017 ASLO Conference

**Table 10.** Products from UH Hilo’s NOAA Coral Reef Conservation Program project from July 2014 to January 2017.

| Product | Number produced |
|---|---|
| Reports | 6 (NOAA, biannual = 5 [2015-2017]; HDAR = 1 [2016]) |
| Manuscript (submitted/in prep) | 2 (Marine Pollution Bulletin) |
| M.S. thesis | 1 (UH Hilo, TCBES, August 2016) |
| B.S. senior theses | 3 (UH Hilo, Marine Science Department, 2015 = 1; 2016 = 2) |
| Presentations | 32 (12 PI, 5 graduate student, 15 undergraduate student) |
| Posters | 5 (1 PI, 1 graduate student, 3 undergraduate student) |
| Community handouts | 4 (PCA, 1 per year from 2014 -2017) |
| Newspaper/magazine/newsletter articles | 3 (UH System News [2015, Fig. 20], Hawai‘i Tribune Herald [2016, Fig. 21], Hawai‘i Business [2017, http://www.hawaiibusiness.com/water-warning/]) |
| Videos | 1 (Coral Reef Alliance [2017, http://coral.org/puako/]) |
| Testimony regarding Hawai‘i state cesspool ban | 2 (1 [2015], 1 [2016]) |
| HCC Land-based pollution conference session | 1 (2015) |


**Figure 19.** Flyer for public lecture on sewage pollution given by Drs. Wiegner and Colbert (September 2015).

(Honolulu, HI). Ms. Sultan received a travel grant through this society's minority students' program. Additionally, five graduate student presentations and one poster were given –ASLO in Granada, Spain (February 2015), UH Hilo TCBES Symposium (April 2015), HCC (August 2015), Ocean Sciences Meeting (OSM) in New Orleans (February 2016), M.S. Thesis defense (April 2016), and Hawai'i Ecosystems Meeting in Hilo (July 2016). Leilani Abaya won best student presentation at the ASLO conference and was also awarded a travel grant through this society's program for minority students. Ms. Abaya also received a travel grant to OSM through their minority students' program. The UH Hilo Marine Science research team organized a session for the HCC (August 2015) on land-based pollution effects on coral reefs and near-shore waters. This project was also highlighted in the UH system-wide news (June 2015; Fig. 20; *see* Appendix H), Hawai'i Tribune Herald (March 2016; Fig. 21; *see* Appendix I) and in the Hawaii Business magazine (*see* Appendix J).

NEWS UNIVERSITY OF HAWAI'I

**Pollution and coral reef health focus of UH Hilo research**

June 10, 2015

Students collect seaweed and water samples along the Puakō coastline for detection of sewage pollution

**Figure 20.** University of Hawai`i System News story highlighting UH-Hilo's NOAA CRCP project June 10, 2015. From left to right: graduate student Leilani Abaya (UHH TCBES), and 2015 PIPES summer interns Devon Aguiar, Bryan Tonga, and Jazmine Panelo (UH-Hilo), and Belytza Velez-Gamez (U. of Puerto Rico). Article by Jaysen Niedermeyer.

**Big Island lawmakers lobbied against cesspool ban**

Published March 15, 2016 - 1:30am

By COLIN M. STEWART Hawaii Tribune-Herald
The state has taken an important step toward addressing water pollution, according to some isle scientists.

A statewide ban on new cesspool construction approved Friday by Gov. David Ige came despite protests from seven Hawaii Island legislators, who claimed the ban would place undue financial burdens on local homeowners who might not be able to afford more expensive sewage systems.

The new rules also implement a 2015 law providing a tax credit of up to $10,000 for cesspools upgraded to sewer or septic system during the next five years, limited to $5 million or about 500 cesspool upgrades a year. Under the law, owners of cesspools located within 200 feet of the ocean, streams or marsh areas, or near drinking water sources, can qualify for the credit.

In announcing the ban, Ige said Hawaii had been the only state in the union that allowed the construction of cesspools.

"Today's action banning new cesspools statewide would stop the addition of pollution from approximately 800 new cesspools per year," he said.

Cesspools, which are effectively "just holes in the ground," according to University of Hawaii at Hilo marine scientist Tracy Wiegner, inject about 55 million gallons of raw, untreated sewage into Hawaii's groundwater every day, potentially spreading diseases and harming the quality of drinking water supplies and recreational waters.

Wiegner applauded the ban on Monday, calling it "a good first step towards reducing sewage pollution in our near-shore waters."

**Figure 21.** Hawaii Tribune Herald article highlighting results from UH-Hilo's NOAA CRCP project March 15, 2016. Picture taken by Steven Colbert.

***H. Related UH Hilo Funded Projects.***

1. NFWF. 2017. Local Engagement for Conservation Solutions: Measuring the Impact of Management Action in South Kohala, Hawai'i Island. Tracy Wiegner (PI), Jim Beets, Steve Colbert, and Courtney Couch. $ 25,020. Contracted through the Coral Reef Alliance.

2. NOAA/HDAR Coral Reef Working Group. 2016. Sewage pollution source tracking on Puakō's coral reefs. Tracy Wiegner (PI), Steve Colbert, Jim Beets, Courtney Couch, and Craig Nelson. $83,918. Recommended for funding. (2018-2019).

3, NOAA. West Hawaii Habitat Focus Area. 2016. Water quality and coral reef health. Stuart Goldberg (PI), Lani Watson, Jamie Gove, Jonathan Martinez, Tracy Wiegner, Steve Colbert, Eric Conklin, Courtney Couch, Chad Wiggins, Kim Falinski. Rebecca Most, and Julia Rose. $99,955. (2016-2017).

4. NOAA/HDAR Coral Reef Working Group. 2016. Sewage pollution source tracking at Puakō and comparison of onsite waste disposal systems for management actions. Tracy Wiegner (PI), Steve Colbert, and Jim Beets. $80,555. (2016-2017)

## I. Collaborators

**Table 11.** Collaborators on UH Hilo's NOAA Coral Reef Conservation Program project from July 2014 to January 2017.

| Organization | Collaborators |
|---|---|
| UH Mānoa, Hawai'i Institute of Marine Biology (HIMB) | Courtney Couch |
| The Nature Conservancy (TNC) | Chad Wiggins, Rebecca Most, Amy Bruno, Eric Conklin, Kim Falinski |
| UH Mānoa, School of Oceanography and Environmental Science and Technology (SOEST), Center for Microbial Oceanography Research and Education (C-MORE) | Craig Nelson, Kristina Remple, Barbara Bruno |
| Puakō Community Association (PCA) | Peter Hackstedde, George Fry, Robby Robertson, Mike O'Toole |
| Coral Reef Alliance | Erica Perez, Jos Hill, Cherrie Kauahi, Danielle Swanson, Wes Crile, Michael Webster |
| South Kohala Conservation Partnerships (SKCP) | Julia Rose, Sierra Tobiason |
| UH Hilo PIPES | Sharon Ziegler-Chong, Noe Puniwai, Rebecca Ostertag, Ulu Ching, Erika Perry, Rita Miller, Linnea Heu |
| NOAA Habitat Blue Print | Lani Watson, Stuart Goldberg |
| Aqua Engineering | Justin Logan |
| Cornell University | C. Drew Harvell, Charles Greene |
| NOAA Coral Reef Conservation Program | Paulo Maurin |
| Seattle Aquarium | Shawn Larson, Amy Green |

## *J. Cited Literature.*


Byappanahalli, M., R. Fujioka. (1998). Evidence that tropical soil environment can support the growth of *Escherichia coli*. Water Science and Technology 38:171-174.

Byappanahalli, M., and R. Fujioka. (2004). Indigenous soil bacteria and low moisture may limit but allow faecal bacteria to multiply and become a minor population in tropical soils. Water Science and Technology 50:27-32.

Dailer, M.L., R.S. Knox, J.E. Smith, M. Napier, and C.M. Smith. (2010). Using $\delta^{15}$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.

David, A., M. Tournoud, J. Perrin, D. Rosain, C. Rodier, C. Salles, C. Bancon-Montigny, and B. Picot. (2013). Spatial and temporal trends in water quality in a Mediterranean temporary river impacted by sewage effluents. Environmental Monitoring and Assessment 185:2517-2534.

Fujioka, R.S., B. Roll, and M. Byappanahalli. (1997). Appropriate recreational water quality standards for Hawaii and other tropical regions based on concentrations of *Clostridium perfringens*. Proceedings of the Water Environment Federation 4: 405-411.

Fujita, R.M. (1985). The role of nitrogen status in regulating transient ammonium uptake and nitrogen storage by macroalgae. Journal of Experimental Marine Biology and Ecology 92:283-301.

Fung, D.Y.C., R. Fujioka, K. Vijayavel, D. Sato, and D. Bishop. 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 Hawaii. Journal of Rapid Methods & Automation in Microbiology 15: 217-229.

Hardina, C., and R. Fujioka. (1991). Soil: The environmental source of *Escherichia coli* and *Enterococci* in Hawaii's streams. Environal Toxicology and Water Quality 6:185-195.

HDOH (2014) State of Hawaii water quality monitoring and assessment report. HDOH CWA §305(b)

Lapointe, B., J. O'Connell, and G. Garrett. (1990). Nutrient couplings between on-site sewage disposal systems, groundwaters, and nearshore surface waters of the Florida Keys. Biogeochemistry 10:289-307.

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

Paytan, A., G.G. Shellenbarger, J.H. Street, M.E. Gonneea, K. Davis, M.B. Young, and W.S. Moore. (2006). Submarine groundwater discharge: An important source of new inorganic nitrogen to coral reef ecosystems. Limnology and Oceanography 51:343-348.

Shenawy, M.E. 2005. *Staphylococcus aureus* and fecal indicators in Egyptian coastal waters of Aqaba Gulf, Suez Gulf, and Red Sea. Egyptian Journal of Aquatic Resources 31: 113-124.

Shibata, T., H. Solo-Gabriele, C.D. Sinigalliano, M.L. Gidley, L.R.W. Plano, J.M. Fleisher, J.D. Wang, S.M. Elmir, G. He, M.E. Wright, A.M. Abdelzacher, C. Ortega, D. Wanless, A.C. Garza, J. Kish, T. Scott, J. Hollenback, L.C. Backer, and L.E. Fleming. (2010). Evaluation of conventional and alternative monitoring methods for a recreational marine beach with nonpoint source of fecal contamination. Environmental Science and Technology 44:8175-8181.

Swart, P.K., S. Evans, T. Capo, and M.A. Altabet. (2014). The fractionation of nitrogen and oxygen isotopes in macroalgae during the assimilation of nitrate. Biogeosciences 11:6147–6157.

Viau, E., K. Goodwin, K. Yamahara, B. Layton, L. Sassoubre, S. Burns, H. Tong, S. Wong, Y. Lu, and A. Boehm. (2011). Bacterial pathogens in Hawaiian coastal streams associations with fecal indicators, land cover, and water quality. Water Research 45:3279-3290.

Wang, Y., J.M. Wilson, and J.M. Vanbriesen. (2015). The effect of sampling strategies on assessment of water quality criteria attainment. Journal of Environmental Management 154:33-39.

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

Yoshioka, R.M., C.J.S. Kim, A.M. Tracy, R. Most, and C.D. Harvell. (2016). Linking sewage pollution and water quality to spatial patterns of *Porites lobata* growth anomalies in Puako, Hawaii. Marine Pollution Bulletin 104:313-321.

Zambrano, L., V. Contreras, M. Mazari-Hiriart, and A. Zarco-Arista. (2009). Spatial heterogeneity of water quality in a highly degraded tropical freshwater ecosystem. *Environmental Management* 43:249-263.

***K. APPENDICES.***

A. UH Hilo handout for Puakō Community and recreational ocean users during deployments in 2015.

B. UH Hilo handout for Puakō Community Association meeting in November 2014 and January 2015

C. UH Hilo and TNC joint handout for the Puakō Community Association annual meeting. January 2016.

D. Joint UH Hilo and TNC handout for Coral Reef Alliance's Wastewater Forum for the Puakō community. January 2017

E. Testimony regarding Hawaiʻi state cesspool ban

F. List of conferences, years, presenters, and title presentations given over the duration of the study.

G. Manuscripts' and M.S. thesis abstracts

H. University of Hawaiʻi System News story highlighting Puakō project June 2015.

I. Hawaiʻi Tribune Herald article highlighting results in March 15, 2016.

J. Hawaiʻi Business article highlighting efforts in January 2017.

*APPENDIX A*

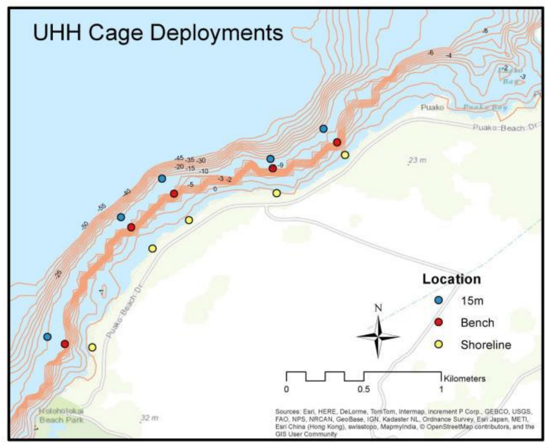
<u>UH Hilo handout for Puakō Community and recreational ocean users during cage deployments in 2015.</u>

# Attention:

# Puakō Boaters & Ocean Users

## (Swimmers, Snorkelers, Surfers)

University of Hawaiʻi at Hilo will be conducting a marine research experiment in the area




**<u>Please be aware</u>**: A short term surface array will be installed at the shoreline and 100 m – 200 m offshore of Puakō. The purpose of the array is to assess water quality in these areas using native algae in cages (pictured right). The arrays extend from the surface to the ocean floor. They will have white buoys at the surface with reflective tape to be visible to boaters at night and can be identified with University of Hawaiʻi signs.

Deployed from June 12 – 19, 2015.

**Please do not moor to, hang on to, or disturb.**

**THANK YOU!**

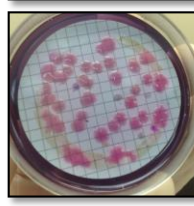
This project is in collaboration with the Puakō Community Association
For more information please contact Jim Beets (808) 932-7600

*APPENDIX B*

UH Hilo handout for Puakō Community Association meeting in November 2014 and January 2015.

# Spatial Distribution and Effects of Sewage on Puakō's Coral Reefs

## Goals



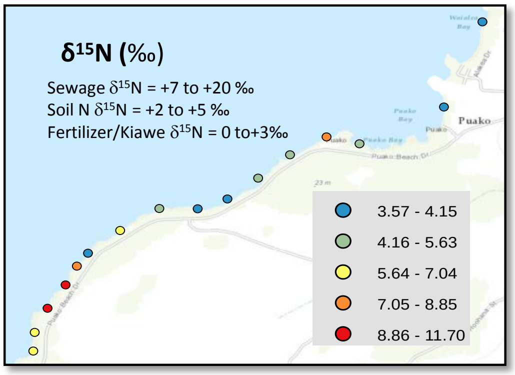
- Use chemical and biological tools to determine if sewage is entering coastal waters
- Determine if sewage is impacting water quality
- Assess coral reef community-level response to sewage

## Objectives

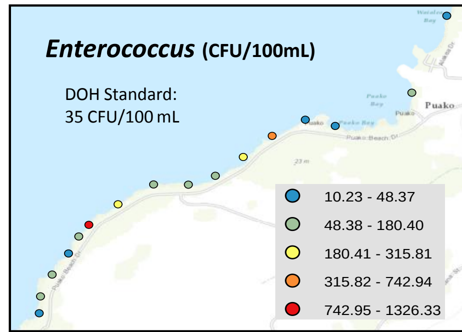
1. Dye Tracer Studies: Use dye to document connection between cesspools and ocean
2. $\delta^{15}N$ Seaweed Measurements: Evaluate presence and spatial extent of sewage near- and offshore
3. Fecal Indicator Bacteria & Nutrient Measurements: Determine if DOH water quality standards are exceeded
4. Benthic Community Responses: Assess responses of corals, fishes, and macroinvertebrates to wastewater

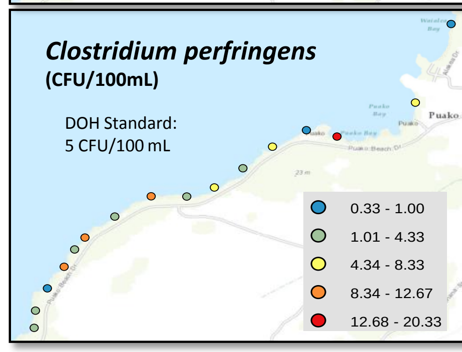
## Findings

Dye travel time was 3 days from cesspool to ocean, only observed at low tide and localized



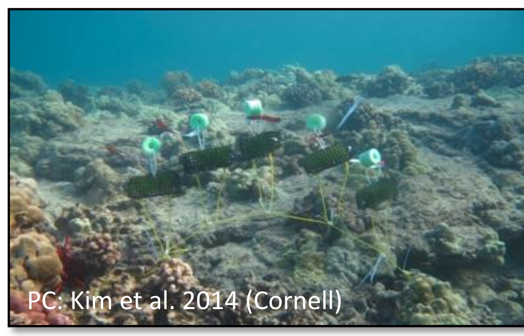

Fecal indicator bacteria (*Enterococcus & C. perfringens*) and $\delta^{15}N$ seaweed values indicate sewage presence at multiple locations




## Remaining Work

- Two more dye tracer experiments
- Nutrient, bacteria, and $\delta^{15}N$ seaweed measurements including offshore seaweed cage experiments
- Coral and fish sampling




Seaweed cage experiments

**UHH Faculty**
*Dr. Tracy Wiegner (PI, water quality) wiegner@hawaii.edu*
*Dr. Jim Beets (Coral & fish) beets@hawaii.edu*
*Dr. Steve Colbert (Dye studies) colberts@hawaii.edu*
*Dr. Jason Adolf jadolf@hawaii.edu*

**Technician:**
*Kaile'a Carlson kaileac@hawaii.edu*

**Graduate Student (supported by PCA):**
*Leilani Abaya labaya@hawaii.edu*

**Undergraduates:**
*Carrie Soo Hoo, Cherie Kauahi, Serina Ki'ili, Ricky Tabandera, Maile Aiwohi, Evelyn Braun*

University of Hawai'i Hilo
200 West Kawili St
Hilo, HI 96720

Funded by NOAA Coral Reef Conservation Program and Puakō Community Association

*APPENDIX C*

UH Hilo and TNC joint handout for the Puakō Community Association annual meeting. January 2016.


# WHAT'S IN OUR WATER?

Meandering underground streams flowing beneath Puakō and entering the ocean through springs and seeps once nourished an abundant fishery and vibrant coral reefs. So, when residents began noticing declines in fish and corals, they enlisted partners to help them understand why these changes were occurring.

Today, Cornell University, the University of Hawai'i at Hilo Marine Science Department (UH Hilo), The Nature Conservancy (TNC), and the Hawai'i Institute of Marine Biology (HIMB) are working with the Puakō Community Association to identify causes of the declines and solutions for restoring coral reef health at Puakō.

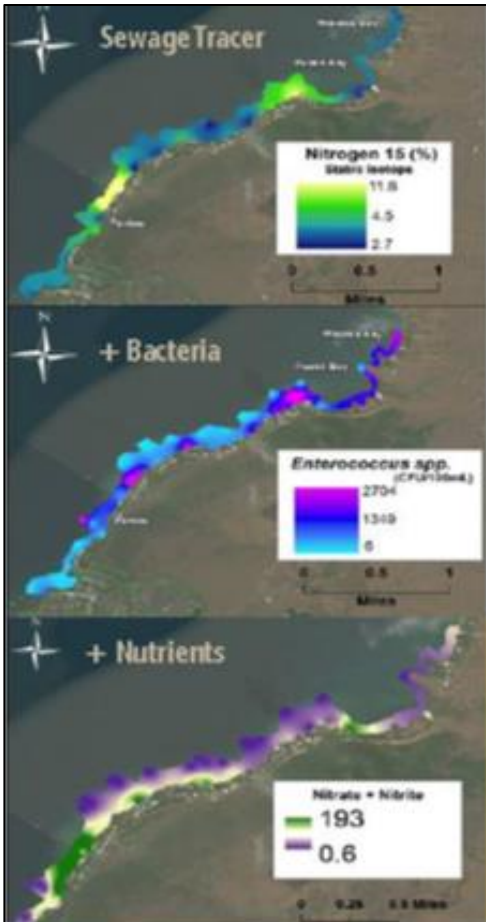
Domestic wastewater (sewage) was suspected as one of the threats to the reef. Research found outdated cesspools leaching untreated sewage through permeable rock to beaches, tide pools, and the reef, impacting nearshore water quality.

How far offshore does the sewage travel from the nearshore seeps? How quickly does sewage from cesspools enter nearshore waters? What are the impacts of sewage to the reef ecosystem? These are the questions currently being addressed by research groups.

## KEY FINDINGS

Indicators of domestic wastewater have been found in coastal and marine areas where they are likely impacting people, coral reefs, and other marine life:

- Dye tracer studies found that sewage from cesspools reached seeps along the Puakō coast within six hours to three days.
- At some shoreline locations, often corresponding to those of the dye tracer studies:
  - Levels of two bacteria associated with sewage often exceeded Hawai'i Department of Health standards.
  - Nitrate levels were two times higher than those in mauka groundwater from Waikoloa and Mauna Lani.
  - Nitrogen isotope measurements in seaweed were indicative of sewage pollution.
- Coral growth anomalies–tumor-like growths on coral skeletons–were highest on reefs with evidence of groundwater input and elevated nutrients.
- Studies conducted across the region show Puakō's reefs have especially high levels of red filamentous algae, which overgrow and can kill corals.




## IMPACTS ON PEOPLE AND OCEAN LIFE

Exposure to sewage can cause skin, urinary, blood, and abdominal infections like gastroenteritis, Hepatitis A, conjunctivitis, salmonellosis, and cholera. Children and the elderly are particularly susceptible to these infections.

Sewage also increases disease risk in reef animals and can shift the balance in favor of fast-growing invasive algae, which smother corals and reduce oxygen levels necessary for other animals to survive.

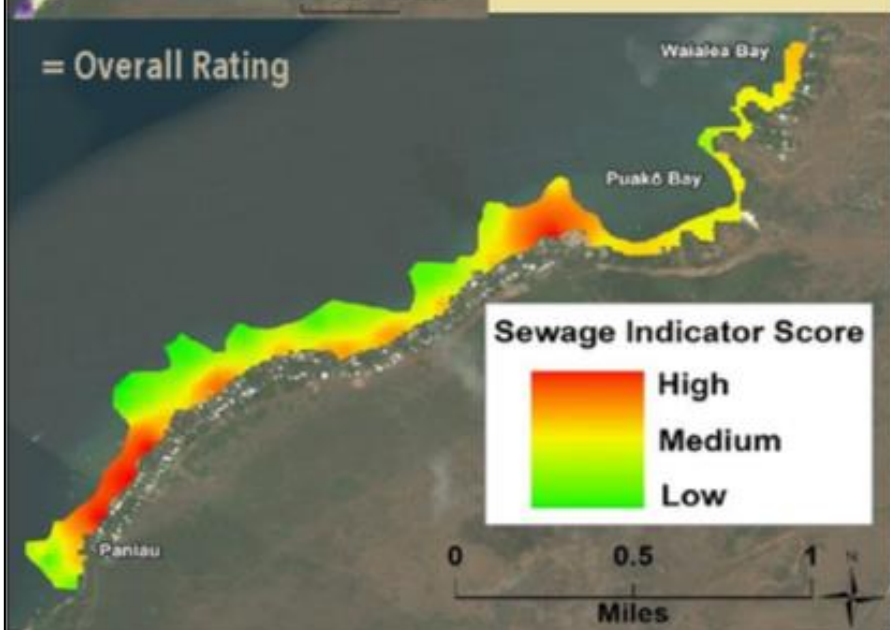
## CONCLUSIONS

The continued use of domestic wastewater systems that do not treat sewage, like cesspools, expose recreational water users, coral reefs, and other marine life to significant health risks. Minimizing the flow of untreated sewage into Puakō's waters is critical to reducing these risks, and making corals more resilient to ocean warming and acidification. Investing in clean, long-term sewage treatment alternatives will not only benefit the coral reef, but all of us who use and care for the ocean.

## FOR ADDITIONAL INFORMATION

Contact Julia Rose, South Kohala Marine Coordinator, at julia.rose@tnc.org

*The sewage indicator score was created by combining multiple water quality metrics to show where the highest sewage inputs are occurring along the Puakō coastline. The water quality metrics used included stable isotope values (Nitrogen 15), bacteria abundance (Clostridium and Enterococcus), and nutrient concentration (nitrate, phosphate, and ammonia).*




*Sewage carries pathogens (bacteria, protozoa, and viruses), pharmaceuticals, nutrients (nitrates and phosphates), cleaning chemicals, and other pollutants into groundwater, onto beaches, and into the ocean. These pollutants have been found in Puakō in areas where people swim, surf, dive, and fish.*

January 2016

*APPENDIX D*

Joint UH Hilo and TNC handout for Coral Reef Alliance's Wastewater Forum for the Puakō community. January 2017.


## WHAT'S IN OUR WATER?

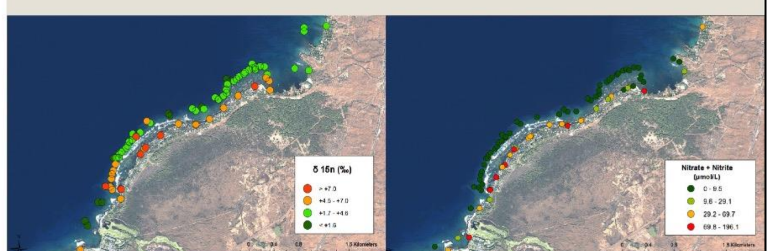
Meandering underground streams flowing beneath Puakō and entering the ocean through springs and seeps once nourished an abundant fishery and vibrant coral reefs. So, when residents began noticing declines in fish and corals, they enlisted partners to help them understand why these changes were occurring.

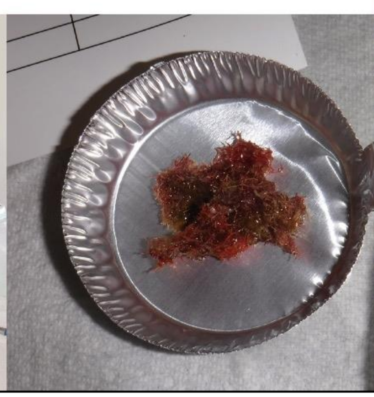
Today, scientists from The Nature Conservancy, University of Hawai'i at Hilo Marine Science Department, Hawai'i Institute of Marine Biology, University of Hawai'i at Mānoa, and Cornell University are working with the Puakō Community Association to identify causes of the declines and solutions for reviving coral reef health at Puakō.

Using a combination of tools, including stable nitrogen isotopes and DNA-based tools which are able to identify the presence of human waste, the research confirms what has long been suspected: cesspools are leaching untreated sewage underground to Puakō's beaches, tide pools, and reef.

### KEY FINDINGS

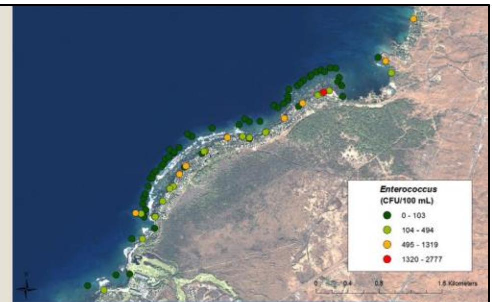
- Nutrients are elevated at coastal springs and seeps, as evidenced by high nitrates across 66% of the sites. Measurements were especially high in areas with high levels of submarine groundwater.
- Stable nitrogen isotope measurements in seaweed (> + 7 ‰) are indicative of sewage pollution at several locations, with the highest values observed at the southern and northern end of Puako's shoreline.
- Elevated levels of stable nitrogen isotopes at several reef stations are indicative of sewage reaching the reef.
- Stable nitrogen isotope measurements showed that groundwater became increasingly polluted with sewage moving downslope to the shoreline, with the highest values being measured within Puakō and lower values found at Waikaloa Village.

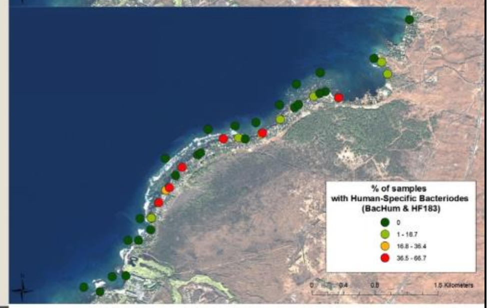


## KEY FINDINGS *(continued)*

- Between 2014 and 2016, measurements at 76% of shoreline sites exceeded Hawai'i Department of Health standard (single sample maximum, 104 CFUs/100ml) for *Enterococcus* concentrations in coastal waters.
- Like the stable nitrogen isotope data, *Enterococcus* concentrations were lower over the reef compared to the shoreline but were relatively high (36-91 CFUs/100ml) at 20% of the reef stations, also suggesting that sewage pollution is reaching some locations along the reef.
- Using DNA-based tools, researchers found that 36-67% of the samples collected during 2015, contained bacteria only found in the human gut, suggesting frequent exposure to sewage pollution.
- Similar to the stable nitrogen isotope seaweed data, the highest values were found in the northern and southern portions of Puakō.




## CONCLUSIONS

Ongoing research provides strong evidence of sewage pollution along Puakō's shoreline and reef. Minimizing the flow of untreated sewage into Puakō's waters by investing in clean, long-term sewage treatment alternatives will reduce risks to human health and to marine life. Our research constitutes a baseline against which reductions in pollution levels can be measured if wastewater treatment improves.

## IMPACTS ON PEOPLE AND OCEAN LIFE

Exposure to sewage can cause skin, urinary, blood, and abdominal infections like gastroenteritis, Hepatitis A, conjunctivitis, salmonellosis, and cholera. Children and the elderly are particularly susceptible to these infections. At *Enterococcus* concentrations of 35 CFU/100ml, like those documented at Puakō, recreational water users have a 3.6% chance of contracting gastroenteritis. Sewage pollution also increases disease risk in reef marine animals and can shift the balance in favor of fast-growing invasive algae, which smother corals and reduce oxygen levels necessary for other animals to survive.

## FOR ADDITIONAL INFORMATION

Contact Julia Rose, South Kohala Marine Coordinator, at julia.rose@tnc.org.

*APPENDIX E*

Testimony regarding Hawai'i State's proposed cesspool ban.

UNIVERSITY of HAWAI'I® HILO

03/04/2016

Dear Governor Ige,

We are writing a letter of support for Hawai'i's Department of Health's (HDOH) proposed revisions to HAR 11-62 to prohibit installation of new cesspools. Several of us in the Marine Science Department at the University of Hawai'i at Hilo (UH-Hilo) have conducted research in Hawai'i Island's coastal waters relative to cesspool pollution. We have worked in Hilo Bay, Wai 'Opae (Vacation Lands, Kapoho), and Puakō- several of the places listed as concerns in the HDOH 'Rational for the Proposed Revisions' document (2015). Through our studies and others, it is clear that wastewater from cesspools leaks into streams and the coastal ocean. This untreated wastewater, which contains pathogens, pharmaceuticals, nutrients, cleaning chemicals, and petroleum products, is negatively impacting public health and coastal ecosystems.

Over half of 50,000 cesspools on the Hawai'i Island are located within the two-year time of travel to a river or the shoreline region (Whittier and El-Kadi 2014). Dye tracer study tests have been conducted both at Wai 'Opae and Puakō, and time of travel from homes to shoreline ranged from 20 min (HDOH 1984) to three days (Colbert et al. unpubl. data). Additionally, wastewater has been shown to be polluting private drinking water wells. In Hawaiian Paradise Park, Hawai'i Island, 50% of drinking water wells sampled, tested positive for fecal indicator bacteria. Pathogens associated with this indicator bacteria can live for months in groundwater. These results indicate that cesspools can be immediate human health hazard.

Cesspools do not remove harmful pathogens (bacteria, protozoa, and viruses). Human health effects from sewage inputs range from abdominal infections (gastroenteritis in swimmers), to skin, urinary, and blood ones (Pinto 1999). Some of these bacteria have a high salt tolerance and have developed resistance to antibiotics, making them potentially life threatening (Hancock and Gilmore 2000). To monitor whether recreational waters are safe to swim in, the HDOH monitors fecal indicator bacteria, including *Enterococcus* and *Clostridium perfringens*. According to USEPA (820-F-12-061, 12/2012), when *Enterococcus* levels are at the geometric mean of 35 CFU/100 mL, the estimated gastrointestinal illness rate is 3.6%. These *Enterococcus* levels are often exceeded in Hilo Bay, Wai 'Opae, and Puakō (range <10 to 2777 CFU 100 $mL^{-1}$; Wiegner et al. 2013; Economy et al. unpubl. data; Wiegner et al. unpubl. data). The presence of *Enterococcus* suggests that disease-causing microorganisms might also be present, especially if they are from human waste. This has been found to be the case on the island of Oahu, where *Enterococcus* levels were positively associated with several waterborne pathogens including: *Salmonella*, *Campylobacter*, and *Staphylococcus aureus* (Viau et al. 2011). In Hilo Bay, it has been confirmed that some of these bacteria are from human waste using microbial source tracking techniques (Evans et al. submitted); comparable measurements have not yet been made in Wai 'Opae and Puakō.

Since cesspools lack any wastewater treatment, the nutrients and pathogens in the sewage enter the groundwater and are transported to the coastal ocean. Ecological effects of sewage pollution include shifts in reef community structure (coral- to algal- dominated systems), eutrophication, declines in the abundance, mortality, and fecundity of corals and reef fish, as well as high occurrence of diseases and infections of reef biota (Hunter and Evens 1995). One of the environmental drivers of coral disease that has been identified is nutrient pollution, often from sewage (Harvell et al. 2007; Kaczmarsky and

Richardson 2010; Haapkylä et al. 2011; Vega Thurber et al. 2013). Because cesspools are aerobic, very little nitrogen in the wastewater is volatilized and most is in the form of nitrate, which is not retained by soil. Chronic nutrient exposure has been shown to lead to increases in disease prevalence and severity, as well as bleaching in scleractinian corals (Vega Thurber et al. 2013). Disease has played a major role in the decline of corals worldwide (Harvell et al. 2007; Ruiz-Mureno et al. 2012). While only a few diseases have been identified in Hawaiʻi, coral diseases are on the increase and a recent outbreak of white syndrome on Kauaʻi Island is of particular concern (Work et al. 2012). Two of the sites where we have worked on Hawaiʻi Island show signs of coral and reef health deterioration – Puakō and Wai ʻOpae- with high prevalence of growth abnormalities, discoloration, and algal overgrowth (Burns et al. 2011; Couch et al. 2014). The reefs at Puakō are reported to be in 'dire straights' due to decreases in fish abundances, coral and crustose coralline algae cover, as well as increases in macroalgal cover (HDAR 2013). In part, these observations are thought to be linked to sewage pollution from cesspools.

It is therefore imperative that Hawaiʻi State adopts these changes to HAR 11-62 and ban the installation of new cesspools. Hawaiʻi is the only state in the U.S. that still allows for new cesspools to be permitted; Rhode Island, the state with the second largest number of cesspools, banned construction of new ones in 1968, 46 years ago. Even in Florida, a warm state like Hawaiʻi where the ground does not freeze, has banned cesspools. Symptoms of sewage pollution are becoming more apparent on the outer Main Hawaiian Islands in rural areas, such as Hawaiʻi Island – as documented in many of UH-Hilo's studies described above. In these areas, coral reefs are still relatively healthy, underscoring the urgency for improved sewage disposal management. Hawaiʻi State needs to lead the nation in protecting its coastal waters. The economy and Hawaiian culture depend on the quality and health of coastal waters. For example, Hawaiʻi's coral reefs contribute ~$800 million dollars annually to the state's economy, and services related to tourism account for 17% (HDLIR 2010). If new cesspool construction continues, human health risks and associated health care costs will increase, and revenue generated by Hawaiʻi's coral reefs will decrease, impacting the state's economy. Therefore, we strongly support HDOH's proposed rules to ban new cesspool construction.

Tracy Wiegner, Ph.D., Professor of Marine Science, UHH
Steve Colbert, Ph.D., Assistant Professor of Marine Science, UHH
Jim Beets, Ph.D., Professor of Marine Science, UHH

**References:**


Burns, J. H. R. et al. 2011. Morphology, severity, and distribution of growth anomalies in the coral, *Montipora capitata*, at Wai ʻōpae, Hawai ʻi. Coral reefs 30: 819-826.

Couch, C. S., et al. 2014. Spatial and temporal patterns of coral health and disease along leeward Hawai'i Island. Coral Reefs 33: 1-12.

Edens, C.J., et al. Submitted 2016 to Marine Pollution Bulletin. Comparison of spatial and temporal microbial pollution patterns in a tropical estuary between high and low river flow conditions.

Hancock, L. E. and M.S. Gilmore. 2000. Pathogenicity of Enterococci. ASM Publications.

Haapkylä, J. et al. 2011. Seasonal rainfall and runoff promote coral disease on an inshore reef. PLos ONE 6: e16893.

Harvell, C.D. et al. 2007. Coral disease, environmental drivers, and the balance between coral and microbial associates. Oceanography 20: 172-195.

HDAR. 2013. South Kohala reefs are in dire straits.

HDLIR. 2010. Hawaii labor market dynamics. Research & Statistics Office, Department of Labor & Industrial Relations, State of Hawaii, Honolulu, HI.

HDOH. 1984. Interim report of a baseline study on water quality at Kapoho Bay, Hawaiʻi.

HDOH. 2015. Rational for the proposed revisions to Department of Health Administrative Rules, Title 11, Chapter 62, Wastewater systems.

Hunter, C.L. and C.W. Evens. 1995. Coral reefs in Kaneohe Bay, Hawaiʻi: Two centuries of western influence and two decades of data. Bulletin of Marine Science 57: 501-515.

Kaczmarsky, L. and L. L. Richarson. 2010. Do elevated nutrients and organic carbon on Philippinne reefs increase the prevalence of coral disease? Coral Reefs 30: 253-257.

Pinto, B. R. et al. 1999. Characterization of 'faecal streptococci' as indicators of faecal pollution and distribution in the environment. Letters in Applied Microbiology 29: 258-263.

Ruiz-Moreno, D. et al. 2012. Global coral disease prevalence associated with sea temperature anomalies and local factors. Diseases of Aquatic Organisms 100: 249-261.

Vega Thurber, R.L. et al. 2013. Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. Global Change Biology doi: 10.1111/gcb.12450.

Viau, E. J. et al. 2011. Bacterial pathogens in Hawaiian coastal streams - associations with fecal indicators, land cover, and water quality. Water Research 45:3279-3290.

Whittier R.B., and A.I. El-Kadi. 2014. Human health and environmental risk ranking of on-site sewage disposal systems for the Hawaiian Islands of Kauai, Molokai, Maui, and Hawaiʻi. Prepared for the State of Hawaiʻi Department of Health, Safe Drinking Water Branch, by the University of Hawaiʻi, Dept. of Geology and Geophysics. Honolulu, HI.

Wiegner, T. N. et al. 2013. A comparison of water quality between low- and high-flow river conditions in a tropical estuary, Hilo Bay, Hawaiʻi. Estuaries and Coasts 36: 319-333.

Work, T. M. et al. 2012. Tissue loss (white syndrome) in the coral *Montipora capitata* is a dynamic disease with multiple host responses and potential causes. Proceedings of the Royal Society B-Biological Sciences 279: 4334-4341.

*APPENDIX F*

List of conferences, years, presenters, and title presentations given over the duration of the study. Presentations were given to a variety of different symposiums and conferences including: the Pacific Internship for Exploring Sciences (PIPES) symposium, Center for Microbial Oceanography: Research Education (CMORE) symposium, Science, Technology, Engineering, and Mathematics (STEM) symposium, Sigm Xi symposium, United States Environmental Protection Agency Greater Research Opportunities (USEPA GRO) symposium, the Association for the Sciences of Limnology and Oceanography (ASLO) conference, the Tropical Conservation, Biology, and Environmental Studies (TCBES) symposium, the Hawai‘i Conservation Conference (HCC), the Ocean Science Meeting (OSM), the Hawai‘i Ecosystem Meeting (HEM), the Ecological Society of America (ESA) conference, the Coral Reef Symposium (CRS), and the NOAA Mokupapapa Discovery Center weekly talks.

| PIPES | | |
|---|---|---|
| Year | Name | Title |
| 2014 | Evelyn Braun | Cesspools discharge pathogens, nutrients, cleaning chemicals, and hydrocarbons that pose a threat to coral reef and human health. |
| 2014 | Maile Aiwohi | Sewage pollution effects in a groundwater-fed coral reef area. |
| 2015 | Bryan Tonga | Is there a significant correlation between the pH and the amount of $\delta^{15}N$ in sewage pollution along Puakō's coast? |
| 2015 | Devon Aguiar | Using *Enterococcus* to identify sewage pollution along the Puakō coastline. |
| 2015 | Jazmine Panelo | Quantification of *Staphylococcus aureus* in Puakō, Hawai'i in association with sewage indicators. |
| 2016 | Saria Sultan | Identifying locations of sewage pollution in the Puakō watershed. |
| 2016 | Christopher Thompson | Characterizing groundwater flow in fractured rock from coastal septic systems. |
| **CMORE** | | |
| Year | Name | Title |
| 2015-2016 | Jazmine Panelo | Quantification of *Staphylococcus aureus* in Puakō, Hawai'i in association with sewage indicators |
| 2015-2016 | Devon Aguiar | *Enterococcus* trends along the Puakō coastline. |
| 2014-2015 | Cherie Kauahi | Cesspool, groundwater and coastal ocean connectivity at Puakō, Hawai'i. |
| 2014-2015 | Devon Aguiar | Highly variable *Enterococcus* concentrations along the Puakō coast. |
| **STEM/SIGMA XI** | | |
| Year | Name | Title |
| 2014-2015 | Carrie Soo Hoo | $\delta^{15}N$ in macroalgae as a proxy for nutrient enrichment from sewage. |

| USEPA GRO | | |
|---|---|---|
| Year | Name | Title |
| 2016 | Serina Kiili | Abundance of *Serratia marcescens* and *Vibrio* spp. at Puakō, Hawaiʻi and their association with sewage indicators |
| **ASLO** | | |
| Year | Name | Title |
| 2017 | Tracy Wiegner | Spatial distribution of sewage pollution on a Hawaiian coral reef . |
| 2017 | Saria Sultan | Identifying locations of sewage pollution in a leeward Hawaiian watershed. |
| 2017 | Jazmine Panelo | Association between *Staphylococcus aureus* and other sewage indicators in coastal waters of Puakō, Hawaiʻi. |
| 2016 | Leilani Abaya | Spatial distribution and effects of sewage in coastal Hawaiian waters (Puakō, Hawaiʻi). |
| 2015 | Leilani Abaya | Spatial distribution and effects of sewage in coastal Hawaiian waters (Puakō, Hawaiʻi). |
| **TCBES Symposium** | | |
| Year | Name | Title |
| 2015 | Leilani Abaya | Spatial distribution and effects of sewage on Puakō's (Hawaiʻi) coral reefs. |
| **HCC** | | |
| Year | Name | Title |
| 2015 | Leilani Abaya | Spatial distribution and effects of sewage on Puakō's (Hawaiʻi) coral reefs. |
| 2015 | Steven Colbert | Linking sewage pollution to near-shore coastal waters through dye tracer, water quality, and fecal indicator bacteria measurements at Puakō, Hawaiʻi |
| **OSM** | | |
| Year | Name | Title |
| 2016 | Leilani Abaya | Spatial distribution and effects of sewage in coastal Hawaiian waters (Puakō, Hawaiʻi). |

| HEM | | |
|---|---|---|
| Year | Name | Title |
| 2014 | Tracy Wiegner | Spatial distribution and effects of sewage on Puakō's coral reefs. |
| 2016 | Leilani Abaya | A multi-indicator approach for identifying hotspots of shoreline sewage pollution adjacent to coral reefs. |
| **ESA** | | |
| Year | Name | Title |
| 2016 | Jazmine Panelo | Association between *Staphylococcus aureus* and other sewage indicators in coastal waters of Puakō, Hawaiʻi. |
| **CRS** | | |
| Year | Name | Title |
| 2016 | Tracy Wiegner | A multi-tracer approach for identifying sewage pollution hotspots on a Hawaiian coral reef. |
| **NOAA Mokupapapa Discovery Center** | | |
| Year | Name | Title |
| 2015 | Tracy Wiegner | Spatial distribution and effects of sewage on Puakō's (Hawaiʻi) coral reefs |

*APPENDIX G*

<u>G1. Abstract submitted to Marine Pollution Bulletin for publication (in prep).</u>

**A multi-indicator approach for identifying hotspots of shoreline sewage pollution adjacent to coral reefs**

Sewage pollution is contributing to the global decline of coral reefs, making identifying sources of sewage pollution a key management priority. We used dye tracer tests, measurements of sewage indicators (fecal indicator bacteria (FIB), $\delta^{15}$N in macroalgae, nutrient concentrations), and a scoring tool to identify shoreline sewage pollution hotspots in Puakō, Hawaiʻi. FIB abundance was high and variable, and $\delta^{15}$N macroalgal values were within sewage range. Shoreline nutrient concentrations were two times higher than those in upland groundwater. Sewage from homes reached shoreline waters within 9 hours to 3 days. A sewage pollution score was created using sewage indicators to identify pollution hotspots. Our study documented sewage entering Puakō's shoreline waters, and highlights the need for a multi-indicator approach and scoring tool to identify sewage pollution hotspots for appropriate management actions. Our approach provides a useful framework for identifying the extent and severity of sewage pollution in other coastal regions.

<u>G2. Abstract submitted to Marine Pollution Bulletin for publication (in prep).</u>

**Spatial distribution of sewage pollution on a Hawaiian coral reef**

Sewage pollution has been shown to affect both human health and nearshore ecosystems, and is especially a concern in tropical regions with coral reefs. Puakō, located on Hawaiʻi Island, is one area of concern because sewage pollution has been detected along on its shoreline; however, the spatial distribution of sewage pollution offshore in surface and benthic waters is unknown. This study examined the spatial extent of sewage pollution using algal bioassays and a combination of sewage indicators (fecal indicator bacteria (FIB), stable nitrogen isotopes ($\delta^{15}$N) in macroalgal tissue, nutrients). FIB counts and nutrients were spatially variable in both surface and benthic waters, with shoreline concentrations exceeding water quality standards. $\delta^{15}$N in macroalgal tissue, along the shoreline were the most enriched and within the range for sewage. However, sewage indicators were not always in agreement on the location and intensity of pollution. To assess water quality with regards to these indicators, a sewage pollution score was created, allowing for locations of sewage pollution hotspots to be identified. This approach for identifying sewage pollution hotspots is valuable for other coastal communities

with documented sewage pollution so that appropriate management actions can be taken to improve water quality, and reduce human and ecosystem health hazards.

G3. Abstract submitted to University of Hawaiʻi at Hilo library in fulfillment of a M.S. degree.

**Identifying hotspots of sewage pollution in coastal areas with coral reefs**

Sewage pollution threatens human and coral reef health. Study goals were to identify sewage pollution hotspots through dye tracer tests, measurements of sewage indicators, and development of a sewage pollution score, along Puakō's (Hawaiʻi) reef. Sewage was localized within 10 m of the shoreline and reached it within 9 hours to 3 days. Shoreline nutrient concentrations were two times higher than upland groundwater. Sewage indicators were higher and more variable along the shoreline than on the reef, and often greater than water quality standards. Shoreline $\delta^{15}N$ macroalgal values were indicative of sewage, while offshore values were indicative of soil or groundwater nitrate. A sewage pollution score was created using several indicators that accurately identified sewage pollution hotspots, as three dye tracer locations had the highest scores. Results highlight the need for a multi-indicator approach and scoring system for identifying sewage pollution hotspots to improve water quality.

*APPENDIX H*

University of Hawai`i System News story highlighting Puakō project June 2015.

# Pollution and coral reef health focus of UH Hilo research

hawaii.edu/news/2015/06/10/pollution-and-coral-reef-health-focus-of-uh-hilo-research/

UH News 6/10/2015

Students collect seaweed and water samples along the Puakō coastline for detection of sewage pollution

For conservation efforts to be effective and long lasting, partnerships between local communities and researchers are necessary, says **Tracy Wiegner**, professor of marine science at the University of Hawaiʻi at Hilo who is part of a research team studying ocean water quality in South Kohala on Hawaiʻi Island. In particular, she says, local communities must see a need for conservation activities and desire for them to occur. It is crucial that they participate in developing these projects to meet their community's desired outcomes, and are committed to the efforts required for long-term success.

For a long time, these types of partnerships were overlooked by university and state and federal agencies, but they are now recognized as essential for any conservation project to be successful.

Wiegner is working on this new type of community-researcher partnership in collaboration with **Steve Colbert**, assistant professor of marine science, and **Jim Beets**, professor of marine science. The research team is investigating sewage pollution in nearshore waters off Puakō, an ocean-side community in South Kohala.

Wiegner, her collaborators, and students are documenting the presence of sewage through bacterial, seaweed and water quality measurements.

"The first step of the project was to document that there was a sewage pollution problem," Wiegner explains. Documentation is essential to establish that a problem exists, she says, and it allows the community to decide, first, if they want to do something about it, and second, to investigate potential solutions.

1/2

**Household waste present in nearshore waters**

To date, results from the project demonstrate that waste from homes in Puakō is present in the nearshore waters. The most telling piece of the research is results from the dye tracer studies where dye was washed down sinks or added to cesspools. Colbert detected the dye in 72 hours in seeps along the shoreline in front of the houses. Wiegner says these results “really demonstrate the connection between the homes and the nearshore waters. You couldn’t ask for more concrete evidence than that.”

Other results have shown that the groundwater upslope of Puakō has much lower nutrient concentrations than the groundwater that enters the ocean. This suggests that there is some source of nutrients at Puakō, possibly sewage.

Coincidently, nearshore seaweed at Puakō has nitrogen values similar to those of sewage. Together, these data suggest that indeed these extra nutrients are from human waste.

Research this summer will further examine how far offshore the sewage can be detected and whether it is coming up through the reef and directly impacting coral.

For the full story, visit the UH Hilo Stories website.

*APPENDIX I*

Hawaii Tribune Herald article highlighting results in March 15, 2016.

# Big Island lawmakers lobbied against cesspool ban

Published March 15, 2016 - 1:30am

By COLIN M. STEWART Hawaii Tribune-Herald

The state has taken an important step toward addressing water pollution, according to some isle scientists.

A statewide ban on new cesspool construction approved Friday by Gov. David Ige came despite protests from seven Hawaii Island legislators, who claimed the ban would place undue financial burdens on local homeowners who might not be able to afford more expensive sewage systems.

The new rules also implement a 2015 law providing a tax credit of up to $10,000 for cesspools upgraded to sewer or septic system during the next five years, limited to $5 million or about 500 cesspool upgrades a year. Under the law, owners of cesspools located within 200 feet of the ocean, streams or marsh areas, or near drinking water sources, can qualify for the credit.

In announcing the ban, Ige said Hawaii had been the only state in the union that allowed the construction of cesspools.

“Today’s action banning new cesspools statewide would stop the addition of pollution from approximately 800 new cesspools per year,” he said.

Cesspools, which are effectively “just holes in the ground,” according to University of Hawaii at Hilo marine scientist Tracy Wiegner, inject about 55 million gallons of raw, untreated sewage into Hawaii’s groundwater every day, potentially spreading diseases and harming the quality of drinking water supplies and recreational waters.

Wiegner applauded the ban on Monday, calling it “a good first step towards reducing sewage pollution in our near-shore waters.”

However, a large contingent of Big Island delegates to the state Legislature had opposed the rule changes. In a Feb. 1 letter, state Reps. Mark Nakashima, Richard Creagan, Richard Onishi, Clift Tsuji and Cindy Evans, as well as state Sens. Russell Ruderman and Lorraine Inouye, asked Ige to refrain from signing the new rules, citing the high costs associated with installing alternative septic systems. Their letter claimed that arguments for not allowing cesspools anywhere in the state were "weak and unsubstantiated," while discriminating against Hawaii's poorest residents.

"The cost of a septic system in Hawaii is in the range of $20,000 to $30,000," the letter reads. "The cost of a cesspool is in the range of $2,000-$3,000. There should thus be a substantial benefit to justify this great difference in cost."

According to the letter, there are more than 50,000 cesspools on Hawaii Island, and the total cost to homeowners could eventually be as high as $1.5 billion to replace them all with septic systems. Meanwhile, the legislators say, the cesspools work well, and it would be a hardship to ask people in areas not near the coastline to install more expensive options.

"In many areas of our Hawaii and Maui counties there is no county water system. Water catchment provides water to over 17,000 homes in Hawaii County alone," the letter reads.

"The use of water in the home and the eventual flows into the cesspools are therefore minimal. These areas should be absolutely excluded from any such ban."

Wiegner and her colleagues, however, said last week that they thought they had substantial data documenting sewage pollution on Hawaii Island, which they hoped Ige would consider as he weighed the proposed rule changes.

UH marine scientists Wiegner, Steven Colbert and Jim Beets wrote in a March 4 letter to the governor that their research showed more than half of the island's cesspools are located within two years of travel to a river or the shoreline for sewage that has seeped out of cesspools.

"Dye tracer study tests have been conducted both at Wai'opae and Puako, and time of travel from homes to shoreline ranged from 20 minutes to three days," the scientists wrote.

"Additionally, wastewater has been shown to be polluting drinking water wells. In Hawaiian Paradise Park … 50 percent of drinking water wells sampled tested positive for fecal indicator bacteria. Pathogens associated with this indicator bacteria can live for months in groundwater. These results indicate that cesspools can be immediate human health hazards."

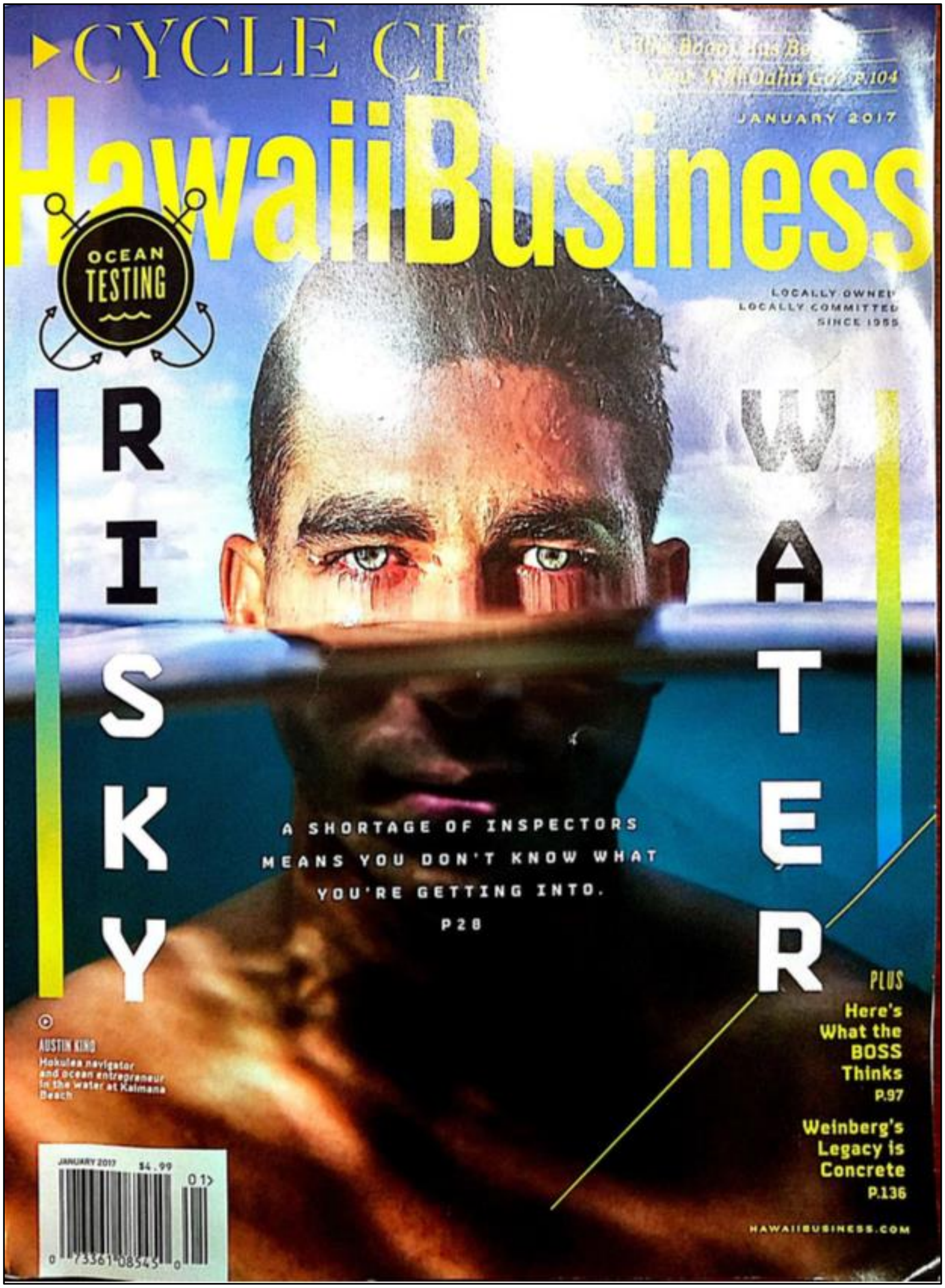
The presence of Enterococcus bacteria in areas such as Hilo Bay suggest that disease-causing bacteria might also be present, especially if they are from human waste, the scientists said.

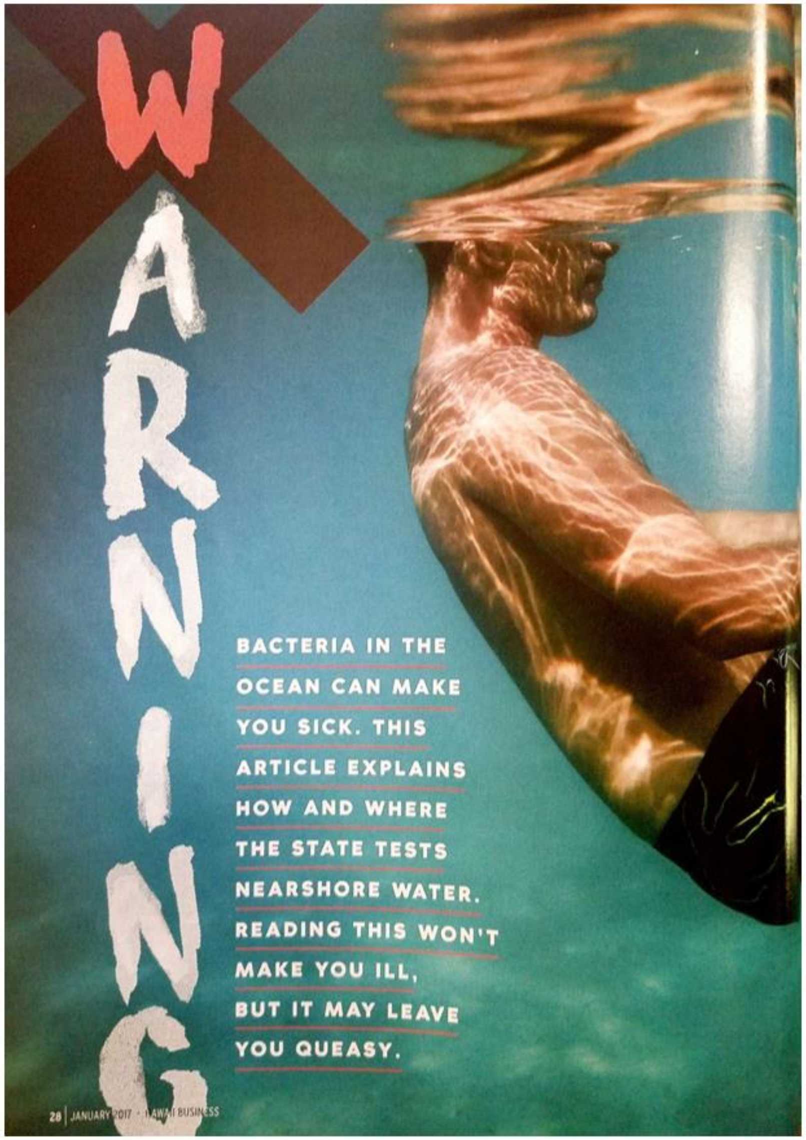
"In Hilo Bay, it has been confirmed that some of these bacteria are from human waste using microbial source tracking techniques," the letter reads. "Comparable measurements have not yet been made in Wai'opae and Puako."

The new administrative rules for the Wastewater Division of the Department of Health will go into effect 10 days after filing with the lieutenant governor's office.

*APPENDIX J*

Hawaii Business article highlighting efforts in January 2017.





# WARNING

BACTERIA IN THE OCEAN CAN MAKE YOU SICK. THIS ARTICLE EXPLAINS HOW AND WHERE THE STATE TESTS NEARSHORE WATER. READING THIS WON'T MAKE YOU ILL, BUT IT MAY LEAVE YOU QUEASY.

28 | JANUARY 2017 · HAWAII BUSINESS

**MOST PEOPLE ARE SMART ENOUGH TO** stay out of the ocean when signs warn about bacteria in the water. The problem is we don't always get that warning, or get it quickly enough, because Hawaii has 303 miles of recreational shoreline and only six state inspectors testing for bacteria.

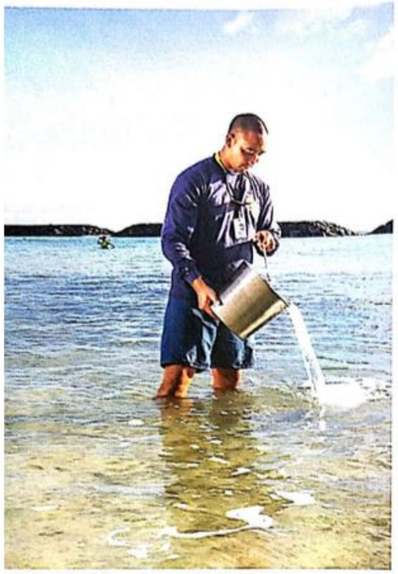
The good news is that volunteers on Kauai and Oahu are also testing the water, and a program proposed for testing in Hilo Bay could give people immediate warnings of polluted water. Best of all, Hawaii's location in the middle of the Pacific helps keep our nearshore water clean.

Bacteria in the ocean can make people with no open wounds sick in many ways: skin, eye, ear and staph infections, as well as gastrointestinal illnesses that lead to nausea, vomiting, diarrhea and fever.

Wastewater that reaches beach waters is the biggest concern, says Watson Okubo, monitoring and analysis section supervisor for the state Department of Health's Clean Water Branch. That's what the branch's six inspectors constantly test for: indicators of human fecal contamination, such as bacterial indicators, nutrients and geochemical parameters such as pH, temperature and turbidity (the cloudiness of the water).

When nearshore waters have elevated levels of bacteria, the branch investigates the cause, which is not always immediately clear. Okubo cites Kahana Bay.

JANUARY 2017 · HAWAII BUSINESS | 29



Wataru Kumagai takes water samples at Magic Island, in Ala Moana Beach Park. The beach park is probably the busiest in Hawaii, so its water gets tested at least once a week by the Hawaii Department of Health's Clean Water Branch.

"You would think that the high counts at the bay would be at the boat ramp and the restroom because of the cess pool, but, actually, the water's coming out of Kahana Stream from higher elevations. And it was feeding the whole bay. it's very challenging to understand bacteria in recreational waters because it's not very simple," he says. "And that's why you really need to understand the venue, the location, the contributing factors, and other testing that was done later on in Kahana, which showed the high bacteria counts were not from humans."

## MONITORING THE WATER

The Clean Water Branch uses two indicator bacteria to determine if a beach is contaminated with fecal matter: enterococci and clostridium perfringens. The two are found together, though a high level of one and a low level of the other doesn't indicate human fecal contamination, Okubo says. It's when both counts are high that a beach may be contaminated, and that's when the branch would do an initial survey and resample the next day. The inspectors and Okubo often have to make a judgment call while awaiting test results: Put up warning signs immediately or wait for the lab results. Because the branch receives funding from the EPA's Beach Act grant, it has to notify the public when recreational waters are not meeting or are not expected to meet applicable quality standards.

Sample sites that exceed water-quality standards half or more of the time could get permanent warning signs. At press time, Okubo said new caution signs created by the Clean Water Branch and Surfrider Foundation's Oahu chapter were being reviewed by stakeholders.

The two kinds of bacteria aren't foolproof clues of human waste. They can both be found in animals, and enterococci, the Environmental Protection Agency-approved indicator, can be found in soils, sediment and decaying matter. Ironically, bacteria from human waste is the most dangerous to humans.

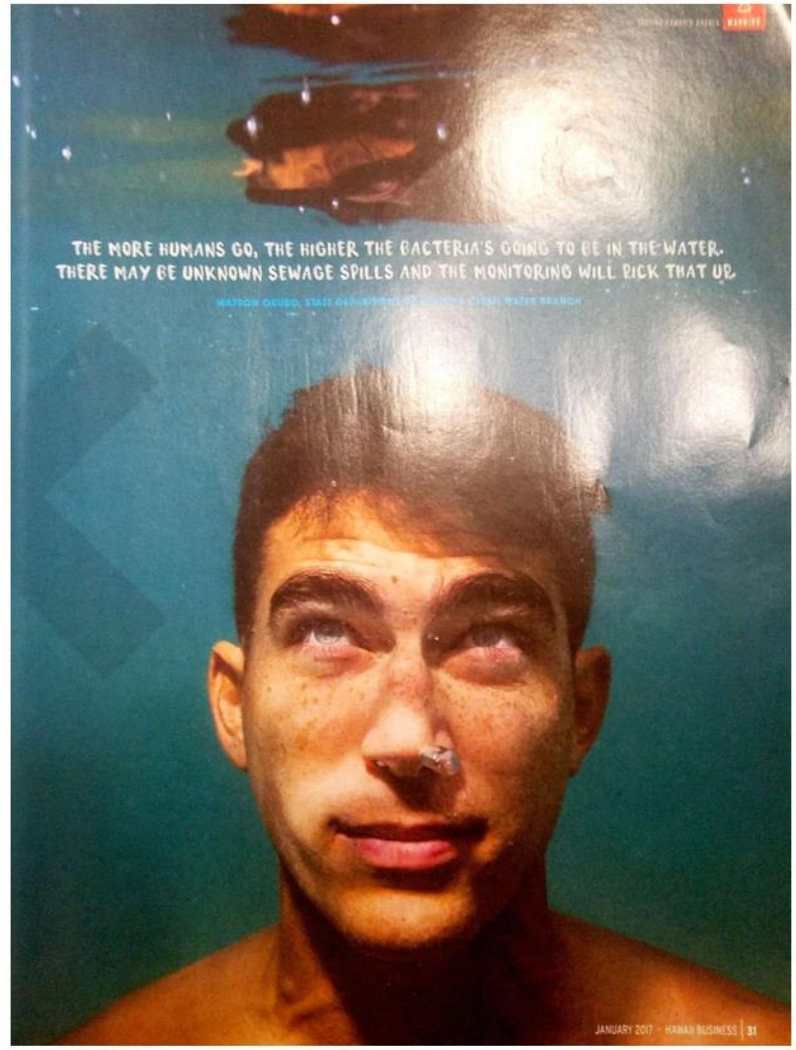
Hawaii has 303 miles of recreational shoreline, according to the 2014 state Water Quality Monitoring and Assessment Report, and the Clean Water Branch focuses on monitoring the nearshore waters: between the shore and 300 meters out. The mouths of streams are also monitored.

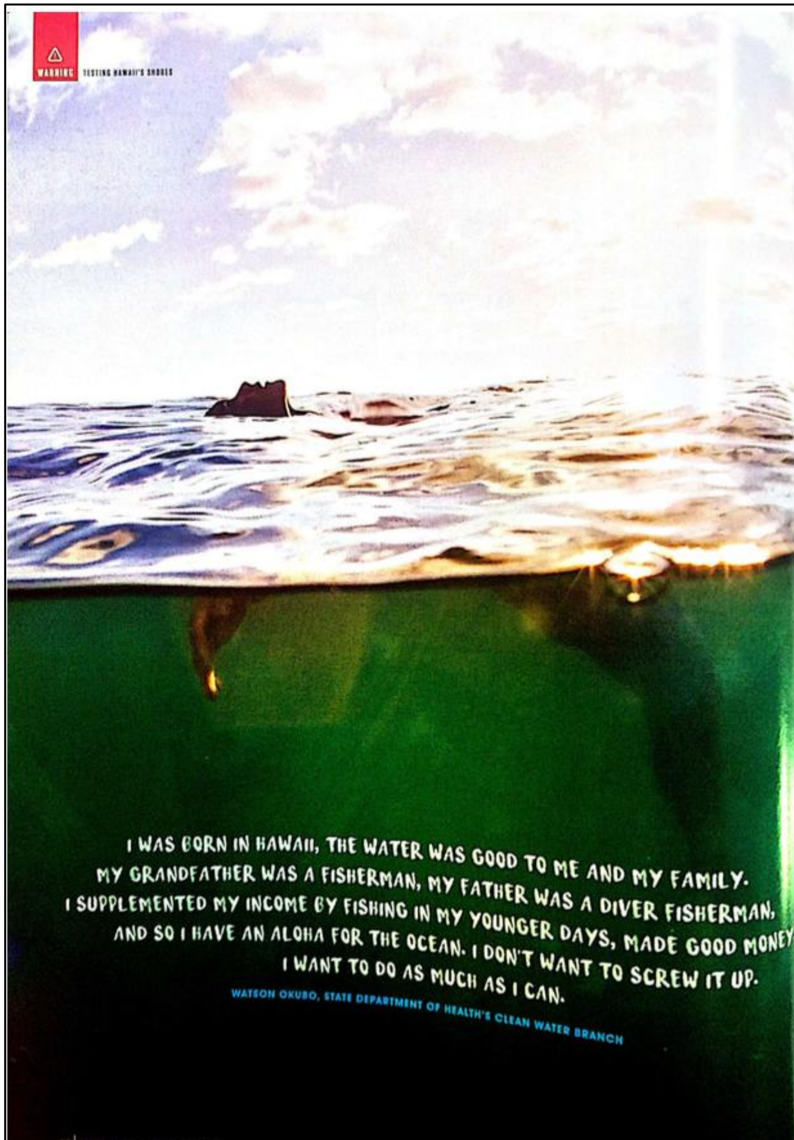
Samples are collected in knee-deep water, with 500 milliliter containers submerged about elbow depth. Measurements for the physical characteristics of the water, such as temperature, salinity, pH and turbidity, are also taken.

Okubo says the major costs of sampling water are equipment and manpower. Testing for enterococci can be done with a kit; however, it's much more complicated for clostridium. The water sample has to be filtered, placed in a petri dish with a gel that helps to isolate and identify clostridium in the water sample, and put in an anaerobic incubator, which will require a full lab to count the colonies of bacteria.

The state water-quality standards say entero...










ric mean of 35 colony-forming units per 100 milliliters over any 30-day period, or a beach action value of 130 colony-forming units per 100 milliliters. For clostridium perfringens, the alert level is 50 colony-forming units per 100 milliliters.

The Clean Water Branch has 446 identified sites to test around the state, but has only six people to do the job. With no labs on Lanai and Molokai to immediately test samples, that leaves one person to test 104 sites on Hawaii Island, one to test 81 sites on Maui and one to test 73 sites on Kauai. The remaining three people test 145 sites on Oahu. EPA funding – $300,000 to $330,000 a year – can't cover all six positions, Okubo says, so most are funded by the state.

With so many sites to test, the Clean Water Branch categorizes beaches based on how likely they are to be contaminated by human fecal matter. Some beaches are tested once a week; others once a year.

High human use, a breakwater, a nearby stream and a nearby storm drain make for a tier-one, high-risk beach. "The more humans go, the higher the bacteria's going to be in the water," Okubo says. "There may be unknown sewage spills and the monitoring will pick that up."

Picture Ala Moana Beach Park during a three-day weekend. Thousands of people will be there, making for an adverse situation, Okubo says. "I know a lot of people don't look at it that way, but, from the health perspective, the more people recreating in one location, the health risk goes up because we're looking at human fecal contamination. ... If you don't want to be at risk, then you go someplace not too many people go."

In addition, degree of dilution plays a role. Generally speaking, if there's no water movement and a lot of people are in the water, there's a bigger risk of exposure to sewage from bathers, especially if there are no bathrooms nearby, according to a 1999 World Health Organization report on health-based monitoring of recreational waters.

## A JUMP IN BACTERIA LEVELS

In 2014, the state found high bacteria levels in Kahaluu Lagoon and the channel leading into Kaneohe Bay. There are an estimated 600 cesspools in the area, so leakage and runoff were suspected as the causes. The state is partnering with UH scientists to study the interaction between the groundwater and surface water to help identify where the contamination is coming from and where it's going.

An earlier study looked at the connection between cesspools and near-shore pollution. Working with the Coral Reef Alliance, UH Hilo marine science researchers Tracy Wiegner and Steven Colbert studied Puako on Hawaii Island, a community of about 160 homes that heavily relies on cesspools and septic tanks to dispose of sewage. Dye tracer studies found that sewage from cesspools could reach the seeps along the coast in as little as nine hours, or up to three or four days, meaning there's little time for any pathogens to be lost or nutrients to be removed from the wastewater.

"The shorter the travel time, the more similar it is to swimming in raw sewage," Colbert says. The travel time depends on how far the cesspool is from the shore and how big the cracks in the rocks are that allow water to flow, he adds. The cesspools in Puako were about 100 feet from the shore.

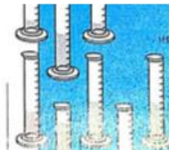
Wiegner says sewage in Puako ocean waters seem to be concentrated within 100 to 200 feet of the shore; however, there also seems to be evidence that wastewater will also discharge through seeps on the seafloor – which is where the team will now be concentrating further efforts to figure out how much sewage is coming up.

Currently, the Coral Reef Alliance and the Puako Community Association are looking at getting a private onsite treatment plant built, the best option according to a feasibility study.

## A LACK OF TREATMENT

The problem with cesspools is they do not treat wastewater; they're unlined holding areas underground that allow untreated wastewater to percolate into the surrounding soil. Until March, Hawaii was the only





## WHICH BEACHES TO TEST?

The state uses a tiered system based on risk to determine which beach waters to sample. To see a full list of all 411 beaches tested in 2015, go to hawaiibusiness.com/watertests.

### TIER 1

These beaches take priority because they are heavily used and have factors that could influence higher bacteria counts, such as nearby streams and storm drains. Tested at least once a week.

- Waikiki
- Waimea Bay
- Ala Moana Beach Park (Diamond Head and center sections)
- Hanauma Bay
- Kailua Beach Park
- Makapuu Beach Park
- Nanakuli Beach Park
- Sandy Beach Park

### TIER 2

These are average beaches, tested at least five times a year.

- Bellows
- Haleiwa Alii Beach Park
- Diamond Head
- Kahala
- Kalama Beach
- Lanikai
- Pipeline

### TIER 3

These beaches have good water quality, no steams entering the area and are located far from human population centers, so they have little human activity. Tested once a year.

- Yokohama Bay
- Mokuleia Beach
- Ehukai Beach Park
- Iroquois Point
- Kahana Bay
- Turtle Bay
- Waianae Regional Park
- Pupukea Beach Park

state that still allowed new construction of small cesspools, meaning cesspools that serve less than 20 people. New small cesspools are now banned. Large-capacity cesspools were banned in 2000 (existing ones had to be upgraded or closed by April 2005). However, there are still 88,000 cesspools in the state, with almost half located on Hawaii Island. Of those, 6,900 are within 750 feet of a shoreline and have a greater potential to introduce harmful pollutants to the ocean than those farther inland, according to Hawaii's Nonpoint Source Management Plan for 2015-2020.

"Our populations are growing, so stopping that input of raw sewage to our shorelines is a very important step, but there's more that can be done," Colbert says.

While connecting residences using cesspools and other on-site disposal systems to wastewater treatment systems seems like a simple solution, Okubo says, there's not enough room to put a sewer line in every community. Sina Pruder, chief of the state's Wastewater Branch, says cost is also a challenge. It would take millions of dollars to install sewer infrastructures in the state's many rural areas, and sewer fees collected in these areas would not be enough to pay for construction and maintenance.

At the beginning of 2016, the Wastewater Branch started its tax-credit program for replacing cesspools located within 200 feet of a shoreline, perennial stream or wetland, or when the sewage takes less than two years to reach a public source of drinking water. However, Pruder says few people have used the credit of up to $10,000 for each qualified cesspool. This money covers a portion of the cost to upgrade to a septic tank or aerobic treatment unit. Pruder says the price will vary based on site conditions, but she estimates a septic tank would cost $8,000 to $20,000 and an aerobic treatment unit $20,000 to $30,000.

When upgrading to a new wastewater disposal system, a home's location is a factor in determining which system to pick. Those near the shore or a stream usually have high groundwater, Pruder says, so, if a homeowner were to put in a leach or drainage field, the Department of Health requires there be three feet separating the bottom of the field and the groundwater. The soil usually provides a natural treatment for the wastewater, so, if homeowners don't have that separation, they have to install an aerobic treatment unit that disinfects the wastewater, she says.

## LEAKS AND SPILLS

Bacteria can also get into nearshore waters thro[ugh leaks] and spills from the sewer system. In 2015, the Cle[an Water] Branch reported 19 sewage spills around the state, [but the spills didn't always] affecting coastal waters, but the spills didn't alwa[ys reach] the nearby beaches. Okubo says this is because spi[lls ...] before reaching beaches.

Marvin Heskett, water-quality expert with Surf[rider] Foundation's Oahu chapter and senior chemist at E[...] Environmental LLC, says nonpoint source pollution [...] concern. Nonpoint source means the pollution orig[inates] from more than one location. During a storm, rain[water] picks up pollutants as it makes its way down to the [ocean].

He cites the area around Waikiki's Kapahulu gro[in as an] example: "That's usually especially bad after long [dry peri]ods, and then you get your first initial storm and it's [...] flushing streets and neighborhoods clean, and all the [mate]rial comes rushing down out of storm-drain pipes."

The Clean Water Branch also watches streams; ho[wever,] no matter which stream is tested, enterococci coun[ts are] going to be high, Okubo says, because of sediment [...] In addition, counts jump each time it rains, so Okub[o began] issuing brown-water advisories after he became sup[ervisor] of the branch's monitoring section in December 20[...].

"I developed the brown-water advisory because [of over]flowing cesspools, unknown chemicals, pesticides, h[erbi]cides, dead animals being washed into the ocean," h[e says.] "So, if the water's brown, stay out. Because you get [...] leptospirosis issues coming up. People think, 'Oh, if [it's] in the salt water you don't have to worry about the l[eptospi]rosis.' It's not true, because it survives long enough i[n] coastal water where all the salinity is depressed."

In the 24 hours it takes to get bacteria test results, beaches may or may not have warning signs based o[n the] judgment of Okubo and his team. That's why Wieg[ner and] Colbert are seeking funding for a pilot project that [would] inform people whether the beach water is safe in re[al time.] Their model would be based on salinity and turbidi[ty,] which appear to be related to bacterial counts, and [would] be recorded by a buoy in Hilo Bay.

"If we have that established relationship betwe[en the] two parameters, we could make calls for bacteria [or] at least predicted bacteria counts based on turbi[dity and] salinity being measured in the water, based on the [buoy,"] Wiegner says.

## HOW A BROWN WATER ADVISORY WORKS

A brown-water advisory begins with a flash-flood warning issued by the National Weather Service and the verification of heavy rains by monitoring staff or trusted observers, says Watson Okubo, monitoring and analysis section supervisor for the state Department of Health's Clean Water Branch.

When debris and turbidity levels return to normal, the Clean Water Branch will take down the brown-water advisory; however, sometimes the branch will await bacteria results before doing so. Okubo says that, if a fecal contamination is suspected [...] possible sources are evident, hi[...] immediately post[...]

1) UH Hilo summer interns and graduate students collect water quality and algae samples at Puako for a project documenting nearshore sewage pollution. The students are Devon Aguiar, Jazmine Panelo, Leilani Abaya, Bryan Tonga, and Delyttra Velez-Gamez.

2) Leilani Abaya, a master's student at UH Hilo's graduate program in Tropical Conservation Biology and Environmental Science, filters water samples from Puako to determine concentrations of fecal indicator bacteria. These bacteria are used to assess whether the water is polluted with sewage.

3) Evelyn Braun, a UH Hilo summer intern with the Pacific Internship Programs for Exploring Science, measures water turbidity (cloudiness) at Waialea Beach, one of the stations for the Puako sewage project.



## ALOHA FOR OUR WATER

Although there may be [illegible] brown water [illegible] Hawaii's beach water [illegible] Foundation's Heskett will [illegible] Surfrider's Oahu and Kauai chapters [illegible] waters, focusing on areas that they [illegible] attention.

On Kauai, that means surf sites [illegible]. That's because Kauai has more waterfalls and rainfall than other islands, meaning bacteria, such as those from cesspools and animal waste, will travel down the streams and into the ocean, Surfrider Kauai chairman Carl Berg says. His chapter has been monitoring water quality for 10 years and has found that some streams are chronically polluted, such as Waiopili Stream and Nawiliwili Stream, which constantly have enterococci counts exceeding state standards.

Both the Kauai and Oahu chapters of the Surfrider Foundation only test for enterococci. According to Heskett, [another] tracer, clostridium perfringens, is not tested [because] it requires an anaerobic chamber, which is outside the scope of Surfrider's equipment and volunteer effort.

However, the main takeaway is that, because the island is in the middle of the Pacific, Kauai's surf sites are generally clean, Berg says. "But, when you start getting water coming off the land, that's when it brings with it all sorts of garbage and bacteria and viruses that can make people sick, and that's why, at the bottom of our list in red, we have places like Hanamaulu Stream, Nawiliwili Stream, Waiopili Stream."

In addition to testing for enterococci, the Oahu Surfrider chapter is also concerned with other pollutants. It has a separate water quality monitoring program that will track four sites around the island for enterococci and clostridium and over 100 pollutants, says Matt Moore, chapter treasurer and water-quality specialist.

The program is funded by a $300,000 grant. The money arises out of a settlement after millions of gallons of storm water leaked from the Waimanalo Gulch Sanitary Landfill into nearshore waters in 2011, Moore says. The program started over the summer and is expected to last two to three years. The test sites will include Nanakuli, Fort DeRussy, Sunset Beach and Castles in Kailua, and the frequency of testing will be based on brown-water events: the group wants to know the levels before, during and after storms.

"We're just trying to inform the public of what's in the water and bring to light some of the issues that have been around for a while without a lot of people knowing," Moore says.

Nevertheless, Hawaii's water quality is a lot better than places on the mainland, Okubo says, citing our location in the middle of the ocean, where currents and winds eventually clear everything away. But, we have to keep addressing the issues that arise.

"I was born in Hawaii, the water was good to me and my family," he says. "My grandfather was a fisherman, my father was a diver fisherman, I supplemented my income by fishing in my younger days, made good money. And so I have an aloha for the ocean. I don't want to screw it up. I want to do as much as I can. All these big issues that are coming up, hopefully I can put down the template for how we are going to do it, do the framework, so I can retire." HB

End of Report