doi:10.7289/V5BK19C3

Baseline Assessment of Faga'alu Watershed: A Ridge to Reef Assessment in Support of Sediment Reduction Activities and Future Evaluation of their Success

NOAA Technical Memorandum CRCP 23

CITATION:

S. Holst Rice, A. Messina, T. Biggs, B. Vargas-Angel, and D. Whitall. 2016. *Baseline Assessment of Faga'alu Watershed: A Ridge to Reef Assessment in Support of Sediment Reduction Activities and Future Evaluation of their Success*. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 23. 44 pp.
doi:10.7289/V5BK19C3

FOR MORE INFORMATION:

For more information about this report or to request a copy, please contact NOAA's Coral Reef Conservation Program at 301-713-3155 or write to: NOAA Coral Reef Conservation Program; NOAA/NOS/OCRM; 1305 East West Highway; Silver Spring, MD 20910 or visit www.coralreef.noaa.gov.

DISCLAIMER:

doi:10.7289/V5BK19C3

Baseline Assessment of Faga'alu Watershed: A Ridge to Reef Assessment in Support of Sediment Reduction Activities and Future Evaluation of their Success

S. Holst Rice, A. Messina, T. Biggs, B. Vargas-Angel, and D. Whitall

National Oceanic and Atmospheric Administration

February 2016

NOAA Technical Memorandum CRCP 23

Table of Contents

Introduction and Purpose

The primary purpose of this document is to provide local and federal partners with baseline information and survey methods to allow for continued monitoring efforts to evaluate the effectiveness of management actions taken at the Samoa Maritime quarry in Fagaʻalu, American Samoa. This document summarizes work completed between 2012 and 2014, and was coordinated and funded by the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Conservation Program (CRCP) to gather baseline data and information before management interventions such as drainage systems, alternative ground cover, and retention ponds were installed at the quarry to reduce land-based sources of pollution inputs to the coral reefs in Fagaʻalu Bay. The work was funded through direct investments made by the NOAA CRCP, through a Cooperative Agreement with American Samoa to the Coral Reef Advisory Group (CRAG), and through a domestic grant awarded to San Diego State University (SDSU) titled, "Monitoring and analysis of sediment accumulation and composition on coral reefs in Fagaʻalu Bay, American Samoa" which extended previous efforts supported by the Department of Interior – Insular Affairs Office through the CRAG.

To carry out these baseline assessments, technical and scientific experts from NOAA and SDSU collaborated to gather baseline information to share with local management authorities in American Samoa. These 2012-2014 activities describe the pre-intervention baseline data collection, analysis, and interpretation needed to evaluate the effectiveness of subsequently planned interventions over time. To quantify effectiveness of these interventions, additional long-term monitoring of sediment loads in Fagaʻalu Stream and coral community structure will be needed for comparison with the baselines presented here. The overall effort required to evaluate the effectiveness of the interventions is large, and requires a close coordination between local and federal efforts.

Background

In a process conducted in 2010 by NOAA's CRCP to identify management priorities in the US coral reef jurisdictions, American Samoan resource management and science advisors identified the Fagaʻalu watershed as one of two priority geographies in American Samoa based on biological value, degree of risk and threat, and management effectiveness (NOAA, 2010). As a result of this priority setting process, three strategic coral reef management goals were identified, including the following which is aimed at reducing LBSP: "*Goal 2: Improve coastal watershed quality and enhance coral reef ecosystem function and health by reducing land-based sources of pollution*".

In 2012, the Village of Fagaʻalu also completed its Watershed Management and Conservation Plan, which was facilitated by NOAA, through funding from the Coral Program, in collaboration with American Samoa's Land-based Sources of Pollution Local Action Strategy (LAS) Group and the village community. This plan identified sedimentation as a key threat to the Fagaʻalu watershed.

In August 2012, Fagaʻalu village, was chosen by the US Coral Reef Task Force (USCRTF) as a priority watershed site for the Watershed Partnership Initiative (WPI). The WPI was launched in Guanica, Puerto Rico in 2009 and is an active effort of the USCRTF to reduce LBSP by facilitating and enhancing coordination, partnership, and contributions of agency resources and expertise to implement geographically specific integrated activities to reduce pollutant loads to coral reef ecosystems. The WPI also promotes consistent and strengthened application and enforcement of laws and authorities intended to address LBSP within the U.S. coral reef jurisdictions. Currently, the WPI is active in three watersheds: Guanica, Puerto Rico; West Maui, Hawaii; and Faga‘alu, American Samoa.

By the end of 2012, with the above processes complete and the village plan as a guide, the CRCP began to provide resources and coordinate activities in Faga‘alu to establish baselines, monitor environmental parameters, and to address the threat of LBSP, specifically sedimentation issues and resulting turbidity found in Faga‘alu Stream and Faga‘alu Bay. Excessive turbidity is in part responsible for placing Faga‘alu on the Clean Water Act 303(d) list of impaired waters according to the American Samoa Environmental Protection Agency (ASEPA). Other parameters that do not meet the American Samoa Water Quality Standards (ASWQS) include total nitrogen, total phosphorus, dissolved oxygen, and *Enterrococcus* bacteria levels.

Geography, Rainfall, and Hydrodynamic Contexts

Figure 1. Overview of Faga‘alu Watershed from Matafao Peak showing watershed boundaries, stream outlet, village, LBJ Hospital, and the northern and southern coral reef flats of Faga‘alu Bay. Photo: Messina (2012)

Geography

Faga‘alu is a relatively small (2.49 km^2), steep coastal watershed located southwest of Pago Pago Harbor on Tutuila Island in American Samoa (Figure 1). Elevation ranges from 0 m at the outlet to the ocean, to 653 m at Matafao Mountain, the highest point on Tutuila. The main Faga‘alu Stream drains 1.86 km^2 and small, ephemeral streams drain the rest of the watershed directly into the adjacent Faga‘alu Bay. The Bay is bounded on the north by Tulutulu Point, and on the south by Niuloa Point. A coral reef flat forms a shallow lagoon extending from the shore several hundred meters into the Bay. The reef is bisected by a deep channel (‘ava’ in Samoan language) which flows out to sea through the forereef crest. The watershed is mainly comprised of undisturbed forest on the steep hillsides, with human disturbed areas and settlements constrained to the lower, flat parts of the watershed near the coast. The watershed includes Fagaʻalu Village (population 910, US Census 2010), the only hospital in American Samoa, a popular public beach park, Matafao Elementary School, and several businesses – including Samoa Maritime Company, an open pit rock quarry located upstream of the village. The quarry is the main source of sediment from the watershed and has increased sediment loading to Fagaʻalu Bay by an estimated 3-4 times above natural levels (Messina & Biggs, n.d.), making it a target for sediment mitigation actions to reduce sediment stress on corals in Fagaʻalu Bay.

Rainfall

Precipitation over Tutuila is generated by cyclones and tropical depressions, isolated thunderstorms, and uplift of trade-wind squalls over the high (300-600 m), mountainous ridge that runs the length of the island. Unlike many other Pacific Islands, the mountainous ridge runs parallel to the predominant winds, and does not cause a significant windward/leeward rainfall gradient. In Fagaʻalu watershed, rainfall records show average annual precipitation varies with elevation from 6,350 mm at Matafao Mountain (653 m) to 3,800 mm on the coastal plain (Craig, 2009; Dames & Moore, 1981; Perreault, 2010; Tonkin & Taylor International Ltd., 1989; Wong, 1996). Tropical cyclones are erratic but occurred on average every 1-13 years from 1981-2014 (Craig, 2009) and bring intense rainfall, flooding, landslides, and high sediment yield events (Buchanan-Banks, 1979).

There are two subtle rainfall seasons: a drier winter season, from June through September and a wetter summer season, from October through May (Izuka, Giambelluca, & Nullet, 2005). Analysis of mean monthly rainfall data for the period 1971-2000 showed 75% of precipitation occurred in the wet seasons and 25% occurred in the dry season (Perreault, 2010; Data from USGS rain gauges and Parameter-elevation Relationships on Independent Slopes Model (PRISM) Climate Group (Daly et al., 2008)). During the drier winter season, the island is influenced by relatively strong, predominantly east to southeast trade winds, lower temperatures, lower humidity and lower total rainfall. During the wet summer season the Inter-Tropical Convergence Zone (ITCZ) moves over the region, causing light to moderate northerly winds, higher temperatures, higher humidity, and higher total rainfall. While total rainfall is lower in the drier trade wind season, large rainfall events are still observed. Analysis of 212 peak discharges at 11 streams on Tutuila showed 65% of annual peak flows occurred during the wet season and 35% of peak flows occurred during the drier Tradewind season (Wong, 1996).

Hydrodynamics

Fagaʻalu reef is comprised of two areas of shallow reef flats (0-1.5 m) with some deeper sand-bottomed pools (3-4 m), divided by a deep ava (15 m) through the reef. Tides vary daily from approximately 0-1 m, exposing parts of the reef at low tide. Fagaʻalu Bay is sheltered from all swell directions except south to east-southeast, and groundswells over 1 m occur throughout the year. Water is forced over the shallow reef crest by wind and waves, then flows clockwise over the southern and northern reefs, and out to sea through the ava channel to Pago Pago Harbor (**Figure 2**).

Sediment stress to corals is controlled by sediment concentration in the overlying water column, residence time of that water, and sedimentation rates. In general, higher sediment concentrations and longer residence times increase sediment stress to corals. Based on hydrodynamic measurements in Fagaʻalu Bay, current speeds are highest and residence times lowest over the southern reef; speeds are lowest and residence times highest near the stream mouth and on the northern reef (**Figure 2**)(Messina, Storlazzi, Biggs, & Washburn, n.d.). During storms, sediment-rich discharge from Fagaʻalu stream flows into the northwest corner of the bay, and is deflected north by the water circulation pattern. This causes sediment accumulation and stress on corals in the northern reef and ava channel areas but leaves the far southern reef relatively unaffected (Messina, Storlazzi, & Biggs, n.d.).

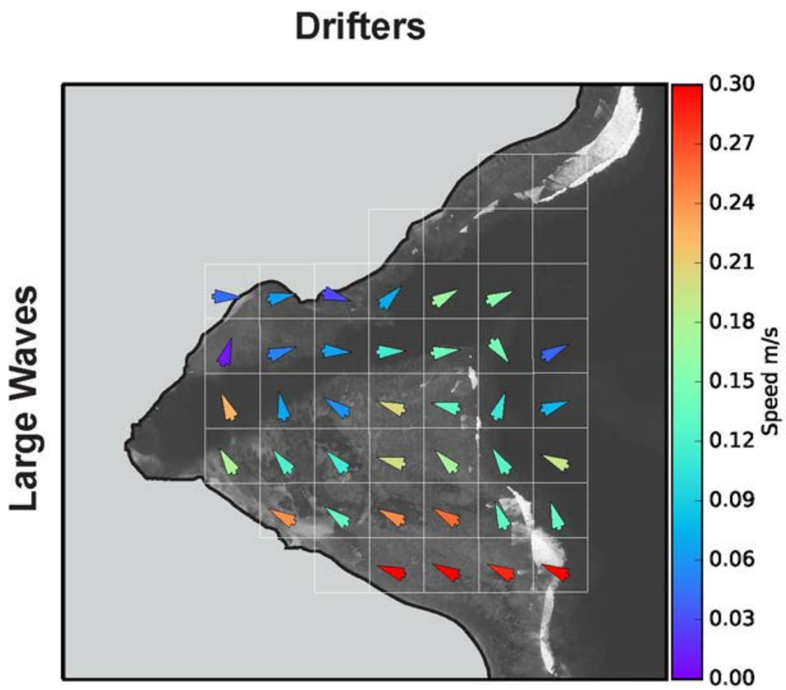


Figure 2. Gridded mean current speeds and directions for 100 m2 grid cells based on GPS-drifter data. Current speeds are highest, and directions less variable during large waves and high winds. Current speeds are slower, and directions more variable during small waves and light winds (Messina, Storlazzi, Biggs, et al., n.d.)**.**

Mitigation Actions/Interventions

Since the designation of Fagaʻalu as a priority site for the WPI, multiple entities, including the National Fish and Wildlife Foundation (NFWF), CRAG, ASEPA, and NOAA CRCP have prioritized the need to address sedimentation over the coral reef during and following major rain events. Suspecting the Samoa Maritime quarry as a major contributor to this episodic flux, local and federal agencies engaged in discussions to implement a corrective action plan at the quarry. This plan included multiple steps to address both storm and non-storm conditions:

1) Prior to intervention, perennial groundwater flows were discharged from a spring in the quarry blast face and flowed over the haul roads, Excavation Platform, and Operational Areas of the quarry, eroding sediment into the stream and elevating suspended sediment concentration (SSC) during non-storm conditions. In August 2012, groundwater drainage diversions to intercept clean groundwater flow were installed at two locations: a) immediately below the exposed rock face at the Excavation Area, and b) between the Excavation Platform and Upper Operational Area (dotted blue lines, Figure 3).

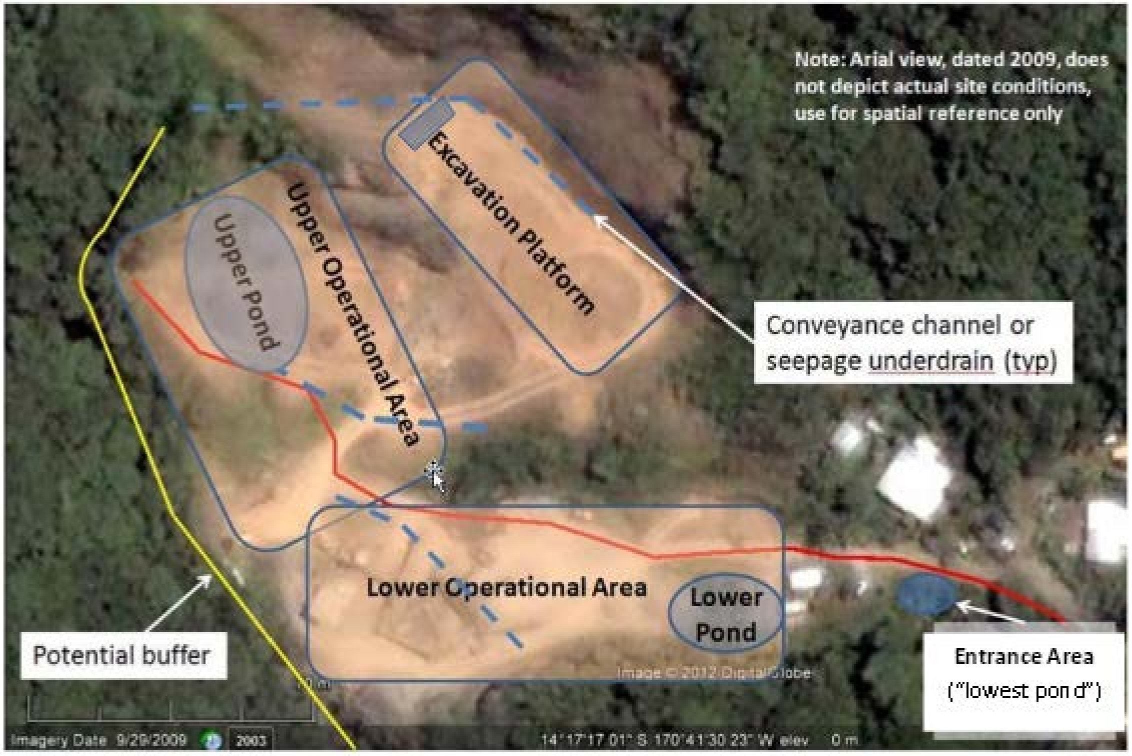


Figure 3. Schematic of retention pond locations at the Samoa Maritime quarry (Horsley Witten Group Inc., 2013). The "conveyance channel/seepage underdrains" (dotted blue lines) were constructed in 2012. Actual locations may vary slightly from this diagram. The underdrain through the Lower Operational Area was routed east of the Lower Pond towards the Entrance Area. The "potential buffer" was installed with the retention ponds in 2014. The "lowest pond" was present in 2012, but reconstructed in 2014 to increase its effectiveness.

2) Between August 2012 and February 2013, all surfaces including haul roads, Excavation Platform, and Operational Areas were covered with large gravel to minimize erosion of surface sediments and reduce tracking from equipment tires during wet conditions (**Figure 4**). Several large piles of soil overburden that were barren and subject to severe erosion in 2012 were naturally overgrown by vegetation from 2012-2014 (**Figure 5**).

Figure 4. Pictures of the Upper Operational Area before (left) and after (right) covering road surfaces in gravel. Pictures taken by Alex Messina

Figure 5. Pictures of the Excavation Platform before (2012, top) and after (2014, bottom) vegetation overgrowth of overburden piles. The groundwater seep is evident in the muddy puddle in the top picture. The groundwater diversion routed this flow to the right in the picture, into the stream before it could erode the Platform surfaces. Pictures taken by Alex Messina.

3) In September-December 2014, to clear space for retention ponds, the large piles of soil overburden were removed from the Excavation Platform and Upper Operational Area (**Figure 6**) and transferred to a dump site near the airport. Rock-lined drains (including the "potential buffer" in **Figure 3**) were installed throughout the quarry to capture storm runoff and route it directly to two large retention ponds: one in the Upper and one in the Lower Operational Area (**Figure 7**). A small retention pond near the quarry Entrance Area ("lowest pond", **Figure 3**) captures runoff from the site that cannot be routed into the large, Lower Pond. These retention ponds capture sediment-rich runoff from the whole site before it can be discharged into the stream during heavy rainfall conditions. The retention ponds allow the sediment-free water to percolate through the ground and into the stream, leaving the sediment behind in the retention pond. The baffle boards installed in the upper cell are designed to slow the flow of water allowing more sediment to settle out. When the ponds fill to a certain depth, standpipes in the retention ponds allow small amounts of sediment-rich water that have already been slowed by the baffle boards to be skimmed from the top of the pond. The water from the standpipe drains directly to the stream. During exceptionally high, infrequent rainfall events when water levels in the pond are high, rubble-lined spillways route excess stormflow into the stream to prevent damage to the retention pond.

Figure 6. Pictures of the Upper Operational Area/Excavation Platform before (left) and after the installation of the Upper Retention Pond. A similar retention pond is also installed at the Lower Operational Area (not shown).

Figure 7. Pictures of the Lower and Upper retention ponds at the Samoa Maritime Quarry, full of sediment-rich runoff following a large rain storm. Both were installed in September-December 2014. The Upper retention pond (right) is a two-pond configuration, connected by a rubble-lined spillway. Stand-pipes are visible in the corner of each retention pond. During major rain events these route water from the pond directly into the stream to prevent overtopping the retention pond banks. Pictures taken by Alex Messina.

The engineering designs for the interventions at Samoa Maritime quarry were developed by Horsley Witten Group, Inc., and were built into the corrective action plan for the quarry to implement using Samoa Maritime's own equipment and time (Horsley Witten, 2013). Funding was provided by NFWF, NOAA, and CRAG to cover supplies and hauling excavated material from the retention ponds. Samoa Maritime, Ltd. assumed any costs exceeding the amount of funds provided. Before any excavation work, all permits were secured and all necessary clearances (e.g. local land-use permit, Endangered Species Act, National Environmental Protection Act) were obtained. ASEPA, CRAG, and NOAA CRCP staff based in American Samoa provided on-site coordination for the work in cooperation with Samoa Maritime staff. Regular site visits were conducted during the implementation of the corrective action plan to ensure that the work was in accordance with the plans prepared by Horsley Witten Group with final sign off responsibility resting with technical staff at ASEPA.

Rationale for Collection of Baseline Data

Land-based sources of pollution (LBSP) are considered a substantial threat to coral reef ecosystems, and sediment is commonly acknowledged to be one of the primary causes of coral reef ecosystem degradation (Rogers 1990; Field et al. 2008). The combination of suspended, re-suspended, and deposited sediment act to limit coral growth, feeding, photosynthesis, recruitment, and survivorship (Fabricius, 2005). However, there has been very limited research that connects management actions taken in watersheds to downstream impacts in coral reef areas. In fact a recent global review concluded that, “examples of watershed management demonstrating the halting or reversing of coral reef decline are not readily available” (Kroon et al. 2014). The efforts described here were implemented proactively to provide baseline data for pertinent variables – sediment loading and deposition, coral community structure and demographics, and chemical contaminant loads – ahead of the interventions so that managers can evaluate their efficacy.

Sediment

Sediment monitoring in Fagaʻalu Stream began in 2012 by San Diego State University (SDSU) (Messina and Biggs, n.d.), with funding from Department of Interior Office of Insular Affairs through the CRAG cooperative agreement. Sediment monitoring in the stream continued through 2015 under an additional grant from CRAG titled, “Expanding monitoring and modeling of land-based sources of pollution to priority coral reefs in American Samoa”. Building upon these two grants, NOAA CRCP funded SDSU for 2 years of work in 2013, for a project titled “Monitoring and analysis of sediment accumulation and composition on coral reefs in Fagaʻalu Bay, American Samoa.” Under this project, monitoring was expanded to include sediment deposition and benthic community composition on the reef.

Data collected through these projects provided a comprehensive baseline of sediment loading from undisturbed and human-disturbed areas in the watershed, and sediment deposition on the reef. Sediment loads can be extremely variable between storm and non-storm conditions, so the monitoring period from 2012-2014 provided enough time to sample a wide range of storm sizes and intensities prior to mitigation efforts at the quarry. The analysis presented here quantifies suspended sediment loads during storms of similar size and intensity, prior to the installation of retention ponds, which can be compared to future sediment monitoring after the mitigation and determine the effectiveness of management actions.

Coral

To obtain pre-intervention baselines for coral community structure and coral demographics in Fagaʻalu Bay, surveys were conducted by NOAA’s CRCP and partners in 2012, and additional benthic surveys focused on coral demographics were completed in 2013 as a sub-activity of NOAA CRCP project “Comprehensive baseline assessment and pilot test of outcome performance measures in Fagaʻalu Bay, American Samoa”. The status of the coral community and the effects of the sedimentation on the coral reefs in Fagaʻalu Bay were characterized using data collected in 2012 and 2013. The data provides baseline information critical to evaluating the effectiveness of reef-to-ridge management practices aimed at reducing land-based sources of pollution threats and improving coral community structure and demographics in Fagaʻalu Bay, American Samoa.

Contaminants

Through conversations in 2013 with ASEPA, SDSU, CRAG, and the National Marine Sanctuary of American Samoa, concerns were raised about the quantity and quality of groundwater flowing through the bedrock in Fagaʻalu. A 2013 study prepared for ASEPA looking at decadal trends in coral reefs near watershed villages (Houk, 2013) showed that significant freshwater input, possibly due to groundwater movements, occurs on the southern coast of Tutuila thereby adding another possible source of LBSP. In 2013, the CRCP also learned the site of the Matafao Elementary School, located on the northern shore of Fagaʻalu Bay, was previously a U.S. military dump site during World War II and presented a potential source of contaminants into Fagaʻalu Bay via groundwater movements. To identify additional stressors (other than sediment from the quarry), the CRCP funded collection of baseline levels of contaminants from surface sediments in the watershed and the bay using standardized methods from NOAA's National Status and Trends Program, in addition to sediment load and coral community information. This contaminant study was a sub-activity of CRCP project "Comprehensive baseline assessment and pilot test of outcome performance measures in Fagaʻalu Bay, American Samoa".

In the sections that follow, the significance of gathering baselines for each of the three areas highlighted above will be discussed. Additionally, for each area the following will be presented: monitoring methods for data collection, data analysis, pre-intervention baseline values, and an outlook of anticipated changes as a result of the interventions.

Section 1. Sediment Monitoring at Fagaʻalu

Trent Biggs, Alex Messina
San Diego State University, Department of Geography

Significance

Sediment is a key stressor to coral reefs by limiting light necessary for photosynthesis, smothering, and promoting disease (Erftemeijer, Riegl, Hoeksema, & Todd, 2012; Fabricius, 2005). At Fagaʻalu, sediment loading from key sediment sources to Fagaʻalu Bay was monitored from 2012-2014 using measurements of streamflow (Q) and suspended sediment concentration (SSC) collected downstream of the undisturbed forest (FG1), the quarry (FG2), and the village (FG3) (Figure 8). During 2014, sediment accumulation rates and composition were also monitored on the reef. Additional details of the sampling methods and results are in Messina & Biggs (n.d.) and Messina, Storlazzi, & Biggs (n.d.). Additional hydrodynamic data were collected to determine the predominant water circulation patterns over the reef; details are presented in Messina, Storlazzi, Biggs, et al. (n.d.). Here, the basic methods are summarized in sufficient detail for data interpretation. Detail sufficient for replicating the monitoring can also be found in a Quality Assurance Plan Protocol (QAPP)(Messina & Biggs, 2013).

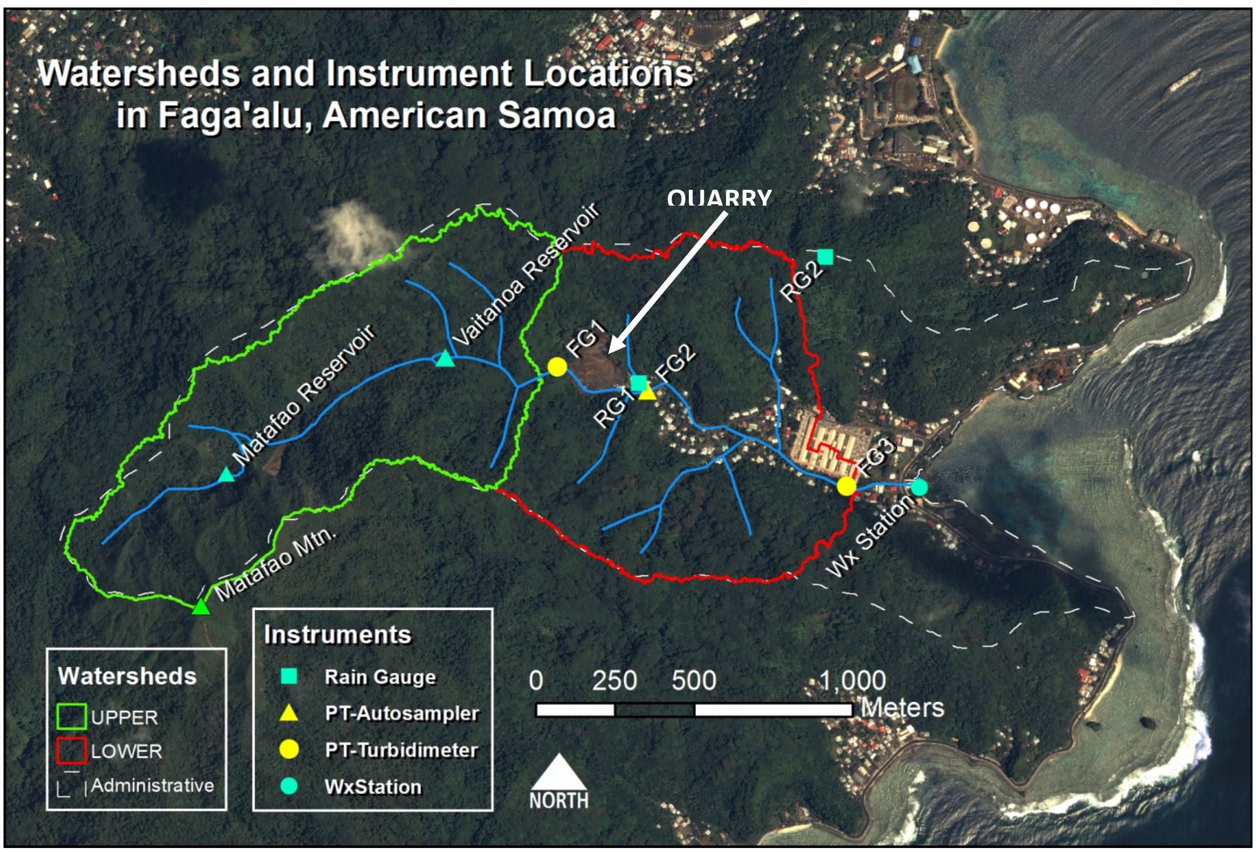


Figure 8. Location map of monitoring sites at Fagaʻalu. "Wx station" is a weather station with a rain gauge, wind speed, and air pressure.

Rationale for Storm Sampling

Most of the sediment discharged to Fagaʻalu Bay occurs during storm events and is derived from human-disturbed areas downstream of the undisturbed forest (between FG1 and the ocean, Figure 8) (Messina & Biggs, n.d.). During non-storm conditions streamflow and sediment concentration are often very low, but increase rapidly with rainfall (Figure 9). The highest sediment concentrations and sediment loads were observed during storm events, thus, sampling of baseflow at a set time every week or two will not effectively measure the sediment load or the impact of management operations. It is very important that sediment monitoring include measurements of sediment concentrations during storm events of various intensities.

Methods

Sediment Loading from the Watershed

Suspended sediment yield from individual storm events (SSY_{EV}), measured upstream and downstream, or pre- and post-mitigation can be compared to determine relative contributions from key sources, or the effectiveness of sediment mitigation (Basher, Hicks, Clapp, & Hewitt, 2011; Hicks, 1990). This approach does not require continuous monitoring for long periods like comparing annual totals, and controls for the variability in storm sizes during different monitoring periods (Rankl, 2004).

Precipitation and discharge variables, “storm metrics,” can be used to predict SSY_{EV} and provide a modeled estimate when SSY_{EV} cannot be measured directly (Duvert et al., 2012). Total precipitation, an index of precipitation intensity (EI30), total streamflow (Q), and peak Q during storm events were tested as predictors of SSY_{EV} from both the forest watershed and from the village watershed. Peak Q proved to be the best predictor of SSY_{EV}, making it possible to measure the impact of mitigation in the future, by predicting the pre-mitigation SSY_{EV} and observing the difference.

Sediment load (tons) at any given instant (tons/sec) is calculated as:

$$SSY = Q \times SSC \tag{1}$$

where Q is streamflow (aka discharge, units L/s) and SSC is suspended sediment concentration (mg/L). Q is calculated using stream depth recorded by a pressure transducer and a relationship between stream depth and flow rate (see “*Streamflow monitoring*” below). Two methods are used to determine SSC: 1) from grab samples taken during a storm (ideal), collected either manually or by an automated sampler (Autosampler), or 2) from continuous turbidity measurements (T). Turbidity measurements recorded by a turbidimeter installed permanently in the stream are translated to SSC by a relationship between SSC and turbidity. The T-SSC relationship is developed using grab samples and simultaneous turbidity data (see “*Suspended sediment monitoring*” below). SSY_{EV} is calculated as the sum of the instantaneous loads (SSY in Equation 1) during a storm event.

Key metric: Sediment loading during storm and inter-storm events

Rainfall monitoring

Rationale:

Rainfall measurements are important for determining water input into the watershed during a storm and the kinetic energy of the rainfall. Rainfall during storm events can be used as a predictor of total sediment load from storms at Fagaʻalu.

Method at Fagaʻalu:

Tipping-bucket rain gauges were installed at the quarry (RG1) and at the church near the outlet of Fagaʻalu stream to the ocean (Wx Station) (Figure 8). Tipping bucket rain gauges record every 0.01 inches of rainfall, which can be converted into rainfall intensity measurements at any time interval – typically 10 or 15 minutes. Rain gauges need to be installed with the top level and away from tall structures or vegetation that may interfere with wind or rainfall. Data is downloaded at least once per month, debris is removed from the bucket, and the batteries are checked.

Streamflow monitoring

Rationale:

Continuous water discharge measurements (Q, units in volume per time) are necessary for calculating SSY_{EV} (Equation 1), and can be used as a predictor of SSY_{EV}. Q is the product of the cross-sectional flow area and the flow velocity. Q is estimated using measured water depth (stream stage) and a mathematical relationship between the stream stage and a few manual measurements of the discharge (a stage-discharge relationship). To measure stream stage continuously, pressure transducers (PTs) submerged at the bottom of the stream measure pressure due to both atmospheric pressure and the depth of water over the PT. The pressure due to the atmosphere is measured by a nearby barometer and subtracted from the total pressure to give the stream stage at 15 min intervals. PTs are very rugged and have provided some of the most reliable data on watershed behavior at Fagaʻalu. Q is measured in the field with a hand-held flowmeter by taking velocity and depth readings at intervals across the stream and calculating Q for the corresponding stream stage. A single Q measurement typically takes approximately 15-30 min. To develop a robust stage-discharge relationship, several Q measurements are needed over the widest range of stream stages possible.

Method at Fagaʻalu:

PVC or metal tube housings were installed in Fagaʻalu Stream at FG1 (upstream of the quarry) and near the hospital (FG3). A staff gage was installed on the concrete pillar of the bridge near the hospital (FG3, **Figure 8**). The stream stage on the staff gage is observed and written down in a notebook at the deployment and retrieval of the PT to correct for any changes in the streambed. Ideally, several readings of stream stage on the staff gage are taken during the PT deployment period over a range of stage heights.

A stage-discharge relationship was developed at each PT location, using a combination of hydraulic equations and discharge measurements to calibrate the equations. See Messina & Biggs (n.d.) and Messina & Biggs (2013) for more detail. The stage-discharge relationship may need updating with measurements of the cross sectional area and flow velocity if vegetation grows in the channel or if sediment deposits in the channel during storm events.

Suspended sediment monitoring

Rationale:

Suspended sediment concentration (SSC) was measured both directly from grab samples and indirectly using turbidity measurements (Messina & Biggs, n.d.). Grab samples are water samples taken from the stream manually using a wide-mouth 500 mL bottle, or with an ISCO Autosampler. In the laboratory, the grab sample is vacuum-filtered onto a pre-weighed filter, dried in an oven, and the dried filter and sediment are weighed. Autosamplers require regular maintenance like charging the battery and clearing the sampling tube if clogged, but they can be automatically triggered by a stream stage sensor to collect critical storm measurements when field staff are unavailable. Field staff are still needed to retrieve the samples out of the Autosampler and perform the lab analyses. As an alternative, turbidity measurements can be used to estimate SSC by developing a mathematical relationship between SSC measured in a few grab samples and a simultaneous turbidity measurement recorded by the turbidimeter.

Method at Faga'alu:

Using a combination of grab-sampling, autosampling, and turbidimeters, SSC was measured during ~60 storm events at Faga'alu above the quarry (FG1), just below the quarry (FG2), and at the hospital (FG3) (**Figure 8**). An Autosampler was installed at FG2 and turbidimeters were installed at FG1 and at FG3 (see Messina and Biggs (n.d.) for details).

Analysis for impact assessment: Relationship between peak discharge and sediment yield

Rationale:

Annual sediment yield (tons/km2/yr) is often used to compare watersheds or to assess the effectiveness of management activities; however annual totals are influenced by the natural variability in number and intensity of storm events. The relationship between streamflow and suspended sediment concentration (Q-SSC relationship) can be used to test for a decrease in sediment at the same streamflow, but there is usually high natural variability in the Q-SSC relationship. At Faga'alu, the Q-SSC relationship was highly variable, due in large part to high SSC on the rising limb of the storm hydrograph, so a simple Q-SSC relationship could not be used to separate the effects of stream discharge from the effects of land use or management activities in Faga'alu (**Figure 9**). Instead, a relationship between "storm metrics" and SSY from storm events was developed and used as a baseline of sediment loading for future comparison.

Method at Faga'alu:

Four "storm metrics," including total precipitation, a precipitation intensity index (EI30), total discharge, and peak discharge, were tested as predictors of SSY_{EV} (**Figure 10**). Peak discharge during the storm event (Qpeak) was the best predictor of SSYEV and illustrates the increased sediment loading between the upstream, forested watershed (FG1) and the watershed that includes the village and quarry (FG3) (**Figure 10**). Management impact would be demonstrated by a change in the Qpeak-SSY_{EV} relationship.

Key Metric: Difference in Slope/intercept of Qmax-SSY relationship between impacted and natural sub-watershed

SEDIMENTATION ON THE REEF

Sediment accumulation

Rationale:

Sediment discharged from the watershed may or may not affect coral health on the reef depending on ocean conditions. If sediment discharge happens during a time of intense ocean circulation, deposition may be much lower than during times of quiescent ocean conditions. Therefore, monitoring sedimentation rates on the reef itself is important to determine the ultimate impact of management activities on a reef.

Method in Faga'alu:

We quantified two metrics of sediment deposition which are critical to coral health:

1. *Gross sediment accumulation* is all sediment that accumulates on a surface with no resuspension. This may be important if even temporary sediment accumulation negatively affects coral organisms. Gross accumulation is measured using PVC tubes, which capture sediment and prevent resuspension (White, 1990).
2. *Net sediment accumulation* is the amount of sediment that accumulates on a surface, minus what is resuspended and removed from the surface by currents induced by waves or wind. Net accumulation may be important if corals are sensitive to prolonged sediment deposition and residence. Net accumulation is measured using a flat, rough concrete surface (SedPods), which are exposed to waves and currents, allowing sediment to be deposited, then resuspended and removed (Storlazzi et al., 2011; Field et al., 2012).

The tubes for measuring gross deposition are constructed from 2" PVC pipe with an end cap. SedPods for measuring net deposition are constructed from 6-inch diameter PVC pipe filled with concrete. The concrete is poured on rough plywood to give it texture that approximates the rough texture of a coral colony. Sediment was collected monthly by trained SCUBA divers, and analyzed in the laboratory for sediment weight, grain size, and composition. Details on sediment collection are in (Messina & Biggs, 2013).

Key metric: Sediment composition and accumulation rates in tubes and on SedPods

Analysis for impact assessment:

Rationale:

The impact of sediment on coral may depend on the sediment size, and the fraction of the sediment that is terrestrial versus marine in origin (Erftemeijer et al., 2012). The fine fraction can be determined with simple sieves in the laboratory, but the methods must be followed very carefully to be consistent with other results. The terrestrial fraction is determined using combustion of the calcium carbonate from marine sediment in an oven (see Messina and Biggs (2013) for details).

Method in Faga'alu:

Sediment collected in simple tubes and SedPods was sieved in a lab at the American Samoa Community College (ASCC) to determine the fine and coarse fractions. The samples were dried, weighed and shipped to SDSU for further composition analysis. The combustion method was used to determine the fraction of the collected sediment that was organic, carbonate, and terrestrial in origin.

Baseline values

SEDIMENT LOADING FROM FAGA'ALU STREAM:

At Faga'alu, particularly in 2012, some high sediment concentrations were observed during non-storm conditions due to 1) consistent flow of groundwater from an excavated rock face over the quarry haul roads, 2) aggregate washing operations at the quarry, and 3) small storms that washed sediment from the quarry into the stream but did not cause a significant rise in stream level. Data from 2014 show that this situation has been addressed through corrective management measures at the quarry, including groundwater diversion drainage and gravel cover over the quarry grounds. Both construction and washing activities have since stopped and high concentrations are no longer observed between storms, with few exceptions (see FG2 in 2014 in Figure 9).

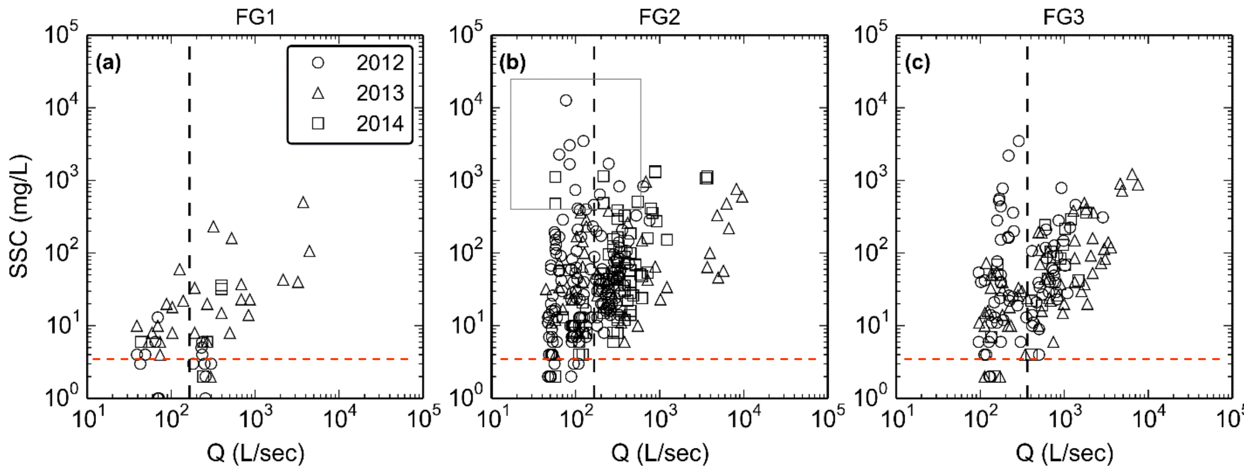


Figure 9. Discharge (Q) versus suspended sediment concentration (SSC) at the (a) forest, (b) quarry, and (c) village sites. The box in (b) highlights where SSC was high during low streamflow, downstream of the quarry, and then slightly diluted downstream near the hospital (c). These were notably absent from the forest site (a), and are hypothesized to be caused by activities at the quarry that ceased after 2012, i.e. washing sediment from the crushed aggregate during non-storm periods, and remediation of groundwater flow eroding sediment from haul surfaces. Red lines indicate the EPA fresh surface water quality standard: average Total Suspended Solids (comparable to SSC) not to exceed 5 mg/L. Vertical dashed lines indicate the threshold for defining stormflow. Discharge above the threshold is defined as stormflow and discharge below the threshold is defined as baseflow. Note that some samples collected under baseflow conditions occurred after rainfall but did not cause sufficient rise in stage to be defined as stormflow.

The scatter in the Q-SSC relationship (Figure 9) means that it is not an ideal method to determine the success of management activities. Instead, a regular relationship was found between total storm sediment yield (SSYEV) and several storm metrics including total storm rainfall, total discharge, and peak discharge (Qpeak) (Figure 10). *The best relationship was found with Qpeak, which can be used to estimate the pre-mitigation sediment load, and compare to future measurements to quantify the impact of management on sediment mitigation.*

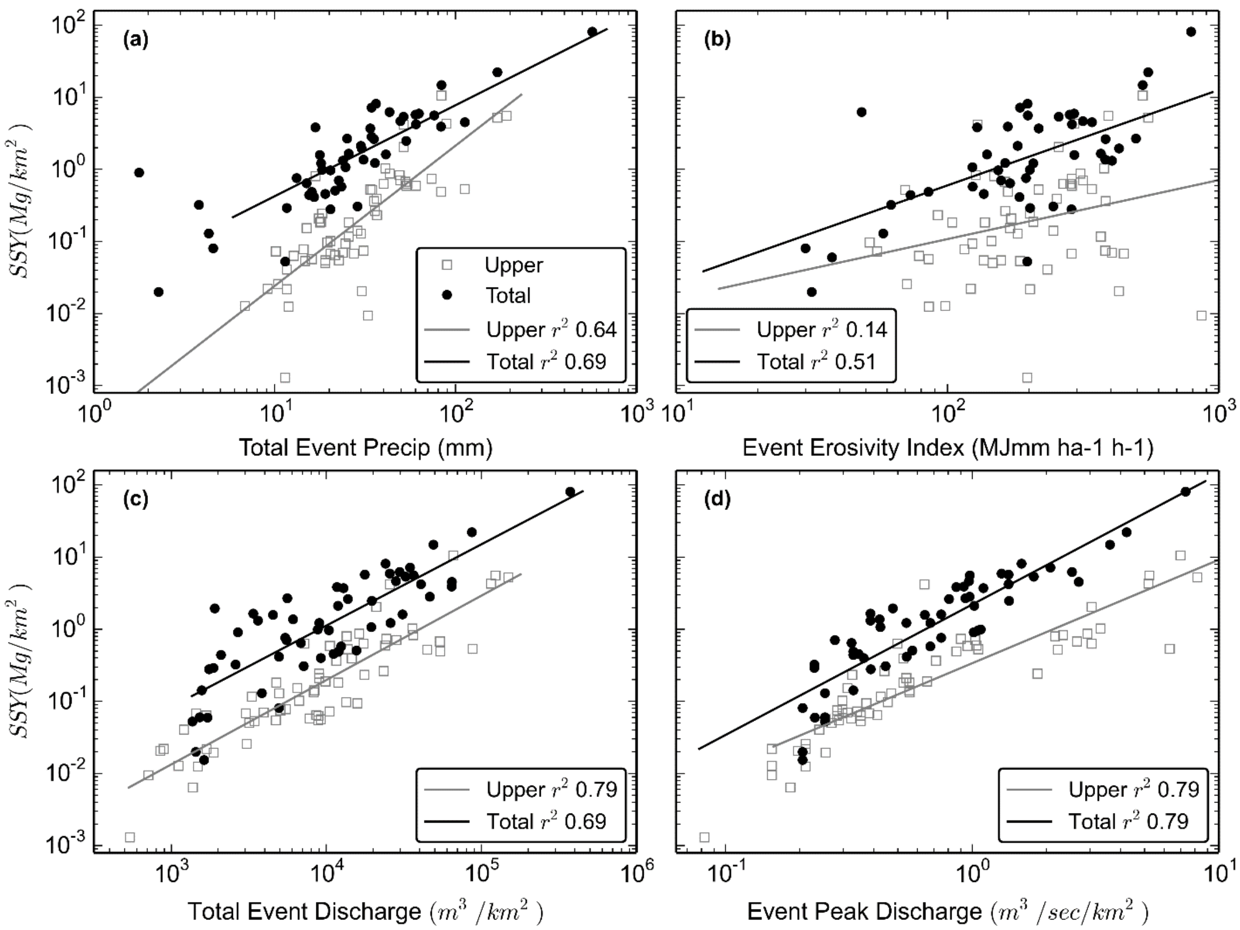


Figure 10. Storm event sediment yield (tons/km2) from the upper watershed (undisturbed forest, FG1 in Figure 8), and from the total watershed (including the quarry and village, FG3 in Figure 8), versus (a) rainfall, (b) rainfall erosivity, (c) event discharge, and (d) event peak discharge. Each point represents the SSY for a single storm event. SSY for the disturbed watershed is higher than for undisturbed upper watershed, indicating human disturbance in the quarry and village has increased SSY_{EV} above natural levels. Qpeak (d) showed the best model fit ($r^2 = 0.79$) for both the Upper and Total watersheds. This model can be used to predict pre-mitigation SSY and compare to post-mitigation SSY, illustrating the effectiveness of mitigation. By reducing SSY through mitigation at the quarry, SSY measured during storms post-mitigation should plot on the model for the upper watershed, indicating SSY from the watershed is back to the natural baseline SSY

SEDIMENTATION ON THE REEF

Sediment accumulation in tubes and SedPods deployed on the reef reflected the water circulation patterns over the reef flat. Water circulation deflects sediment-rich waters from Faga'alu Stream outlet in the northwest corner of the Bay over the northern reef flat, constraining the impacts of sediment deposition to the northern reef and area surrounding the ava channel (Figure 11). Both gross and net sediment accumulation and the percent terrigenous follow this pattern.

Sediment accumulation in SedPods-April 2014

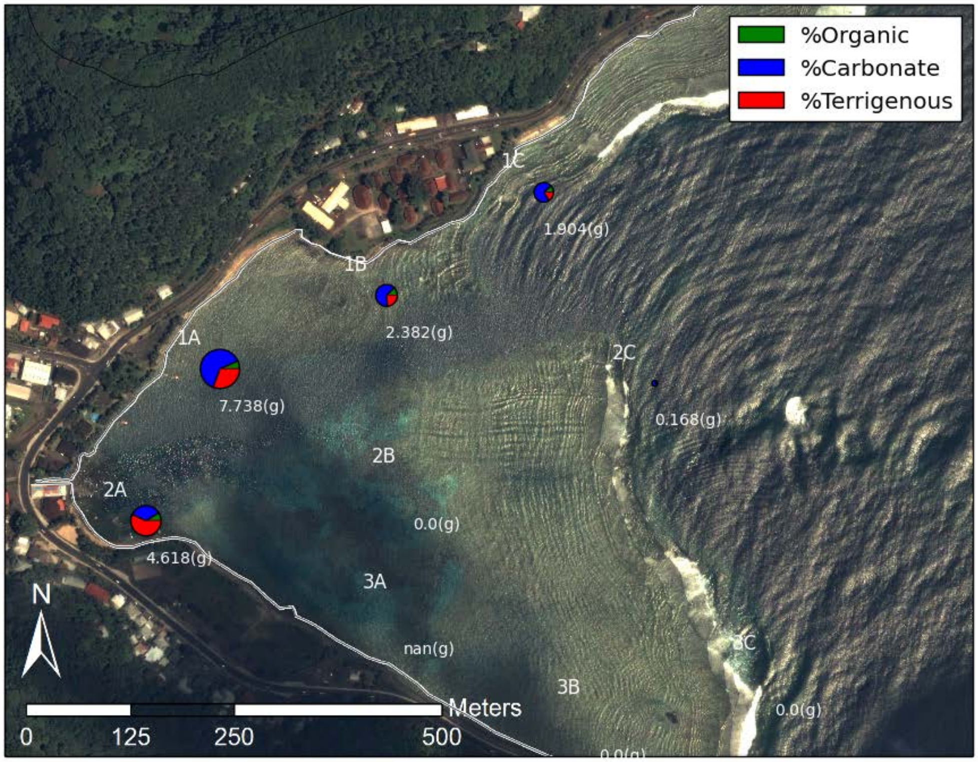


Figure 11. Map showing locations of co-located SedPods and tubes, and sample plots with amounts (circle size) and the organic, carbonate and terrestrial fractions, for one month of sedimentation in April 2014. Similar data was collected April 2014-April 2015 but not presented here.

Areas on the northern and parts of the central reef experience the highest chronic sediment stress, exceeding coral health thresholds in some months (Figure 12). There is some evidence that gross sediment accumulation (in tubes) is correlated with precipitation, where precipitation can be understood as a proxy for sediment loading to the Bay. However to prove this correlation true further analysis is required, including a consideration of decreased sediment loading following the sediment mitigation actions at the quarry in September 2014 and monthly ocean circulation conditions.

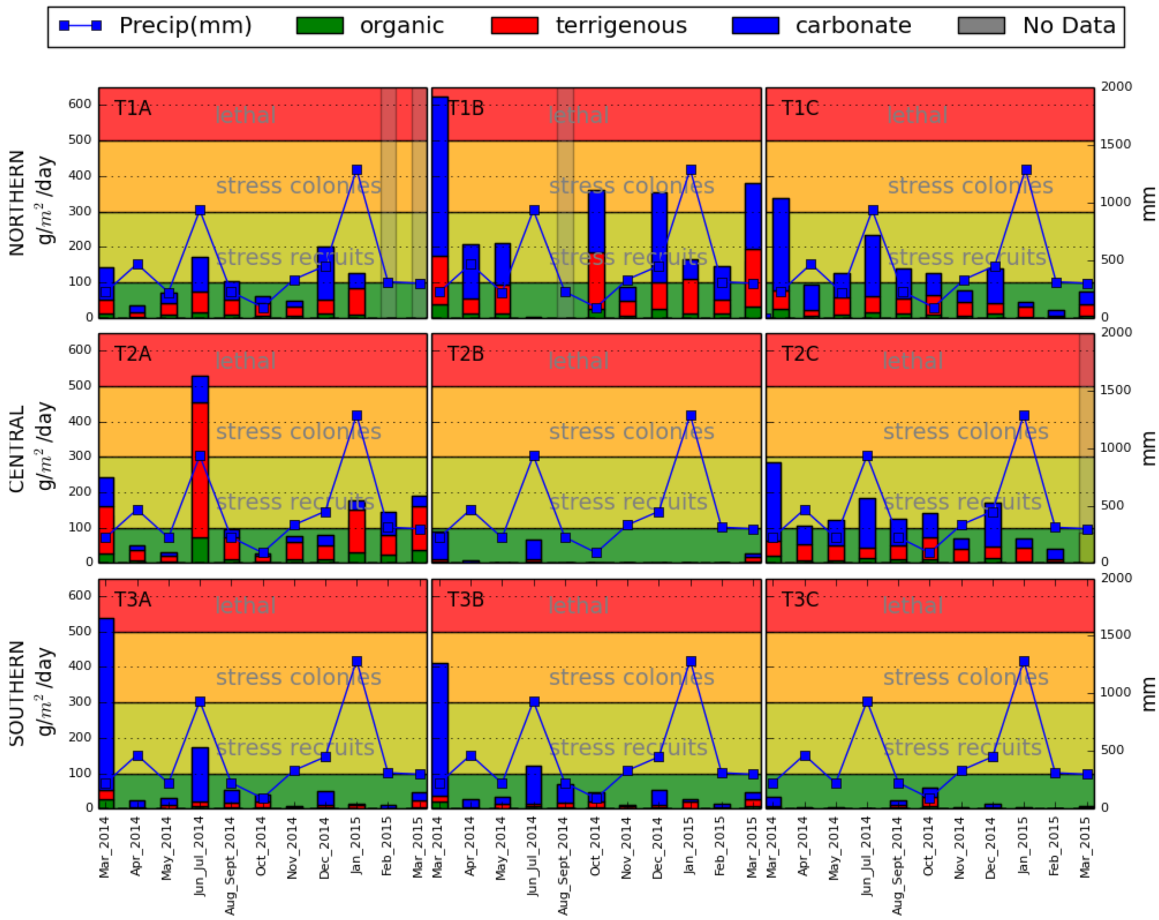


Figure 12. Time series of sediment accumulation in the tubes, March 2014-March 2015. Thresholds vary by coral species but most sources agree sedimentation rates over 500 g/m2/day are usually lethal (Erftemeijer et al., 2012; Fabricius, 2005).

Outlook: Anticipated changes due to mitigation activities

Continued monitoring recommendations

Based on the amount of scatter in the Qpeak-SSY_{EV} relationship (Figure 10), we anticipate that SSY_{EV} will need to be quantified for at least 10 storms in order to establish any change in the Qpeak-SSY_{EV} relationship that could be attributed to sediment management. Storm sampling includes taking at least 5 stream samples per storm at each monitoring location, at 5-30 minute intervals, or deployment of a continuous recording turbidimeter. If manual sampling is used, care should be taken to sample on the rising limb, peak, and falling limb of the hydrograph.

We expect that the mitigation activities at the quarry will have immediate impacts on sediment loading in the stream. Prior to the installation of the two large sediment retention basins in 2014, several mitigation measures were implemented at the quarry, detailed above (see Mitigation Actions/Interventions). Preliminary observations in October-December 2014 suggest that the large retention ponds are successfully retaining runoff and sediment from the quarry during storms, resulting in immediate qualitative improvement of stream SSC. Results from continued sampling in 2014-2015 will provide quantitative estimates of those impacts for several storms.

The main long term challenge will be to maintain the retention capacity of the ponds. Ponds fill up with both water and sediment, and their effectiveness will likely diminish between cleanings. There may be reduced retention capacity, particularly after large events. Proper maintenance of the ponds is essential for continued effectiveness of the ponds as tools for sediment mitigation. See Appendix A.

The impact of reduced sediment loading on sedimentation rates observed on the reef is more uncertain and may have a temporal lag of several years or more; very little literature exists detailing a similar recovery. Sediment in reef systems can have residence times of years to decades or more, and natural resuspension of those sediments can result in continued turbidity, deposition on the reef, and persistent health impacts on corals (Brodie, Wolanski, Lewis, & Bainbridge, 2012). We anticipate that the accumulation of fine terrigenous sediment will decrease following mitigation activities but it may not fall to natural levels for several years. For comparability, we recommend continued use of both tube and SedPods for monitoring future sediment accumulation and documentation of effectiveness of the mitigation efforts at the quarry.

Section 2. Comprehensive baseline assessment of coral reef community structure and demographics in Faga`alu Bay, American Samoa

Bernardo Vargas-Ángel
NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division

Significance

Parts of the reef at Fagaʻalu Bay are severely affected by siltation stress, due to excessive terrigenous runoff resulting from prolonged and deficient land use practices within the boundaries of the adjacent watershed. Additional secondary impacts to reef corals and associated communities in the Bay include nutrient loading (nitrogen and phosphorus), lowered levels of dissolved oxygen, and elevated bacterial counts from urbanization and inadequate waste management (Rodgers 1990; Fabricius 2005). By documenting coral reef benthic community structure and demographic parameters in a spatially comprehensive manner, this work provides baseline information that is critical to evaluate the effectiveness of reef-to-ridge management practices aimed at reducing land-based sources of pollution threats in Fagaʻalu Bay. This information is also of use as the basis to track and improve water quality, enhance ecosystem resilience, and update coral reef protection measures.

Methods

A stratified random sampling design was implemented to survey the coral reef communities at Fagaʻalu; the survey domain encompassed nearly 90% of the mapped area of reef and hard bottom habitat, which was divided into four strata based on reef zone (backreef and forereef) and location (north and south). Survey depths in the backreef habitat ranged between 0.5 m and 2.5 m; and between 3 m and 20 m for the forereef habitat. The ava channel was the feature implemented to delineate the boundaries between the north and south sectors of the reef. Allocation of sampling effort was relative to strata area and sites were randomly selected within each stratum. Rapid ecological assessments, totaling surveys at 40 sites (Figure 13), were conducted between March 2012 and August 2013 by staff of NOAA's Coral Reef Ecosystem Division (CRED), with three sites (north bay, south bay, and ava channel) marked permanently for future visits and reassessments.

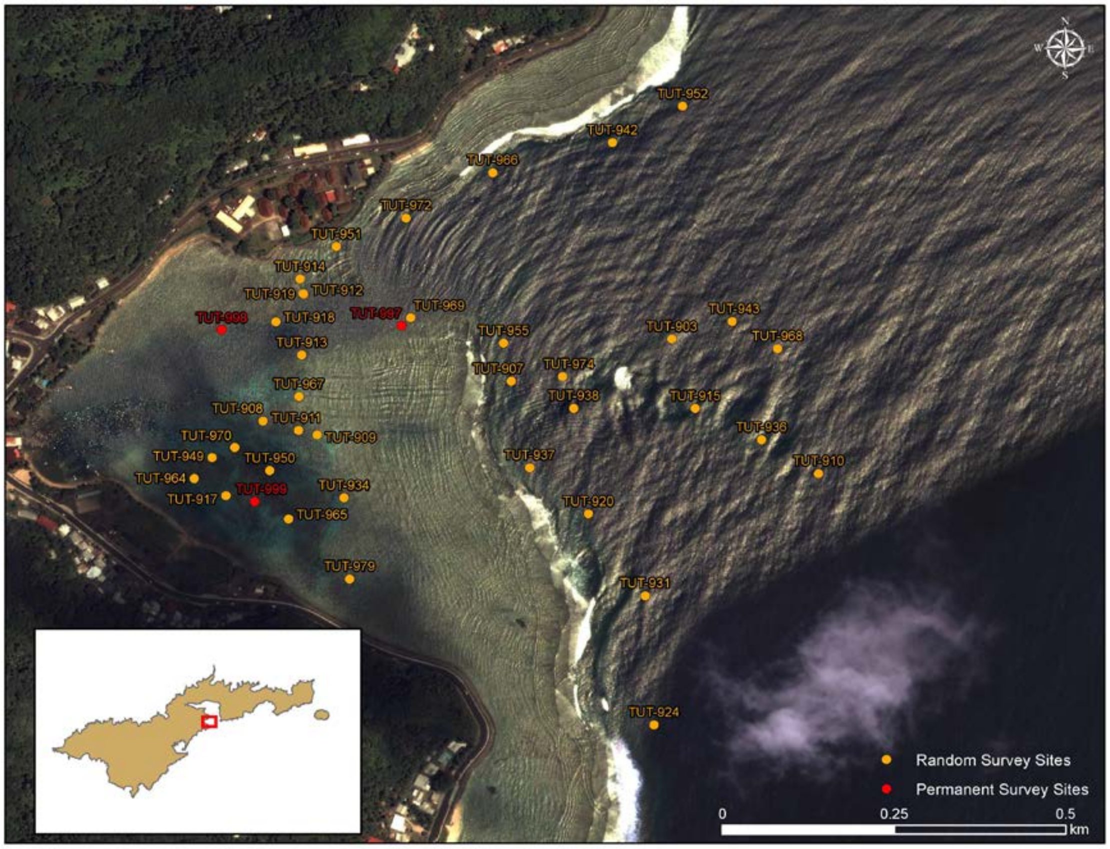


Figure 13. Location of the benthic sites surveyed at Faga'alu Bay, American Samoa, between March 2012 and August 2013. Backreef sites indicated in orange and forereef sites indicated in yellow. Red symbols indicate permanent sites; 2 backreef and 1 forereef. All sites were selected using a stratified random design.

At each site the belt-transect method, with two 25-m transect lines as the focal point of the survey, was implemented to quantitatively assess benthic community structure and demographics. Along each transect five 2.5-m^2 segments were surveyed (0–2.5 m; 5.0–7.5 m; 10–12.5 m; 15–17.5 m; 20–22.5 m), whereby all coral colonies whose center fell within 0.5 m on either side of each transect line were identified to the highest possible level of taxonomic detail and measured for two planar size metrics: maximum diameter and diameter perpendicular to the maximum diameter (NOAA 2015). Coral recruits (defined as attached colonies smaller than 5 cm in diameter) were also quantified, measured, and identified to the highest possible level of taxonomic detail. For each coral colony identified within belt-transect surveys, the extent of mortality – both recent and old – were estimated, dedicating special attention to any evidence of disease and sediment-related damage or stress. In addition, the Line-Point-Intercept methodology at 20 cm intervals was implemented to derive information on benthic percent composition, relative abundance, and cover (NOAA 2015).

Data Analysis

Analysis of benthic community structure and demographics data

Spatial patterns of mean percent coral cover and colony densities were tested implementing independent two-way ANOVA models, using reef zone (backreef vs. forereef) and location (north vs. south) as factors. Cover data was analyzed using natural logarithmic transformation to fulfill parametric statistical requirements. ANOVA analyses were performed using SYSTAT 12 version 12.02.00 (SYSTAT 2007).

Baseline values

Benthic composition and community structure

The quantitative survey data support the benthic community patterns that previously had been anecdotally reported and observed in the field: coral development is conspicuously prominent along the southern portions of the reef in Faga`alu Bay (**Figure 14a, b, Figure 15**), compared to the northern areas, where coral development is limited and depauperate (**Figure 14c, d, Figure 15**).

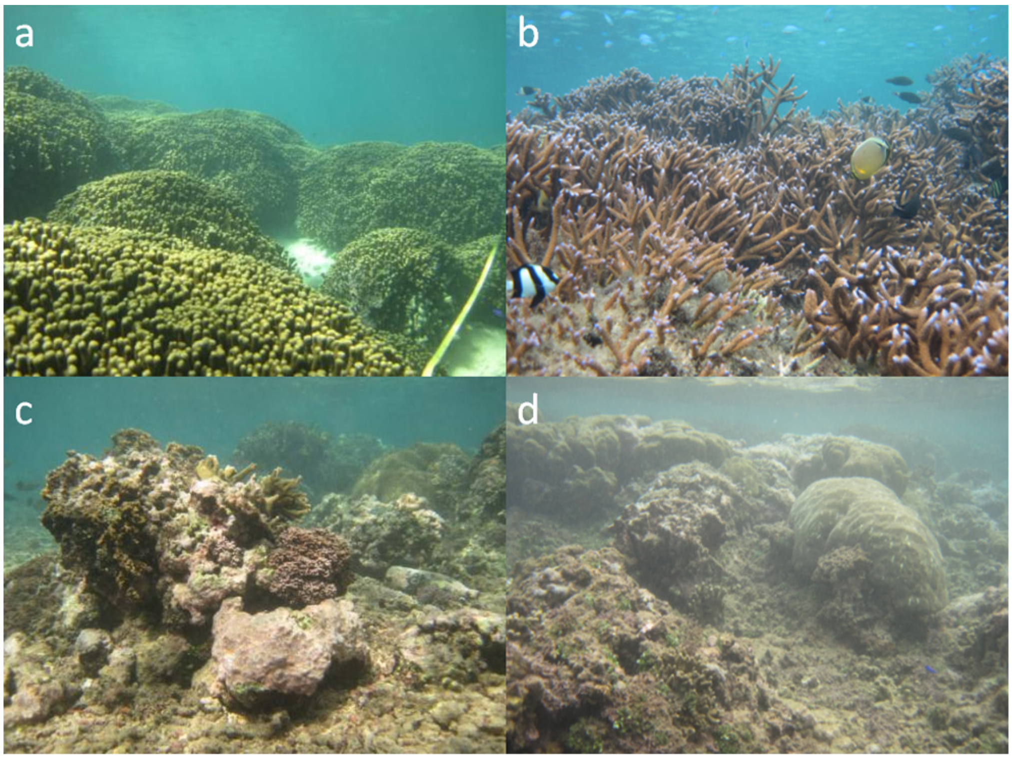


Figure 14. Visual, spatial comparison of coral growth, development, and appearance of shallow habitats of the (a, b) south and (c, d) northern areas of the backreef in Faga'alu Bay, American Samoa. NOAA photos by Bernardo Vargas-Ángel.

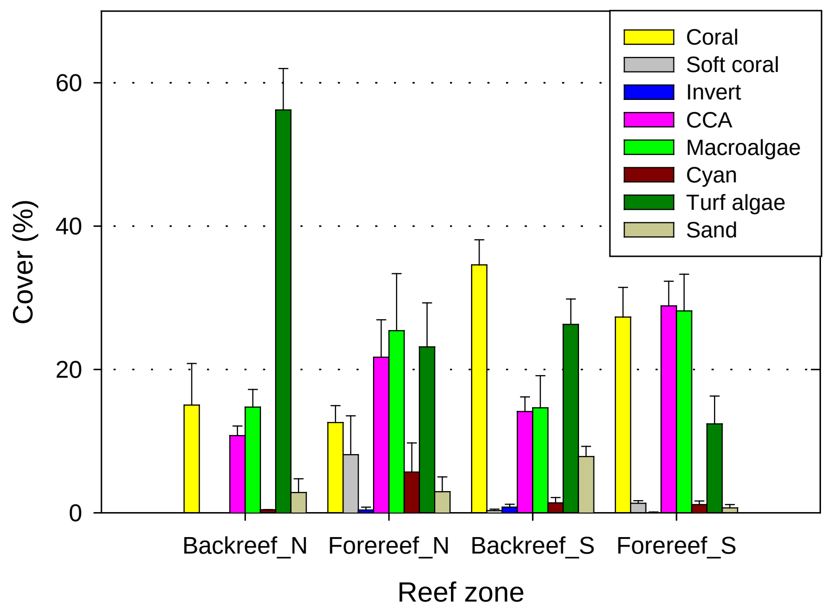


Figure 15. Spatial comparison of mean benthic percent cover of shallow habitats of the northern and southern backreef and forereef areas in Faga'alu Bay, American Samoa, derived from line-point-intercept surveys conducted in March 2012 and August 2013.

Mean percent live coral cover was nearly twice as high along the southern area of the reef compared to the northern sector (**Figure 15**, **Figure 16a,** Table 1) and those differences were significant. Differences between forereef and backreef were not significant with no interaction effects between factors (Table 1). Levels of crustose coralline algae were not distinctly different between the northern and southern sectors of the reef (16.8% SE 3.4, 22.5% SE 0.26, respectively), but statistically greater on the forereef compared to the backreef) (**Figure 15**, **Figure 16b**) (two-way ANOVA, P=0.26; P=0.004, respectively). Percent cover of turf algae was significantly different between reef zones and location; no factor interaction effects however (two-way ANOVA, P<0.009; P=0.002, respectively) (**Figure 15**, **Figure 16c,** Table 1). The northern areas of the reef in Faga`alu Bay are directly affected by terrigenous siltation and runoff. Surveys corroborate this appraisal, as exemplified by the "reef-builder ratio," which is the proportion of corals and crustose coralline algae to non-carbonate accreting organisms (macroalgae and turfalgae) calculated with values of mean percent cover. The reef-builder ratio was greater along the southern backreef and forereef than along the coral-impoverished northern reef and those differences were statistically significant (two-way ANOVA, P<0.002; P=0.23, respectively) (**Figure 15**, **Figure 16d,** Table 1).

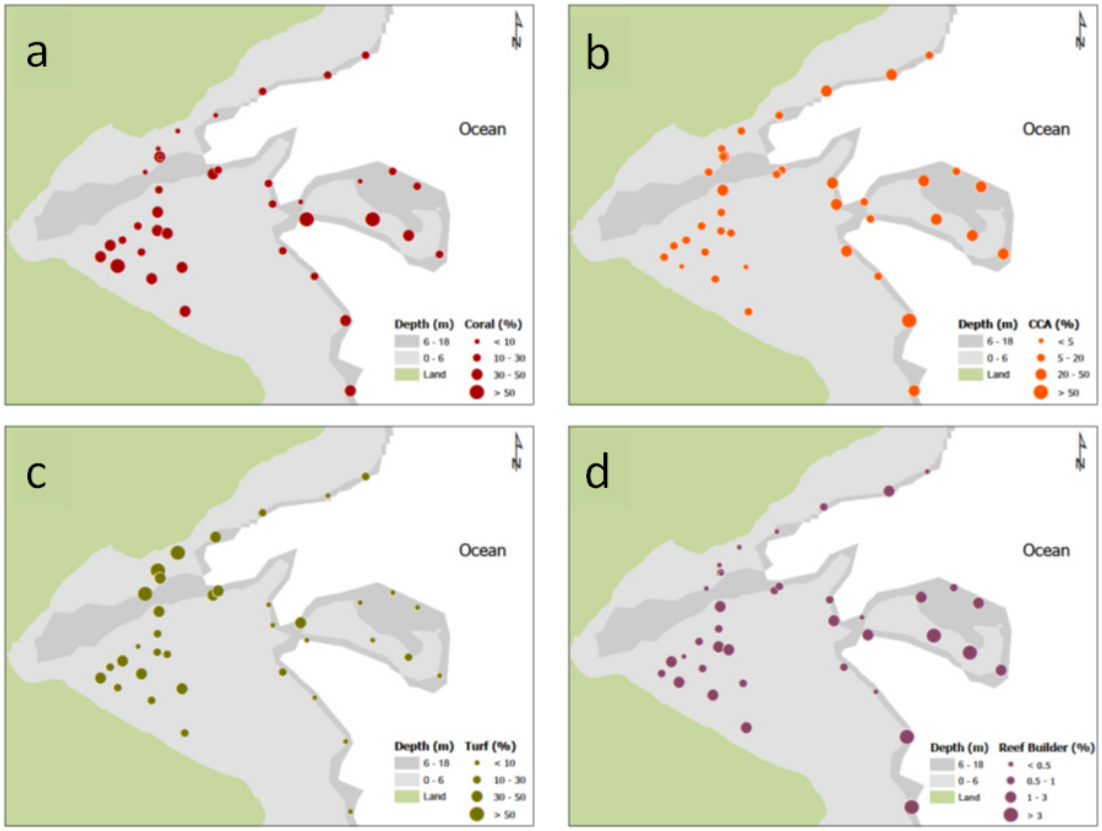


Figure 16. Spatial comparison of mean cover (%) values for (a) live hard corals, (b) crustose coralline algae (CCA), (c) turf algae, and (d) values of the reef-builder ratio (ratio of mean cover for corals and crustose coralline algae combined to cover for non-accreting organisms) from line-point-intercept surveys conducted in March 2012 and August 2013 in Faga`alu Bay.

Table 1. Summary statistics and P values for two-way ANOVA models run for mean percent benthic cover (% ± SE) and mean coral colony densities (col/m^2 ± SE), based on line-point-intercept surveys conducted in March 2012 and August 2013 in Faga'alu Bay. Data were ln-transformed or square root-transformed (*) to comply with parametric statistics requirements.

	Location			Reef zone			Location x Reef zone
	North	**South**	**P**	**Backreef**	**Forereef**	**P**	**P**
Cover							
Coral	13.7 ± 2.7	30.2 ± 2.7	0.004	28.9 ± 3.6	23.6 ± 3.3	0.33	0.48
CCA	16.8 ± 3.4	22.5 ± 2.5	0.26	13.3 ± 1.6	27.3 ± 2.9	0.004	0.71
Turf	37.8 ± 7.1	18.1 ± 2.9	0.009	33.3 ± 4.3	14.3 ± 3.3	0.002	0.59
Macroalgae*	24.0 ± 4.8	24.2 ± 3.5	0.40	15.8 ± 3.3	30.5 ± 4.0	0.11	0.97
Reef builder	0.6 ± 0.2	2.2 ± 0.6	0.002	1.1 ± 0.2	2.4 ± 0.8	0.23	0.62
Density							
Coral	9.3 ± 1.7	13.4 ± 0.9	0.006	12.2 ± 1.3	12.9 ± 1.2	0.02	<0.001

Colony Densities and Condition

Figure 17a illustrates estimates of colony density of 6 important reef-building coral genera in Faga`alu Bay. Colony densities for all coral taxa combined were significantly higher along the southern backreef and forereef (13.44 colonies/m2, SE 0.99) than along the northern sector of the reef (9.34 colonies/m2, SE 1.70). Differences between reef zones were statistically significant (two-way ANOVA, P=0.02) and there was an interaction effect between factors, indicating a clear segregation of the four strata when considering reef location (Table 1). Additional differences in coral generic composition and density were evident: corals of the genus Porites were dominant along the shallow northern backreef while corals of the genus Montipora occurred primarily along the channel and southern forereef. Additional notable spatial and structural differences indicated a preponderance of encrusting and foliose corals of the genera Montipora and Pavona, respectively, along the shallow northern backreef and, in contrast, the presence of branching corals of the genus Acropora throughout the southern backreef. Fast-growing branching corals such as Acropora appear to be better adapted to the shallow, well-lit habitats of the southern backreef, compared to encrusting and foliose species that appeared to tolerate the lower levels of light and conditions of higher turbidity prevalent on the northern backreef (Rodgers 1990; Crabbe and Smith 2005; Erftemeijer et al. 2012). Differences among habitats also were observed in values of coral generic richness (Figure 17b), with a greater mean number of genera occurring along the deeper forereef (10.95, SE 0.67) compared to the shallow backreef (6.29, SE 0.25), and these differences also were statistically significant (*P*=0.001, Student's *t*-test). Such variation is expected given the disparate range of environmental conditions (for example, light, depth, water circulation) of available microhabitats present on the forereef compared to the shallow, relatively homogeneous backreef.

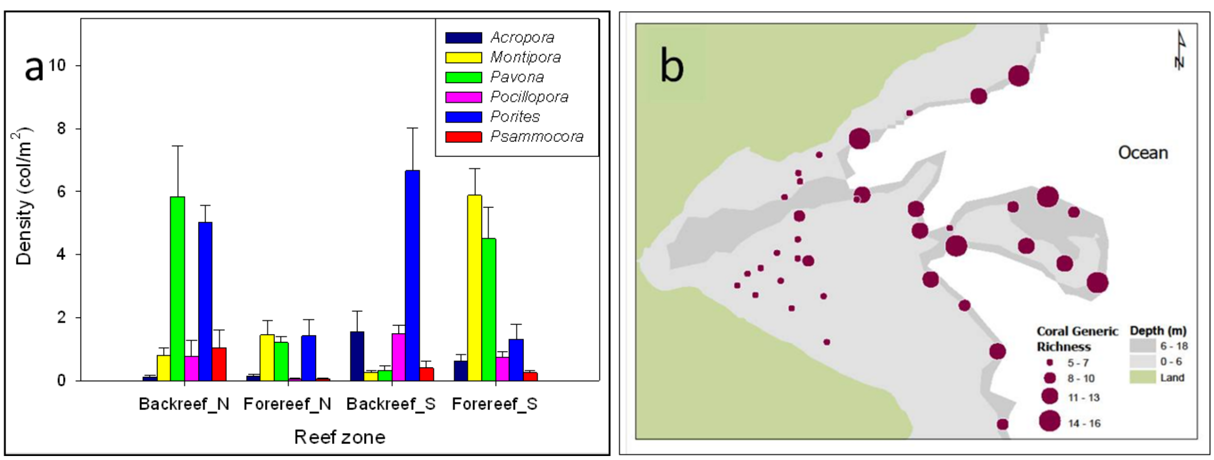


Figure 17. Spatial comparison of (a) coral-colony density (colonies/m2) and (b) total coral generic richness from belt-transect surveys conducted in March 2012 and August 2013 in Faga'alu Bay. The color-coded bars indicate densities of selected dominant coral genera

Except for one site on the southern backreef, low levels of bleaching were commonplace across habitats and depths in Faga'alu Bay (Figure 18). Similarly, mean prevalence of coral disease was low overall (0.1%, SE 0.02); however, non-tissue loss lesions resulting in compromised health were greater at northern backreef sites (0.77%, SE 0.39) than at southern sites (0.62%, SE 0.12). Although small, these differences could be associated with the elevated, chronic terrigenous runoff and sedimentation that affects these areas (Pollock et al. 2014).

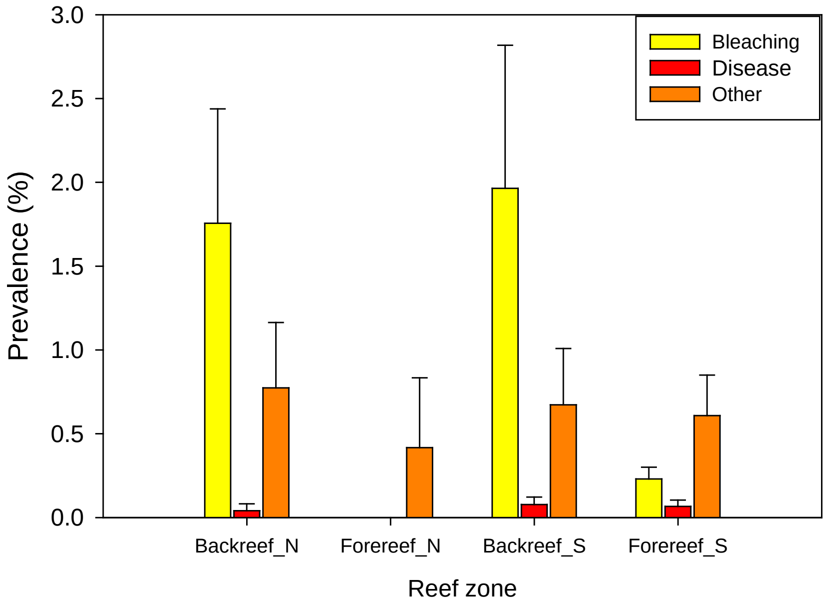


Figure 18. Spatial comparison of prevalence (%) of bleaching and disease from belt-transect surveys conducted in March 2012 and August 2013 in Faga`alu Bay.

Outlook: Anticipated changes due to mitigation activities

In actively growing coral reefs, calcifying organisms including corals, crustose coralline algae, and other carbonate-accreting taxa, typically dominate the shallow, well-lit habitats. In contrast, communities dominated by noncalcifiers, such as turf algae, cyanobacteria, and other macroalgae, are common in areas with suboptimal conditions. In addition to the elevated levels of turf and macroalgae, regardless of the cause, reductions in coral dominance often results in increased rates of bioerosion, leading to gradual destruction of the reef framework and habitat loss (Fabricius 2005; Glynn and Maté 1997). Impacts to the benthic communities in Faga‘alu Bay, particularly corals, result from the combined effects of increased turbidity, sedimentation, and nutrient influx. Although upslope quarry mitigation activities are expected to result in changes to the composition and structure of the adjacent coral reef benthos, the spatial and temporal constructs of these changes may take years to decades. Reef sediments tend to have prolonged residence times (years to decades or more) and natural resuspension processes can result in continued turbidity and sediment deposition, leading to persistent health impacts to corals (Brodie et al. 2012).

Because turf and macroalgal communities can quickly respond to changes in water quality conditions, once established, these turf- and algal-dominated communities can be difficult to reverse. Algae that dominate benthic communities following acute and/or chronic environmental disturbances can be hardy, chemically defended species, including filamentous cyanobacteria which are relatively unpalatable to herbivores (Fong and Paul 2011). Terrigenous sedimentation and siltation stress is often accompanied by increased nutrient levels which facilitate algal proliferation. As such, preserving and promoting healthy fish and invertebrate herbivore communities will be pivotal to the reestablishment of functional coral communities at Fagaʻalu, particularly those along the northern portion of the reef which exhibit the greatest levels of siltation impact. It can be speculated that the first signs of change may be quantifiable as reductions in the cover of fleshy macroalgal elements and an increase in calcifying coralline algae. However, because corals exhibit a lesser competitive superiority compared to algae, their recovery will depend on the reduction of the algal populations, together with improvement of water clarity, the reduction of excess sediment and nutrient inputs, as well as the availability and establishment of recruits.

One element to consider however is the fact that the northern shallow reef is located under the direct influence of the drainage of the Fagaʻalu stream. Recurrent, low-salinity pulses associated with heavy downpours and storm flood events can be implicated with decreased levels of calcification and potentially lesser development of corals and other calcifying reef-dwelling benthos (Jokiel et al. 1993). In addition, the historic landfill located on the premises of the current Matafao Elementary School site is potentially a source of contaminants, particularly arsenic, which may preclude, or delay the recovery of shallow benthic assemblages on this side of the fringing reef (Downs et al. 2005).

Section 3. Contaminant Pollution in Surface Sediments of Faga‘alu Bay and Watershed, American Samoa

David Whitall
NOAA National Centers for Coastal and Ocean Science, Center for Coastal Monitoring and Assessment, Coastal & Oceanographic Assessment, Status and Trends

Significance

Despite their ecological, economic and cultural value, over half of the world’s coral reefs are threatened by human activity (Bryant *et al.*, 1998). Increased runoff of sediment, nutrients, and pollutants has been correlated to the degradation of coral reefs (Fabricius, 2005). Although pollution is a known cause of the decline of coral reefs, details of the relationship between contaminants and corals are not well understood. There are currently no established thresholds for individual pollution stressors indicating concentration limits above which corals are harmed. This study (Whitall and Holst, 2015) presents a baseline assessment of the magnitude and spatial distribution of pollution in the coral reef ecosystem of Faga‘alu Bay. This information will provide ecosystem managers a reference point against which to evaluate the success of upland watershed best management practices.

Methods

A. *SAMPLING DESIGN*

A stratified random sampling design allowed this study to assess the overall contaminant condition of the ecosystem, and to be able to make geographically explicit conclusions about how pollutants vary spatially. In this method, all areas within a stratum had an equal chance of being selected as a sampling site. The four strata were: Inner Bay, South Bay, North Bay and Channel. Additionally, four targeted sediment sites were selected in the watershed and one targeted site was sampled near the school/landfill. A total of seventeen sediment sites were sampled in January of 2014.

B. *FIELD SAMPLING*

Sediment samples were collected using standard NOAA National Status and Trends (NS&T) Program protocols (Lauenstein and Cantillo, 1998). Briefly, surface sediment samples (top 2 cm) were collected directly into certified pre-cleaned HPDE 250 ml jars. Field personnel wore disposable nitrile gloves to prevent cross contamination between sites. Jars were stored on ice while in the field, then kept frozen until analysis.

C. *LABORATORY ANALYSES*

Sediment samples were analyzed via standard NS&T techniques at the NS&T contract lab (TDI Brooks International, College Station, Texas). Detailed analytical methods can be found in Kimbrough *et al.* 2006 and Kimbrough and Lauenstein 2006. Briefly, PAHs were analyzed in the laboratory using gas chromatography/mass spectrometry in the selected ion monitoring (SIM) mode (Kimbrough *et al.* 2006). Selected chlorinated organics (PCBs and pesticides) were analyzed using gas chromatography/electron capture detection (Kimbrough *et al.* 2006). Butyltins were analyzed using gas chromatography/flame photometric detection (Kimbrough *et al.* 2006).

Silver, cadmium, copper, lead, antimony, and tin were analyzed using inductively coupled plasma - mass spectrometry. Aluminum, arsenic, chromium, iron, manganese, nickel, silicon and zinc were analyzed using inductively coupled plasma - optical emission spectrometry. Mercury was analyzed using cold vapor - atomic absorption spectrometry. Selenium was analyzed using atomic fluorescence spectrometry (Kimbrough and Lauenstein, 2006). For each element, total elemental concentration (i.e. sum of all oxidation states) was measured.

Data Analysis

Statistical Analysis

Because the data were not normally distributed, a non-parametric multiple comparisons test (Dunn Method for Joint Ranking, α=0.05) was used to evaluate differences among strata. Because they were not randomly selected, the targeted sites (four watershed sites, plus one site by the school) were included in the summary statistics for the entire study area, but were excluded from the statistical analysis of differences between strata. Spearman Rank correlations (α =0.05) were examined to evaluate the relationships between sediment variables.

Providing Context for Results

In addition to comparing contamination results between strata, these findings can be compared to previously published numerical sediment quality guidelines (SQG) known as ERL (effects range-low) and ERM (effects range-median) developed by Long and colleagues (Long and Morgan, 1990; Long *et al*., 1995, Long et al. 1996, Long et al. 1998, Long and MacDonald, 1998). For the purposes of discussion, when a sample exceeds the ERM, toxicity to benthic infauna is said to be probable. When a sample exceeds the ERL but not the ERM, toxicity to benthic infauna is possible. It should be noted that SQG were designed for marine systems, so they are not directly applicable to freshwater stream sites. Stream sites are included here purely for reference. It is also important to note that SQG do not consider the additive impact of multiple pollutants on organisms.

Baseline Values and Key Findings

In general, pollution in Faga'alu Bay is relatively low. The ERM sediment quality guidelines were exceeded only for nickel (1 site in the watershed and 1 site in the Inner Bay) and zinc (1 site in the watershed). This suggests probable toxicity to benthic infauna at these sites. The ERL but not the ERM guideline was exceeded for at least one site for the following analytes: silver, arsenic, chromium, copper, zinc, nickel, chlordane and PCBs (Table 2). This suggests that there is the possibility of toxicity to sediment infauna at these sites. Most analytes are higher in the watershed than in the Bay, suggesting a terrestrial source (e.g. **Figure 19**). An exception to this is arsenic where the highest value was measured in the North Bay strata (**Figure 20**). This may be related to the historical land fill located on the current Matafao elementary school site. Metals quantified in this study are generally well correlated with crustal elements that are generally not considered to be pollutants (e.g. Aluminum (Al), Iron (Fe), Manganese (Mn), Silicon (Si). This is particularly true for Zinc (Zn) (**Figure 21**) and Nickel (Ni), meaning that despite their relatively elevated sediment concentrations, these levels are likely natural and the product of the erosion of watershed bedrock material. Conversely, arsenic is not well correlated with other crustal elements (Figure 22). Legacy organic contaminants (e.g. chlordane, DDTs, PCBs) found in the Bay are likely due to their widespread historical use and environmental persistence, rather than any new sources of those pollutants in the system.

This data set serves as an important baseline against which to measure future change, including the efficacy of ongoing watershed management activities (e.g. improved management practices at the quarry). Although Faga'alu Bay is not especially polluted with toxic contaminants, there are some reasons for concern, including potential leaching of metals and organics from the legacy landfill on the north shore of the Bay. Furthermore, crustal element loads may decrease following changes in management practices at the quarry, which could be quantified with future sampling.

Outlook: Anticipated changes due to mitigation activities

The mitigation activities discussed above were not designed specifically to reduce the input of toxic contaminants to the Bay. However, data presented here suggest that mining activities at the quarry are increasing the rate at which naturally occurring crustal metals (e.g. nickel and zinc) are reaching the Bay. Therefore, best management practices at the quarry designed to reduce sediment flux may have the added benefit of decreasing the crustal metal flux to the Bay. It should be noted that unlike organic contaminants (e.g. DDT, PCBs) which decay over time into less harmful compounds elemental metals do not degrade. As a result, decreases in sediment (and therefore metal) load may not result in decreases in sediment metal concentrations, unless metals are being otherwise removed from the system. For example, metals may become less bioavailable (i.e. through burying by new sediments), may be taken up by resident flora and fauna, or may be flushed from the system during extremely large storm events.

Additionally, data presented in this study suggest that the legacy landfill could be a source of some pollutants to the Bay. This warrants further research, including groundwater measurements, and could require additional mitigation activities in the future.

Table 2: Summary statistics for sediment samples in Faga'alu Bay and watershed (January 2014). Summary statistics include targeted (e.g. watershed) sites.

Analyte	Units	*Min*	*Max*	*Mean*	*Median*	*StDev*	*Number of Sites Exceeding ERL/ERM*
Ag	ug/g	0	2.74	0.49	0	0.81	4/0
Al	ug/g	475	72400	25682	8250	28817	NA
As	ug/g	1.19	11.5	4.44	3.91	2.90	3/0
Cd	ug/g	0	0.31	0.10	0.07	0.09	0/0
Cr	ug/g	7.13	191	39.47	25.7	46.42	1/0
Cu	ug/g	0	37.7	8.53	5.74	9.67	1/0
Fe	ug/g	712	103000	28484	18300	29827	NA
Hg	ug/g	0.000764	0.0163	0.01	0.01	0.00	0/0
Mn	ug/g	20	1250	467	184	495	NA
Ni	ug/g	4.19	211	35.13	12.6	50.66	4/2
Pb	ug/g	0.641	45.5	13.15	8.46	12.93	0/0
Sb	ug/g	0	0.472	0.18	0.196	0.15	NA
Se	ug/g	0	0.127	0.02	0	0.04	NA
Si	ug/g	105	256000	74608	13300	97244	NA
Sn	ug/g	0.27	15.40	4.50	4.37	3.73	NA
Zn	ug/g	3.70	416.00	109.69	53.70	119.72	3/1
Total PAHs	ng/g	1.35	2097.48	177.80	27.49	501.36	0/0
Total HCH	ng/g	0	0.10	0.03	0	0.04	NA
Total Chlordane	ng/g	0	4.60	0.62	0	1.30	5/0
Total DDT	ng/g	0	2.29	0.23	0.11	0.54	1/0
Total PCBs	ng/g	2.19	92.89	14.35	2.32	29.06	3/0
Monobutyltin	ng/g	0	2.00	0.18	0	0.54	NA
Dibutyltin	ng/g	0	0.60	0.08	0	0.17	NA
Tributyltin	ng/g	0	0.98	0.07	0	0.24	NA
Tetrabutyltin	ng/g	0	0	0	0	0	NA
Clostridium perfringens	CFU/g	0	1722	302	125	432	NA

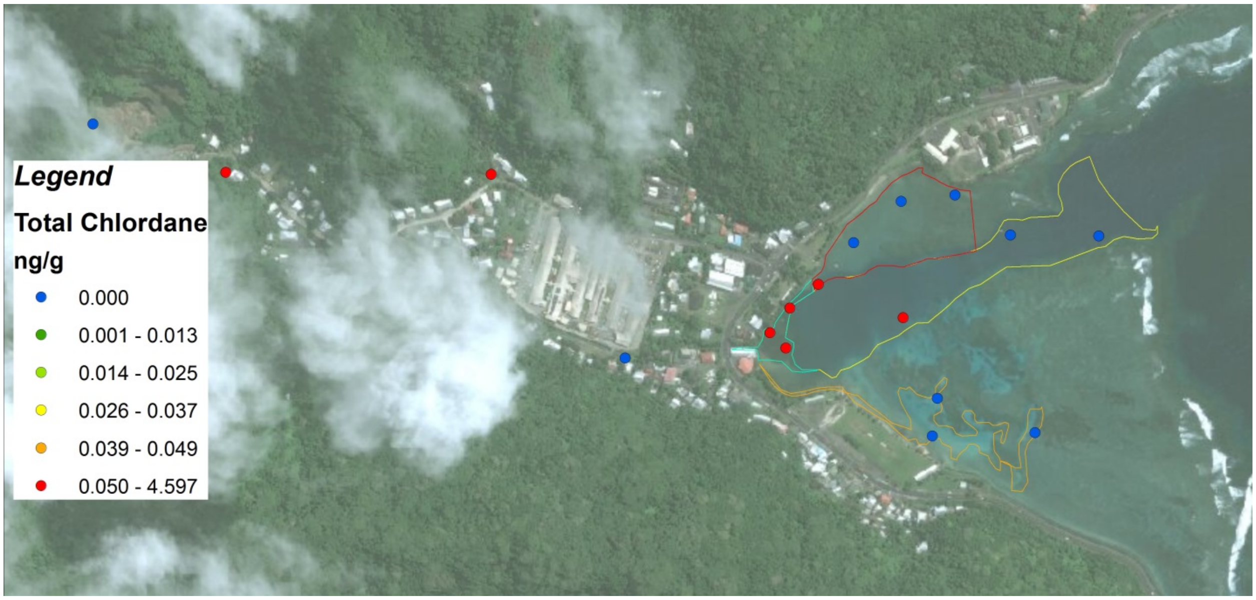


Figure 19. Total chlordane concentrations in sediments (January, 2014). This is a representative figure showing a strong watershed pollutant source.

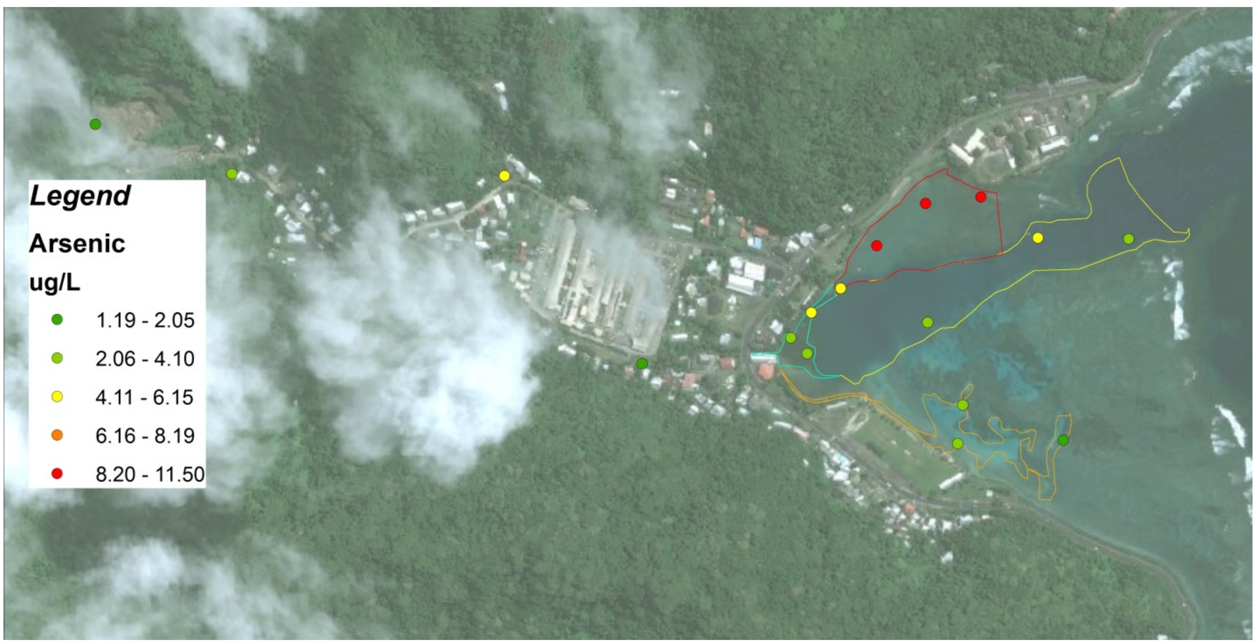


Figure 20. Arsenic concentrations in sediments (January, 2014). Note: highest concentration are in the North Bay area.

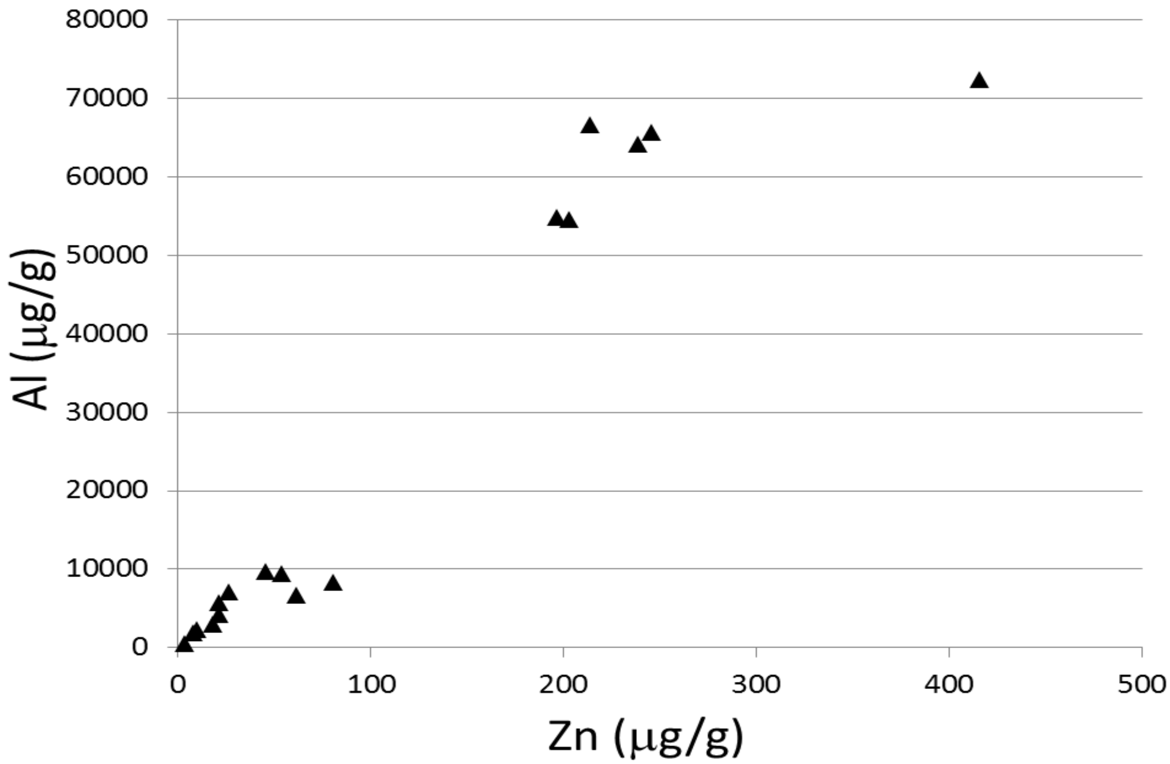


Figure 21. Scatter plot of sediment Zinc (Zn) versus sediment Aluminum (Al). The high degree of correlation between these two crustal elements (Spearman rho=0.96) suggests that even though Zn exists at high levels, this is most likely naturally occurring Zn.

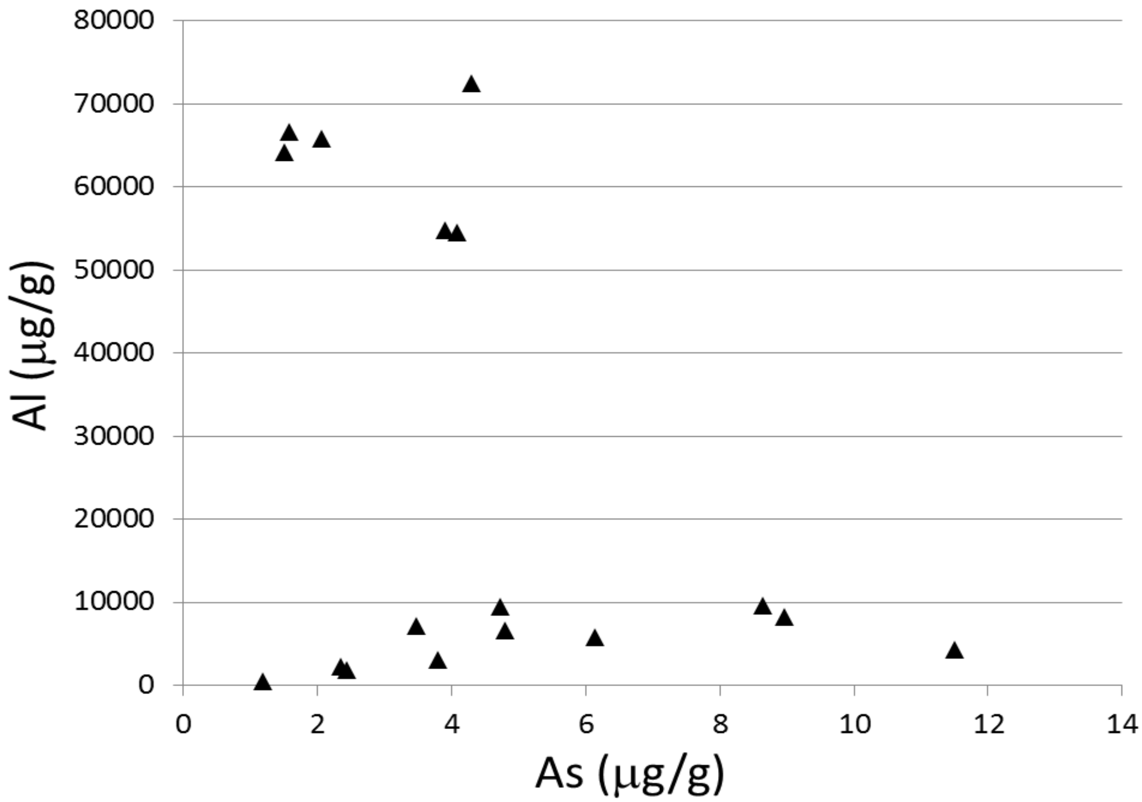


Figure 22. Scatter plot of sediment Arsenic (As) versus sediment Aluminum (Al). The lack of correlation between these two crustal elements suggests that high arsenic levels are likely due to anthropogenic sources.

Key Findings and Recommendations

Sediment

KEY FINDINGS:

- Sediment loading from Faga‘alu has been tripled by the unmitigated runoff from the Samoa Maritime quarry prior to the intervention.
- There is significant spatial variability in sediment stress on corals as a result of water circulation patterns over the reef, with the highest impacts near the stream mouth and on the northern reef.
- Sediment mitigation at the quarry, including large retention ponds, should dramatically reduce sediment loading from the stream and sediment stress on the reef.

RECOMMENDATIONS

- Continued monitoring of sediment loading during storms is necessary to document decreased sediment loading from the quarry and sediment stress on the corals.
- Continued maintenance of the retention ponds and mitigation measures at the quarry is necessary for prolonged success of sediment mitigation and the long-term recovery of coral health.
- Update existing village watershed plan by integrating the findings and recommendations in this document to improve future efforts to reduce sedimentation impacts.
- Future sediment mitigation should focus on additional sediment sources in the village and agricultural plots on the hillsides.

Coral

KEY FINDINGS:

- The coral community at Faga‘alu bay exhibits a measurable gradient in benthic composition whereby mean percent live coral cover was nearly twice as high along the southern area of the reef compared to the northern sector, and those differences were statistically significant; differences in mean percent cover of turf algae between the north and south sectors of the reef were also significant.
- Colony densities for all coral taxa combined were higher along the southern backreef and forereef than along the northern sector of the reef, and these differences were statistically significant.
- Mean prevalence of coral disease was low overall; however, non-tissue loss lesions resulting in compromised health were slightly greater at north-facing backreef sites compared to south-facing sites which could be associated with the elevated, chronic terrigenous runoff and sedimentation that affects these areas (Pollock et al. 2014).
- The historic landfill located on the premises of the current Matafao Elementary School site is potentially a source of contaminants, particularly arsenic, which may preclude, or delay the recovery of shallow benthic assemblages on this side of the fringing reef (Downs et al. 2005).

Recommendations:

- It can be speculated that the first signs of change may be quantifiable as reductions in the cover of fleshy macroalgal and turf algal elements and an increase in calcifying coralline algae.
- Preserving and promoting healthy fish and invertebrate herbivore communities will be pivotal to the reestablishment of functional coral communities in Faga‘alu Bay. The recent establishment of a marine protected area in Faga‘alu Bay is a promising step towards this recommendation and sufficient resources should be allocated for management and enforcement of its rules and regulations.
- Although upslope quarry mitigation activities are expected to result in changes to the composition and structure of the adjacent coral reef benthos, the spatial and temporal constructs of these changes may observe protracted lags ranging from years to decades; recovery will hinge on the reduction of the algal populations, together with improvement of water clarity, the reduction of excess sediment and nutrient inputs, as well as the availability and establishment of recruits.

Contaminants

Key Findings:

- Based on established sediment quality guidelines, potential for sediment toxicity in the Bay is relatively low. Possibly toxic levels were measured for at least one site for silver, arsenic, chromium, copper, zinc, nickel, chlordane and PCBs, but only two analytes (nickel and zinc) exceeded levels where probable toxicity was likely.
- The use of some commonly detected contaminants, such as chlordane and DDT, has been banned for many years. Their presence in the environment is common and is owed to their environmental persistence, rather than any new/illegal use of these chemicals.
- Of the analytes that are elevated, most appear to have strong watershed sources (e.g. nickel) and are likely entering the Bay via the stream. An exception to this is arsenic, which appears to have some other source, possibly the legacy Department of Defense landfill on the north shore.

Recommendations:

- Additional data collection, including groundwater studies, is warranted to further explore the possibility that arsenic and other toxins (e.g. DDT) may be leaching from the landfill.

Partners and contributors

American Samoa Community College; American Samoa Coral Reef Advisory Group; American Samoa Department of Commerce; American Samoa Department of Marine and Wildlife Resources; American Samoa Environmental Protection Agency; Department of Geography, San Diego State University; Faga‘alu Village; Faga‘alu Watershed Committee; Horsley Witten Group; National Fish and Wildlife Foundation; NOAA Coral Reef Conservation Program; NOAA National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment, Coastal &

Oceanographic Assessment, Status and Trends; NOAA National Marine Sanctuary of American Samoa; NOAA Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division; NOAA Pacific Islands Regional Office; Samoa Maritime Inc.; United States Geological Survey, Pacific Coastal and Marine Science Center.

References

Basher, L., Hicks, D., Clapp, B., & Hewitt, T. (2011). Sediment yield response to large storm events and forest harvesting, Motueka River, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, *45*(3), 333–356. doi:10.1080/00288330.2011.570350

Brodie, J., Wolanski, E., Lewis, S., & Bainbridge, Z. (2012). An assessment of residence times of land-sourced contaminants in the Great Barrier Reef lagoon and the implications for management and reef recovery. *Marine Pollution Bulletin*, *65*(4-9), 267–79. doi:10.1016/j.marpolbul.2011.12.011

Bryant, D., Burke, L., McManus, J., Spalding, M. Reefs at Risk: A Map-based Indicator of Threats to the World's Coral Reefs. World Resources Institute, Washington, DC, 1998.

Buchanan-Banks, J. (1979). *The October 28, 1979 Landslidng on Tutuila. Open File Report 81-81*. U.S. Geological Survey.

Crabbe MJC, Smith DJ. 2005. Sediment impacts on growth rates of Acropora and Porites corals from fringing reefs of Sulawesi, Indonesia. Coral Reefs 24:437–441

Craig, P. (2009). Natural History Guide to American Samoa. (N. P. of A. Samoa, Ed.). Pago Pago, American Samoa.

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., … Passteris, P. P. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*, *28*(15), 2031. doi:10.1002/joc

Dames & Moore. (1981). Hydrologic Investigation of Surface Water for Water Supply and Hydropower. Honolulu, HI: U.S. Army Engineer District, Honolulu.

Downs CA, Fauth JE, Robinson CE, Curry R, Lanzendorf B, Halas JC, Halas J, Woodley CM.2005. Cellular diagnostics and coral health: Declining coral health in the Florida Keys. Mar. Poll. Bull. 51: 558–569

Duvert, C., Nord, G., Gratiot, N., Navratil, O., Nadal-Romero, E., Mathys, N., … Esteves, M. (2012). Towards prediction of suspended sediment yield from peak discharge in small erodible mountainous catchments (0.45–22km2) of France, Mexico and Spain. *Journal of Hydrology*, *454-455*, 42–55. doi:10.1016/j.jhydrol.2012.05.048

Erftemeijer, P. L. a, Riegl, B., Hoeksema, B. W., & Todd, P. a. (2012). Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin*, *64*(9), 1737–1765. doi:10.1016/j.marpolbul.2012.05.008

Fabricius KE. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Marine Pollution Bulletin 50: 125–146.

Field ME, Cochran SA, Logan JB, and Storlazzi CD, eds. 2008. The coral reef of South Molokai, Hawaii; Portrait of a sediment-threatened reef. U.S. Geological Survey Scientific Investigations Report 2007-5101.

Glynn, P.W., Mate, J.L., 1997. Field guide to de Pacific coral reefs of Panama. Proc. 8th Int. Coral Reef Symp. 1: 145–166

Fabricius, K. E. (2005). Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin*, *50*(2), 125–46. doi:10.1016/j.marpolbul.2004.11.028

Field, M. E., Chezar, H., & Storlazzi, C. D. (2012). SedPods: a low-cost coral proxy for measuring net sedimentation. *Coral Reefs*, 1–5.

Fong P, Paul VJ. 2011. Coral Reef Algae. In: Dubinsky Z, Stambler N. (eds). Coral Reefs: An Ecosystem in Transition. Springer Science + Business Media B.V pp. 241-272

Hicks, D. M. (1990). Suspended sediment yields from pasture and exotic forest basins. In *Proceedings of the New-Zealand Hydrological Society Symposium*. Auckland, New Zealand.

Horsley Witten Group Inc. (2013). Faga'alu Watershed Plan Implementation Supplement. Sandwich, MA: Center for Watershed Protection, Inc.

Houk P, D Benavente and S Johnson. 2013. Watershed-based coral reef monitoring across Tutuila, American Samoa: Summary of decadal trends and 2013 assessment. 37 pp.

Izuka, S. K., Giambelluca, T. W., & Nullet, M. A. (2005). Potential Evapotranspiration on Tutuila , American Samoa. U.S. Geological Survey Scientific Investigations Report 2005-5200. U.S. Geological Survey.

Jokiel PL, Hunter CL, Taguchi S, Watarai L. 1993. Ecological impact of a fresh-water "reef kill" in Kaneohe Bay, Oahu, Hawaii. Coral Reefs. 12: 177–184

Kimbrough, K.L. and G.G. Lauenstein (eds). 2006. Major and trace element analytical methods of the National Status and Trends Program: 2000-2006. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 29. 19 pp.

Kimbrough, K.L., G.G. Lauenstein and W.E. Johnson (eds). 2006. Organic contaminant analytical methods of the National Status and Trends Program: Update 2000-2006. NOAA Technical Memorandum NOS NCCOS 30. 137 pp.

Kroon FJ, Schaffelke B and Bartley R. 2014. Informing policy to protect coastal coral reefs: Insight from a global review of reducing agricultural pollution to coastal ecosystems. Marine Pollution Bulletin 85(115): 33–41.

Lauenstein, G.G., and Cantillo, A.Y. (1998). Sampling and Analytical Methods of the National Status and Trends Program Mussel Watch Project: 1993-1996 Update. U.S. Dept. Comm., NOAA Tech. Memo. 130, NOS ORCA, Silver Spring, Maryland.

Long, E.R. and Morgan, L.G. 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. NOAA Tech. Memo NOS OMA 52. NOAA, Seattle, WA. 175 pp.

Long, E.R., MacDonald, D.D., Smith, S.L., and Calder, F.D. 1995. Incidence of adverse biologival effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19: 81-97.

Long, E.R., Robertson, A., Wolfe, D.A., Hameedi, J. and Sloane, G.M. 1996. Estimates of the spatial extent of sediment toxicity in major U.S. estuaries. Environmental Science and Technology 30(12):3585-3592.

Long, E.R., L.J. Field and D.D. MacDonald. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. Environmental Toxicology and Chemistry 17(4): 714-727.

Long, E.R., and D.D. MacDonald. 1998. Recommended uses of empirically derived, sediment quality guidelines for marine and estuarine ecosystems. Human and Ecological Risk Assessment 4(5): 1019-1039.

Messina, A. T., & Biggs, T. W. (n.d.). *Contributions of human activities to suspended sediment yield during storm events from a steep, small, tropical watershed*.

Messina, A. T., & Biggs, T. W. (2013). Quality Assurance Plan Protocol for sediment monitoring in Fagaʻalu, American Samoa. San Diego State University.

Messina, A. T., Storlazzi, C. D., & Biggs, T. W. (n.d.). *Watershed and oceanic controls on spatial and temporal patterns of sediment accumulation in a fringing reef flat embayment*.

Messina, A. T., Storlazzi, C. D., Biggs, T. W., & Washburn, L. (n.d.). *Eulerian and Lagrangian measurements of flow and residence time on a fringing reef flat embayment, American Samoa*.

National Oceanic and Atmospheric Administration (NOAA). 2010. American Samoa's Coral Reef Management Priorities. The Territory of American Samoa and NOAA Coral Reef Conservation Program. Silver Spring, MD. Available at: http://coralreef.noaa.gov/aboutcrcp/strategy/reprioritization/managementpriorities/resources/amsam_mngmnt_clr.pdf

National Oceanic and Atmospheric Administration (NOAA). 2015. Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division, Survey Methods. Available at: http://www.pifsc.noaa.gov/cred/survey_methods.php#benthic_monitoring_rea. Accessed January 2015.

Perreault, J. (2010). *Development of a Water Budget in a Tropical Setting Accounting for Mountain Front Recharge: Tutuila, American Samoa*. University of Hawai'i.

Pollock FJ, Lamb JB, Field SN, Heron SF, Schaffelke B, Shedrawi G, Bourne DG, Willis BL. 2014. Sediment and turbidity associated with offshore dredging increase coral disease prevalence on nearby reefs. PLoS ONE 9(7): e102498. doi:10.1371/journal.pone.0102498

Rankl, J. G. (2004). *Relations Between Total-Sediment Load and Peak Discharge for Rainstorm Runoff on Five Ephemeral Streams in Wyoming. U.S. Geological Survey Water-Resources Investigations Report 02-4150*. Denver, CO.

Rogers CS. 1990. Responses of coral reefs and reef organisms to sedimentation. Mar Ecol Prog Ser 62:185–202.

Storlazzi, C., Field, M., & Bothner, M. 2011. The use (and misuse) of sediment traps in coral reef environments: theory, observations, and suggested protocols. Coral Reefs, 30(1), 23-38. http://doi.org/10.1007/s00338-010-0705-3.

SYSTAT®. 2007. SYSTAT 12 Statistics_I_II_III_IV. SYSTAT Software Inc., San Jose, California.

Tonkin & Taylor International Ltd. (1989). Hydropower feasibility studies interim report - Phase 1. Ref: 97/10163.

Whitall, D. and S. Holst. 2015. Pollution in Surface Sediments in Faga'alu Bay, Tutuila, American Samoa. NOAA Technical Memorandum NOSS/NCCOS 201. Silver Spring, MD

White, J. (1990). The use of sediment traps in high-energy environments. *Marine Geophysical Research*, *12*(1), 145–152.

Wong, M. (1996). Analysis of Streamflow Characteristics for Streams on the Island of Tutuila, American Samoa. U.S. Geological Survey Water-Resources Investigations Report 95-4185. Honolulu, HI: U.S. Geological Survey.

APPENDIX A

Operation and Maintenance protocols excerpted from Horsley Witten Basis of Design Memo for Samoa Maritime Erosion and Sediment Control Corrective Action Plan

8.0 Operation and Maintenance

The operation and maintenance of the erosion and sediment control practices should be included as part of the daily quarry operations. Daily routine inspections of the site perimeter will identify possible deficiencies in the sediment control measures or areas in need of repair before sediment leaves the site.

Basic ongoing operational control of the site to confine equipment and truck traffic to the designated travel-ways, and keep the redundant sediment control measures clean and operational will result in less sediment leaving the site.

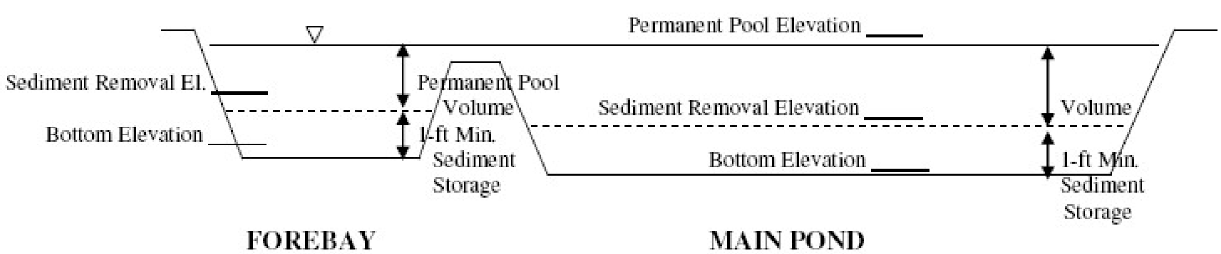
The following provides for the periodic maintenance and inspection items for the various practices on the site. The quarry operator should keep a daily log of activities and conduct and document inspections on a minimum schedule of one inspection per week.

8.1 Sediment Basins:

1. Inspect each sediment basin at least weekly and after each significant (1/2 inch or greater) rainfall event and repair immediately.
2. Remove sediment and restore the basin to its original dimensions when it accumulates to one-half the design depth. Place removed sediment in an area with sediment controls. Dewatering may be required prior to sediment removal. See plan sheet for dewatering instructions. Care should be taken to avoid direct discharge of turbid water to stream during basin dewatering process.

Basin	Bottom Elevation	Permanent Pool Elevation	Sediment Removal Elevation
#1 Forebay	118	121.5	~120
#1 Main Cell	117	120.5	~119
#2	86	89.5	~88
#3	TBD	TBD	TBD

Clean Out Guidance



3. Verify the stability and continued function of the baffles.
4. Check the upstream and downstream face of the embankment in the area of the

outlet pipe for any signs of leakage, sloughing of the embankment soil, or erosion.

5. Inspect the spillways and outlet for erosion damage, and inspect the embankment for piping and settlement. Make all necessary repairs immediately.
6. Remove all trash and other debris from the riser and pool area.

8.2 Baffles:

1. Ensure access to the baffles is maintained.
2. Inspect baffles at least once a week and after each rainfall. Make any required repairs immediately.
3. If a baffle collapses, tears, decomposes, or becomes ineffective, replace it promptly.
4. Remove sediment deposits when reaches half full, to provide adequate storage volume for the next rain and to reduce pressure on the baffles. Take care to avoid damaging the baffles during cleanout, and replace if damaged during cleanout operations. Sediment depth should never exceed half the designed storage depth.

8.3 Channels and Drainage Pipes:

1. Inspect each conveyance channel and drainage pipe at least weekly and after each significant (1/2 inch or greater) rainfall event for sediment accumulation or damage to pipe inlets and outlets. Give special attention to the outlet and inlet sections and other points where concentrated flow enters.
2. Carefully check stability at all culvert inlets and outlets. Look for indications of piping, scour holes, or bank failures.
3. Repair any damage immediately.
4. Remove sediment and any other debris.

8.4 Erosion Control Blankets

1. Inspect Rolled Erosion Control Products (RECP)at least weekly and after each significant rainfall event (1/2 inch or greater) repair immediately.
2. Ensure that good contact is maintained with the ground, and that erosion is not occurring beneath the matting.
3. Any areas of matting that are damaged or not in close contact with the ground shall be repaired and stapled.
4. Monitor and repair the RECP as necessary until ground cover is established.

8.5 Trench Drains:

A properly designed and installed subsurface drain requires little maintenance. However, the drains should be checked periodically (and especially after significant rainfall events) to ensure that they are operating properly.

8.6 Diversion Berms

Depending on traffic loads and frequency, these diversions will need to be inspected regularly and reshaped as needed to maintain dimensions and to ensure proper function.

Routine Maintenance: Other routine maintenance includes the removal of trash and litter from the site and perimeter areas.

United States Department of Commerce
Penny S. Pritzker
Secretary

National Oceanic and Atmospheric Administration
Dr. Kathryn D. Sullivan
Under Secretary of Commerce for Oceans and Atmospheres

National Ocean Service
Dr. Russell Callender
Assistant Administrator for the National Ocean Service