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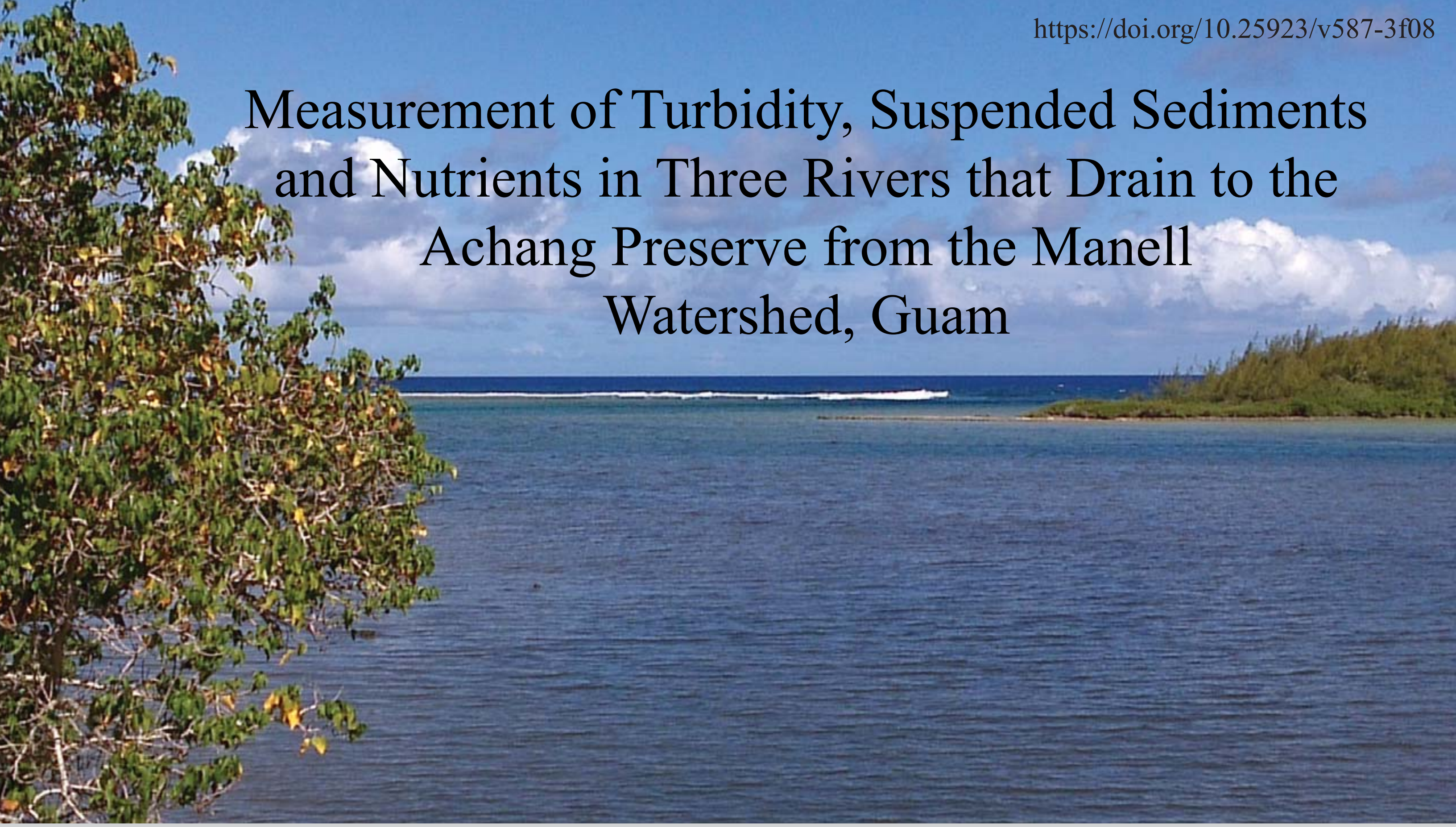

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Measurement of Turbidity, Suspended Sediments and Nutrients in Three Rivers that Drain to the Achang Preserve from the Manell Watershed, Guam

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ABSTRACT

The goal of this project, funded by NOAA's Coral Reef Conservation Program and requested by local partners, was to monitor water quality in three rivers that drain to the Achang Reef Flat Marine Preserve at the southern tip of Guam, in order to provide a baseline of conditions for environmental managers. The spatial and temporal variation of turbidity, suspended sediment concentration (SSC), and nutrients were determined at sites on the Ajayan, As Liyog, and Sumay rivers.

Using Guam EPA water quality standards, SSC and turbidity in the rivers were generally classified as excellent to good, although occasionally the waters were ranked as fair, particularly on the As Liyog River during higher rainfall. Overall, nitrate was found to be in the excellent range, and orthophosphate generally in the good to fair range.

There was some evidence that a number of the parameters showed decreasing trends in concentration during the project. Further monitoring would help determine if these decreases are real, which could be an indication of the benefits of the ongoing restoration activities in the watershed, evidence of natural revegetation subsequent to wildfires, or a combination of both. In any case, additional restoration efforts along with public education and outreach would be helpful to further reduce runoff to the rivers that drain to the Achang Reef Flat Marine Preserve.

Figure 1. The island of Guam.

INTRODUCTION

Guam is the most southerly and largest (both in area and population) member of the Mariana Islands, a crescent-shaped archipelago in the western North Pacific Ocean. The Mariana Island chain extends from Guam towards Japan, and is part of the larger island group referred to as Micronesia. The island of Guam has a land area of approximately 550 square kilometers, and a maximum altitude of 406 meters (Emery, 1962). The capitol of Guam is Hagåtña, located towards the middle of the island (Figure 1).

The northern half of Guam is a broad limestone plateau bordered by steep cliffs, while the southern half of the island is a dissected volcanic upland fringed with limestone, primarily along the east coast (Tracey *et al*., 1964). At the southern tip of Guam is Cocos Lagoon (Figure 1), an atoll-like coral reef lagoon. Geologically, Cocos Lagoon is thought to have grown on the basement of the Umatac formation, a thick sequence of volcanic rock which occupies the southern central portion of Guam, and named after the town of Umatac on the west coast of the island (Tracey *et al*., 1964).

Manell Watershed

The Manell and Geus watersheds on the northeastern border of Cocos Lagoon were designated as a Habitat Focus Area for NOAA's Habitat Blueprint, and the watersheds and lagoon are a NOAA Coral Reef Conservation Program

(CRCP) priority for Guam. A map of the Manell and Geus watersheds can be seen in Figure 2. In 1997, a network of marine preserves was established in Guam in response to decreasing nearshore fish stocks (NOAA, 2007). The Achang Reef Flat Marine Preserve (Figure 2), located on the eastern end of Cocos Lagoon, was established by the Division of Aquatic and Wildlife Resources of the Guam Department of Agriculture.

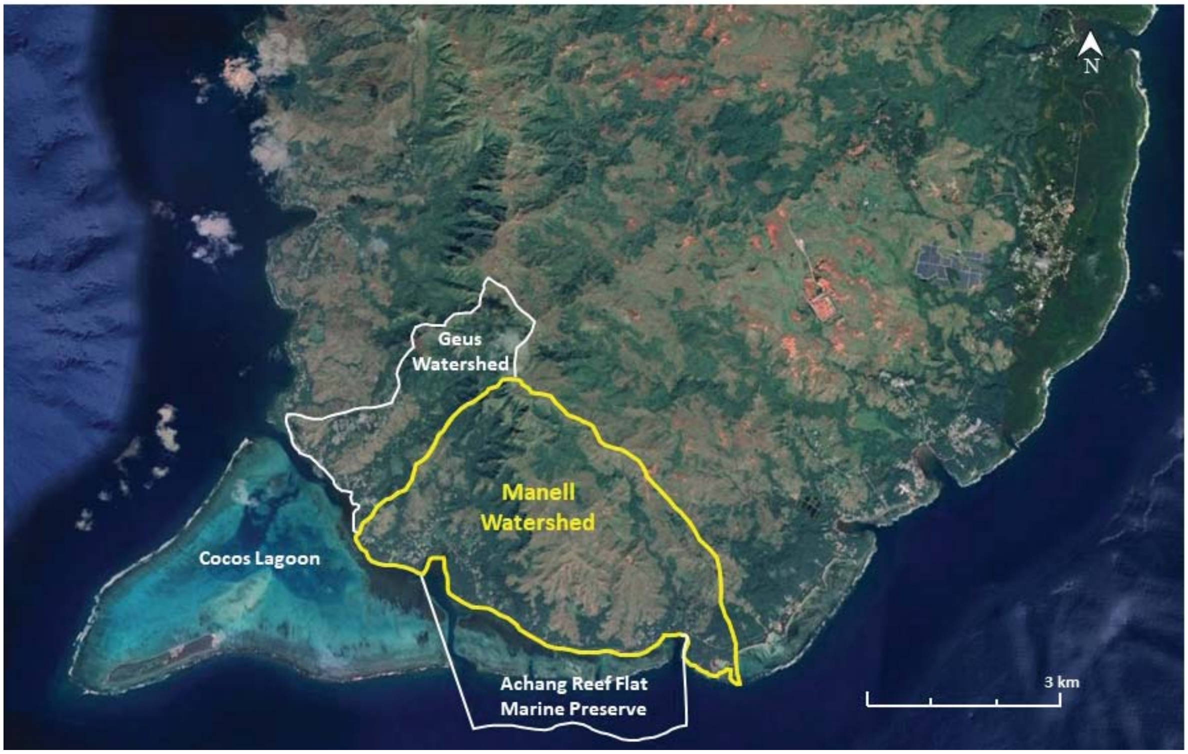

Figure 2. Boundaries of the Manell watershed, along with the Geus watershed and the Achang Reef Flat Marine Preserve.

There are extensive patch reefs and seagrass beds within Cocos Lagoon, and seagrass beds are abundant in the shallow waters of the Achang Preserve. The seagrass beds in the Preserve provide valuable nursery habitat for a variety of fish and are an important habitat for green and hawksbill sea turtles. Since the establishment of the Preserve, fish stocks have increased there by 115%, while surveys at comparison sites outside the Achang Preserve in Cocos Lagoon have shown a further 4% decrease (Porter *et al*., 2005).

The watersheds incorporate some interesting landscapes, resulting from the geological formation of the island. The geomorphology of southern Guam with a narrow limestone fringe along the coast, has a volcanic origin that has resulted in steep hills within the watersheds (Tracey *et al*. 1964). Behind the coastal plain, elevations rise rapidly to over 400 meters. The tallest peak in Guam is Mount Lamlam at 406 meters, which is within 2 km of the coastline in the southwest part of Guam, near the town of Agat (Figure 1).

Table 1. Land use in the Manell watershed.

Land Use	%	km^2
Urban	23.4	2.76
Forest	33.2	3.91
Burned	4.22	0.50
Barren	0.77	0.09
Grassland	37.6	4.43

From: Wen *et al*., 2009

The Manell watershed (Figure 2) has an area of approximately 11.8 square kilometers. The adjacent Geus watershed has an area of approximately 4.5 square kilometers. In the Manell watershed, Mount Sasalaguan, is within 2.5 km of the coast, and has an elevation of 337 meters.

The Manell watershed contains a variety of land uses including grassland, forest, and urban areas (Table 1). Grassland savanna with steep slopes comprise the highest land use, while forested areas are limited to ravines (EA Engineering, 2014). An image of the Manell watershed taken from the Achang Reef Flat Marine Preserve can be seen in Figure 3.

From the watershed, a series of rivers flow into the Achang Preserve including the Ajayan, As Liyog, and Sumay rivers, which are the focus of this report. Urban areas comprise approximately 23 percent of the land use in the watershed. The municipality and town of Merizo (Figure 1) is located within the Manell and Geus watersheds. The population of Merizo was 1,850 in 2010 (Guam Bureau of Statistics and Plans, 2011). Tourism accounts for roughly 60% of the economy in Guam (NOAA, 2007), and tourism is also important in Merizo.

Within the watershed, grazing by feral animals, off-roading vehicles, and in particular wildfires, promote erosion of soils from the steep hillsides and along stream banks.

Wildfires are a constant threat in the Manell watershed, and burning the grasslands leaves the soil bare, facilitating erosion. The fires also inhibit the growth of trees and shrubs that would hold the soil and absorb rainfall. Many of the fires are reportedly caused by arson, set by poachers for the purpose of encouraging the emergence of new grasses for grazing by Philippine deer and feral pigs which are hunted (EA Associates, 2014). Winds exacerbate the destruction caused by the wildfires. The dry season on Guam occurs from December to April, which also has some of the higher average wind speeds (~14 km/hour).

Within the watershed, high velocity runoff events of relatively short duration are frequent in the mountainous areas of southern Guam. Increased runoff can also lead to the flooding of downstream areas. It has been estimated that in the last five years, nearly 60 percent of the residents in the town of Merizo (Figure 1) have been affected by flooding.

Figure 3. Photograph of the steep hillsides in the Manell watershed that border the Achang Reef Flat Marine Preserve.

Eroded soils from the hillsides are transported as suspended sediments to the freshwater streams and rivers in the watershed, impacting the aquatic organisms there. The sediments which are then transported out into to the Achang Preserve in Cocos Lagoon, can impact water quality in the seagrass areas and patch reefs (Khosrowpanah *et al*., 2015; NOAA, 2007). Sedimentation on coral reefs can have serious impacts (Fabricius, 2005; Burke *et al*., 2011; Waddell *et al*., 2005). The deposition of sediments in reef areas can act to smother corals and physically abrade coral tissues. At the very least, sediments deposited on corals results in the organisms having to expend more energy to remove sediment particles, meaning there is less energy available for other functions including growth and reproduction. Elevated sedimentation has been linked to less coral cover, lower diversity and recruitment, along with lower growth and calcification rates (ISRS, 2004; Rogers, 1990).

Sediments associated with runoff have been identified as one of the most significant threats to coral reef ecosystems in Guam (Burdick, *et al*., 2008). Fires, erosion and sedimentation were all identified as high threats in the Manell and Geus watersheds, and sedimentation was also identified as a high threat to coral reef ecosystems during the Manell/Geus Conservation Action Planning (CAP) Workshop (GCMP, 2013).

Nutrients originating from wildlife, septic systems and agricultural activities (crops and livestock) can also make their way into streams and rivers and out onto the Achang Preserve and the rest of Cocos Lagoon. While dissolved nutrients are essential to productivity in aquatic systems, an overabundance of nutrients can trigger macroalgae and phytoplankton blooms, resulting in degradation of water quality and habitat (Bricker *et al*., 2007). In coral reef systems, algal blooms can lead to the algae out-competing and then smothering juvenile and adult corals, ultimately resulting in the loss of those corals (D'Angelo *et al*., 2014; Box and Mumby, 2007). It has also been shown that nutrients can have direct effects on corals. Ammonium and phosphate in parts per billion (ug/l or ppb) concentrations can impact fertilization success (Harrison and Ward, 2001), while elevated nitrate has been shown to decrease calcium deposition in corals (Marubini and Davis, 1996).

A variety of watershed restoration activities have been undertaken to try and restore vegetation and reduce erosion in the upland areas in the Manell and adjacent watersheds. These include public education and outreach, planting of native species to help reduce erosion in upland areas as well as along streambanks, installation of riparian buffer strips, and removal of non-native bamboo (GCMP, 2013; EA Associates, 2014). Bamboo is specifically targeted and removed because it can block drainage culverts during storms, leading to flooding of roads and populated areas.

NOAA/NCCOS Involvement
In 2016, local resource managers reached out to NOAA's National Centers for Coastal Ocean Science (NCCOS) for help with monitoring water quality in three rivers that flow into the Achang Preserve. With funding from NOAA's CRCP, NCCOS scientists met with local resource managers and scientists from the Guam Environmental Protection Agency (Guam EPA), CRCP and NOAA's National Marine Fisheries Service Pacific Islands Regional Office, to develop a project to monitor turbidity, suspended sediments, and nutrients (e.g., nitrogen and phosphorus), for a period of two years. The goal was to assess the condition of these rivers, and establish a baseline which could then be used to assess the efficacy of planned restoration efforts within the Manell watershed.

Figure 4. Location of the monitoring sites in the Manell watershed, along with the location of the rain gauge station.

MATERIALS AND METHODS
Field sampling events occurred several times a month beginning in December 2016 through December 2018. The purpose of these field visits was to take water quality measurements, and to collect water samples for the analysis of the suspended sediments concentration (SSC) and nutrients at locations on the Ajayan, As Liyog, and Sumay rivers in the Manell watershed. Observations were also made to document weather and stream conditions. During these visits, data logger downloads and maintenance of the automated turbidity logger placed in the Ajayan River and the two instream level loggers placed in the Ajayan and the As Liyog rivers were also conducted.

In total, 76 rounds of sampling were completed over the two-year data collection period. At times, the collection of water samples could not occur because of storm events that led to flooding of the roads, making it too dangerous to travel to the sampling sites.

A map of the sample locations can be seen in Figure 4, along with the site coordinates in Table 2. The location of the rain gauge station, used to monitor rainfall for this project, is also shown in the figure and table. Towards the end of the project, a site was added on the Geus River and sampled between July 2018 and December 2018, for comparison. Below is a more detailed description of each of the sample collection and analysis techniques.

Table 2. Latitude and longitude coordinates of the sampling sites for this project.

Site Name	Latitude (DD)	Longitude (DD)
Ajayan River	13.25132	144.71881
As Liyog River	13.24716	144.70738
Sumay River	13.24800	144.70005
Geus River	13.27067	144.67933
Rain Gauge Station	13.26278	144.71761

Water Quality Field Measurements

In situ field measurements were conducted prior to each sample collection for the following water quality parameters: temperature, dissolved oxygen, specific conductance, salinity, and turbidity. To limit the influence of seawater mixing from the rising tide as much as possible, samples were collected during low tide or during a falling tide.

All water quality measurements, with the exception of turbidity, were measured using a YSI Professional Plus (Pro Plus) hand-held field instrument. Turbidity (Hach turbidity) was measured using a Hach 2100Q Portable Turbidimeter. All water quality instruments were calibrated and maintained according to the manufacturer recommendations. Water quality measurements were recorded at each sample location along with any other environmental conditions of potential significance (i.e., stream debris, weather, wildfires, etc.).

Data Logging Instrumentation

Three data logging instruments were set-up at the sites within the Manell watershed; two stream level loggers (Ajayan and As Liyog sites) and one turbidity logger (Ajayan site). In addition, a data logging rain gauge was installed in the mountain ridge upland of the Ajayan River (Figure 4).

The stream level loggers were HoboWare® U20 water level data loggers with a range of 0 to 30 ft and an accuracy of 0.015 ft. These loggers use pressure (in psi) to determine the height of the water column above. The level loggers were suspended at the bottom of PVC housings secured to the bridge abutments at Ajayan River and As Liyog River. In addition, one pressure logger was placed at a secure location outside of the water, to monitor changes in atmospheric pressure. Stream level was calculated by subtracting the atmospheric pressure from the streambed pressure readings.

A turbidity logger was deployed in the Ajayan River, within a separate dedicated PVC housing secured to the Ajayan Bridge (Figure 5). The turbidity logger was suspended in the water column approximately 0.46 m above the streambed. The turbidity logger was a Manta 2 water quality logging sonde with a turbidity sensor equipped with a self-cleaning wiper. The As Liyog River was too shallow for a turbidity logger.

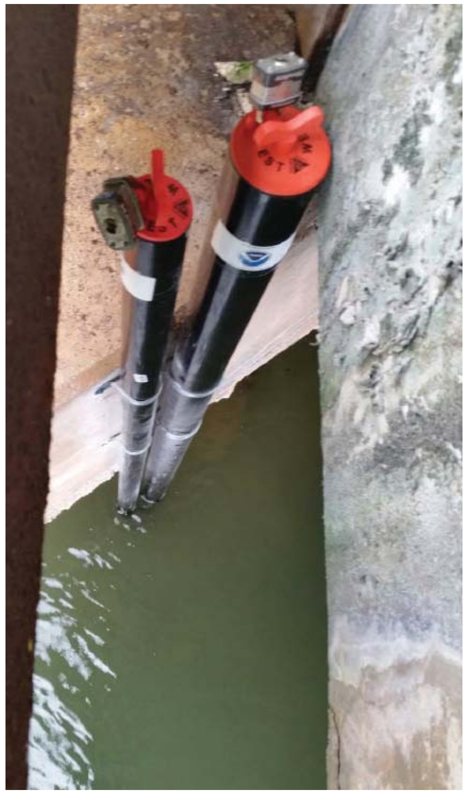

Figure 5. Photograph of turbidity logger (right) and level logger (left) housings attached to the Ajayan River bridge abutment.

Rainfall data for the Manell watershed was collected using a HoboWare® rain gauge installed along the eastern mountain ridge of the watershed, in an area known as Ija. The rain gauge uses two tipping buckets that collect water as it falls, recording each time the tipping buckets are activated representing a specific quantity of rainfall (0.01 in. per tip).

All data loggers (turbidity logger, level loggers, and rain gauge) were programmed to collect readings every 15-minutes. The data loggers were deployed from December 2016 through December 2018. Periodically, the data loggers were briefly taken out of service for calibration and maintenance. Calibration and maintenance were completed in accordance with the manufacturer's recommendations. The turbidity logger was calibrated monthly or as needed. HoboWare® data loggers were factory calibrated. All the data logging instruments required periodic cleaning and the time and date were calibrated on a regular basis.

Nutrient Samples

Nutrient samples (surface) were collected at the designated sample locations during each field visit. Disposable nitrile gloves were worn during the collection of samples. Water samples were collected by hand into 125 ml HDPE bottles from the shore, labeled with the collection time, date, and location. Prior to sample collection, each bottle was pre-rinsed three times with sample water. Samples were then placed on ice and transferred to the sample freezer on the same day, at the Guam EPA laboratory.

Frozen samples for nutrient analysis were sent off in batches for analysis by the Geochemical and Environmental Research Group (GERG) at the Texas A&M University. GERG was subcontracted to TDI-Brooks, Inc, a NOAA analytical contract laboratory. All nutrient samples were analyzed for nitrate, nitrite, ammonium, total nitrogen, orthophosphate, total phosphate, and silica.

Figure 6. Locations of the three monitoring sites in the Manell watershed.

The following is a brief summary of methods used for the analysis of nutrients in the water samples collected. Nitrate and nitrite analyses were based on the methodology of Armstrong *et al*. (1967) and use a ground cadmium column for reduction of nitrate to nitrite. Orthophosphate was measured using the methodology of Bernhardt and Wilhelms (1967), with the modification of hydrazine as a reductant. Silicate determination was accomplished using the methods of Armstrong *et al*. (1967) using stannous chloride.

Ammonium analysis was based on the method of Harwood (Harwood and Kuhn, 1970) using dichloroisocyanurate as an oxidizer. Urea was measured using diacetyl-monoximine and themicarbozide. Total nitrogen and total phosphorus concentrations were determined after an initial decomposition step. This method involves persulfate oxidation while heating the sample in an autoclave (Hansen and Koroleff 1999). After oxidation of the samples, nutrient determinations were conducted on a Technicon® II analyzer.

Suspended Sediment Concentration (SSC)

Water samples for SSC analysis were collected at the three sites (Figure 6) during each field visit starting in April 2017 through December 2018. Sample water was collected in 500 ml plastic amber bottles, labeled with the collection time, date, and location. Samples were immediately placed in a cooler on ice.

Upon return to the laboratory, samples were kept chilled in a refrigerator awaiting laboratory analysis. All SSC samples were analyzed at the Guam Environmental Protection Agency (GEPA) laboratory within one week from the date of sample collection. SSC sample analyses were completed in accordance with the ALS Environmental (2011) methods and guidance. Briefly, each sample was filtered through a pre-weighed glass fiber filter mounted in a suction flask apparatus. The filtered sample was rinsed several times with deionized water in order to remove salts, then dried at 105° C, and weighed to the nearest 0.001 g. SSC was calculated as follows:

SSC (mg/L) = ([A-B]*1000)/C

Where A = End weight of the filter in grams (g)
B = Initial weight of the filter in grams (g)
C = Volume of water filtered

Shipping

There was no direct overnight shipping available from Guam to TDI-Brooks in College Station, Texas. As a result, the samples were first shipped overnight to the NOAA Pacific Islands Fisheries Science Center in Honolulu, Hawaii. The water samples were then placed in a walk-in freezer at the facility for a few days, and then shipped out to TDI-Brooks.

Statistical Analyses

The data were analyzed using JMP® statistical software Version 12.1.0. To assess differences in turbidity, suspended sediments and nutrients between sites, a Shapiro-Wilk test was first run on the data to see if it was normally distributed. None of the data were normally distributed, and transformations were not effective. As a result, the Wilcoxon nonparametric test was used for two groups, and the Kruskal-Wallis nonparametric test was used when there were more than two groups. Pairwise comparisons were carried out using the Wilcoxon nonparametric test on each pair within JMP, which is the nonparametric version of the Student's t-test. Finally, Spearman's correlations were also calculated.

RESULTS AND DISCUSSION

Water Quality Parameters

A summary of results from the water quality monitoring by river can be seen in Table 3. More detailed results can be found in Appendix A. In general, the Sumay River site was different from the Ajayan and As Liyog sites. Temperature varied significantly at some of the sites (Chi-Square =

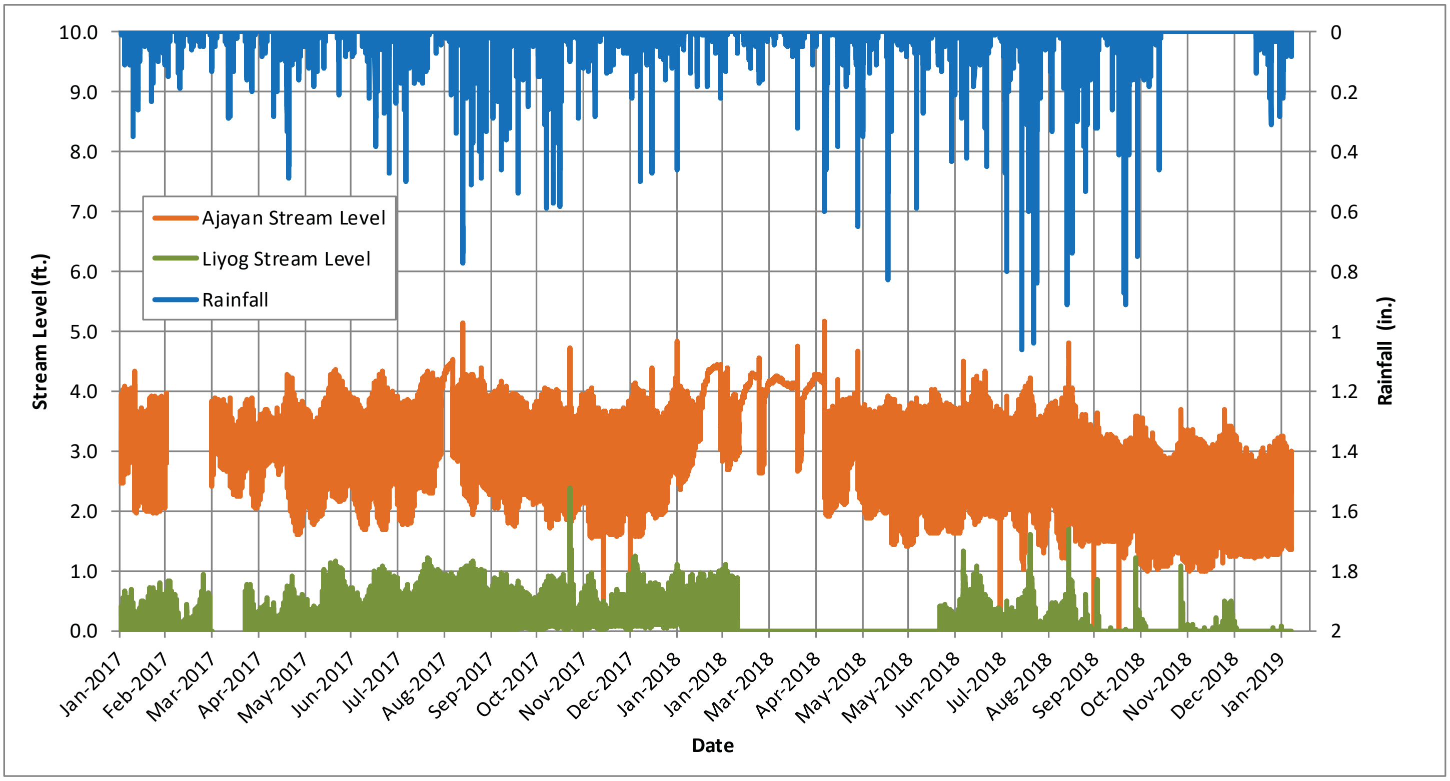

Figure 7. Stream level and rainfall at the Ajayan and As Liyog river sites.

69.7613, $p < 0.0001$). The Kruskal-Wallis nonparametric test indicated that temperature in the Sumay River site was significantly different (lower) than the As Liyog and Ajayan River sites. However, temperature in the As Liyog and Ajayan river sites were not significantly different from each other. Dissolved oxygen was also significantly different among the sites (Chi-Square = 10.4423, $p = 0.0054$). As with temperature, the Sumay River site had significantly lower dissolved oxygen than the Ajayan and As Liyog sites.

Specific conductivity (Chi-Square = 124.9015, $p < 0.0001$) and salinity (Chi-Square = 123.5802, $p < 0.0001$) were lower at the Sumay River site compared to the As Liyog and Ajayan sites (Table 3). The three sites for this project were established at the bridges that go over the rivers along Route 4 in southern Guam. Both the Ajayan and As Liyog sites (Figure 6) are more open to the Achang Reef Flat Marine Preserve waters than the Sumay River site, and have significant deltas which may facilitate the mixing of tidal seawater with the freshwater flowing down these two rivers. The Sumay River, on the other hand, does not have a well developed delta, and the sampling site for the Sumay River appears more separated and upstream from where it flows into the Achang Preserve (Figure 6). At the beginning of this project, attempts were made to locate sampling sites further upstream on the As Liyog and Ajayan rivers, however, the dense jungle along these rivers did not allow sites further upstream to be established, even when using a kayak. In addition, there were uncertainties related to land ownership in the areas further upstream.

Table 3. Water quality parameters of sites in the Manell watershed.

Site	Temperature (°C)	Dissolved Oxygen (mg/l)	Specific Conductivity (µs/cm)	Salinity (ppt)
	Mean ±SE	Mean ±SE	Mean ±SE	Mean ±SE
Ajayan River	30.8 ±0.2	4.10 ±0.13	32042 ±20	20.2 ±1.1
As Liyog River	30.5 ±0.2	5.24 ±1.05	41439 ±26	26.3 ±0.9
Sumay River	28.7 ±0.1	3.54 ±0.13	5138 ±3	2.9 ±0.6

Results from Automated Data Logging

The results from the automated data logging for stream level at the Ajayan and the As Liyog river sites can be seen in Figure 7. Note that the units in Figure 7 are in feet (stream level) and inches (rainfall). Approximately 73,000 observations were made using the automated stream and rainfall loggers in the Ajayan and As Liyog rivers over the two year period. Water or stream level was used as a proxy for

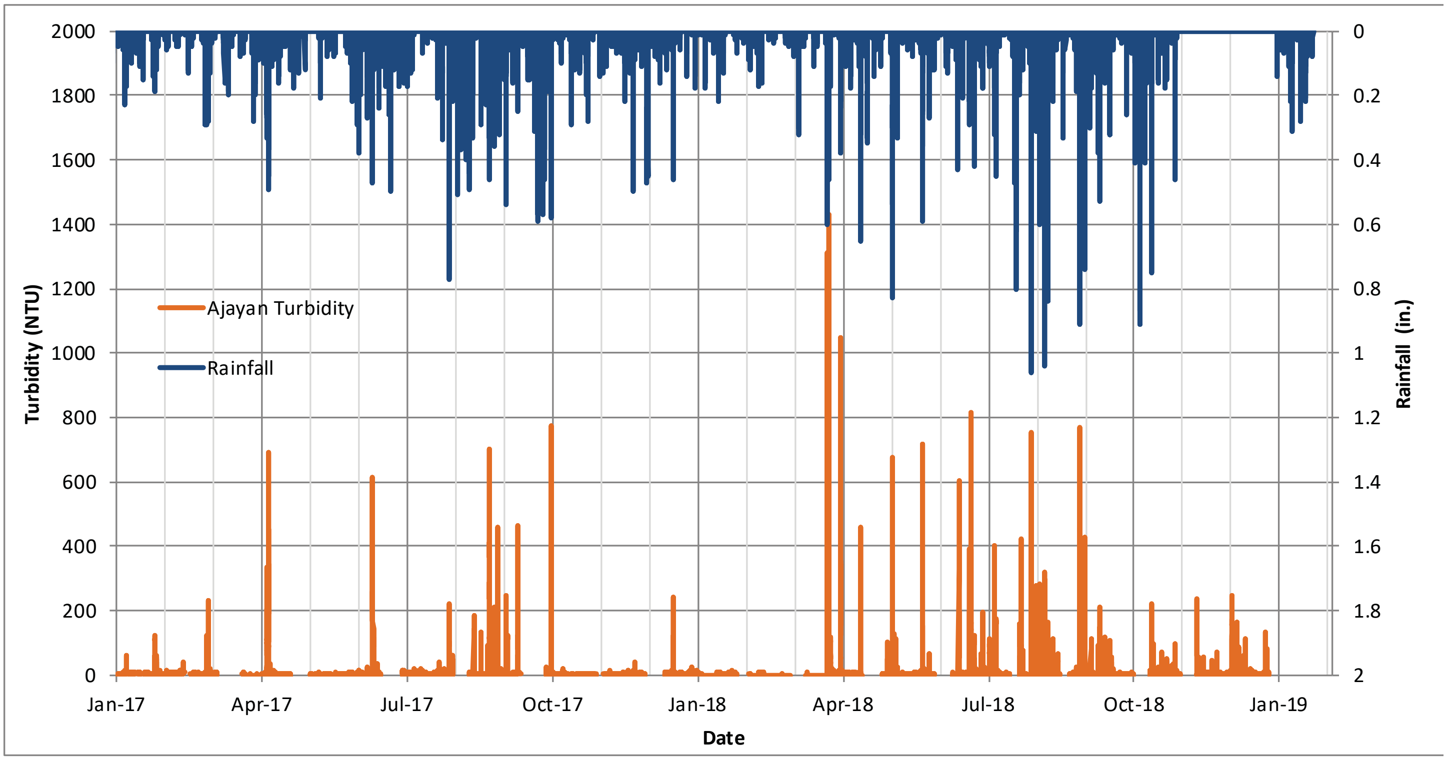

Figure 8. Stream level and turbidity at the Ajayan River site.

stream flow. Automated data logging could not be carried out in the Sumay River, as the water level at the site was too low to deploy the equipment.

From Figure 7, it can be seen that in general, the water level at the As Liyog River site was substantially lower than at the Ajayan River site. The mean water level during the monitoring in the Ajayan River was 0.91 meters (Table 4), or 3 ft. In the As Liyog, the mean water level was 0.03 meters. Nonparametric analysis of data from the automated monitoring revealed a significant and positive correlation (Spearman's Rho = 0.0147, p = 0.0001) between Ajayan stream level and rainfall (Appendix B). Likewise, there was a significant positive correlation (Spearman's Rho = 0.0335, p < 0.0001) between rainfall and stream level in the As Liyog River. This indicates that rainfall had a significant effect on the water levels in these two rivers, rising with increasing rainfall.

Table 4. Mean stream level (meters) at the Ajayan and As Liyog river sites.

	Mean ±SE	Minimum	Maximum
Ajayan River	0.91 ±0.00	0	1.58
As Liyog River	0.03 ±0.00	0	0.73

Notes: SE, standard error

From Figure 7, it can be seen that rainfall varied through the course of the year. In Guam, the wet season is roughly from May through November, and the dry season from December through April. Data from the stream level measurements for both the Ajayan and As Liyog rivers were classified as occurring either in the dry or the wet season. The data were then analyzed using Wilcoxon's nonparametric test. Results indicated that the stream level in the Ajayan River varied significantly (Chi-Square = 915.6 p < 0.0001), with higher stream levels occurring in the wet season. The same was true for the As Liyog, that is the months classified as part of the wet season had higher (Chi-Square = 591.8 p < 0.0001) water levels than during the dry season.

For both the Ajayan and As Liyog river sites, there was a short span of time, typically between 15 and 30 minutes, between when a significant rain event occurred and the water level in these rivers rose, highlighting the role that the steep slopes in the watershed play in quickly delivering runoff to downstream areas. In the adjacent Geus watershed, Khosrowpanah *et al.* (2015), found that the Geus River returned to normal flow within an hour and a half after a rainfall event The same appeared to be true for the Ajayan and As Liyog rivers.

At the Ajayan River site, a turbidity logger (Manta 2 water quality sonde) was installed. As with the level loggers, the turbidity logger was programmed to take readings every 15 minutes. A graph of turbidity versus rainfall can be seen in Figure 8. There was a significant (Spearman's Rho = 0.0880, p < 0.0001) positive correlation between rainfall and turbidity as measured by the Manta 2 automated turbidity sonde, indicating that turbidity was more likely to increase with rainfall, resulting from surface water runoff carrying sediments from the watershed into the Ajayan River, and ultimately out into the Achang Preserve.

There were a number of events during the monitoring when increased rainfall led to spikes in the turbidity readings from the Manta automated turbidity sonde. Between 6 and 8 April 2018, approximately 10.4 cm (4.09 inches) of rain fell, resulting in high turbidity levels, with readings over 1,400 NTUs (nephelometric turbidity units) (Figure 8). In the Geus River, Khosrowpanah *et al.* (2015) recorded turbidity readings as high as high 1,000 NTUs. Around 17 October 2017, approximately 8.8 cm (3.46 in) of rain fell in the Manell watershed over a 24 hour period, producing turbidity readings as high as 774 NTU. However, in July 2018, a rainfall total of only 3.7 cm (1.46 in) produced a turbidity reading of over 800 NTUs, perhaps demonstrating the variability of the system.

Table 5. Classification of Guam marine and surface waters.

Marine Waters

Category	Ranking	Description
M1	Excellent	Suitable to protect whole body contact recreation, and also to ensure preservation of marine life
M2	Good	Allows for propagation and survival of marine organisms
M3	Fair	Suitable for general, commercial and industrial use

Surface Waters

Category	Ranking	Description
S1	High	Suitable for drinking water, wildnerness areas,propagation and preservation of aquatic life, whole body contact and recreational enjoyment
S2	Medium	Suitable for recreational purposes, including whole body contact recreation, and as use as potable water after adequate treatment is provided.
S3	Low	Primarily used for commercial, agricultural, and industrial activities

From these results, it appears that both the Ajayan and the As Liyog rivers respond rapidly to rainfall in terms of stream height and as was shown for the Ajayan, also for turbidity. This is perhaps not surprising given the slope of the watershed, which results in the rapid delivery of water and eroded soils to the lower elevations of the watershed. This rapid response highlights the need for restoring and maintaining good soil cover in the watershed, in order reduce the amount of water and sediment transported into the rivers and then out onto the Achang Preserve and the rest of Cocos Lagoon.

Guam Water Quality Standards

The marine and surface waters in Guam have been classified (Guam EPA, 2001) based on their use and desired water quality. Those classifications are shown in Table 5. Marine and surface waters have been divided into three categories. M1 (marine) and S1 (surface waters) are the designations given to those waters that should exhibit excellent or the highest water quality, either for recreational activities and the preservation of marine life (M1), or for drinking water and preservation of aquatic life (S1). The next categories M2 and S2, are classified as good or medium water quality either for the propagation of marine life (M2), or for recreational activities or as drinking water after suitable treatment (S2). The third category (M3 and S3) is a designation given to those waters suitable for commercial or industrial use.

Guam EPA has developed a water classification map with areas designated as to their desired water quality (Guam EPA, 2001). Cocos Lagoon is designated as M1. The Manell watershed appears to be designated as S2.

Water quality standards for Guam were adopted in accordance with the US Water Pollution Control Act (Clean Water Act), Public Law 92-500, and the Guam Water Pollution Control Act (Guam EPA/USEPA, 2018). For the current project, four standards, including those for the suspended sediment concentration, turbidity, nitrate and orthophosphate, were most relevant. By necessity, the sites monitored in the Ajayan, As Liyog and Sumay rivers were located where they were accessible, that is adjacent to the highway bridges that cross these rivers. For the Ajayan and the As Liyog rivers, the locations represent the interface between marine waters and surface waters. Because of this, the figures presenting the results for the four parameters include both the marine and the surface water standards (e.g., M1 and S1).

Table 6 contains a summary of the monitoring of the suspended sediment concentration (SSC), Hach turbidity (also measured in NTUs), and nutrients. The Ajayan and As Liyog rivers were sampled and analyzed a total of 76 times. The site in the Sumay River was added a little later in the project, and was sampled 71 times. Table 7 lists the Guam water quality standards for SSC, turbidity, nitrate, and orthophosphate.

Suspended Sediment Concentration (SSC)

The mean SSC across all sites was 12.7 ±1.20 mg/l SSC (Table 6). More detailed data from the analysis of SSC can

Table 6. Summary of results for the monitoring of suspended sediments, Hach turbidity, and nutrients from the three rivers in the Manell watershed.

	Ajayan River (n = 76)			As Liyog River (n = 76)			Sumay River (n = 71)			Overall		
Parameter	Mean ±SE	Minimum	Maximum	Mean ±SE	Minimum	Maximum	Mean ±SE	Minimum	Maximum	Mean ±SE	Minimum	Maximum
Suspended Sediment Concentration (SSC) (mg/l)	7.52 ±1.21	1.4	82.2	23.4 ±2.67	3.23	129.1	7.51 ±1.43	1.45	71.6	12.7 ±1.20	1.4	129
Hach Turbidity (NTU)	10.6 ±2.19	1.13	135.5	17 ±2.11	3.38	146	7.53 ±1.43	1.43	75.6	11.8 ±1.16	1.13	146
Nitrate (NO_3^-) (mg/l N)	0.01 ±0.00	0.0	0.09	0.01 ±0.00	0.0	0.09	0.19 ±0.01	0.02	0.34	0.07 ±0.01	0.00	0.34
Nitrite (NO_2^-) (mg/l N)	0.01 ±0.00	0.0	0.01	0.01 ±0.00	0.0	0.01	0.0 ±0.00	0.0	0.01	0.01 ±0.00	0.00	0.01
Ammonium (NH_4^+) (mg/l N)	0.07 ±0.00	0.01	0.22	0.09 ±0.01	0.03	0.25	0.04 ±0.00	0.02	0.16	0.07 ±0.00	0.01	0.25
Urea (NH_2CONH_2) (mg/l N)	0.02 ±0.00	0.0	0.05	0.02 ±0.00	0.1	0.06	0.01 ±0.00	0.0	0.08	0.02 ±0.00	0.00	0.08
Orthophosphate ($HPO_4^{=}$) (mg/l P)	0.08 ±0.01	0.01	0.31	0.1 ±0.01	0.01	0.32	0.05 ±0.01	0.01	0.46	0.08 ±0.00	0.00	0.46
Silica ($HSIO_3^-$) (mg/l)	10.32 ±0.78	1.74	29.01	7.77 ±0.62	0.81	23.99	23.07 ±1.21	3.43	40.0	13.5 ±0.68	0.81	40.0
Total Nitrogen (mg/l N)	0.5 ±0.04	0.27	2.95	0.54 ±0.02	0.31	0.99	0.57 ±0.02	0.4	1.27	0.53 ±0.01	0.27	2.95
Total Phosphorus (mg/l P)	0.12 ±0.01	0.03	0.35	0.14 ±0.01	0.05	0.37	0.10 ±0.01	0.03	0.83	0.12 ±0.01	0.03	0.83

Abbreviation: SE, standard error

be found in Appendix A. With a mean of 23.4 ±2.67 mg/l, SSC at the As Liyog site was the highest. The maximum SSC recorded during this project was also at the As Liyog site, at 129 mg/l, and occurred in October 2017. SSC was significantly different in the three rivers (Chi-Square = 82.7, $p < 0.0001$). The correlation between SSC and water level was highly significant for both the Ajayan (Spearman's Rho = 0.3670, $p < 0.0001$) and the As Liyog sites (Spearman's Rho = 0.2944, $p < 0.0001$), indicating that increased water level (proxy for flow and runoff from the watershed) was correlated with increasing sediment in the water column.

The SSC mean for the Ajayan and Sumay rivers (Table 6) can be compared to the water quality standard for SSC (Table 7). The means for both the Ajayan and the Sumay river sites were below the M2/S2 (good) standard of 20 mg/l, but slightly higher than the M1/S1 (excellent) standard of 5 mg/l. The mean for SSC at the As Liyog River site (23.4 ±2.67 mg/l) was between the M2/S2 and the M3/S3 (good to fair) standard.

Table 7. Guam water quality standards for suspended sediments, turbidity and nutrients.

	Category		
Marine Waters	M1	M2	M3
Suspended sediment concentration (SSC)	5 mg/l	20 mg/l	40 mg/l
Turbidity*	0.5 NTU	1.0 NTU	1.0 NTU
Nitrate nitrogen (NO_3-N)	0.10 mg/l	0.20 mg/l	0.50 mg/l
Orthophosphate (PO_4-P)	0.025 mg/l	0.05 mg/l	0.10 mg/l
	Category		
Surface Waters	S1	S2	S3
Suspended sediment concentration (SSC)	5 mg/l	20 mg/l	40 mg/l
Turbidity*	0.5 NTU	1.0 NTU	1.0 NTU
Nitrate nitrogen (NO_3-N)	0.10 mg/l	0.20 mg/l	0.50 mg/l
Orthophosphate (PO_4-P)	0.025 mg/l	0.05 mg/l	0.10 mg/l

* Above ambient concentration

Figure 9a and 9b show results of the SSC analysis graphically. The sampling for SSC did not begin until April 2017. The SSC graphs were divided in two in order to make it easier to view the results over the course of the project. Also superimposed on the graphs are the Guam water quality standards for SSC. The collection of water samples on 14 October 2017, indicated substantially elevated SSC in all three rivers, with SSC values higher than the 40 mg/l SSC water quality standards for M3 and S3 (fair) waters (Figure 9a). The As Liyog River recorded an SSC value of 129.1 mg/l, substantially higher than the fair SSC standard. During this period, nearly 25 cm (9.82 in) of rain fell, which likely lead to increased amounts of SSC. As will be seen, there was an increase in turbidity during this time as well.

In Figure 9b, it appears that SSC could have been lower in the second half of 2018. A variety of factors could impact the SSC found in the rivers. Lower rainfall would reduce the amount of runoff, however, rainfall during this period (Figure 8) was

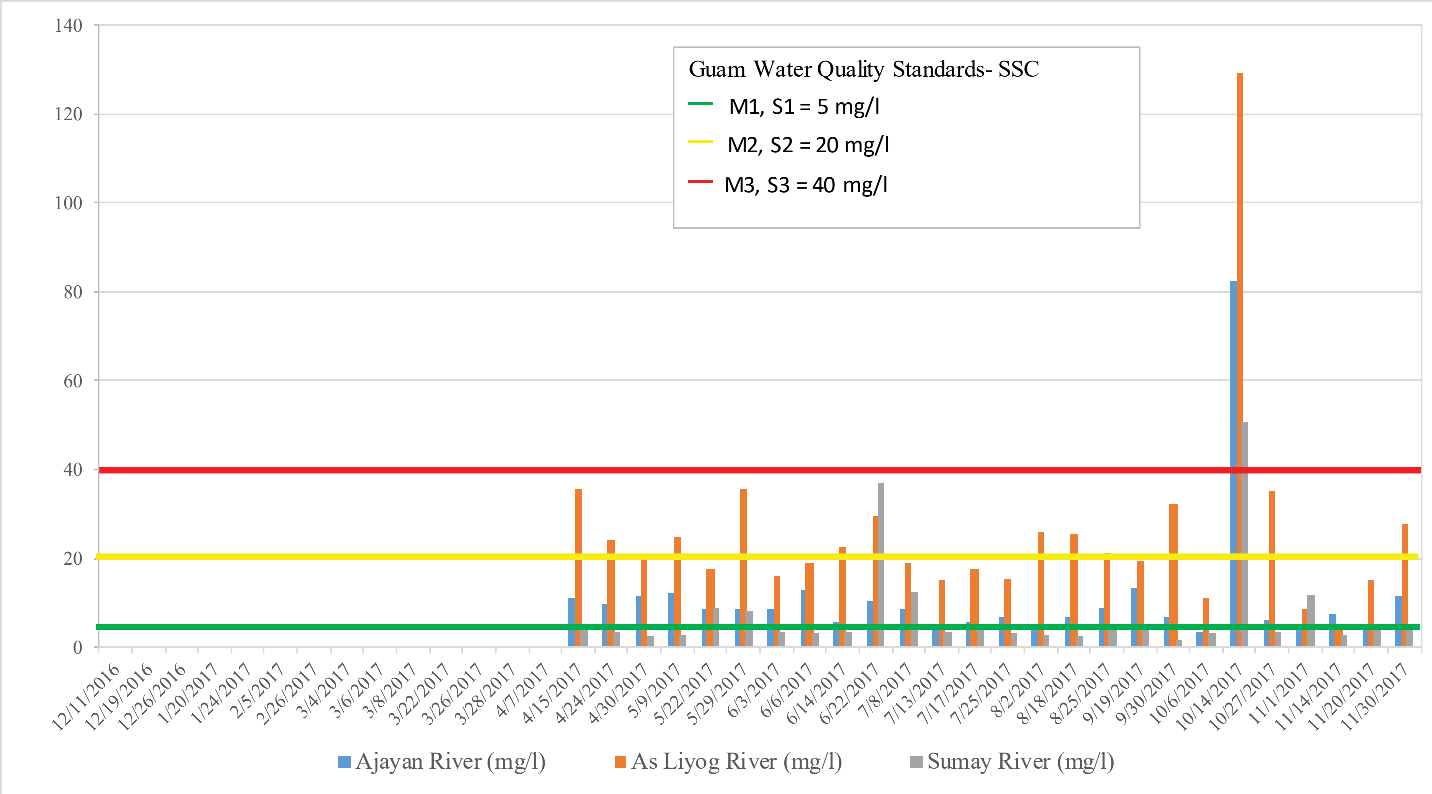

Figure 9a. Suspended sediment concentration (SSC) (mg/l) in the three rivers for the period 12/11/2016 - 11/30/17 compared to Guam water quality standards.

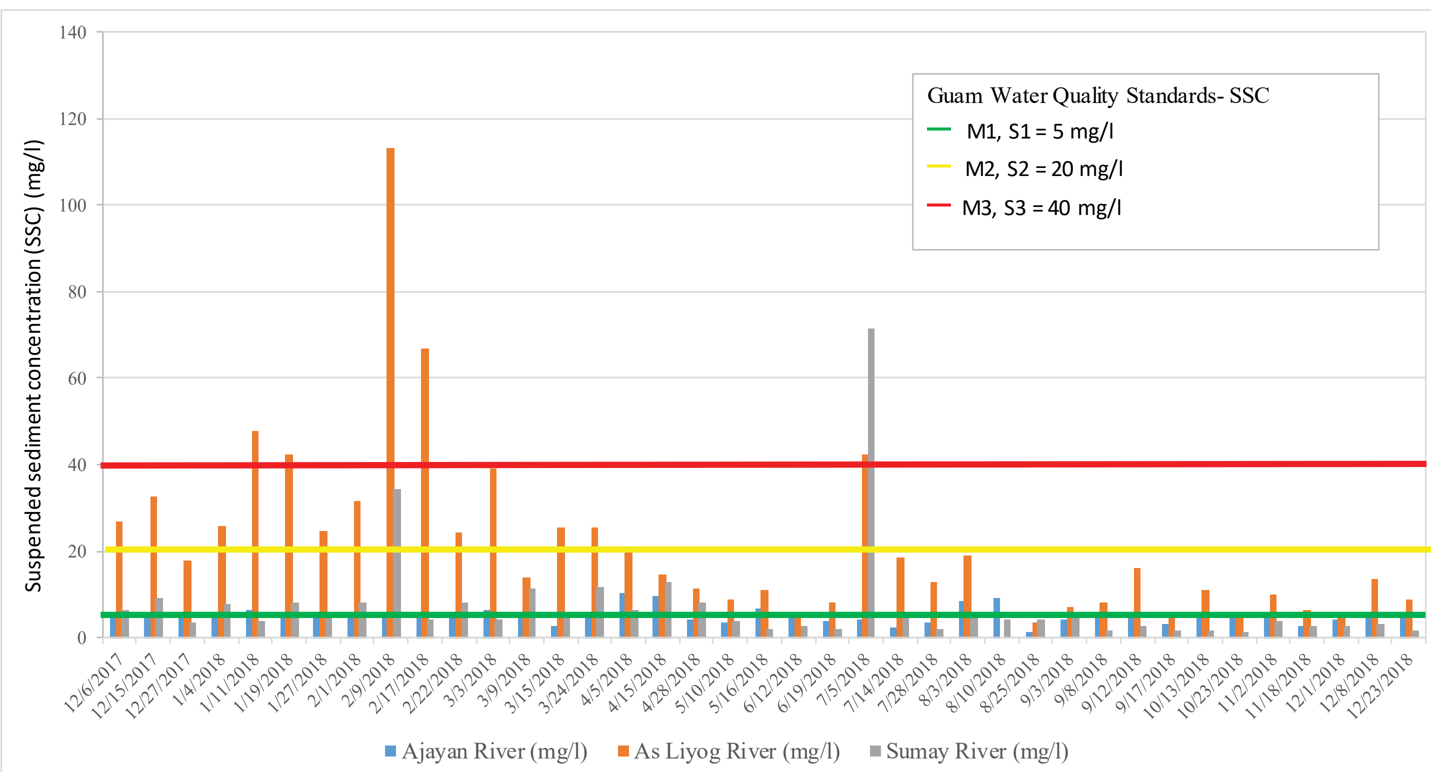

Figure 9b. Suspended sediment concentrations (SSC) (mg/l) in the three rivers for the period 12/6/2017 - 12/23/2018 compared to Guam water quality standards.

fairly normal, with some of the higher rainfall totals in the July to October timeframe, as is typical for Guam. Another possibility is the effect of restoration activities in the Manell watershed, including the planting of vegetation along the hillsides in order to reduce erosion. One of these efforts has focused on the As Liyog River, since 2014 (EA Associates, 2014).

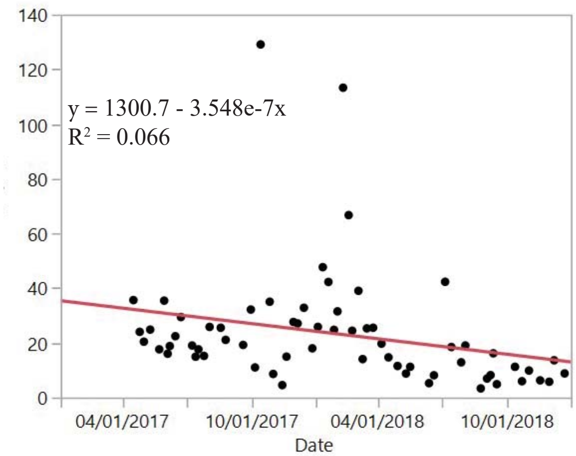

Figure 10. Bivariate fit of SSC over time in the As Liyog River.

A plot of SSC versus time for the As Liyog River site can be seen in Figure 10. The line has a negative slope. Although the R^2 value is small (0.066), the p value ($p = 0.0402$) was significant. The same plot for the Ajayan and the Sumay river sites both showed negative slopes, but with smaller R^2 values. It is not clear if there was any temporal trend in SSC at the As Liyog River site. In addition to the restoration efforts in the watershed, the effects of wildfires leaving the soil bare, followed by revegetation either naturally or as a part of restoration efforts, could lead to a decrease in the amount of bare soil present, and perhaps to less erosion. Additional monitoring, and surveys of ground cover would help to determine any trends.

Towards the end of the project, an additional site was established on the Geus River in the adjacent Geus watershed. The Geus River site was sampled a total of nine times. The mean SSC concentration on the Geus River was lower, 2.55 ±1.53 mg/l. SSC data from EPA's STORET (WQP, 2019) for Guam was also reviewed. Most if not all of the SSC data appeared to have been generated by the US Geological Survey, for the La Sa Fua River near Umatac, and the Ugum River near Talofofo. The mean SSC concentration was 676.5 ±48.1 mg/l, quite a bit higher than what was found in the current study.

Figure 11. Outflow from the Ajayan River into the Achang Preserve. Note the turbidity plume going out into the Preserve.

Hach Turbidity

Turbidity measurements using a Hach turbidimeter (Hach turbidity) were also made in the three rivers during each sampling event, when water samples were collected for SSC and nutrients. Figure 11 shows an image of the turbidity plume moving out into the Achang Preserve from the Ajayan River.

The mean Hach turbidity measured during this project was 11.8 ±1.16 NTU (Table 6). Turbidity varied by site (Chi-Square = 82.7, $p < 0.0001$). The highest average turbidity by site, as with SSC, was in the As Liyog River with a mean turbidity of 17 NTU, followed by the Ajayan (10.6 NTU) and the Sumay (7.53 NTU) rivers (Table 6). Not surprisingly, turbidity was highly correlated with SSC (Spearman's Rho = 0.7336, $p < 0.0001$). Turbidity was also correlated with water level in the rivers. An analysis of the data indicated significant correlations between water level and turbidity for both the Ajayan (Spearman's Rho = 0.2204, $p < 0.0010$) and the As Liyog (Spearman's Rho = 0.1369, $p < 0.0445$) sites.

Graphs of the results of the Hach turbidity measurements over time can be seen in Figures 12a and 12b. The Guam turbidity standards for M1/S1 waters have been designated as 0.5 NTU above the ambient concentration (Table 7). For the other two marine (M2 and M3) and surface water (S2 and S3) classifications, the standard is 1.0 NTU above the ambient turbidity. As an estimate of ambient turbidity for the three sites in the project, the mean turbidity value (11.5 NTU) was used.

As with SSC, there were a number of occasions when turbidity exceeded the estimated Guam turbidity standards. The highest turbidity recorded as with SSC, was during the collection of the 14 October 2017 samples (Figure 12a), and as noted, was also during a period of increased (approximately 25 cm) rain. The highest turbidity measured during this time was at the

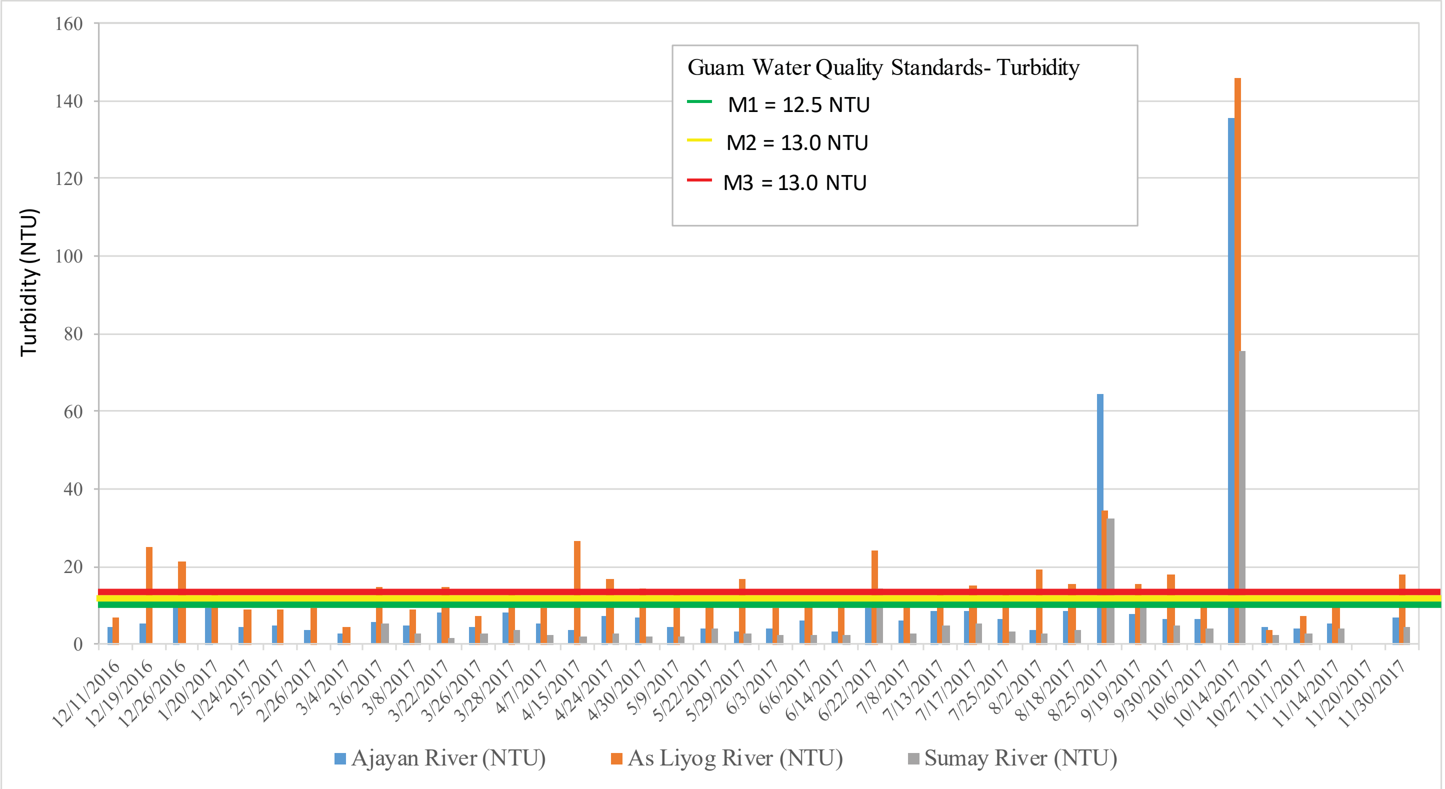

Figure 12a. Turbidity (NTU) in the three rivers for the period 12/11/2016 - 11/30/17 compared to Guam water quality standards.

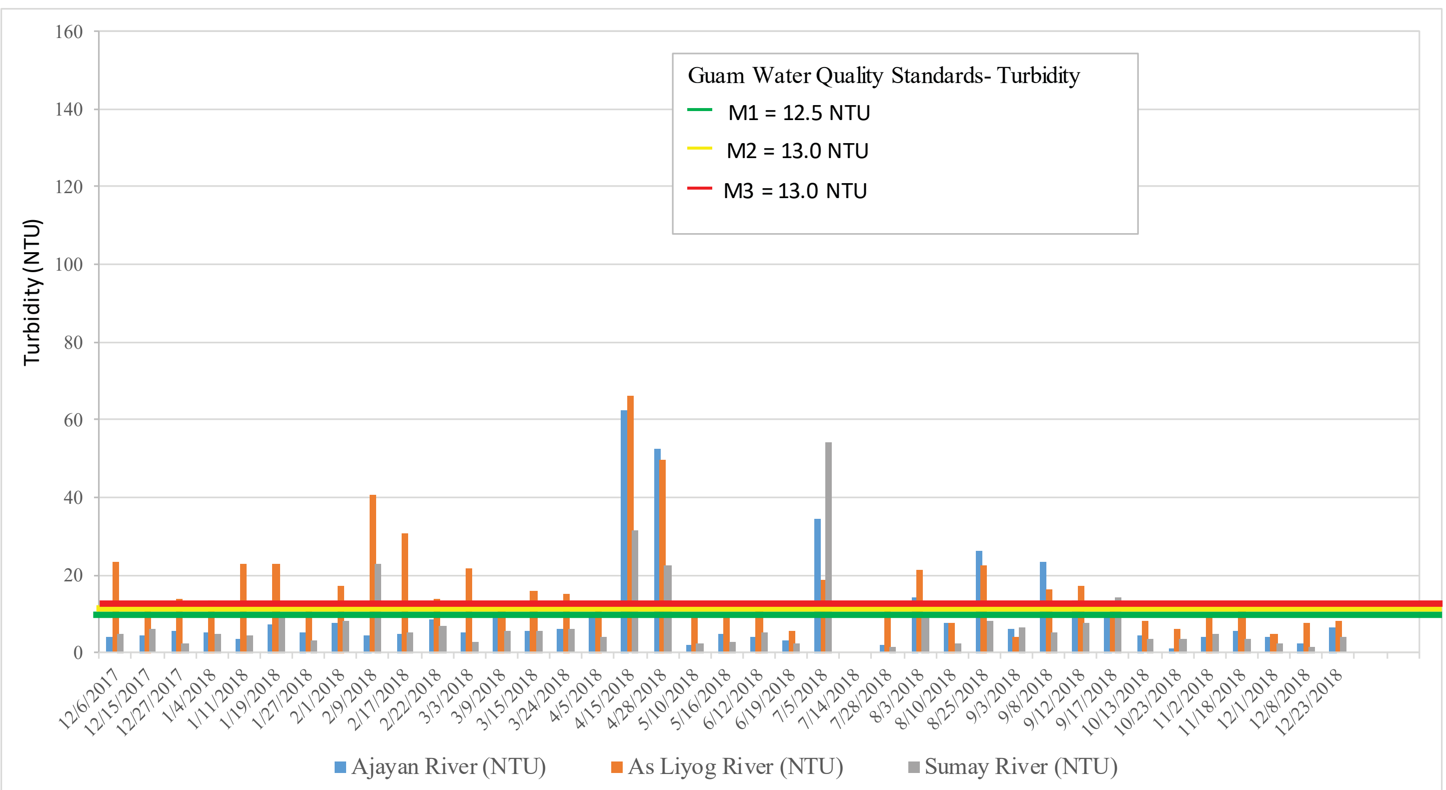

Figure 12b. Turbidity (NTU) in the three rivers for the period 12/6/2017 - 12/23/2018 compared to Guam water quality standards.

As Liyog River site with 146 NTU, followed by the Ajayan (135.5 NTU) and Sumay (75.6 NTU) rivers. Turbidity was also found to be high during the 15 April and 28 April 2018 sampling (Figure 12b). Rainfall during this time was approximately 18.6 cm or 6.62 in.

The town (and municipality) of Merizo (Figure 13) is split between the Manell and Geus watersheds. In the Geus watershed, the mean turbidity from the nine samplings conducted towards the end of this project was lower, 3.34 NTU. Data from EPA's STORET (WQP, 2019) for Guam was assessed for turbidity measurements. The mean turbidity for Guam was 33.6 ±4.01 NTU, higher than the mean found for the current project.

Figure 13. Houses in the town of Merizo bordering Cocos Lagoon.

Nitrate

The results from the analysis of the water samples for nitrate are also summarized in Table 6. More detailed information can be found in Appendix C. Sources of nitrogen can be varied and include agricultural activities such as the growing of crops and animals, wildlife, and septic systems (CUCE, 2005).

The mean nitrate concentration across all three sites was 0.07 ±0.01 mg/l N. Nitrate varied significantly across the three rivers (Chi-Square = 165.3, $p < 0.0001$). The highest mean nitrate of any site occurred at the Sumay River site with a mean of 0.19 ±0.01 mg/l N. Nitrate at the Sumay River site was significantly higher than at the Ajayan and As Liyog sites. There was no difference, however, in the mean nitrate concentration between the Ajayan and As Liyog river sites.

As noted earlier, the Sumay River site appears to have less influence from tidal waters (Table 3), being located further upstream than either the Ajayan or As Liyog sites, which may limit mixing with waters from the Achang Preserve. Results of monitoring nitrogen in the Manell watershed can be seen in Figures 14a and 14b. The Sumay River site had some of the higher nitrate values recorded during the project. Superimposed on the graphs are the Guam water quality standards (Table 7) for nitrate. The Sumay River site was frequently higher than the M2/S2 (good) standard for nitrate, putting it in the good to fair range. The Ajayan and the As Liyog sites were in the excellent to good range.

It is not clear why nitrate at the Sumay River site was higher than either the Ajayan or the Liyog river sites. One possibility is the location of the Sumay River site, which is further upstream, and likely experiences less mixing with tidal waters. Another possibility are the few dwellings near the site on the Sumay River, which could be a source of nitrogen.

A series of Spearman's nonparametric correlations were calculated for nitrate. Nitrate was negatively correlated with salinity (Spearman's Rho = -0.7853, $p < 0.0001$). Higher nitrate concentrations would more likely be associated with terrestrial sources. As noted, the Sumay River site is further upstream, and the salinity was lower than at either the Ajayan or Liyog sites.

Nitrate was also negatively correlated (Spearman's Rho = -0.3038, $p < 0.0001$) with SSC, and with Hach turbidity (Spearman's Rho = -0.3926, $p < 0.0001$). Nitrate was not significantly correlated with water level at either the Ajayan (Spearman's Rho = 0.1243, $p = 0.0664$) or the As Liyog (Spearman's Rho = 0.0965, $p = 0.1594$), although the Ajayan correlation was not too far from being significant.

Nadeau and Denton (2016) assessed nutrients in the Togcha River along the southeast coast of Guam, and detected nitrate at concentrations up to 0.36 mg/l N, similar to what was found in the current study. Denton *et al*. (2005) conducted a study in Agana Bay and Tumon Bay, popular tourist areas on the west coast of Guam, and found elevated levels of nitrate, ranging from 1.34 to 4.01 mg/l N in Agana Bay, and in Tumon Bay nitrate concentrations ranged from 0.08 to 0.79 mg/ N, higher than was found in the current

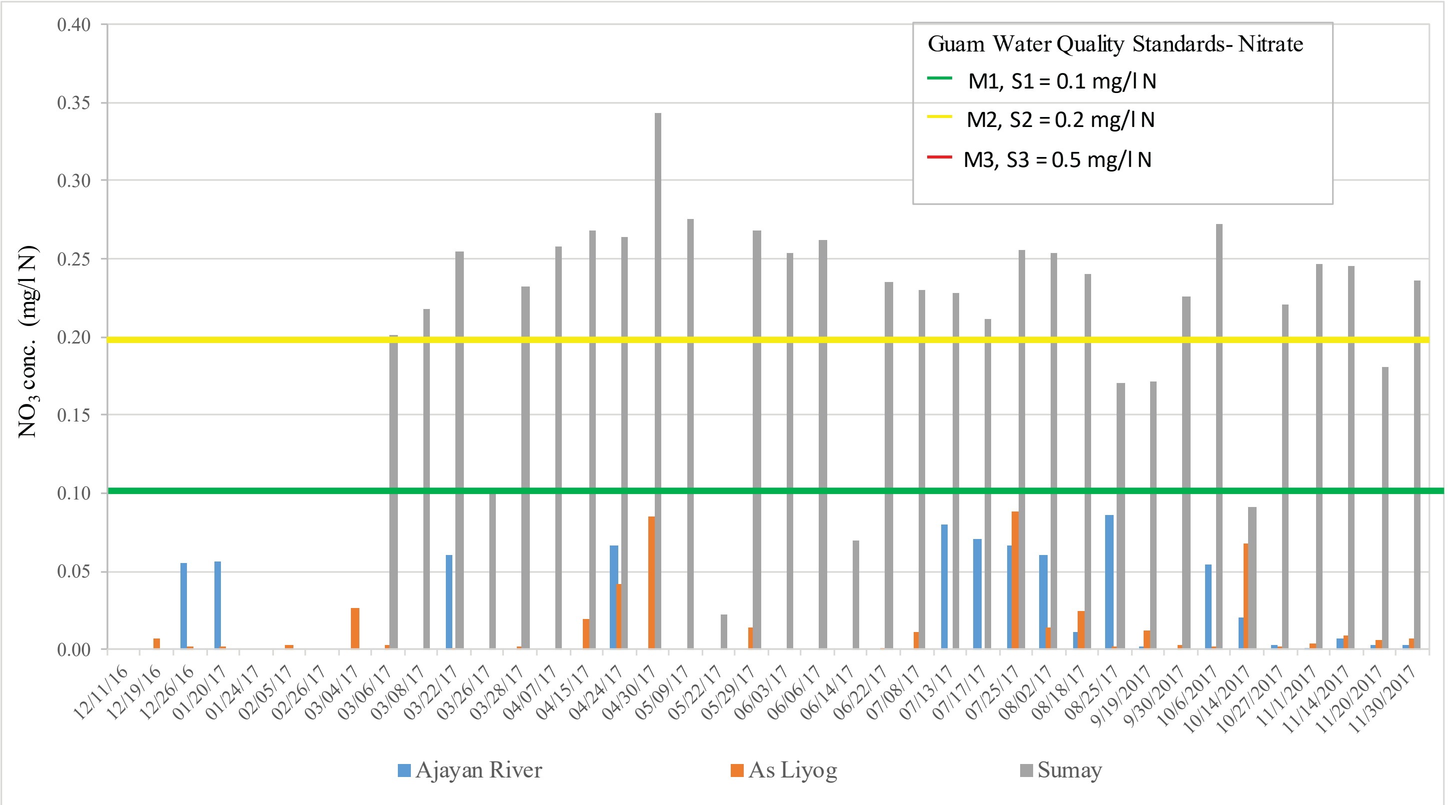

Figure 14a. Nitrate concentrations (mg/l) in the three rivers for the period 12/11/2016-11/30/17 compared to Guam water quality standards.

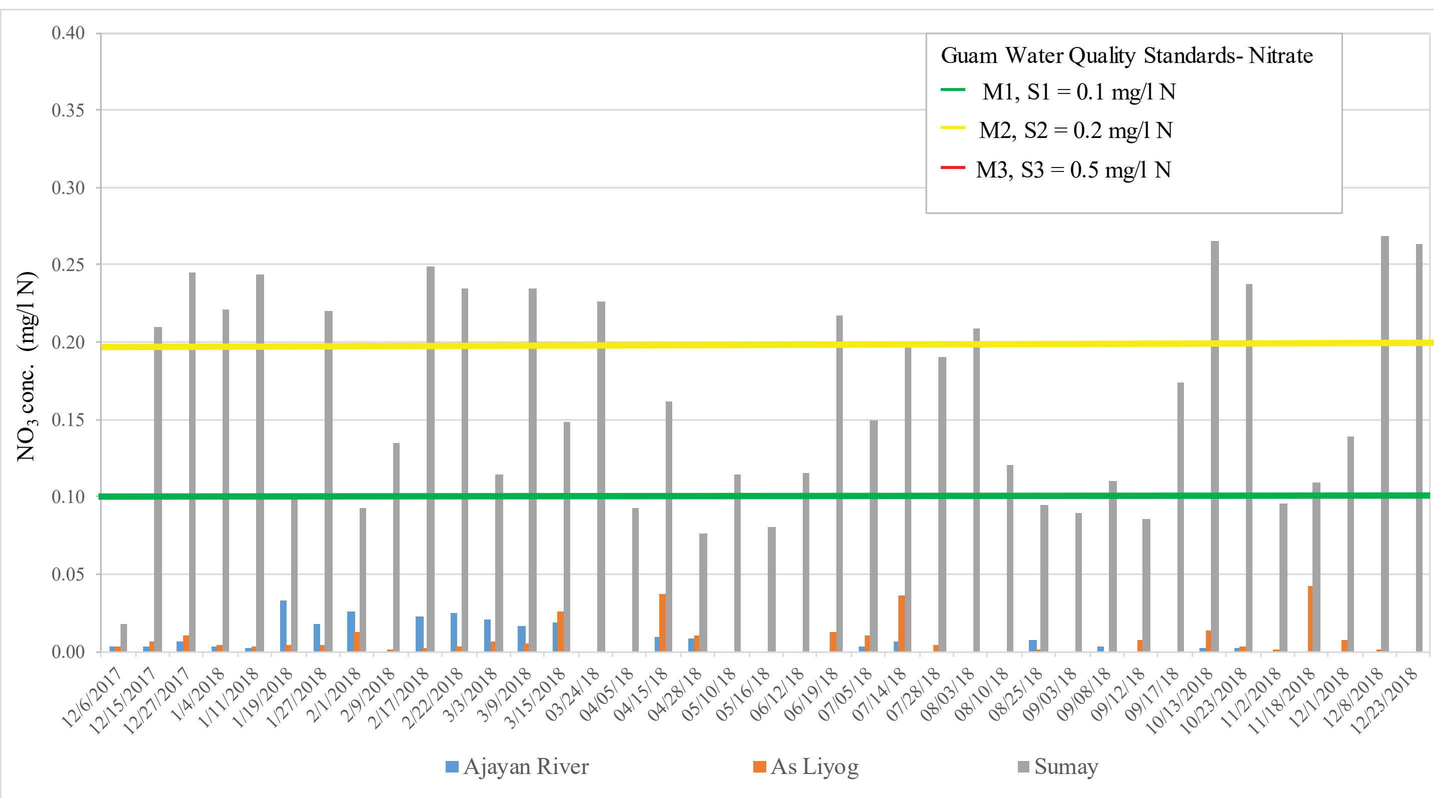

Figure 14b. Nitrate concentrations (mg/l) in the three rivers for the period 12/6/2017-12/23/18 compared to Guam water quality standards.

study. A review of STORET data (WQP, 2019), indicated a mean of 0.010 ±0.00 mg/g N for nitrate for Guam environmental sampling, which is slightly above the mean found in the current study.

Orthophosphate

While sources of orthophosphate ($HPO_4^{=}$) include natural weathering from rocks, the major human-influenced sources include sewage, runoff from agricultural sites (fertilizers and farm animals), and application of lawn fertilizers (Oram, 2014). Phosphorus is an important element for both plants and animals. Orthophosphate is readily taken up by plants and in unpolluted waters, the concentration is typically at very low concentrations.

Elevated levels of nutrients such as orthophosphate in freshwater and marine environments can lead to an overabundance of phytoplankton and algae, and in the marine environment can shade out corals and seagrasses. In seagrasses, an overabundance of nutrients has also been shown to result in increased epiphytes, which can lead to reduced seagrass growth and survival as a result of shading (Nelson, 2017).

Figure 15. As Liyog River looking upstream from the Route 4 bridge.

A summary of the results from the analysis of orthophosphate in the water samples are included in Table 6. Detailed results can be found in Appendix C. The overall mean of orthophosphate was 0.08 ±0.00 mg/l P, which is higher than the Guam water quality M2/S2 (good) limit. As with nitrate, the highest orthophosphate reading (0.46 mg/l P) occurred at the Sumay River site. However, the highest mean orthophosphate (0.1 mg/l P) (Table 6) occurred at the As Liyog River site (Figure 15). Orthophosphate varied across the sites (Chi-Square = 54.076, $p < 0.0001$). In addition, a Kruskal-Wallis test indicated that all three sites were different from one another. There was a positive correlation between orthophosphate and Hach turbidity (Spearman's Rho = 0.1714, $p = 0.0114$), as well as between orthophosphate and SSC (Spearman's Rho = 0.4148, $p < 0.0001$).

The results of the monitoring of orthophosphate for the Ajayan, As Liyog and Sumay river sites are shown graphically in Figure 16a and 16b. Superimposed on both graphs are the Guam water quality standards for orthophosphate for marine and surface waters. In Figure 16a, it can be seen that all three sites exceeded not only the M1/S1 (excellent) and M2/S2 (good) standards, but at times, all three sites exceeded the M3/S3 (fair) standard of 0.025 mg/l orthophosphate.

In Figure 16b, there appear to be far fewer exceedences of the M3/S3 standard for the period December 2017 through December 2018. It is not clear why there was a difference in the two time periods. A nonparametric Wilcoxon test indicated that there was a significant (Chi-Square = 74.0285, $p < 0.0001$) difference in the concentrations of orthophosphate between the two time periods. The separation of results in Figures 16a and 16b was somewhat arbitrary in order to better present the data, however, it appears there was a difference in the orthophosphate concentrations between these two designated time periods.

In Figure 17a, the concentration of orthophosphate in the water samples from the Ajayan River is plotted against time. An overall negative slope can be seen in this graph. The R^2 value for this line was 0.408, and $p < 0.0001$. In Figure 17b, orthophosphate in the As Liyog River is also plotted against time. Again, there is a negative slope to the line, however the R^2 value ($R^2 = 0.149019$, $p = 0.0006$) was less than that for the Ajayan site.

A graph of the rainfall during the course of the project can be seen in Figure 17c. The slope of the line is slightly positive. If, for example, rainfall during the period between November 2017 and December 2018 was much lower than the period from December 2016 to October 2017, it might be expected that less rainfall could result in less surface water runoff, and subsequently lower orthophosphate levels. As noted, orthophosphate is more likely to be associated with surface water runoff than nitrate, as nitrate tends to percolate through the soil into groundwater.

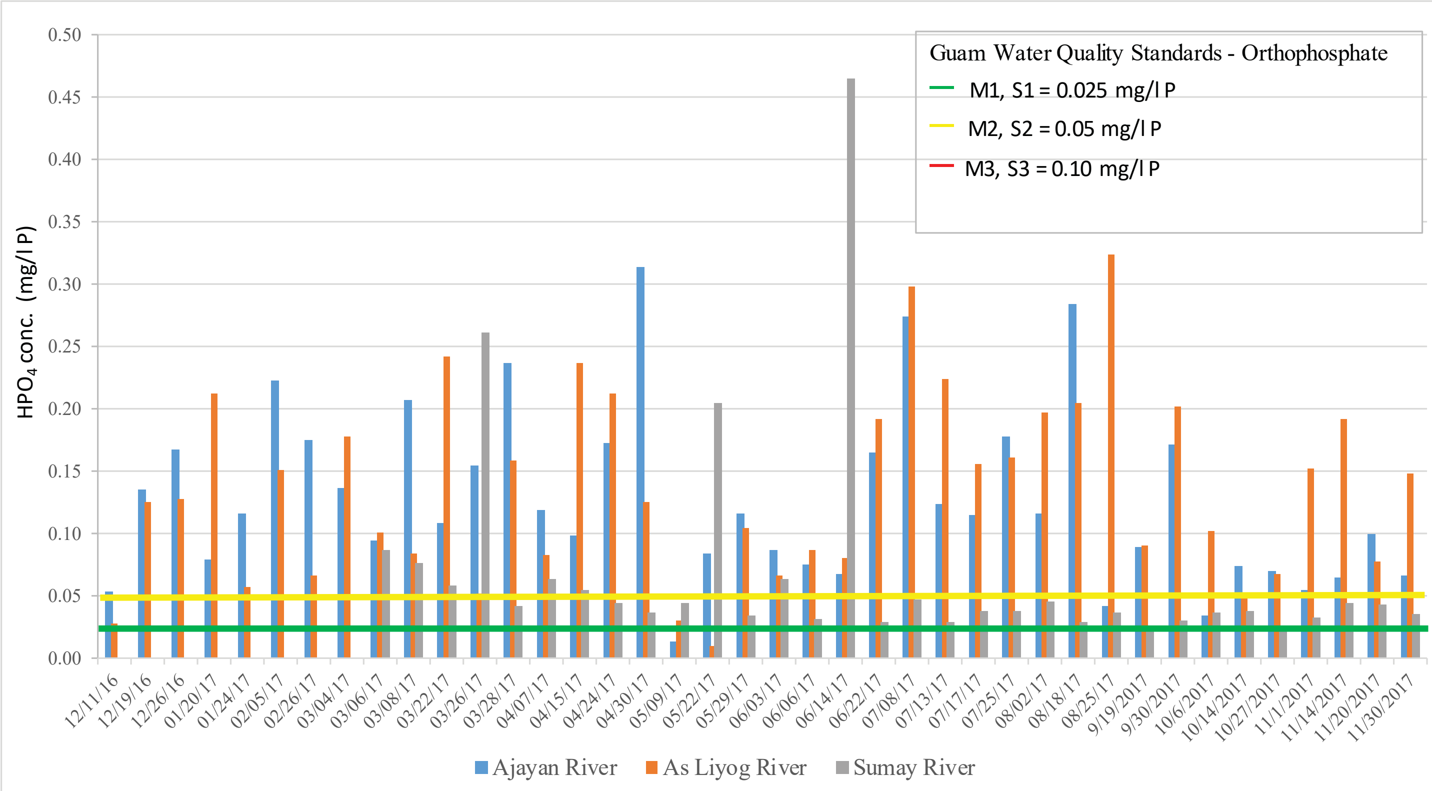

Figure 16a. Orthophosphate ($HPO_4^{=}$) concentrations (mg/l) in the three rivers for the period 12/11/2016-11/30/17 compared to Guam water quality standards.

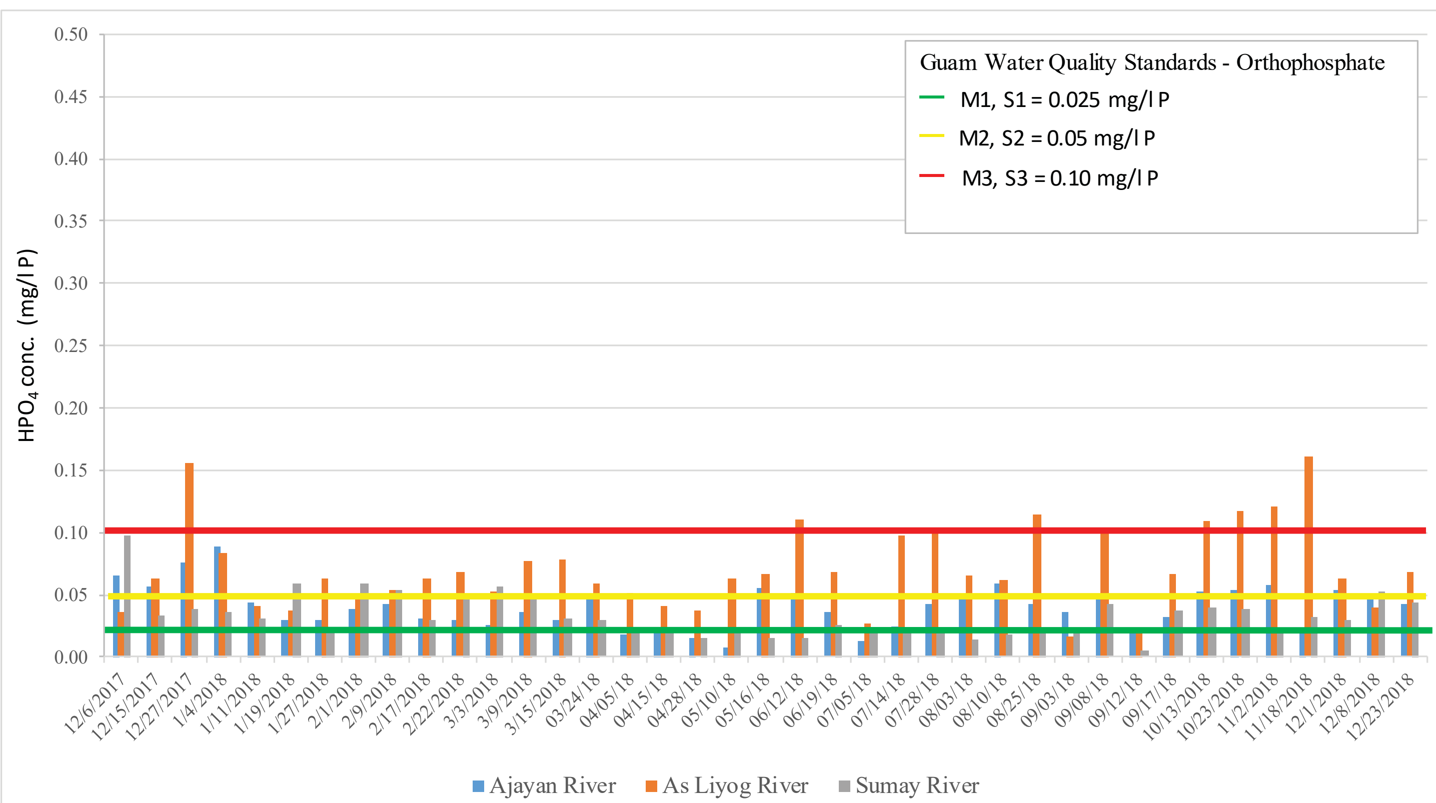

Figure 16b. Orthophosphate ($HPO_4^{=}$) concentrations (mg/l) in the three rivers for the period 12/6/2017 - 12/23/2018 compared to Guam water quality standards

It's possible there is a link between revegetation of the hillsides either through restoration efforts (e.g., replanting of native species of plants) or natural regrowth of grasses after wildfires, to reduced inputs of SSC and orthophosphate into the rivers. However, additional monitoring would be necessary to better understand the relationship between ground cover and inputs of SSC over time.

In the Togcha River on the southeast coast of Guam, Nadeau and Denton (2016) detected orthophosphate up to 0.02 mg/l P, lower than what was found in the current study. In their study in the popular tourist areas of Agana Bay and Tumon Bay on the west coast of Guam, Denton *et al*. (2005) found levels of orthophosphate, ranging from 0.13 to 0.31 mg/l P in Agana Bay, and in Tumon Bay orthophosphate concentrations ranged from below detection limit to 0.39 mg/l P, similar to the range found in the current study. A review of STORET data (WQP, 2019), indicated a mean orthophosphate concentration of 0.22 ±0.01 mg/g P for Guam environmental sampling, slightly above the mean found in the current study.

Other Nutrients

The results from the analysis of other nutrients can be seen in Table 6 and in Appendix C. Results for a couple of the additional nutrients are summarized below.

Ammonium**.** The mean concentration of ammonium was 0.07 ±0.00 mg/l N. The highest concentration detected during this project was 0.25 mg/l N (Table 6). A Kruskal-Wallis analysis indicated a significant (Chi-Square = 54.0382, $p < 0.0001$) difference in the ammonium concentration among sites, and that the Liyog River site was significantly higher. Ammonium was significantly correlated with Hach turbidity (Spearman's Rho = 0.2776, $p < 0.0001$), and with SSC (Spearman's Rho = 0.5052, $p < 0.0001$). Ammonium was correlated with water level in the As Liyog (Spearman's Rho = 0.3295, $p < 0.0001$), but not correlated with daily rainfall (Spearman's Rho = -0.0324, p = 0.7809).

The presence of ammonium is pH dependent. At a lower pH (below 7), the ammonia (NH_3) is ionized to ammonium (NH_4^+). The reverse is true at a higher pH. Guam EPA does not have standards for ammonium, but does have standards for ammonia, however it is for toxicity to aquatic animals. The first ammonia standard is the Criteria Chronic Concentration (CCC), which is the 30 day average concentration for all waters that should not be exceeded more than once every three years. The second standard is the Criteria Maximum Concentration or CMC, which is the one hour concentration that should not be exceeded more than once

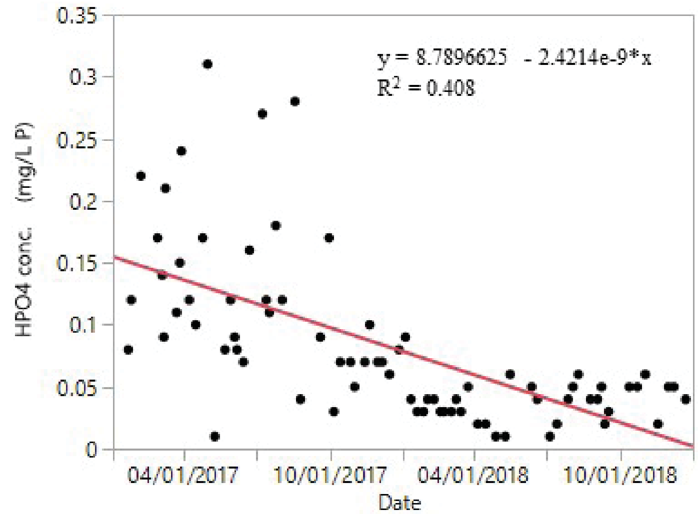

Figure 17a. Orthophosphate over time in water samples from the Ajayan River site.

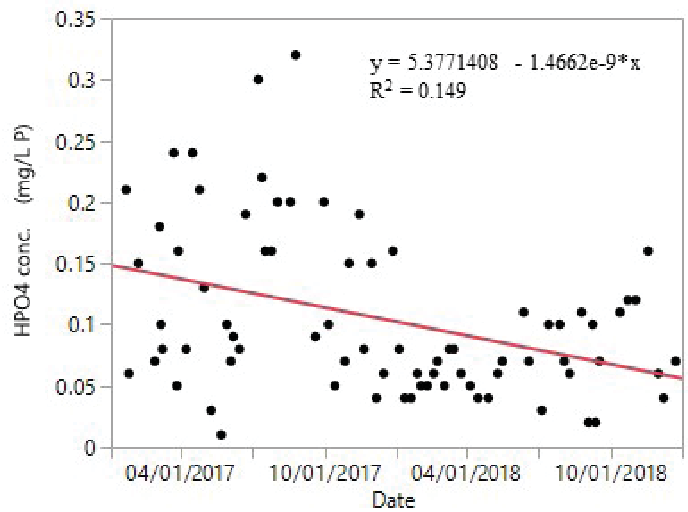

Figure 17b. Orthophosphate over time in water samples from the As Liyog River site.

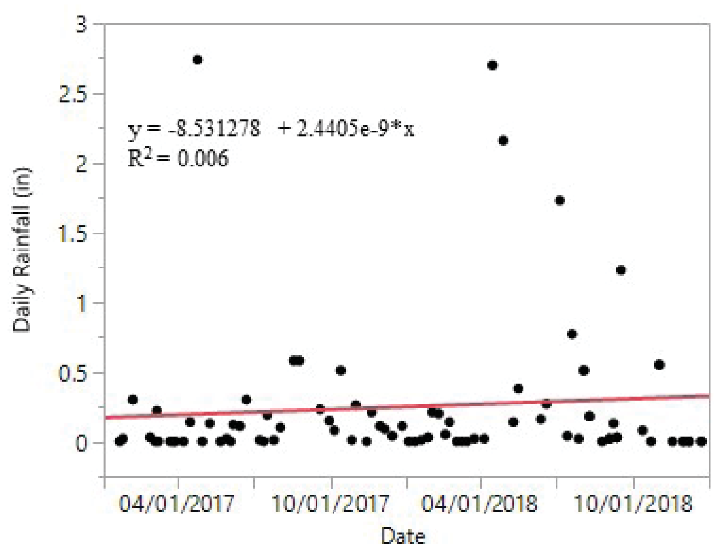

Figure 17c. Rainfall in the Manell watershed study area over time.

every three years. At a pH of 7.5, the CCC is 2.28 mg/l N; at a pH of 8, the CCC is 1.27 mg/l N. At a pH of 7.5, the CMC is 19.9 mg/l N; at a pH of 8, the CMC is 8.40. The highest concentration of ammonium found in this study was 0.25 mg/l N. At a pH between 7 and 8, approximately 10 to 20 percent of the ammonium would be in the ammonia form. Given that, the estimated amount of ammonia present would be below both the CMC and CCC.

As with orthophosphate, ammonium in the water samples varied over time. Plots of the ammonium concentration during the project by river can be seen in Appendix D. The slopes of the lines for ammonium were negative, although the R^2 values for the Ajayan ($R^2 = 0.2834$), As Liyog ($R^2 = 0.1638$), and the Sumay ($R^2 = 0.1939$) river sites were not high.

In the Togcha River in Guam, Nadeau and Denton (2016) detected ammonium ranging from below the detection limit to 2.54 mg/l N, higher than what was found in the current study. In their study in Agana Bay and Tumon Bay, Denton *et al*. (2005) found ammonium concentrations ranging from below the detection limit to 0.23 mg/l N in Agana Bay, and in Tumon Bay ammonium concentrations ranged from below detection limit to 0.39 mg/l N, higher than that found in the current study.

Table 8. Spearman correlations between nutrient species.

Nutrient	by Nutrient	Spearman Rho	Prob>|ρ|
$HPO4^{=}$	NO_3^-	-0.3913	< 0.0001
$HSIO_3$	$HPO4^{=}$	-0.0395	0.5578
$HSIO_3^-$	NO_3^-	0.7228	<0.0001
NH4	$HPO4^{=}$	0.7089	<0.0001
NH4	$HSIO_3^-$	-0.1249	0.0626
NH_4^+	NO_3^-	-0.3905	<0.0001
NO_2^-	NO_3^-	-0.5531	<0.0001
NO_2^-	NH_4^+	0.7416	<0.0001
NO_2^-	$HPO4^{=}$	0.5922	<0.0001
NO_2^-	$HSIO_3^-$	-0.3556	<0.0001
Total N	NO_3^-	0.3999	<0.0001
Total N	NO_2^-	-0.1871	0.0051
Total N	NH_4^+	0.0982	0.1436
Total N	$HPO4^{=}$	0.0682	0.3103
Total N	$HSIO_3^-$	0.2705	<0.0001
Total P	NO_3^-	-0.1894	0.0045
Total P	NO_2^-	0.2792	<0.0001
Total P	NH_4^+	0.4439	<0.0001
Total P	$HPO4^{=}$	0.6976	<0.0001
Total P	$HSIO_3^-$	-0.0596	0.3758
Urea	NO_3^-	-0.369	<0.0001
Urea	NO_2^-	0.6729	<0.0001
Urea	NH_4^+	0.6582	<0.0001
Urea	$HPO4^{=}$	0.5837	<0.0001
Urea	$HSIO_3^-$	-0.1825	0.0063

Silica. The mean concentration of silica ($HSiO_3^-$) was 13.5 ±0.68 mg/l. The highest concentration detected during this study was 40 mg/l at the Sumay River site (Table 6). A Kruskal-Wallis analysis indicated that silica varied by site (Chi-Square = 76.2688, $p < 0.0001$), with all sites being significantly different from one another.

Somewhat surprisingly, silica was negatively correlated with both SSC (Spearman's Rho = -0.2979, $p < 0.0001$ and Hach turbidity (Spearman's Rho = -0.3190, $p < 0.0001$). As silica is sometimes used as an indicator of surface water runoff and erosion from terrestrial areas, it was thought that these two parameters might be linked to silica.

As with ammonium, silica in the water samples varied over time. Plots of the silica concentration by river can be seen in Appendix E. The slopes of the lines for silica over time were negative, but the R^2 values for the Ajayan ($R^2 = 0.17528$), As Liyog ($R^2 = 0.02224$), and the Sumay ($R^2 = 0.23116$) river sites were relatively small.

Urea. Urea (CH_4N_2O) is a product of the metabolism of nitrogen-containing compounds like proteins, formed in the liver from ammonia, and excreted in the urine by mammals. Urea is also used in fertilizers.

The mean concentration of urea in the water samples from the Manell watershed was 0.02 ±0.00 mg/l N. The highest concentration (0.08 mg/l N) was from the Sumay River site. A Kruskal-Wallis nonparametric analysis indicated a significant difference between sites (Chi-Square = 37.1476, $p < .0001$), with all sites being significantly different from one another. Urea, however, was not correlated with daily rainfall (Spearman's Rho = 0.0241, $p = 0.8360$).

Relationships Between Nutrients

Spearman's rank correlation coefficient analysis between nutrients for the three sites in this project can be seen in Table 8. Whitall *et al*. (2013) examined correlations between nutrient species, leaving out those that are autocorrelated (e.g., orthophosphorus and total phosphorus), and found that ammonium, urea and orthophosphorus are associated with runoff, while the oxidized forms of nitrogen (e.g., nitrate) tend to percolate into soils during rainfall events, and eventually into groundwater. The results of the analysis indicated significant correlations between ammonium and urea (Spearman's Rho = 0.6582, $p < 0.001$), ammonium and orthophosphate (Spearman's Rho = 0.7089, $p < 0.0001$), and urea and orthophosphate (Spearman's Rho = 0.5837,

$p < 0.0001$), nutrients more associated with runoff. As noted by Whitall *et al*. (2013), urea and ammonia should be tightly linked as the urea can be converted to ammonium through enzymatic processes.

The more oxidized nitrate were not positively correlated with any of these nutrients. Somewhat surprisingly, however, nitrite (NO_2^-) was negatively correlated with nitrate, and positively correlated with urea, ammonia, and orthophosphate (Table 8). However, this could be a function of the very low detections for nitrite throughout the study (Appendix C).

Silica ($HSiO_3^-$) can be a useful indicator of erosion, as silica accounts for nearly 60 percent of the composition of the Earth's crust. A series of correlations carried out for silica indicated that it was correlated with stream height in the Ajayan (Spearman's Rho = 0.4431, $p < 0.0001$), and the As Liyog (Spearman's Rho = 0.3295, $p < 0.0044$), however, it was not significantly correlated with either Hach turbidity (Spearman's Rho = 0.2242, $p = 0.0548$), or SSC (Spearman's Rho = -0.0563, $p = 0.6559$), which could be an indication of the confounding factors of tidal flow into and out of the Ajayan and As Liyog river sites. Another factor could be a possible decreasing trend in silica concentration over time. Appendix E contains graphs showing the concentration of silica over time at the three sites for this project.

While it appears that a number of nutrient species were predictively positively correlated, there were some that were not correlated as expected. More local sources of nutrient input could also be a factor for the differences. Additional monitoring in these rivers would help in better understanding the sources of the nutrients as well as the possibility of more local inputs.

SUMMARY AND CONCLUSIONS

This project, funded by NOAA's Coral Reef Conservation Program, and requested by local partners, resulted in the monitoring of water quality in three rivers that drain to the Achang Reef Flat Marine Preserve. Local resource managers had expressed concern that inputs from the Manell watershed could be impacting the Achang Preserve. This study described the spatial and temporal variation for a series of parameters including turbidity, suspended sediment concentration (SSC), and nutrients at sites on the Ajayan, As Liyog, and Sumay rivers. The project was carried out to provide a baseline of conditions for these parameters, so that local resource managers could better understand the condition of these rivers, and also provide the means for assessing the efficacy of restoration activities being carried out or planned for the Manell watershed.

The sites monitored on the Ajayan and As Liyog rivers were near where these rivers empty into the Achang Preserve. Because of this, there was some mixing of seawater with the freshwater flowing down the rivers. The Sumay River site was a little further upstream of where it empties into the Achang Preserve. The salinity/conductivity measurements taken reflected the influence of the saline waters from the Achang Preserve at the sites, with much higher readings in the Ajayan and As Liyog site, compared to the Sumay River site. Sites further upstream for the Ajayan and the As Liyog rivers were not possible due to dense jungle that could not be penetrated even with a kayak, along with uncertainties regarding land ownership. A total of 76 sampling events occurred in the Ajayan and As Liyog rivers sites. The Sumay River (71 sampling events) site was added somewhat later in the project. There were times during the project when the collection of water samples for SSC and nutrient analyses could not be carried out due to flood waters covering the roads to the sites, making it too difficult and too dangerous to attempt sample collection.

Automated stream level monitoring was carried out during the course of the project in the Ajayan and As Liyog rivers; the water level in the Sumay River was too low for the automated stream level monitoring. At the Ajayan River site, an automated turbidity logger was also put in place. An automated rain gauge was established further up in the Manell watershed as well. Results indicated that stream level, which was used as a proxy for stream flow, was correlated positively with rainfall in the Ajayan and As Liyog rivers. At the Ajayan River site, rainfall was correlated with turbidity from the automated logger. Stream level also varied during the year. Results for stream level were classified as occurring either in the wet season (approximately May through November), or the dry season (approximately December through April). It was found that stream level for both the Ajayan and As Liyog river sites were positively correlated with this grouping, that is, higher stream levels were associated with the wet season.

The results from the monitoring of SSC, turbidity, nitrate, and orthophosphate were compared to the Guam Environmental Protection Agency water quality standards. The marine and surface waters in Guam have been classified according to their expected water quality. Waters are classified as either excellent, good or fair, and have assigned water quality standards for various parameters, and the concentrations of those parameters needed to achieve the expected or desired water quality. The area where this project was carried out was classified in the excellent to good range.

SSC was found to vary across the sites in the three rivers. The mean concentration of SSC at the As Liyog River site was in the good to fair range for SSC. The mean SSC values for the Ajayan and Sumay river sites were in the excellent to good water quality range.

In addition to the automated turbidity readings at the Ajayan River site, turbidity readings were also taken with a Hach turbidimeter during each round of water sample collections. Results indicated that turbidity was correlated with SSC and water level. The Guam water quality standard for turbidity is set between 0.5 and 1.0 NTUs (nephelometric turbidity units) above the ambient concentration. For this study, the mean turbidity measurement across sites was used as the ambient concentration. Given that, there were a number of times when the water quality was only in the good to fair range for turbidity in both the Ajayan and the As Liyog river sites. In some cases, the exceedence of the standard appeared to be linked to significant rainfall events.

Measurements of nitrate and orthophosphate from the three sites were also compared to the Guam water quality standards. The overall mean nitrate concentration for the three river sites was in the excellent range. However, for the Sumay River, nitrate was frequently only in the good to fair range. It is not clear why the nitrate concentration in the Sumay River site was higher than at the Ajayan and As Liyog sites. Because the Sumay River site was a little further upstream than the sites on either the Ajayan or As Liyog rivers, there may have been less mixing with seawater.

For orthophosphate, the mean concentration across sites was in the good to fair range. The As Liyog River site had the highest mean orthophosphate concentration, and was in the fair range.

During the project, a possible temporal trend was seen for a number of parameters. The concentrations of SSC, orthophosphate, and perhaps ammonium and silica showed some evidence of a negative or downward slope in concentrations over time. Although the R^2 or coefficient of determination for these parameters was not high, there was at least the suggestion of a downward trend in the concentration of these parameters across sites over time. Rainfall amounts during the two years of this project appeared to be normal, with typical wet and dry season rainfall amounts.

Erosion has been a serious issue in the Manell watershed. Grazing by feral animals, the presence of off-roading vehicles, and in particular wildfires set by poachers, all likely promote the erosion of soils through the removal of vegetative cover from the steep hillsides, and along stream banks. There have been various watershed restoration efforts including public education and outreach, planting of native species, and the installation of riparian buffer strips. In addition to these restoration efforts, the effects of wildfires leaving the soil bare, followed by revegetation either naturally or enhanced as a part of ongoing restoration efforts, could all result in a decrease of bare soils present, and perhaps a detectable reduction in parameters related to erosion.

If the apparent decreases in SSC, orthophosphate, ammonium and silica seen during the course of this project are real and are linked to decreases in runoff from the watershed, it would suggest the need for continued restoration efforts, as well as public education and outreach. Even if a reduction in erosion was due to natural revegetation of the hillsides following wildfires, it would still point to the need for continued public education and outreach, to further reduce the incidence of the wildfires, and also highlight the need for a continuation of the replanting efforts in the watershed. As noted earlier, since the establishment of the Achang Preserve, fish stocks there have increased relative to the rest of Cocos Lagoon. Given that, reductions in the input of sediments and nutrients into the Achang Preserve would likely benefit the Preserve, and the rest of Cocos Lagoon.

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Appendix A. Results of water quality monitoring in the Manell Watershed, Guam.

Location	ID	Date	Time	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Conductivity (µs/cm)	Salinity (ppt)	Turbidity (NTU)	SSC (mg/l)
Liyog Bridge	L001-01	12/11/2016	1625	32.3	7.39	100	48,124	30.90	6.99	
Ajayan Bridge	A001-01	12/11/2016	1700	31.0	5.15	73.5	40,274	26.88	4.51	
Liyog Bridge	L002-01	12/19/2016	1640	29.1	5.99	90.1	44,106	28.36	24.80	
Ajayan Bridge	A002-01	12/19/2016	1700	29.3	5.80	88.4	41,448	26.73	5.31	
Liyog Bridge	L003-01	12/26/2016	1615	31.6	6.02	95.1	46,435	30.13	21.35	
Ajayan Bridge	A003-01	12/26/2016	1650	30.1	5.46	75.5	14,515	11.54	11.35	
Liyog Bridge	L004-01	1/20/2017	1525	31.0	6.48	100	48,122	31.25	13.95	
Ajayan Bridge	A004-01	1/20/2017	1610	28.8	5.83	80.5	14,681	8.83	9.50	
Liyog Bridge	L005-01	1/24/2017	1610	30.4	6.11	97.7	49,081	31.89	8.73	
Ajayan Bridge	A005-01	1/24/2017	1635	29.2	5.79	86.2	40,965	25.50	4.23	
Liyog Bridge	L006-01	2/5/2017	1610	30.7	6.20	95.1	47,160	30.55	8.88	
Ajayan Bridge	A006-01	2/5/2017	1625	29.0	5.36	78.2	33,349	20.83	4.95	
Liyog Bridge	L007-01	2/26/2017	1650	31.8	5.65	89.9	49,420	32.07	9.14	
Ajayan Bridge	A007-01	2/26/2017	1710	30.5	5.48	82.7	36,655	22.54	3.78	
Liyog Bridge	L008-01	3/4/2017	1540	28.9	3.54	54.0	41,469	26.51	4.27	
Ajayan Bridge	A008-01	3/4/2017	1605	30.4	4.53	70.7	42,315	27.12	2.70	
Liyog Bridge	L009-01	3/6/2017	925	27.0	78.70	78.7	49,559	32.44	14.65	
Ajayan Bridge	A009-01	3/6/2017	1000	27.8	4.10	60.9	40,800	26.55	5.45	
Sumay Bridge	S009-01	3/6/2017	1010	28.2	4.30	59.5	21,723	12.74	5.41	
Liyog Bridge	L010-01	3/8/2017	1700	30.3	5.02	79.8	47,887	31.05	8.90	
Ajayan Bridge	A010-01	3/8/2017	1720	31.2	3.12	48.6	40,277	25.52	4.98	
Sumay Bridge	S010-01	3/8/2017	1735	28.8	3.94	52.5	9,360	4.09	2.87	
Liyog Bridge	L011-01	3/22/2017	1700	34.1	5.75	97.6	48,966	31.64	14.85	
Ajayan Bridge	A011-01	3/22/2017	1735	30.9	4.39	65.4	26,624	16.37	8.03	
Sumay Bridge	S011-01	3/22/2017	1755	28.4	3.71	48.1	1,412	0.70	1.57	
Liyog Bridge	L012-01	3/26/2017	1735	32.4	5.87	96.5	49,443	32.64	7.32	
Sumay Bridge	S012-01	3/26/2017	1750	32.1	5.23	80.4	36,239	24.31	2.67	
Ajayan Bridge	A012-01	3/26/2017	1800	33.1	4.29	70.4	44,141	28.61	4.40	
Liyog Bridge	L013-01	3/28/2017	1545	34.4	5.66	95.5	49,323	31.82	13.60	
Sumay Bridge	S013-01	3/28/2017	1605	28.3	3.81	49.0	1,674	0.84	3.68	
Ajayan Bridge	A013-01	3/28/2017	1620	31.9	4.41	66.6	34,327	21.23	8.12	
Liyog Bridge	L014-01	4/7/2017	1550	33.7	5.39	90.1	49,585	32.15	9.54	
Sumay Bridge	S014-01	4/7/2017	1605	30.1	4.57	64.6	15,004	8.52	2.44	
Ajayan Bridge	A014-01	4/7/2017	1625	34.5	3.89	64.6	39,793	25.31	5.31	
Liyog Bridge	L015-01	4/15/2017	1650	30.8	1.39	21.1	36,039	22.69	26.80	35.60
Sumay Bridge	S015-01	4/15/2017	1720	28.3	3.51	45.5	1,635	0.82	2.04	4.80
Ajayan Bridge	A015-01	4/15/2017	1735	33.3	4.26	68.0	45,418	29.23	3.39	11.20
Liyog Bridge	L016-01	4/24/2017	1330	30.2	4.50	65.5	36,144	22.61	16.70	24.00
Sumay Bridge	S016-01	4/24/2017	1405	28.6	3.68	47.7	1,683	0.84	2.82	3.40
Ajayan Bridge	A016-01	4/24/2017	1430	31.3	2.24	32.6	23,766	14.62	7.11	9.60
Liyog Bridge	L017-01	4/30/2017	1805	31.6	4,27	62.8	21,809	12.77	14.10	20.40
Sumay Bridge	S017-01	4/30/2017	1820	28.4	3.60	46.5	1,802	0.90	1.84	2.30
Ajayan Bridge	A017-01	4/30/2017	1840	31.9	4.77	73.7	33,584	21.07	6.75	11.40
Liyog Bridge	L018-01	5/9/2017	1540	35.0	5.80	95.0	46,410	29.94	13.60	24.80
Sumay Bridge	S018-01	5/9/2017	1550	28.7	3.48	45.3	2,265	1.15	1.86	2.60
Ajayan Bridge	A018-01	5/9/2017	1615	35.0	4.07	69.9	49,298	32.04	4.40	12.20
Liyog Bridge	L019-01	5/22/2017	1600	32.7	5.62	93.5	51,121	33.32	9.62	17.60
Sumay Bridge	S019-01	5/22/2017	1615	31.6	5.43	83.1	34,197	21.33	4.16	8.93
Ajayan Bridge	A019-01	5/22/2017	1630	33.1	5.07	82.7	45,331	29.22	4.08	8.40
Liyog Bridge	L020-01	5/29/2017	1250	30.6	3.68	57.9	45,400	29.28	16.90	35.40
Sumay Bridge	S020-01	5/29/2017	1305	29.3	2.79	37.1	6,448	3.52	2.90	8.20
Ajayan Bridge	A020-01	5/29/2017	1320	31.7	3.72	58.4	40,303	25.46	3.34	8.40
Liyog Bridge	L021-01	6/3/2017	1705	33.7	4.95	82.9	48,714	31.48	9.34	16.00
Sumay Bridge	S021-01	6/3/2017	1730	30.0	3.91	53.5	10,583	6.00	2.45	3.40
Ajayan Bridge	A021-01	6/3/2017	1755	34.6	5.32	88.1	44,737	28.62	4.08	8.60
Ajayan Bridge	A022-01	6/6/2017	1025	31.2	2.50	39.5	45,083	29.01	6.10	12.80
Liyog Bridge	L022-01	6/6/2017	1045	31.2	2.36	36.9	42,650	27.23	11.25	18.80
Sumay Bridge	S022-01	6/6/2017	1105	29.0	3.29	43.2	2,732	1.42	2.15	3.00
Sumay Bridge	S023-01	6/14/2017	1112	30.0	3.35	51.6	33,345	21.09	2.53	3.33
Liyog Bridge	L023-01	6/14/2017	1132	30.6	3.34	53.5	49,788	32.35	12.10	22.40
Ajayan Bridge	A023-01	6/14/2017	1144	31.4	3.98	65.7	50,862	33.35	3.29	5.60
Ajayan Bridge	A024-01	6/22/2017	1344	33.3	5.02	77.2	29,617	18.79	9.27	10.27
Liyog Bridge	L024-01	6/22/2017	1412	31.2	0.96	16.1	50,240	32.72	24.10	29.40
Sumay Bridge	S024-01	6/22/2017	1435	28.6	3.56	45.4	1,976	1.00	14.25	36.80
Liyog Bridge	L025-01	7/8/2017	1235	32.7	2.53	38.8	29,777	18.29	10.55	19.00

Notes: mg/l, milligrams/liter; µs/cm, microsiemens/centimeter; ppt, parts per thousand; NTU, nephelometric turbidity unit; SSC, suspended sediment concentration

Appendix A. Results of water quality monitoring in the Manell Watershed, Guam (cont.).

Location	ID	Date	Time	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Conductivity (µs/cm)	Salinity (ppt)	Turbidity (NTU)	SSC (mg/l)
Sumay Bridge	S025-01	7/8/2017	1250	29.0	3.16	41.4	2,315	1.09	2.85	12.40
Ajayan Bridge	A025-01	7/8/2017	1310	33.1	2.75	42.1	33,010	20.48	6.20	8.60
Liyog Bridge	L026-01	7/13/2017	1210	30.4	4.83	72.4	45,075	29.96	14.00	14.93
Sumay Bridge	S026-01	7/13/2017	1240	28.8	2.63	34.4	3,245	1.67	4.65	3.33
Ajayan Bridge	A026-01	7/13/2017	1305	32.2	2.83	41.2	17,359	9.94	8.52	4.67
Liyog Bridge	L027-01	7/17/2017	1610	30.1	6.21	95.3	46,992	30.64	15.20	17.60
Sumay Bridge	S027-01	7/17/2017	1625	28.3	3.41	44.0	1,457	0.72	5.37	4.27
Ajayan Bridge	A027-01	7/17/2017	1640	30.3	3.57	52.0	26,571	16.60	8.39	5.60
Liyog Bridge	L028-01	7/25/2017	1415	33.5	3.42	53.4	26,441	16.01	13.10	15.20
Sumay Bridge	S028-01	7/25/2017	1430	29.1	1.82	23.8	2,006	1.02	2.99	3.20
Ajayan Bridge	A028-01	7/25/2017	1445	33.4	2.01	31.1	29,204	17.86	6.28	6.80
Liyog Bridge	L029-01	8/2/2017	955	30.2	2.25	34.3	37,425	23.51	19.10	25.80
Sumay Bridge	S029-01	8/2/2017	1010	28.6	2.81	36.2	2,421	1.25	2.92	2.67
Ajayan Bridge	A029-01	8/2/2017	1030	31.3	2.19	32.4	26,353	15.92	3.43	3.87
Liyog Bridge	L030-01	8/18/2017	920	30.4	1.60	25.4	49,865	32.48	15.55	25.49
Sumay Bridge	S030-01	8/18/2017	930	28.5	3.03	39.7	3,322	1.73	3.39	2.50
Ajayan Bridge	A030-01	8/18/2017	940	31.1	2.20	33.0	31,338	19.25	8.53	6.73
Liyog Bridge	L031-01	8/25/2017	1310	31.9	4.45	71.0	42,447	26.73	34.35	21.06
Sumay Bridge	S031-01	8/25/2017	1325	28.3	3.53	45.9	3,321	1.61	32.35	5.00
Ajayan Bridge	A031-01	8/25/2017	1340	28.5	3.65	48.7	8,508	4.77	64.55	8.87
Sumay Bridge	S032-01	9/19/2017	830	28.4	2.83	37.1	12,060	6.75	9.81	5.33
Liyog Bridge	L032-01	9/19/2017	850	29.4	2.44	37.4	49,149	32.35	15.45	19.21
Ajayan Bridge	A032-01	9/19/2017	910	30.1	2.73	41.4	35,882	21.56	7.62	13.27
Liyog Bridge	L033-01	9/30/2017	855	29.8	1.35	20.4	42,137	27.38	17.80	32.14
Sumay Bridge	S033-01	9/30/2017	910	28.2	3.74	48.0	1,838	0.91	4.74	1.52
Ajayan Bridge	A033-01	9/30/2017	925	30.7	2.91	45.0	44,898	28.52	6.45	6.83
Liyog Bridge	L034-01	10/6/2017	1120	29.9	2.94	24.6	39,551	24.97	10.30	10.99
Sumay Bridge	S034-01	10/6/2017	1135	28.9	2.86	38.5	10,998	5.40	4.06	3.01
Ajayan Bridge	A034-01	10/6/2017	1150	31.1	3.66	54.4	24,593	14.90	6.63	3.39
Liyog Bridge	L035-01	10/14/2017	1055	27.2	6.70	83.3	683	0.33	146.00	129.06
Sumay Bridge	S035-01	10/14/2017	1110	27.3	4.79	60.2	586	0.28	75.55	50.60
Ajayan Bridge	A035-01	10/14/2017	1145	26.6	6.26	78.1	498	0.24	135.50	82.17
Liyog Bridge	L036-01	10/27/2017	1655	33.5	4.41	72.8	43,386	27.26	3.38	35.00
Sumay Bridge	S036-01	10/27/2017	1710	28.6	3.30	43.2	1,469	0.73	2.24	3.43
Ajayan Bridge	A036-01	10/27/2017	1735	30.8	4.86	73.5	35,236	22.04	4.33	5.98
Liyog Bridge	L037-01	11/1/2017	835	28.9	2.33	36.3	43,922	27.67	7.46	8.60
Sumay Bridge	S037-01	11/1/2017	850	28.3	3.11	40.4	1,619	0.81	2.96	11.89
Ajayan Bridge	A037-01	11/1/2017	900	29.6	2.86	43.0	39,094	24.77	3.91	4.77
Liyog Bridge	L038-01	11/14/2017	1100	29.4	2.87	41.3	28,834	18.81	9.61	4.53
Sumay Bridge	S038-01	11/14/2017	1125	28.5	3.39	43.9	1,549	0.77	3.99	2.68
Ajayan Bridge	A038-01	11/14/2017	1155	30.4	3.76	58.4	44,017	28.24	5.30	7.48
Liyog Bridge	L039-01	11/20/2017	1405	30.2	3.57	55.6	49,862	29.30	----	14.93
Sumay Bridge	S039-01	11/20/2017	1420	28.9	2.84	37.1	1,693	0.85	----	4.33
Ajayan Bridge	A039-01	11/20/2017	1430	30.7	3.73	59.1	47,551	30.78	----	5.36
Liyog Bridge	L040-01	11/30/2017	1040	28.2	2.55	36.9	34,725	21.75	18.00	27.61
Sumay Bridge	S040-01	11/30/2017	1050	28.3	3.04	39.2	1,479	0.74	4.60	4.15
Ajayan Bridge	A040-01	11/30/2017	1105	28.9	3.91	59.5	44,894	28.92	7.05	11.28
Liyog Bridge	L041-01	12/6/2017	1145	28.8	5.30	82.3	50,645	33.10	23.20	27.06
Sumay Bridge	S041-01	12/6/2017	1210	29.2	5.07	73.0	29,252	17.89	4.61	6.50
Ajayan Bridge	A041-01	12/6/2017	1220	29.5	4.90	74.5	42,091	26.89	4.16	5.43
Liyog Bridge	L042-01	12/15/2017	1105	28.6	4.62	70.2	45,593	29.43	13.15	32.80
Sumay Bridge	S042-01	12/15/2017	1115	26.6	3.59	46.6	1,474	0.73	5.96	9.39
Ajayan Bridge	A042-01	12/15/2017	1130	29.3	3.67	54.1	34,664	21.68	4.54	4.92
Liyog Bridge	L043-01	12/27/2017	905	28.4	3.53	50.8	32,888	20.48	13.95	17.97
Sumay Bridge	S043-01	12/27/2017	935	28.0	3.77	48.3	1,455	0.72	2.18	3.53
Ajayan Bridge	A043-01	12/27/2017	955	29.1	2.61	39.1	39,566	25.12	5.58	5.88
Liyog Bridge	L044-01	1/4/2018	1540	29.2	4.13	63.0	44,230	28.43	13.40	25.81
Sumay Bridge	S044-01	1/4/2018	1600	28.5	3.49	45.3	2,008	1.02	4.68	7.89
Ajayan Bridge	A044-01	1/4/2018	1610	30.3	3.15	48.4	41,131	26.19	5.09	5.89
Liyog Bridge	L045-01	1/11/2018	1045	27.8	6.35	95.5	46,100	29.82	22.85	47.65
Sumay Bridge	S045-01	1/11/2018	1100	28.1	3.64	46.8	1,527	0.76	4.51	3.82
Ajayan Bridge	A045-01	1/11/2018	1115	30.3	3.51	54.3	43,138	27.62	3.41	6.25
Liyog Bridge	L046-01	1/19/2018	1605	29.0	5.04	77.6	47,090	30.50	22.90	42.24
Sumay Bridge	S046-01	1/19/2018	1620	28.7	4.00	52.5	4,553	2.41	9.22	8.24
Ajayan Bridge	A046-01	1/19/2018	1635	30.4	3.64	50.7	14,121	8.11	7.26	5.53

Notes: mg/l, milligrams/liter; µs/cm, microsiemens/centimeter; ppt, parts per thousand; NTU, nephelometric turbidity unit; SSC, suspended sediment concentration

Appendix A. Results of water quality monitoring in the Manell Watershed, Guam (cont.).

Location	ID	Date	Time	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Conductivity (µs/cm)	Salinity (ppt)	Turbidity (NTU)	SSC (mg/l)
Liyog Bridge	L047-01	1/27/2018	900	25.9	4.86	70.8	46,212	29.96	12.45	24.73
Sumay Bridge	S047-01	1/27/2018	910	27.9	3.78	48.2	1,450	0.72	3.08	5.09
Ajayan Bridge	A047-01	1/27/2018	925	28.3	4.29	56.3	7,870	4.33	5.30	4.76
Liyog Bridge	L048-01	2/1/2018	1445	28.8	4.98	76.3	47,018	30.46	17.25	31.49
Sumay Bridge	S048-01	2/1/2018	1455	28.5	4.21	54.6	1,816	0.91	7.97	8.18
Ajayan Bridge	A048-01	2/1/2018	1510	30.1	3.54	50.5	22,179	13.26	7.66	5.45
Liyog Bridge	L049-01	2/9/2018	1600	30.1	5.33	84.3	49,747	32.40	40.55	113.25
Sumay Bridge	S049-01	2/9/2018	1615	28.2	4.31	55.8	3,667	1.92	23.10	34.27
Ajayan Bridge	A049-01	2/9/2018	1650	30.9	4.61	71.4	41,318	26.30	4.39	6.17
Liyog Bridge	L050-01	2/17/2018	1440	29.7	5.63	88.2	48,944	31.83	30.80	66.67
Sumay Bridge	S050-01	2/17/2018	1455	28.7	3.38	43.9	1,600	0.80	5.14	4.20
Ajayan Bridge	A050-01	2/17/2018	1505	31.3	3.28	46.3	14,188	8.14	4.73	4.71
Liyog Bridge	L051-01	2/22/2018	1620	28.5	4.31	65.4	45,598	29.44	13.85	24.40
Sumay Bridge	S051-01	2/22/2018	1635	28.6	1.16	15.2	7,089	3.87	6.67	8.21
Ajayan Bridge	A051-01	2/22/2018	1650	31.1	5.17	72.2	11,358	6.40	8.41	6.18
Liyog Bridge	L052-01	3/3/2018	1405	29.3	4.91	76.4	48,731	31.69	21.75	39.00
Sumay Bridge	S052-01	3/3/2018	1420	28.5	0.97	12.7	7,429	4.07	2.81	4.17
Ajayan Bridge	A052-01	3/3/2018	1430	32.0	2.99	43.2	17,448	10.18	5.14	6.37
Liyog Bridge	L053-01	3/9/2018	1645	27.9	3.61	54.1	44,906	28.96	12.15	14.03
Sumay Bridge	S053-01	3/9/2018	1700	28.4	0.72	9.5	9,061	5.04	5.60	11.49
Ajayan Bridge	A053-01	3/9/2018	1720	32.4	3.63	52.3	14,705	8.45	10.25	5.90
Ajayan Bridge	A054-01	3/15/2018	1035	29.7	3.71	50.7	12,293	6.99	5.58	2.73
Liyog Bridge	L054-01	3/15/2018	1050	28.0	4.02	63.6	49,187	12.06	16.00	25.27
Sumay Bridge	S054-01	3/15/2018	1115	28.4	2.97	38.4	2,337	1.19	5.76	4.96
Liyog Bridge	L055-01	3/24/2018	1640	28.7	3.65	55.4	44,821	28.87	15.05	25.49
Sumay Bridge	S055-01	3/24/2018	1650	28.6	2.01	26.1	2,210	1.12	5.96	11.88
Ajayan Bridge	A055-01	3/24/2018	1700	31.5	4.39	64.7	25,190	15.22	5.88	4.98
Liyog Bridge	L056-01	4/5/2018	1605	32.0	3.30	52.3	42,298	26.97	11.10	19.68
Sumay Bridge	S056-01	4/5/2018	1620	29.1	0.53	7.0	5,540	2.97	4.18	6.34
Ajayan Bridge	A056-01	4/5/2018	1640	31.8	3.73	52.8	12,391	7.03	9.69	10.41
Liyog Bridge	L057-01	4/15/2018	1405	26.8	6.24	78.4	1,469	0.73	66.05	14.67
Sumay Bridge	S057-01	4/15/2018	1415	27.2	4.31	54.5	917	0.45	31.55	12.93
Ajayan Bridge	A057-01	4/15/2018	1625	26.4	6.11	76.1	765	0.37	62.45	9.79
Sumay Bridge	S058-01	4/28/2018	1340	28.3	0.29	3.8	1,438	0.72	22.60	8.26
Liyog Bridge	L058-01	4/28/2018	1350	29.2	1.70	23.1	12,280	6.98	49.60	11.52
Ajayan Bridge	A058-01	4/28/2018	1410	28.7	5.60	72.7	1,340	0.66	52.70	4.14
Liyog Bridge	L059-01	5/10/2018	1725	33.8	5.22	84.8	41,533	26.36	8.77	8.74
Sumay Bridge	S059-01	5/10/2018	1740	28.6	3.29	42.6	1,620	0.81	2.30	3.70
Ajayan Bridge	A059-01	5/10/2018	1755	31.7	6.15	91.8	27,768	16.93	1.99	3.64
Liyog Bridge	L060-01	5/16/2018	1345	32.2	3.32	52.2	39,553	25.02	9.73	11.21
Sumay Bridge	S060-01	5/16/2018	1405	29.9	6.47	88.2	10,434	5.85	2.57	2.01
Ajayan Bridge	A060-01	5/16/2018	1420	33.3	3.44	55.5	41,556	26.40	4.70	6.78
Liyog Bridge	L061-01	6/12/2018	1105	29.2	6.51	96.9	37,911	24.12	12.95	5.23
Sumay Bridge	S061-01	6/12/2018	1120	28.4	3.67	47.3	1,354	0.67	5.22	2.90
Ajayan Bridge	A061-01	6/12/2018	1140	30.6	4.37	66.9	39,194	24.81	4.13	5.23
Liyog Bridge	L062-01	6/19/2018	1540	31.0	4.18	63.5	35,417	22.16	5.82	8.12
Sumay Bridge	S062-01	6/19/2018	1600	28.6	2.86	37.1	1,808	0.91	2.49	2.06
Ajayan Bridge	A062-01	6/19/2018	1615	32.3	4.61	71.8	36,569	22.93	3.21	3.93
Liyog Bridge	L063-01	7/5/2018	1625	26.7	6.23	78.1	1,391	0.69	18.75	42.29
Sumay Bridge	S063-01	7/5/2018	1645	27.6	4.60	58.5	978	0.48	54.35	71.57
Ajayan Bridge	A063-01	7/5/2018	1700	26.8	5.95	74.6	1,061	0.52	34.60	4.34
Liyog Bridge	L064-01	7/14/2018	1255	32.4	2.52	36.0	12,576	7.13	----	18.45
Sumay Bridge	S064-01	7/14/2018	1310	28.9	3.02	39.3	1,617	0.81	----	4.95
Ajayan Bridge	A064-01	7/14/2018	1320	30.9	4.21	57.9	8,162	4.49	----	2.40
Geus End of E.R.	G03-65	7/20/2018	1000	26.3	8.05	99.8	265	0.12	----	2.32
Geus Dam	G01-65	7/20/2018	1030	26.2	8.73*	100	246	0.12	----	2.54
Geus Bridge (E.R.)	G00-65	7/20/2018	1100	26.7	7.43	92.8	296	0.14	----	0.72
Geus Bridge (Rt.4)	G02-65	7/20/2018	1115	27.1	6.92	87.1	351	0.17	----	2.73
Liyog Bridge	L065-01	7/28/2018	1255	32.5	3.41	55.1	45,789	29.45	10.75	12.85
Sumay Bridge	S065-01	7/28/2018	1310	29.1	3.81	49.9	1,554	0.78	1.57	1.99
Ajayan Bridge	A065-01	7/28/2018	1330	32.4	3.56	55.2	34,833	21.95	1.74	3.61
Liyog Bridge	L066-01	8/3/2018	1545	30.6	4.24	65.6	42,286	27.00	21.25	19.00
Sumay Bridge	S066-01	8/3/2018	1550	27.9	4.02	51.4	1,110	0.55	9.63	5.71
Ajayan Bridge	A066-01	8/3/2018	1610	29.1	4.66	70.3	41,632	26.58	14.30	8.39
Geus Bridge (Rt.4)	G02-66	8/3/2018	1630	27.2	7.04	89.6	367	0.17	3.55	2.46

Notes: mg/l, milligrams/liter; µs/cm, microsiemens/centimeter; ppt, parts per thousand; NTU, nephelometric turbidity unit; SSC, suspended sediment concentration

Appendix A. Results of water quality monitoring in the Manell Watershed, Guam (cont.).

Location	ID	Date	Time	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (%)	Conductivity (µs/cm)	Salinity (ppt)	Turbidity (NTU)	SSC (mg/l)
Geus Bridge (E.R.)	G00-66	8/3/2018	1650	27.0	7.41	93.0	304	0.14	12.65	14.58
Geus End of E.R.	G03-66	8/3/2018	1700	26.8	7.93	99.2	258	0.12	40.75	24.49
Liyog Bridge	L067-01	8/10/2018	1440	32.8	6.06	98.9	46,636	30.05	7.77	
Sumay Bridge	S067-01	8/10/2018	1455	28.8	4.2	54.5	937	0.46	2.51	4.13
Ajayan Bridge	A067-01	8/10/2018	1510	33.3	8.47*	100	46,896	30.22	7.66	9.23
Geus Bridge (Rt.4)	G02-67	8/10/2018	1525	29.4	7.44	97.6	493	0.23	0.68	1.30
Geus Bridge (E.R.)	G00-67	8/10/2018	1545	28.0	6.57	84.0	429	0.2	0.83	0.97
Geus End of E.R.	G03-67	8/10/2018	1555	27.6	7.28	92.3	414	0.2	0.86	0.98
Geus Dam	G01-67	8/10/2018	1625	26.8	7.7	96.4	384	0.18	1.60	1.37
Liyog Bridge	L068-01	8/25/2018	1435	31.7	2.07	33.4	48,238	31.25	22.55	3.32
Sumay Bridge	S068-01	8/25/2018	1500	28.8	3.88	50.4	1,144	0.56	8.26	4.33
Ajayan Bridge	A068-01	8/25/2018	1525	30.4	7.68*	100	6,448	3.49	26.35	1.40
Liyog Bridge	L069-01	9/3/2018	1550	32.9	6.46*	100	51,180	33.36	4.03	6.92
Sumay Bridge	S069-01	9/3/2018	1605	29.7	4.4	60.0	11,528	6.52	6.33	4.63
Ajayan Bridge	A069-01	9/3/2018	1620	32.9	6.83*	100	48,916	31.7	6.10	4.32
Geus Bridge (Rt.4)	G02-69	9/3/2018	1635	28.9	7.39	96.1	496	0.24	0.95	0.42
Geus Bridge (E.R.)	G00-69	9/3/2018	1650	27.0	6.72	84.4	428	0.2	1.01	0.38
Geus End of E.R.	G03-69	9/3/2018	1700	26.4	6.82	84.7	417	0.2	1.62	0.75
Geus Dam	G01-69	9/3/2018	1735	26.4	7.67	95.3	415	0.2	1.90	0.56
Liyog Bridge	L070-01	9/8/2018	1225	30.0	3.2	50.2	47,730	30.94	16.35	8.17
Sumay Bridge	S070-01	9/8/2018	1240	29.2	6.7	88.0	2,129	1.08	5.17	1.81
Ajayan Bridge	A070-01	9/8/2018	1250	30.4	3.51	50.4	23,061	13.83	23.40	5.81
Sumay Bridge	S071-01	9/12/2018	1350	28.6	4.28	55.4	1,066	0.52	7.76	2.77
Ajayan Bridge	A071-01	9/12/2018	1410	28.7	5.2	70.5	14,895	8.61	13.40	5.29
Liyog Bridge	L071-01	9/12/2018	1425	29.3	4.67	62.2	6,082	3.28	17.20	16.14
Geus Bridge (Rt.4)	G02-71	9/12/2018	1440	28.8	6.55	84.9	391	0.19	2.69	1.02
Geus Bridge (E.R.)	G00-71	9/12/2018	1450	27.7	6.81	86.7	3,397	0.16	3.30	0.39
Geus End of E.R.	G03-71	9/12/2018	1500	27.6	7.68	97.6	309	0.15	5.15	2.98
Geus Dam	G01-71	9/12/2018	1535	27.6	7.78	98.7	279	0.13	3.66	1.77
Liyog Bridge	L072-01	9/17/2018	1625	32.6	7.57*	100	50,334	32.75	12.60	4.86
Sumay Bridge	S072-01	9/17/2018	1640	28.6	4.41	57.1	1,051	0.52	14.40	1.81
Ajayan Bridge	A072-01	9/17/2018	1650	31.3	7.19*	100	39,445	24.97	9.33	3.29
Liyog Bridge	L073-01	10/13/2018	1455	32.3	5.33	87.2	49,349	32.04	8.13	11.21
Sumay Bridge	S073-01	10/13/2018	1510	28.8	4.41	57.3	1,324	0.66	3.38	1.62
Ajayan Bridge	A073-01	10/13/2018	1555	31.3	4.47	71.2	46,189	29.78	4.34	5.63
Liyog Bridge	L074-01	10/23/2018	1000	28.9	3.69	56.9	48,018	31.18	6.17	5.94
Sumay Bridge	S074-01	10/23/2018	1010	28.3	3.57	46.1	1,220	0.6	3.43	1.45
Ajayan Bridge	A074-01	10/23/2018	1025	29.7	2.77	43.6	50,159	32.72	1.13	4.72
Liyog Bridge	L075-01	11/2/2018	830	29.7	2.00	31.0	46,150	29.8	9.99	9.84
Sumay Bridge	S075-01	11/2/2018	850	28.2	3.73	47.9	1,255	0.62	4.97	3.83
Ajayan Bridge	A075-01	11/2/2018	900	29.8	3.24	51.1	49,453	32.2	4.12	4.82
Geus Bridge (Rt.4)	G02-75	11/2/2018	930	27.7	7.70	98.0	470	0.22	1.32	0.51
Geus Bridge (E.R.)	G00-75	11/2/2018	945	27.2	6.77	85.2	400	0.19	2.24	0.38
Geus End of E.R.	G03-75	11/2/2018	955	26.9	7.03	88.1	379	0.18	2.99	0.19
Geus Dam	G01-75	11/2/2018	1030	26.7	7.65	95.6	354	0.17	3.14	0.59
Liyog Bridge	L076-01	11/18/2018	1035	31.0	0.77	12.3	47,912	31.03	12.30	6.27
Sumay Bridge	S076-01	11/18/2018	1050	28.6	3.77	48.8	1,170	0.58	3.42	2.85
Ajayan Bridge	A076-01	11/18/2018	1105	30.0	3.34	52.9	50,821	33.2	5.54	2.89
Geus Bridge (Rt.4)	G02-77	12/1/2018	1525	29.4	8.93*	100	412	0.2	1.12	1.77
Geus Bridge (E.R.)	G00-77	12/1/2018	1545	27.5	7.06	89.5	351	0.17	3.04	1.44
Ajayan Bridge	A077-01	12/1/2018	1620	31.6	5.02	80.6	47,351	30.61	3.97	4.10
Liyog Bridge	L077-01	12/1/2018	1635	34.3	7.69*	100	45,178	28.95	4.81	5.76
Sumay Bridge	S077-01	12/1/2018	1650	28.5	3.53	45.7	1,202	0.59	2.48	2.91
Liyog Bridge	L078-01	12/8/2018	1135	28.3	4.91	74.4	45,828	29.61	7.53	13.59
Sumay Bridge	S078-01	12/8/2018	1150	28.6	4.33	56.0	736	0.36	1.43	3.16
Ajayan Bridge	A078-01	12/8/2018	1205	29.0	4.36	67.1	46,892	30.36	2.37	4.46
Geus Bridge (Rt.4)	G02-78	12/8/2018	1215	28.5	11.57*	100	437	0.21	1.76	3.32
Geus Bridge (E.R.)	G00-78	12/8/2018	1235	27.6	6.83	86.7	437	0.21	2.48	3.33
Liyog Bridge	L079-01	12/23/2018	1310	29.1	6.31	96.1	43,913	28.21	8.13	8.79
Sumay Bridge	S079-01	12/23/2018	1315	28.2	3.91	50.3	1,266	0.63	4.15	1.61
Ajayan Bridge	A079-01	12/23/2018	1335	29.0	6.08	93.6	47,191	30.57	6.27	4.73
Geus Bridge (Rt.4)	G02-79	12/23/2018	1350	27.6	7.02	89.2	428	0.2	1.17	0.83
Geus Bridge (E.R.)	G00-79	12/23/2018	1405	26.9	6.90	86.6	379	0.18	1.19	0.78

Notes: mg/l, milligrams/liter; µs/cm, microsiemens/centimeter; ppt, parts per thousand; NTU, nephelometric turbidity unit; SSC, suspended sediment concentration

Appendix B. Spearman correlation coefficients between parameters.

Variable	Variable	Spearman's Rho	p value
Ajayan Water Level	SSC (mg/L)	0.3670	<0.0001
Ajayan Water Level	Turbidity (NTU)	0.2204	0.001
As Liyog Water Level	SSC (mg/L)	0.2944	<0.0001
As Liyog Water Level	Turbidity (NTU)	0.1369	0.0445
$HPO_4^{=}$ (mg/l)	Turbidity (NTU)	0.1714	0.0114
$HPO_4^{=}$ (mg/l)	SSC (mg/L)	0.4148	<0.0001
As Liyog Water Level	Ajayan Water Level	0.5607	<0.0001
NH_4^+ (mg/l-N)	Turbidity (NTU)	0.2776	<0.0001
NH_4^+ (mg/l-N)	SSC (mg/L)	0.5052	<0.0001
NH_4^+ (mg/l-N)	Ajayan Water Level	0.3295	<0.0001
NH_4^+ (mg/l-N)	As Liyog Water Level	0.0335	<0.0001
NH_4^+ (mg/l-N)	Rainfall (in)	-0.0324	0.7809
NH_4^+ (mg/l-N)	DO (mg/L)	-0.2348	0.0004
NO_3^- (mg/l-N)	Salinity (ppt)	-0.7853	<0.0001
NO_3^- (mg/l-N)	SSC (mg/L)	-0.3038	<0.0001
NO_3^- (mg/l-N)	Turbidity (NTU)	-0.3926	<0.0001
NO_3^- (mg/l-N)	Ajayan Water Level	0.1243	0.0664
NO_3^- (mg/l-N)	As Liyog Water Level	0.0965	0.1594
Rainfall (in)	Ajayan Water Level	0.0147	0.0001
Rainfall (in)	As Liyog Water Level	0.0335	<.0001
Rainfall (in)	Turbidity (NTU)	0.0880	<.0001
Rainfall (in)	SSC (mg/L)	0.1434	0.0412
Rainfall (in)	Salinity (ppt)	-0.1503	0.022
SSC (mg/L)	Turbidity (NTU)	0.7336	<0.0001

Appendix C. Results of nutrient monitoring in the Manell Watershed, Guam.

Sample ID	Site	Collection Date	NO_3^- conc. (umol/l)	NO_3^- conc. (mg/l N)	$HPO_4^=$ conc. (umol/l)	$HPO_4^=$ conc. (mg/l P)	$HSiO_3^-$ conc. (umol/l)	$HSiO_3^-$ conc. (mg/l SiO_3)	NH_4^+ conc. (umol/l)	NH_4+ conc. (mg/l N)	NO_2^- conc. (umol/l)	NO_2^- conc. (mg/l N)	Urea conc. (umol/l)	Urea conc. (mg/l N)	NO_3^-+NO_2^- conc. (uM)	Total N conc. (umol/l)	Total N conc. (mg/l N)	Total P conc. (umol/l)	Total P conc. (mg/l P)
A001-01	Ajayan	12/11/16	0.00	0.00	1.73	0.05	41.84	3.18	2.58	0.04	0.18	0.00	0.42	0.01	0.18	22.66	0.32	2.21	0.07
A002-01	Ajayan	12/19/16	0.00	0.00	4.37	0.14	168.51	12.82	5.61	0.08	0.39	0.01	1.12	0.02	0.39	19.14	0.27	4.58	0.14
A003-01	Ajayan	12/26/16	3.97	0.06	5.39	0.17	145.36	11.06	3.34	0.05	0.58	0.01	2.54	0.04	4.54	24.26	0.34	7.78	0.24
A004-01	Ajayan	01/20/17	4.01	0.06	2.54	0.08	277.08	21.08	2.99	0.04	0.32	0.00	1.02	0.01	4.32	22.91	0.32	5.37	0.17
A005-01	Ajayan	01/24/17	0.00	0.00	3.76	0.12	116.51	8.86	3.81	0.05	0.29	0.00	0.81	0.01	0.29	34.51	0.48	4.16	0.13
A006-01	Ajayan	02/05/17	0.00	0.00	7.20	0.22	207.37	15.78	6.85	0.10	0.46	0.01	1.32	0.02	0.46	21.06	0.29	7.03	0.22
A007-01	Ajayan	02/26/17	0.00	0.00	5.64	0.17	211.78	16.11	4.92	0.07	0.41	0.01	1.42	0.02	0.41	26.94	0.38	5.70	0.18
A008-01	Ajayan	03/04/17	0.00	0.00	4.39	0.14	158.96	12.09	4.35	0.06	0.34	0.00	1.15	0.02	0.34	22.39	0.31	5.02	0.16
A009-01	Ajayan	03/06/17	0.00	0.00	3.06	0.09	110.56	8.41	3.86	0.05	0.28	0.00	0.85	0.01	0.28	24.71	0.35	3.79	0.12
A010-01	Ajayan	03/08/17	0.00	0.00	6.69	0.21	272.47	20.73	6.59	0.09	0.51	0.01	1.71	0.02	0.51	19.70	0.28	7.83	0.24
A011-01	Ajayan	03/22/17	4.33	0.06	3.48	0.11	283.05	21.54	6.25	0.09	0.36	0.01	1.26	0.02	4.69	54.83	0.77	5.45	0.17
A012-01	Ajayan	03/26/17	0.00	0.00	5.00	0.15	197.91	15.06	5.88	0.08	0.38	0.01	1.28	0.02	0.38	43.31	0.61	5.78	0.18
A013-01	Ajayan	03/28/17	0.00	0.00	7.62	0.24	277.42	21.11	8.86	0.12	0.53	0.01	2.08	0.03	0.53	28.84	0.40	9.23	0.29
A014-01	Ajayan	04/07/17	0.00	0.00	3.84	0.12	134.50	10.23	3.95	0.06	0.31	0.00	1.08	0.02	0.31	29.03	0.41	4.13	0.13
A015-01	Ajayan	04/15/17	0.00	0.00	3.16	0.10	116.53	8.87	3.23	0.05	0.30	0.00	0.70	0.01	0.30	30.98	0.43	3.98	0.12
L001-01	As Liyog	12/11/16	0.00	0.00	0.88	0.03	46.97	3.57	2.02	0.03	0.13	0.00	0.31	0.00	0.13	29.61	0.41	2.19	0.07
L002-01	As Liyog	12/19/16	0.48	0.01	4.04	0.13	81.07	6.17	4.78	0.07	0.41	0.01	0.68	0.01	0.88	37.92	0.53	5.48	0.17
L003-01	As Liyog	12/26/16	0.10	0.00	4.12	0.13	96.51	7.34	4.60	0.06	0.28	0.00	0.78	0.01	0.38	26.48	0.37	3.98	0.12
L004-01	As Liyog	01/20/17	0.10	0.00	6.83	0.21	161.48	12.29	6.87	0.10	0.43	0.01	1.31	0.02	0.52	44.28	0.62	6.71	0.21
L005-01	As Liyog	01/24/17	0.00	0.00	1.82	0.06	58.68	4.46	2.36	0.03	0.13	0.00	0.22	0.00	0.13	43.39	0.61	1.76	0.05
L006-01	As Liyog	02/05/17	0.19	0.00	4.85	0.15	105.70	8.04	4.84	0.07	0.31	0.00	0.98	0.01	0.50	48.32	0.68	4.78	0.15
L007-01	As Liyog	02/26/17	0.00	0.00	2.14	0.07	58.60	4.46	2.42	0.03	0.18	0.00	0.40	0.01	0.18	48.67	0.68	2.36	0.07
L008-01	As Liyog	03/04/17	1.90	0.03	5.75	0.18	148.75	11.32	7.33	0.10	0.53	0.01	1.28	0.02	2.43	38.30	0.54	5.79	0.18
L009-01	As Liyog	03/06/17	0.23	0.00	3.27	0.10	81.66	6.21	2.65	0.04	0.20	0.00	0.42	0.01	0.43	39.88	0.56	4.35	0.13
L010-01	As Liyog	03/08/17	0.00	0.00	2.71	0.08	65.63	4.99	2.91	0.04	0.19	0.00	0.53	0.01	0.19	41.82	0.59	3.15	0.10
L011-01	As Liyog	03/22/17	0.08	0.00	7.81	0.24	177.33	13.49	7.45	0.10	0.51	0.01	1.57	0.02	0.58	29.44	0.41	7.84	0.24
L012-01	As Liyog	03/26/17	0.00	0.00	1.69	0.05	56.96	4.33	2.42	0.03	0.12	0.00	0.28	0.00	0.12	22.94	0.32	2.13	0.07
L013-01	As Liyog	03/28/17	0.12	0.00	5.11	0.16	135.76	10.33	6.29	0.09	0.39	0.01	0.96	0.01	0.51	52.62	0.74	5.03	0.16
L014-01	As Liyog	04/07/17	0.00	0.00	2.69	0.08	72.27	5.50	2.85	0.04	0.17	0.00	0.38	0.01	0.17	51.84	0.73	2.89	0.09
L015-01	As Liyog	04/15/17	1.37	0.02	7.65	0.24	252.13	19.18	10.49	0.15	0.60	0.01	1.47	0.02	1.97	58.10	0.81	8.12	0.25
S009-01	Sumay	03/06/17	14.36	0.20	2.78	0.09	355.88	27.08	2.36	0.03	0.36	0.00	1.50	0.02	14.72	48.74	0.68	5.51	0.17
S010-01	Sumay	03/08/17	15.53	0.22	2.47	0.08	395.31	30.08	2.55	0.04	0.23	0.00	0.64	0.01	15.76	49.09	0.69	4.78	0.15
S011-01	Sumay	03/22/17	18.19	0.25	1.88	0.06	398.48	30.32	2.35	0.03	0.17	0.00	0.32	0.00	18.37	49.08	0.69	3.58	0.11
S012-01	Sumay	03/26/17	7.28	0.10	8.40	0.26	392.27	29.85	7.62	0.11	0.53	0.01	1.69	0.02	7.81	28.78	0.40	9.03	0.28
S013-01	Sumay	03/28/17	16.56	0.23	1.35	0.04	400.42	30.47	2.93	0.04	0.17	0.00	0.32	0.00	16.73	49.73	0.70	3.57	0.11
S014-01	Sumay	04/07/17	18.41	0.26	2.06	0.06	372.03	28.31	3.57	0.05	0.28	0.00	1.01	0.01	18.70	57.70	0.81	4.31	0.13
S015-01	Sumay	04/15/17	19.15	0.27	1.75	0.05	389.30	29.62	2.72	0.04	0.18	0.00	0.17	0.00	19.33	49.43	0.69	3.98	0.12
L016-01	As Liyog	04/24/17	3.02	0.04	6.86	0.21	216.82	16.50	13.63	0.19	0.81	0.01	1.78	0.02	3.83	52.15	0.73	8.53	0.26
A016-01	Ajayan	04/24/17	4.74	0.07	5.55	0.17	195.49	14.87	3.94	0.06	0.60	0.01	2.68	0.04	5.33	66.97	0.94	8.30	0.26
S016-01	Sumay	04/24/17	18.81	0.26	1.44	0.04	400.84	30.50	3.03	0.04	0.19	0.00	0.29	0.00	19.00	91.02	1.27	3.81	0.12
L017-01	As Liyog	04/30/17	6.07	0.09	4.04	0.13	217.19	16.52	6.64	0.09	0.32	0.00	1.41	0.02	6.39	51.92	0.73	6.16	0.19
A017-01	Ajayan	04/30/17	0.00	0.00	10.10	0.31	64.91	4.94	12.87	0.18	0.83	0.01	3.30	0.05	0.83	48.04	0.67	11.36	0.35
S017-01	Sumay	04/30/17	24.48	0.34	1.18	0.04	358.30	27.26	4.61	0.06	0.17	0.00	0.90	0.01	24.65	48.74	0.68	3.75	0.12
L018-01	As Liyog	05/09/17	0.00	0.00	0.96	0.03	57.67	4.39	10.60	0.15	0.73	0.01	2.75	0.04	0.73	41.89	0.59	3.62	0.11
A018-01	Ajayan	05/09/17	0.00	0.00	0.44	0.01	30.57	2.33	8.54	0.12	0.57	0.01	2.04	0.03	0.57	36.21	0.51	2.09	0.06
S018-01	Sumay	05/09/17	19.67	0.28	1.42	0.04	398.84	30.35	3.14	0.04	0.23	0.00	0.43	0.01	19.90	49.18	0.69	3.88	0.12
L019-01	As Liyog	05/22/17	0.00	0.00	0.31	0.01	10.64	0.81	9.92	0.14	0.64	0.01	2.43	0.03	0.64	34.54	0.48	2.27	0.07
A019-01	Ajayan	05/22/17	0.00	0.00	2.70	0.08	37.83	2.88	7.41	0.10	0.51	0.01	1.66	0.02	0.51	43.55	0.61	2.35	0.07
S019-01	Sumay	05/22/17	1.56	0.02	6.60	0.20	68.03	5.18	10.26	0.14	0.70	0.01	2.78	0.04	2.26	30.97	0.43	7.68	0.24
L020-01	As Liyog	05/29/17	1.03	0.01	3.38	0.10	106.55	8.11	6.09	0.09	0.43	0.01	0.80	0.01	1.46	50.24	0.70	4.00	0.12
A020-01	Ajayan	05/29/17	0.00	0.00	3.75	0.12	51.33	3.91	10.10	0.14	0.73	0.01	2.55	0.04	0.73	27.86	0.39	4.06	0.13
S020-01	Sumay	05/29/17	19.14	0.27	1.11	0.03	364.62	27.74	3.82	0.05	0.24	0.00	0.51	0.01	19.38	50.48	0.71	4.22	0.13
L021-01	As Liyog	06/03/17	0.00	0.00	2.14	0.07	44.88	3.41	9.18	0.13	0.61	0.01	2.26	0.03	0.61	50.95	0.71	2.54	0.08
A021-01	Ajayan	06/03/17	0.00	0.00	2.80	0.09	116.18	8.84	2.68	0.04	0.23	0.00	0.64	0.01	0.23	28.13	0.39	3.96	0.12
S021-01	Sumay	06/03/17	18.12	0.25	2.04	0.06	390.88	29.74	3.07	0.04	0.30	0.00	0.79	0.01	18.42	49.95	0.70	4.70	0.15
L022-01	As Liyog	06/06/17	0.00	0.00	2.78	0.09	66.55	5.06	12.38	0.17	0.80	0.01	2.54	0.04	0.80	67.12	0.94	5.30	0.16
A022-01	Ajayan	06/06/17	0.00	0.00	2.43	0.08	60.10	4.57	9.79	0.14	0.67	0.01	2.53	0.04	0.67	45.05	0.63	3.71	0.11
S022-01	Sumay	06/06/17	18.72	0.26	1.02	0.03	406.06	30.89	2.90	0.04	0.19	0.00	0.30	0.00	18.92	53.80	0.75	3.71	0.11
L023-01	As Liyog	06/14/17	0.00	0.00	2.58	0.08	56.11	4.27	8.56	0.12	0.60	0.01	1.82	0.03	0.60	36.07	0.51	3.02	0.09
A023-01	Ajayan	06/14/17	0.00	0.00	2.17	0.07	67.89	5.17	9.69	0.14	0.68	0.01	2.24	0.03	0.68	25.24	0.35	4.17	0.13
S023-01	Sumay	06/14/17	4.93	0.07	15.01	0.46	144.84	11.02	11.77	0.16	0.90	0.01	3.31	0.05	5.83	37.77	0.53	26.89	0.83
L024-01	As Liyog	06/22/17	0.03	0.00	6.20	0.19	99.66	7.58	14.82	0.21	0.82	0.01	2.79	0.04	0.85	57.25	0.80	10.53	0.33
A024-01	Ajayan	06/22/17	0.00	0.00	5.30	0.16	66.76	5.08	11.45	0.16	0.75	0.01	2.42	0.03	0.75	40.51	0.57	8.14	0.25
S024-01	Sumay	06/22/17	16.80	0.24	0.92	0.03	410.92	31.26	2.94	0.04	0.19	0.00	0.09	0.00	16.99	49.43	0.69	3.44	0.11
L025-01	As Liyog	07/08/17	0.79	0.01	9.60	0.30	113.29	8.62	14.79	0.21	0.72	0.01	2.03	0.03	1.51	39.85	0.56	10.63	0.33
A025-01	Ajayan	07/08/17	0.00	0.00	8.84	0.27	83.39	6.34	12.24	0.17	0.81	0.01	2.91	0.04	0.81	32.71	0.46	9.33	0.29
S025-01	Sumay	07/08/17	16.39	0.23	1.50	0.05	387.59	29.49	2.96	0.04	0.19	0.00	0.46	0.01	16.58	44.64	0.63	3.61	0.11
L026-01	As Liyog	07/13/17	0.00	0.00	7.23	0.22	59.75	4.55	12.18	0.17	0.75	0.01	2.61	0.04	0.75	48.88	0.68	7.94	0.25
A026-01	Ajayan	07/13/17	5.71	0.08	4.01	0.12	259.40	19.74	5.47	0.08	0.46	0.01	1.72	0.02	6.17	44.93	0.63	5.86	0.18
S026-01	Sumay	07/13/17	16.31	0.23	0.91	0.03	398.65	30.33	2.96	0.04	0.19	0.00	0.44	0.01	16.50	35.73	0.50	4.05	0.13
L027-01	As Liyog	07/17/17	0.00	0.00	5.03	0.16	51.00	3.88	12.26	0.17	0.74	0.01	2.46	0.03	0.74	34.69	0.49	5.51	0.17
A027-01	Ajayan	07/17/17	5.01	0.07	3.69	0.11	280.95	21.38	6.73	0.09	0.60	0.01	1.95	0.03	5.60	36.91	0.52	6.25	0.19
S027-01	Sumay	07/17/17	15.13	0.21	1.23	0.04	400.16	30.45	2.61	0.04	0.18	0.00	0.27	0.00	15.31	53.44	0.75	3.82	0.12
L028-01	As Liyog	07/25/17	6.29	0.09	5.19	0.16	258.51	19.67	6.86	0.10	0.55	0.01	2.33	0.03	6.83	70.82	0.99	7.55	0.23
A028-01	Ajayan	07/25/17	4.75	0.07	5.74	0.18	208.21	15.84	4.59	0.06	0.68	0.01	2.74	0.04	5.43	53.74	0.75	7.47	0.23
S028-01	Sumay	07/25/17	18.27	0.26	1.23	0.04	383.73	29.20	2.58	0.04	0.17	0.00	0.31	0.00	18.44	42.87	0.60	3.61	0.11
L029-01	As Liyog	08/02/17	1.03	0.01	6.36	0.20	65.19	4.96	13.27	0.19	0.72	0.01	2.11	0.03	1.74	62.68	0.88	6.79	0.21
A029-01	Ajayan	08/02/17	4.32	0.06	3.74	0.12	300.24	22.84	3.41	0.05	0.45	0.01	1.84	0.03	4.77	46.16	0.65	5.59	0.17
S029-01	Sumay	08/02/17	18.10	0.25	1.45	0.04	389.92	29.67	2.89	0.04	0.20	0.00	0.36	0.01	18.30	43.59	0.61	3.23	0.10
L030-01	As Liyog	08/18/17	1.77	0.02	6.58	0.20	177.67	13.52	17.58	0.25	0.59	0.01	1.82	0.03	2.36	50.90	0.71	7.03	0.22

NO_3^-, nitrate; $HPO_4^=$, orthophosphate; $HSiO_3^-$, silica; NH_4^+, ammonium; NO_2^-, nitrite; Total N, total nitrogen; Total P, total phosphorus

Appendix C. Results of nutrient monitoring in the Manell Watershed, Guam (cont.).

Sample ID	Site	Collection Date	NO_3^- conc. (umol/l)	NO_3^- conc. (mg/l N)	$HPO_4^=$ conc. (umol/l)	$HPO_4^=$ conc. (mg/l P)	$HSiO_3^-$ conc. (umol/l)	$HSiO_3^-$ conc. (mg/l SiO_3)	NH_4^+ conc. (umol/l)	NH_4+ conc. (mg/l N)	NO_2^- conc. (umol/l)	NO_2^- conc. (mg/l N)	Urea conc. (umol/l)	Urea conc. (mg/l N)	NO_3^-+NO_2^- conc. (uM)	Total N conc. (umol/l)	Total N conc. (mg/l N)	Total P conc. (umol/l)	Total P conc. (mg/l P)
A030-01	Ajayan	08/18/17	0.76	0.01	9.16	0.28	232.80	17.71	15.46	0.22	0.62	0.01	2.22	0.03	1.38	42.99	0.60	10.05	0.31
S030-01	Sumay	08/18/17	17.17	0.24	0.94	0.03	367.45	27.96	4.53	0.06	0.30	0.00	0.38	0.01	17.47	49.08	0.69	3.34	0.10
L031-01	As Liyog	08/25/17	0.16	0.00	10.43	0.32	251.70	19.15	10.75	0.15	0.65	0.01	2.22	0.03	0.81	38.69	0.54	10.57	0.33
A031-01	Ajayan	08/25/17	6.16	0.09	1.34	0.04	140.40	10.68	3.88	0.05	0.21	0.00	0.72	0.01	6.37	61.09	0.86	3.91	0.12
S031-01	Sumay	08/25/17	12.18	0.17	1.16	0.04	351.35	26.73	2.79	0.04	0.17	0.00	0.63	0.01	12.35	43.78	0.61	3.28	0.10
L032-01	As Liyog	9/19/2017	0.88	0.01	2.90	0.09	171.20	13.03	4.69	0.07	0.43	0.01	1.21	0.02	1.31	25.53	0.36	3.59	0.11
A032-01	Ajayan	9/19/2017	0.16	0.00	2.87	0.09	213.59	16.25	5.56	0.08	0.93	0.01	2.05	0.03	1.08	23.77	0.33	3.72	0.12
S032-01	Sumay	9/19/2017	12.22	0.17	0.86	0.03	390.60	29.72	2.45	0.03	0.15	0.00	0.27	0.00	12.37	31.52	0.44	1.30	0.04
L033-01	As Liyog	9/30/2017	0.20	0.00	6.51	0.20	68.14	5.18	7.58	0.11	0.93	0.01	2.10	0.03	1.12	30.55	0.43	8.45	0.26
A033-01	Ajayan	9/30/2017	0.00	0.00	5.52	0.17	53.91	4.10	7.85	0.11	0.93	0.01	2.33	0.03	0.93	47.34	0.66	8.25	0.26
S033-01	Sumay	9/30/2017	16.12	0.23	0.99	0.03	498.12	37.90	2.15	0.03	0.15	0.00	0.19	0.00	16.27	33.45	0.47	1.95	0.06
L034-01	As Liyog	10/6/2017	0.12	0.00	3.29	0.10	157.55	11.99	5.88	0.08	0.80	0.01	1.83	0.03	0.92	35.65	0.50	3.76	0.12
A034-01	Ajayan	10/6/2017	3.84	0.05	1.11	0.03	381.34	29.01	6.50	0.09	0.47	0.01	1.77	0.02	4.31	22.25	0.31	1.12	0.03
S034-01	Sumay	10/6/2017	19.40	0.27	1.19	0.04	525.09	39.95	3.13	0.04	0.21	0.00	0.32	0.00	19.61	28.58	0.40	1.23	0.04
L035-01	As Liyog	10/14/2017	4.83	0.07	1.55	0.05	315.26	23.99	3.05	0.04	0.16	0.00	0.29	0.00	4.99	22.44	0.31	1.76	0.05
A035-01	Ajayan	10/14/2017	1.44	0.02	2.36	0.07	179.02	13.62	2.98	0.04	0.14	0.00	0.22	0.00	1.58	43.78	0.61	2.44	0.08
S035-01	Sumay	10/14/2017	6.53	0.09	1.21	0.04	281.10	21.39	2.53	0.04	0.17	0.00	0.12	0.00	6.69	49.57	0.69	3.01	0.09
L036-01	As Liyog	10/27/2017	0.14	0.00	2.18	0.07	98.64	7.50	4.79	0.07	0.71	0.01	2.37	0.03	0.85	35.49	0.50	2.52	0.08
A036-01	Ajayan	10/27/2017	0.17	0.00	2.26	0.07	180.41	13.73	5.26	0.07	0.81	0.01	2.23	0.03	0.97	29.07	0.41	3.27	0.10
S036-01	Sumay	10/27/2017	15.77	0.22	0.82	0.03	342.99	26.10	1.99	0.03	0.17	0.00	0.18	0.00	15.94	35.76	0.50	1.46	0.05
L037-01	As Liyog	11/1/2017	0.28	0.00	4.90	0.15	282.54	21.50	7.49	0.10	0.82	0.01	1.88	0.03	1.09	30.67	0.43	5.39	0.17
A037-01	Ajayan	11/1/2017	0.06	0.00	1.76	0.05	84.62	6.44	5.32	0.07	0.77	0.01	1.67	0.02	0.83	19.55	0.27	2.44	0.08
S037-01	Sumay	11/1/2017	17.57	0.25	1.06	0.03	440.11	33.49	2.42	0.03	0.17	0.00	0.13	0.00	17.74	37.60	0.53	1.94	0.06
L038-01	As Liyog	11/14/2018	0.61	0.01	6.17	0.19	69.39	5.28	8.56	0.12	0.98	0.01	2.14	0.03	1.59	43.17	0.60	12.09	0.37
A038-01	Ajayan	11/14/2018	0.51	0.01	2.10	0.07	181.89	13.84	4.31	0.06	0.59	0.01	1.08	0.02	1.10	26.27	0.37	2.79	0.09
S038-01	Sumay	11/14/2018	17.51	0.25	1.44	0.04	490.46	37.32	2.70	0.04	0.17	0.00	0.13	0.00	17.68	35.97	0.50	2.27	0.07
L039-01	As Liyog	11/20/2018	0.40	0.01	2.52	0.08	99.83	7.60	5.29	0.07	0.74	0.01	1.89	0.03	1.14	30.82	0.43	3.14	0.10
A039-01	Ajayan	11/20/2018	0.19	0.00	3.20	0.10	92.93	7.07	5.22	0.07	0.78	0.01	1.70	0.02	0.97	22.31	0.31	4.21	0.13
S039-01	Sumay	11/20/2018	12.92	0.18	1.40	0.04	328.31	24.98	5.37	0.08	0.43	0.01	1.31	0.02	13.35	33.57	0.47	1.43	0.04
L040-01	As Liyog	11/30/2017	0.46	0.01	4.77	0.15	251.51	19.14	7.85	0.11	0.82	0.01	1.75	0.02	1.27	39.30	0.55	5.68	0.18
A040-01	Ajayan	11/30/2017	0.22	0.00	2.14	0.07	116.55	8.87	5.13	0.07	0.79	0.01	1.56	0.02	1.02	26.75	0.37	2.85	0.09
S040-01	Sumay	11/30/2017	16.83	0.24	1.15	0.04	488.92	37.20	2.44	0.03	0.18	0.00	0.35	0.00	17.01	36.84	0.52	1.95	0.06
L041-01	As Liyog	12/6/2017	0.22	0.00	1.16	0.04	12.16	0.93	5.03	0.07	0.81	0.01	1.74	0.02	1.03	28.27	0.40	2.01	0.06
A041-01	Ajayan	12/6/2017	0.21	0.00	2.11	0.07	128.20	9.75	5.19	0.07	0.80	0.01	1.74	0.02	1.00	26.74	0.37	2.77	0.09
S041-01	Sumay	12/6/2017	1.23	0.02	3.16	0.10	176.26	13.41	5.82	0.08	0.90	0.01	1.94	0.03	2.14	28.69	0.40	4.03	0.12
L042-01	As Liyog	12/15/2017	0.45	0.01	2.04	0.06	49.33	3.75	6.05	0.08	0.79	0.01	2.12	0.03	1.09	46.34	0.65	3.00	0.09
A042-01	Ajayan	12/15/2017	0.25	0.00	1.82	0.06	78.65	5.98	5.81	0.08	0.81	0.01	1.68	0.02	1.06	35.51	0.50	2.29	0.07
S042-01	Sumay	12/15/2017	14.97	0.21	1.07	0.03	249.61	18.99	4.22	0.06	0.27	0.00	0.90	0.01	15.24	41.21	0.58	1.17	0.04
L043-01	As Liyog	12/27/2017	0.74	0.01	5.02	0.16	155.57	11.84	10.21	0.14	0.90	0.01	2.07	0.03	1.64	44.03	0.62	7.70	0.24
A043-01	Ajayan	12/27/2017	0.45	0.01	2.46	0.08	170.61	12.98	7.07	0.10	0.80	0.01	1.64	0.02	1.25	35.05	0.49	3.11	0.10
S043-01	Sumay	12/27/2017	17.46	0.24	1.26	0.04	258.86	19.70	2.67	0.04	0.13	0.00	0.24	0.00	17.59	36.48	0.51	2.06	0.06
L044-01	As Liyog	1/4/2018	0.32	0.00	2.69	0.08	65.86	5.01	6.67	0.09	0.83	0.01	1.77	0.02	1.15	40.13	0.56	3.42	0.11
A044-01	Ajayan	1/4/2018	0.23	0.00	2.87	0.09	149.84	11.40	6.19	0.09	0.87	0.01	1.74	0.02	1.10	29.02	0.41	3.63	0.11
S044-01	Sumay	1/4/2018	15.77	0.22	1.14	0.04	270.11	20.55	4.01	0.06	0.30	0.00	0.66	0.01	16.07	35.74	0.50	1.35	0.04
L045-01	As Liyog	1/11/2018	0.21	0.00	1.34	0.04	29.89	2.27	5.45	0.08	0.68	0.01	1.47	0.02	0.89	32.30	0.45	2.42	0.08
A045-01	Ajayan	1/11/2018	0.16	0.00	1.42	0.04	68.96	5.25	5.27	0.07	0.71	0.01	1.42	0.02	0.87	29.52	0.41	2.38	0.07
S045-01	Sumay	1/11/2018	17.40	0.24	1.01	0.03	301.59	22.95	2.86	0.04	0.18	0.00	0.43	0.01	17.58	38.42	0.54	1.03	0.03
L046-01	As Liyog	1/19/2018	0.29	0.00	1.20	0.04	19.58	1.49	4.95	0.07	0.77	0.01	1.71	0.02	1.05	29.97	0.42	2.29	0.07
A046-01	Ajayan	1/19/2018	2.38	0.03	0.96	0.03	177.42	13.50	5.52	0.08	0.24	0.00	0.82	0.01	2.62	39.55	0.55	1.24	0.04
S046-01	Sumay	1/19/2018	7.19	0.10	1.91	0.06	337.09	25.65	6.16	0.09	0.58	0.01	1.84	0.03	7.77	28.36	0.40	2.15	0.07
L047-01	As Liyog	1/27/2018	0.27	0.00	2.04	0.06	48.29	3.67	5.79	0.08	0.79	0.01	1.77	0.02	1.06	28.93	0.41	2.81	0.09
A047-01	Ajayan	1/27/2018	1.25	0.02	0.93	0.03	248.39	18.90	1.92	0.03	0.09	0.00	0.43	0.01	1.34	33.71	0.47	0.93	0.03
S047-01	Sumay	1/27/2018	15.69	0.22	0.73	0.02	304.04	23.13	2.98	0.04	0.18	0.00	0.57	0.01	15.87	35.69	0.50	0.87	0.03
L048-01	As Liyog	2/1/2018	0.88	0.01	1.51	0.05	75.29	5.73	2.51	0.04	0.26	0.00	2.36	0.03	1.14	39.96	0.56	2.81	0.09
A048-01	Ajayan	2/1/2018	1.86	0.03	1.26	0.04	267.37	20.34	3.81	0.05	0.32	0.00	1.13	0.02	2.18	38.05	0.53	1.44	0.04
S048-01	Sumay	2/1/2018	6.57	0.09	1.89	0.06	356.73	27.14	6.20	0.09	0.58	0.01	2.09	0.03	7.15	30.59	0.43	2.14	0.07
L049-01	As Liyog	2/9/2018	0.08	0.00	1.74	0.05	14.45	1.10	5.07	0.07	0.82	0.01	1.83	0.03	0.89	39.55	0.55	3.06	0.09
A049-01	Ajayan	2/9/2018	0.00	0.00	1.35	0.04	39.71	3.02	4.62	0.06	0.76	0.01	1.64	0.02	0.76	35.79	0.50	1.87	0.06
S049-01	Sumay	2/9/2018	9.63	0.13	1.73	0.05	308.13	23.44	5.68	0.08	0.48	0.01	1.64	0.02	10.11	41.41	0.58	1.73	0.05
L050-01	As Liyog	2/17/2018	0.12	0.00	2.02	0.06	37.77	2.87	4.92	0.07	0.72	0.01	1.41	0.02	0.84	34.36	0.48	3.34	0.10
A050-01	Ajayan	2/17/2018	1.60	0.02	0.98	0.03	296.08	22.53	2.56	0.04	0.16	0.00	0.73	0.01	1.76	35.02	0.49	0.96	0.03
S050-01	Sumay	2/17/2018	17.79	0.25	0.94	0.03	326.29	24.83	3.62	0.05	0.19	0.00	0.81	0.01	17.99	46.86	0.66	0.94	0.03
L051-01	As Liyog	2/22/2018	0.22	0.00	2.21	0.07	67.98	5.17	6.52	0.09	0.83	0.01	1.85	0.03	1.04	39.02	0.55	2.93	0.09
A051-01	Ajayan	2/22/2018	1.80	0.03	0.97	0.03	251.49	19.13	2.07	0.03	0.13	0.00	0.65	0.01	1.93	44.92	0.63	0.94	0.03
S051-01	Sumay	2/22/2018	16.73	0.23	1.50	0.05	322.91	24.57	2.90	0.04	0.10	0.00	0.60	0.01	16.84	70.99	0.99	2.10	0.07
L052-01	As Liyog	3/3/2018	0.42	0.01	1.68	0.05	53.58	4.08	3.52	0.05	0.37	0.01	0.60	0.01	0.79	30.36	0.43	2.80	0.09
A052-01	Ajayan	3/3/2018	1.50	0.02	0.83	0.03	260.09	19.79	2.93	0.04	0.22	0.00	0.76	0.01	1.72	52.01	0.73	1.17	0.04
S052-01	Sumay	3/3/2018	8.17	0.11	1.82	0.06	439.22	33.42	5.97	0.08	0.50	0.01	1.41	0.02	8.67	41.18	0.58	1.84	0.06
L053-01	As Liyog	3/9/2018	0.37	0.01	2.47	0.08	82.42	6.27	6.40	0.09	0.82	0.01	1.79	0.03	1.19	29.30	0.41	3.11	0.10
A053-01	Ajayan	3/9/2018	1.17	0.02	1.17	0.04	273.42	20.80	2.87	0.04	0.19	0.00	0.58	0.01	1.37	210.94	2.95	1.23	0.04
S053-01	Sumay	3/9/2018	16.73	0.23	1.56	0.05	415.14	31.59	2.65	0.04	0.10	0.00	0.13	0.00	16.83	56.13	0.79	2.35	0.07
L054-01	As Liyog	3/15/2018	1.85	0.03	2.52	0.08	75.93	5.78	8.04	0.11	0.78	0.01	2.13	0.03	2.64	29.43	0.41	3.08	0.10
A054-01	Ajayan	3/15/2018	1.36	0.02	0.97	0.03	260.83	19.84	2.70	0.04	0.18	0.00	0.56	0.01	1.54	39.13	0.55	1.18	0.04
S054-01	Sumay	3/15/2018	10.58	0.15	0.98	0.03	355.05	27.01	4.86	0.07	0.40	0.01	1.11	0.02	10.98	33.16	0.46	1.68	0.05
L055-01	As Liyog	03/24/18	0.00	0.00	1.92	0.06	68.97	5.25	5.04	0.07	0.67	0.01	1.33	0.02	0.67	37.06	0.52	2.76	0.09
A055-01	Ajayan	03/24/18	0.00	0.00	1.53	0.05	156.27	11.89	1.35	0.02	0.08	0.00	0.76	0.01	0.08	25.53	0.36	3.36	0.10
S055-01	Sumay	03/24/18	16.16	0.23	0.94	0.03	441.93	33.62	1.93	0.03	0.11	0.00	0.78	0.01	16.27	33.40	0.47	3.03	0.09
L056-01	As Liyog	04/05/18	0.00	0.00	1.66	0.05	81.88	6.23	6.18	0.09	0.55	0.01	1.10	0.02	0.55	30.77	0.43	2.65	0.08
A056-01	Ajayan	04/05/18	0.00	0.00	0.58	0.02	46.11	3.51	0.63	0.01	0.01	0.00	0.14	0.00	0.01	29.90	0.42	3.40	0.11

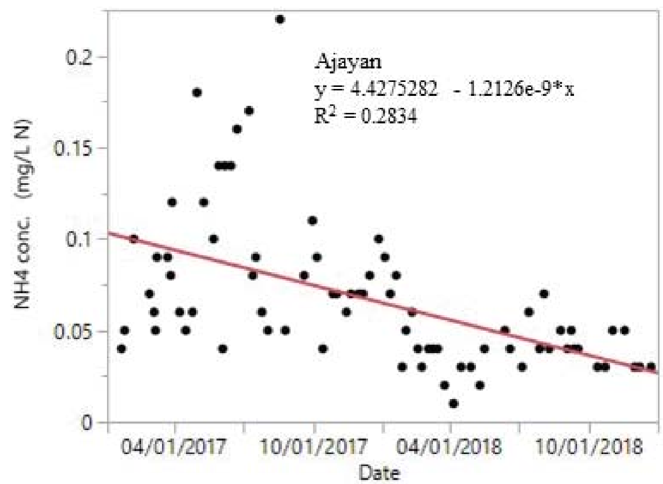
NO_3^-, nitrate; $HPO_4^=$, orthophosphate; $HSiO_3^-$, silica; NH_4^+, ammonium; NO_2^-, nitrite; Total N, total nitrogen; Total P, total phosphorus

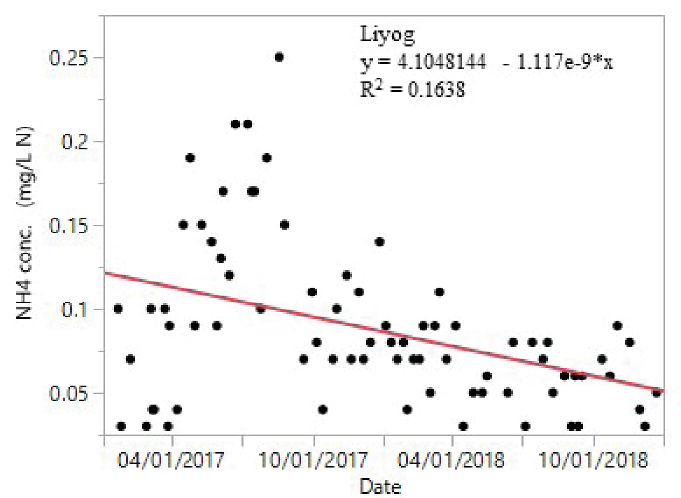
Appendix C. Results of nutrient monitoring in the Manell Watershed, Guam (cont.).

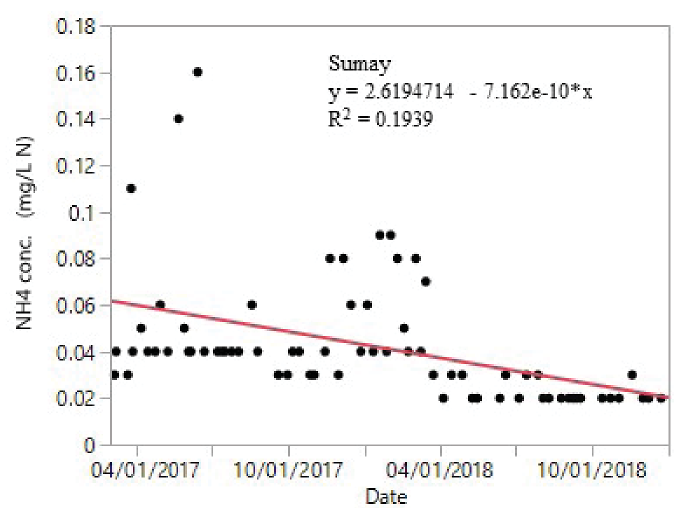
Sample ID	Site	Collection Date	NO_3^- conc. (umol/l)	NO_3^- conc. (mg/l N)	$HPO_4^=$ conc. (umol/l)	$HPO_4^=$ conc. (mg/l P)	$HSiO_3^-$ conc. (umol/l)	$HSiO_3^-$ conc. (mg/l SiO_3)	NH_4^+ conc. (umol/l)	NH_4+ conc. (mg/l N)	NO_2^- conc. (umol/l)	NO_2^- conc. (mg/l N)	Urea conc. (umol/l)	Urea conc. (mg/l N)	NO_3^-+NO_2^- conc. (uM)	Total N conc. (umol/l)	Total N conc. (mg/l N)	Total P conc. (umol/l)	Total P conc. (mg/l P)
S056-01	Sumay	04/05/18	6.59	0.09	0.70	0.02	47.54	3.62	1.39	0.02	0.06	0.00	0.15	0.00	6.65	34.67	0.49	1.64	0.05
L057-01	As Liyog	04/15/18	2.66	0.04	1.31	0.04	45.22	3.44	2.22	0.03	0.08	0.00	0.04	0.00	2.74	49.65	0.70	5.43	0.17
A057-01	Ajayan	04/15/18	0.66	0.01	0.66	0.02	41.38	3.15	2.40	0.03	0.08	0.00	0.00	0.00	0.75	40.81	0.57	2.99	0.09
S057-01	Sumay	04/15/18	11.56	0.16	0.69	0.02	285.16	21.70	2.46	0.03	0.26	0.00	0.19	0.00	11.81	37.33	0.52	1.61	0.05
L058-01	As Liyog	04/28/18	0.77	0.01	1.21	0.04	29.75	2.26	3.26	0.05	0.06	0.00	0.00	0.00	0.83	36.28	0.51	3.98	0.12
A058-01	Ajayan	04/28/18	0.63	0.01	0.48	0.01	32.95	2.51	2.27	0.03	0.06	0.00	0.00	0.00	0.68	42.88	0.60	2.83	0.09
S058-01	Sumay	04/28/18	5.43	0.08	0.49	0.02	66.92	5.09	2.21	0.03	0.11	0.00	0.00	0.00	5.54	40.44	0.57	2.99	0.09
L059-01	As Liyog	05/10/18	0.00	0.00	2.04	0.06	77.47	5.89	3.38	0.05	0.61	0.01	1.48	0.02	0.61	23.61	0.33	1.98	0.06
A059-01	Ajayan	05/10/18	0.00	0.00	0.24	0.01	41.95	3.19	1.10	0.02	0.10	0.00	0.82	0.01	0.10	20.76	0.29	3.89	0.12
S059-01	Sumay	05/10/18	8.19	0.11	0.69	0.02	61.99	4.72	1.59	0.02	0.10	0.00	0.32	0.00	8.29	30.43	0.43	2.95	0.09
L060-01	As Liyog	05/16/18	0.00	0.00	2.18	0.07	87.58	6.66	4.55	0.06	0.66	0.01	1.46	0.02	0.66	34.00	0.48	2.83	0.09
A060-01	Ajayan	05/16/18	0.00	0.00	1.80	0.06	35.24	2.68	2.72	0.04	0.57	0.01	1.29	0.02	0.57	27.42	0.38	1.90	0.06
S060-01	Sumay	05/16/18	5.70	0.08	0.50	0.02	131.26	9.99	1.70	0.02	0.08	0.00	0.42	0.01	5.78	31.48	0.44	2.73	0.08
L061-01	As Liyog	06/12/18	0.00	0.00	3.56	0.11	36.39	2.77	3.85	0.05	0.80	0.01	1.94	0.03	0.80	26.42	0.37	6.96	0.22
A061-01	Ajayan	06/12/18	0.00	0.00	1.64	0.05	62.42	4.75	3.29	0.05	0.52	0.01	1.01	0.01	0.52	31.92	0.45	2.00	0.06
S061-01	Sumay	06/12/18	8.20	0.11	0.51	0.02	74.62	5.68	1.36	0.02	0.08	0.00	0.00	0.00	8.29	29.00	0.41	2.58	0.08
L062-01	As Liyog	06/19/18	0.91	0.01	2.19	0.07	166.94	12.70	5.36	0.08	0.22	0.00	2.10	0.03	1.13	32.25	0.45	3.08	0.10
A062-01	Ajayan	06/19/18	0.00	0.00	1.16	0.04	54.10	4.12	2.86	0.04	0.58	0.01	1.19	0.02	0.58	22.07	0.31	1.47	0.05
S062-01	Sumay	06/19/18	15.52	0.22	0.83	0.03	326.70	24.86	2.03	0.03	0.18	0.00	0.29	0.00	15.70	31.37	0.44	2.88	0.09
L063-01	As Liyog	07/05/18	0.75	0.01	0.89	0.03	61.54	4.68	1.90	0.03	0.08	0.00	1.47	0.02	0.83	49.47	0.69	5.27	0.16
A063-01	Ajayan	07/05/18	0.25	0.00	0.43	0.01	46.36	3.53	1.85	0.03	0.05	0.00	0.00	0.00	0.30	38.68	0.54	2.78	0.09
S063-01	Sumay	07/05/18	10.65	0.15	0.68	0.02	244.84	18.63	1.70	0.02	0.16	0.00	1.33	0.02	10.81	39.57	0.55	2.80	0.09
L064-01	As Liyog	07/14/18	2.54	0.04	3.16	0.10	179.40	13.65	5.70	0.08	0.16	0.00	0.41	0.01	2.70	31.97	0.45	4.53	0.14
A064-01	Ajayan	07/14/18	0.42	0.01	0.80	0.02	70.62	5.37	4.37	0.06	0.07	0.00	0.03	0.00	0.49	26.97	0.38	3.25	0.10
S064-01	Sumay	07/14/18	14.02	0.20	0.67	0.02	312.29	23.76	1.97	0.03	0.15	0.00	2.21	0.03	14.17	31.86	0.45	2.74	0.08
L065-01	As Liyog	07/28/18	0.32	0.00	3.18	0.10	40.52	3.08	5.12	0.07	0.80	0.01	1.63	0.02	1.11	27.60	0.39	6.70	0.21
A065-01	Ajayan	07/28/18	0.00	0.00	1.35	0.04	83.47	6.35	2.97	0.04	0.55	0.01	1.22	0.02	0.55	23.33	0.33	1.38	0.04
S065-01	Sumay	07/28/18	13.61	0.19	0.71	0.02	145.32	11.06	1.89	0.03	0.14	0.00	0.11	0.00	13.75	34.97	0.49	2.73	0.08
G00-65	Geus	07/20/18	7.81	0.11	0.34	0.01	102.72	7.82	0.96	0.01	0.06	0.00	0.16	0.00	7.87	26.48	0.37	1.89	0.06
L066-01	As Liyog	08/03/18	0.00	0.00	2.11	0.07	80.92	6.16	5.60	0.08	0.65	0.01	1.46	0.02	0.65	36.51	0.51	2.35	0.07
A066-01	Ajayan	08/03/18	0.00	0.00	1.64	0.05	56.79	4.32	4.77	0.07	0.69	0.01	1.50	0.02	0.69	29.88	0.42	1.69	0.05
S066-01	Sumay	08/03/18	14.88	0.21	0.44	0.01	275.69	20.98	1.39	0.02	0.18	0.00	1.43	0.02	15.06	50.31	0.70	2.46	0.08
G00-66	Geus	08/03/18	5.00	0.07	0.21	0.01	186.82	14.21	0.76	0.01	0.09	0.00	0.39	0.01	5.09	24.58	0.34	2.26	0.07
L067-01	As Liyog	08/10/18	0.00	0.00	1.98	0.06	100.55	7.65	3.58	0.05	0.61	0.01	1.48	0.02	0.61	28.53	0.40	2.26	0.07
A067-01	Ajayan	08/10/18	0.00	0.00	1.90	0.06	75.88	5.77	2.55	0.04	0.53	0.01	1.15	0.02	0.53	26.29	0.37	1.75	0.05
S067-01	Sumay	08/10/18	8.56	0.12	0.57	0.02	122.26	9.30	1.49	0.02	0.09	0.00	0.00	0.00	8.65	31.41	0.44	2.71	0.08
G00-67	Geus	08/10/18	3.83	0.05	0.32	0.01	80.44	6.12	0.99	0.01	0.05	0.00	1.60	0.02	3.87	17.42	0.24	2.12	0.07
L068-01	As Liyog	08/25/18	0.02	0.00	3.70	0.11	30.80	2.34	4.51	0.06	0.88	0.01	1.96	0.03	0.90	33.60	0.47	7.02	0.22
A068-01	Ajayan	08/25/18	0.50	0.01	1.37	0.04	121.03	9.21	3.90	0.05	0.08	0.00	1.23	0.02	0.58	30.87	0.43	2.94	0.09
S068-01	Sumay	08/25/18	6.75	0.09	0.63	0.02	63.37	4.82	1.34	0.02	0.09	0.00	0.85	0.01	6.84	32.11	0.45	2.33	0.07
L069-01	As Liyog	09/03/18	0.00	0.00	0.53	0.02	88.18	6.71	2.48	0.03	0.00	0.00	1.65	0.02	0.00	23.24	0.33	1.60	0.05
A069-01	Ajayan	09/03/18	0.00	0.00	1.17	0.04	90.44	6.88	2.99	0.04	0.65	0.01	1.30	0.02	0.65	37.83	0.53	1.47	0.05
S069-01	Sumay	09/03/18	6.38	0.09	0.72	0.02	45.07	3.43	1.70	0.02	0.08	0.00	0.70	0.01	6.46	33.54	0.47	2.54	0.08
G00-69	Geus	09/03/18	5.23	0.07	0.56	0.02	208.09	15.83	0.87	0.01	0.05	0.00	1.98	0.03	5.28	23.33	0.33	1.99	0.06
L070-01	As Liyog	09/08/18	0.00	0.00	3.30	0.10	39.50	3.01	4.36	0.06	0.81	0.01	1.63	0.02	0.81	28.32	0.40	6.91	0.21
A070-01	Ajayan	09/08/18	0.23	0.00	1.49	0.05	85.38	6.50	3.90	0.05	0.34	0.00	1.50	0.02	0.57	38.59	0.54	3.27	0.10
S070-01	Sumay	09/08/18	7.82	0.11	1.35	0.04	86.38	6.57	1.47	0.02	0.10	0.00	0.44	0.01	7.92	35.41	0.50	2.73	0.08
L071-01	As Liyog	09/12/18	0.52	0.01	0.69	0.02	45.28	3.44	1.85	0.03	0.07	0.00	0.21	0.00	0.59	35.99	0.50	3.72	0.12
A071-01	Ajayan	09/12/18	0.00	0.00	0.76	0.02	73.86	5.62	2.75	0.04	0.30	0.00	0.70	0.01	0.30	22.91	0.32	3.74	0.12
S071-01	Sumay	09/12/18	6.10	0.09	0.17	0.01	69.51	5.29	1.23	0.02	0.07	0.00	0.38	0.01	6.17	32.93	0.46	2.19	0.07
G00-71	Geus	09/12/18	5.22	0.07	0.42	0.01	279.07	21.23	0.68	0.01	0.05	0.00	1.35	0.02	5.27	23.36	0.33	1.67	0.05
L072-01	As Liyog	09/17/18	0.00	0.00	2.16	0.07	86.40	6.57	4.04	0.06	0.64	0.01	1.51	0.02	0.64	42.26	0.59	2.14	0.07
A072-01	Ajayan	09/17/18	0.00	0.00	1.02	0.03	58.56	4.46	3.14	0.04	0.57	0.01	1.29	0.02	0.57	26.44	0.37	1.22	0.04
S072-01	Sumay	09/17/18	12.38	0.17	1.20	0.04	417.80	31.79	1.49	0.02	0.14	0.00	2.08	0.03	12.51	39.35	0.55	2.77	0.09
L073-01	As Liyog	10/13/2018	0.94	0.01	3.53	0.11	199.81	15.20	5.10	0.07	0.31	0.00	4.41	0.06	1.25	33.50	0.47	4.22	0.13
A073-01	Ajayan	10/13/2018	0.13	0.00	1.68	0.05	27.58	2.10	1.84	0.03	0.45	0.01	0.90	0.01	0.58	19.63	0.27	3.69	0.11
S073-01	Sumay	10/13/2018	18.97	0.27	1.28	0.04	279.86	21.29	1.46	0.02	0.13	0.00	5.57	0.08	19.10	43.46	0.61	2.96	0.09
L074-01	As Liyog	10/23/2018	0.21	0.00	3.78	0.12	63.68	4.85	4.00	0.06	0.75	0.01	2.51	0.04	0.96	31.89	0.45	3.84	0.12
A074-01	Ajayan	10/23/2018	0.15	0.00	1.75	0.05	22.84	1.74	1.95	0.03	0.44	0.01	0.59	0.01	0.59	22.38	0.31	3.75	0.12
S074-01	Sumay	10/23/2018	16.94	0.24	1.24	0.04	353.44	26.89	1.77	0.02	0.14	0.00	1.35	0.02	17.08	33.98	0.48	2.74	0.08
L075-01	As Liyog	11/2/2018	0.06	0.00	3.91	0.12	46.86	3.57	6.37	0.09	0.76	0.01	2.14	0.03	0.82	46.82	0.66	4.81	0.15
A075-01	Ajayan	11/2/2018	0.00	0.00	1.86	0.06	38.67	2.94	3.25	0.05	0.50	0.01	0.65	0.01	0.50	24.62	0.34	3.73	0.12
S075-01	Sumay	11/2/2018	6.80	0.10	0.63	0.02	50.03	3.81	1.31	0.02	0.07	0.00	0.13	0.00	6.86	34.42	0.48	2.86	0.09
G00-75	Geus	11/2/2018	4.11	0.06	0.22	0.01	80.60	6.13	1.07	0.02	0.01	0.00	0.37	0.01	4.12	21.54	0.30	1.98	0.06
L076-01	As Liyog	11/18/2018	3.04	0.04	5.20	0.16	221.20	16.83	5.99	0.08	0.83	0.01	4.15	0.06	3.87	34.99	0.49	6.08	0.19
A076-01	Ajayan	11/18/2018	0.00	0.00	0.61	0.02	98.30	7.48	3.76	0.05	0.25	0.00	0.11	0.00	0.25	27.42	0.38	3.65	0.11
S076-01	Sumay	11/18/2018	7.75	0.11	1.05	0.03	62.03	4.72	1.85	0.03	0.07	0.00	0.94	0.01	7.82	35.23	0.49	3.28	0.10
L077-01	As Liyog	12/1/2018	0.53	0.01	2.01	0.06	175.17	13.33	2.56	0.04	0.23	0.00	2.13	0.03	0.76	29.32	0.41	4.03	0.12
A077-01	Ajayan	12/1/2018	0.00	0.00	1.73	0.05	64.79	4.93	2.36	0.03	0.49	0.01	0.81	0.01	0.49	21.75	0.30	3.50	0.11
S077-01	Sumay	12/1/2018	9.88	0.14	0.95	0.03	135.90	10.34	1.38	0.02	0.07	0.00	2.36	0.03	9.95	35.42	0.50	3.08	0.10
G00-77	Geus	12/1/2018	1.83	0.03	0.43	0.01	52.78	4.02	1.23	0.02	0.01	0.00	2.47	0.03	1.84	28.35	0.40	2.25	0.07
L078-01	As Liyog	12/8/2018	0.04	0.00	1.30	0.04	103.70	7.89	2.41	0.03	0.08	0.00	0.97	0.01	0.13	25.26	0.35	3.94	0.12
A078-01	Ajayan	12/8/2018	0.00	0.00	1.51	0.05	32.91	2.50	2.36	0.03	0.50	0.01	0.87	0.01	0.50	20.65	0.29	5.69	0.18
S078-01	Sumay	12/8/2018	19.20	0.27	1.72	0.05	456.09	34.70	1.71	0.02	0.13	0.00	2.76	0.04	19.32	34.42	0.48	3.32	0.10
G00-78	Geus	12/8/2018	6.56	0.09	0.54	0.02	326.33	24.83	1.31	0.02	0.04	0.00	2.11	0.03	6.60	19.46	0.27	2.07	0.06
L079-01	As Liyog	12/23/2018	0.00	0.00	2.19	0.07	77.39	5.89	3.42	0.05	0.61	0.01	0.91	0.01	0.61	26.79	0.38	3.70	0.11
A079-01	Ajayan	12/23/2018	0.00	0.00	1.38	0.04	76.75	5.84	2.05	0.03	0.35	0.00	0.66	0.01	0.35	25.61	0.36	3.56	0.11
S079-01	Sumay	12/23/2018	18.80	0.26	1.41	0.04	435.32	33.12	1.72	0.02	0.12	0.00	1.57	0.02	18.93	34.34	0.48	2.63	0.08
G00-79	Geus	12/23/2018	8.07	0.11	0.56	0.02	337.95	25.71	1.23	0.02	0.03	0.00	1.14	0.02	8.10	25.09	0.35	1.93	0.06

NO_3^-, nitrate; $HPO_4^=$, orthophosphate; $HSiO_3^-$, silica; NH_4^+, ammonium; NO_2^-, nitrite; Total N, total nitrogen; Total P, total phosphorus

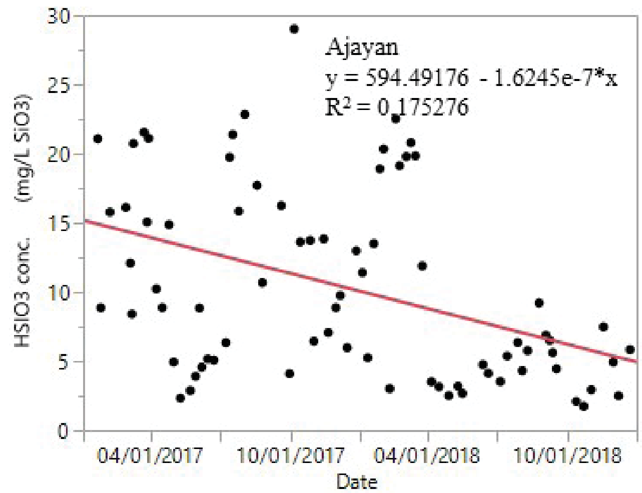
Appendix D. Ammonium concentrations over time at the three sites in the Manell watershed.

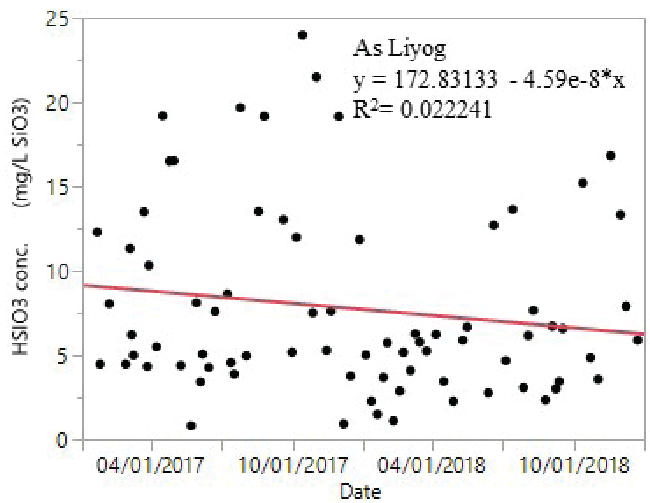


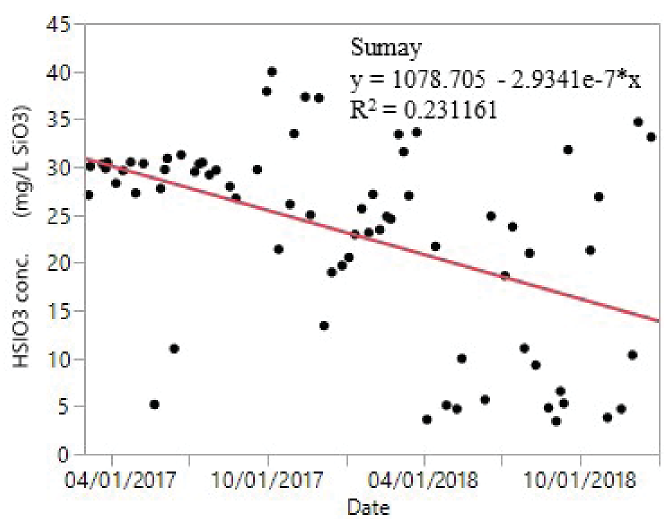




Appendix E. Silica ($HSiO_3$-) concentrations over time at the three sites in the Manell watershed.







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