ASSESSMENT OF TURBIDITY IN THE GEUS RIVER WATERSHED IN SOUTHERN GUAM

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Abstract

In February 2014, the National Oceanic and Atmospheric Administration (NOAA) announced the designation of Manell-Geus Watersheds as a Habitat Focus Area because it is valuable as a natural resource to the coastal community of Merizo. As a Habitat Focus Area more resources are dedicated to the development and implementation of watershed management plans and conservation actions. To implement effective watershed management practices, it is important to a) have a better understanding of the available information about the watershed, b) have baseline information of the hydrologic conditions (ie., stream flow, stream level, turbidity, and precipitation over time) and, c) understand the behavior of the watershed. This study was funded by NOAA through the University of Guam Water and Environmental Research Institute (WERI) via the Guam Bureau of Statistics and Plans, Guam Coastal Management Program. The study determines baseline hydrologic conditions of the Geus Watershed, through field observations and hydrologic data collected from December 2013 to January 2015. Results show a strong correlation between stream level, turbidity, and rainfall within the watershed, suggesting the watershed is highly dynamic. The response of stream level and turbidity to rainfall in the Geus River was observed on time scales of hours. Field data collected also produced a stage discharge curve which increases the efficiency of future watershed management by providing an estimate of stream flow from a simple measure of water level. Supplemental analyses based on the results of soil samples and a GIS-based erosion model identified areas within the watershed with higher contributions to erosion potential. A synthesis of the information in this watershed study allows for recommendations of effective watershed management strategies and opens the way for evaluating progress within the Geus Watershed with continued monitoring.

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Introduction

Soil erosion is one of the most critical environmental issues affecting island ecosystems today. Erosion is a process by which soil particles are detached, transported, and deposited elsewhere by erosive agents such as wind or water. Water induced erosion is a critical form of erosion pollution, because soil that is suspended and transported by water can settle downstream and accumulate over time (Golabi et al., 2005a). This process degrades the quality of the topsoil and the welfare of both freshwater and marine ecosystems. The severity of the problem may be overlooked because of the subtle and often imperceptible rate at which land erodes, and the fact that erosion rates differ by location (Khosrowpanah et al., 2007a). Runoff events on Guam commonly occur as high velocity episodes with relatively short duration (*i.e.*, flash floods) (Wolanski et al., 2003; Golabi et al., 2005b). Sedimentation due to upland erosion remains one of the most significant threats to Guam's coastal reef ecosystems (Burdick et al., 2008).

The mountains of southern Guam are highly susceptible to erosion from human activities and other forms of environmental degradation (Minton, 2006; Khosrowpanah et al., 2012). Human development and natural forces that result in a decrease in vegetative cover with a concurrent increase in exposed soil, forms areas known as *'badlands'* which continually erode along the sloping topography especially during heavy rain events (Scheman et al., 2002). Although badlands may occupy a relatively small area, it can be unproportionally responsible for the total soil loss due to its high erosion potential (Khosrowpanah et al., 2007a).

The Geus Watershed is one of the smaller watersheds in southern Guam. It has one major river, the Geus River, with several upland tributaries surrounded by high slopes. It is one of three watersheds located in the southern-most village of Merizo, and is situated between the high peaks of Mt. Shroeder, Mt. Finansanta, and Mt. Sasalaguan (Figure 1). It also is bordered by Cocos Lagoon along the coast, with the Geus River discharging directly into the interior portion of the lagoon.

In February 2014, the National Oceanic and Atmospheric Administration (NOAA) announced the designation of the Manell-Geus Watersheds as a Habitat Focus Area because it is valuable as a natural resource to the coastal community of Merizo. As a Habitat Focus Area more resources are dedicated to the development and implementation of watershed management plans and conservation actions. Under the Guam Coastal Nonpoint Control Program (GCNPCP), Section 6217 of the Coastal Zone Act Reauthorization Amendment (CZARA) of 1990 includes guidelines in agreement with the Habitat Focus Area requirements. To implement effective watershed management practices, it is important to; a) have a better understanding of the available information about the watershed, b) have baseline information of the hydrologic conditions (i.e., stream flow, stream level, turbidity, and precipitation over time) and, c) understand the behavior of the watershed.

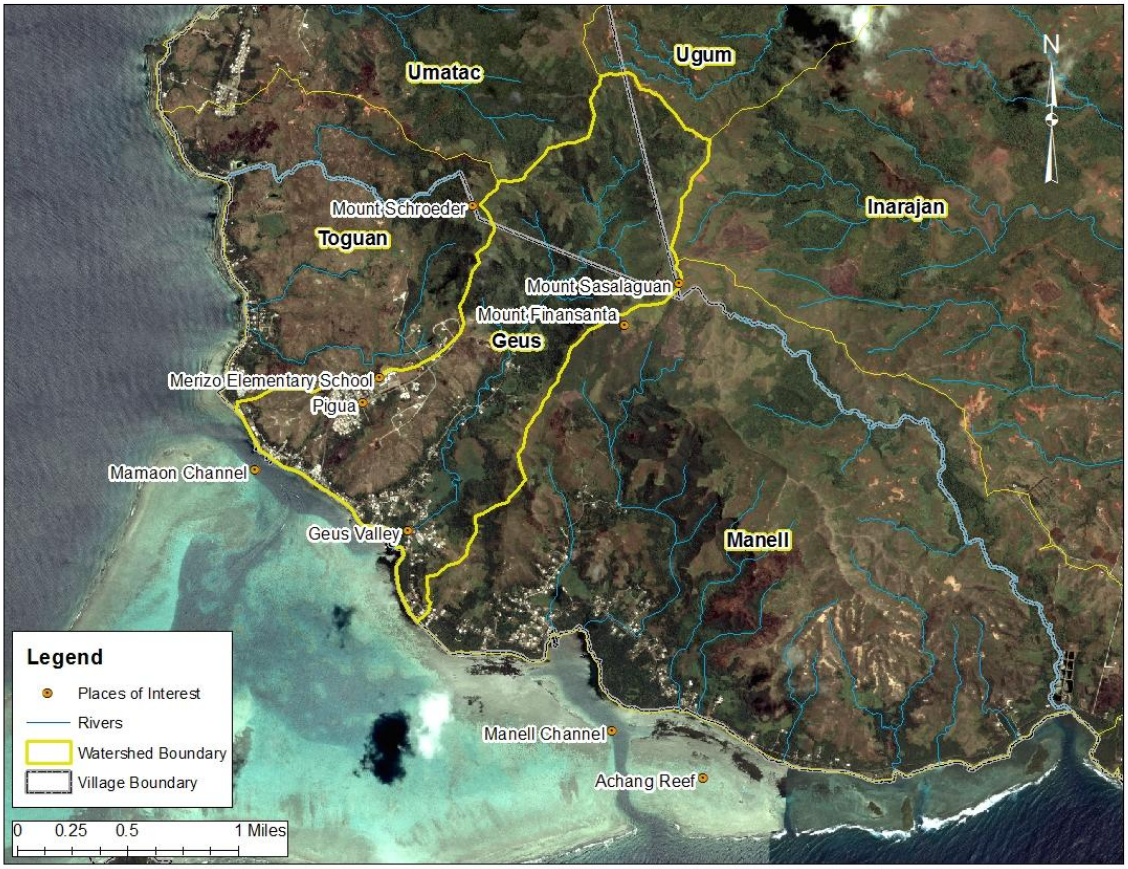


Figure 1. Geus Watershed location in the village of Merizo in southern Guam.

Study Area

1. Location

At the Southern tip of Guam, the Geus Watershed is bound at the coast by Cocos Lagoon. With an area of 1.7 square miles (mi^2) (4.5 square kilometers [km^2]), Geus is the second smallest of the major watersheds in southern Guam. However, it has the second highest mean slope (33 percent [%]) (FSRD, 2010). It has one major perennial river, the Geus River, which is about 2.71 mi (4.36 km) long with several upland tributaries. The Geus River discharges to the interior of Cocos Lagoon and the Mamaon Channel (Figure 2). Access into the Geus Valley is provided via Espinosa Street, which extends about one mile inland along the river and is sparsely developed for residential purposes. Of the surrounding ridges, only the western ridge contains significant developments including residential housing and the Pigua subdivision, Merizo Elementary School and Ball Park, and the Merizo Community Center and Mayor's Office.

In Merizo, traditional fishing practices remain an important part of the residents' livelihoods. Being at the interior of the Cocos Lagoon and adjacent to the Achang Reef Flat Marine Preserve, the coastal sea grass and coral reef communities are highly valuable to the local population but also highly susceptible to increased environmental stressors. Manell-Geus was singled out as a

Habitat Focus Area with the idea that NOAA's habitat conservation investments can be maximized at this coastal community with benefits for marine resources and local residents (NOAA, 2014).

Figure 2. Aerial photograph of the Geus Watershed discharge location along the coast (Khosrowpanah et al., 2007b).

2. Climate

The climate of Guam is characterized by a dry season (from January through June) which provides about 30% of the annual total rainfall, and a rainy season (from July through December) averaging 70% of the annual total (Lander and Guard, 2003). There can be significant year-to-year variations in rainfall totals and average intensity due to irregular occurrences of tropical cyclones/typhoons and patterns of El Niño. Between 1957 and 1992 one long-term weather station on Guam recorded a mean annual rainfall of 101.84 inches (in) (2,587 millimeters [mm]) with a standard deviation of 22.2 in (564 mm) (Lander and Guard, 2003).

Locally, rainfall distribution is influenced by topographical variances and the general orientation of the island except during the more extreme rain events (Lander and Guard, 2003). In general, rainfall patterns are oriented in a north-northeast to south-southwest manner. However, rainfall during typhoon conditions is distributed based on the structure and path of the storm. Average annual rainfall over the Geus Watershed ranges from 90 to 95 in (2,290 to 2,410 mm) along the coast to 105-110 in (2,670-2,790 mm) atop the inland mountains (Figure 3).

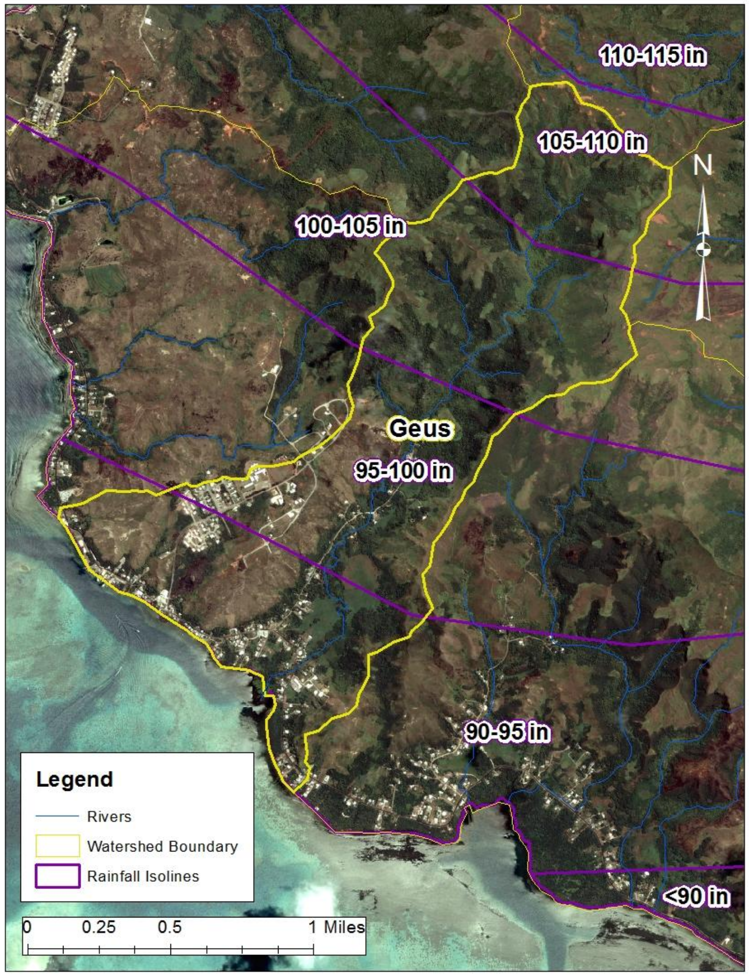


Figure 3. Average annual rainfall distribution over the Geus Watershed (Lander and Guard, 2003).

3. Geology

The Geus Watershed extends over two miles inland with increasingly steep topography and a maximum elevation of 833 feet (ft) (254 meters [m]) at the northeast corner of the watershed (Figure 4) (Khosrowpanah et al., 2007b). The geology consists of rock formations from the Facpi and Umatac episodes of Guam's volcanic history (Siegrist et al., 2008). These formations are relatively impermeable in comparison with the limestone material that constitutes much of Northern Guam. As a result, they do not support a viable groundwater aquifer; instead surface water features (springs and rivers) are more prominent.

The Facpi formation is Guam's oldest rock member. It forms a short stretch of Guam's surface extending from the southwestern part of the Geus Watershed and northwest along the coast to Facpi Point. The eastern ridge and interior highlands of the Geus Watershed is composed of Umatac formation rock of varying flow members; Geus flow member, Schroeder flow member, Bolanos pyroclastic member, and Umatac formation undifferentiated (Siegrist et al., 2008). Alluvial clay deposits occupy the surface between the Facpi and Umatac formations, along the coast and valley floor (Figure 5) (Siegrist et al., 2008).

Figure 4. USGS Topographic Map

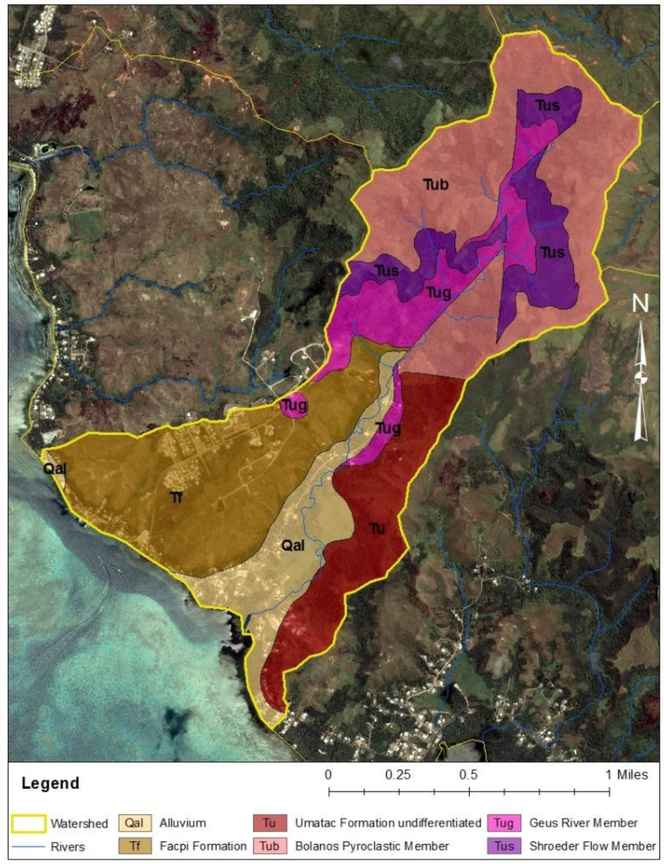


Figure 5. Geus Geology (Siegrist et al., 2008)

The Facpi formation consists of high-calcium boninite basalts which formed into pillow lavas as it was exuded below the sea surface more than 34 million years ago (Reagan and Miejer, 1984). Breccias, hyaloclastites, and sandstones of the same lithology may also be observed in Facpi formation. The Umatac formation has an estimated aggregate thickness of 2,200 ft (670 m) with minor interbedded limestone and calcareous shale (Tracy et al., 1964). The Bolanos pyroclastic member creates the high mountain peaks of the back valley from Mt. Schroeder to Mt. Sasalaguan and Mt. Finansanta (Siegrist et al., 2008). It consists of tuffaceous breccias with fragments of limestone, tuffaceous sandstone, and volcanic conglomerates extending from 750 to 1,000 ft (230 to 300 m) deep (Tracy et al., 1964). The Schroeder flow member is older than the Bolanos type and consists of pillow basalts with interbedded sandstones in the upper layer. Its estimated thickness is 100 to 400 ft (31 to 120 m) (Siegrist et al., 2008). The Geus flow member is the oldest of the Umatac formation members and includes interbedded limestones, sandy and tuffaceous limestones, sandstones, and volcanic conglomerates with an estimated thickness of 250 to 300 ft (76 to 91 m) (Siegrist et al., 2008).

4. Soils

Much of the Geus Watershed soils are derived from the weathered volcanic rock substrate. They consist of clays and silty clays with rock outcrops in the upper elevations. Soil types and topographic conditions are common for areas of southern Guam susceptible to badland development. Based on the information describing vegetation (below), badlands occupy about 1.7% (18.5 acres or 74,730 m^2) of the Geus Watershed (Khosrowpanah et al., 2007b).

About 45.95% of Geus badlands are located on Agfayan-Akina-Rock outcrop association, extremely steep soils. Akina-Agfayan association, steep contain about 37.2% of Geus badlands, and about 16.6% of the badlands are on Agfayan-Akina association, extremely steep (Young, 1988; Khosrowpanah et al., 2007b). Ylig clay comprises only a fraction of one percent (0.25%) of the Geus badlands (Young, 1988; Khosrowpanah et al., 2007b).

In general, the Agfayan-Akina-Rock outcrop and Agfayan-Akina associations dominate the interior of the valley and uplands with Akina-Urban land complex, Togcha-Ylig complex, and Akina-Badland complex covering a small developed area on the western (Pigua) ridge (Figure 6) (Young, 1988). Inarajan clay dominates the lower river valley adjacent to a small patch of Ylig clay (inland) and Inarajan sandy clay loam (along the coast) (Young, 1988).

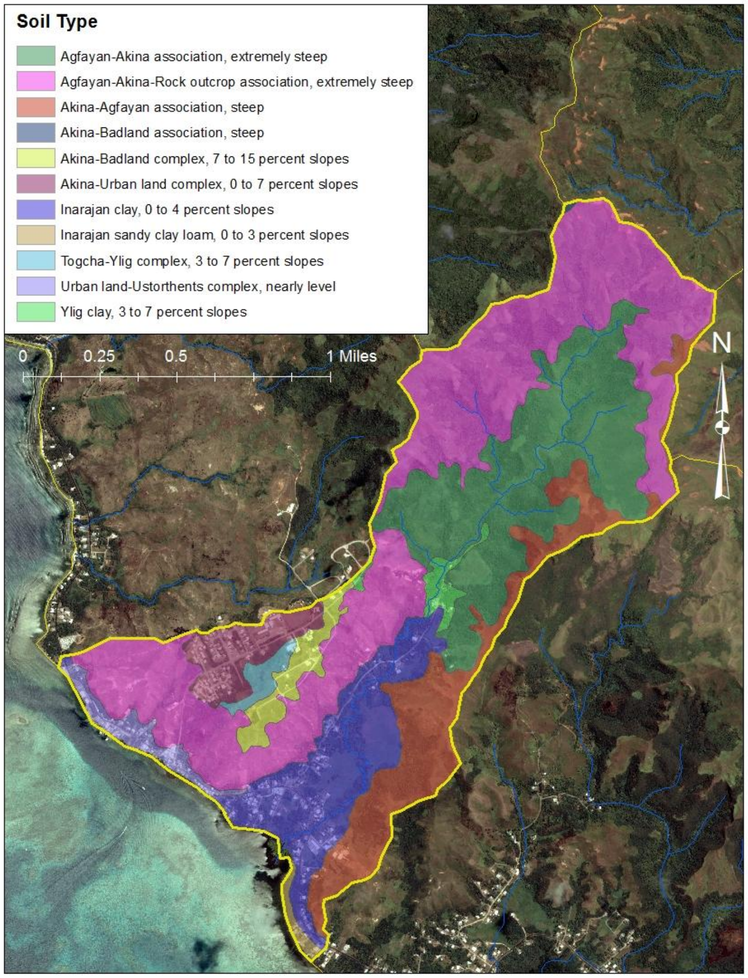


Figure 6. Soil types and location within the Geus Watershed (Young, 1988).

5. Vegetation

The most dominant vegetation types in the Geus Watershed are forests, savanna/grassland, and scrub/shrub forest (Table 1) (Khosrowpanah et al., 2007b). Ravine forests occupy most of the interior portion of the valley, grading into savanna along the tops of the ridges (Figure 7). Scrub forests become more abundant in the lower reaches and closer to the coast mixed in with patches of urban built-up, urban cultivated, and wetland areas. Some urban lands and badlands are also present in small patches along the ridges closer to the coast.

Table 1. Summary of Geus Vegetation Types (Khosrowpanah et al., 2007b)

Vegetation Description	% Area	Area (m^2)	Area (acres)
Bad Land	1.7	74,730	18.47
Forest	46.0	2,055,435	507.91
Savanna/Grassland	29.4	1,314,432	324.80
Scrub/Shrub Forest	9.1	408,160	100.86
Urban Built-up	8.7	387,864	95.84
Urban Cultivated	0.03	1,508	0.37
Wetland	5.1	225,887	55.82

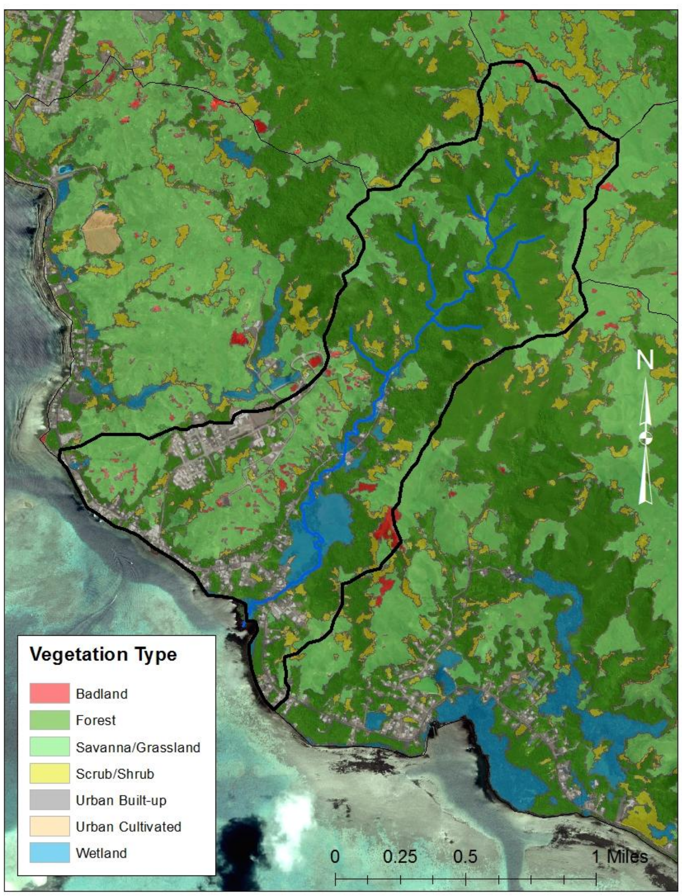


Figure 7. Vegetation types and distribution within the Geus Watershed.

6. Land Use

The Geus Watershed is primarily uninhabited except at its lower reaches where there are some residential developments and farmlands. Based on the 2011 remote sensing land cover data from the NOAA Ocean Service, Coastal Services Center (Khosrowpanah et al., 2007b), only about 10% of the watershed is occupied by developed and impervious surfaces. Less than 1% of the watershed is cultivated and 1.7% is occupied by badland.

The upper reaches of the Geus River and its upland tributaries are largely forested, grading to grasslands and some badlands on the surrounding high slopes (Figure 8). There is very little off-roading in this watershed, with some four-wheel traffic (mainly hunters) along the ridges on the north and east sides of the watershed boundary. The uplands contain many early Chamorro artifacts. There are likely a very large number of ungulates (wild pigs and deer) inhabiting the area. Wildfires are common in the dry season, and occur primarily in the grassy areas located on the steep slopes and highest terrain of the surrounding mountains.

Figure 8. Aerial photograph in the Geus Watershed in southern Guam (June 17, 2014).

Project Goals and Objective

This study has the following goals:

- Examine the dynamic behavior of the Geus Watershed by determining how different levels of rainfall trigger responses in stream level, stream flow, and turbidity.
- Determine baseline hydrologic conditions by examining stream flow, stream level, turbidity, and precipitation during dry and rainy season conditions. This will be important

in assessing how future restoration or other developments affect the environmental condition of the watershed.

- Establish a stage discharge curve that will increase the efficiency of future watershed management strategies, providing stream flow from a simple water level measurement.
- Identify areas that have a high potential for contributing the most soil erosion within the watershed using GIS-modeling techniques based on the Revised Universal Soil Loss Equation (RUSLE).

The goals of this project were accomplished in three phases. First, a watershed assessment was completed using all available physical and environmental information. Second, hydrologic data and soil samples were collected in the field to quantify and correlate baseline environmental conditions. Finally, all the data collected was analyzed and compared with data from similar studies that have occurred at other watersheds in southern Guam. The goal includes recommendations for watershed management strategies to help address issues with sedimentation on land and in near-shore communities.

Review of Literature

1. Erosion and Sedimentation on Guam

The problems associated with erosion and sedimentation on Guam are almost exclusive to the southern volcanic region. Erosion runoff may contribute to non-point sources of pollution such as nutrients, pesticides, or sediment deposits. This affects the water quality of freshwater resources and ecosystems (Khosrowpanah and Jocson, 2005) as well as near-shore marine habitats (Wolanski et al., 2003; Burdick et al., 2008) which provide important natural and economic benefits to Guam. Unlike the karst northern limestone plateau, southern Guam consists primarily of highly weathered soils formed from impermeable volcanic rock which are easily erodible along the steep mountainous terrain.

In a report summarizing *The State of Coral Reef Ecosystems of Guam* (Burdick et al., 2008), it was suggested that upland erosion in southern Guam remains one of the most significant threats to coral reefs ecosystems of the island. In fact, based on a consensus by local coral reef experts of the list of top five Coral Reef Management Priorities, NOAA’s top ranked priority is to “improve the condition of coral reefs ecosystems by reducing the amount of sediment and pollution from development, fires, recreational users and agriculture in Guam’s watersheds” (NOAA, 2010).

There are several types of water-induced erosion with varying degrees of severity (Dumaliang and Khosrowpanah, 1998; Khosrowpanah and Jocson, 2005). Upland erosion is typically in the form of sheet erosion caused by raindrop impact, or rill erosion caused by concentrated surface runoff with no development of a water channel. Surface runoff combines creating concentrated flow erosion, which may form eroded channels contributing to gully formation. The most extreme flow conditions cause stream channel erosion, including river bank erosion, and mass wasting or landslides. The severity of erosion within a watershed is influenced by the rate of rainfall (duration and intensity), soil conditions, topography, geology, vegetation cover, and land use activities. Turbidity, or the concentration of suspended particulate matter in runoff water, is commonly measured as an indicator of erosion levels (Neubauer, 1981).

The effects of land-clearing in southern Guam's watersheds were examined early on by Neubauer (1981). After hand-clearing of ravine forests in southern Guam, the experimental plots became repopulated by savanna vegetation. This suggested savanna vegetation is an earlier stage of succession and ravine forest is the climax vegetation type for this environment (Neubauer, 1981). Results of turbidity measurements showed that hand-clearing of vegetation did not significantly contribute to erosion (Neubauer, 1981). However, since the vegetation regime that grew back was more susceptible to fire, turbidity and erosion were likely to increase if the vegetation subsequently burns (Neubauer, 1981).

Erosion on Guam is heavily influenced by climatic patterns that create significant rainfall variability (Dumaliang and Khosrowpanah, 1998), including El Niño Southern Oscillation (ENSO) cycles (Lander, 1994). During rainy season, rainfall totals may differ from 0.1 inches per day from tradewind showers, to up to 30 inches per day from tropical cyclones. The more intense rain storms create flash-flood conditions causing high flow velocities and increasing the transport potential for more (and larger) sediment over greater distances. Therefore, the erosivity, or ability to erode, may also differ dramatically by storm event (Dumaliang and Khosrowpanah, 1998). This trend was also exhibited in the Ugum watershed where the majority of sediment transported occurred during a relatively short period of the year (i.e., during the heaviest storm conditions) (Khosrowpanah et al., 2007a; FSRD, 2010).

Erosivity is also dependent on ground cover, soil conditions, and topography. Barren undeveloped areas, known as badlands, have been proven to have the highest erosion rates when compared with other land cover types (Lewis, 1999; Scheman et al., 2002; Minton, 2006). Badlands are actively eroding areas of very deep, well-drained saprolite derived from tuff and tuff breccia mostly consisting of heavily eroded Akina or Atate soils (Young, 1988). In general, areas with greater vegetation cover experience less sheet and rill erosion due to reduced raindrop impact and increased resistance to the flow of surface runoff (Golabi et al., 2005a). However at the La Sa Fua Watershed, Scheman et al. (2002) also observed increased erosion among grasslands during heavy rain events. Observations at La Sa Fua suggested that physical conditions of that watershed promoted gully and stream channel erosion, and slope was a major driving factor for increased erosion during rain events (Scheman et al., 2002). Finally, likely due to a lag time between rainfall and stream flow, suspended sediment levels more closely correlated with surface water discharge rather than rainfall accumulation (Scheman et al., 2002).

The La Sa Fua Watershed discharges into the ocean via the La Sa Fua River at Fouha Bay in the southern village of Umatac. Around the same time Scheman et al. (2002) studied sources of upland erosion at the La Sa Fua Watershed, Wolanski et al. (2003) examined the dynamics of the sediment plumes deposited into Fouha Bay from the La Sa Fua River. The results of this study suggested that the main threat to corals in Fouha Bay is the deposition of sediment during normal calm conditions, rather than the freshwater effects on salinity (Wolanski et al., 2003). However, during storm swell conditions sediment seemed to get effectively flushed out providing opportunities for coral regeneration. The implications of this study suggested that successful management of the fringing reefs, adjacent to stream discharge points, can be achieved if land use management improvements are implemented to decrease the total sediment load from upland erosion (Wolanski et al., 2003). If the severity of sedimentation is minimized, seasonal ocean storm surges may wash out accumulated sediment before it reaches levels harmful to corals. Wolanski et al. (2003) also observed discharge plumes as short-lived flash-floods, with large sediment loads that settled quickly during normal conditions.

Several studies examined the problem of erosion and how it is exacerbated by human activities, such as increased development (Manibusan, 2012), off-road trailing (Khosrowpanah and Jocson, 2005; Kottermair, 2010), and wildfires (Minton, 2006) most of which are intentionally set (Neill and Rea, 2004), at different watersheds in southern Guam. Khosrowpanah and Jocson (2005) assessed non-point sources of pollution in the Ugum Watershed. The findings of this environmental assessment identified impacts of erosion from upland locations, bank erosion, and land sliding (Khosrowpanah and Jocson, 2005). Following the completion of the environmental assessment, Park (2007) developed a GIS-based erosion model to assess soil erosion in the Ugum Watershed based on the RUSLE equation.

Expanding on the use of GIS-based analysis of watersheds, Wen et al. (2009a and 2009b) assessed land cover change in 14 watersheds of southern Guam. The analysis was based on a comparison between satellite images from 1973 and 2001. Land cover was characterized by five different classes; forest, grassland, barren land, urban area, and water. The results for all 14 watersheds combined showed that forest coverage increased from 43.56% to 46.46%, while grassland coverage decreased from 48.10% to 31.04%. This meant the total vegetation coverage decreased from 91.66% in 1973, to 77.50% in 2001 (Wen et al., 2011). The urban area coverage increased from 3.43% to 16.66%, while barren land coverage decreased from 4.48% to 3.56%. This was a bad indicator for urban runoff but good in terms of erosion control. In general, watershed land cover change in southern Guam was greatly affected by anthropogenic activities. However, natural forces also showed some effect on change over time (Wen et al., 2011).

Since barren land/badlands are considered the most detrimental land cover class in terms of erosion, Kottermair, M. (2010) conducted important research using GIS modeling to investigate the dynamics of badlands over time. Based on a 50-year period of study, badland dynamics (development and re-vegetation) were determined to be complex attributable to various human and natural factors (Kottermair, 2010). Human-induced activities including burning and off-road trailing were considered two of the largest contributors to badland development, especially along steep windward facing slopes and at higher elevations (Kottermair, 2010).

Once a disturbance exposes an area there is a greater potential for erosion of the nutrient-rich top soil. If the erosion occurs faster than the vegetation can repopulate the affected area, then a pattern develops contributing to continued erosion and a decrease in soil productivity (Golabi et al., 2005a). This is especially problematic in the tropics where nutrients are more effectively stored and recycled in organic matter, rather than in soils which would otherwise get quickly leached out during heavy rain events. Chemical and physical soil attributes resulting in badlands include high clay content, low pH, low nutrient levels, and low to no organic matter (Kottermair, 2010). Work by Golabi et al. (2005a) suggests these adverse conditions can be reversed by controlling the erosion and re-vegetating the area.

Most recently, a significant amount of research was conducted to assess sources of erosion in an area threatened by major future developments, the Piti-Asan Watershed (Minton, 2006; Kottermair, 2012; Manibusan, 2012). Minton (2006) conducted a thorough assessment of fire, erosion, and sedimentation in the Piti-Asan Watershed and the War in the Pacific National Historical Park, Guam. The results found erosion rates to be highest in badlands and recently burned savanna. The Piti-Asan Watershed Management Plan was completed by Kottermair (2012), detailing the major threats to the overall health of the watershed. These threats included erosion and sedimentation, development, wildland fires, invasive species, and pollutants. Specific goals were considered for improving the overall water quality, habitats, and public support in light of proposed developments. Around the same time, Manibusan (2012) collected empirical data of hydrological and soil conditions within the Piti-Asan Watershed, and applied the RUSLE GIS-based erosion model developed by Park (2007). The model was modified to estimate changes in future erosion potential based on the proposed development scenarios.

2. Geus Watershed Research

The Geus River Watershed is of particular importance because of its ecological value, and its direct effect on coastal resources that are culturally significant to the traditional fishing community of Merizo (NOAA, 2014). However, there is very little literature available concerning the Geus Watershed.

Kami et al. (1974) was one of the first to document natural aspects of the Geus River Watershed, by studying the physical environmental setting and biological resources. Based on observations of several distinct biotopes within the Geus Valley, this study found that the once heavily disturbed ravine forests were naturally making a comeback. However, the upland savanna was still heavily disturbed and threatened by frequent fires, as well as the flat valley with increasing pressures from cultivation and urbanization. Other than general maintenance of the natural state of the Geus River Valley, Kami et al. (1974) recommended fire control measures and reforestation of the upland savanna as restoration priorities.

The more recent studies that examined aspects of the Geus watershed are based on computer modeling and GIS-derived analyses. Neill and Rea (2004) assessed the risk and hazard of wildfires on Guam based on the distribution of vegetation, general topography, resources at risk, and history and behavior of wildfires. The GIS-derived analysis determined there is a high fire hazard around the watershed ridges closer to the coast due to high frequency and accessibility. There is a small section in the back valley where the fire hazard is considered very high because of its isolation and greater ability for fire to spread.

Wen et al. (2009a) assessed land cover change in the Geus watershed. The most significant land cover changes were in urban areas and barren land coverage. Urban areas covered 0.14% of the Geus Watershed in 1973 and increased to 21.95% in 2001. Barren land covered 4.91% of the watershed in 1973, but decreased to 0.58% in 2001. Forests covered 45.2% of the Geus watershed, and increased slightly to 45.56% in 2001. Finally, grasslands decreased from 49.75% to 20.95% in 2001. The majority of grassland cover was converted to urban areas or forests. To a lesser degree, some forests were also converted to urban areas and grasslands. Almost half of the barren lands were converted into grasslands and urban areas and forests also took over some of the badlands (Wen, 2009a).

The Guam Statewide Forest Resource Assessment and Resources Strategy, completed by the Department of Agriculture, Forestry & Soil Resources Division (FSRD, 2010), included an analysis of estimated average annual sediment transported by watershed. The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) GIS model was applied to 18 southern Guam watersheds including Geus. The N-SPECT model computes a grid-based analysis in GIS using principles of the RUSLE, similar to the model developed by Park (2007). The result is an estimate of average annual sediment erosion and delivery to streams from surface and rill erosion, but not mass wasting, gully, or stream bank erosion. The estimated delivered sediment yield for the Geus watershed was 7.9 tons/acre/year (FSRD, 2010).

3. GIS-based Erosion Model and the Revised Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) was developed by Wischmeier and Smith (1965) to predict average annual soil loss based on several factors that are statistically determined and calculated from small (standard USLE) field plot experiments. The procedures for determining the different factors have been improved in the development of the RUSLE by Renard et al. (1997). The result of the RUSLE is a product of factors representing rainfall erosivity, soil erodibility, slope length, slope steepness, cover crop management, and management practices (Renard et al., 1997).

The factors for rainfall and runoff (R) and soil erodibility (K) represent the cause and effect of soil erosion, and provide the units for average annual soil loss (A) (Park, 2007). The R factor is a function of local rainfall patterns (Dumaliang and Khosrowpanah, 1998). It represents rainfall's erosive power on soil regardless of soil type. Consideration for soil type is in the K factor, which represents the level of resistance different soil types have against the erosive power of rainfall. The factors for slope-length and slope gradient (LS), cover management (C), and erosion control practices (P) are dimensionless ratios that represent real world conditions, and allow for site-specific adjustments from the standard field plot conditions (Khosrowpanah et al., 2007a).

The application of the RUSLE on Guam was assisted by the work of Dumaliang and Khosrowpanah (1998). This study developed an isoerodent map and erosivity factor (R) derived from continuous rainfall data collected from an experimental site, as well as historical rainfall data for Guam (Dumaliang, 1998). K factors for each of Guam's major soil types had been determined by the Natural Resource Conservation Service (NRCS) and listed in the soil survey of Guam (Young, 1988).

Scheman et al. (2002) compared predicted erosion rates using the RUSLE with measured erosion rates from badlands in the La Sa Fua Watershed. This study found that the RUSLE soil loss estimates were more accurate when the LS-factors were empirically derived or field tested, rather than using NRCS variables. Additionally, Scheman et al. (2002) suggested that the RUSLE is not an effective tool for predicting soil loss within Guam's watersheds because it consistently overestimated erosion rates. Although it was not a specific objective of Lewis (1999), the same pattern was observed based on measured badland retreat rates in the Taelayag Watershed.

The use of the RUSLE on Guam was revisited by Park (2007) by incorporating the technological benefits of GIS. GIS software provides the ability to analyze complex spatial data by organizing different attribute information in a grid/raster format of small cells that can then be mathematically operated on for several attributes over a large area (Khosrowpanah et al., 2007a). This study attempted to improve on the deficiencies identified by Scheman et al. (2002), by computing the LS-factors using a downloadable program which derives LS from a digital elevation model (DEM) (Van Remortel et al., 2004). Although improvements on RUSLE accuracy of estimated annual soil loss values have not been thoroughly assessed, Park (2007) and Khosrowpanah et al. (2007a) suggested their model estimates the maximum possible soil erosion rate. Nevertheless, this methodology may be used as an effective management tool that identifies areas within a watershed with the highest relative soil erosion potential.

The GIS-erosion model was applied to the Piti-Asan Watershed by Manibusan (2012). Manibusan (2012) used the same methods at Park (2007) to determine areas within the Piti-Asan Watershed that contribute the most to soil erosion (Khosrowpanah et al., 2012). In addition, changes in erosion potential based on planned future developments were analyzed. Results of the GIS-based erosion model estimated 8.05 tons/acres/year of average annual soil loss from the Asan Watershed, and 5.15 tons/acre/year from the Piti Watershed (Khosrowpanah et al., 2012). This means the average estimated soil loss for both watersheds combined was 6.6 tons/acre/year. Actual data collected of sediment accumulation in the reef off Piti-Asan, estimated the terrestrial sources of erosion contributed about 6.7 tons/acre/year of sediment at both watersheds combined (Minton, 2006). Additionally, a similar analysis of sediment loss using the N-SPECT model, which also applies principles of the RUSLE, estimated 6.8 tons/acre/year of sediment is yielded from Piti-Asan (FSRD, 2010). Therefore, a comparison between two separate GIS-based RUSLE models, and empirical data collected for the Piti-Asan Watershed as whole, appear reasonably consistent.

4. Turbidity Information for other Guam Watersheds

A majority of previous studies concerning aspects of erosion in southern Guam watersheds quantified soil loss rates on relatively large scales, such as ton/hectare/week (Dumaliang and Khosrowpanah, 1998) or ton/acre/year (Lewis, 1999; Scheman et al., 2002; Golabi et al., 2005a). This is useful for understanding long-term soil loss and for assessing the accuracy of erosion model estimates based on the RUSLE (Scheman et al., 2002; Minton, 2006; Park, 2007; FSRD, 2010; Manibusan, 2012). However, it masks the impacts of sediment plume dynamics and patterns of high volume sediment loading characteristic of flash-flood conditions common on Guam.

An empirical understanding of high volume sediment loading over shorter, heavy rainfall events is better assessed by analyzing suspended solid concentrations over shorter durations. As a result, previous studies that correlated levels of turbidity, rainfall, and other hydrological factors in different watersheds of southern Guam were reviewed for this study (Khosrowpanah et al., 2007a; Manibusan, 2012).

Khosrowpanah et al. (2007a) reported daily average turbidity measurements correlated with stream flow and rainfall in the Ugum Watershed from January 2004 through November 2006. The results of the hydrologic analysis for this study found that the Ugum Watersheds responds rapidly to rainfall then recedes at a more constant rate. During the heavier rain storms recorded (3-4 inches per day or more), daily average turbidity spiked to 200-300 nephelometric turbidity units (NTUs), and streamflow increased to greater than 150 cubic feet per second (cfs) (Khosrowpanah et al., 2007a).

Manibusan (2012) collected hydrologic field data in the Masso and Asan Rivers from July 2011 through June 2012. The data was correlated with continual stream level and rainfall measurements, as well as weekly stream flow readings. In the Piti Watershed, the Masso River level peaked within 45 minutes of major rain events. Whereas, the Asan River stream level peaked within 30 minutes of heavy rains, based on data collected at 15-minute intervals. This suggested that the dynamic response to rainfall is greater in the Asan Watershed than in the Piti Watershed (Manibusan, 2012). Turbidity readings were collected bi-weekly therefore assessing the dynamics of suspended solid plumes was more limited. The highest turbidity readings in the Masso River was 76.3 NTU, measured on October 24, 2011 with a corresponding 24-hour rainfall of 0.48 inches and stream level increase of about 3 feet. The maximum turbidity recorded in the Asan River was 101 NTU on October 5, 2011 with a corresponding 24-hour rainfall of 0.74 inches and an increase in stream level of about 2 feet (Manibusan, 2012). Turbidity in the Piti-Asan Watershed was rarely ever measured above 50 NTU, and tended to be slightly higher in the Asan Watershed. Elevated turbidity from normal rainy season conditions in the Piti and Asan Watersheds in 2011 ranged from about 20-40 NTU (Manibusan, 2012).

5. Watershed Management Strategies

The importance of watershed management strategies on Guam has been increasing since the threats of anthropogenic activities continues to grow. Section 6217 of the Coastal Zone Act Reauthorization Amendment (CZARA) of 1990 of the Guam Coastal Nonpoint Pollution Control Program (GCNPCP), requires the development of a multi-year watershed restoration strategy to include a watershed assessment and identification of opportunities to reduce non-point source pollution. In addition, a Unified Watershed Assessment was created under the Clean Water Action Plan for Guam (GovGuam, 1998), in response to a federal initiative protect and restore our waters. The Geus Watershed was determined to be a Category 1 watershed (needing restoration), because of its impacts to the marine environment (GovGuam, 1998). Of the 20 watersheds identified, 13 were designated Category 1, and the remaining seven were Category 4 (watersheds with insufficient data to make an assessment).

Despite the policies created to advance the understanding of Guam's Watersheds, very few studies to-date have actually examined existing watershed conditions. The watersheds that have gained the most focus from previous studies include Ugum (Khosrowpanah and Jocson, 2005; Park and Khosrowpanah et al., 2007a; NRCS, 2009; Kottermair, 2010), La Sa Fua (Scheman et al., 2002; Wolanski et al., 2003), and Piti-Asan (Minton, 2006; Kottermair, 2012; Manibusan, 2012). These studies have helped document baseline conditions at these three watersheds which is essential in evaluating progress of future watershed activities. Previous studies have also specified the need to collect data for more than one year due to rainfall variability from seasonal patterns and regional cycles, such as ENSO (Dumaliang and Khosrowpanah, 1998; Lewis, 1999).

Finally, there is a group of previous studies that have used GIS-based analysis as a tool for determining major contributing factors of soil erosion over time (Wen et al., 2009a; Park and Khosrowpanah, 2007a; FSRD, 2010). These tools can be effective in the decision making process because it can assess major contributing factors of soil erosion on a large-scale. Although quantitatively the margin of error in these models should be re-assessed, it can still be useful in comparing conditions between watersheds, and identifying areas within a watershed with the highest relative soil erosion potential.

In terms of actual implementation of management strategies on Guam, several studies have used qualitative evaluation criteria to recommend a range of specific management actions (Minton, 2005; FSRD, 2010; Kottermair, 2012; Manibusan, 2012). Although the evaluation approach could be relevant across other Guam watersheds, the rankings for specific actions were heavily influenced by site-specific circumstances. The Piti-Asan Watershed has recently been the subject of one of Guam's most thorough evaluations of watershed management strategies (Minton, 2006; Kottermair, 2012; Manibusan, 2012). However, the details of what actions were actually completed and follow-on evaluation of actual effectiveness (based on a comparison of pre-restoration/baseline conditions) has not been quantified to-date.

Golabi et al. (2005a) is one of the few studies that examined the effectiveness of a specific erosion mitigation technique using more controlled experimental methods. Using controlled plots, runoff from the vetiver system was compared with runoff from other surface conditions common in savanna habitats of southern Guam (specifically, natural savanna vegetation, burned savanna, and exposed surface/no-soil cover). Vetiver is a dense, bunch-type grass with stiff stems, extremely strong roots, high reliance to fire and drought, and does not produce a fertile seed (Golabi et al., 2005a). After 16 months of data collection, the results showed that the rate of soil loss from the vetiver plot (1.47 tons/hectare/year) was significantly less than soil loss from the other soil surface conditions, controlled burn (14.13 tons/hectare/year); bare soil (104.75 tons/acre/year); and natural savanna (5.22 tons/hectare/year).

Methodology

1. Field observations

Field visitations were conducted on a weekly basis from December 2013 through January 2015. During each visit, potential elements that may contribute to erosion and sedimentation that were observed were documented. These include vegetation types, badland locations, slope and topography, and fires or other human activities (Figures 9 and 10). In addition, aerial surveys were conducted to observe land coverage and identify areas with more potential susceptibility to erosion.

Figure 9. Badlands atop the Pigua Ridge in Merizo, southern Guam (March 15, 2014).

Figure 10. Burned Savanna along the Geus Slopes in southern Guam (April 2, 2014).

2. Hydrologic Data

Hydrologic conditions were examined by quantifying rainfall, stream level, stream flow, and turbidity during dry and wet season conditions. The data was collected in the field with an array of instrumentation setup strategically within the watershed. In addition, manual field measurements were collected regularly during site visits for analyses and data quality evaluations. A primary hydrologic data collection station was setup at a selected location downstream from most of the major tributaries and ¾ of a mile inland from the coast (Figure 11). Hydrologic data collection began on January 15, 2014 and data was collected through January 15, 2015.

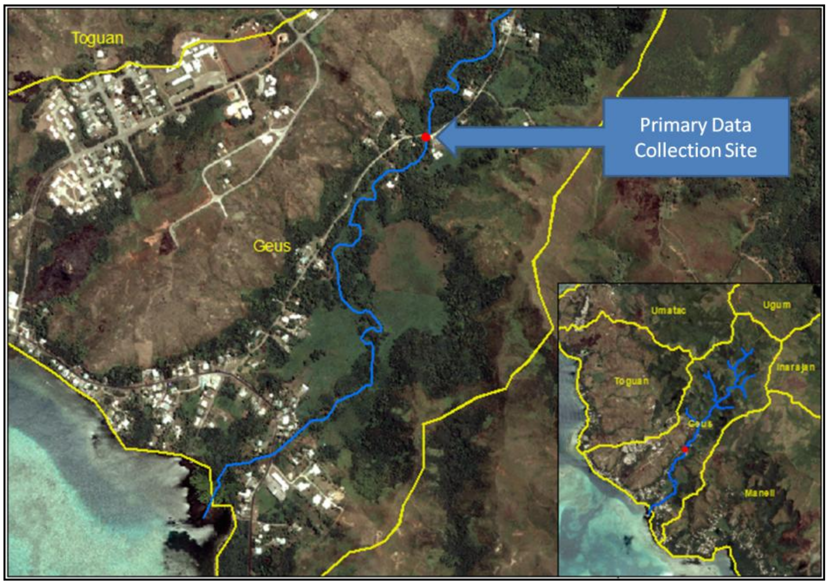


Figure 11. Location of the hydrologic data collection station in the Geus River.

Stream Level

Stream level is simply the height of the Geus River water column at the data collection site. Stream level was measured using two HoboWare® U20 water level data loggers with a range of 0 to 30 ft and an accuracy of 0.015 ft (Figure 12 and 13). The level loggers were collocated with one level logger resting at the bottom of the water column and the other logger outside of the water column to account for atmospheric pressure variations. Pressure readings were collected at 5-minute intervals, and the pressure difference between the river level logger and the atmosphere level logger provided the pressure (in psi) attributed to the water column. During data post-processing, a correction factor was applied to account for the actual location of the pressure sensor based on its orientation in the PVC housing and stream level baseline height established during dry season conditions. This was necessary to provide a more accurate stream level height and a consistent reference point for the stage discharge curve.

Figure 12. Installation of data loggers in the Geus River in southern Guam (January 15, 2014).

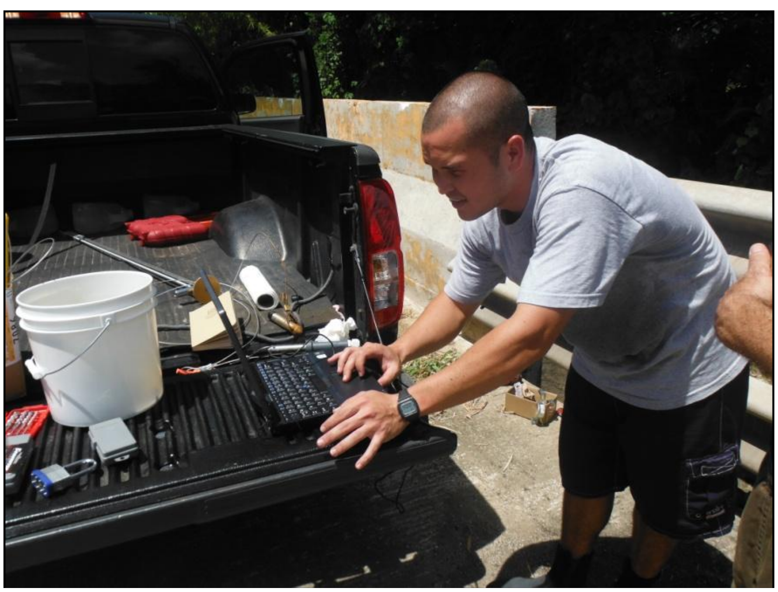


Figure 13. Field download of Geus River data logger information (March 5, 2014).

Stream Flow

Stream flow was measured close to the primary data collection station during weekly site visits (Figure 14). A Flow-mate™ Model 2000 Portable Flowmeter was used to collect readings (in cfs) along a transect set perpendicular to flow direction. A correlation between total flow and stream level over time produces a discharge rating curve.

Figure 14. Stream flow measurement in the Geus River in southern Guam (January 15, 2014).

Turbidity

Turbidity was measured using a turbidity logger and a hand-held turbidity meter. An Analite NEP495P Turbidity Logging Probe was installed to collect turbidity readings at 15-minute intervals in the water column (Figure 15). In addition, during weekly site visits water samples were collected and analyzed using an Omega TRH444 Portable Turbidity Meter. Both turbidimeters measure suspended particles in a solution based on the amount of light scatter produced with infrared light. Accuracy of the portable turbidity meter was verified prior to each use. The turbidity logger was calibrated prior to deployment and accuracy was assessed weekly by comparison with the portable turbidity meter. Maintenance was conducted weekly during long-term deployment and recalibration was conducted periodically as necessary.

Figure 15. Turbidimeter housing installation in the Geus River (March 5, 2014).

Rainfall

Daily rainfall quantities were recorded by a rain gauge located on the Pigua ridge just upland from the primary data collection site. Toward the later part of the data collection period the Pigua rain gauge became faulty and no longer was supplying valid data. Therefore, supplemental rainfall data was also used from a rain gauge located in the Ugum Watershed (Figure 16). The rain gauges use two tipping buckets that collect water as it falls, recording each time the tipping buckets are activated representing a specific quantity of rainfall (0.01 in per tip).

Figure 16. Rain gauge locations in and around the Geus Watershed in southern Guam.

3. Soil Sampling

Soil samples from seven locations were collected and tested in the soil lab to identify the various soil types represented in the Geus Watershed (Figure 17 and 18). Samples were collected as composites from sample locations selected based on exposed soil observations or dominant vegetation types. Four samples were collected along the upland ridge including areas consisting of the more prominent badlands and grasslands. Three samples were collected in the interior of the valley and along the River where more forest vegetation dominates. Each composite sample consisted of five individual sample aliquots, collected to the depth of 12 in (30 cm) from the surface.

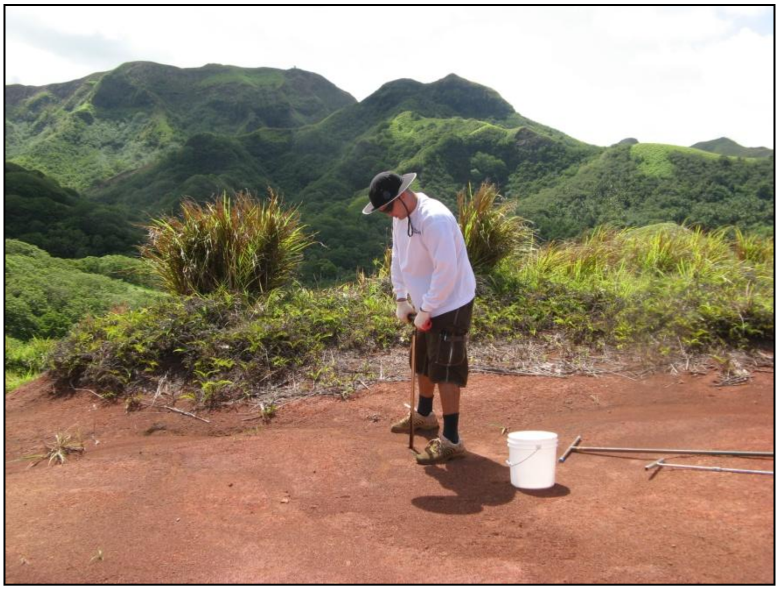


Figure 17. Soil sample collection in a badland location in the Geus Watershed (June 3, 2014).

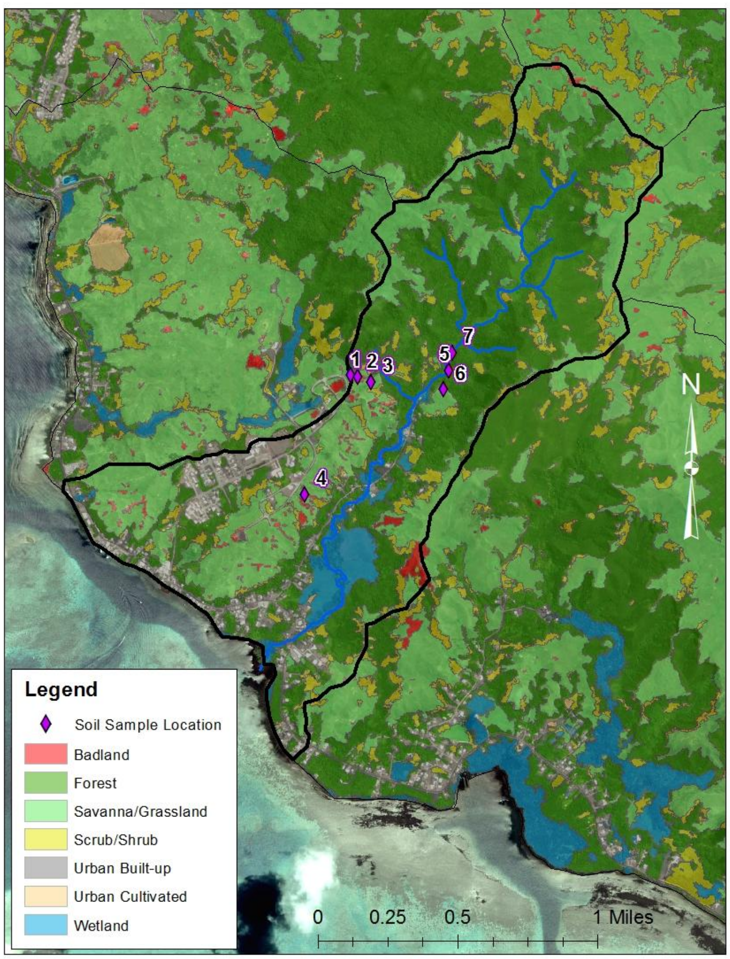


Figure 18. Soil sample locations within the Geus Watershed in Southern Guam.

Upon collection all samples were processed and analyzed at the University of Guam Soil Laboratory. Samples were dried, ground, then sifted through a standard two millimeter sieve. Sample aliquots were individually analyzed for pH, soil texture, organic matter content, and nutrients.

Soil pH was measured by mixing 10 ml of water with 10.0 grams (g) soil creating a 1:1 soil to water ratio solution. An electronic Oaktron pH meter was used to provide the pH value of the sample solution (Figure 19). This pH meter uses a combination electrode (glass and reference electrodes) that measures pH based on the electrical potential created from pH differences in an internal and sample solution around the glass electrode in comparison to the reference electrode.

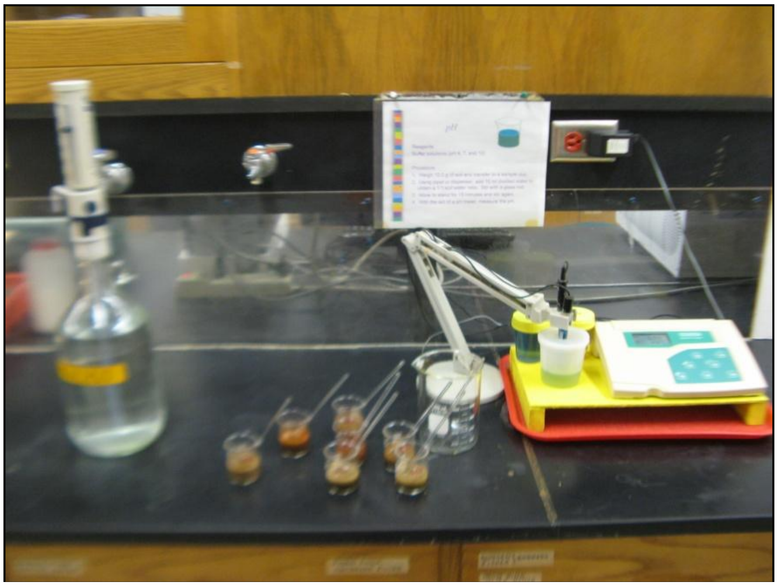


Figure 19. Soil analysis conducted at the University of Guam Soil Laboratory.

The soil texture analysis determines the proportion of sand, silt, and clay particles in a soil sample. The method of analysis was based on the understanding that soil particle size directly influences the rate at which it will settle in a solution. Settling velocity was derived by timed density measurements using a Bouyoucos hydrometer which is established on the fundamentals of Stoke's Law. Hydrometer measurements were taken at specific time intervals in 500 ml of distilled water with a dispersing agent and 50 g of soil per sample. Temperature was also recorded to correct for the density effects caused by temperature.

Soil organic matter was determined by measuring the soil carbon using a rapid dichromate oxidation procedure known as the Walkley-Black Method (Schumacher, 2002). However, because no additional heating was used only about 76% of the organic carbon was recovered, therefore a correction factor of 1.3 was applied.

Nutrients analyses were conducted for available phosphorus (P), potassium (K), calcium (Ca), and Magnesium (Mg). Available P was extracted using an acid solution, and then analyzed by a Spectronic meter. This is known as the Olsen method (Olsen et al., 1954). The routine nutrient analyses quantified the remaining nutrients (K, Ca, and Mg).

4. GIS-RUSLE Model

The GIS-based soil erosion model was applied to the Geus Watershed with the same data processing procedures as described by Park (2007). The R-factor, for the erosive power of rainfall, was digitized based on the isoerodent lines calculated by Dumaliang (1998). The K-factor, for soil-loss rate per erosion index unit, was taken as listed for each soil type in the Soil Survey of Guam (Young, 1988). The Geus Watershed soil types were obtained from the Digital Guam Atlas (Khosrowpanah et al., 2007b). The L and S factors, for ratios of soil loss from field slope length and gradient, was calculated by the C++ program based on a 1m DEM (Van Remortel et al., 2004). The C-factor, for land cover and management, was based on the 2011 landcover information provided in the Digital Guam Atlas (Khosrowpanah et al., 2007b) reclassified as was done by Park (2007). The P-factor, for soil loss with support practices, was assigned as 1 because there are no soil support practices currently taking place. The output of the GIS-based model was a color coded map that differentiated areas that have a higher potential to contribute to soil erosion within the Geus Watershed.

5. Aerial Photography

An aerial photo survey was conducted in June 2014 using a custom built radio-controlled hexacopter equipped with a video camera. The main focus of the survey was general vegetation cover and the extent of the more critical high erosion areas within the Geus watershed. Limitations with this technology included shorter air time due to limited battery power, and narrower coverage and distance limits from the radio control. However, the lower elevation aerial footage allows for higher resolution photos.

Results and Discussion

1. Expected Results

The results of this study provides a clearer understanding of the dynamics of the Geus Watershed, or the degree to which rainfall correlates with stream level, stream flow, and turbidity. A strong response to rainfall in the Geus River suggests the Geus Watershed is very dynamic. Furthermore, a correlation between stream levels and stream flow rates provides a stage discharge curve, which with a large amount of reliable data points can be useful in estimating stream flow based on a simple stream level measurement. This information has not been thoroughly examined prior to this study, and would be essential for proper watershed management during future restoration or development within the watershed.

In addition to determining the watershed dynamics, soil samples were collected to assess physical and chemical properties of the soil at representative locations within the Geus Watershed. An aerial survey was also conducted to gain an understanding of land cover and the extent of badlands which is one of the major contributors of soil erosion and sedimentation. The GIS-based RUSLE erosion model was also used to identify areas that contribute most to soil erosion within the watershed. Recommendations for restoration efforts within the watershed are made more effectively with the consideration of all the data collected.

2. Hydrologic Data

Hydrologic data collected in this study was used to examine the relationship between rainfall, stream level (h), and turbidity (Figures 20, 21, and 22). Since stream flow is a function of stream level (h), stream level used for this correlation and the relationship between stream flow and stream level was used in the determination of the stage discharge curve. Over the course of data collection period (from January 2014 to January 2015), rainfall, stream level, stream flow, and turbidity showed the most variability from July through November. This was consistent with the typical rainy season period (Lander and Guard, 2003).

Based on the data, it appears there is a strong correlation between stream level and rainfall in the Geus Watershed (Figure 20). In general, when daily rainfall averaged one to two inches, the stream level increased on the order of one to two feet. During heavier rain events, with daily totals reaching almost four to five inches, stream level showed significant spikes upwards of four to five feet depending on the intensity of the rainfall. There also appeared to be a strong correlation between turbidity in the Geus River and rainfall (Figure 21). This observation is supported by overlaying stream level with stream turbidity measurements (Figure 22). As a result, it was evident that the intensity of the storm was a key factor influencing erosion and runoff as indicated by levels of turbidity.

The dynamic response of the Geus watershed was also evident as rainy season storms produced high velocity flow events with maximum recorded turbidity readings. In fact, the largest rain event (Tropical Storm Halong) on July 30, 2014, caused so much sediment build-up around the turbidimeter that it affected the validity of the data until manual cleaning was completed. During this storm event the maximum stream level recorded was 7.0 ft at 2:05 am, and the duration at that height was not longer than that 5-minute interval. During that spike, stream level was greater than 6 ft for 30 minutes, greater than 5 ft for 40 minutes, and greater than 4 ft for 70 minutes. Based on this data, the stream level doubled then came back down (from 3.5 to 7 ft) in less than an hour and a half (Figure 23). A similar pattern was exhibited in the turbidity data, which recorded a maximum concentration of 964.9 NTU from 2:15 am to 2:30 am (Figure 23). Turbidity above 900 NTUs lasted about an hour and a half, and significant increased were observed when stream level rose to greater than three feet. Routed rainfall data at a 15-minute delay correlated well with the 5-minute stream level data (Figure 23). The coefficient for rainfall routing best fit the stream level response with a delay of 15-20 minutes between peak rainfall and peak streak level. This storm event is one example that shows how dynamic the Geus Watershed is.

A time series during a period of storm activity in October 2014 also depicts the response time between rainfall, stream level, and turbidity (Figure 24). Based on the dimension of the Geus Watershed, the river floods appear to last less than a couple of hours. This shows that the dynamics of river runoff and suspended sediment fluctuated at a times scale of hours or less. Therefore, this is an important consideration for understanding the magnitude of sediment plumes versus the long-term erosion rate.

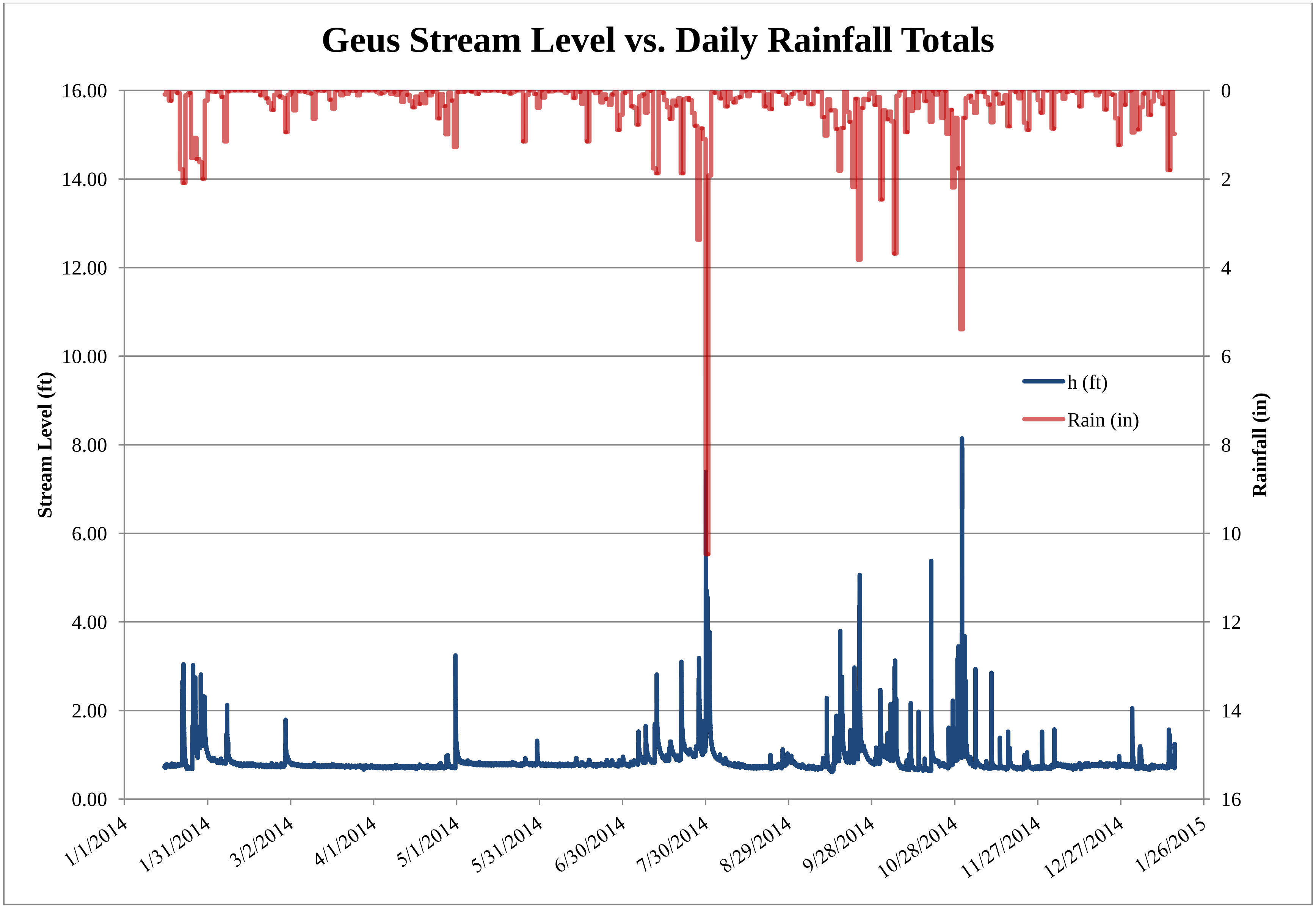


Figure 20. 5-Minute stream level and daily rainfall totals.

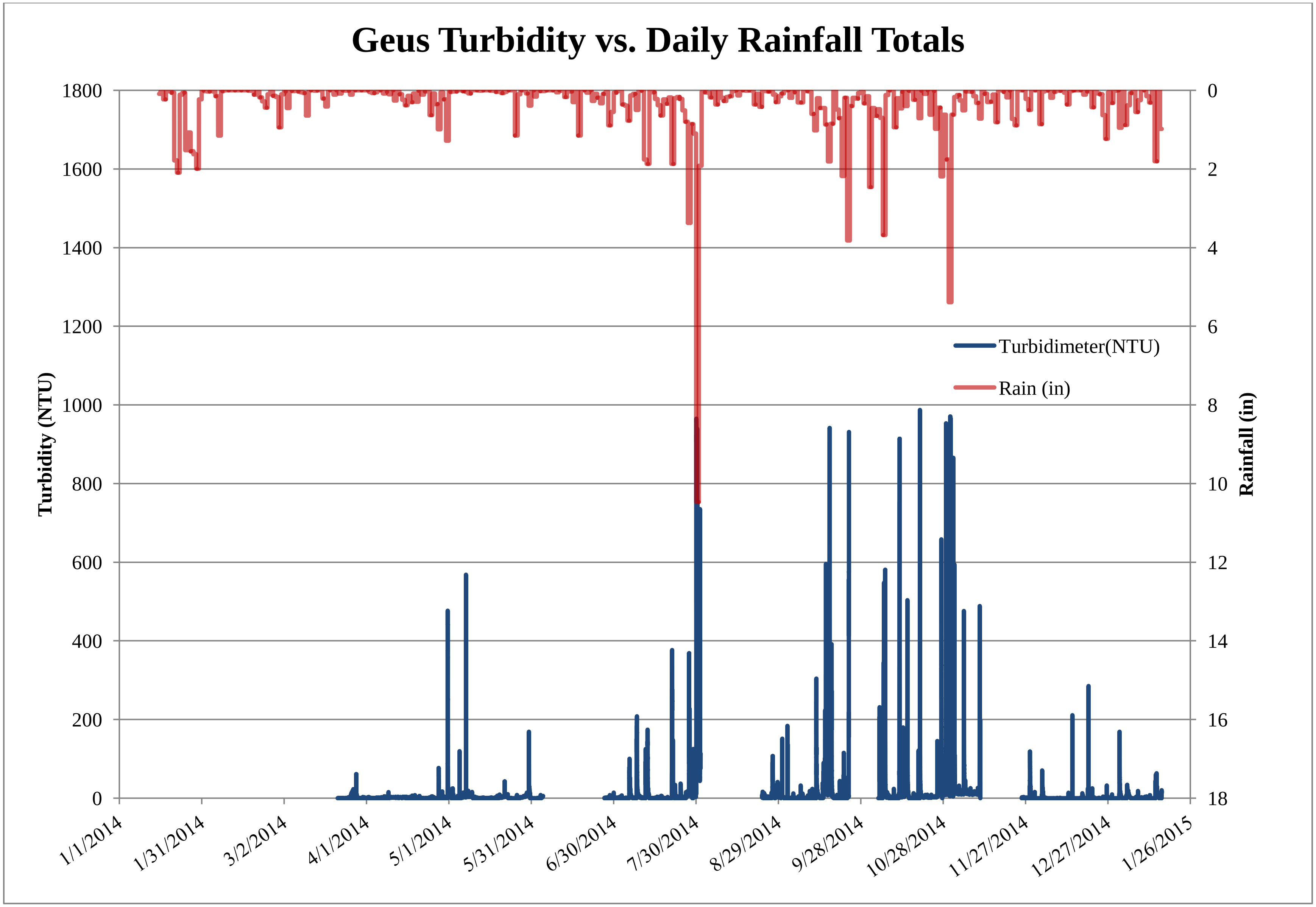


Figure 21. 15-Minute turbidity readings and daily rainfall totals.

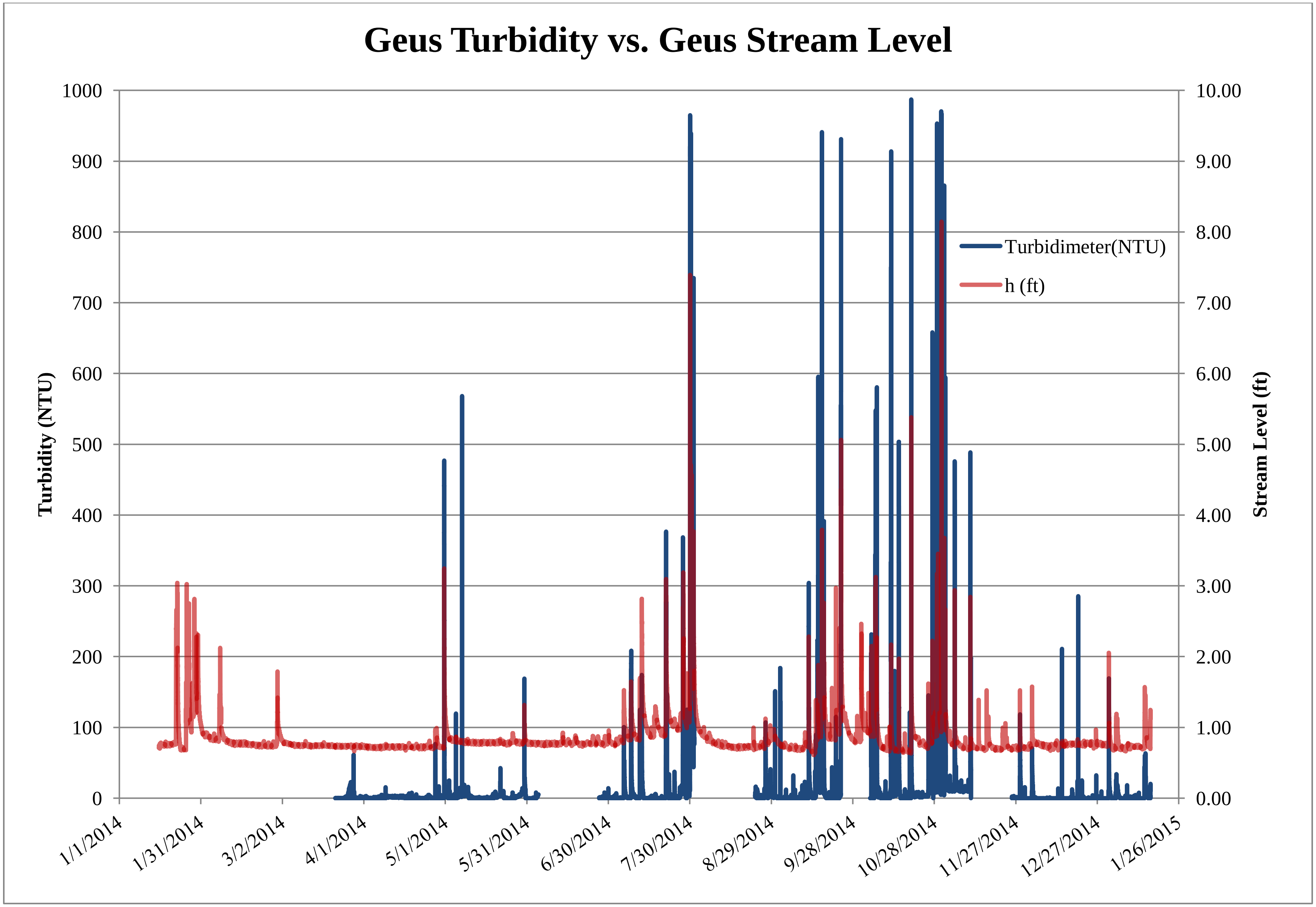


Figure 22. 15-Minute turbidity readings and 5-minute stream level.

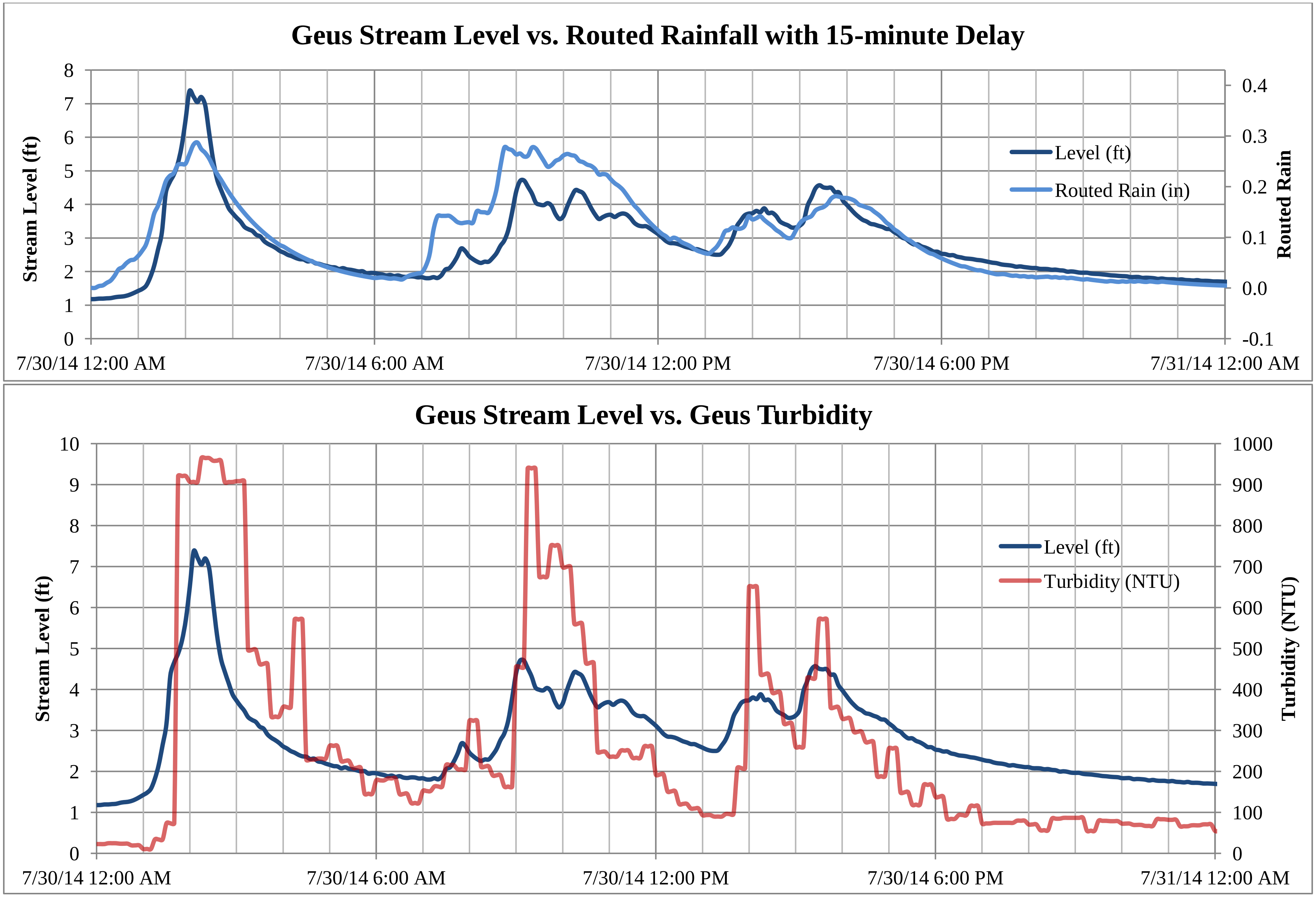
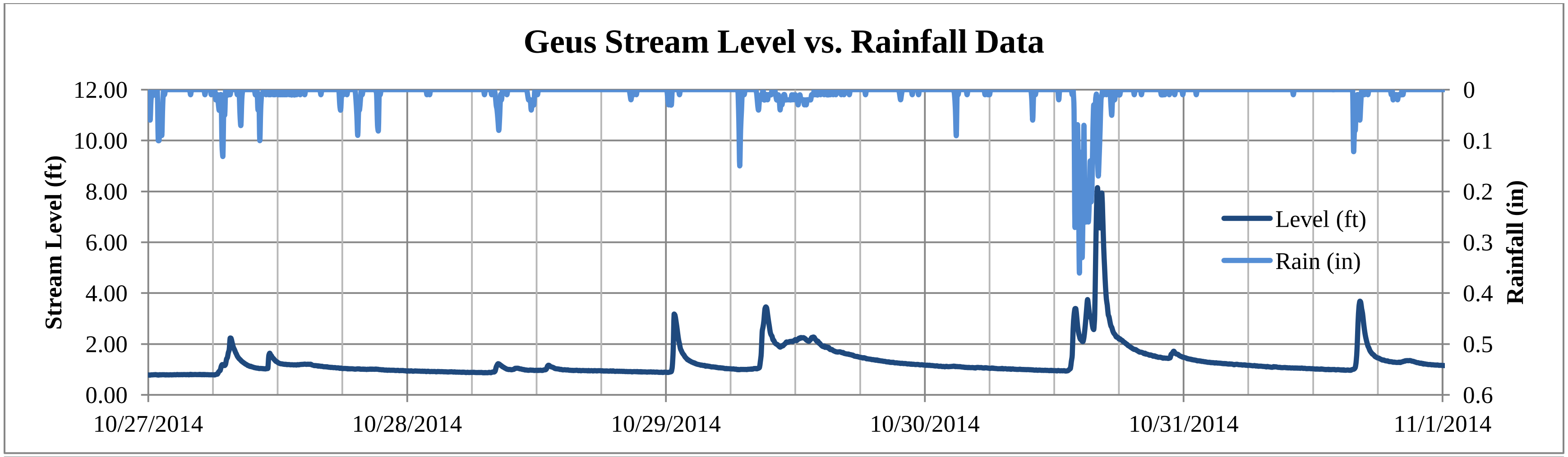


Figure 23. Routed rainfall & 15-minute turbidity, versus 5-minute stream level data.



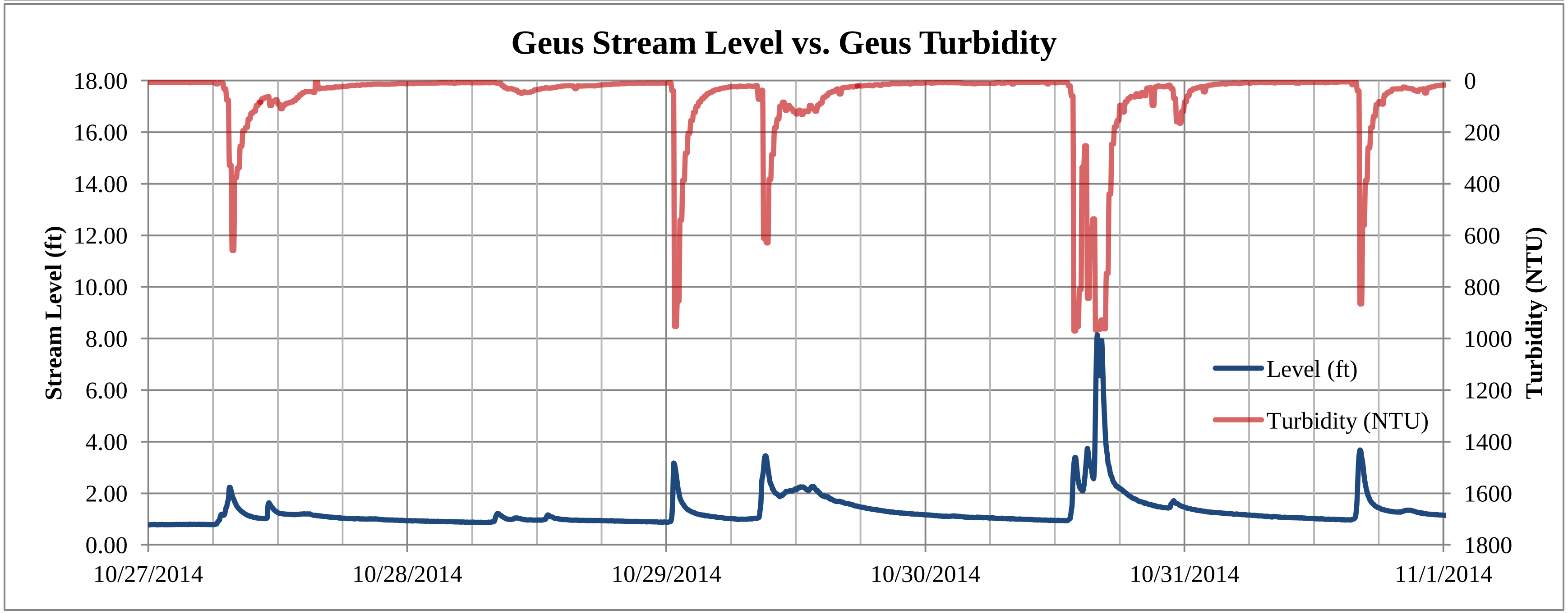


Figure 24. 5-minute rainfall & 15-minute turbidity, versus 5-minute stream level data.

Based on the data collected, it was evident the intensity of the storm was a key factor influencing erosion and runoff as indicated by levels of turbidity. When rainfall occurs at higher intensities runoff contribution to the stream to increases up to a certain threshold, then turbidity begins to increase dramatically. This was observable during the worse conditions with the deployment of the turbidimeter which can log turbidity readings when it may otherwise be too dangerous for data collection at the time of the event (Figure 25). This information is important to understanding the baseline conditions of the watershed and helps to predict how the watershed may respond to future developments.

Figure 25. Geus River conditions before and during Tropical Storm Halong (July 18, 2014 and July 30, 2014, respectively)

3. Development of Stage Discharge Curve for the Geus River

The preliminary stage discharge curve is presented below (Figure 26). The stage discharge curve will gain greater accuracy as more data under a range of flow regimes continues to be collected over the course of several years or more. This watershed management tool will provide an estimate of flow based on measured stream levels.

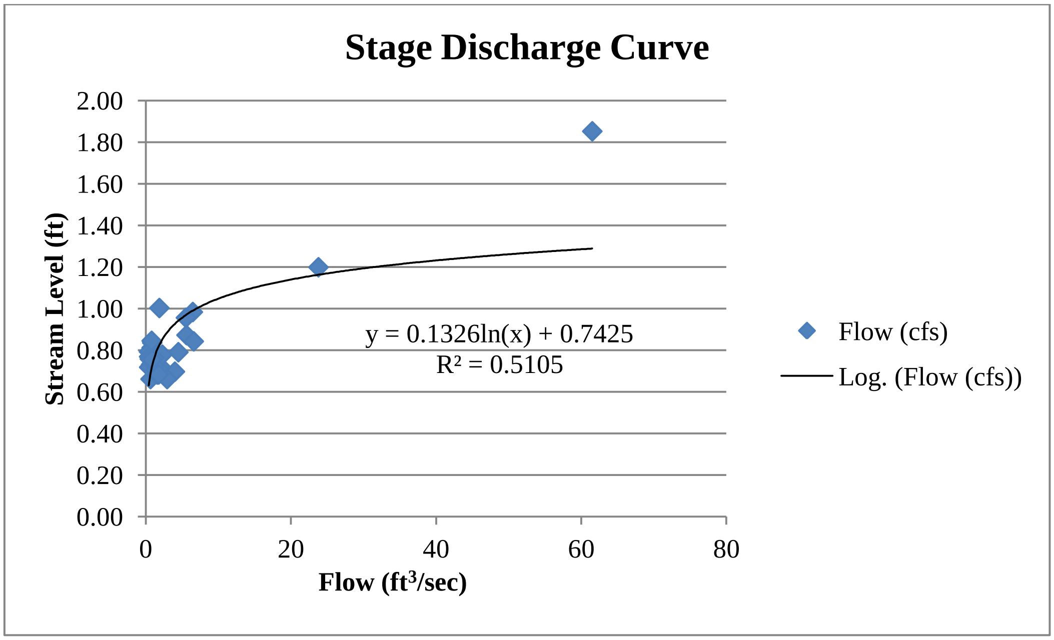


Figure 26. Preliminary Stage Discharge Curve for Geus River based on data collected.

4. Soil Sample Results

Most soil pH ranges between 3.5 and 10.0. Soil pH is important because it has many affects, including influence on availability of nutrients and toxicity for plants, and soil organism activities. Soil organic matter, such as plant, animal, microbial residue, and highly carbonized compounds such as coal, have important and potentially beneficial qualities. Organic compounds in soil may increase the holding capacity for plant nutrients and water, increase the cation exchange capacity, and lower bulk density. High organic matter in soil generally signifies sustainable fertility over the long-term. Available P is typically just a fraction of total P. However, it is important because it represents the amount usable P in the system. The concentration of nutrients in general is an indicator of the ability of soil to support vegetation.

Soil sample results are presented in Table 2. Samples 1 and 2 were collected at some of the more extensive badlands in the Geus Watershed. The low organic matter and lower levels of available nutrients suggests soils from this zone are very erodible. The lower levels of organic matter decreases the buffer effect provided by organic matter in soils and can correspond with lower pH. Clayey soil texture means soil particles may not settle as quickly in the water column, heightening the effects of sedimentation. Samples 3 and 4 were also collected along the Geus Valley ridge where savanna-type vegetation dominates. There was slightly more organic matter and nutrients in the soil under vegetated conditions. However, the soil texture, little to moderate organic matter, and low P suggests the soil type that supports the savanna within the Geus Valley are unproductive hence, fairly susceptible to erosion. Samples 5, 6, and 7 were collected along the central portion of the valley bottom. The vegetation supported by these soil types consisted mostly of ravine forest. In comparison to the samples collected along the ridge, the later samples showed higher organic matter, higher pH, and more available nutrients in general These soils are likely less erodible.

Table 2. Soil Sample Results

Sample Identifier	pH	% OM	Soil Texture	K (ppm)	Ca (ppm)	Mg (ppm)	P (ppm)
1	4.04	0.00	Clayey	44	787	691	0.56
2	3.73	0.00	Clayey	105	373	4,617	0.11
3	6.70	2.74	Clayey	82	12,389	2,585	1.15
4	6.01	1.77	Loam	195	89,085	2,928	0.67
5	6.17	2.58	Sandy Clay Loam	288	7,870	988	1.15
6	5.66	6.12	Clay Loam	462	5,916	909	2.03
7	6.37	5.15	Sandy Clay Loam	778	12,149	1,251	3.28

Based on sample results from all the soil samples combined, P was considerably low and is possibly one of the limiting nutrients in the Geus Valley soils. Additionally, Mg was very high in all of the samples, even up to toxicity levels. These results are signs that the Geus Watershed may not be suitable for agricultural uses unless it is heavily managed. Therefore, the native or existing vegetation is likely adapted for these conditions.

5. GIS-RUSLE Model

The results of the GIS-based erosion model are shown in Figure 27. Based on the results of the model, the mean annual rate of soil loss for the entire watershed is an estimated 16.78 tons/acre/year, with a standard deviation of 26.77 tons/acre/year. The range of estimated annual soil erosion potential (maximum of 1,141.56 tons/acre/year) is considered an estimate that could be further evaluated based on empirical data. However, this data provides a general understanding of areas within the watershed that have the potential to contribute the most to soil erosion. The badland locations along the ridges appear to be hotspots contributing the most to soil erosion (Figure 27). However, proximity to the river or its tributaries is an important factor in determining the likelihood that sedimentation can impact downstream communities. Therefore, the steep terrain at the back of the valley appears to also have some level of increased contribution to erosion based on this model.

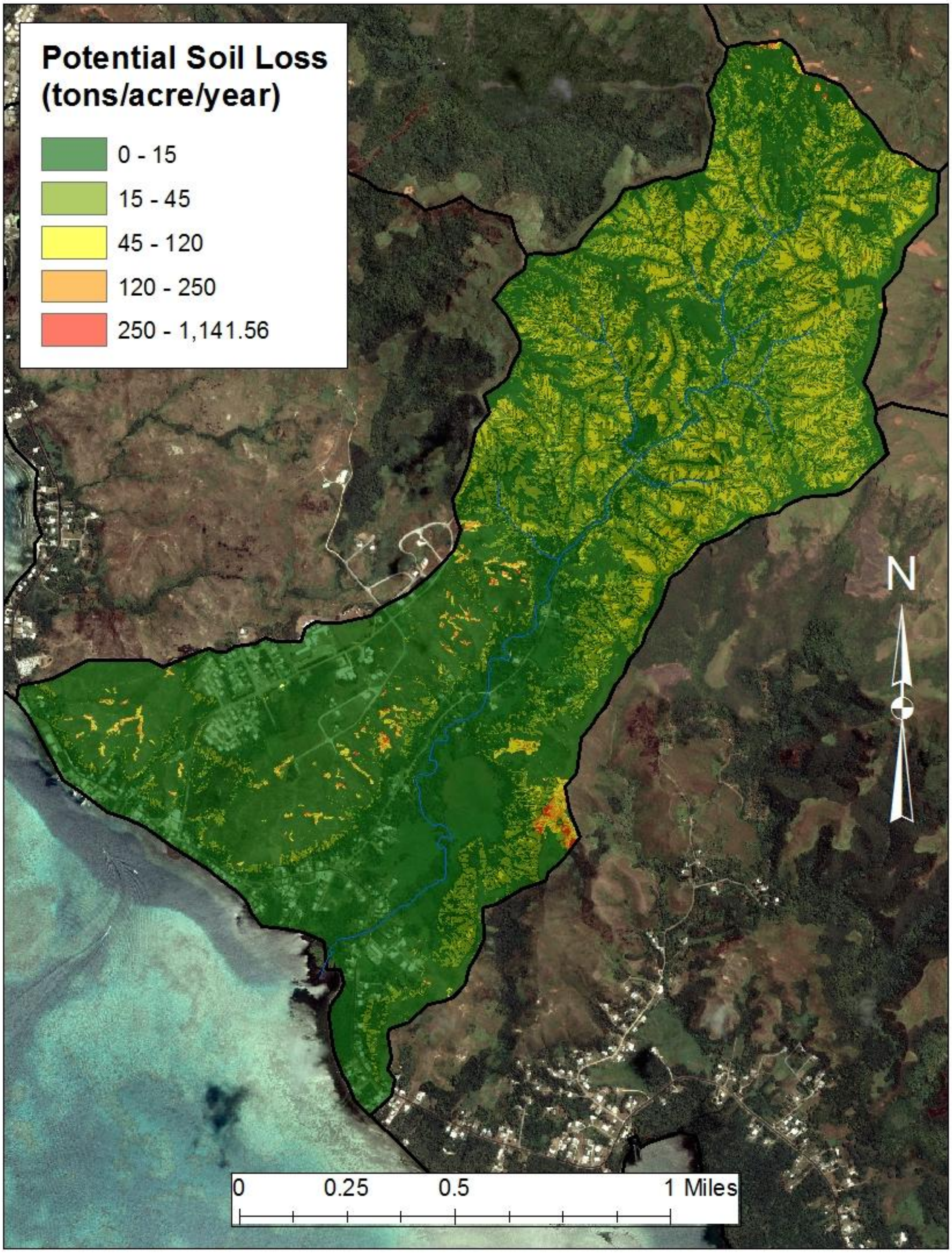


Figure 27. Results of GIS-Based Erosion Model showing areas within the Geus Watershed that have a higher contribution to erosion potential.

Conclusions and Recommendations

The Geus Watershed has physical and geographical attributes characterized as having a relatively small catchment area, with steep valley walls carved out by rainfall over geologic time scales. Rainfall, one of the main forces that drive erosion on Guam, is distributed with extreme levels of intensity based on seasonal patterns and the occurrence of storms. The hydrologic data collected shows that there is a rapid response to rainfall in the Geus River Watershed. Corresponding turbidity levels and stream flow increases with stream level during heavy rain events. On the time scale of hours, rainy season downpours can result in sediment plumes that travel downstream and can settle, accumulating in near-shore reef communities.

To support the hydrologic data collected, field visits, aerial surveys, and GIS-erosion models were conducted to provide a more qualitative understanding of watershed attributes that may contribute to erosion. In general, the Geus Watershed can be characterized by two separate but interacting regions, not relating to the way water flows (i.e., not in terms of sub-watersheds): a northern (inland) region, and a southern (coastal) region.

The southern (coastal) half of the watershed bridges the land and the sea. It is easily accessible with roads that extend up the Pigua-side along the ridge, as well as at the base of the valley along the river. This region has a higher chance of human disturbance from fire, small-scale agriculture, and light residential developments. Due to frequency and the scale of the affected area, fire may be the most significant form of disturbance contributing to a higher erosion potential in this area.

Also lower coastal region, the Geus River bottom has a less dramatic slope likely causing an accumulation of water and debris from upstream during heavy flow conditions. As a result, the stream channel here is more susceptible to flooding. In addition, the valley walls also have a more moderate slope. However, it supports heavily degraded savanna vegetation with patches of badlands, especially along the Pigua Ridge. With decreased ground cover, sediment from surface erosion in these uplands can accumulate in small eroded channels and eventually into the River, having to travel a shorter distance to make it to the coast. Properties of soil in this region classify the soil as erodible.

Based on these characteristics, this area will not likely improve naturally, especially if it continues to burn periodically. It also will not benefit from any restoration or vegetative cover improvements unless public support to minimize the threat of fire can be achieved. The recommended options include outreach focused on the local community and more effective enforcement of Guam's laws against fugitive burning.

The northern (inland) half of the watershed is bound by the high peaks of the mountains. It is characterized by steep valley walls and deep channels eroded from heavy rain events causing fast-flow conditions. The back valley is more inaccessible and remains relatively undisturbed. The interior is dominated by ravine forests while stretches of savanna occupying the higher elevations. The savanna in this region appeared to be denser with more ground cover, likely affected by fire less frequently. Also, the interior valley vegetation is supported by more productive soil. Although it may burn less frequently, it would be more difficult to fight a fire in the back valley due to access limitations.

Based on these features, erosion from this region is associated more with the steepness of the terrain. Abundance of areas with greater erosion potential and proximity to the stream is a greater concern here. But the proximity to the ocean and the magnitude of erosion potential may be less detrimental to direct impacts along the coast.

Considering these findings, it is recommended that any future restoration activities be focused on the disturbed portions of the watershed. First of all it seems logical that areas that are more directly impacted by human activities could be more effectively managed by human activities. Additionally, the ease of access which makes the area more susceptible to detrimental human actives also makes it more convenient for restoration. This study did not include an analysis of efficiency of different management options. But, habitat restoration of the degraded savannas should be one of the goals. Since fire presents one of the most significant threats of disturbance, increased educational outreach and enforcement focused directly on the local community should help to ensure the longevity of restoration efforts. Now that baseline conditions have been determined, continued monitoring is recommended for evaluating the effectiveness of future restoration actions.

Along with presenting findings of baseline conditions, this study also alludes to aspects of the Geus Watershed that should be further investigated. For example, it is recommended that an additional monitoring station is installed upstream to quantify differences between the more easily accessible/developed regions of the watershed and the undisturbed regions. This will determine the extent of sedimentation that the north (inland) region of the watershed contributes downstream. A similar, but more rigorous investigation can include monitoring stations at each of the major tributaries during rainy season. Finally, since one of the main goals of watershed management is the protection of Guam's near-shore reef ecosystems, an in-depth study to determine the quantity of sediment actually being discharged into the ocean from the Geus River should be conducted.

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