Sewage Pollution in Keaukaha, Hawaiʻi, U.S.A. : An Area Impacted by Cesspools and Offshore Wastewater Outfall

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By
Shayla Waiki

Thesis Committee:
Dr. Steven Colbert
Dr. Tracy Weigner
Dr. Noelani Puniwai

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Abstract

Sewage pollution in coastal waters is concerning for the health of coastal ecosystems and communities worldwide. Sewage enters the environment directly from sewage spills and treated effluent from sewage outfall pipes, or indirectly through groundwater discharge as treated or untreated effluent from on-site sewage disposal systems (OSDS) and injection wells. The presence of sewage pollution in coastal waters can lead to nutrient enrichment impacting coastal water quality and human exposure can also cause health problems. Keaukaha, Hawaiʻi, is an area susceptible to sewage pollution due to the presence of two sewage pollution sources: OSDS and the Hilo Wastewater Treatment Plant (HWTP) sewage outfall pipe. Conducting dye tracer tests, the use of a multi-indicator approach, and including a citizen science survey (the *Pilau*-meter) the goals of this study was to: 1) identify the connectivity of OSDS to nearshore waters, 2) characterize water quality from HWTP inlet to outfall, 3) compare water quality of OSDS-impacted springs to HWTP outfall plume, and 4) document the intensity of sewage and other smells encountered in Keaukaha using the *Pilau*-meter and identify environmental factors associated with the presence of specific smells. Dye tracer tests found that sewage from OSDS reached shoreline springs within 20 h – 3 d, with faster flow rates than reported elsewhere in Hawai'i. HWTP influent samples were an order of magnitude higher in FIB concentrations compared to effluent samples, supporting the effectiveness of the wastewater treatment process. Nutrient concentrations increased from influent to pre-outfall samples, while DOC concentrations were three times lower. Shoreline stations were higher in nutrients except for NH_4^+ and DOC compared to the sewage plume. Sewage smells reported on the *Pilau*-meter were associated with HDOH advisories on two occasions. Our study confirms the effectiveness of using dye tracers test to determine the travel of OSDS contaminants to nearby shorelines,

highlights the effectiveness of chlorination as a wastewater treatment mechanism for reducing FIB, and expands the field of odor science and using the sense of smell in research.

1. Introduction

Coastal waters worldwide are an important resource to coastal communities, providing food for subsistence living, areas of recreation, and are a part of the livelihoods and culture of the local people. Unfortunately, treated and untreated sewage is polluting coastal waters, contaminating them with inorganic nutrients, pathogens, endocrine disruptors, heavy metals, and many other toxins (Wear and Vega Thurber 2015). Untreated or minimally-treated sewage is released into the environment from sewage spills and as effluent from on-site sewage disposal systems (OSDS) like cesspools and septic systems, while higher levels of treated sewage can enter the environment from aerobic treatment units (ATUs) and from wastewater treatment plants via injection wells and sewage outfall pipes. Swimming and recreating in sewage-polluted waters results in ~ 120 million gastrointestinal diseases and 50 million cases of severe respiratory diseases annually worldwide (Shuval 2003). In addition, the consumption of filter-feeding organisms, like oysters, harvested from these waters have caused 4 million cases of Hepatitis A and E, and 40,000 cases of chronic disability annually (Shuval 2003). In tropical systems, sewage pollution negatively affects coastal coral reef ecosystems by causing macroalgal blooms, which can result in a phase shift from coral- to macroalgal-dominated ecosystems (Barnes 1973, Lapointe 1997, Smith et al. 2005, Dailer et al. 2010). In addition, sewage pollution in coastal waters has been linked to the prevalence and severity of coral disease (Sutherland et al. 2010, Redding et al. 2013, Yoshioka et al. 2016, Prouty et al. 2017). Nutrient enrichments associated with sewage in coastal waters also affects coral growth rates, community diversity, and species abundance (Pastorok and Bilyard 1985, Parsons et al. 2008).

Due to the complex and variable composition of sewage, multiple indicators have been identified. Fecal indicator bacteria (FIB) are the most widely used sewage indicators. The United States Environmental Protection Agency (USEPA) uses *Enterococcus* spp. as an FIB to monitor recreational waters. In Hawai‘i, a secondary FIB, *Clostridium perfringens,* is also utilized because of the variability of *Enterococcus* spp. in tropical locations (Fujioka 2001, Fujioka et al. 2015). Both FIB, *Enterococcus* spp. and *C. perfringens*, are linked to human fecal waste, while *C. perfringens* is thought to more accurately detect sewage pollution because it does not multiply in tropical soils, is not capable of regrowth, and spores are viable for longer durations in water environments (Hardina & Fujioka 1991, Stelma 2018, Miller-Pierce & Rhoads 2019). Stable nitrogen (N) isotopic measurements in macroalgal tissue are also used to detect sewage pollution in coastal waters because sewage has a distinct stable N isotopic composition more positive than other N sources (Savage 2005, Dailer et al. 2012, Amato et al. 2020). High nutrient concentrations from the breakdown of organic matter are also found in sewage-polluted regions (Lapointe et al. 1990). Microbial source tracking (MST) is another tool used to identify sewage pollution by targeting human specific bacteria like *Bacteroides* spp., that are specifically related to human waste and present in high abundance within the gastrointestinal tract of humans. Dye tracer tests can be used to determine the connectivity between OSDS and injection wells and the nearby shoreline, indicating if sewage contaminants from OSDS are contributing to sewage pollution in coastal waters (Hunt 2007, Hunt & Rosa 2009, Glenn et al. 2013). While a single sewage indicator alone can be highly variable, the use of these indicators in concert allow for a more thorough documentation and identification of sewage pollution. The use of a sewage pollution scoring tool (e.g. Abaya et al. 2018) takes into account the measurements of these sewage indicators combined, providing regions with a sewage pollution score from low to high.

Another indicator of sewage can be smell. Scientists have identified that humans are able to distinguish between at least 1 trillion olfactory stimuli, more than they are able to distinguish using any other sense (Bushdid et al. 2014). Instruments such as the nasal ranger have been created to measure odors to help further understand the sense of smell (Choi-Schagrin 2022). Smell based research can be a powerful form of participatory science, such as using online mapping that allows users to annotate pre-design base maps with different odor markers (Henshaw 2013). Measuring odors can be difficult but incorporating the sense of smell can provide important information about places and even identify relationships between other environmental parameters (Gostelow et al 2001).

The State of Hawaiʻi relies heavily on OSDS to dispose of sewage, with high densities of OSDS located close to shore. In Hawaiʻi, there are approximately 110,000 OSDS, 49,000 of which are classified as cesspools and located on Hawaiʻi Island (HDOH 2018). The Hawaiian Islands are made up of porous and highly permeable basalt rock, which allows untreated sewage from cesspools to rapidly seep into basal groundwater and be transported to nearby shorelines (Whittier and El-Kadi 2014). Due to impacts of sewage pollution on human and coastal ecosystem health, the Hawai'i State Legislature passed Act 125 which requires the replacement of all cesspools by the year 2050, and also advised HDOH to identify regions of priority for cesspool upgrade or conversion (HDOH 2015, HDOH 2018). Since this transition will cost approximately $54.7 million per year until 2049 for the current inventory of cesspools in the State of Hawaiʻi to be upgraded, data on the impact of sewage from cesspools on coastal ecosystems is necessary to aide in prioritizing cesspool removal (HDOH 2018).

On the east side of Hawai’i Island, the Keaukaha region of Hilo, HI, is susceptible to the effects of sewage pollution due to two sources. The Hilo Wastewater Treatment Plant (HWTP) is located southeast of the neighborhood, and the sewage outfall pipe extends 1.3 km offshore near the center of the community at the popular beach park known as Puhi Bay. In addition, many homes within Keaukaha utilize OSDS (cesspools and septic tanks) to dispose of untreated or minimally treated sewage. With the combined sources of a sewage outfall and high densities of OSDS, Keauhaka could face the effects of sewage pollution in coastal waters, impacting both the health of the community and coastal ecosystems.

The goal of this study is to: 1) identify the connectivity of OSDS to nearshore waters, 2) characterize water quality from HWTP inlet to outfall, 3) compare water quality of OSDS-impacted springs to HWTP outfall plume, and 4) document the intensity and extent of sewage and other smells encountered in Keaukaha and identify any environmental factors that are associated to the presence of the odor. This study provides a thorough water quality dataset for the community of Hilo and Keaukaha using multiple sewage indicators: FIBs, macroalgal tissue %N and δ^{15}N, δ^{15}N- and δ^{18}O-NO_{3^-}, nutrient concentrations, and MST to hopefully aid in decision making processes and inform areas of priority for cesspool upgrade or conversion.

2. Methods

2.1 Site Description

This study was conducted along the Keaukaha coastline, located within the ahupuaʻa of Waiākea and in the moku of Hilo on the Island of Hawaiʻi, Hawai'i, USA (Pukui et al. 1974). Keaukaha sits on the east flank of Mauna Loa volcano, an area of highly-permeable subaerial basalt lava flows (Takasaki 1993). The Keaukaha coastline ranges from a rugged rocky shore, to black sand and a few white sand pocket beaches and has numerous freshwater springs. Keaukaha is known for its *loko iʻa*, fishponds, which are a cultural asset to the community. In 1924, Keaukaha became the second established Hawaiian Homestead in the State of Hawaiʻi, with 60

Native Hawaiian families who became lessees (DHHL 2014). As of 2019, the population was 1,721 (DBEDT 2020). Puhi Bay is a *wahi pana*, special place, to the Keaukaha community, where recreational and cultural activities take place frequently.

Keaukaha could be a region susceptible to sewage pollution due to two possible sources: the close proximity of the HWTP outfall pipe to shore and the use of OSDS in the area. HWTP is located just Southeast of the Keaukaha region and is Hilo's only municipal wastewater treatment facility. HWTP has a design capacity of ~ 22,730 m^3 per day but currently operates and disposes ~13,638 m^3 of treated sewage into the ocean per day (Tetra Tech USEPA 2010). HWTP is a secondary sewage treatment facility and uses chlorination as its final treatment mechanism. However, many homes in Keaukaha utilize on-site sewage disposal systems (OSDS) to dispose of untreated or minimally treated sewage. Currently, the Hilo Bay region on Hawaiʻi Island, which includes Keaukaha, isnʻt classified with the highest priority (Priority 1) for cesspool upgrade or conversion and is classified as a Priority 3 as sewage potentially impacts sensitive waters or coastal ecosystems including coral reefs, impaired waterways, and waters with endangered species (HDOH 2018). The use and high densities of OSDS (321 OSDS, 260 of which are cesspools in Keaukaha, Hawaiʻi) within these coastal communities could also be contributing to sewage pollution in nearshore waters.

2.2 Dye Tracer Tests

Four dye tracer tests (3 cesspools, 1 septic tank) were conducted at homes utilizing OSDS to determine the connectivity of OSDS and shoreline springs. For this study, 0.5-2.0 kg of Fluorescein dye (Amresco Fluorescein Sodium Salt) was added to the OSDS over approximately 10 h. Each hour, 100- 200 g of dye was mixed with 20 L of tap water and slowly added to the

OSDS. Additional tap water was added throughout the day and its volume recorded to calculate the initial dye concentration.

Water samples were collected at 12-13 springs along the shoreline before, during, and after dye tracer addition to determine where and when the dye emerged. Additional springs were sampled when the point of maximum dye concentration was not identified at one of the initial sampling springs. Samples were collected in opaque brown high-density polyethylene bottles to prevent photodegradation, and stored at 4 °C until analysis within 1 month of collection. During the first 12 h of the dye tracer study, samples were collected every 2 h to identify any fast-flow pathways. Then, two samples were collected at each spring within an hour of the lowest-low tide each day for up to 14 d after. Approximately two days after dye was observed visually at the shoreline springs, the number of springs sampled was reduced to 6 – 8. For fluorescein analysis, samples were brought to room temperature, filtered (Whatman^{TM} GF/F), and analyzed using a Turner AU10 fluorometer. Sample conductivity was measured (Fisher Scientific Accumet AB200) and converted to PSS-78 salinity (UNESCO 1981).

2.3 Water Quality Sample Collection

Water samples were collected at shoreline springs, the HWTP, and HWTP outfall surface waters for water quality analysis. All water samples were collected in sterile, acid-washed, polypropylene 1L bottles. At the springs where dye presence was identified, samples from springs were taken during the lowest morning low tide of each month from July 2020 to October 2021. Composite macroalgal samples were also collected and analyzed for %N and δ^{15}N. HWTP influent, effluent, pre-outfall, were also collected once every month from July 2020 to October 2021. Water from the treated sewage plume produced by the HWTP sewage outfall pipe was accessed via boat in June 2021 and August 2021, and water samples were collected above the halocline, where the sewage plume has been previously observed (Birmingham et al. 2008). The warm, low-salinity sewage discharge plume was identified using a CTD (Xylem Castaway) and water samples were collected in a Niskin bottle twice at depths of 0.5, 1, 1.5, 2, and 2.5 m. All water samples were analyzed for FIB, δ^{15}N- and δ^{18}O-NO_{3^-}, nutrient concentrations, and *Bacteroides* spp.

2.4 Fecal Indicator Bacteria Analysis

Triplicate water samples from the shoreline springs, HWTP, and the sewage plume were analyzed for three different FIB: *Enterococcus* spp., *C. perfringens*, and *Bacteroides* spp. Sample processing was conducted within 6 h of sample collection. *Enterococcus* spp. in water samples was analyzed using the Enterolert MPN method with QuantiTray/2000 from the IDEXX Laboratories Inc (Chen et al. 1996). During analysis, when no wells fluoresced blue in QuantiTray, *Enterococcus* spp. concentrations were reported at 5 MPN/100mL, half of the detection limit. *C. perfringens* was quantified using a membrane filtration technique, where a sample of 100 mL of water was filtered through a 0.45-µm pore size cellulose nitrate filter (Whatman^{TM}), placed on mCP agar plates, and incubated in an anaerobic jar at 45ºC for 18-24 hours (Bisson and Cabelli 1979). For human-associated *Bacteroides* spp. (HF183) analysis, 250-500 mL of water from was filtered through a 0.22-µm mixed cellulose ester membrane filter (Millipore, USA) and stored frozen until analysis. DNA was extracted using the FastDNA spin kit for soil with a modified protocol where cells were mechanically lysed using a MP Biomedicals FastPrep-96 bead beater. DNA was stored at -40ºC for later sequencing. DNA samples were amplified via polymerase chain reaction targeting bacteria and archaea.

2.5 δ^{15}N Macroalgal Analysis

Macroalgal samples collected at the springs were placed on ice and transported back to the lab, where they were rinsed with deionized water and dried at 60 °C. After rinsing, small portions of macroalgal tissue were stored in 4% formalin for identification (Abbott 1999; Huisman et al. 2007). Remaining dried algal tissue samples were ground, and ~ 1-2 mg of tissue were placed in 4x6 mm tin capsules. Macroalgal tissues were analyzed for % N and $\delta^{15}N$ using a Thermo-Finnigan™ Delta V Advantage isotope ratio mass spectrometer (IRMS) with a Conflo III interface and a Costech™ ECS 4010 Elemental Analyzer located at the UH Hilo Analytical Lab. Data were normalized to the United States Geological Service (USGS) standard NIST 1547. Isotopic signatures were expressed as standard (δ) in units of part per million (‰) and calculated using the following equation:

$\delta^{15}N = [(R_{Sample} - R_{Standard}) / R_{Standard}] \times 1000‰$, where $R = {}^{15}N/{}^{14}N$

2.6 Nutrient and Stable Isotopes of Nitrate Analyses

One of the triplicate water samples from each station was filtered through a pre-combusted (500°C for 6 hours) 0.7-µm pore size GF/F filters (Whatman™) and stored frozen until analysis. Filters were also stored frozen for later Chl *a* analysis. Nutrients in water samples were analyzed on a Pulse Technicon II autoanalyzer using standard methods for: $NO_3^- + NO_2^-$ [Detection Limit (DL) 0.07 µmol/L, USEPA 353.4], NH_4^+ [DL 0.36 µmol/L, USGS I-2525], PO_4^{3-} [DL 0.03 µmol/L, Technicon Industrial Method 155-71 W], total dissolved phosphorus (TDP) [DL 0.5 µmol/L, USGS I-4650-03], H_4SiO_4 [DL 1 µmol/L, USEPA 366., total dissolved nitrogen (TDN) was analyzed by high temperature combustion, followed by chemiluminescent detection of nitric oxide (DL 5 µmol/L , Shimadzu TOC-V, TNM-1) (Sharp et al. 2002). Filters for Chl *a* analysis were analyzed using a Turner 10-AU fluorometer using the USEPA method 445.0. Turbidity was measured using the Hach 2100Q Turbidimeter. For $\delta^{15}N$ and $\delta^{18}O$ in NO_3^-

analysis, water samples were filtered through a 0.22 um cellulose acetate filter (Whatman^{TM}) and analyzed on a Thermo-Finnigan^{TM} Delta Plus IRMS using chemical NO_3^- reduction. Data was normalized to United States Geological Service (USGS) standards (USGS32, USGS34, USGS35).

2.7 Sewage Pollution Scoring Tool

Using the sewage pollution scoring tool developed by Abaya et al. (2018a), sampling springs were given a sewage pollution score using three sewage indicators: FIB, $\delta^{15}N$ macroalgae, and nutrients. Sewage pollution score categories were: low = 11 – 17, medium = 18 – 25, and high = 26 – 33.

2.8 Citizen Science Survey, the *Pilau*-meter

A GoogleForm survey called the *Pilau*-meter (Hawaiian for stink, rotten, foul), was developed to obtain and document the intensity and extent of the smells encountered around Puhi Bay in Keaukaha with community participation (Appendix A). The survey consisted of 13 questions and collected information on: date, time, demographics, types of sewage smells, severity of sewage smells, and environmental conditions (Appendix A, D). The survey period began in June 2021 and concluded in March 2022. Flyers with QR codes accessing the *Pilau*-meter were posted at Puhi Bay and in person interactions with beachgoers also took place during the weekends. The study protocol was approved by the Institutional Review Board at the University of Hawaiʻi, Protocol #: 2021-00694 on 12/02/2021. Environmental data from June 2021 to March 2022, including tides, wind, wave activity, rainfall, and river flow, were obtained from NOAA Hilo Bay tide gauge #1617760 (NOAA 2022), CDIP Hilo Bay wave buoy #51206 (CDIP 2022), USGS Wailuku River #16704000 (USGS 2022), and NCEI Hilo Airport

#91285021504 (NCEI 2022). Wave data was only available from November 2021 to March 2022 (CDIP 2022). A dataset combining both *Pilau*-meter responses and environmental data was used to analyze associations between presence of odor and environmental factors. HDOH water quality advisories (CWB 2022) were accessed and analyzed for association with the presence of the odor as well.

2.9 Data Analyses

Data were tested for assumptions of parametric statistical tests using Shapiro-Wilk normality test and equal variances, when assumptions were not met, data transformations were performed. A One-way Analysis of Variance (ANOVA) was used to determine if FIB, $\delta^{15}N$ in macroalgae**,** nutrients, and $\delta^{15}N$- and $\delta^{18}O\text{-}NO_3^-$ differed among treatment stages of HWTP samples, and different depths within the offshore sewage plume. A two-sample t-test was used to determine if FIB, $\delta^{15}N$ in macroalgae**,** nutrients, and $\delta^{15}N$- and $\delta^{18}O\text{-}NO_3^-$ differed among dye tracer stations. When assumptions of normality and equal variances were not met, a Kruskal-Wallis test used to determine if FIB, $\delta^{15}N$ in macroalgae**,** nutrients, and $\delta^{15}N$- and $\delta^{18}O\text{-}NO_3^-$ differed among treatment stages of HWTP samples, and different depths within the offshore sewage plume. When assumptions of normality and equal variances were not met a Mann-Whitney test was used to determine if FIB, $\delta^{15}N$ in macroalgae**,** nutrients, and $\delta^{15}N$- and $\delta^{18}O\text{-}NO_3^-$ differed among dye tracer stations. A Tukey's multiple comparisons post-hoc test or a Wilcoxon rank sum test was used on variables that were found to be significantly different to indicate the stations grouping. All statistical test were completed in R version 4.0.3 with α=0.05.

To identify any environmental factors that were associated with the presence of odors, observations from the *Pilau*-meter and all environmental variables were combined into one dataset in Python. Environmental data were resampled on Python into 15-min intervals, except for high and low tides which were resampled at 6- min intervals for better resolution of tide data. Time from low tide (T_{Low}) was created by calculating the time before and after low tide (Appendix B). TimePrecip was created by calculating the sum of precipitation from each 15-min interval (Appendix B). The three most common odor observations, good/normal, fishy, and sewage were analyzed. Correlations were analyzed between type of odor, intensity of the odor, and environmental variables on Python (Appendix B).

2.10 Stable Isotope Mixing Models

δ^{15}N- and δ^{18}O-NO_3^- data were used in stable isotope mixing models to identify N sources and determine their relative percent contributions to the NO_3^- pool. The stable isotope mixing model package "simmr" was used in the program R (version 4.0.3) for this analysis. Potential N sources used in the mixing model included OSDS within Keaukaha, sewage effluent from HWTP, and groundwater sampled from wells.

3. Results

3.1 Dye Tracer Tests

Dye was detected at the shoreline from all four dye tracer tests and was observed at 2-3 shoreline springs. Dye reached the shoreline from 20 h to 3 d, calculated from the difference in time from the start of the dye addition to the OSDS until the first appearance at the shoreline (Table 1). The flow rate for dye to travel from the OSDS to the shoreline ranged from 130 to 213 m/d (Table 1).

At the springs where dye was observed, variable patterns were observed for the multiple sewage indicators. *Enterococcus* spp. and *C. perfringens* were similar among areas with cesspools, Cesspool 1 and 2, ranging from 8-405 MPN/ 100 mL and 0-1 CFU/ 100mL, respectively (Table 2). *C. perfringens* was not detected at shoreline spring monitored for

Cesspool 1, but was detected in low concentrations at the other shoreline springs. $NO_3^- + NO_2^-$, TDN, $\delta^{15}N$-NO_3^- were all higher at shoreline spring monitored for Cesspool 1 and 2 (Fig. 2). Springs monitored for dye presence were similar in PO_4^{3-}, H_4SiO_4, NH_4^+, TDP, and DOC concentrations. The % N in macroalgal tissue present at shoreline springs ranged from 1.22- 2.94 %, while $\delta^{15}N$ ranged from 0.7-4.4 ‰, and significantly different among springs (W=7, p=0.006 ; W=85, p<0.001) (Table 2). Shoreline spring monitored for Cesspool 2 had the highest sewage pollution score of 21, remaining in the medium sewage pollution category, while shoreline spring monitored for Cesspool 1 had the lowest sewage pollution score of 17, remaining in the low sewage pollution category (Table 2).

3.2 HWTP and Outfall Pipe Sampling

FIB was present in all influent, effluent, and pre-outfall samples obtained from HWTP. Influent samples were an order of magnitude higher *Enterococcus* spp. and *C. perfringens* concentrations, compared to effluent samples (Figure 3, Table 3). However, pre-outfall *C. perfringens* concentrations were similar to the influent, and four times higher than effluent (Figure 3, Table 3). *Bacteroides* spp. were also detected in the influent, effluent, and pre-outfall samples from HWTP (Table 3). FIB concentrations within the sewage plume produced by HWTP outfall pipe were less than 12 MPN/100 ml and 1 CFU/100 ml for *Enterococcus* spp. and *C. perfringens*, respectively. FIB concentrations were similar across all depths sampled within the sewage plume (Table 4).

Nutrient concentrations changed differently among the treatment stages of the HWTP, depending on the parameter. $NO_3^- + NO_2^-$, PO_4^{3-}, and TDP concentrations significantly increased from influent to effluent, and did not significantly differ from effluent to pre-outfall (Figure 3, Table 3). In contrast, DOC concentrations significantly decreased from influent to effluent samples and continued to decrease in pre-outfall samples, although not significantly. (Figure 3, Table 3). Offshore, within the treated sewage plume produced by HWTP outfall pipe, most nutrients were similar across depths, except for H_4SiO_4, which significantly decreased from <1 m to 2-3 m (F= 5.46, p=0.028) (Table 4).

3.3 Comparison between Groundwater, Ocean, Shoreline Springs, and Sewage Plume

Both *Enterococcus* spp. and *C. perfringens* were highest at shoreline springs and within the sewage plume compared to background groundwater and ocean samples (Table 5). $NO_3^- + NO_2^-$ and TDN were significantly higher in shoreline springs than ocean samples and within the sewage plume. NH_4^+ was also highest within the sewage plume. PO_4^{3-}, H_4SiO_4, TDP, $\delta^{15}N\text{-}NO_3^-$, and $\delta^{18}O\text{-}NO_3^-$ were highest in groundwater samples and significantly higher than the sewage plume (Table 5). DOC was significantly higher in the ocean samples and within the sewage plume, averaging 1952.83 ± 41.45 and 1932.24 ± 27.79 µmol/L, respectively (Table 5).

3.4 Mixing Model

Using the simmr mixing model, proportions of NO_3^- were determined for three shoreline springs (Figure 4). Sewage from HWTP contributed 67% of the NO_3^- at shoreline spring monitored for Cesspool 3, higher than any other contribution to any other shoreline spring. Groundwater contributed 81% of NO_3^- to the shoreline spring monitored for Cesspool 2, while its lowest contribution was to the shoreline spring monitored for Cesspool 3. OSDS contributions to shoreline springs were all below 20%.

3.5 The *Pilau*-meter

The *Pilau*-meter surveying period recorded a total of 85 observations from June 2021-March 2022. The three odors analyzed, 65% of observations (n = 55) reported good/ normal odors, 17% a fishy odor (n =14), and 13% a sewage odor (n = 11) (Appendix C). Strong smells (smell severity of 5) were reported the least amount of times (1.2%), while smells with a lower severity (4 and below) were reported more often (55%) (Appendix C). There was a positive correlation between good/ normal odors and sea surface temperature ($r = 0.418$, $p = 0.011$) and air temperature ($r = 0.310$, $p = 0.023$) (Table 6). Fishy odors were not correlated with any environmental variable (Table 6). However, sewage odors were significantly correlated with wave period, waves from the North contributed to days where sewage odors were observed (Table 6). The time of day and the time from low tide were not significant indicators of any type of smell within this study. However, reporting of the presence of sewage odors on the Pilau-meter occurred during times that coincided with water quality advisories posted by Hawaiʻi Department of Health (HDOH).

4. Discussion

4.1 Dye Tracer Tests

Dye tracer tests demonstrated that effluent from OSDS in Keaukaha, Hawaiʻi, is reaching the nearby shoreline. This study determined that sewage from OSDS reached the shoreline in 20 h -3 d, with minimum flow rates ranging from 130- 213 m/d (Table 1). Previous dye tracer studies in Puakō, Hawaiʻi, were similar, reaching the shoreline in 5 h -11 d, but at considerably slower flow rates of 3 – 137 m/d (Abaya et al. 2018, Wiegner et al. 2021). In Lahaina, Maui, dye tracer test highlighted the hydrological connections between a wastewater treatment plant injection well and coastal waters, with maximum flow rates of 8.6 – 9.5 m/d (Glenn et al. 2013). The flow rates identified in Keaukaha are much faster than those documented in Lahaina which could be due to the high permeability of very young basalt lava on Hawaiʻi Island, especially in Keaukaha, and the large amounts of groundwater discharge (Whittier & El-Kadi 2014). Hawaiʻi

Island is the youngest of all Main Hawaiian Islands with shallow and porous soil. The thin layer of soil and high permeability of rock would allow sewage contaminants in Keaukaha to travel faster than older Hawaiian Islands.

A modeling study by the Hawaii DOH used a two-year time of travel to estimate OSDS that pose the greatest risk in nutrient loading to the coastal environment, and in Hilo, the two-year time of travel was 6 - 8 km inland from the shoreline (Whittier & El Kadi 2014). However, using the average of flow rates measured in this study (170 m/d), it would only take 47 d for sewage from OSDS located 8 km inland to reach the shoreline, approximately 15 times faster than the predicted two-year travel time. Previously the Keaukaha region was prioritized as a Priority 3, almost the lowest priority for cesspool upgrade or conversion, recently the Hawaiʻi Cesspool Hazard Assessment & Prioritization Tool has Hilo placed in the Priority 2 and 3 category, but with fast travel times as fast as those determined in this study, the time of which biological processes are able to treat wastewater and rid them of harmful bacteria are greatly reduced which could severely impact water quality and human health in this region, therefore prioritization should be further researched and re-evaluated as necessary (HDOH 2018, Mezzacapo 2021).

4.2 Sewage Indicators

Our study identifies lower FIB measurements at shoreline springs than compared to previous research. *Enterococcus* spp. concentrations ranged from 8 – 405 MPN/100 mL and *C. perfringens* concentrations ranged from 0 – 1 CFU/100 mL. The HDOH Standard Threshold Value of 130 MPN/ 100mL was exceeded only in one sample, shoreline spring monitored for Cesspool 2. *C. perfringens* concentrations did not exceed the recommended 5 CFU/ 100 mL standard at any of the shoreline springs. Our findings reveal lower FIB concentrations in comparison to other studies that analyzed FIB concentrations at the shoreline. Measurements of *Enterococcus* spp. ranged from 18 to 2777 MPN/100 mL in a study done in Puakō, Hawaiʻi (Abaya et al. 2018a). *Enterococcus* spp. concentrations at one station in Puakō was up to two orders higher in magnitude compared to other stations within the area (Abaya et al. 2018a). The same findings were also observed in another study done in Puakō, Hawaiʻi, with *Enterococcus* spp. concentrations at the Puakō shoreline averaging 410 ± 83 MPN/ 100 mL (Wiegner et al. 2021). *C. perfringens* concentrations recorded along the Puakō, Hawaiʻi shoreline were also higher than the findings in this study, average concentrations of 5 ± 3 CFU/ 100 mL and 4 ± 1 CFU/ 100 mL were identified while this study indicated an average *C. perfringens* concentrations 0 – 1 CFU/100 mL (Abaya et al. 2018a, Weigner et al. 2021). In another study conducted in Malibu, California, *Enterococcus* spp. concentrations ranged from <10 – 1210 MPN/100 mL collected in nearshore waters suggesting the effects of OSDS to nearby beaches, which is higher than concentrations found in this study (Izbicki et al. 2012).

Elevated concentrations of nutrients are oftentimes a result of sewage pollution and can alter coastal marine ecosystems (Smith et al. 2005, Lapointe et al. 2019). In this study, nutrient concentrations at shoreline springs where dye was observed were similar, except for $NO_3^- + NO_2^-$ and TDN concentrations. Average $NO_3^- + NO_2$, TDN, and H_4SiO_4 concentrations of 65.51 ± 5.21, 77 ± 5, 447 ± 88 µmol/L were higher at Puakō shoreline stations than the range of average concentrations for those nutrients found in this study (Wiegner et al. 2021) (Table 2). Average NH_4^+ and PO_4^{3-} concentrations of 1.64 ± 0.10 and 1.60 ± 0.15, respectively, at Puakō shoreline stations are similar and in the range of average NH_4^+ and PO_4^{3-} concentrations found in this study (Wiegner et al. 2021) (Table 2). Another study along the coast of Puakō, Hawaiʻi reported average $NO_3^- + NO_2^-$, NH_4^+, TDN, PO_4^{3-}, TDP and H_4SiO_4 concentrations similar to that found in this study (Abaya et al. 2018a). The average concentrations found in our study for all nutrients except NH_4^+ remained within the ranges and similar to concentrations detected along the Puakō shoreline, while NH_4^+ concentrations were higher at 3.35 µmol/L. In the Florida Keys, a study identified that nutrient enrichment were occuring in waters impacted by sewage pollution from OSDS. The highest concentrations of NH_4^+, $NO_3^- + NO_2^-$, and soluble reactive phosphate occured in areas adjacent to OSDS. In comparison to control groundwaters, OSDS impacted groundwaters were highly enriched in nitrogen compared to soluble reactive phosphate (Lapointe et al. 1990). The range of average NH_4^+ concentrations found in our study (1.21 – 3.35 µmol/L) were more similar to the average NH_4^+ concentrations found in surface waters adjacent to OSDS of residential waterfront properties which was 1.69 ± 1.48 µM in the summer, while the range of average $NO_3^- + NO_2^-$ concentrations in our study (22.49 – 39.11 µmol/L) were more similar to midpoint samples (groundwaters midway to adjacent canal) of residential waterfront properties of 30.7 ± 89.9 µM in the summer. Areas affected by sewage injection also show elevated concentrations of nutrients (Miller- Pierce & Rhoads 2016, Glenn et al. 2013). In Kihei, Maui, concentrations of $NO_3^- + NO_2^-$, NH_4^+, and total phosphorus exceeded the geometric mean calculated for coastal sites (Miller-Peirce & Rhoads 2016). Marine surface water in Lahaina, Maui, had average concentrations of PO_4^{3-} of 4.5 µg/L, NO_3^- of 5.7 µg/L, NO_2^- of 0.5 µg/L and NH_4^+ of 1.4 µg/L (Glenn et al. 2013). In comparison to the findings in our study, average PO_4^{3-} concentrations ranged from 1.89 – 2.24 µmol/, average $NO_3^- + NO_2$ concentrations ranged from 22.49 – 39.11 µmol/ L, and average NH_4^+ concentrations ranged from 1.21 – 3.35 µmol/ L. $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ have also been used to detect sewage pollution and differentiate between different sources of nitrate (Hunt 2007, Wiegner et al. 2016). $\delta^{15}N\text{-}NO_3$ in areas impacted by sewage injection wells were identified to be +18 ‰ in Kihei, Maui, only slightly heavier than effluent samples (+15 ‰) (Hunt 2007). The water samples outside areas of probable influence of the plume had lighter $\delta^{15}N\text{-}NO_3^-$ values of +6 - +8 ‰ (Hunt 2007). Samples collected in Lahaina, Maui, had maximum $\delta^{15}N\text{-}NO_3^-$ values of +40 ‰ and intermediate values of +13 ‰ (Hunt 2007). The heavy $\delta^{15}N\text{-}NO_3^-$ values suggests that nitrogen-rich effluent discharges along Maui beaches, both in Kihei and Lahaina (Hunt 2007). Average $\delta^{15}N\text{-}NO_3^-$ values recorded in our study at shoreline springs ranged from -1.46 to 3.88 ‰, while average $\delta^{15}N\text{-}NO_3^-$ values in HWTP effluent were 9.1 ± 2.75 ‰. Shoreline springs in this study did not have $\delta^{15}N\text{-}NO_3^-$ values as heavy as seen in Kihei and Lahaina which could suggest the dilution of sewage contaminants and groundwater contributing to lighter $\delta^{15}N\text{-}NO_3^-$ values.

Bacteroides spp. is the bacteria commonly used in microbial source tracking which allows for the identification of sources of fecal pollution (Bernhard and Field 2000). *Bacteroides* spp. is abundantly found in the human gut and is not likely to replicate in the environment, serving as a possible marker for human fecal contamination (Bernhard and Field 2000). The human-associated *Bacteroides* spp. markers used in research are HF183 and BacHum (Ahmed et al. 2016). In our study, HF183 were present in all samples from all three stages of wastewater treatment (influent, effluent, and pre-outfall) (Table 3), while none was found at shoreline springs. A study done in Malibu, California, found the presence of HF183 in OSDS samples, while none were detected in wells, Malibu Lagoon, and nearshore waters (Izbicki et al 2012). The presence of HF183 in OSDS samples and absence in shoreline stations correlates with our findings in this study, suggesting that the absence of HF183 could be due to dilution or removal of human fecal associated microorganisms (Izbicki et al 2012).

4.3 HWTP and Sewage Plume

In urban areas, where a tremendous amount of sewage is generated from the large, dense populations, sewage treatment is required for public health safety. In more rural areas, OSDS are used due to less dense populations, and lack of infrastructure. Hilo is unique in that it has both a wastewater treatment plant and OSDS, posing two different kinds of challenges for coastal water quality. Hilo's Wastewater Treatment Plant infrastructure is a secondary wastewater treatment system that uses chlorination for disinfection before releasing treated effluent from the facility to an ocean outfall. Influent, effluent, and pre-outfall samples were analyzed to assess water quality at each stage of wastewater treatment. In this study, influent samples contained the highest *Enterococcus* spp. and *C. perfringens* concentrations. Untreated wastewater FIB concentrations have been reported to range from 10,000 – 100,000 MPN/100 mL for *Enterococcus* spp. and 1,000 – 100,000 MPN/100 mL for *C. perfringens* (Metcalf & Eddy 2003). *Enterococcus* spp. concentrations from our influent samples fall within this range, as the geometric mean was 65,467 ± 67065 MPN/ 100 mL. *C. perfringens* concentrations averaged 200 ± 59 CFU/100 mL, an order of magnitude lower than previous studies (Metcalf & Eddy 2003). At all wastewater treatment plants, a primary goal is to reduce pathogens in the effluent before it is discharged into the environment. At new facilities, nutrient removal capabilities are also included. In Hilo, the treated sewage effluent samples from HWTP were significantly lower in FIB concentrations compared to influent samples. This suggests that the secondary treatment process and use of chlorination as a disinfectant implemented by HWTP is reducing FIB concentrations in wastewater. The secondary treatment process utilized removes biodegradable organic matter and suspended solids in the primary phase of wastewater treatment, then further disinfects wastewater by the use of biological and chemical processes (Metcalf & Eddy 2003).

Cesspools contain untreated sewage and likely have a similar composition to WWTP influent. At Puakō, Hawai‘i, cesspools had concentrations of $NO_3^- + NO_2^-$, PO_4^{3-}, and NH_4^+ of 20.76 ± 10.50, 378.58 ± 16.59, and 6370.00 ± 806.16 µmol/L, respectively (Abaya et al. 2018a). These values are lower than the average concentrations of $NO_3^- + NO_2^-$, PO_4^{3-}, and NH_4^+ in influent samples found in this study (Table 3). In addition, our findings also coincide with a study done in Kapoho, Hawai‘i, where the concentrations of PO_4^{3-}, H_4SiO_4, NH_4^+, and TDP, were highest in sewage samples compared to other N sources. (Wiegner et al. 2016). The variability could be due to dilution, additional sources of freshwater, and groundwater leaking into pipes. Nitrogen in treated wastewater effluent in Kihei and Lahaina, Maui, were found to have $NO_3^- + NO_2$ concentrations of 451 and 176 µmol/L, respectively, which was lower than measured at HWTP (Hunt and Rosa 2009). In this study, nutrient concentrations of $NO_3^- + NO_2^-$, PO_4^{3-} , and TDP increased from influent to effluent, while all other nutrients decreased. NH_4^+ concentrations in treated wastewater effluent in Kihei and Lahaina, Maui were 19 and 189 µmol/L, respectively, while TDN concentrations were 523 and 437 µmol/L, respectively (Hunt and Rosa 2009). NH_4^+ and TDN concentrations were higher in effluent samples of this study compared to effluent measured in Kihei and Lahaina, Maui.

Sewer pipe systems provide environments for microbial communities to thrive due to characteristics of being aqueous, dark, high in nutrient, less variable temperatures, and fluctuating oxygen levels (McLellan and Roguet 2019). In this study, after the effluent was released from HWTP and traveled ~ 3.5 km in the sewer to the sewage outfall pipe, pre-outfall samples collected in this study from the pumping station onshore were found to have higher concentrations of both FIB compared to effluent samples. Nutrient concentrations of $NO_3^- + NO_2^-$, PO_4^{3-} , H_4SiO_4, and TDP increased from effluent to pre-outfall samples, while NH_4^+, DOC, and TDN concentrations decreased. Increases in microbes within the system suggest that fecal-originated strains can thrive ans grow in the pipe environment (e.g. McLellan and Roguet 2019).

Offshore, in the near-surface water above the sewage outfall, at all depths within the treated sewage plume, *Enterococcus* spp. concentrations did not exceed the HDOH statistical threshold value (STV) of 130 MPN/100 ml. *C. perfringens* concentrations only exceeded the recommended 5 CFU/ 100ml standard in one sample at a depth of 2-3 m within the treated sewage plume. A study done in Avalona Bay located on the SE end of Catalina Island also reflect these findings (Boehm et al. 2003). Low FIB concentrations (<10 MPN/ 100mL) of *Enterococcus* spp, total coliform, fecal coliform, *Escherichia coli* were found in samples collected directly over a wastewater outfall (Boehm et al. 2003). The low concentrations of FIB within the sewage plume produced by HWTP outfall pipe could be due to dilution and mixing of the plume when disposed into surrounding water. Rapid initial dilution can be a result of the momentum of the discharge exiting the diffusers or the buoyancy of the discharged effluent (Wu et al. 1994, Birmingham et al. 2008). In a field experiment at Ipanema Beach in Rio de Janeiro, Brazil , the plume from an ocean sewage outfall was found to be trapped below the thermocline and dilution was low (35 to 1), whereas in unstratified conditions, the plume surfaces and the dilutions increased significantly to more than 100 to 1 (Carvalho et al. 2002). The dilution factor identified in our study was similarly 35 to 1.

4.4 *Pilau*-meter

Incorporating the sense of smell into scientific research provides additional data on environmental landscapes. In the Hawaii state rules regulating water quality, water pollution includes anything that “changes the...odor of the waters” (HAR 11-54). The community of Keaukaha, Hawaiʻi, collected most of the observations for this survey and documentation of the sewage smell came as a recommendation and interest of the community. The citizen scientists were clearly able to distinguish several different smells, including good/normal, sewage, fishy, and diesel/exhaust. In this study, good air quality days occurred with warm conditions, while sewage odors were observed when waves were coming from the north, and fishy odors were not significantly correlated with any environmental variables (Table 6). The presence of sewage odors coincided with water quality advisories posted by Hawaiʻi Department of Health (HDOH) for Puhi Bay, Hawaiʻi. During June 17, 2021- June 21, 2021, sewage smells were reported on the *Pilau*-meter, which was then followed by an HDOH advisory that was posted on June 24, 2021 stating the presence of high bacterial counts for Puhi Bay. Sewage smells were also reported during January 29, 2022 – February 22, 2022, right after an HDOH advisory was posted on January 28, 2022 stating to avoid water near Puhi Bay and the HWTP sewage outfall as wastewater was discharged from the treatment plant due to a power outage. HDOH lifted this advisory on January 31, 2022. The nearly significant correlation between fishy odors and low tidal height could be a result of the exposure of intertidal habitats during the low tides. During this time, organisms that have not successfully transitioned with the dropping tide are exposed to the air and sun for longer periods of time. Our study contributes to further developing research using the human sense of smell to record odors encountered in different areas of urban places. A study done in the UK, Europe, and USA has documented "smell-walks" where locals were asked to identify distinct odors and describe them which resulted in the first urban smell dictionary (Quercia et al. 2015). In addition, geo-referenced social media tags that match with different classifications of urban smells along with air quality data were also used to identify a positive correlation between pollution concentrations and categories of smells in social media tags (Quercia et al. 2015). Our study adds to previous research that indicates that using the human sense of smell can provide important information about places and even identify relationships between other environmental parameters. Future research should be geared towards further studying these correlations between environmental factors of sea surface temperature, water temperature, tidal height, and wave peak direction and the presence of the three different types of odors. In addition to these analyses, the location of the HWTP pumping station could be another factor contributing to the presence of the odor in this area.

5. Conclusion

In conclusion, dye tracer tests in our study confirmed that sewage contaminants from OSDS in Keaukaha, Hawaiʻi are reaching nearby shorelines within 20 h – 3 d, faster than previously reported in other areas of Hawaiʻi which may suggest further research in prioritizing the Hilo region for cesspool upgrade or conversion. Our study also identified trends in FIB concentrations in HWTP samples suggesting the effectiveness of wastewater treatment at HWTP, however nutrient concentrations of $NO_3^- + NO_2^-$, PO_4^{3-}, and TDP remained elevated in pre-outfall samples, while DOC concentrations decreased. The sewage plume produced by HWTP outfall pipe were generally lower in *Enterococcus* spp. and all other nutrients except for NH_4^+ and DOC as well as *C. perfringens* concentrations compared to shoreline springs which attributes to dilution occuring in the area of the outfall pipe. Lastly, the use of the *Pilau*-meter and sense of smell in this study contributed to the developing field of odor science research and successfully determined correlations between good/normal and sewage odors while fishy odors were not significantly correlated with any environmental variable.

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Table 1. Travel time, flow rate, dilution of dye, and direction of flow for four dye tracer test conducted between June and October 2021, in Keaukaha, Hawaiʻi .

Dye Tracer Test	Travel time (d)	Flow rate (m/d)	Dilution (ppm)	Direction of flow (deg)
Cesspool 1	3.2	129.9	3.2	318.67
Cesspool 2	0.8	178.4	28.9	350.36
Cesspool 3	0.9	213.3	16.4	14.8
Septic Tank	1.9	157.4	2.4	328.36

Table 2. Mean ± SE and [range] of sewage indicators measured at three of the shoreline springs where dye was confirmed from the dye tracer test in June 2021- October 2022 in Keaukaha, Hawaiʻi. Results from Two samples t-test and Mann-Whitney, letters denoting significant differences based on Wilcoxon tests are shown as superscripts ($\alpha = 0.05$). are superscripts with letters indicating significant differences ($\alpha = 0.05$). n = sample size. *= Nitrate values too low for detection. NA= no data for shoreline spring.

Dye Tracer Test	Cesspool 1	Cesspool 2	Cesspool 3	Septic Tank
n	5	17	1	NA
Enterococcus spp. (MPN/100 mL)	8 ± 2 [5-30]	405 ± 252 [5-9804]	17 ± 20	NA
C. perfringens (CFU/100mL)	0 [0]	0.058 ± 0.056 [0-1]	1 ± 1	NA
$NO_3^- + NO_2^-$ (μmol/L)	39.11 ± 5.21^{a} [28.49-57.82]	22.49 ± 1.55^{b} [13.3-42.07]	31.39	NA
PO_4^{3-} (μmol/L)	2.144 ± 0.31 [1.64-3.37]	1.89 ± 0.13 [0.75-3.43]	2.24	NA
H_4SiO_4 (μmol/L)	312.73 ± 50.26 [138.39-399.63]	348.43 ± 31.06 [143.88-580.33]	420.05	NA
NH_4^+ (μmol/L)	1.21 ± 0.21 [0.59-1.69]	1.54 ± 0.66 [0.18-11.7]	3.35	NA
TDP (μmol/L)	2.44 ± 0.33 [1.67-3.62]	2.50 ± 0.15 [1.66-4.19]	2.38	NA
DOC (μmol/L)	180.56 ± 137.14 [37.4-729]	76.94 ± 34.59 [5-625.7]	5	NA
TDN (μmol/L)	53.58 ± 11.38^{a} [31.75-86.2]	33.34 ± 3.90^{b} [19-74.49]	65.7	NA
$\delta^{15}N\text{-}NO_3^-$ (‰)	3.88 ± 0.68^{a} [2.5-5.4]	-1.46 ± 1.33^{b} [-9.5-5.2]	*	NA
$\delta^{18}O\text{-}NO_3^-$ (‰)	-1.675 ± 1.19 [-3.8-1.1]	-1.76 ± 1.23 [-13.2-3.8]	*	NA
% N in Macroalgae	1.72 ± 0.22^{a} [1.22-2.26]	2.37 ± 0.05^{b} [1.96-2.94]	NA	NA
Algal δ15N (‰)	3.7 ± 0.23^{a} [3.0-4.4]	1.16 ± 0.09^{b} [0.7-2.1]	NA	NA
Sewage Pollution Score	17	21	NA	NA

Table 3. Geomean (± SE) and [range] of *Enterococcus* spp. in influent, effluent, and pre-outfall samples obtained from HWTP, Hilo, HI. Mean (± SE) and [range] of sewage indicators measured in influent, effluent, and pre-outfall samples obtained from HWTP, Hilo, HI. Letters denoting significant differences based on either Tukey's or Wilcoxon tests are shown as superscripts ($\alpha = 0.05$). Presence of *Bacteriodies* spp. (HF183) in HWTP, Hilo, HI samples were also identified in all three wastewater treatment stages. *= 12 sampling

HWTP Sample	Influent	Effluent	Pre-Outfall
HF183 (P/A)	P	P	P
Enterococcus spp. *(MPN/100 mL)*	65466 ± 67065^{a} [5288.9-942366.7]	187 ± 12541^{b} [11.3-201111.1]	1385 ± 220732^{b} [50.7-3314355.6]
C. perfringens (CFU/100 mL)	200 ± 59^{a} [0-767]	6 ± 2^{b} [0-25]	31 ± 9^{a} [0-128]
$NO_3^- + NO_2^-$ (µmol/L)	6.92 ± 2.36^{a} [0.25-40.07]	91.71 ± 14.79^{b} [7.85-244.33]	145.25 ± 18.87^{b} [2.83-286.35]
PO_4^{3-} (µmol/L)	28.13 ± 3.16^{a} [9.21-54.52]	44.73 ± 3.66^{b} [12.31-64.42]	46.39 ± 3.15^{b} [29.6-63.88]
H_4SiO_4 (µmol/L)	437.57 ± 31.86 [101.32-673.98]	412.49 ± 39.29 [174.55-732.96]	429.53 ± 37.35 [147.99-683.15]
NH_4^+ (µmol/L)	590.85 ± 38.86 [302.65-875.71]	558.63 ± 44.27 [251.34-920.96]	514.09 ± 34.11 [351.02-747.63]
TDP (µmol/L)	35.60 ± 4.09^{a} [11.75-67.84]	55.30 ± 3.67^{b} [15.5-76.52]	58.45 ± 3.17^{b} [37.5-79.97]
DOC (µmol/L)	1895.13 ± 286.05^{a} [165.6-5004.7]	619.87 ± 173.16^{b} [227.9-3151.2]	579.7 ± 172.73^{b} [154.9-2925.5]
TDN (µmol/L)	1038.33 ± 84.85 [558.75-1685.79]	1020.12 ± 81.14 [679.95-1742.6]	968.16 ± 86.36 [606.82-1706.89]
$\delta^{15}N\text{-}NO_3^-$ (‰)	10.09 ± 2.98* [0.4-25.1]	9.1 ± 2.75* [-4.1-33.1]	3.56 ± 2.14* [-7.3-12.5]
$\delta^{18}O\text{-}NO_3^-$ (‰)	8.6 ± 0.97* [2.3-12.3]	8.46 ± 2.25* [1.1-26.7]	4.49 ± 0.79* [-2-8.1]

Table 4. Mean (± SE) and [range] of sewage indicators measured in depths of <1, 1-2, and 2-3 meters within the treated outfall sewage plume produced by the HWTP outfall pipe. Results from One-way ANOVA or Kruskal-Wallis, with letters denoting significant differences based on either Tukey's or Wilcoxon tests are shown as superscripts ($\alpha = 0.05$). *= Nitrate values too low for detection.

Depth (m)	< 1	1-2	2-3
Enterococcus spp. *(MPN/100mL)*	8 ± 2	12 ± 3	6 ± 1
	[5-20]	[5-41]	[5-10]
C. perfringens (CFU/100 mL)	0.44 ± 0.18	0.6 ± 0.19	0.64 ± 0.54
	[0-1]	[0-2]	[0-6]
$NO_3^- + NO_2^-$ (µmol/L)	2.18 ± 1.01	1.90 ± 0.41	0.87 ± 0.16
	[0.57-4.6]	[1.02-3.19]	[0.44-1.17]
PO_4^{3-} (µmol/L)	0.25 ± 0.23	0.57 ± 0.29	0.16 ± 0.15
	[0.015-0.72]	[0.015-1.66]	[0.015-0.60]
H_4SiO_4 (µmol/L)	23.85 ± 6.62^{a}	16.89 ± 2.22^{a}	7.95 ± -0.71^{b}
	[11.99-34.87]	[9.45-22.97]	[6.08-9.54]
NH_4^+ (µmol/L)	3.20 ± 1.40	4.7 ± 1.47	4.29 ± 1.23
	[1.53-5.97]	[1.82-9.8]	[2.37-7.88]
TDP (µmol/L)	1.20 ± 0.60	1.76 ± 0.40	1.97 ± 0.86
	[1.12-1.32]	[0.72-3.17]	[0.98-4.55]
DOC (µmol/L)	1835.67 ± 86.58	1946.56 ± 12.14	1983.78 ± 34.65
	[1662.7-1929.2]	[1907.6-1984.2]	[1883.4-2039.2]
TDN (µmol/L)	15.43 ± 2.71	15.66 ± 1.63	17.49 ± 1.59
	[11.46-20.62]	[9.26-18.37]	[13.18-20.51]
$\delta^{15}N\text{-}NO_3^-$ (‰)	*	*	*
$\delta^{18}O\text{-}NO_3^-$ (‰)	*	*	*

Table 5. Mean (± SE) and [range] of sewage indicators measured in groundwater, ocean, shoreline springs, and sewage plume samples. Results from One-way ANOVA or Kruskal-Wallis, with letters denoting significant differences based on either Tukey's or Wilcoxon tests are shown as superscripts ($\alpha = 0.05$). NA= No data available due to nitrate values being too low.

Sample	Groundwater	Ocean	Shoreline Springs	Sewage Plume
n	7	3	23	12
Enterococcus spp. (MPN/100 mL)	0 ± 0	6 ± 1	302 ± 284	9 ± 2
	[0]	[5-7]	[5-6546]	[5-34]
C. perfringens (CFU/100mL)	0 ± 0	0 ± 0	0.076 ± 0.037	1 ± 0
	[0]	[0]	[0-1]	[0-2]
$NO_3^- + NO_2^-$ (µmol/L)	25.17 ± 2.51	0.92 ± 0.27	26.49 ± 2.13	1.63 ± 0.35
	[11.91-31.01]	[0.43-1.34]	[13.3-57.82]	[0.44-4.6]
PO_4^{3-} (µmol/L)	2.49 ± 0.41	0.015 ± 0	1.96 ± 0.12	0.35 ± 0.14
	[1.13-3.9]	[0.015]	[0.75-3.43]	[0.015-1.66]
H_4SiO_4 (µmol/L)	413.22 ± 21.21	10.10 ± 2.06	343.78 ± 25.30	15.65 ± 2.48
	[331.24-502.2]	[7.38-14.13]	[138.39-580.33]	[6.08-34.87]
NH_4^+ (µmol/L)	1.02 ± 0.21	1.35 ± 0.20	1.55 ± 0.49	4.19 ± 0.77
	[0.43-1.83]	[0.95-1.63]	[0.18-11.7]	[1.53-9.8]
TDP (µmol/L)	3.45 ± 0.50	1.19 ± 0.36	2.49 ± 0.13	1.69 ± 0.32
	[1.85-5.72]	[0.63-1.86]	[1.66-4.19]	[0.72-4.55]
DOC (µmol/L)	755.93 ± 46.69	1952.83 ± 41.45	96.33 ± 38.54	1932.24 ± 27.79
	[625.8-1003.8]	[1898.4-2034.2]	[5-729]	[1662.7-2039.2]
TDN (µmol/L)	28.76 ± 2.40	9.21 ± 1.82	39.15 ± 4.23	16.21 ± 1.02
	[15.81-34.3]	[7.34-12.85]	[19-86.2]	[9.26-20.62]
$\delta^{15}N\text{-}NO_3^-$ (‰)	0.66 ± 0.24	NA	-0.27 ± 1.17	NA
	[-0.5-1.3]		[-9.5-5.4]	
$\delta^{18}O\text{-}NO_3^-$ (‰)	2.46 ± 0.43	NA	-1.74 ± 1.01	NA
	[1.5-4.8]		[-13.2-3.8]	

Table 6. Correlation table between good/ normal, fishy, and sewage odors and environmental conditions. Bold represents significant correlations between the type of smell and environmental conditions ($\alpha = 0.05$). Italics represent almost significant correlations between the type of smell and environmental conditions.

Envrionmental Conditions	Sewage smell		Fishy smell		Good smell		Reference
	r	p	r	p	r	p	
Water Temperature (ºC)	-0.269	0.424	*-0.495*	*0.072*	-0.187	0.175	NOAA Tide Guage
Significant Wave Height (m)	0.082	0.877	-0.324	0.478	-0.049	0.775	Hilo Wave Buoy
Wave Peak Period (s)	**0.832**	**0.040**	0.074	0.874	-0.081	0.639	Hilo Wave Buoy
Wave Peak Direction (deg)	*0.766*	*0.076*	-0.026	0.955	-0.031	0.857	Hilo Wave Buoy
Average Wave Period (s)	0.002	0.997	0.082	0.861	0.076	0.660	Hilo Wave Buoy
Sea Surface Temperature (ºC)	-0.353	0.492	-0.108	0.818	**0.418**	**0.011**	Hilo Wave Buoy
Wind Speed (m/s)	-0.326	0.327	-0.230	0.428	0.020	0.885	NOAA Tide Guage
Wind Direction (deg)	0.263	0.434	*0.438*	0.117	-0.197	0.153	NOAA Tide Guage
Wind Gust (m/s)	-0.324	0.331	-0.098	0.740	0.083	0.550	NOAA Tide Guage
Air Temperature (ºC)	-0.237	0.482	-0.253	0.384	**0.310**	**0.023**	NOAA Tide Guage
Air Pressure (mb)	0.466	0.149	-0.056	0.848	-0.200	0.147	NOAA Tide Guage
Tide (m)	-0.078	0.819	*0.502*	*0.067*	0.141	0.308	NOAA Tide Guage
River Discharge (m^3/s)	-0.361	0.275	-0.432	0.123	-0.083	0.551	USGS Wailuku River
River Gage Height (m)	-0.362	0.274	*-0.464*	*0.095*	-0.112	0.418	USGS Wailuku River
Temperature (ºC)	-0.271	0.421	-0.208	0.476	0.197	0.154	NWS Hilo Airport
Air Pressure (mHg)	0.448	0.167	-0.043	0.885	-0.185	0.179	NWS Hilo Airport
Wind Direction (deg)	0.348	0.294	0.412	0.143	-0.078	0.574	NWS Hilo Airport
Wind Speed (m/s)	0.188	0.579	0.396	0.161	-0.095	0.493	NWS Hilo Airport
Time Precip	0.104	0.760	0.079	0.788	-0.129	0.354	NWS Hilo Airport
Time of Day (Hour)	0.403	0.219	0.281	0.331	0.194	0.161	
Time from Low Tide	-0.145	0.671	0.375	0.186	0.173	0.216	

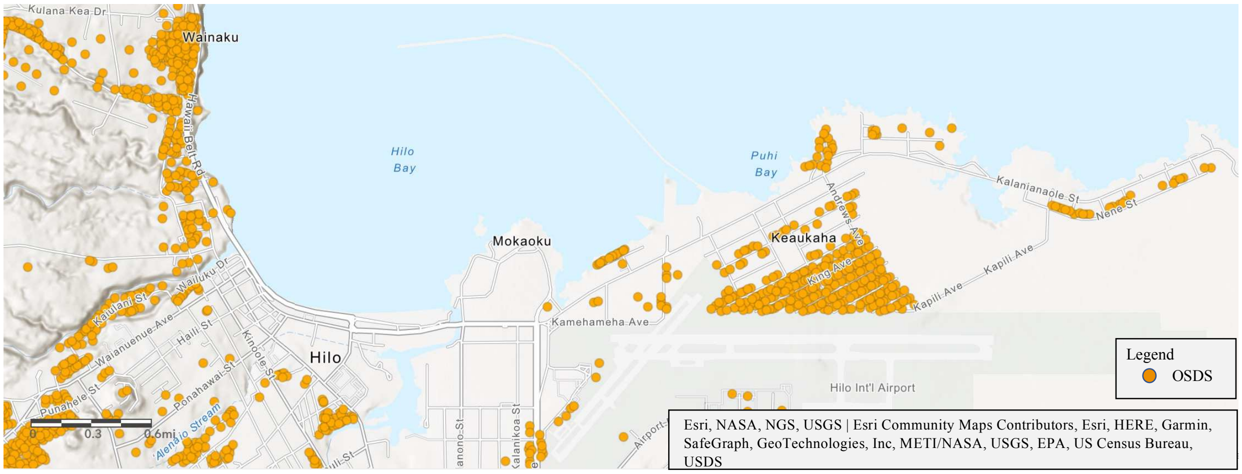

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Figure 1. Map of Keaukaha, Hawai'i with OSDS in the region represented as orange dots. Water quality sampling and dye tracer testing were conducted throughout the study period of July 2020-October 2021.

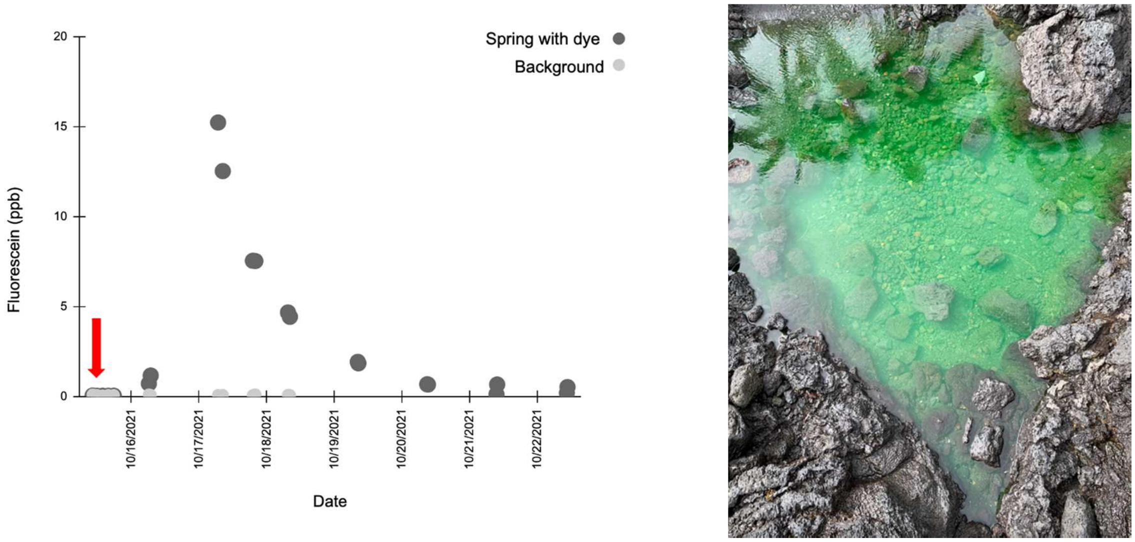


Figure 2. Example of results from a dye tracer test conducted in Keaukaha, Hawai'i of fluorescein concentration over a 6 d period, comparing a spring with the highest concentration of fluorescein to a nearby spring that remained at background concentration. For this dye tracer test dye was added to the OSDS at 9:25 am on 10/15/2021 indicated by the red arrow on figure and first dye presence at the spring was observed at 6:14 am on 10/16/2021.

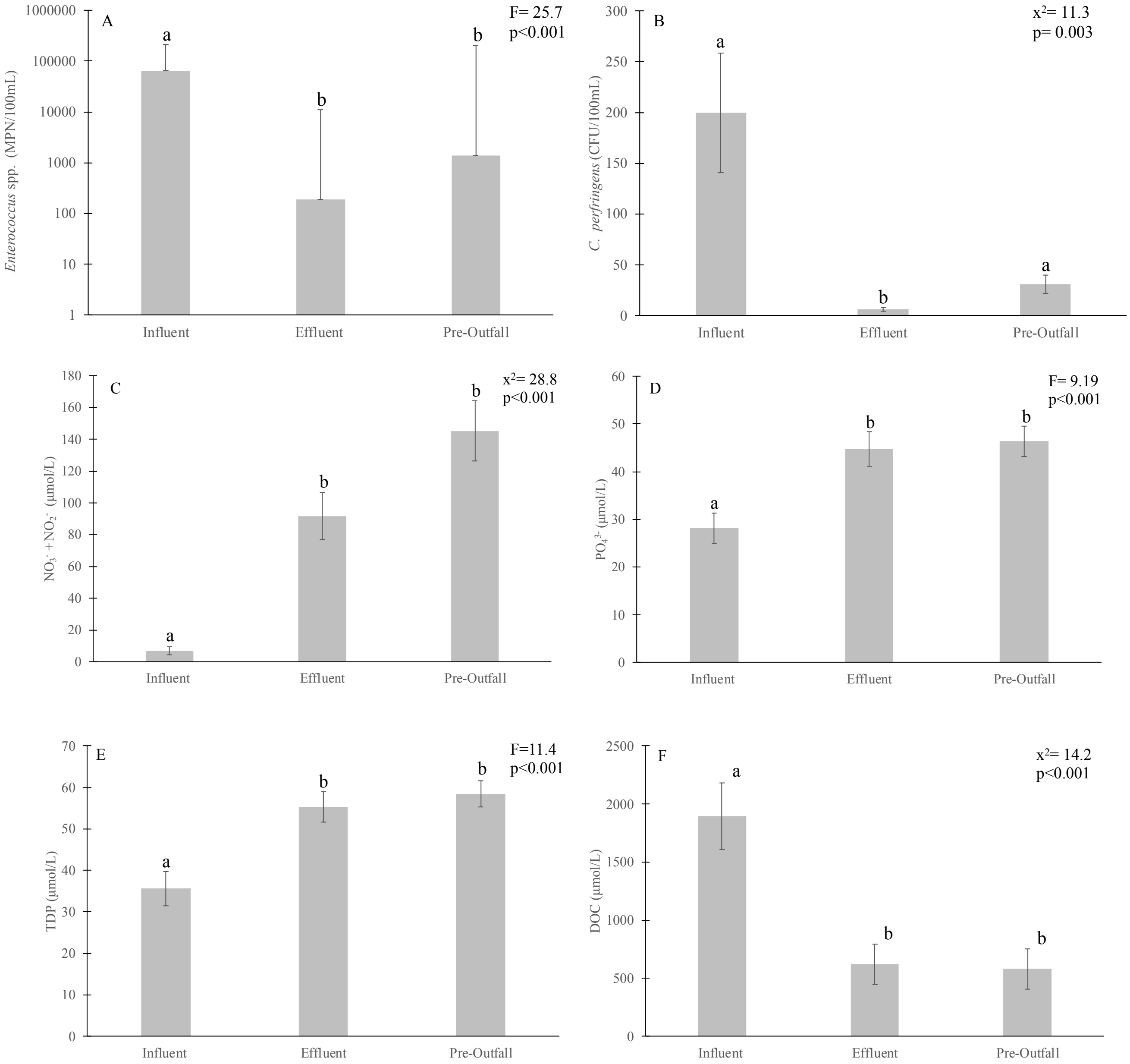


Figure 3. Mean (± SE) A) *Enterococcus* spp., (B) *C. perfringens*, (C) $NO_3^- + NO_2^-$, (D) PO_4^{3-} , (E) TDP, and (F) DOC in influent, effluent, and pre-outfall samples obtained from HWTP, Hilo, HI. Results from One-way ANOVA or Kruskal-Wallis, with letters denoting significant differences based on either Tukey's or Wilcoxon tests are shown on the figure ($\alpha = 0.05$).

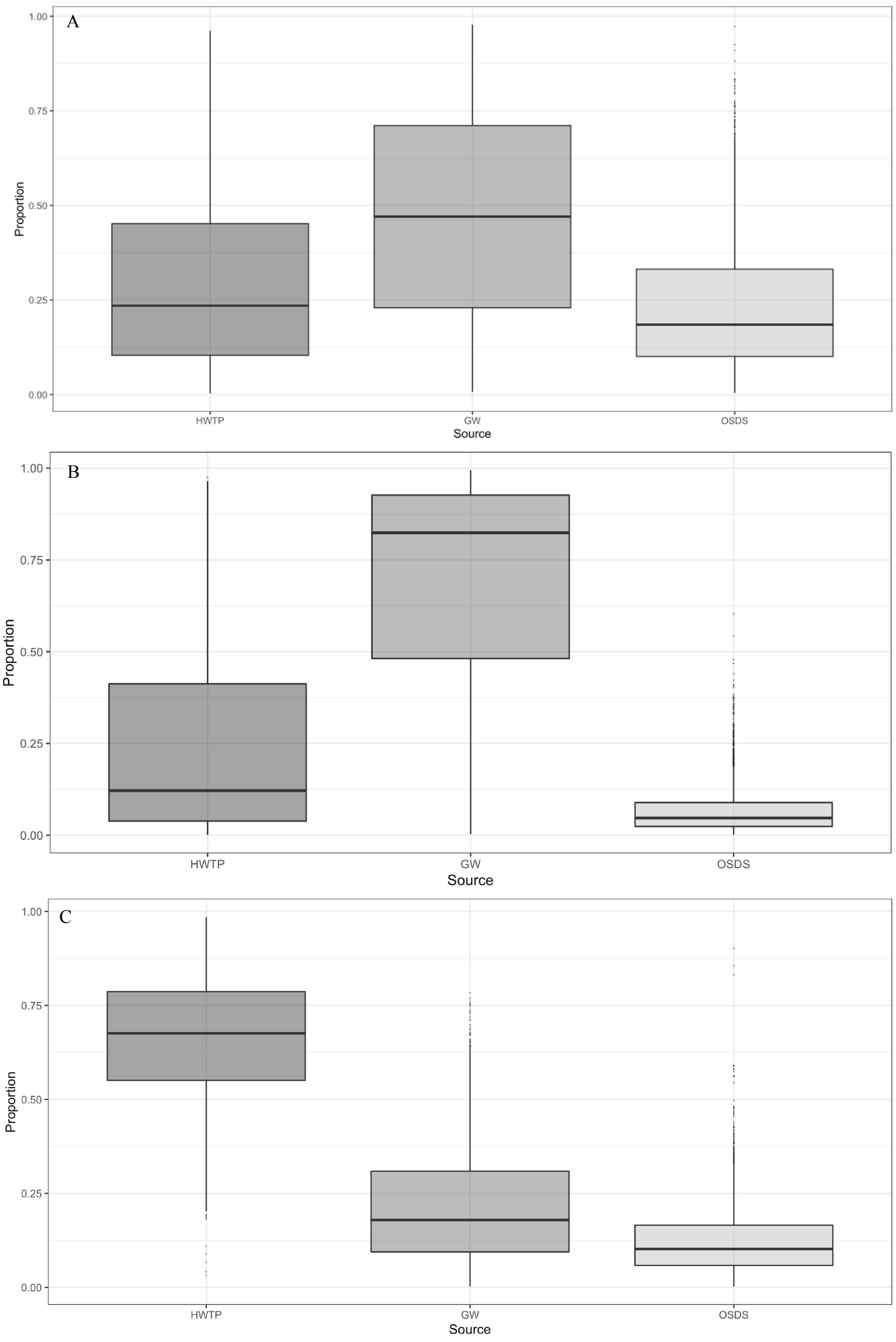
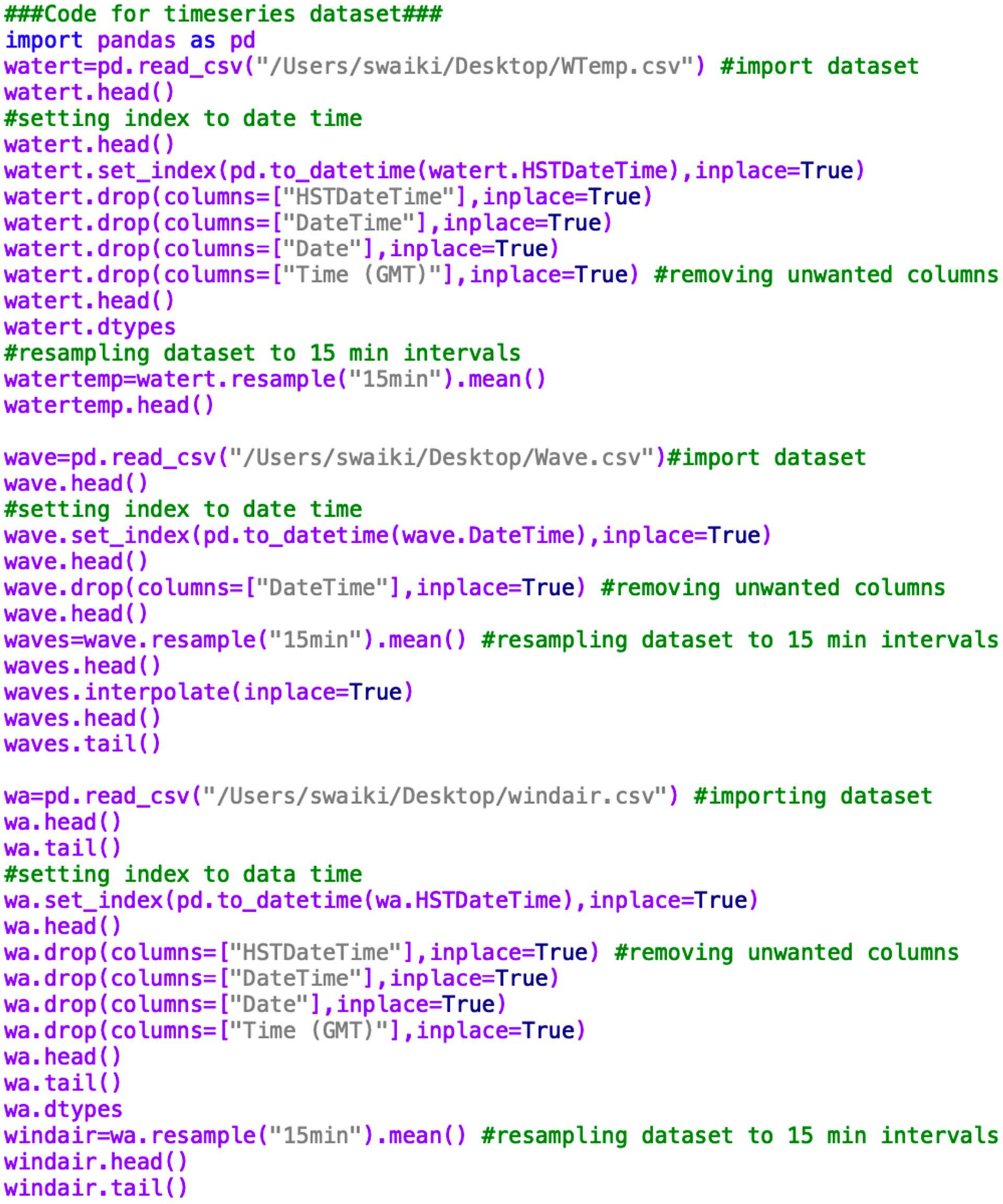


Figure 4. Simmr mixing model results displaying the proportion (%) of each N source contributed to three shoreline springs along the Keaukaha, Hawai‘i coastline A) Cesspool 1, B) Cesspool 2 , and C) Cesspool 3, in July 2020 - October 2021. Sources included in the model are HWTP (influent, effluent, pre-outfall), OSDS, and Groundwater (freshwater). Vertical bars display SE, while horizontal bars display the mean value.

Appendix A. *Pilau*-meter questions and possible answers on survey

Pilau-meter Questions	Possible Answers
Your observation takes place during what day?	
Your observation takes place at what time?	
What are the environmental conditions like at the time you are completing this survey?	Sunny
	Overcast/ Cloudy
	Rainy
	Windy
	Low Tide
	Other
Which region are you reporting from?	Region 1- PACRC to 1st gate at Puhi Bay (Hilo Side)
	Region 2- 1st gate at Puhi Bay to community tent
	Region 3- Community tent to 2nd gate at Puhi Bay (Middel, by side road)
	Region 4- 2nd gate to restrooms and parking lot
	Region 5- Restroon to gate by Chock's
What type of smell is it?	Sewage
	Sulfur
	Fishy
	No smell
	A bad smell I cannot describe
How severe is the smell?	1- no detectable odor
	2- not too stink
	3- getting stink
	4- stink
	5- extremely stink
What is your age?	18-29 years old
	30-39 years old
	40-49 years old
	50+ years old
Where do you live? (Please select the best description.)	Keaukaha Community
	Hilo
	Local to Hawai'i Island (Excluding Hilo)
	Neighbor Island
	Out of State/ Country
How often do you go to Puhi Bay?	Once or twice a week
	Every other week
	Once a month
	Once every 3 months
	Once every 6 months
	Once every year
What brings you to Puhi Bay?	Swimming
	Fishing
	Paddling
	Diving
	Working
If you selected "Working" as your answer to the question above, what is your occupation?	
What is your educational level?	High School
	Community College
	University- Undergraduate
Are there any other observations of this situation you would like to report?	

Appendix B. Python code for *Pilau*-meter correlation with environmental variables



```
###Code for timeseries dataset###
import pandas as pd
watert=pd.read_csv("/Users/swaiki/Desktop/WTemp.csv") #import dataset
watert.head()
#setting index to date time
watert.head()
watert.set_index(pd.to_datetime(watert.HSTDateTime),inplace=True)
watert.drop(columns=["HSTDateTime"],inplace=True)
watert.drop(columns=["DateTime"],inplace=True)
watert.drop(columns=["Date"],inplace=True)
watert.drop(columns=["Time (GMT)"],inplace=True) #removing unwanted columns
watert.head()
watert.dtypes
#resampling dataset to 15 min intervals
watertemp=watert.resample("15min").mean()
watertemp.head()

wave=pd.read_csv("/Users/swaiki/Desktop/Wave.csv")#import dataset
wave.head()
#setting index to date time
wave.set_index(pd.to_datetime(wave.DateTime),inplace=True)
wave.head()
wave.drop(columns=["DateTime"],inplace=True) #removing unwanted columns
wave.head()
waves=wave.resample("15min").mean() #resampling dataset to 15 min intervals
waves.head()
waves.interpolate(inplace=True)
waves.head()
waves.tail()

wa=pd.read_csv("/Users/swaiki/Desktop/windair.csv") #importing dataset
wa.head()
wa.tail()
#setting index to data time
wa.set_index(pd.to_datetime(wa.HSTDateTime),inplace=True)
wa.head()
wa.drop(columns=["HSTDateTime"],inplace=True) #removing unwanted columns
wa.drop(columns=["DateTime"],inplace=True)
wa.drop(columns=["Date"],inplace=True)
wa.drop(columns=["Time (GMT)"],inplace=True)
wa.head()
wa.tail()
wa.dtypes
windair=wa.resample("15min").mean() #resampling dataset to 15 min intervals
windair.head()
windair.tail()
```

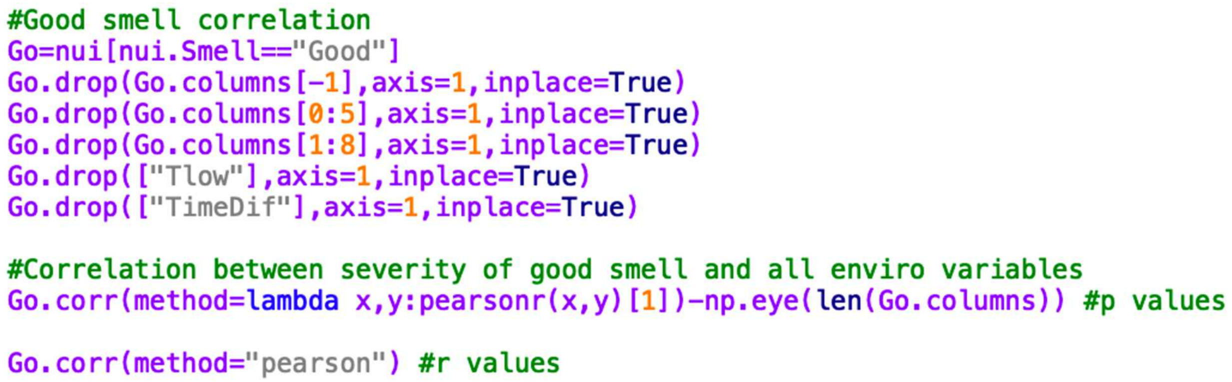
```
t=pd.read_csv("/Users/swaiki/Desktop/Tides.csv") #importing dataset
t.head()
#setting index to date time
t.set_index(pd.to_datetime(t.HSTDateTime),inplace=True)
t.head()
t.drop(columns=["DateTime"],inplace=True) #removing unwanted columns
t.drop(columns=["Predicted "],inplace=True)
t.drop(columns=["Date"],inplace=True)
t.drop(columns=["Time (GMT)"],inplace=True)
t.drop(columns=["HSTDateTime"],inplace=True)
t.head()
tide=t.resample("15min").mean() #resampling dataset to 15 min intervals
tide.head()
tide.tail()

#combining all datasets to one
wtwaveswatide=pd.concat([watertemp,waves,windair,tide],axis=1)
wtwaveswatide.head()
wtwaveswatide.tail()

HL=pd.read_csv("/Users/swaiki/Desktop/HLTides.csv") #importing dataset
HL.head()
#setting index to date time
HL.set_index(pd.to_datetime(HL.HSTDateTime),inplace=True)
HL.head()
HL.HSTDateTime=pd.to_datetime(HL.HSTDateTime)
HL.drop(columns=["DateTime"],inplace=True)
HL.head()
HighLow=HL.resample("6min").max() #resampling for 6 mins instead of 15 mins
HighLow.head()
#
HighLow["DTafter"]=HighLow.HSTDateTime
HighLow["DTbefore"]=HighLow.HSTDateTime
HighLow["HLbefore"]=HighLow["HighLow"]
HighLow["HLafter"]=HighLow["HighLow"]
#Forward and backfilling all empty tide data
HighLow.DTafter.interpolate(method="ffill",inplace=True)
HighLow.HLafter.interpolate(method="ffill",inplace=True)
HighLow.DTbefore.interpolate(method="bfill",inplace=True)
HighLow.HLbefore.interpolate(method="bfill",inplace=True)
#
HighLow["Tafter"]=HighLow.index-HighLow.DTafter
HighLow["Tbefore"]=HighLow.index-HighLow.DTbefore
```

```
#Creating a time before or after low tide column
HighLow["Tlow"]=HighLow.Tafter[HighLow.HLafter=="L"]
HighLow["Tlow"].loc[HighLow.HLbefore=="L"]=HighLow.Tbefore.loc
[HighLow.HLbefore=="L"]
HighLow.Tlow.interpolate(method="ffill",inplace=True)
HighLow.head()

HighLow.interpolate(method="bfill",inplace=True)
HighLow.tail()
HighLow.head()
HighLow.drop(columns=["HSTDateTime"],inplace=True) #removing unwanted columns
HighLow.drop(columns=["Predict"],inplace=True)
HighLow.drop(columns=["HighLow"],inplace=True)
HighLow.drop(columns=["DTafter"],inplace=True)
HighLow.drop(columns=["DTbefore"],inplace=True)
HighLow.drop(columns=["HLbefore"],inplace=True)
HighLow.drop(columns=["HLafter"],inplace=True)
HighLow.drop(columns=["Tafter"],inplace=True)
HighLow.drop(columns=["Tbefore"],inplace=True)
HighLow=HighLow.resample("15min").nearest()
HighLow.head()

#combining datasets
wtwaveswatideHL=pd.concat([watertemp,waves,windair,tide,HighLow],axis=1)
wtwaveswatideHL.head(30)
wtwaveswatideHL.tail(30)

riv=pd.read_csv("/Users/swaiki/Desktop/River.csv") #importing dataset
riv.head()
#setting index to date time
riv.set_index(pd.to_datetime(riv.DateTime),inplace=True)
riv.head()
riv.drop(columns=["DateTime"],inplace=True) #removing unwanted columns
riv.drop(columns=["Discharge"],inplace=True)
riv.drop(columns=["Gage height"],inplace=True)
riv.head()
river=riv.resample("15min").mean() #resampling dataset to 15 min intervals
river.head()

wtwaveswatideHLriver=pd.concat([watertemp,waves,windair,tide,HighLow,river]
                             ,axis=1) #combining datasets
wtwaveswatideHLriver.head(50)
wtwaveswatideHLriver.head()
wtwaveswatideHLriver.tail()
```

```
# changing column names
colnames=["Date","Temp","Precip","Press","WindDir","WindGust","WindSp"]
#importing dataset with changed columns names
rain=pd.read_csv("/Users/swaiki/Desktop/Rain.csv",names=colnames,header=0)
rain.head()
#setting index to date time
rain.set_index(pd.to_datetime(rain.Date),inplace=True)
rain.head()
rain.drop(columns=["Date"],inplace=True) #removing unwanted columns
rain.loc[rain.Precip.str[-1]=="s","Precip"]="" #replacing
rain.loc[rain.Precip=="T","Precip"]="0.005"
rain.loc[rain.WindDir=="VRB","WindDir"]=""
rain.dtypes

#changing coulmns to numeric
rain.Temp=pd.to_numeric(rain.Temp,errors="coerce")
rain.Precip=pd.to_numeric(rain.Precip,errors="coerce")
rain.WindDir=pd.to_numeric(rain.WindDir,errors="coerce")
rain.dtypes
rain.head()

#Convert to metric
rain.Temp=(rain.Temp-32)*5/9
rain.Precip=rain.Precip*25.4
rain.Press=rain.Press*25.4
rain.WindGust=rain.WindGust/2.237
rain.WindSp=rain.WindSp/2.237
rain.head()

#Fill gaps in winddir by filling down
rain.WindDir.interpolate(method="ffill",inplace=True)

#resampling dataset to 15 minute intervals
rainfall=rain.resample("15min").mean()
rainfall.head()

rainfall.Temp.interpolate(method="linear",inplace=True)
rainfall.Press.interpolate(method="linear",inplace=True)
rainfall.WindSp.interpolate(method="linear",inplace=True)
rainfall.WindDir.interpolate(method="ffill",inplace=True)
rainfall.head()

rainfall.Precip=rain.Precip.resample("15min").sum()
rainfall.head()
```

```
rainfall["TimePrecip"]=rainfall.Precip.rolling(24).sum()
rainfall.head(50)

#Fully combined timeseries data
wtwaveswatideHLriverrain=pd.concat([watertemp,waves,windair,tide,HighLow,river,
                                    rainfall],axis=1)
wtwaveswatideHLriverrain.head(80)



#Reding in Pilau-meter responses
pilau=pd.read_csv("/Users/swaiki/Desktop/Pilaumeter.csv")
pilau.head()
pilau.set_index(pd.to_datetime(pilau.Timestamp),inplace=True)
pilau.head()
pilau.drop(columns=["Timestamp"],inplace=True)
pilau.head()

#Fixing input so that only one of each region remains in the responses
pilau.loc[pilau.iloc[:,3]=="Region 1- PACRC to 1st gate at
          "Puhi Bay (Hilo side)"
          ,"Which region are you reporting from?"]="Region 1"
pilau.loc[pilau.iloc[:,3]=="Region 2- 1st gate at Puhi Bay to community tent"
          ,"Which region are you reporting from?"]="Region 2"
pilau.loc[pilau.iloc[:,3]=="Region 3- Community tent to 2nd gate at Puhi Bay
          (Middle, by side road)","Which region are you reporting from?"]=
          "Region 3"
pilau.loc[pilau.iloc[:,3]=="Region 4- 2nd gate to restrooms and parking lot",
          "Which region are you reporting from?"]="Region 4"
pilau.loc[pilau.iloc[:,3]=="Region 5- Restrooms to gate by Chock‘s",
          "Which region are you reporting from?"]="Region 5"

#Combining pilau meter responses and timeseries dataset
nui=pd.merge_asof(pilau,wtwaveswatideHLriverrain,left_index=True
                  ,right_index=True)

#Creating new column TimeDif
nui["TimeDif"]=nui.index.to_series().diff()

nui["Hour"]=nui.index.to_series().dt.hour+nui.index.to_series().dt.minute/60

#Creating a new column for time before and after low tide in hours
nui["TimeLow"]=abs((nui.Tlow.dt.days+nui.Tlow.dt.seconds/(24*3600))*24)
```

```
#Creating new smell column in dataset and determing the category they belong
#in
nui["Smell"]="Good"
nui.loc[nui.iloc[:,4]=="Fishy","Smell"]="Fishy"
nui.loc[nui.iloc[:,4]=="Sewage","Smell"]="Sewage"
nui.loc[nui.iloc[:,4]=="Sulfur","Smell"]="Sewage"
nui.loc[nui.iloc[:,4]=="A bad smell I cannot describe","Smell"]="Sewage"
nui.loc[nui.iloc[:,4]=="Exhaust","Smell"]="Exhaust"
nui.loc[nui.iloc[:,4]=="Exhaust/gas","Smell"]="Exhaust"

#Grouping 2 different options into one
nui.loc[nui.iloc[:,6]=="18-28 years old","What is your age?"]="18-29 years old'
nui.loc[nui.iloc[:,6]=="19-29 years old","What is your age?"]="18-29 years old'

#Finding dups
#nui[nui.TimeDif<"00:05:00"]

#Stats
from scipy.stats import pearsonr
import numpy as np

#Sewage smell correlation
st=nui[nui.Smell=="Sewage"]
st.drop(st.columns[-1],axis=1,inplace=True)
st.drop(st.columns[0:5],axis=1,inplace=True)
st.drop(st.columns[1:8],axis=1,inplace=True)
st.drop(["Tlow"],axis=1,inplace=True)
st.drop(["TimeDif"],axis=1,inplace=True)

#Correlation between severity of sewage smell and all enviro variables
st.corr(method=lambda x,y:pearsonr(x,y)[1])-np.eye(len(st.columns)) #p values

st.corr(method="pearson") #r values

#Fishy smell correlation
fi=nui[nui.Smell=="Fishy"]
fi.drop(fi.columns[-1],axis=1,inplace=True)
fi.drop(fi.columns[0:5],axis=1,inplace=True)
fi.drop(fi.columns[1:8],axis=1,inplace=True)
fi.drop(["Tlow"],axis=1,inplace=True)
fi.drop(["TimeDif"],axis=1,inplace=True)

#Correlation between severity of fishy smell and all enviro variables
fi.corr(method=lambda x,y:pearsonr(x,y)[1])-np.eye(len(fi.columns)) #p values

fi.corr(method="pearson") #r values
```



```
#Good smell correlation
Go=nui[nui.Smell=="Good"]
Go.drop(Go.columns[-1],axis=1,inplace=True)
Go.drop(Go.columns[0:5],axis=1,inplace=True)
Go.drop(Go.columns[1:8],axis=1,inplace=True)
Go.drop(["Tlow"],axis=1,inplace=True)
Go.drop(["TimeDif"],axis=1,inplace=True)

#Correlation between severity of good smell and all enviro variables
Go.corr(method=lambda x,y:pearsonr(x,y)[1])-np.eye(len(Go.columns)) #p values

Go.corr(method="pearson") #r values
```

Appendix C. *Pilau*-meter responses, response count and percent

Pilau-meter Questions	Response	Percent	Count
Your observation takes place during what day? (Month)	June	38.8	33
	Feburary	29.4	25
	March	16.5	14
	January	12.9	11
	August	1.2	1
	April	1.2	1
Your observation takes place at what time? (24 Hour time)	11	17.6	15
	12	16.5	14
	16	9.4	8
	10	8.2	7
	15	5.9	5
	6	5.9	5
	9	4.7	4
	13	4.7	4
	19	4.7	4
	14	3.5	3
	8	3.5	3
	20	2.4	2
	7	2.4	2
	21	2.4	2
	3	2.4	2
	22	2.4	2
	4	1.2	1
	18	1.2	1
	17	1.2	1
What are the environmental conditions like at the time you are completing this survey?	Sunny	35.3	36
	Overcast/Cloudy	25.5	26
	Low tide	17.6	18
	High tide	11.8	12
	Windy	4.9	5
	Rainy	3.9	4
	Slight breeze	1.0	1
Which region are you reporting from?	Region 2	54.8	46
	Region 3	20.2	17
	Region 1	17.9	15
	Region 4	3.6	3
	Region 5	3.6	3
What type of smell is it?	Good	65.5	55
	Fishy	16.7	14
	Sewage	13.1	11
	Exhaust	4.8	4
How severe is the smell?	1	54.8	46
	2	26.2	22
	3	10.7	9
	4	4.8	4
	5	1.2	1

Appendix D. *Pilau*-meter participant demographics

Demographics	Repsonse	Percent	Count
What is your age?	18-29 years old	76.9	50
	30-39 years old	15.4	10
	40-49 years old	4.6	3
	50+ years old	3.1	2
Where do you live? (Please select the best description.)	Local to Hawaiʻi Island (excluding Keaukaha community)	59.1	39
	Out of State/ Country	21.2	14
	Keaukaha Community	15.2	10
	Neighbor Island	4.5	3
How often do you go to Puhi Bay?	Once or twice a week	60	30
	Once every year	14	7
	Every other week	10	5
	Once a month	10	5
	Once every 3 months	6	3
What brings you to Puhi Bay?	Diving	46.7	21
	Swimming	35.6	16
	Fishing	6.7	3
	For picnic	2.2	1
	Whale/ dolphin watching	2.2	1
	Hang out	2.2	1
	Cruising	2.2	1
	Lounging	2.2	1
If you selected "Working" as your answer to the question above, what is your occupation?	Fisherman		1
	Security guard		1
What is your educational level?	University- Undergraduate	52	26
	University- Graduate	18	9
	Community College	16	8
	High School	14	7