Talakhaya Watershed Soil Loss Assessment

Phase II Stream Monitoring Report

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Prepared for:
NOAA Coral Reef Conservation Program

Report Prepared by:
Horsley Witten Group, Inc. and Malcolm Johnson

Data Collection by: Malcolm Johnson, Kathryn Graziano, Autumn Poisson, Max Muña, and James Manglona

Acknowledgements

This study is a continuation of a previous monitoring effort started in 2012 by the University of Guam in conjunction with an extensive, long-term revegetation project led by DLNR Forestry. This phase of the monitoring project was funded by the NOAA Coral Reef Conservation Program and coordinated by Dana Okano. Field data collection was conducted by NOAA Coral Fellows Malcolm Johnson and Autumn Poisson stationed on Rota, with extensive field support from Kathryn Graziano and Max Muña. Critical logistical support was provided by James Manglona with DLNR Rota Forestry and Xerxes Camacho. Lab sample processing was conducted in-house at the BECQ labs on Saipan. Dr. Golabi from the University of Guam and former research associate Sydonia Manibusan (currently at Rutgers University) helped with interpretation of Phase I data collection methods and review of the proposed Phase II approach. GIS data was provided by Bill Pendergrass and Robbie Greene (BECQ).

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1.0 Introduction

The purpose of this report is to provide a comprehensive summary of results from a two-phase, stream monitoring study of soil loss in the Talakhaya Watershed on Rota, CNMI between 2012 and 2017. This NOAA-supported study was conducted to assess and to quantify the change in soil loss from Talakhaya badlands in conjunction with revegetation efforts led by Rota DLNR-Forestry staff that started in 2007. Phase I of the monitoring study was conducted by the University of Guam (UOG) between 2012 and 2014. This study attempted to measure localized precipitation, establish stream stage-discharge relationships, and quantify turbidity and total suspended solids at fixed monitoring stations in four streams. The monitored streams were strategically selected to represent subwatersheds with varying levels of vegetated cover, including a mostly forested subwatershed, two areas where revegetation efforts had occurred or were underway, and a "control" subwatershed that included eroding badlands. UOG researchers concluded that reductions in soil loss were observed, with the caveat that the differences between unvegetated and revegetated streams were not significant. Further, they suggest that more time was needed for plants to establish (Golabi and Manibusan, 2014) and that additional monitoring was required to quantify the information with statistical certainty.

There was a fifteen month gap in stream monitoring, during which time revegetation efforts continued. Monitoring was resumed in 2016-2017 by NOAA Coral Fellows. Phase II monitoring protocols were based on the methodology used in Phase I, but were adapted to account for progress in the revegetation efforts. Specifically, a new control subwatershed (barren areas) was added since DLNR revegetation efforts had expanded into the original control subwatershed from Phase I. Unfortunately, lack of rain and flowing streams, as well as staffing and equipment issues during Phase II, limited the number of additional water quality samples and flow data collected.

Talakhaya is frequently referenced as an example where empirical monitoring data have shown improvement in water quality due to watershed restoration efforts. Based on an analysis of Phase I and Phase II results, however, this conclusion should not be made with any certainty due to a number of limitations (e.g., few number of samples, equipment issues, lack of information on the extent of vegetative cover or other sediment sources in each subwatershed). Comparing water quality across subwatersheds or trends in improvement over time based on stream monitoring, particularly in remote mountainous island watersheds, is challenging. Estimating reductions in sediment loss, or even showing relative improvement in the revegetated watersheds over time, is not feasible with existing data. However, the lack of stream data support should not diminish the anticipated benefit of the revegetation effort or dampen enthusiasm over this herculean effort. While few definitive conclusions can be drawn directly from the stream monitoring data to date, a number of recommendations for improving and expanding future monitoring in the watershed and redefining more obtainable project goals and objectives are provided. In addition, recommendations are provided for utilizing other metrics to measure revegetation performance.

1.1 Watershed Background

The five subwatersheds of focus for this study encompass a 1,090-acre area within the greater Sabana/Talakhaya/Palie watershed on Rota, CNMI (**Figure 1**). Rota is the southernmost island in the CNMI and is located approximately 50 miles north of Guam. Similar to Saipan and Tinian, the geology of Rota includes an underlying volcanic core covered in limestone plateaus originating from coral reefs. Rota's topography has five geomorphic subdivisions including coastal lowlands, a northern plateau, a southern plateau (the Sabana), a volcanic area, and the western peninsula. The Sabana plateau has an elevation over 1,400 ft, and its southern boundary terminates in the dramatic limestone cliffs above the volcanic, eroding terraces of Talakhaya. The Sabana/Talakhaya/Palie watershed is approximately 4,900 acres (20 square miles) and is located on the southwestern side of the island. The Talakhaya area of the watershed is comprised of steep terrain with slopes ranging from 5 to 99 percent, and reportedly contains the only perennial streams on Rota, although the streams monitored for this study did experience dry periods. These streams are fed by the Sabana water caves, springs, and runoff from the contributing watershed. Studies of the Matan Hanom Spring discharge an average daily flow of 1.8 million gallons per day (mgd) with a variable range in discharge of 5.4 to 0.5 mgd during wet and dry seasons, respectively. Nearly all of the fresh water on the island comes from these caves. Rota has average annual precipitation of 80+ inches with monthly rainfall averages of 10.7 inches during the wet season (July-Nov) and 3.8 inches per month during the dry season (Jan-May) (NRCS, 2007).

Sixty percent of the Talakhaya area is comprised of the Akina soil series, which consists of moderately deep, well drained soils on volcanic uplands. The soil unit is characterized by 20 to 40 inches of soil over highly weathered rock (saprolite), is acidic with few nutrients, and may have plant-toxic levels of soluble aluminum (NRCS 2007). Much of the Talakhaya region is considered badlands, areas of saprolite where soil has been nearly or completely eroded. These soils, as confirmed by soil tests done by UOG, lack available nutrients to establish large vegetation (Golabi and Manibusan, 2014).

Where there is vegetative cover in the lower terraces, it is dominated by introduced grasses with thickets of native forest along the riparian corridors that are some of the island's most pristine forests (Bickel, 2012). *Chrysopogon zizanioides* (vetiver grass), *Paspalum notatum* (bahia grass), and *Acacia* species are currently being introduced to the area by natural resource agencies through the badland revegetation program (**Figure 2**). The Sabana area and the lower parts of the Talakhaya area contain productive and economically important commercial and subsistence agricultural. The use of the area is also important for passing on of traditional farming practices and medicinal plant collection. There are important cultural sites in the area, particularly near the perennial streams and caves (Bickel, 2012). **Figure 3** shows vegetation/land cover map derived from BECQ 2016 GIS.

Bickel (2012) reports that the coral reefs below the Talakhaya watershed appear to be heavily impacted by sedimentation, although reef monitoring efforts are relatively young, starting in 2007. A large portion of the Sabana was formally designated as public conservation land in 1994 specifically for endangered species protection. In 2007, additional land within Talakhaya was added to the designated conservation area (Bickel, 2012). A Conservation Action Plan was created in 2012 for the Sabana/Talakhaya Conservation Area, highlighting the critical need for continued revegetation efforts. A goal of the 2012 CAP was to reduce soil loss in Talakhaya's highly eroding areas by 25% by 2015.

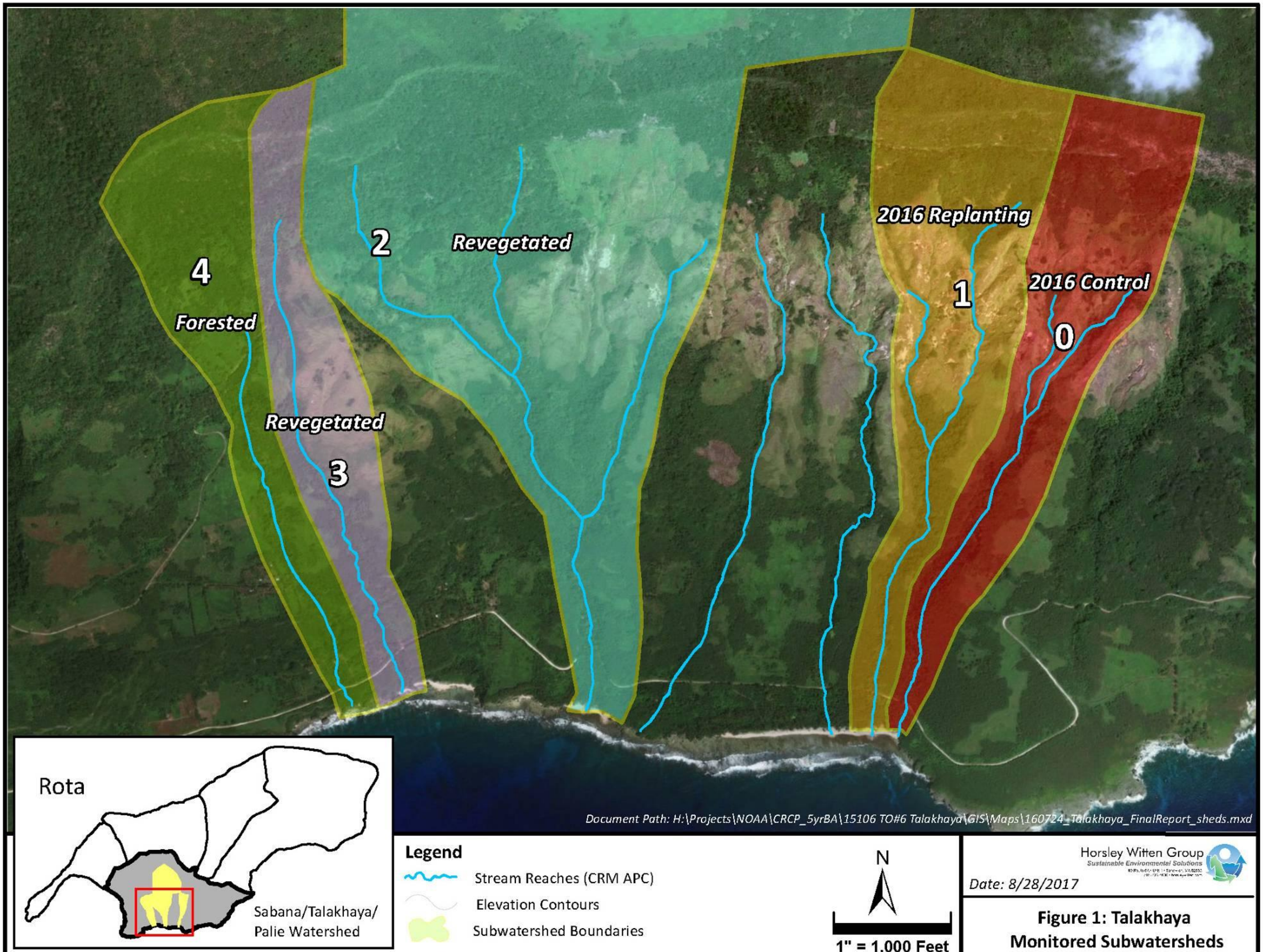


Figure 1: Talakhaya Monitored Subwatersheds

Figure 2. (Top) Steep limestone cliffs leading from the Sabana plateau, into the eroding, grassed slopes of Talakhaya. (Bottom Left) Active planting of Talakhaya badlands in 2016. (Bottom Right) Rows of vetiver grass and resulting vegetative establishment are clearly visible in previously planted areas.

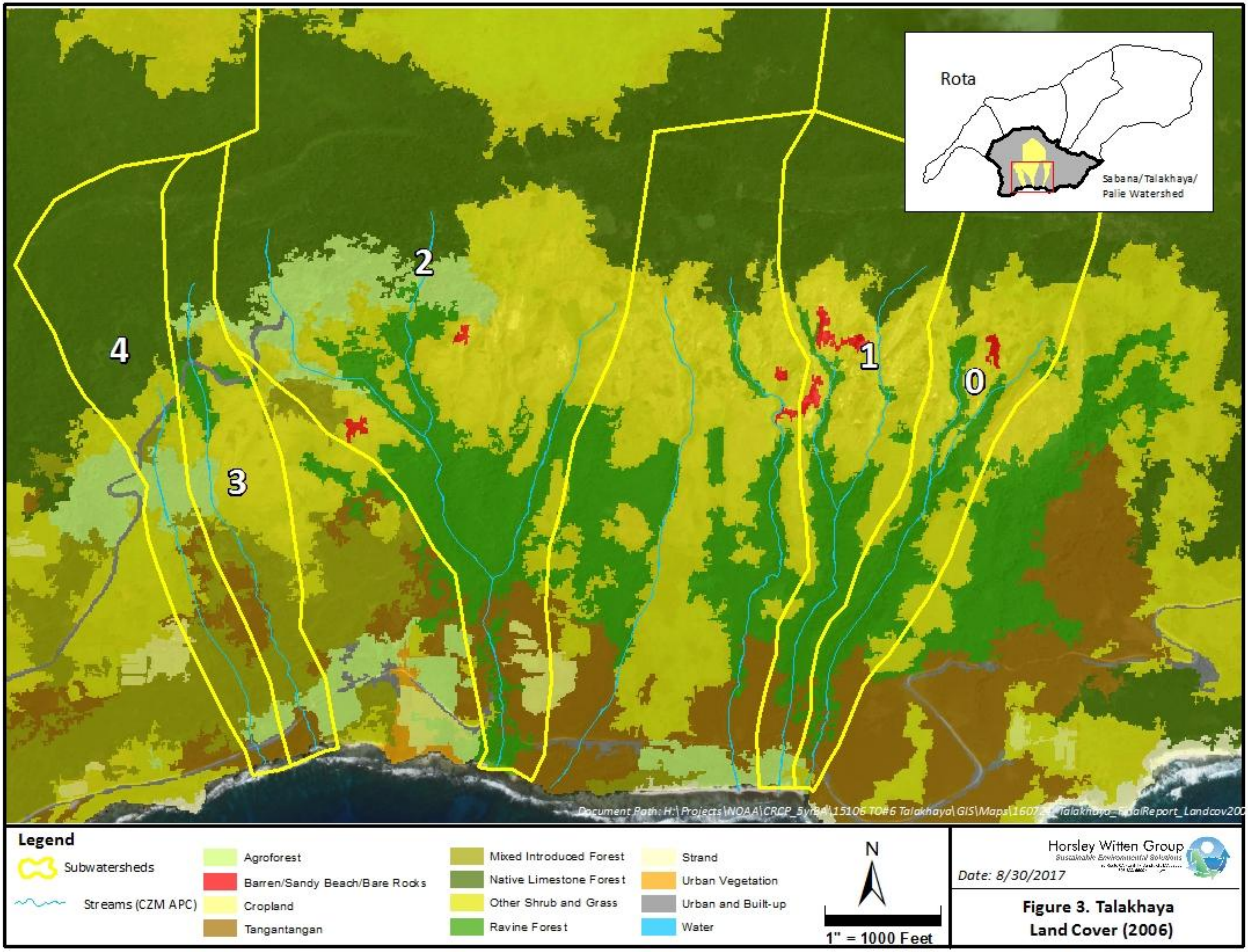


Figure 3. Talakhaya Land Cover (2006)

1.2 Revegetation Efforts

The Talakhaya watershed is a Coral Reef Management Priority site for the CNMI. Since 2006, CNMI resource management agencies have collaborated on restoring the Talakhaya watershed badlands. Starting in 2007, the Department of Land and Natural Resources (DLNR) has led the extensive revegetation project in the Talakhaya Conservation Area. Each year, planters are hired using the Luta Livelihoods Project, which seeks to employ locals for temporary positions that benefit the island. Before the planting season (July through September), DLNR and BECQ conduct site assessments at locations with exposed soils to evaluate the feasibility of replanting.

Fires occurred in the area in 2009, 2012, 2013, and 2017 complicating the revegetation efforts. These fires resulted in damage to revegetated areas, encouraged undesirable plants, and exposed more erodible area. Despite a decade of planting, extensive areas with exposed soils still remain and there is a constant threat of intentionally set fires, which can set back years of efforts in a single burning event.

Due to the poor quality of the soil, the primary species used for the revegetation project are non-native species that are effective at erosion control, including vetiver grass and Bahia grass, as well as *Acacia confusa*. Part of the Phase I project was to test new planting methods to improve establishment success rates. The current method involves creating hedgerows with vetiver grass, and filling the areas between with Bahia grass. Rock check dams are also used to help slow runoff velocity and prevent gullies during large rain events. Managers have identified a long-term strategy for reintroducing native forest species as revegetated areas mature (Bickel, 2012). In fact, over the last five years, the project has begun a transition into planting native tree species grown in a nursery prior to the planting months. The team is currently conducting research to determine the most resilient species to both herbivores and in the exposed cliff-side habitats of the watershed. In order to restore the habitat of the watershed to historic baselines, it is necessary to continue the revegetation project into a complete transition into native tree species.

The revegetation program has resulted in over 25,000 seedlings planted each year since the beginning of the program. There currently is a lack of reliable mapping information to determine the extent of bare land or total acres planted. Planted area estimates are anywhere from 60-100 acres depending on the method (**Figure 4**). Drones and GPS equipment have been deployed to provide more comprehensive land cover data of the project area; however, the challenge of accessing the landscape, the patchwork nature of bare and revegetated areas, and the learning curve associated with these technologies has slowed progress.

Figure 5 shows results of imagery analysis to estimate barren and sparsely vegetated areas within the revegetation areas between 2010 and 2014 (per Bill Pendergrass). The derivation of this information is unknown, but appears promising. A GIS file of 2013 bare areas, however, shows far fewer bare areas than that shown in the 2014 analysis, however. **Figure 6** shows an alternative approach to evaluating revegetation success, showing extent of vegetative gain or loss at specific planting sites between 2010 and 2014 (provided by Malcolm Johnson).

At a minimum, it appears evident that more watershed area is being stabilized with vegetation over time. It is estimated that approximately 60-70% of the Conservation Area has been revegetated, with varying degrees of success with regards to the establishment of the plants due to soil characteristics, storms, fires, and the landscape. In order to guarantee the success of the project, it has been determined that another 5-10 years of revegetation efforts is necessary to meet the Goals and Objectives outlined in the Conservation Action Plan (per comm., Malcolm Johnson).

Despite the many challenges facing the revegetation effort, anecdotal data suggests it has been increasingly successful. Fisherfolk off the coast of Talakhaya have noticed significantly less sediment plumes in the waters following heavy storm events. Residents of the watershed have noted that visually the area looks greener/less brown compared to before the project. Additionally, results from marine monitoring suggest some positive trends in key biological indicators. Redefining monitoring and evaluation methods, as well as developing targeted actions reflective of the current status of the revegetation project, are necessary for documenting the continued success of conservation in the Talakhaya Watershed.

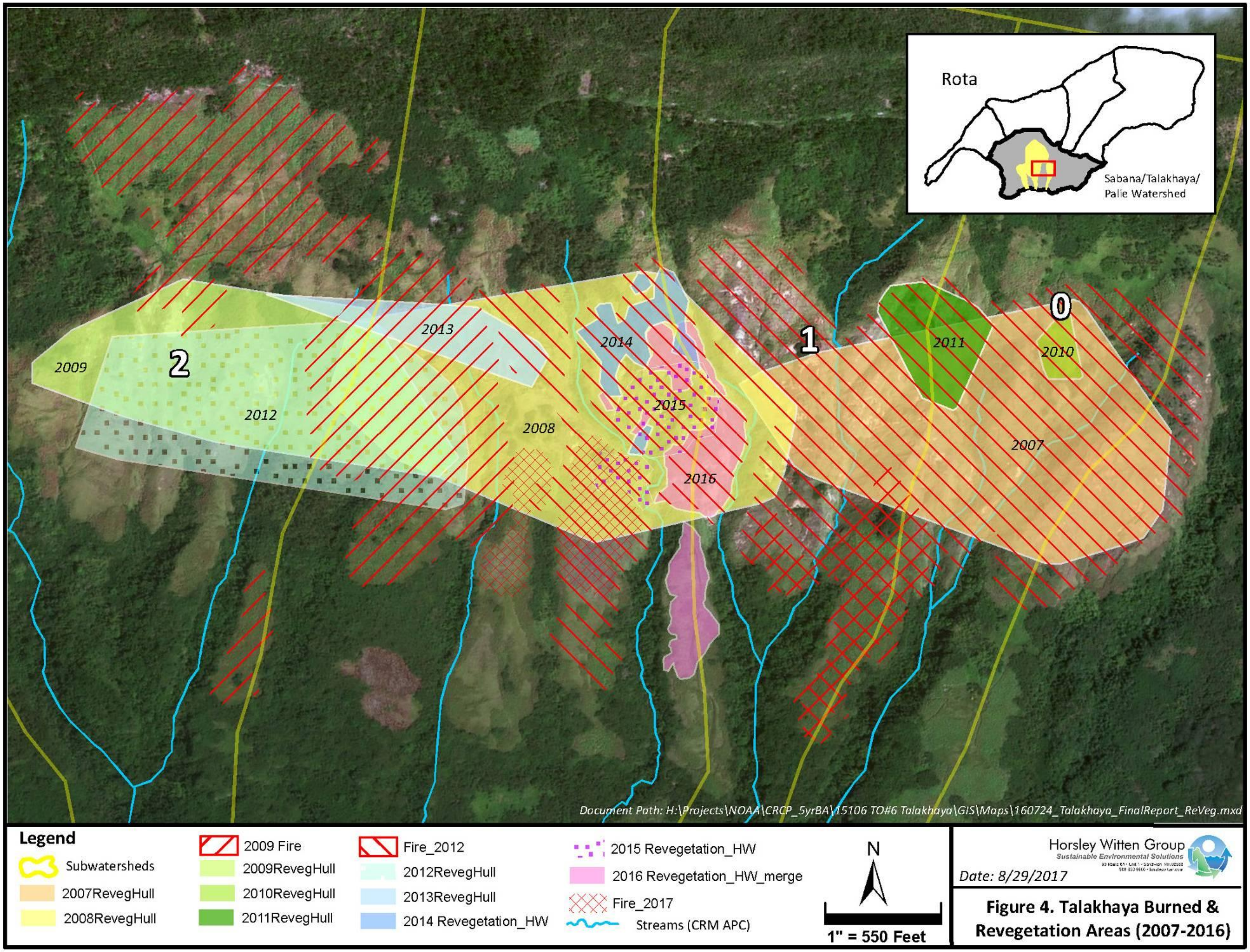


Figure 4. Talakhaya Burned & Revegetation Areas (2007-2016)

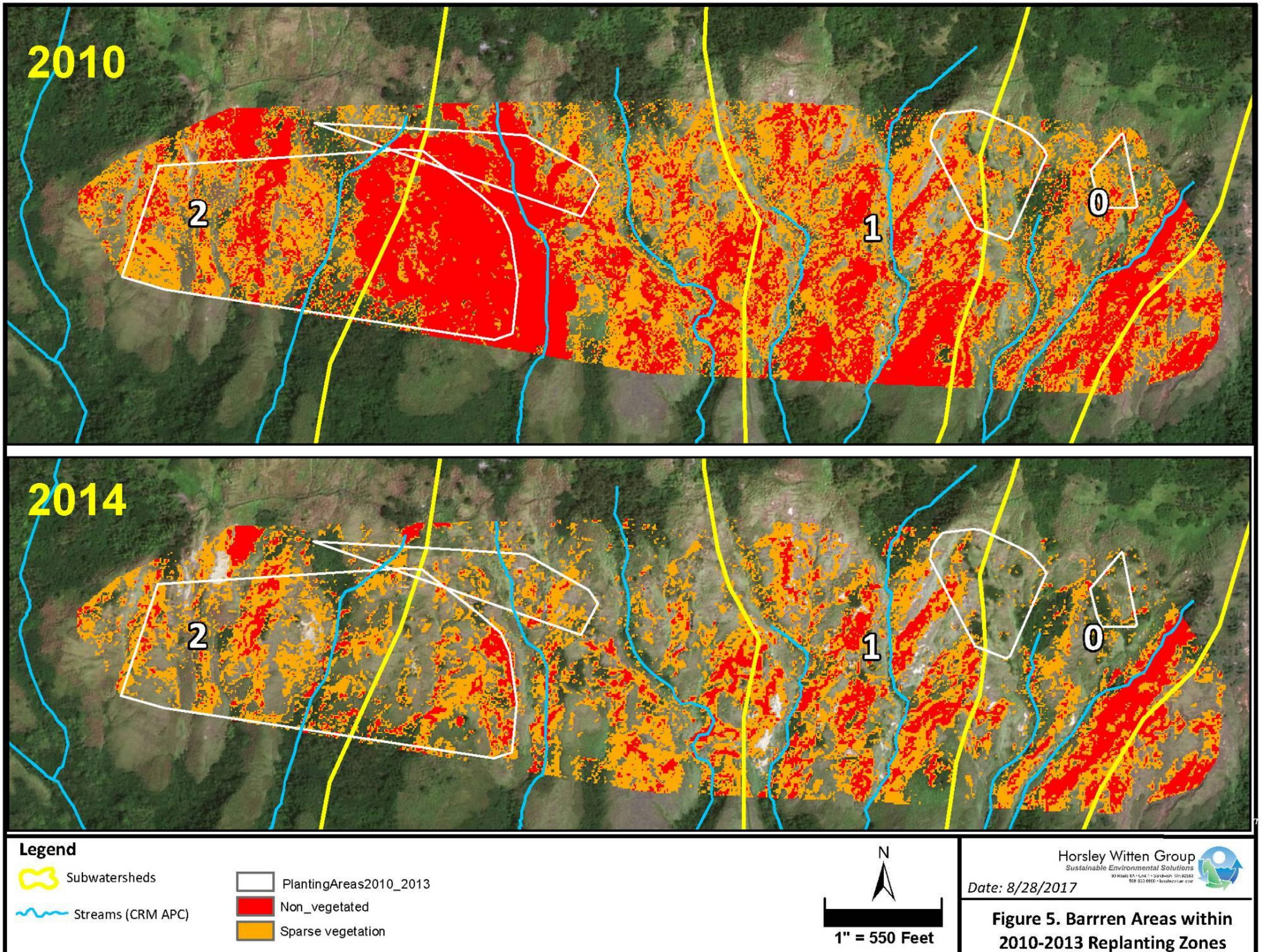


Figure 5. Barrren Areas within 2010-2013 Replanting Zones

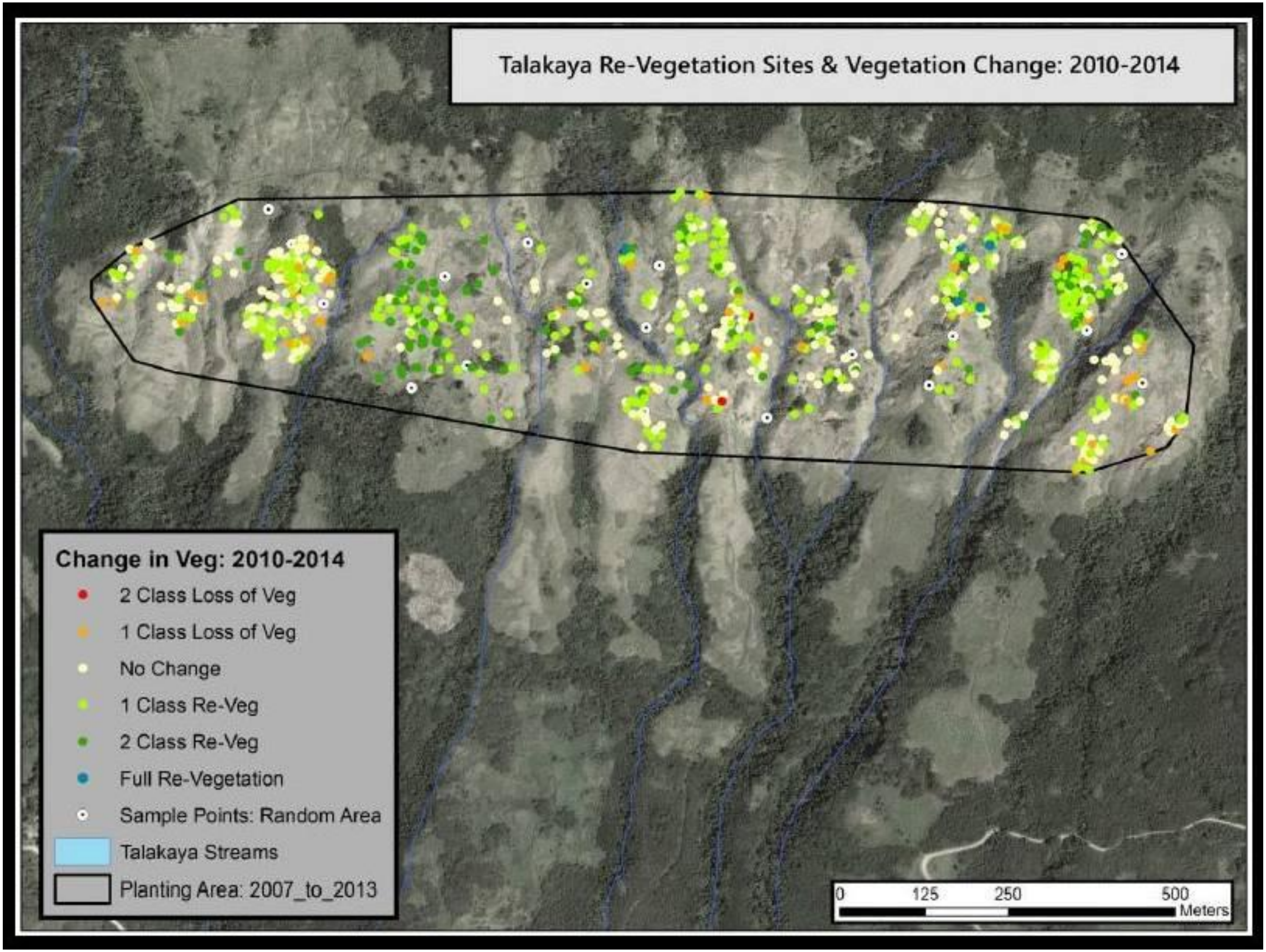


Figure 6. Vegetation sites change analysis map (Malcolm Johnson)

1.3 Subwatershed Characteristics

There were five different streams monitored under this effort, and the subwatershed characteristics of each are summarized in **Table 1** and discussed further in Section 2.1. These streams were selected to 1) represent various upstream vegetation types within the Talakhaya revegetation area; 2) help illustrate the effects of restoration activities on the lower stream reaches; and 3) compensate for lack of baseline data collected prior to the initiation of revegetation efforts. They include two un-vegetated stream sites (coded TK1 and TK0), two already re-vegetated areas within the project (coded TK2 and TK3), and a naturally, well-vegetated site just outside of the project scope (coded TK4). The subwatershed boundaries were estimated based on available GIS contour data. It should be noted that there are significant differences between these subwatersheds (e.g., land use, size of the drainage area, and stream geomorphology), making this an imperfect comparative watershed study. Also of note is that although the stream sites chosen were indicated by local residents as having been historically perennial streams, the observations over the project have shown the studied streams to behave more intermittently.

Table 1. Characteristics of the Monitored Subwatersheds

ID	Total Acres	Stream Ave. Slope (%)	Description
TK0	97.8	5.3%	UNVEGETATED CONTROL (Phase II only) • Eastern most subwatershed • Not monitored in Phase I; used as control in Phase II as TK1 was already being revegetated • No flow data or stage-discharge curves are available
TK1	117.4	5.7%	UNVEGETATED CONTROL (Phase I) • Most hydrologically dynamic • Stream has become more intermittent • Debris dams and sediment deposits regularly impacted monitoring
TK2	722.1	6.3%	REVEGETATED • Largest subwatershed with most revegetation efforts • Discovered a stream diversion at the end of Phase II; impacts unknown at this time
TK3	69.3	6.0%	REVEGETATED • Smallest subwatershed • Unclear when this area was revegetated
TK4	84.2	6.0%	FORESTED • A subwatershed without current or previous badlands • Area does support farming/grazing activities

1.4 Goals of Stream Monitoring Study

The primary goal of Phases I and II of this stream monitoring study is to measure and compare sediment loads in Talakhaya streams in order to quantify the sediment reduction benefits of the upland revegetation efforts by DLNR Rota Forestry. The hypothesis being tested is that the amount of suspended sediment in the stream (measured in turbidity and total suspended solids) will decrease as the extent and maturity of subwatershed vegetative cover increases.

The objectives of this project include:

1. Directly address management objectives from the Talakhaya CAP (2012) to establish methodologies, purchase equipment, and train agency staff on monitoring protocols for annually assessing the rate of soil loss in the watershed;
2. Collect localized precipitation data at a high, middle, and low watershed elevations;
3. Establish stage discharge relationships and measure turbidity and TSS in streams with varying levels of subwatershed vegetative cover;
4. Evaluate and, when applicable, modify existing methods to assess the rate of soil loss off of the Talakhaya/Sabana watershed;
5. Assess the rate of soil loss in the watershed; and
6. Re-evaluate the goal reduction of soil loss, which is presently set at 25%, based on measurements of total soil loss and what the reduction would mean for conservation targets downstream.

Based on a comprehensive review of the data collected during Phase I and Phase II of this project, these objectives have been partially met. The study design was originally framed as a "paired watershed" study; however, it has become apparent that there are significant differences between the subwatersheds other than just land cover that prevent direct comparisons. These subwatershed variables, as well as insufficient monitoring data, have made the soil loss quantification and revised reduction target objectives unmet at this time. Objectives related to methodologies, equipment, training, and precipitation data were met.

2.0 Phase II Methodology

This section focuses on the monitoring methodology implemented during Phase II of this study, but also discusses Phase I methodologies when significantly different. In general, data was collected to develop a correlation with the amount of rainfall, stream water level, stream flow, and water turbidity and total suspended solids (TSS) as a representation of sediment loss.

2.1 Site Description

Monitoring stations were originally chosen during Phase I based on site visits with Rota DLNR Forestry staff. There are two main types of stations monitored for this study: stream stations and rain gauge stations. Factors considered when choosing the stream station sites included subwatershed characteristics (areas with no badlands, revegetated badlands, and unvegetated badlands), perennial stream conditions, safety, easiest access, and fewest ownership/land use conflict issues. In Phase I, 10 fixed in-stream monitoring stations were installed on four streams (TK1-4), with 4 associated fixed "air" stations (discussed further in Section 2.2 and 2.3). In Phase II, one in-stream station was added along a previously unmonitored stream (TK0), while one in-stream and one air station on stream TK4 were removed.

The fixed rain gauge stations were chosen at four locations to collect rainfall data throughout the watershed at varying altitudes to provide a representative rainfall total for the monitored subwatersheds. The locations of these gauges were chosen in areas that were un-obstructed by vegetation or buildings and that were relatively easy to access while also limiting visibility to reduce vandalism. The original four locations from Phase I were maintained in Phase II. The final monitoring stations are shown in **Figure 7,** and station descriptions are provided below.

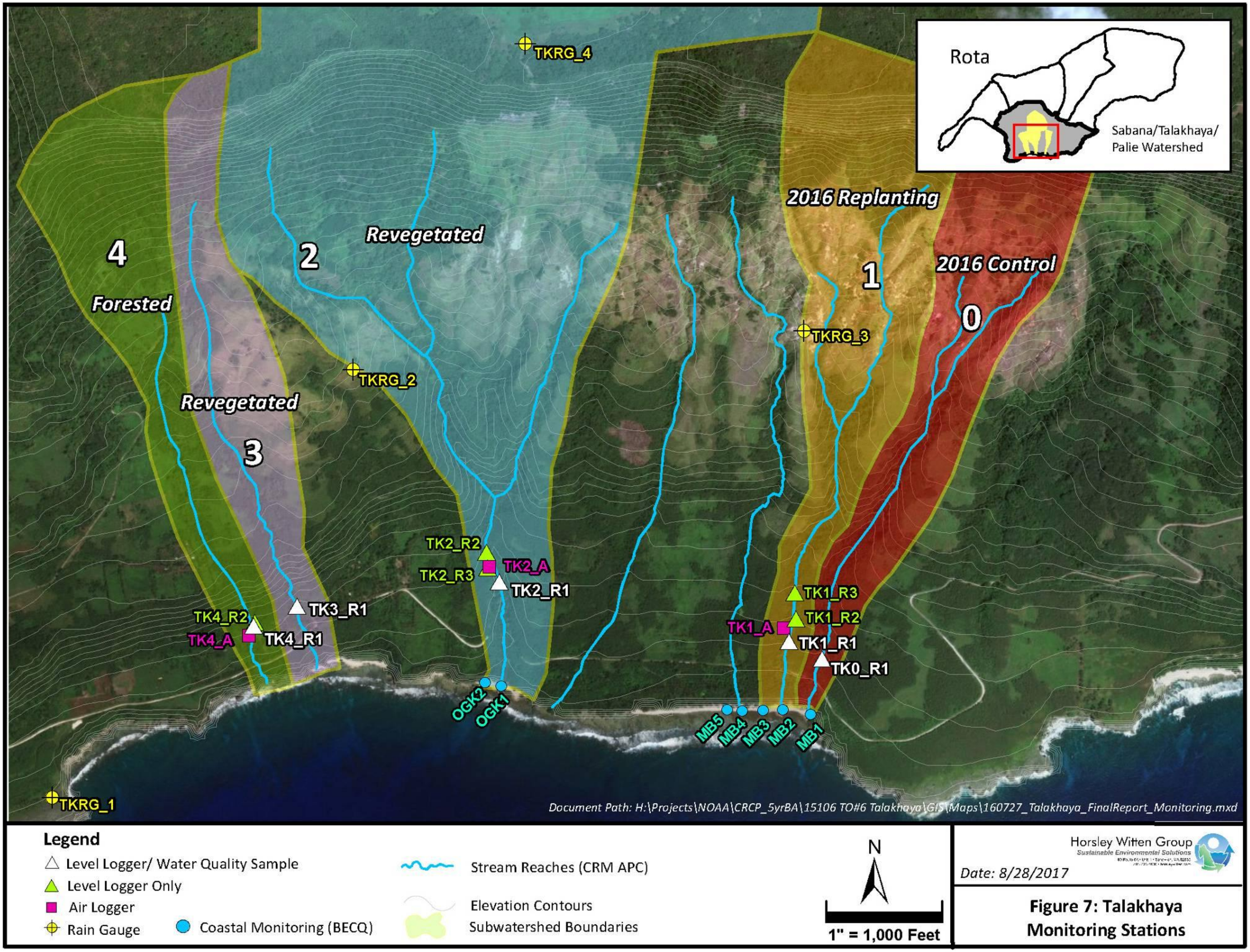


Figure 7: Talakhaya Monitoring Stations

Stream Stations

<u>TK0 – Phase II Control "Unvegetated" Subwatershed</u>
Station TK0-R1 was added in June 2016 to represent the new "control" subwatershed since revegetation efforts were advanced into the Phase I control badlands starting in July 2016. This new sampling station was added to provide additional data representing a stream with unvegetated badlands. As shown in **Figure 4**, there had been previous revegetation efforts (2007-2010) in this area, but the 2012 fire had recreated badlands. This stream was flowing throughout the Phase II sampling period.

Figure 8. Installation of the new station at TK0-R1 occurred June 15, 2016 (left photo); this subwatershed is similar to TK1 in size and the stream was perennial (right photo).

<u>TK1 – Phase I Control "Unvegetated" Subwatershed</u>
This stream was chosen in Phase I to represent stream water quality conditions for a subwatershed with unvegetated badlands. However, in July 2016, Rota DLNR-Forestry staff started revegetation efforts in the western portion of this subwatershed. DLNR had been steadily progressing their planting throughout the Talakhaya badlands moving from west to east, and this was the next feasible area to revegetate. Rather than requesting a delay in planting efforts, NOAA and the monitoring team opted to add a station at TK0 to the east (described above) while continuing to monitor at the existing stations. In addition to adding the new control, it was hypothesized that significant stream water quality benefits from the TK1 revegetation would not occur immediately as postulated by Golabi and Manibusan (2014), and thus, Phase II data from this stream could still be useful.

The TK1 stream was described during Phase I as most "flashy" or hydrologically dynamic of the sites in Phase I, with widely varying flows throughout the year. Not surprisingly, this stream has had the most data collection issues with debris build-up creating dams and sediment deposits that have buried and even swept away the loggers at the three in-stream stations (**Figure 9**). Access to the stations was dangerous during rain events and occasionally blocked afterwards.

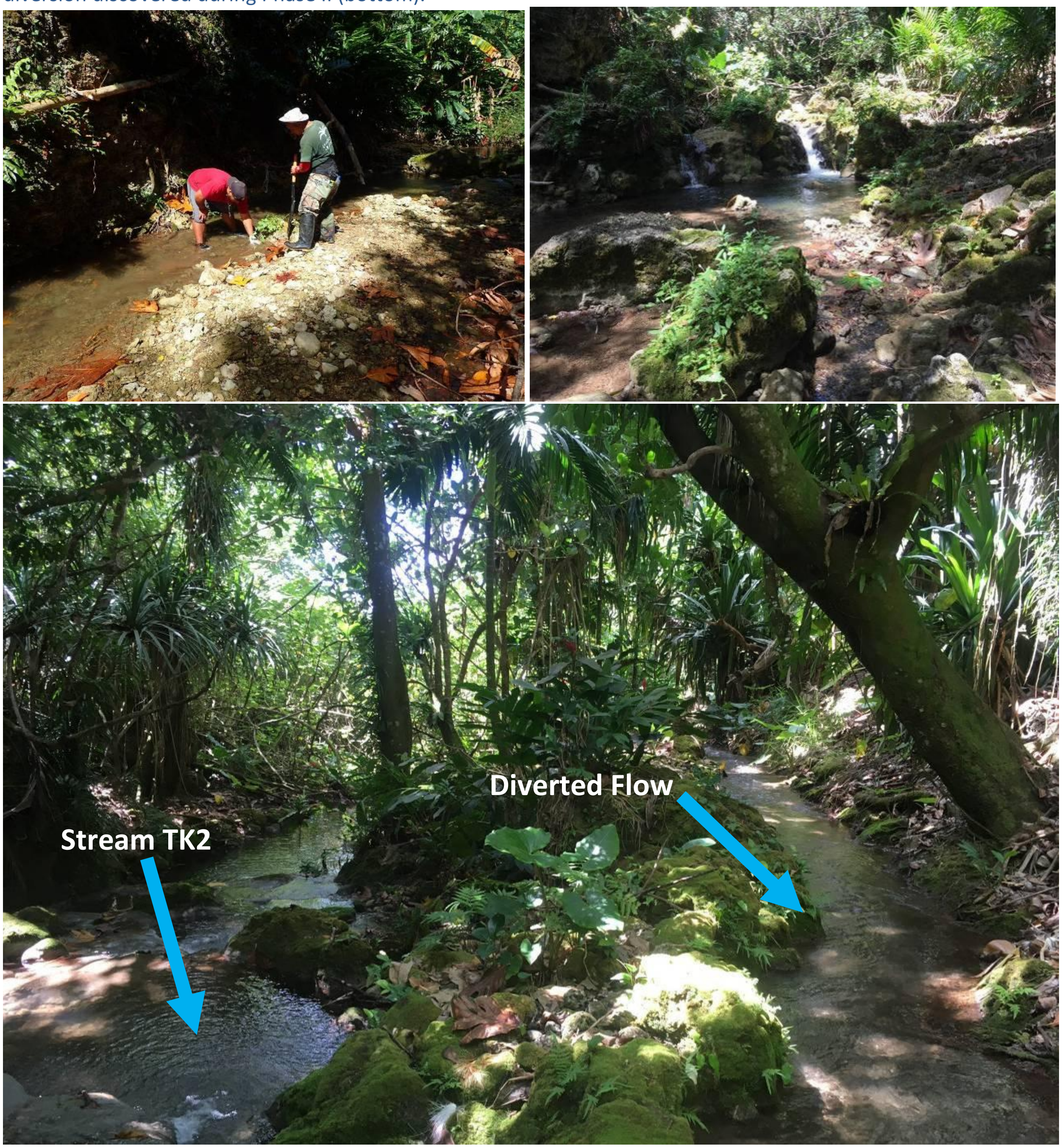
Figure 9. Field team searching for logger under bamboo at TK1-R2 (left); removing sediment build-up at Station TK1-R3; and carrying in a chainsaw to improve access and break-up a debris dam at TK1-R1 (bottom).

<u>TK2 – Revegetated Subwatershed</u>

Stream TK2 carries flow from the largest subwatershed in the study; more than 7 times larger than the next largest subwatershed (TK1). Not surprisingly, this subwatershed also had the largest extent of badlands that had been revegetated by DLNR Forestry. The data from this stream were expected to best illustrate the effects of the revegetation efforts on stream water quality over time. This stream is mostly perennial as would be expected from the large drainage area; however, it did stop flowing occasionally during both Phase I and Phase II. Toward the end of Phase II monitoring, a historic Japanese-era manmade diversion structure was brought to our attention upstream from the monitoring stations (**Figure 10**). Another agricultural diversion further upstream was also reported.

During Phase I, Golabi and Manibusan (2014) noted that there were still high turbidity levels during high rainfall events in this stream, and that continued monitoring would be required to determine the effects as the new vegetation matured, became more established, and improved their sediment barrier capacities.

Figure 10. Looking for the logger at Station TK2-R3 (left); waterfall just upstream from TK2-R2 (right); and the flow diversion discovered during Phase II (bottom).



TK3 – Revegetated Subwatershed

The one station on stream TK3 was chosen to represent another subwatershed with revegetated badlands in addition to TK2. However, this subwatershed does not include any mapped revegetated areas between 2007-2016 (see **Figure 4**), so it is unknown when revegetation occurred. This stream has the smallest drainage area of the monitored subwatersheds, but the stream is mostly perennial with easy access to the monitoring station (**Figure 11**).

Figure 11. Stream characteristics near station TK3-R1 (left); logger location for TK3-R1 (right).

TK4 – Forested Subwatershed

Stream TK4 represents a vegetated subwatershed (without badlands). As described by Golabi and Manibusan (2014), this stream was intended to represent "an ideal vegetative cover that the revegetation sites should reflect or surpass in sedimentation and stream turbidity." However, this subwatershed does have certain characteristics that differ from the other monitored subwatersheds: 1) land uses include active farming and cattle grazing; 2) road erosion from a dirt road to the water caves was observed in this subwatershed (could also be a factor for TK2 and TK3); and 3) field teams noted that stream TK4 was always flowing more/faster than any of the others, with more waterfalls in the stretches just upstream from the sampling points at TK4-R1 and R2 (**Figure 12**). In addition, Stations TK4-R1 and R2 were just upstream from a culvert under the road. The condition/capacity of the culvert was not inspected or measured during the monitoring period, and it was not assessed to determine if the loggers were far enough upstream to remain unaffected, particularly if the culvert became clogged or damaged.

Phase I of the study included three stations on this stream, but on April 25, 2016, Station TK4-R3 was removed from the study due to the following reasons:

- Private property issues made consistent data collection difficult;
- Accessing TK4-R3 presented a safety issue, particularly during the rainy season, as the stream morphology was very different than the other sites, characterized by extremely steep banks approximately 9 – 12 ft high and a very narrow (< 6 ft) channel width; and
- The station was located at approximately 570 ft in elevation, whereas all other monitoring locations are located at approximately 240-300 ft.

Figure 12. A cow encountered in this subwatershed (left); Stream at TK-R2 (right); and field team climbing out of TK4-R3 before the station was removed.

Rain Gauge Stations

<u>TKRG1 – Pona Point</u>

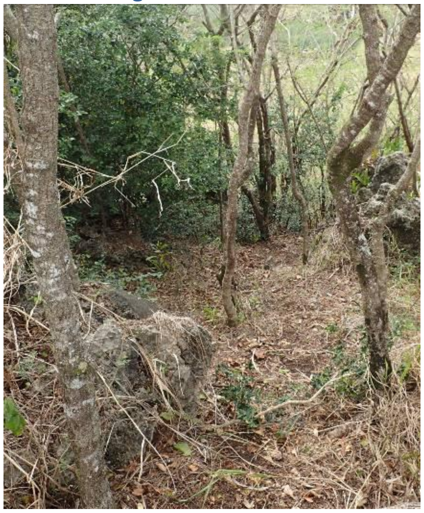
The rain gauge at Pona Point is located closest to the coast with the easiest access from the main road (**Figure 13**). This gauge was the most visible to the public, and was removed at one point during Phase II by someone. Luckily, the field team was able to recover the rain gauge, which had been abandoned nearby. Unfortunately, the gauge was later shot and destroyed and had to be replaced with a new unit.

Figure 13. Rain gauge at Pona Point - TKRG1.

<u>TKRG2 – Talakhaya West (Lupok)</u>

TKRG2 was located along the western edge of Subwatershed TK2. The area was mostly open grasslands with steep cliffs and some vegetated ravines, and is popular to local hunters. The rain gauge at TKRG2 was perhaps the most difficult to access, requiring the field team to scale a nearly vertical path down a cliff only possible with the aid of a rope (**Figure 14**). This gauge provided the least amount of data in Phase II due to the access difficulty to download data and replace batteries, as well as interference/damage from the public.

Figure 14. Nearly vertical path to TKRG2 where a rope was installed to help the field team access the site (left); downloading data at TKRG2.



<u>TKRG3 – Talakhaya East</u>

TKRG3 was located along the western edge of Subwatershed TK1. The area was mostly open grasslands with some exposed badlands, steep cliffs, and ravines (**Figure 15**). This site was only accessible by an extremely rough road that was barely passable by vehicle; luckily, this location was adjacent to the 2016 planting area, so the field team was able to ride along with DLNR Forestry staff to access the rain gauge. This rain gauge provided the most consistent rainfall data of the four sites.

Figure 15. Rain gauge at TKRG3, near the 2016 revegetation site.

TKRG4 – Sabana

This rain gauge is located in the Sabana Protected Area, high on the Sabana Plateau and accessed only from the north (i.e., taking the main road from Songsong rather than the roads near the study area). The Sabana Plateau in this area is a mix of open grasslands and forests, and is protected for threatened and endangered species as well as for the water caves and other local interests. This site had no issues with vandalism, but was occasionally overrun by nesting ants (**Figure 16**).

Figure 16. Rain gauge on the Sabana Plateau-TKRG4(top); ant nest affecting the tipping bucket (bottom left); removing ants from rain gauge (bottom right).

2.2 Equipment and Installation

Equipment for this project falls into four categories based on type of measurements collected: rainfall, stream level, water quality, and stream flow. In general, the equipment was consistent from Phase I to Phase II, with minor differences listed in **Table 2**. Descriptions of this equipment and associated installation or use is provided below.

Table 2. Equipment inventory for Phases I and II.

Measurement	Phase I	Phase II
Rainfall	HoboWare® data logging rain gauges (4 locations)	HoboWare® data logging rain gauges (4 locations)
Stream Level	HOBO® Level Logger – 13 ft (14 total on 4 streams)	HOBO® Level Logger – 13 ft (13 total on 5 streams)
Water Quality	HORIBA multiple parameter water quality meter	YSI® Meter Hach® portable turbidimeter
Stream Flow	Hach® portable flow meter	Hach® portable flow meter (not used)

Rainfall

Rainfall data was collected using HoboWare® rain gauges at four locations in the watershed. Each gauge has a rugged, aluminum housing with a funnel on top that directs rainfall into a tipping bucket that measures and records every 0.01” of rainfall (**Figure 17**). The gauge is battery powered, and the data is downloaded via USB cord or a waterproof shuttle. The rain gauges were installed with couplers onto a metal post. The rain gauge at TKRG2 was replaced in March 2016 due to cracked housing, TKRG4 was replaced in August 2016 when it failed for unknown reasons, and TKRG1 was replaced after it was shot.

Figure 17. Inside of rain gauge showing tipping bucket (bottom left); Downloading data from the Hoboware Rain Gauge (right).

Stream Level

Stream water level, also referred to as “stage,” was collected with HOBO® Level Loggers placed in the stream bed at each in-stream station to record water pressure, as well as somewhere near each stream to record atmospheric (i.e., air) pressure (**Figure 18; Figure 19**). These loggers are ideal for measuring levels in shallow (0-13 ft range) freshwater systems. The pressures were recorded continuously on a 1-hour interval and used to determine stream stage. The in-stream level loggers were installed at specific locations in the stream where: (1) they were most likely to remain in water (rather than an area that would become dry during periods of no or low flow); (2) they would be less visible to passersby to reduce vandalism; and (3) they would be easy to access by the field team. The loggers were attached to rebar pounded into the streambed. Data was downloaded from the loggers via a USB cord or a waterproof shuttle. The Phase II field team encountered missing or damaged Phase I loggers that had to be replaced at the following locations:

- TK1-R1– This logger was missing (near large debris and sediment dam) and replaced on March 9, 2016.
- TK1-R3 – This logger was missing, and replaced on March 9, 2016.
- TK2-R1– This logger was completely coated with calcium deposits, and replaced on same rebar on March 10, 2016.
- TK2-R2– Logger was melded (from calcium deposits) with rebar and had to be replaced on March 10, 2016 (**Figure 20**).
- TK0-R1 was installed on June 15, 2016
- TK1-R2 failed on July 20, 2016; replaced on August 19, 2016.

Figure 18. HOBO level loggers were used for determine barometric pressure ("air" loggers; left photo); stream depth (attached to rebar in stream; right photo); and downloading logger data onto laptop in the field (bottom).

Figure 19. Placement of data logger for recording atmospheric pressure near in-stream station (left); installing rebar for in-stream level logger (right).

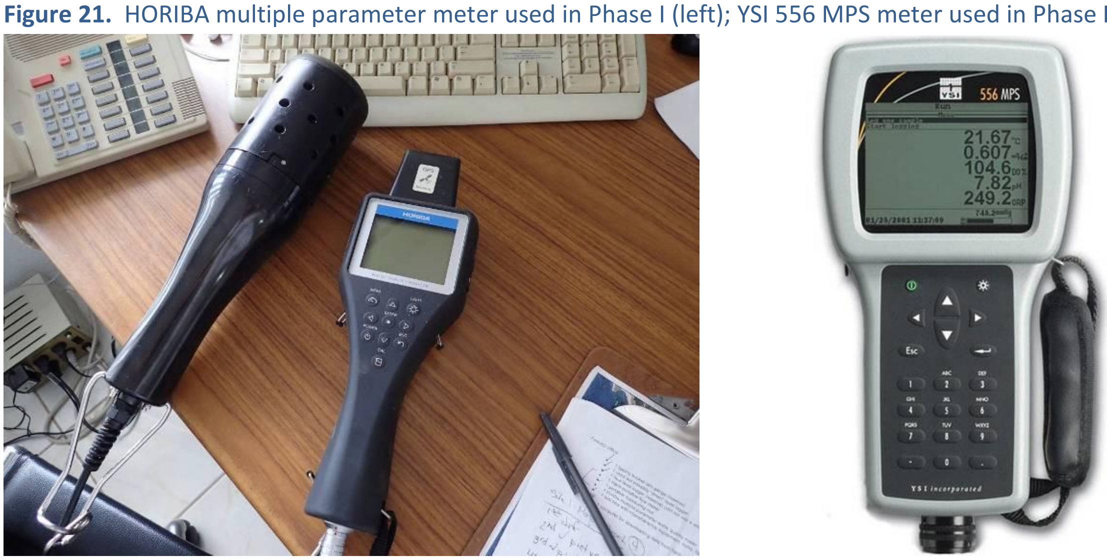
Figure 20. Logger and rebar melded together.

Water Quality

Stream water quality was measured at least monthly when the streams were flowing using a multi-parameter water quality meter (see **Figure 21**: Phase I – HORIBA meter; Phase II – borrowed BECQ's YSI® meter, with a separate Hach® meter for turbidity) to collect data on: acidity (pH), dissolved oxygen (DO), turbidity, total dissolved solids (TDS), and conductivity. Water quality data were recorded by hand on field data sheets for entering into a spreadsheet back in the office. For the purpose of this Phase II report, only turbidity data were analyzed and discussed in Section 3. The meters were calibrated when possible to try to maintain level of accuracy.

For Phase I, the primary water quality measure used was turbidity[1]. In Phase II, the field team added total suspended solids (TSS) sampling to the monitoring protocol in an attempt to quantify the amount of sediment relative to turbidity measurements. TSS samples were not collected in Phase I due to logistic difficulties with transporting samples back to Guam in a timely manner for analysis. The TSS sampling method involved collecting a water sample from 6-12 inches below the water surface by hand; however, the water was rarely deep enough to collect more that 6 inches below the surface without scraping the stream bottom. The TSS sample volume was one liter (in HDPE or PP screw-cap bottles). At least one field duplicate was collected each sampling event. A one-inch air space was provided in the bottles to allow for proper mixing of the sample at time of analysis. Bottles were labeled and placed on ice during transportation, with date, time, location, and sampler name on recorded on the field data sheet. The samples had a maximum holding time of seven days from the time of collection to time of analysis – the field team sent the samples via airplane to the BECQ lab on Saipan for processing. Non-detect readings from the lab were recorded as 0 mg/L; it is important to note that the detection limit lowered during Phase II from 5 mg/L to 1.5 mg/L.

Figure 21. HORIBA multiple parameter meter used in Phase I (left); YSI 556 MPS meter used in Phase II (right)



[1] Stream turbidity is a measure of the cloudiness of the water in terms of Nephelometric Turbidity Units (NTU), which indicates the amount of sediment carried in the stream. The turbidimeter is a device which measures the transmission of light reflected by particles through a solution.

Stream Flow

In Phase I, flow was measured weekly at the four streams using a Hach® portable flow meter. Flow measurements were taken along transects set perpendicular to the flow from bank to bank using the handheld device and a probe connected to a wading rod (**Figure 22**). The flow meter provides real-time velocity and depth measurements at specific points along the transect and calculates flow (cfs) once the transect is complete. Data is downloaded via a USB cord.

The proper selection of transect locations is very important to adequately measure stream flow. The best locations are those that have the following characteristics:

- Are as straight as possible;
- Have as few flow disturbances as possible (e.g., contributing tributaries, large rocks, debris, etc.);
- Do not have visible swirls, eddies, vortices, back-flow or dead zones;
- Do not have vertical drops.

Meeting all these ideal location criteria was not possible at all the monitored stream stations, but the field team chose the best sites possible.

In Phase II, collection of additional flow data was prevented by no flow/dry stream conditions, temporary loss of the flow meter, and lack of training of replacement staff.

Figure 22. Using the HACH portable flow meter in the field.

2.3 Data Collection Schedules

There are two general types of data measurements collected during this monitoring effort: continuous (level loggers and rain gauges) and field (water quality and streamflow). Continuous measurements were collected/downloaded on a monthly basis when stream/weather conditions permit safe access and retrieval of the loggers. The following field measurements were also collected during the monthly monitoring when the streams were flowing: Water quality measurements with the YSI multi-parameter probe, in-field turbidity measurements, and TSS samples.

For Phase II, in addition to the monthly monitoring, event-based field measurements/ collections were intended to be taken for streamflow, turbidity, and TSS. These measurements should have been conducted when increased runoff was observed during or following a rainfall event. However, the field team was unable to do event-based measurements due to safety and logistical issues (e.g., knowing when it was actually raining at the sites, having transport to get there, etc.). In addition, there were certain times when BECQ needed to use the YSI and turbidity meters so that it was unavailable for use by the Talakhaya field team, and when logistical issues exceeded the maximum TSS holding time (7 days) before lab analysis.

Table 3 includes a summary of the various important aspects of both field and continuous measurements, and **Table 4** summarizes the data collected during Phase I and Phase II of this study.

Table 3. Summary of Phase II Monitoring Elements

	FIELD MEASUREMENTS		CONTINUOUS MEASUREMENTS	
	Water Quality	**Flow**	**Water level and Air pressure**	**Rainfall**
Where is the data collected? See **Figure 7.**	5 water quality stations (white triangles)	5 water quality stations (white triangles)	10 water level logger stations (green AND white triangles) and 3 air logger stations (pink squares)	4 rain gauges (yellow circles)
What data is collected?	Physical sediment grabs from water column, turbidity and some other WQ parameters	Stream flows (cfs) based on measured velocities and cross-sectional areas	Raw data to be downloaded to laptop	
When is data collected?	A minimum of monthly for baseflow monitoring; during or soon after rainfall for event-based monitoring *3 hrs per event*		Monthly. *assume full day each trip*	
What equipment is needed?	Sample bottles, cooler, YSI meter, turbidimeter	Flow meter	Laptop, connector cable, shuttle	
What happens to the samples/data?	Send TSS bottles to BECQ lab on Saipan; record YSI and turbidimeter readings on data sheet	Either record readings on data sheet or download when back at office	Save raw files to computer for processing.	

Table 4. Summary of Phase I and Phase II Data Collection

Data Type	Phase I	Phase II
Rainfall	Some Data: 6/13-9/13; 7/14-12/14	Some Data: 3/16-10/16; 3/17-5/17
	Complete Data: 9/13-7/14	Complete Data: 10/16-3/17
Stream Level	All 4 streams from 3/13 go 9/14 Some streams from 10/14-12/14	3/16 - 5/17
Turbidity*	200 total measurements (between 38 and 69 in each of the 4 monitored streams)	15 at streams TK1-4; 14 at stream TK0
TSS Samples*	None	16 at streams TK1-4; 15 at stream TK0
Flow	108 total measurements (9 and 47 in each stream)	None

**Samples and measurements only taken when stream was flowing.*

2.4 Data Analysis

Rainfall

Rainfall data were collected from each of the four rain gauges. The gauges recorded the date and time of every 0.01 inch of rain; these data were combined to calculate hourly rainfall, which was then averaged across all rain gauges. Rainfall was used to show the relationship between rain events and stream levels/flows, as well as sediment levels in the stream. Monthly rainfall was compared between Phase I and Phase II to identify any significant changes in weather patterns between the sampling periods.

Stream Level/Stream Flow

The recorded pressure of the in-stream loggers was compensated with the measured atmospheric pressure from the air loggers using the HOBO software barometric compensation tool; the output was an hourly measurement of stream depth.

In Phase I, collected flow data were plotted against stream level to create a “stage-discharge curve” using a best fit trendline showing the relationship between stream depth and discharge. The purpose of these curves is to be able to calculate stream flow with only stage, or stream level, information. However, the relationships shown by Golabi and Manibusan (2014) had low coefficients of determination (R^2) values[2] ranging from below 0.02 to just under 0.4, indicating a poor fit to the polynomial trend line. With R^2 values that low, using stage with the resulting equations would most likely result in extremely inaccurate flows. In addition, the Phase I stage-discharge curve for some of the streams was created using stages from multiple stations. Since each logger is placed at different locations both vertically and longitudinally along the stream channel, a different curve would be expected for each station; using multiple stations in one curve reduces the accuracy.

[2] A statistical measure of how close the data are to the fitted regression line.

For Phase II of the project, no flow data was collected to support Phase I data; we relied exclusively on Phase I data. These curves were modified by excluding unrealistic/erroneous data points (e.g., where high flows were recorded at 0 feet stream depth); only using data from the most consistent logger station on each stream throughout both Phases (happened to be R1 on each of the four streams with flow data); and changing the regression equation from polynomial to power, which better matches the expected relationship between stage and discharge, i.e., a higher flow at higher stream depths. At this time, there is no stage-discharge relationship for the added Stream TK0.

Water Quality

Phase I and II turbidity and TSS data were compared to rainfall and stream level data to observe correlations between hydrology and sediment loading to the watershed. In addition, Phase I and Phase II turbidity data were compared with each other to evaluate changes over time.

2.5 Data Limitations

It is important to understand some of the limitations of the collected data before discussing results and conclusions. We have summarized the most important limiting factors below:

1. Study Length – Phase I and II only spanned portions of four calendar years. In addition, there was a 15-month gap in data collection between the phases. To ensure more accurate and significant results, the monitoring study should cover a longer, continuous length of time with more samples/data points covering a wide range of rain events through multiple dry and wet seasons.
2. Environmental Variability – While there is a general dry and wet season on Rota, the daily and monthly weather patterns varied significantly through the study period. Phase I had heavy rain during the wet season, particularly in 2014 including a typhoon (Typhoon Vongfong on October 5, 2014). Phase II had a much drier "wet season" than Phase I, leading to longer periods of streams with no flow and thus, fewer water quality samples. Rains after extended dry periods produced large amounts of sediment and debris that were carried downstream, adding to physical impacts to data loggers.
3. Safety and Access Issues – The Talakhaya Watershed is an extremely steep, rugged area with flashy stream systems, private property, nearly unpassable roads, and the potential of encountering hunters, fires, and bees. These factors made it difficult and dangerous for field teams in both phases to access the monitoring sites as often as planned, particularly during rain events (i.e., no event-based sampling at all during Phase II), resulting in fewer data points than desired for this study.
4. Change in Staff – Phase I had a consistent field team led by seasoned UOG researchers. Phase II had intermittent staffing - starting with a new on-the-ground leader (NOAA Coral Fellow) who left partway through the sampling season. BECQ staff from Saipan filled in until a new Coral Fellow arrived and was trained. On-island staffing gaps were one factor contributing to lack of event-based sampling. Consistent staff helps to ensure reliable and comparable data, as well as maintaining institutional knowledge on data collection procedures and sampling equipment and troubleshooting methods (e.g., using the flow meter).

5. Change in Equipment – Some of the equipment was damaged, lost, or replaced between Phase I and II. Most importantly, the water quality meter differed between phases, with turbidity being measured with a turbidimeter in Phase II and with a multi-parameter meter in Phase I. Using different meters with different sensitivities and calibration methods can reduce the comparability of the resulting data. In addition, the YSI meter and turbidimeter used in Phase II belonged to BECQ and occasionally were needed off-island, and thus, were unavailable to the Talakhaya field team.

   While many of the loggers and rain gauges remained in place through both phases, some had to be replaced due to equipment failure (e.g., stopped working, damaged from vandalism), environmental impacts (e.g., ants, mud, calcium deposits), or where they were missing. In most cases, they were replaced in the same or nearly same locations; but occasionally, the entire station was relocated to better protect the equipment from human or environmental impacts. These adjustments add variability to the data.

6. Change in Data Collected – TSS was unable to be collected during Phase I due to inability of finding a lab to process data within the time period required. Both turbidity and TSS data were collected in Phase II, but the majority of data was collected during non-rain events. Thus, TSS data is limited and cannot be compared with earlier stream/ watershed conditions during the wetter time period of Phase I. In addition, the BECQ lab analysis method changed in Phase II, with a lower non-detect (ND) limit dropping from 5 to 1.5 mg/l. Given that a majority of the earlier Phase II samples were ND, this change in analysis sensitivity affects the TSS comparison in a given stream over time.

7. Watershed Changes – There were changes/variability in watershed conditions that were out of the field team's control. The revegetation project progressed faster than anticipated, which is a success for badland stabilization, but limited comparisons of the original control (TK1) between Phase I and Phase II. In addition, it was discovered at the end of Phase II that TK2 (revegetated subwatershed) had a man-made water diversion structure upstream of the monitoring stations. It is anticipated that this diversion influences stream level, flow, and potentially water quality at the TK2 monitoring stations, particularly during the dry season, but this impact has not yet been quantified. Finally, accurate information on the total area of bare vs. vegetated cover in each subwatershed does not exist in order to compare coverage between 2014 and 2017.

3.0 Results and Discussion

3.1 Overall data quality

The focus of this section is on reporting results of additional data collected during Phase II, as specific data quality issues relative to the Phase I monitoring cannot be verified by the Phase II team. However, the Phase I data was included in this section for comparison purposes and to allow for longer-term data analysis where feasible. Please keep in mind that even without the data limitations summarized in Section 2.5, quantification of soil loss reductions from revegetation efforts would be difficult to estimate given the short timeframe of the study and lack of sufficient information on subwatershed conditions.

3.2 Rainfall Data

Precipitation monitoring provided a mostly continuous rainfall dataset throughout the study period. The four gauges throughout the watershed provided a redundancy in the event that one or more gauges were not operational. The rain events indicated by the data, particularly the large events, were confirmed by observations made by the field team. For these reasons, we believe that these data are reliable/high quality.

Table 5 summarizes the rainfall data by month for each calendar year in the study. Typical dry and wet seasons are indicated by color, and the highest monthly totals are shown in bold. Rainfall is also included on most of the graphs in the sections below.

Dry Season

While Phase II shows more "highest monthly totals" (for Feb-Apr in 2017), these totals are only slightly larger than the same months in 2014. In contrast, Jan 2014 shows a total rainfall that is almost 3 times the monthly total recorded in Jan 2017.

Wet Season

Phase I shows "highest monthly totals" (for Jul, Sep, and Oct in 2014) that are roughly twice the corresponding amount in Phase II (2016). However, Phase II rainfall was significantly greater than Phase I in Nov and Dec.

Table 5. Summary of total monthly rainfall (inches) throughout the study period. Phase I covered 2013-2014; Phase II covered 2016-2017.

Month	Monitoring Year			
	2013	2014	2016	2017
Jan		**22.75**		7.88
Feb		6.72		**6.78**
Mar		6.02		**6.22**
Apr		2.50	0.97	**5.28**
May		**5.93**	1.37	
Jun	1.89	**3.56**	1.65	
Jul	5.29	**18.70**	*0.29**	
Aug	4.70	4.61	**5.59**	
Sep	15.13	**17.74**	8.85	
Oct	7.88	**13.61**	7.94	
Nov	2.64	1.84	**7.30**	
Dec	3.28	0.84	**6.32**	

(tan)	Dry Season
(blue)	Wet Season
BOLD #s	Highest measured rainfall for that month
*	Only includes data from first week of the month due to data download issues in all four rain gauges

Given the significantly higher monthly rainfall totals in 2014, we would expect there to be larger soil loss and thus reduced stream quality during Phase I than Phase II regardless of revegetation efforts and establishment as heavy rains erode exposed soil and move sediment through the stream system.

3.3 Stream Level and Water Quality Data

Figure 23 illustrates the relationship between hourly rainfall, stream level, and water quality (both turbidity and TSS as available) for each of the five streams monitored in Phase II (TK0-4). Phase I data was also shown where available. Hourly rainfall data was averaged across the four rain gauges, and compensated stream level data at the first station on each stream is shown (i.e., R1). Please note that stream level does not necessarily indicate absolute depth of water, but instead, is measuring depth of water relative to the vertical placement of the logger in the stream. Weeks in which the stream was noted to be dry or not flowing by Phase II study team members are highlighted in bright red, while the Phase I time period is shaded in grey. **Table 6** lists averaged daily turbidity and TSS measurements taken at each stream during Phases I and II. Daily maximum values are indicated with bold font.

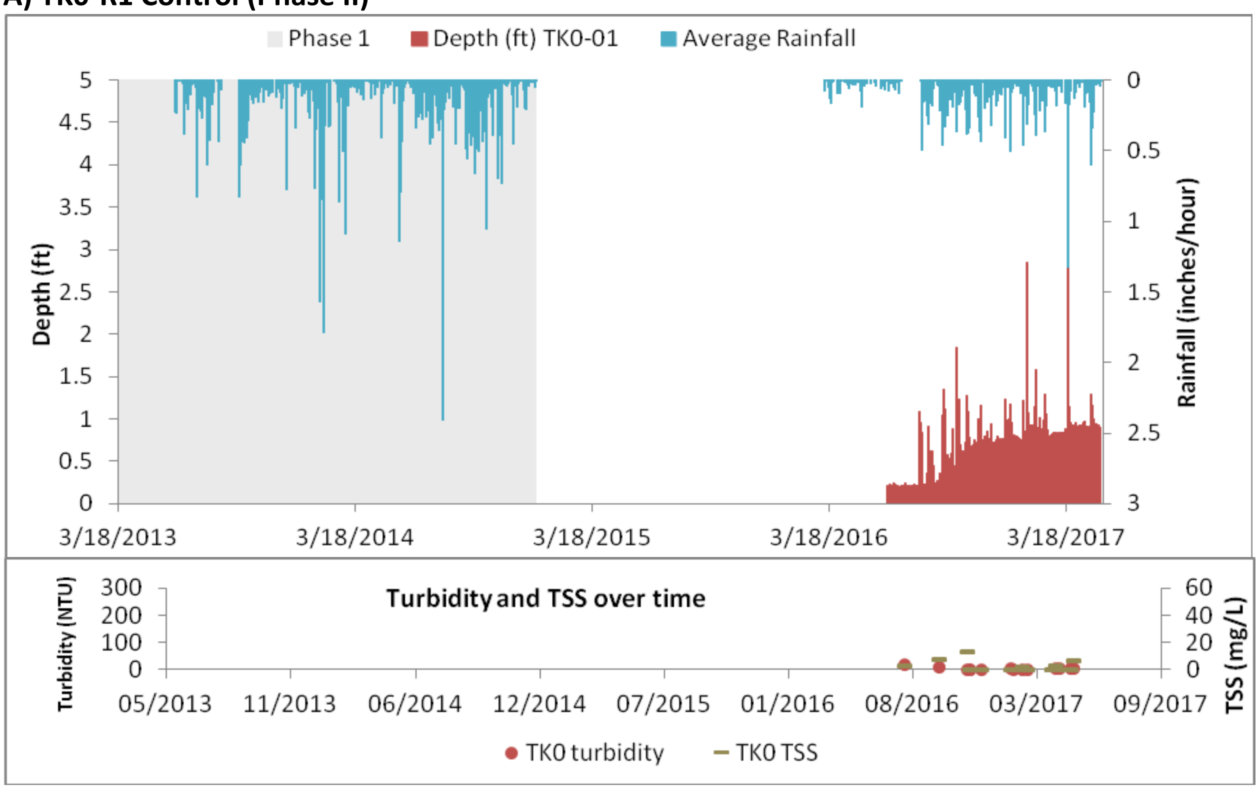
Table 6. Summary of Phase I and Phase II turbidity and TSS measurements for each stream by date.

Sample Date		TK0		TK1		TK2		TK3		TK4	
		Turb.	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*
PHASE I	9/23/2013			0.7		**15.1**		10.3		10.8	
	9/23/2013			52.6							
	9/25/2013			3.4		22.7		12.1		**41.5**	
	9/30/2013			6.7		5.6		**15.7**			
	10/16/2013			**189**		81.4		117.5			
	10/22/2013			**27.1**		21.5					
	10/24/2013			72.1		**115**				81	
	10/29/2013			31.9		19.7		**65.7**		25.9	
	11/2/2013			5.4		**93.6**		37		31.6	
	11/6/2013			101							
	11/20/2013			67.4		75.1		**165**			
	11/26/2013			19		**104**		**104**			
	12/3/2013			76.2		70.7		**91.7**			
	12/5/2013			**80.8**		50.8					
	12/5/2013					43.4		53		**89.3**	
	12/18/2013			41.8		37.8		20.7		**54.1**	
	12/21/2013			24.8		31.7		14.8		**45.2**	
	12/28/2013					**64.7**		41.3		59.3	
	12/31/2013					51.3		4		**98.8**	
	3/14/2014			15.3		17.7		17.8		**24.2**	
	4/25/2014					20.1				**25.9**	
	5/28/2014					**63.8**		22.9		62.7	
	9/14/2014			61.8		31.7		**116.5**		32.7	
	10/27/2014			43.7		45.6		**94.4**		33.3	
	10/30/2014									28.7	

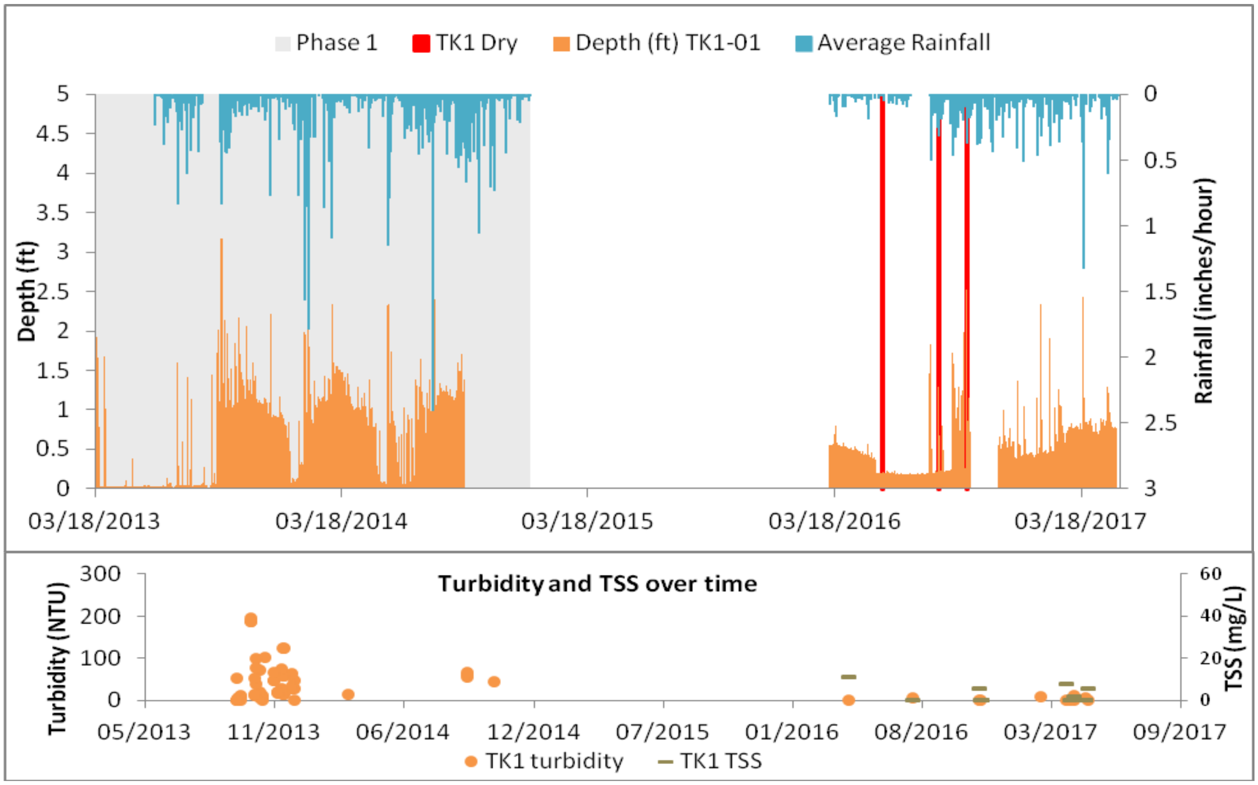
Sample Date		TK0		TK1		TK2		TK3		TK4	
		Turb.	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*	*Turb.*	*TSS*
PHASE II	4/26/2016			3.0	0.0	1.1	0.0	1.0	**50.5**	**28.9**	43.5
	8/4/2016	18.8	**7.6**	**23.0**	5.8						
	9/28/2016	**9.7**	**13.0**			3.0	0.0			4.9	6.8
	11/14/2016	1.6	0.0	0.8	0.0	1.9	0.0	1.5	0.0	**5.2**	**5.2**
	11/17/2016	1.3	0.0	0.8	0.0	1.2	0.0	**1.8**	0.0	1.5	0.0
	11/18/2016	1.5	0.0	0.0	0.0	1.2	0.0	1.7	0.0	**4.7**	**2.6**
	12/5/2016	1.6	0.0	1.4	0.0	1.2	0.0	1.4	0.0	**4.6**	0.0
	1/23/2017	2.0	0.0	0.0	0.0	1.9	0.0	2.1	0.0	**5.9**	**4.1**
	1/27/2017	1.3	0.0			1.7	0.0	1.8	0.0	**5.6**	**7.2**
	2/10/2017	1.2	0.0	0.0	0.0	1.1	0.0	1.4	0.0	**6.2**	**6.2**
	2/17/2017	1.6	0.0	2.0	8.0	**5.4**	**9.0**	3.4	0.0	5.3	6.2
	3/30/2017		2.6		0.0		0.0		5.0		**6.2**
	4/4/2017	1.9	0.0	0.9	1.6	1.1	1.8	1.9	2.2	**5.3**	**7.8**
	4/11/2017	1.8	0.0	2.5	5.5	1.5	0.0	1.8	2.0	**7.4**	**11.0**
	4/28/2017	3.2	4.8	4.0	5.4	3.5	2.6	4.8	4.2	**8.5**	**11.6**
	5/2/2017	2.7	1.8	1.6	0.0	1.3	1.8	1.5	0.0	**8.7**	**11.4**

Figure 23. Rainfall across Talakhaya compared to daily stream level, turbidity and TSS in TK0 (A), TK1 (B), TK2 (C), TK3 (D) and TK4 (E).

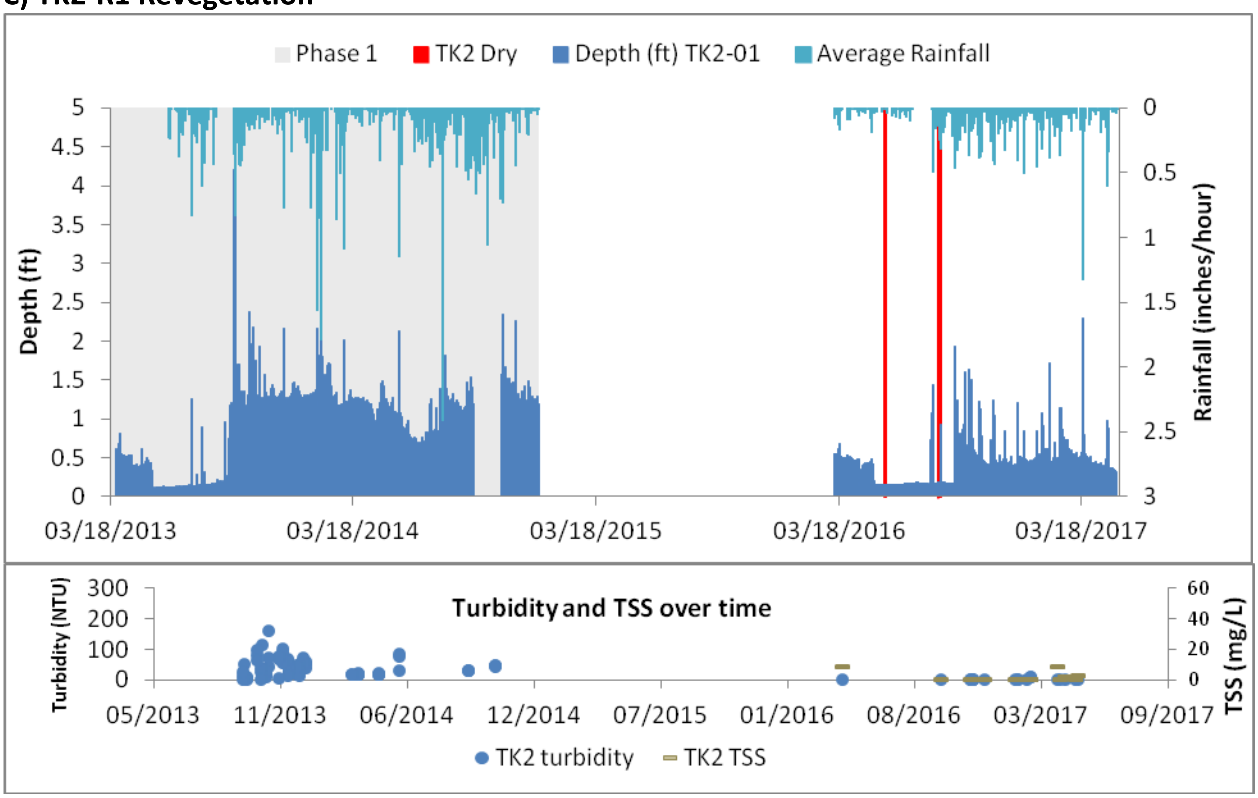
A) TK0-R1 Control (Phase II)



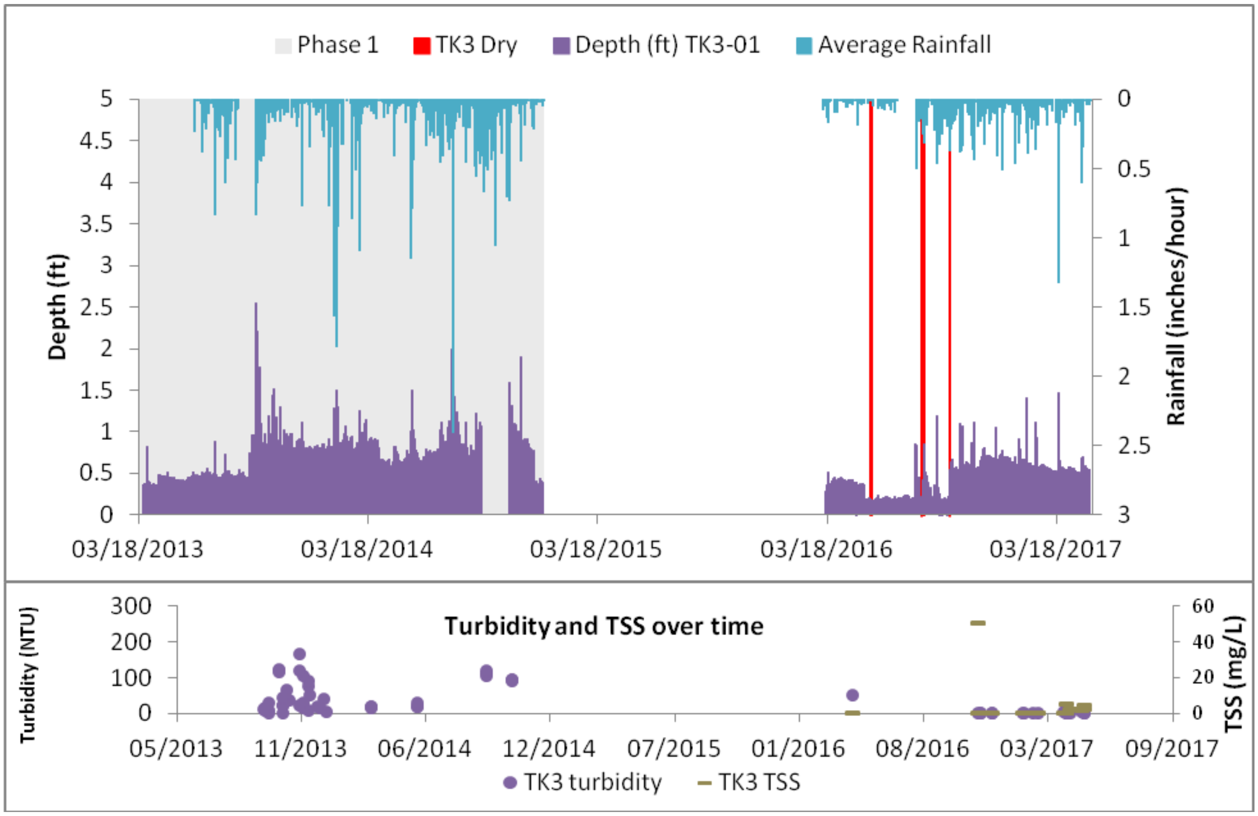
B) TK1-R1 Control (Phase I)



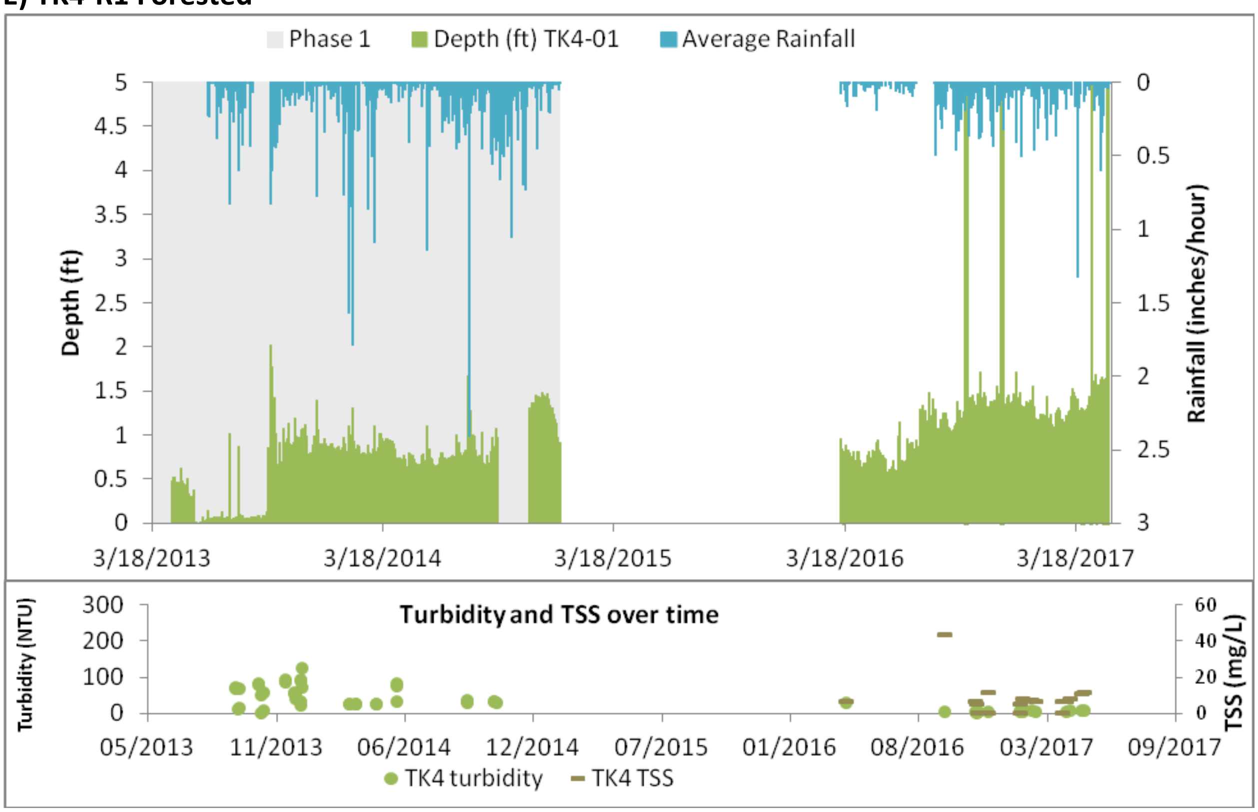
C) TK2-R1 Revegetation



D) TK3-R1 Revegetation



E) TK4-R1 Forested



Stream Levels

In general, the graphs above show stream levels that rise and fall with high intensity rain events and seasonal changes in precipitation. Short periods of rain, particularly during the dry season, do not appear to noticeably influence stream levels.

At several points throughout Phase II, the field team noted that some of the streams had no flow. Because the loggers measure relative depth rather than absolute depth, it is expected that during these time periods, the level reading may not be 0 feet. However, in a few streams (TK 1 and 3), the loggers continued to record slight fluctuations in the stream depth during these dry periods, indicating some level of error with the loggers. In addition, the relative depth during no-flow conditions should be the same between Phase I and Phase II if the loggers were consistent. While we do not have specific field notes identifying the no-flow periods from Phase I, it appears as though streams TK1 and TK2 had no flow during portions of the 2013 dry season. During that time, levels for TK2 track closely with Phase II date; however, TK1 levels are consistently lower compared to Phase II. This difference is most likely due to the new location for the TK1-R1 station in Phase II when the original station was completely missing after large amounts of debris and sediment built up in that area.

For the most part, stream levels also track similarly between Phase I and II, with Phase I levels somewhat higher due to the higher rainfall. However, TK4 Phase II data show higher levels than Phase I, particularly in the dry season, as well as higher spikes during large rain events. In fact, several of the peaks reach levels of up to 28 ft, which is outside the range of the logger (accurate for depths of 0-13 ft) and not realistic for the site. This logger was not moved or replaced during Phase II, so this change in stream level is either indicative of logger malfunction or a change in stream characteristics that were impacting the logger, or both. One possible explanation for the higher Phase II levels and perhaps the unrealistic spikes is that the culvert just downstream from TK4-R1 became clogged or damaged, backing up flow and perhaps debris, affecting the logger readings. TK4-R2 data (not shown here) do not have similar peak stream levels, which could indicate that the R2 station is far enough upstream such that the logger is not affected by the culvert. However, information on the condition and effects of the culvert is not known at this time.

Water Quality

The majority of the Phase I turbidity data points were collected around the end of the 2013 wet season (~Nov 2013). When evaluated in isolation, this dataset indicates a slightly inverse relationship between level of vegetation and stream turbidity levels, with the control (TK1) showing the highest peak turbidity (195 NTUs); the revegetated subwatersheds (TK2 & 3) showing slightly lower peaks (162 and 165 NTUs, respectively); and the forested subwatershed (TK4) with the lowest peak at 125 NTUs. The data collected later in Phase I (2014) do not show a significant relationship. In fact, TK3 has the highest turbidity peak in September 2014 of 112 NTUs.

The Phase II turbidity data are significantly lower than in Phase I. As tempting as it may be to claim the results support reductions in sediment loss over time, it is important to first consider the data limitations. The Phase II data points are fewer and more sporadic throughout the sampling period vs. clustered like the Phase I data. Most importantly, none of the Phase II data was event-based, meaning that the monitoring most likely missed the peak turbidity and TSS measurements and is more reflective of baseflow conditions. Equipment and sample analysis limitations described in Section 2.5 further reduce the reliability of these data. The highest peak TSS measurements were recorded for TK3 and 4 (50.5 and 43.5 mg/l, respectively), but corresponding turbidity measurements were quite low (<5 NTUs). No significant relationship exists between TSS and turbidity in this dataset. Turbidity and TSS is further discussed in Section 3.5 and in Section 4.

3.4 Flow Data

No flow data were collected during Phase II. However, stage-discharge relationships developed from Phase I data were used with stage data collected in Phase II to approximate flow. **Figure 24** shows the revised stage-discharge curves for Phase I data, which differ from the curves reported by Golabi and Manibusan (2014) as discussed in Section 2.4. The amount of flow data collected during Phase I and Phase II is inadequate to develop high-quality stream stage-discharge relationships. Therefore, results presented are preliminary, and should be seen as the initial step towards establishing such curves. Please note that no stream flow data was collected for stream TK0 during Phase II, and because it is a new station, there was no stage/discharge relationship established under Phase I. Without flow data, the water quality information collected here cannot be analyzed in the context of flow. **Figure 25** compares stream flow to hourly rainfall for each of four streams, showing both Phase I and Phase II calculated flows. Flow is represented on a base-10 log axis due to high data variability.

Figure 24. Revised stage discharge curves using Phase I flow data points.

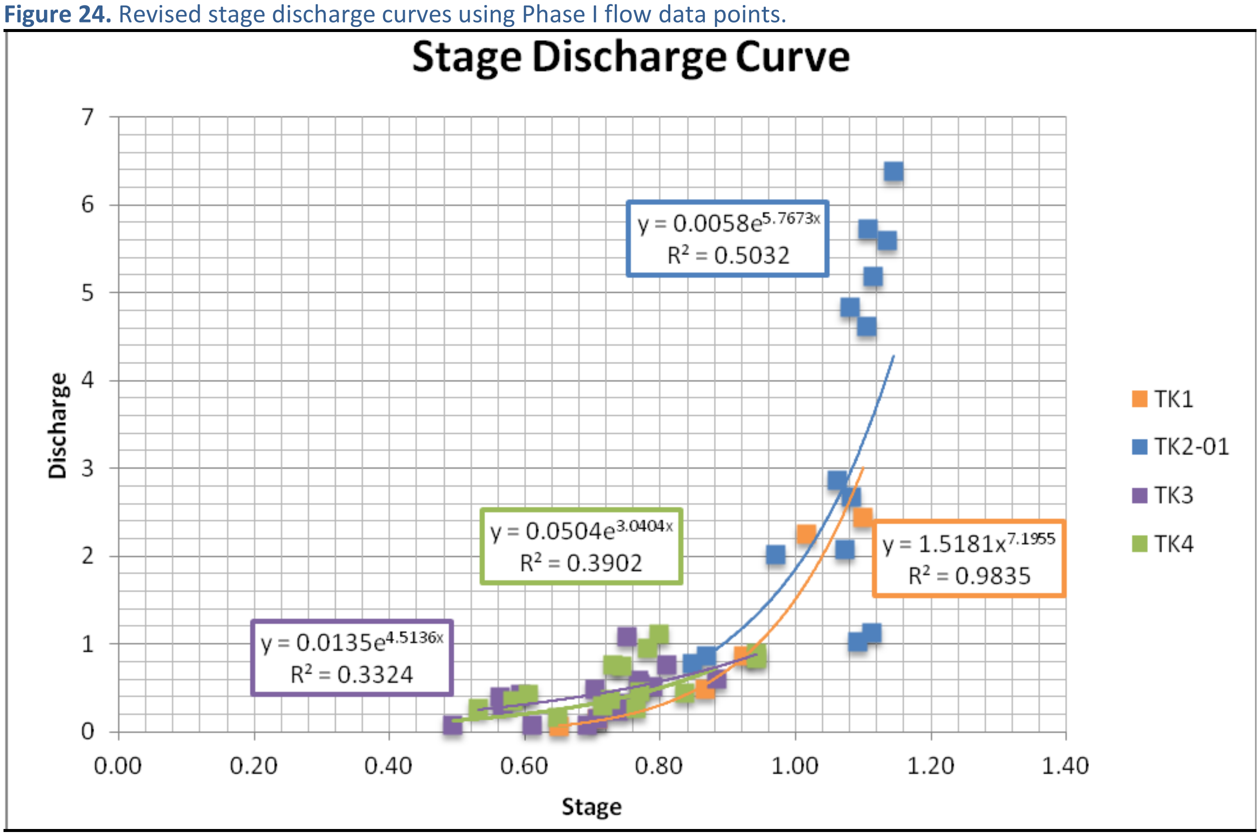
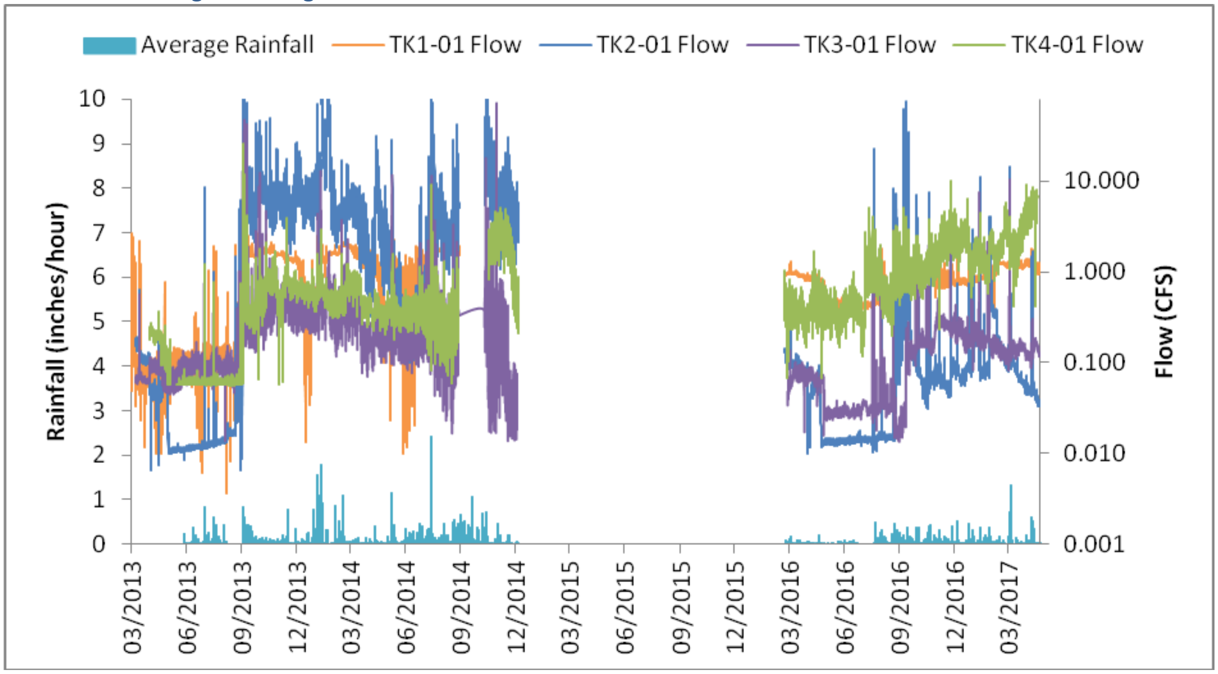


Figure 25. Calculated flow for streams TK1, TK2, TK3, and TK4 vs. rainfall for Phases I and II of the study based on each stream's stage-discharge curve.



As expected, TK1 is the most hydrologically dynamic with the most widely varying flows during and after rain events. In general, this graph follows the same trends as the stream level graph, which is expected since these data are calculated flows from the stage-discharge relationships rather than measured flows.

3.5 Additional Turbidity and TSS Data Relationships

Figure 26 compares turbidity values with recent rainfall, showing Phase II data with bold squares, and Phase I data with faded circles. Color is consistent for each stream (i.e., TK-1 is orange for both Phase I and Phase II data points). For this graph, rainfall data was averaged for all rain gauges in the 24 hours between noon of sample collection and noon of the previous day. The goal of this graph is to look for trends between recent rainfall and turbidity levels, with the expectation that higher recent rain would show the highest turbidity (i.e., and upward trend), particularly for the unvegetated subwatersheds. It is also expected that the unvegetated subwatersheds would show a higher turbidity level than the vegetated subwatersheds regardless of recent rain amounts.

However, the scatter plot below shows very few trends amongst the data, except that turbidity was consistently higher in Phase I than Phase II at all levels of recent rain amounts. Given some of the issues previously discussed, this data should not be interpreted as necessarily showing a significant reduction in turbidity over time (although it is a possibility). For Phase II data, the TK4 (forested) is showing the highest average turbidity readings across all rainfall amounts, followed by the unvegetated sites (TK0 and 1), with the TK3 and 4 (revegetated sites) showing the lowest average. It should be noted that Golabi and Manibusan (2014) found that the best relationship for Phase I data to show peak turbidity reaction to recent rainfall was between 6 and 12 hours; however, given that Phase II data were non-event based, we were not able to use the 6 and 12-hr rainfall period.

Figure 26. Comparison between turbidity values and recent rainfall (inches in the previous 24 hours).

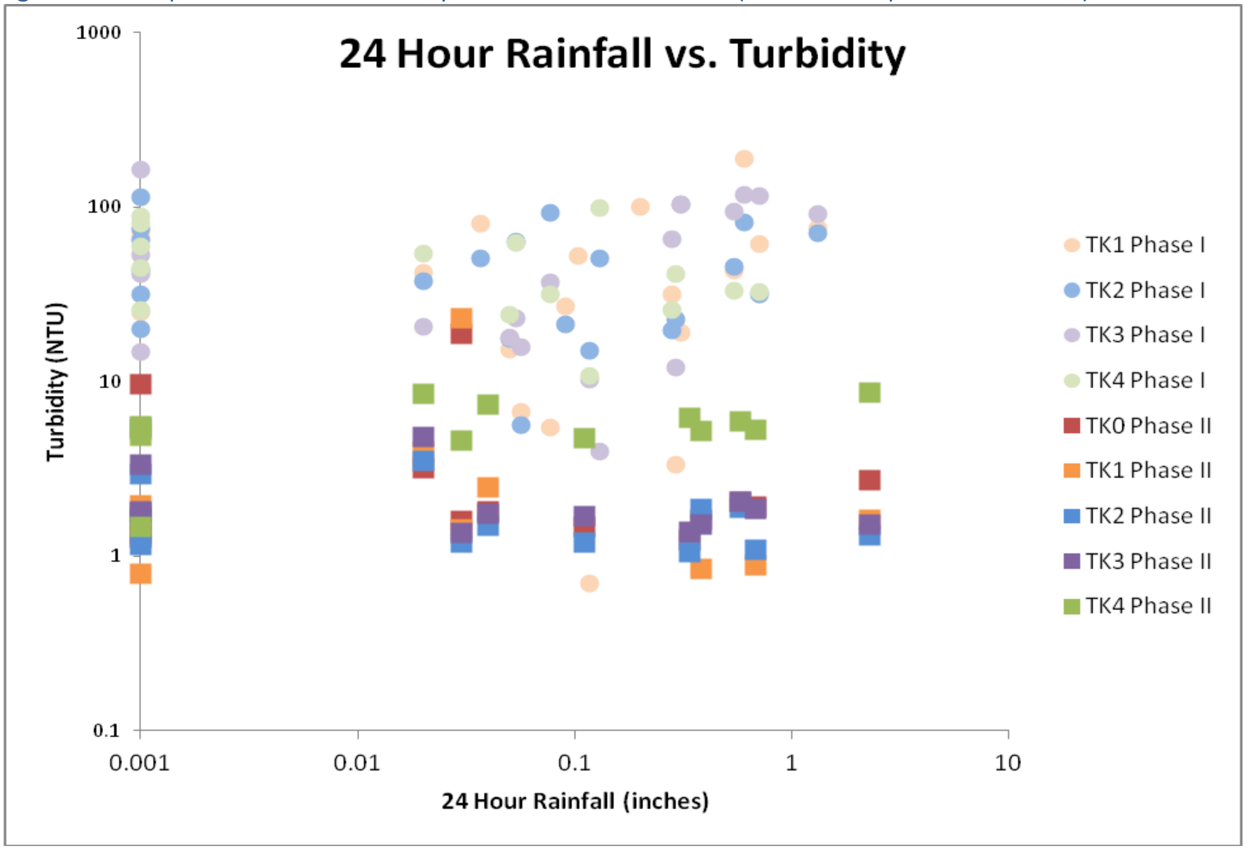


Figure 27 also uses recent rainfall to compare the Phase II TSS measurements taken at all of the streams. Similarly, it is expected that there would be a positive (upward) relationship between recent rain amounts and TSS, as well as overall higher TSS for the unvegetated subwatersheds. This comparison indicates that rainfall in the past 24 hours was not a reliable metric for predicting sediment in stream water based on our limited dataset.

Figure 28 looks at the relationship between calculated streamflow and turbidity levels at each stream. Comparison between turbidity levels and calculated flow indicates a positive correlation for TK2 and 3, with no correlation for TK1 and 4.

Figure 27. Comparison between total suspended solids and recent rainfall during Phase II.

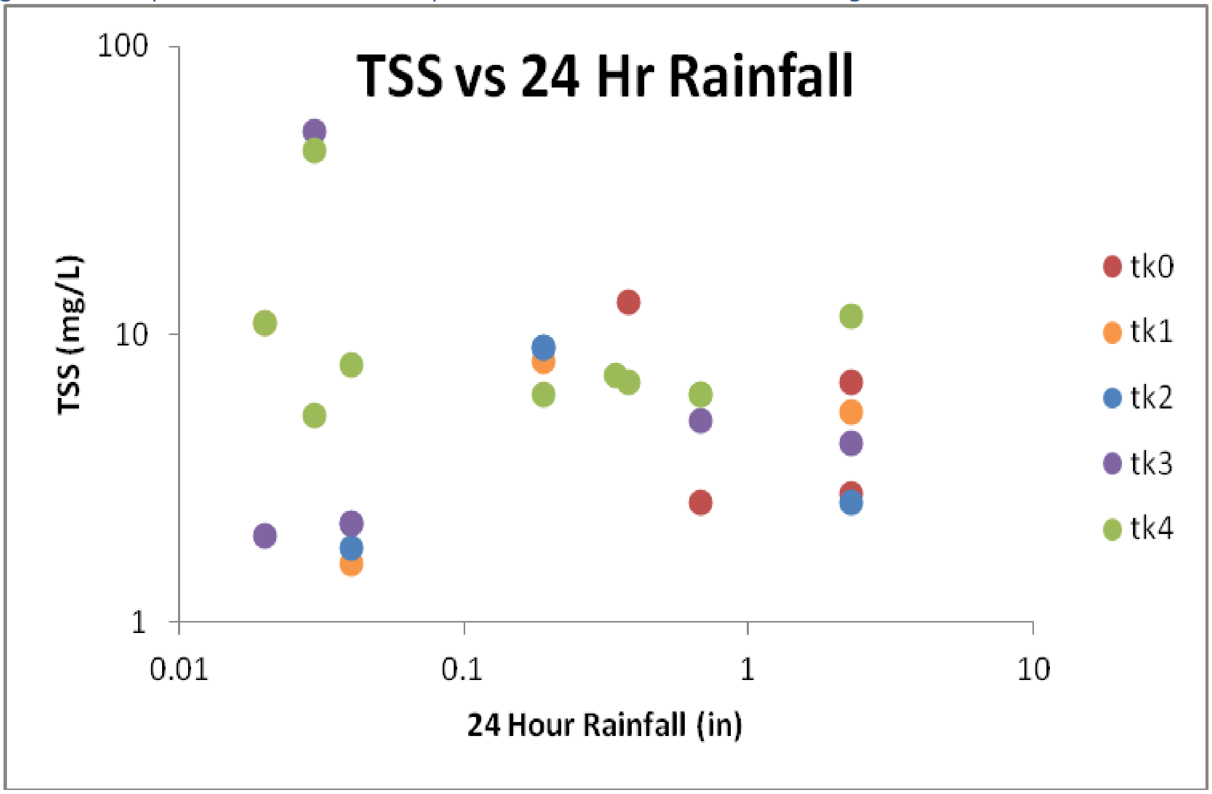
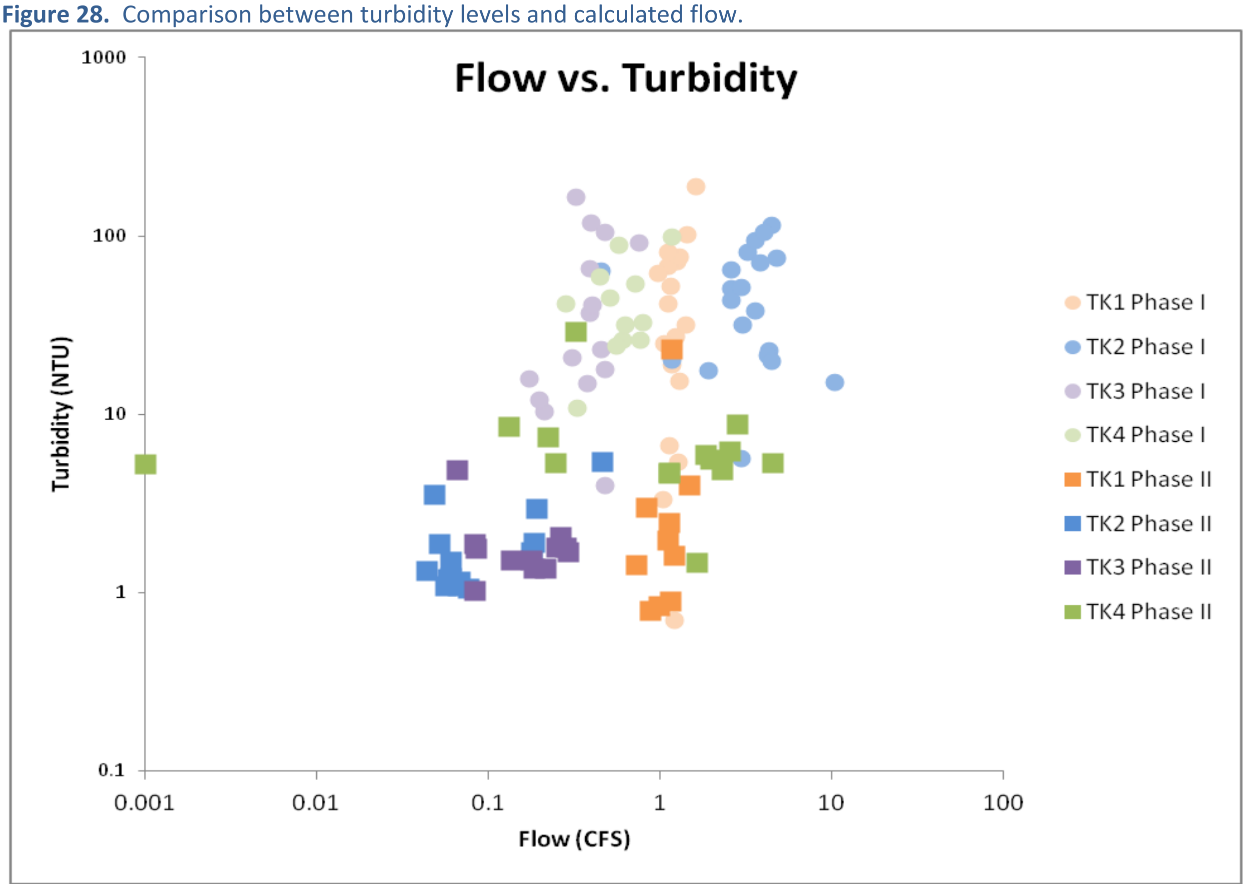


Figure 28. Comparison between turbidity levels and calculated flow.



4.0 Recommendations/Lessons Learned

The revegetation project in the badlands of Talakhaya is a truly herculean effort to stabilize well over 100 acres of extremely steep slopes and, ultimately, re-establish the native forest. The remote conditions and rocky terrain pose great challenges to mobilizing a workforce to spend long hours in extreme weather conditions on exposed slopes, not to mention the logistical issues with transporting people, plants, and equipment up what can only loosely be referred to as a road. The success to date of extensive, established planted areas are a true testament to this labor of love that DLNR Forestry has undertaken.

The stream monitoring effort to measure performance of restoration work is equally ambitious, and not surprisingly, has faced a diversity of logistical challenges. Quantifying soil loss via stream monitoring is difficult, and the production of meaningful results elusive even in smaller watersheds. While it is tempting to interpret the differences in turbidity measurements between Phase I and Phase II as evidence of reduced soil loss over time, there are too few data (and too many issues) to draw this conclusion with any certainty. At this time, we caution managers from pointing to Talakhaya as a definitive example of where monitoring efforts have measured direct improvements in downstream condition from watershed interventions.

However, the long-term Talakhaya restoration efforts are of a significant magnitude that we recommend continued monitoring, particularly since a monitoring framework is already established. A number of recommendations for improving the effectiveness of monitoring efforts include:

1. <u>Support a long-term monitoring program</u>: Given that the newly planted grasses and trees will take several years to effectively stabilize the badlands and hopefully help to transition those areas into early successional forest, stream monitoring data is expected to be valuable for years to come. However, to monitor it effectively, a consistent long-term program is required. To ensure a successful monitoring program in this location, we recommend the following:
    a. Plan for a 5-10 year long-term monitoring program.
    b. Refine/narrow the project goals and objectives to focus more on identifying changes in stream sediment load in each subwatershed over time as the restoration efforts progress rather than attempting to compare between dissimilar subwatersheds.
    c. Hire an on-the-ground manager with extensive field and analysis experience. This person should train field staff, schedule data collection, maintain and calibrate equipment, ensure consistent data collection and analysis protocols, perform data management and quality control, perform educational outreach about the project to locals, and coordinate closely with forestry management and BECQ coastal water quality efforts.
    d. Provide a dependable vehicle that can maneuver on Talakhaya's difficult terrain.
    e. Purchase all required equipment that will be used for this project alone.

f. Set up local lab extension with TSS analysis capabilities so that samples do not need to be sent off-island to avoid conflicts with holding times and to provide a hands-on consistency between data collection and data analysis. For the most part, utilizing BECQ's lab on Saipan during Phase II was not a limiting factor, but on-island lab capabilities would be particularly important during periods of extreme weather or compromised infrastructure (e.g., interrupted plane schedules).

2. Collect more data! A continuous theme throughout this report is that the limited number of data points makes it difficult to find significant trends and relationships. We recommend that any continued monitoring program focuses on collecting the following data:
   a. Flow and water quality data during rain events. Ideally, for large/long rain events, data would be collected at several times throughout the same event in an attempt to capture peak measurements.
   b. Establish stage-discharge relationship in TK-0.
   c. Data representing baseflow conditions during both wet and dry seasons.
   d. Multiple turbidity readings per sample (as in Phase I) given the high variability in readings.
3. Focus on flow: The stage-discharge relationship is very important for a monitoring program. To develop significant curves for predicting flow with stage data, many years of data should be collected throughout both wet and dry seasons (when flowing), and ideally, during rain events as safety permits. Any subwatershed land use activity that would affect flow should be identified and quantified if possible (e.g., man-made water diversion in TK2, downstream culvert in TK4, bridges, etc.) as those can greatly affect monitoring results.
4. Develop a relationship between turbidity and TSS: Turbidity, as an optical characteristic of water, is one of the more difficult parameters to measure consistently, as it is more qualitative than quantitative. The units have no inherent value and there is no standard conversion between turbidity and TSS. However, correlations can be made between turbidity and TSS using regression analysis, provided enough data is collected. Since turbidity is easier to collect, there is a benefit to developing this relationship to reduce collection efforts over a long period. However, care should be taken to consistently calibrate turbidimeters and provide multiple measurements for averaging at each time period since turbidity readings are very sensitive, particularly if there are large particles in the sample.
5. Quantify revegetation progress and annual land cover changes: Better estimates of bare and revegetated areas over time will help identify relationships with sediment monitoring. GIS information collected from drones will help with this process.
6. Collect additional subwatershed information: Determining other potential sources of sediment in each subwatershed will help to better understand trends and outliers. For example, while TK4 is considered forested, better understanding the levels of farming/ranching in this area will help to understand sediment levels. Other sources could be road and streambank erosion. Better mapping of the stream systems will also help to understand similarities/differences between stream morphology and conditions that may

affect sampling locations (e.g., backups caused by culverts, increased localized turbidity due to upstream waterfalls).

7. Connect the sampling dots: BECQ conducts regular water quality sampling in the nearshore coastal area. A long-term monitoring program should further investigate the connection between the stream and coastal sampling. For example, determine which streams most likely contribute to which coastal points. This is a more difficult task than it seems since the streams fan out toward the beach downstream from the road, and in some cases, drop off in steep cliffs at the coastline.
8. Consider other measures of performance. Other monitoring techniques that could support this effort may be helpful. For example, installing temporary sediment traps closer to revegetated and bare areas and measuring deposition rates could help quantify soil loss rates more directly. Particle size distribution analysis of TSS samples may be used in conjunction with results of UOG Phase I soils tests to determine source of sediment in streams (e.g., badland derived soils from stream bank erosion. Changes in the ratio of badland soils to other sources of sediment could be a measure of revegetation performance.
9. Model Changes in Subwatershed Sediment Loads. Use water quality data and direct measurements described in #8 to calibrate a sediment load model to show and predict trends over time as well as isolate impacts from restoration efforts vs. other changes in the watershed.

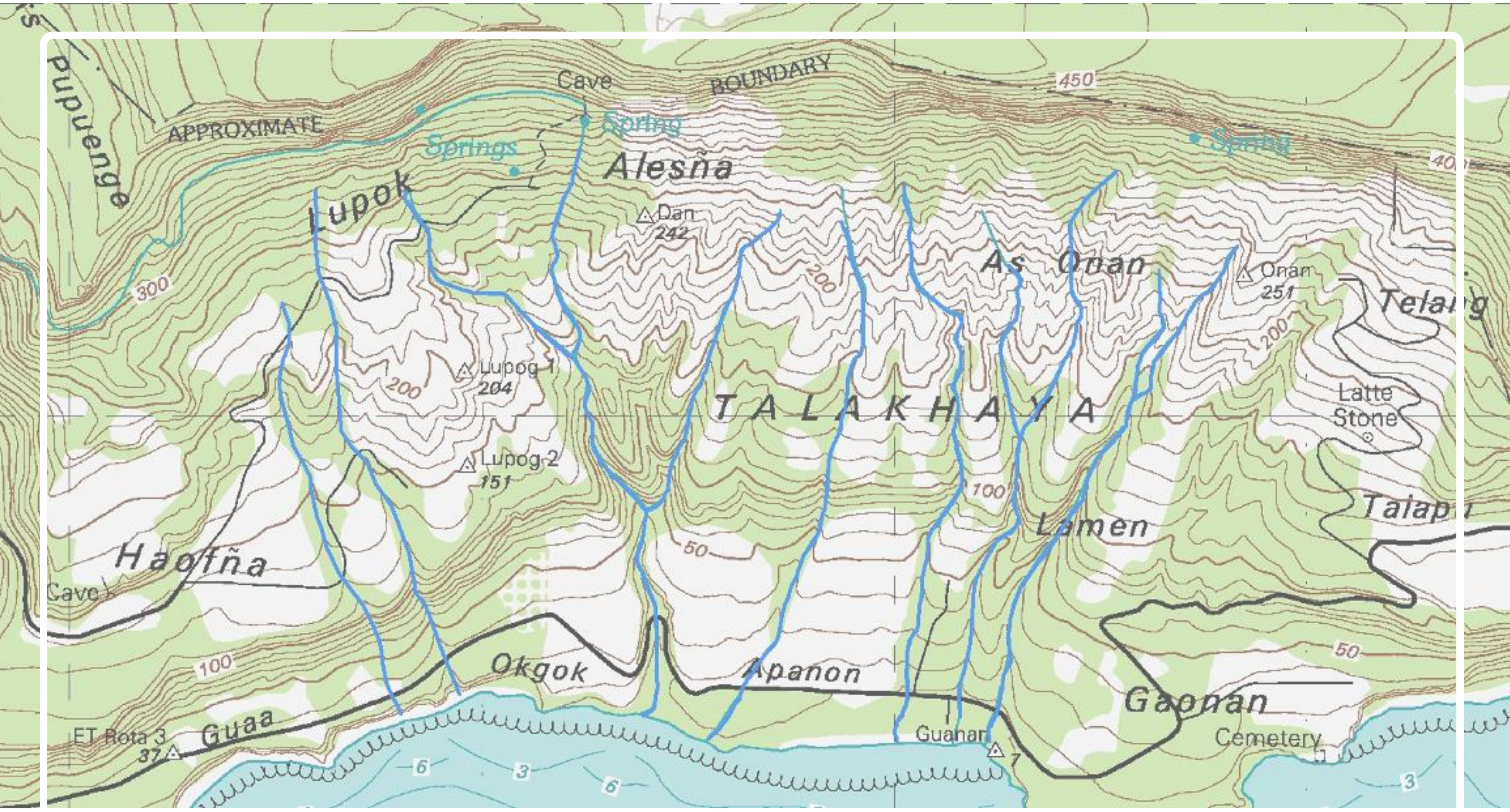
The watershed restoration activities in Talakhaya are truly impressive and are likely having a positive impact on the nearby flora and fauna, including the coral reefs. To confidently show this with monitoring data will take an equally monumental effort, but would certainly be celebrated throughout the coral community and provide a great example for others in challenging, remote locations to learn from.

5.0 References

Bickel, Aric. 2012. Talakhaya / Sabana Conservation Action Plan. Prepared for the Commonwealth of the Northern Marianas Islands (CNMI) Division of Environmental Quality (DEQ) Office of the Governor.

Mohammad H. Golabi, M. and S. Manibusan. 2014. Talakhaya Watershed Soil Loss Assessment Project Status Report as of November, 2014. 25 pp.

United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). 2008. Engineering Technical Note No. 3: Rainfall-Frequency and Design Rainfall Distribution for Selected Pacific Islands.



Pupuenge
APPROXIMATE
Cave
BOUNDARY
Springs
Spring
Spring
Alesña
Lupok
Dan
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300
Lupog 1
204
200
Lupog 2
151
TALAKHAYA
As Onan
Onan
251
Latte
Stone
Haofña
Cave
Okgok
Apanon
Lamen
Guaa
ET Rota 3
37
Guanan
Gaonan
Cemetery
100
50
450