Introduction

The island of Oahu is naturally boarded by a coral fringed reef and lined with both natural and manmade watersheds beginning at the top of the mountains to the mouth of the stream which leads into the ocean. The increase of human population as well as the human activity and industry has been a leading cause in the degradation of the island's marine life and overall water quality. This is especially so in the nearshore environment and embayments (Wolanski, E., Martinez, J. A., & Richmond, R. H. 2009). Over the decades, the onset of urbanization has increased along the coasts up into the valleys of Oahu. This contributes to nonpoint source pollutants (NPS), which is pollution that comes from multiple sources, rather than one specific point. These NPS pollutants flow into the watersheds, and discharge into the ocean, especially during heavy precipitation. These streams consist of both perennial and intermittent streams lined along the island. Perennial streams are defined by its continuous flow of water year round while intermittent streams flow during rainy seasons such as the winter and spring, and there is an absence of water during dry seasons (Environmental Protection Agency, 2017).

Since human activities within the coastal regions heavily affect the watersheds, this demands the study of quantifying the impact of watershed urbanization on coral reefs. Both physical and biological processes affect coral reef degradation, but there is a lack of data quantifying the link between watershed development and coral reef degradation. By focusing on the watersheds' pollutant contribution to the coastal region, there may be a clearer understanding and available data to the decline in ocean water quality due to watershed urbanization. Maunalua Bay is one example of an impaired body of water due to it's watershed pollutants in Hawaii

(Wolanski, E. et al, 2009). The question I asked is, "How do the nutrient loads compare among perennial and intermittent streams of Maunalua Bay?" Both types of streams, whether flowing or not, contain freshwater that carries nutrients, bacteria, algae, and sediment which then flow into the ocean.

A previous study was conducted on the comparison of nutrient retention in perennial streams and intermittent streams. Within a span of two years, nutrient levels for both types of streams were assessed seasonally, annually, and inter-annually. The researchers predicted that the intermittent streams would have a higher nutrient retention than the perennial streams due to the effect of droughts on biological communities responsible for nutrient uptake. In the end, the study found that variability in nutrient retention was not greater in the intermittent stream, suggesting a high resilience of biological communities responsible for nutrient uptake. However, their findings pointed to the heavy impact local climate conditions and land use has on nutrient retention in stream ecosystems (Schiller, D. V., Martí, E., Riera, J. L., Ribot, M., Argerich, A., Fonollà, P., & Sabater, F. 2008). Similarly, the water quality of Maunalua Bay has been in decline with the increase in human activities, urban planning and development strategies, and insufficient resources and management. As for Hawaii's climate regime, the islands receive the heaviest rains from winter storms between October to April. Not only that, but Hawaii is predicted to have more short periods of heavy rainfall, increasing the watersheds activities throughout the seasons (NOAA, 2018).

Studies specifically pertaining to Maunalua Bay have also been reviewed such as the mercury dynamics within the coastal region and its effects, sources, and movement. This study allowed researchers to consider the influence of groundwater-seawater interaction on mercury dynamics in coastal waters since Maunalua Bay has been impacted by urban development (Ganguli, P. M., Swarzenski, P. W., Dulaiova, H., Glenn, C. R., & Flegal, A. R. 2014). It is important to consider other areas of pollutants other than watersheds in Maunalua bay that can affect the ocean water quality. Another project studied the necropsy and liver histopathology of 100 fish collected and autopsied in Maunalua Bay to assess if there was an impact by periodically monitoring the captured fish that lived in the sewage discharged. The researchers looked for liver neoplasms and pre-neoplastic changes within the fish but found no significant damage (Brock, J.A. 1994). Although there was no signs of damage from sewage to fish, this was done in 1995, many years before Maunalua Bay was found to be impaired. Now that over 23 years have passed, this may change the results and the biological health of the fish in Maunalua bay can be significantly different now.

The biostratinomy, the study of an organism after it dies but before its complete burial, of minute aquatic crustaceans, from a small reef flat in the bay was also studied to better understand the sedimentation and the remains of organisms in Maunalua Bay (Izuka, S. K., & Kaesler, R. L. 1986). Much of this journal contained detailed information on the environmental setting of Maunalua bay which helped understand the reef composition, rainfall patterns, and tide in the area for my research. Although these sources held valid and important information regarding Maunalua Bay's water quality, none contained information on the nutrient outputs from watersheds and a few agreed that there was a lack of data in this area of study. The most relatable to my study was done during the summer of 2017 which assessed the overall water quality of Maunalua Bay and the reasons for its rapid decline over the decades along with possible solutions and projects to help restore the body of water (Corey, K., Lariosa, K., Markel, A., Torigoe, S., & Wehr, N. 2017). This scholarly project was published by the Natural Resources and Environmental Management branch of the University of Hawaii. They sampled the mouths of multiple watersheds along the bay for nutrient levels during the summer. However, this study avoided two intermittent streams because there was a lack of water during that time. Overall, there is not data prior to my project that has tested the nutrient levels of these two intermittent stream mouths of Maunalua Bay: Wailupe and Pia stream. As previously mentioned, while other studies have focused on perennial streams and other biological factors in Maunalua Bay, there has been little focus on the nutrient loads of intermittent streams and how their intermittent flow impacts the environment. If there are significant amounts of nutrients in the intermittent streams compared to the perennial streams that were tested previously, monitoring and action can be emphasized for intermittent streams during heavy rainfall. If the nutrient in these intermittent streams come from NPS during heavy precipitation and collect in the stream during the time it is not flowing and therefore the water is stagnant containing growing bacteria and algae, the nutrient loads may be greater in the intermittent streams: Wailupe and Pia.

The worldwide idea of the the water-energy-food nexus is another important reason to why nutrient input from streams to open waters should be better understood. Linkages between land and ocean processes in Hawaii are found between coastal watersheds, aquifers, submarine groundwater discharge, and their association with nutrient flows. Hawaii is also vulnerable to the expected sea level rise and climate variability which also affects the nutrient levels in watersheds (Endo, A., Tsurita, I., Burnett, K., & Orencio, P. M. 2017). Focusing on land-based sediment and contaminant runoff, any increase in precipitation and urbanization would mean more runoff containing pollutants in the form of nutrients to drain into the bay. Despite streams being highly dynamic ecosystems, very few studies have focused on the temporal variation of nutrient retention within streams (Schiller, D. V. et al). This emphasizes the importance of researching the source and further impacts of high nutrient levels in Maunalua Bay's overall watershed system.

Background

Watersheds are defined as catch-basins or drainage basins for rain and condensate to funnel into stream beds that either join other stream beds or drain into the sea. High nutrient levels entering the bay through watersheds have had a major impact on Hawaii's declining coral reefs. Land-based sediment and contaminant runoff flow into the ocean can prevent photosynthesis, smothers corals, and exposes the marine life to contaminants including high nutrient levels (Takesue, R. K., & Storlazzi, C. D. 2017).

Nutrient levels indirectly but significantly damage marine life because nutrients are a source for algae to photosynthesize and grow. Invasive algae such as the common *Avrainvillea amadelpha,* found in Maunalua Bay, spread rapidly throughout the coast and take over native algae. Oxygen consuming bacteria feed off of the abundant algae and the dissolved oxygen level goes down, leaving less oxygen for other marine organisms. Past research projects have tested the nutrient levels of perennial streams, but there is a lack of nutrient testing on intermittent streams and research journals have concluded that more information on nutrient-related environmental problems is needed (Schiller, D. V. et al).

In 1855, there was little to no human settlement along the coast of the bay. During this time, the reef crest was near the ocean's surface and there was a large lagoon, currently a marina, on the east side of the bay called Kuapa Pond. Since the peninsula separating the lagoon from the reef flat was too narrow, there was no human settlement in this area. However, a large fish pond was created the same year near the mouth of Wailupe stream. By 1900, mangroves and halophytes finged the pond and more man-made fish ponds were present as well. In 1927, the seasonal wetlands fringing Kuapa Pond was used as pastures as there was a dairy farm in Aina Haina but human settlement was still low. Not until the 1960s, there was a rapid increase in urbanization. During this time, two navigation channels traversed the bay; one on the east side of the bay and another in the central region near the Wailupe stream mouth. Kuliouou stream that once discharged into Paiko Lagoon now flowed directly into Maunalua Bay. Now all of the coastal region and surrounding hills along the bay have been entirely urbanized and the surface area of Kuapa Pond was decreased by 30% when urbanized into a marina. Many of the streams were also channelized and lined with concrete. New houses were built and even to this day, more are being constructed on steep and highly erodible slopes with flimsy sediment curtains being used for mitigation. During heavy rainfall where there are runoff events, the curtains quickly fold and fail to trap sediment and is therefore caught in the watersheds (Wolanski, E. et al, 2009).

Eventually, in the year of 2002, the water quality of Maunalua Bay did not meet the required parameters of a healthy body of water and was therefore deemed an impaired body of water by the State of Hawaii's Department of Health (Department of Health 2006, Malama Maunalua, 2009). The State uses a tiered system based on risk to determine which beach waters to sample. The six inspectors for the state Department of Health's Clean Water Branch test for bacterial indicators, nutrients and geochemical parameters e.g. pH, temperature and turbidity.

Methods

Four streams were chosen from the ten watersheds of Maunalua Bay. These watersheds were determined by the Hawaii Division of Aquatic Resources and published the description of each watershed in the Hawaii Watershed Atlas including their stream type classification. Two of the streams were identified as perennial, consistently flowing throughout the year. Two more were identified as intermittent, flowing periodically based on season and precipitation (Parham, J. E, 2008). Starting at the westmost point to eastmost point, Waialae stream was perennial, Wailupe stream was intermittent, Niu stream was intermittent, and Kuliouou was perennial (See in Fig. 1). In summary, both intermittent streams were located between the two perennial streams in Maunalua Bay. Two more sites were determined approximately 250 yards directly from the mouth of the intermittent stream into the bay. This method of testing further out into the bay was based off of the previous study on Maunalua Bay by the University of Hawaii where they intended to see how present the nutrient levels were dispersed from the stream mouths. Their study also tested the nutrient levels of the perennial stream mouths, Waialae and Kuliouou.

Fig. 1 Stream Mouth and 250 yard approximations for perennial and intermittent streams.

Both chosen perennial streams could be accessed by a public park situated along the stream mouth. The intermittent stream mouths needed to be accessed by kayak because no other convenient public access points from land could be found near Wailupe stream or Pia stream.

The YSI ProDSS Multiparameter Water Quality Meter was used at the sites to find basic water parameters including the following: temperature (ºC), mercury (mmHg), dissolved oxygen percentage, total dissolved solids (mg/L), salinity (ppt), pH, Oxidation-reduction potential (mV), turbidity (NTU). The tide level (ft) and precipitation level (in) was found on online databases for public use. These measurements are components that were used to justify nutrient level findings and better understand each stream mouth environment. At each site, the YSI probe was slowly lowered into the water and left to stabilize for no less than a minute.

The nutrient levels of nitrate and phosphate were tested using the LaMotte Smart3 Colorimeter.

At the five test sites, the YSI was used first and then the water samples were collected in 10 mL brown plastic bottles that were previous acid washed to avoid contamination. Each sample bottle was rinsed with clean water three times, acid washed once, and rinsed with ultra pure water before being used to collect a sample. The bottles were brown to prevent light from coming through and allowing the algae that may have been inside to photosynthesize. The water samples were kept in a cooler or refrigerator when not being sampled and every sample was tested within 24 hours.

Data Analysis

After collecting three rounds of water samples, and testing for nitrate and phosphate levels, the nutrient levels were recorded as well as basic water parameters: salinity, temperature, dissolved oxygen, time, tide, and the composition of the stream bed. There was a total of 6 sites tested.

The first round was conducted on December 23, 2017. The nitrate levels in µmol/L were found for all six as the following: Waialae stream mouth: 2.42, Kuliouou stream mouth: 3.23 (Perennial streams). Wailupe stream mouth: 4.03, Pia stream mouth: 2.85 (Intermittent streams). The two sites tested approximately 250 yards from the mouth of both intermittent streams read 0.14 for both of the sites 250 yards from Niu and Wailupe stream mouth into the ocean.

The second round of testing for nitrates on January 21, 2018 was found for all six sites as the following: Waialae stream mouth: 1.78, Kuliouou stream mouth: 1.94 (Perennial streams). Wailupe stream mouth: 0.81, Pia stream mouth: 5.48 (Intermittent streams). The 250 yard sites read 0.07 for Niu and 0.12 for Wailupe.

The third round of testing for nitrates on March 4, 2018 was found for all six sites as the following: Waialae stream mouth: 1.45, Kuliouou stream mouth: 2.74, (Perennial streams). Wailupe stream mouth: 1.45, Pia stream mouth: 1.61. The two approximated 250 yard test sites were 2.26 for Pia and 1.94 for Wailupe.

Coming back to the first round of testing, phosphate levels were also found and recorded for all six sites and are the following read in µmol/L: Waialae stream mouth: 3.05, Kuliouou stream mouth: 1.68 (Perennial streams). Wailupe stream mouth: 1.58, Pia stream mouth: 1.68 (Intermittent streams). The two sites tested approximately 250 yards from the mouth of the intermittent streams read 0.12 for Pia and 0.07 for Wailupe.

The second round of testing for phosphates continue as the following: Waialae stream mouth: 1.79, Kuliouou stream mouth: 3.47 (Perennial streams). Wailupe stream mouth: 1.68, Pia stream mouth: 2.0 (Intermittent streams). The two sites tested approximately 250 yards from the mouth of the intermittent streams read 0.04 for Pia and 0.05 for Wailupe.

The third round of testing for phosphates continue as the following: Waialae stream mouth: 2.98, Kuliouou stream mouth: 1.84 (Perennial streams). Wailupe stream mouth: 4.86, Pia stream mouth: 5.42. The 250 yard approximation sites for phosphates were 0.67 for Pia and 4.43 for Wailupe.

As for the tide when testing at each specific site, both rounds of testing were consistent in tide levels. For the perennial streams, Waialae and Kuliouou, the samples were collected during high tides all within 1.44-1.83 feet. The intermittent streams were all collected at low tide within 0.21-0.30 feet. There was no positive or negative relationship between tide level and nutrient level that was statistically significant.

The recorded salinity levels at each site on both rounds fluctuate greatly. Round one on December 23, 2017 for Waialae, Kuliouou, Pia, and Wailupe were 24.29, 15.15, 24, and 28.35 in parts per thousand (ppt) respectably. The second round of testing with salinity on January 21, 2018 for Waialae, Kuliouou, Pia, and Wailupe were 21.88, 32.21, 31.26, and 33.88 respectably. Similar to tide levels, there was no significant relationship between salinity level and nutrient level.

Table of water quality measurements in Maunalua Bay

Site	Date	Time	Test	Salinity ppt	Tempera ture ºC	Tide ft	DO %	Nitrate µmol/L	PO4 µmol/L
Kuliouou Mouth	12/23/17	8:21	1	15.15	19.6	1.65	76.7	3.23	1.68
	1/21/18	6:56 AM	2	34.21	22.8	1.72	74.2	1.94	3.47
	3/4/18	7:38 AM	3	30.19	21.4	1.01	59.1	2.74	1.84
			AVE	26.52	21.27	1.46	70.00	2.64	2.33
			STDEV	10.05	1.60	0.39	9.52	0.65	0.99

Waialae Mouth	12/23/17	9:07 AM	1	24.29	22.4	1.44	32.2	2.42	3.05
	1/21/18	6:24 AM	2	21.88	22.4	1.83	85.3	1.78	1.79
	3/4/18	7:18 AM	3	24.57	21.4	1.13	62.2	1.45	2.98
			AVE	23.58	22.07	1.47	59.90	1.88	2.61
			STDEV	1.48	0.58	0.35	26.62	0.49	0.71
Pia Mouth	12/23/17	2:51 PM	1	24	22.6	0.21	68	2.58	1.68
	1/21/18	2:53 PM	2	31.26	24.9	0.25	95.3	5.48	2
	3/4/18	10:58 AM	3	28.45	22.4	-0.09	78.4	1.61	5.42
			AVE	27.90	23.30	0.12	80.57	3.22	3.03
			STDEV	3.66	1.39	0.19	13.78	2.01	2.07
Wailupe Mouth	12/23/17	3:28 PM	1	28.35	24.6	0.23	133.9	4.03	1.58
	1/21/18	3:22 PM	2	33.88	27.3	0.3	154.3	0.81	1.68
	3/4/18	11:42 AM	3	29.25	23.2	-0.12	81.2	1.45	4.86
			AVE	30.49	25.03	0.14	123.13	2.10	2.71
			STDEV	2.97	2.08	0.23	37.72	1.70	1.87

Fig. 2 Water parameter measurements, averages, and standard deviation from YSI probe for each site and all three test days.

Variance of Nitrate and Phosphate Levels at Maunalua Bay Stream Mouths

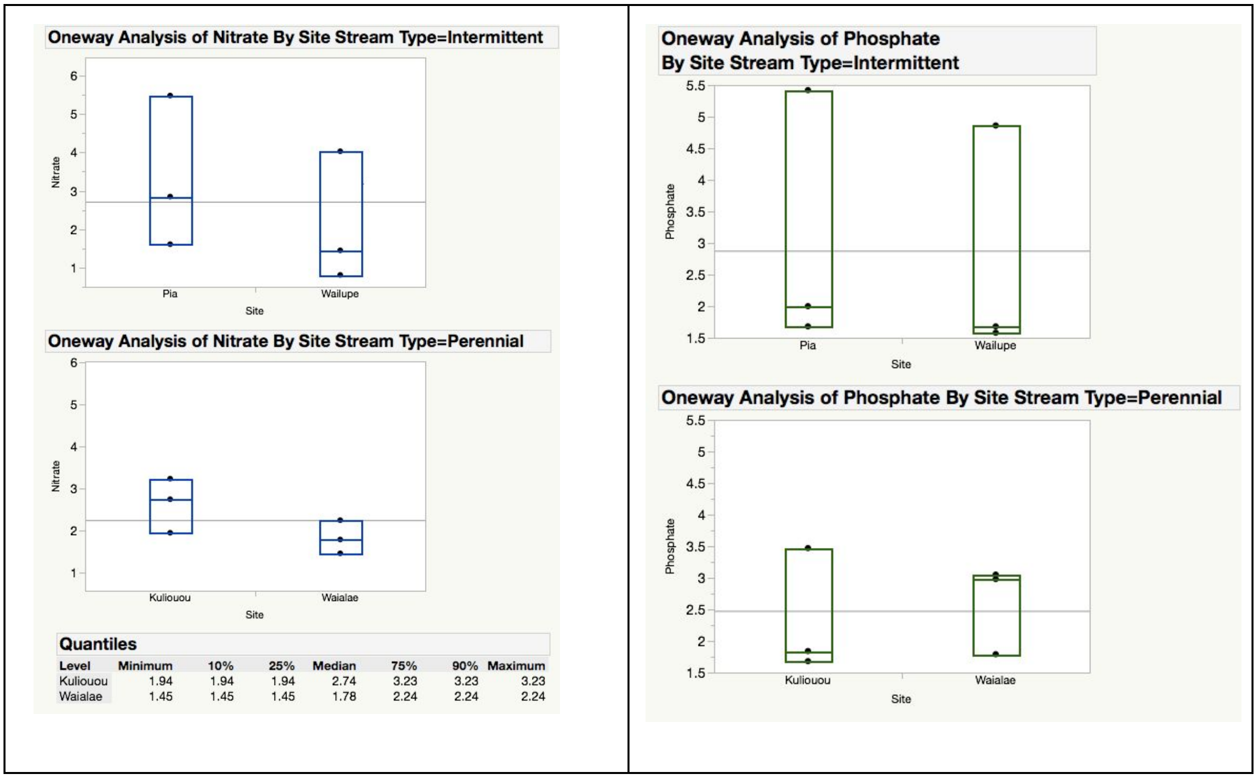

Fig. 3 Variance chart of nitrate levels in µmol/L for each site by stream type (left) Variance chart of phosphate levels in µmol/L for each site by stream type (right).

Discussion

Returning to my original research question, "How do the nutrient loads compare among perennial and intermittent streams of Maunalua Bay?" I predicted that the nutrient levels would be greater in the intermittent streams than the nutrient levels in perennial streams. I will draw interpretations based on my data.

Looking at the first round of testing, the highest level of nitrate was Wailupe stream mouth as 4.03 µmol/L, an intermittent stream, and Waialae stream mouth, a perennial stream, was lowest in nitrate as 2.42 µmol/L. However, looking at phosphate levels, the results were reverse. Waialae contained 3.05 µmol/L of phosphate, the highest of all four sites and the lowest in phosphate was Wailupe, 1.58 µmol/L. These comparisons exclude the two sites tested 250 yards from shore as they are not relevant in directly comparing the nutrient inputs at the mouth of streams.

Looking at the second round of testing, the highest level of nitrate was Pia at 5.48 µmol/L, the other intermittent stream and lowest was found to be Wailupe, 0.81 µmol/L which was the highest in the first round. The highest in phosphate for the four sites was the perennial stream mouth of Kuliouou as 3.47 µmol/L and the lowest was the intermittent stream mouth of Wailupe at 1.68 µmol/L.

Finally, the third round of testing contained the highest level of nitrate was Kuliouou at 2.74 µmol/L and lowest at Waialae and Wailupe which were both 1.45 µmol/L. The highest in phosphate was Pia at 5.42 µmol/L and the other intermittent stream Wailupe closely behind as 4.43 µmol/L. Both were the highest phosphate readings among all three test rounds.

Variance charts were made for the four stream mouth sites and their nutrient levels for both nitrate and phosphate. There was a greater variance in both nitrate and phosphate levels for intermittent streams in comparison to the small variance in nitrates and phosphates for perennial streams.

Based off of my three rounds of testing, my hypothesis is supported. The highest level in nitrate and phosphate was found in the intermittent streams. However, low levels were also found in the intermittent streams on the two other test days.

The environment around each stream could also affect the nutrient levels of each stream and its specific nutrient. For example, ammonia retention is normally expected to be less likely influenced by changes in environmental variables and therefore less variable than soluble reactive phosphorus (Daniel von Schiller et al, 2008). In the same study, ammonia was positively correlated with soluble reactive phosphorus yet consistently higher and reached a maximum value during the wet period. However, both phosphorus and ammonia increased with discharge following power functions, or a significant change in climate or rainfall. One major difference between the perennial and intermittent streams was ammonia in which it was greater in perennial than intermittent streams. One reason for this would be the relatively high dissolved inorganic nitrogen (DIN) and low soluble reactive phosphorus (SRP) availability in the intermittent stream indicative of a lower potential for nitrate limitation.

Based off of the environment of streams, the sites highest in nitrates support the idea that fertilizers, animal waste, and pollution are in the runoff of the streams which contribute to the high nutrient levels. Aina Haina and Niu Valley, the residential areas associated with the intermittent streams, Wailupe and Pia are densely populated and its environment is suited for high nitrate retention, the ability to hold nutrients within its properties, in its urban area. A probable reason for the high phosphate levels in the perennial streams could be caused by the fertilizer used in the Kahala Golf Course which is aligned on the side of the Waialae stream. The Kuliouou stream is also situated right in front of the Paiko Lagoon Wildlife Fish Sanctuary, contributing to the phosphate and nitrate levels. Between the two intermittent streams, Pia had the highest nitrate and phosphate levels: 5.48 μmol/L and 5.42 μmol/L.

The precipitation of 1.69 inches of rain about an hour before my second round of testing could have also caused the nutrient levels to change because the nutrients could have been washed farther into the water and no longer stayed at the mouth of the stream when the samples were collected such as Wailupe. Another possibility would be that the nutrients could have been high at the mouth after the rainfall because it was sampled right at the moment where nutrients collected at the mouth before being dispersed into the ocean. In conclusion, my data supports the idea that nutrient levels vary on stream type and there is a correlation in the stream type with the type of nutrient being tested.

Tide level may also be a contributing factor for the nutrient results. Since both perennial streams samples were always collected during high tide, there could be an indirect relationship between tide and nutrients. In other other words, when the tide is high, nutrient levels may typically be lower and when the tide is lower, nutrient levels may be higher.

My data suggest that perennial streams in the Maunalua watershed system have consistent nutrient retention in the rainy seasons in comparison to the intermittent streams. Nitrate and phosphate levels for the perennial streams would be easier to predict because there was a small variance range compared the the range in the intermittent streams. Predicting the nutrient levels for the intermittent streams during this season would be harder because each round of test results are inconsistent and therefore there is a wider variance range for the intermittent streams.

Understanding the temporal variation of nutrients within intermittent streams can lead to better management and restoration plans because a large source of total nutrient input comes from the intermittent streams within the season of testing. If a pattern can be found in nutrient discharge and it can be predicted when these levels are expected be highest, runoff prevention and control measures can alleviate further degradation to Maunalua Bay’s reef and coral reefs impacted from runoff can recover. More remediation strategies can also be explored once hydrodynamic controls of nearshore pollutant transport is understood. Due to the expectation of Hawaii to have more precipitation in the upcoming years, watershed systems will be more active in transporting runoff water containing pollutants into the ocean. There are many other coastal regions facing the same problem such as Kaneohe Bay, where the coast is lined with watersheds that discharge runoff water in large volumes that the bay may not be able to keep up with. Overall, this study emphasizes the significance of local climate conditions in regulating nutrient retention and points to potential effects of changes in land use and climate regimes on the functioning of stream ecosystems in Hawaii.

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