PROGRESS REPORT

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 is a progress report for on-going work on the Geus River 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.

Introduction

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) (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 Gues Watershed is one of the smaller more pristine watersheds in southern Guam. It has one major river, the Gues 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 Gues River discharging directly into the interior portion of the lagoon.

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. 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 (ie., stream flow, stream level, turbidity, and precipitation over time) and, c) understand the behavior of the watershed.

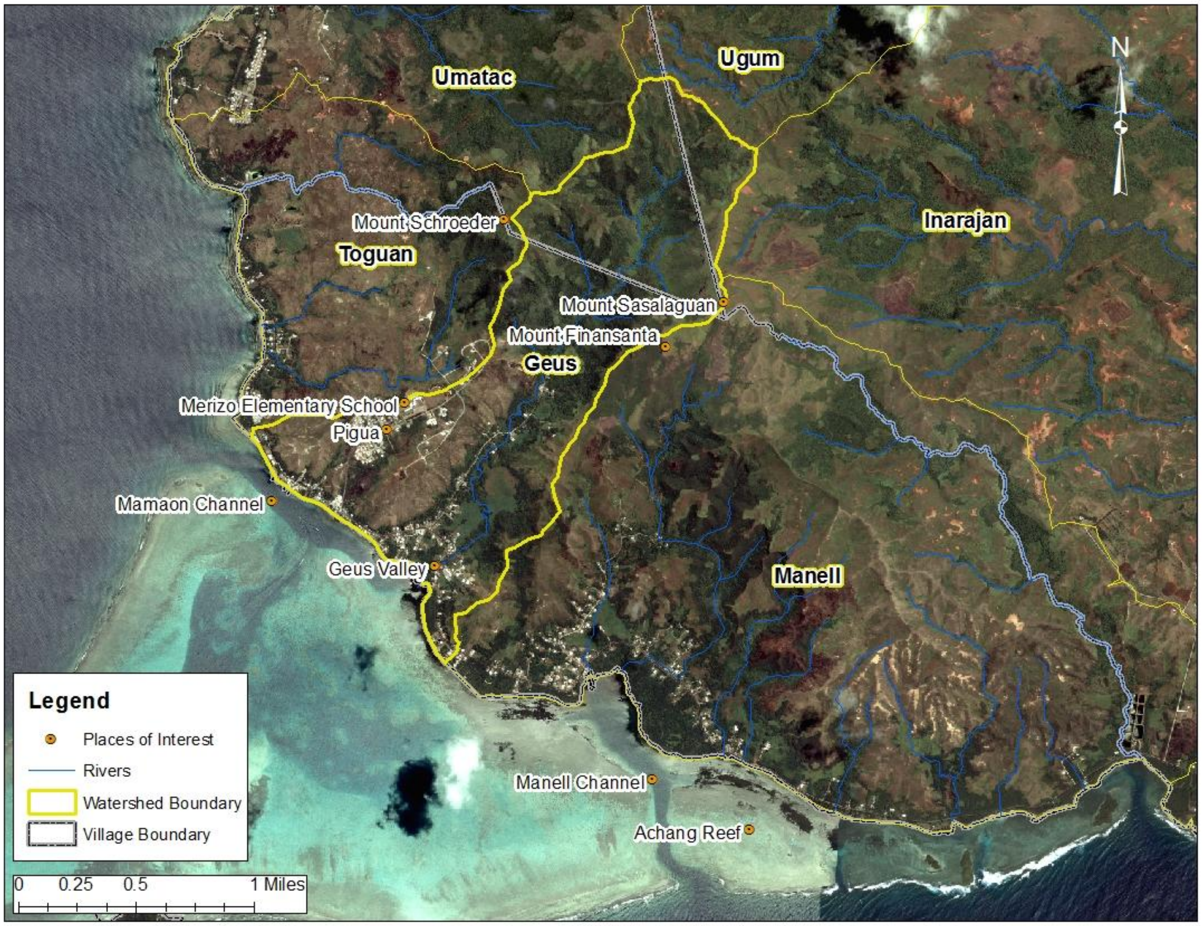

Figure 1. Geus Watershed Location

Study Area

1. Location

At the Southern tip of Guam, the Geus Watershed is bound at the coast by Cocos Lagoon. With 1.73 sq. miles (4.48 km^2) it is the second smallest of the 14 major watersheds in southern Guam. The Geus River is about 2.7 miles long with several upland tributaries. The river discharges to the interior of Cocos Lagoon and the Mamaon Channel (Figure 2). Access into the Geus Valley along the river is provided via Espinosa Street, which extends about one mile into the watershed 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 seagrass 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 this coastal community with benefits for marine resources and local residents (NOAA, 2014).

Figure 2. Geus Watershed, Merizo (Khosrowpanah et al, 2007b)

2. Climate

Climate is a key factor influencing erosion in southern Guam watersheds. 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). Between years there can be significant variations in rainfall totals and average intensity due to occurrences of tropical cyclones/typhoons and patterns of El Niño. Between 1957 and 1992 one weather station on Guam recorded a mean annual rainfall of 101.84 inches with a standard deviation of 22.2 inches (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 90-95 inches along the coast to 105-110 inches atop the inland mountains (Figure 3).

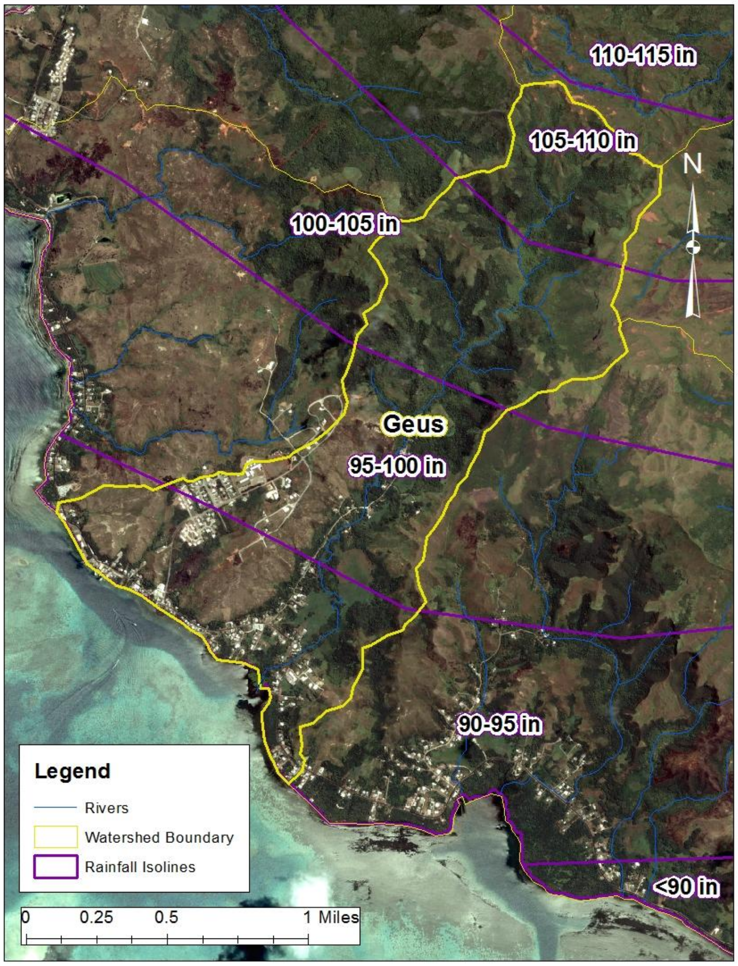

Figure 3. Average Annual Rainfall Distribution (Lander and Guard, 2003)

3. Geology

The Geus Watershed extends over two miles inland with increasingly steep topography and a maximum elevation of 833 feet at the north east 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, Shroeder 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).

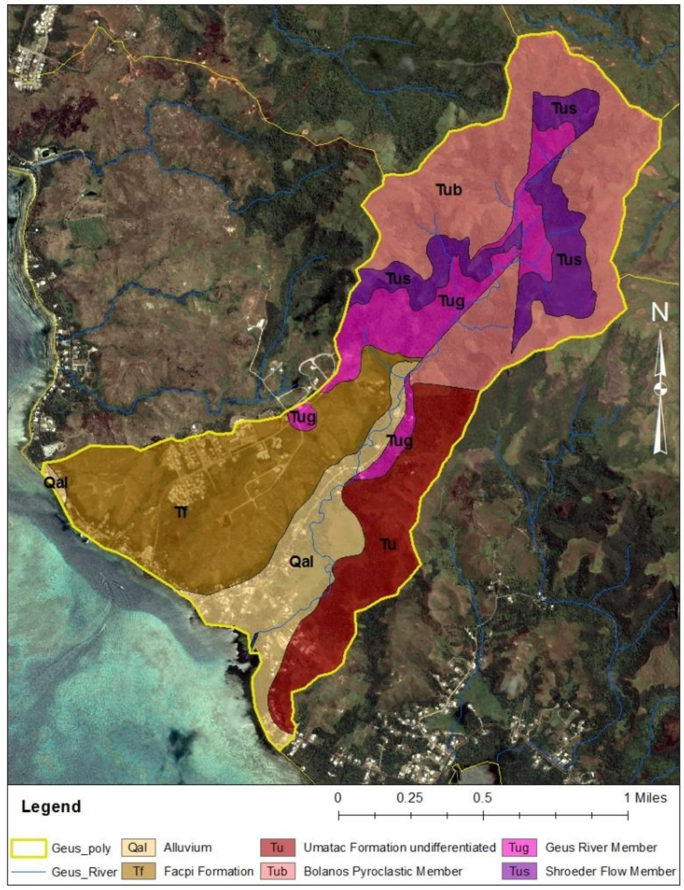

Figure 4. USGS Topographic Map

Figure 5. Geus Geology (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 percent (74,730 square meters) of the Geus Watershed.

About 45.95 percent of Geus badlands are located on Agfayan-Akina-Rock outcrop association, extremely steep soils. Akina-Agfayan association, steep contain about 37.2 percent of Geus badlands, and about 16.6 percent of the badlands are on Agfayan-Akina association, extremely steep. Ylig clay has only a fraction of one (0.25) percent of Geus badlands.

Soil type coverage and composition are summarized in the following table:

Soil Type	Major Components	Slope	% Area	Area (m^2)
Agfayan-Akina-Rock outcrop association	50% Agfayan clay, 25% Akina silty clay, 20% Rock outcrop	40% - 99%	39.66	1,772,099
Agfayan-Akina association	60% Agfayan clay, 30% Akina silty clay	40% - 99%	23.14	1,034,252
Akina-Agfayan association	50% Akina silty clay, 30% Agfayan clay	30% - 60%	12.95	578,625
Akina-Badland association	60% Akina silty clay, 25% Badland	20% - 60%	0.05	2,263
Akina-Badland complex	65% Akina silty clay, 30% Badland	7% - 15%	2.58	115,385
Akina-Urban land complex	60% Akina silty clay, 30% Urban land	0% - 7%	4.08	182,210
Inarajan clay	95% Inarajan clay	0% - 4%	12.56	561,334
Inarajan sandy clay loam	85% Inarajan sandy clay loam	0% - 3%	0.56	25,136
Togcha-Ylig complex	60% Togcha silty clay, 35% Ylig Clay	3% - 7 %	1.08	48,239
Urban land-Ustorthents complex	60% Urban land, 30% Ustorthents	0% - 3%	2.10	94,059
Ylig clay	90% Ylig clay	3% - 7%	1.23	55,158

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). Inarajan clay dominates the lower river valley adjacent to a small patch of Ylig clay (inland) and Inarajan sandy clay loam (along the coast).

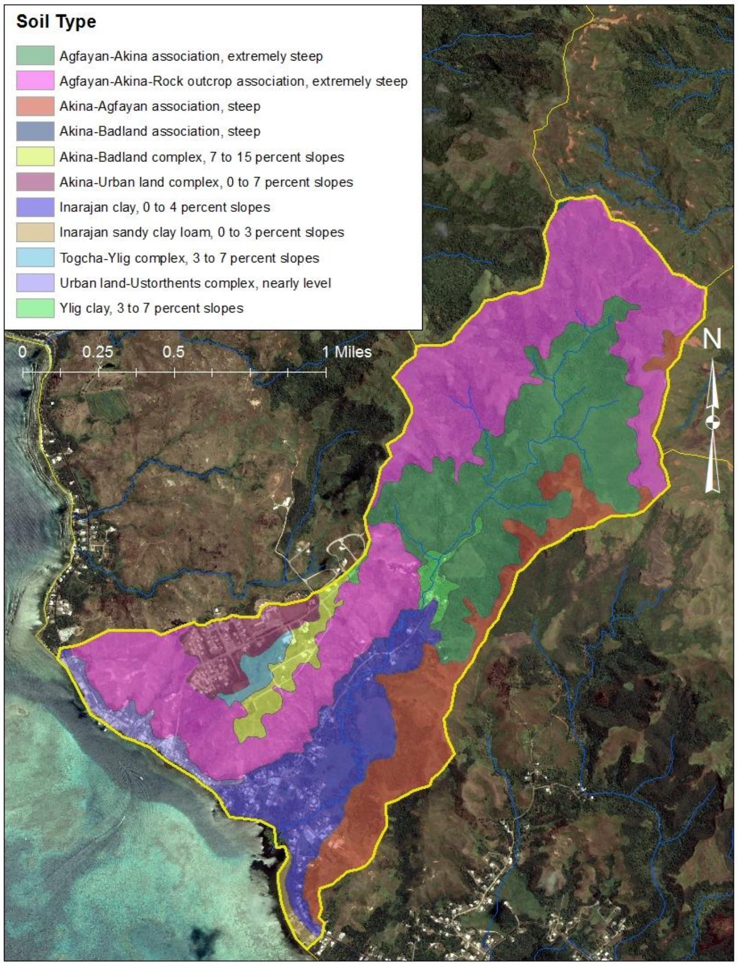

Figure 6. Geus Soils (Young, 1988)

5. Vegetation

The vegetation types and area coverage within the Geus Watershed are summarized in the following table:

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

The most dominant vegetation types in the Geus Watershed are forests, savanna/grassland, and scrub/shrub forest. In general, 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.

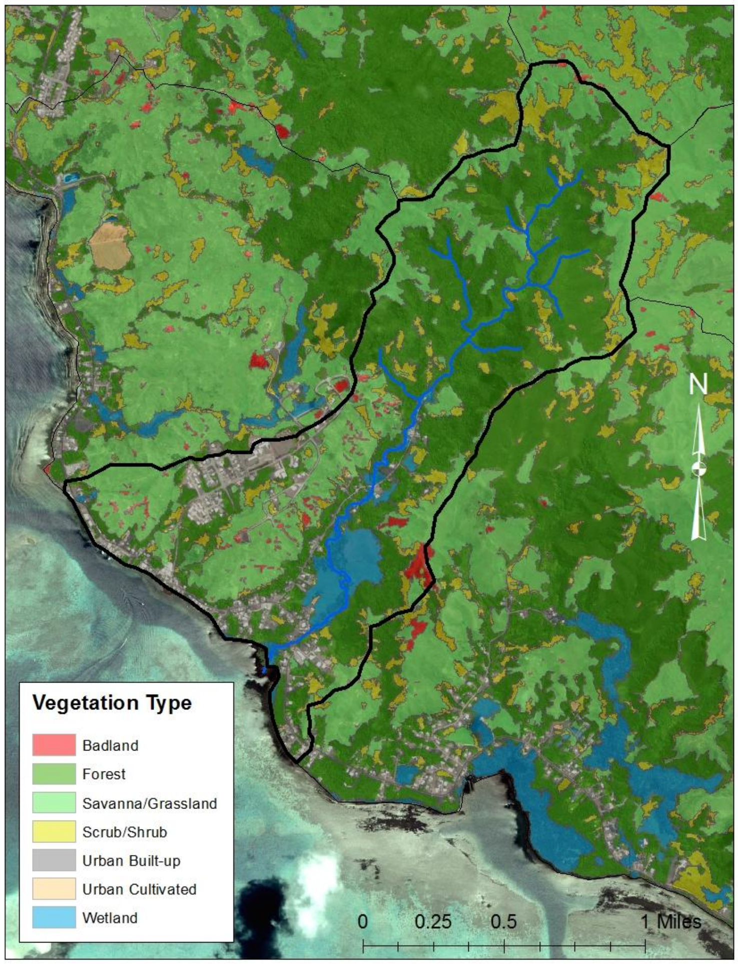

Figure 7. Vegetation Types

6. Land Use

The Geus Watershed is considered one of the more pristine watersheds on Guam. This watershed is primarily uninhabited except at its lower reaches where there are some residential developments and farmlands. Along the southwestern ridge is the Pigua residential subdivision along with the Merizo Elementary School, ballpark, and Community Center. Based on the 2011 remote sensing land cover data (from NOAA Ocean Service, Coastal Services Center, cited in Khosrowpanah et al, 2007b) processed via ArcGIS, 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 are the site of 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. Geus Watershed, Merizo (June 17, 2014)

Project Goals and Objective

This study has three main goals and objectives:

- Examine the dynamic behavior of the Geus Watershed by determining how different levels of rainfall triggers 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

Dumaliang, P.P. and S. Khosrowpanah (1998) developed an isoerodent map and erosivity factor (R) for application of the Universal Soil Loss Equation (USLE) on Guam. They measured soil loss of Akina clay from standard USLE plots and documented an average loss of about 1 ton/ha/week, based on 1-minute rainfall data.

Scheman, N.D. and S. Khosrowpanah (2003) measured erosion rates and sediment sources from badlands in the La Sa Fua Watershed of southern Guam. They found that RUSLE erosion estimates were more accurate when the LS-factors were empirically derived or field tested. Also, small patches of badlands in southern Guam watershed contributed considerably more to sedimentation than other vegetation cover types. Therefore, estimated rates of soil erosion were consistently higher than empirically derived rates.

Khosrowpanah and Jocson (2005) assessed non-point source pollution sources in the Ugum Watershed of southern Guam. They conducted site visits, model studies, and aerial photographs to recommend ways for reducing impacts of non-point sources with their potential impact on streams.

Park, M. and S. Khosrowpanah et al (2007a) developed a GIS-based erosion model to assess soil erosion in the Ugum Watershed based on the RUSLE equation. A digitized version of the isoerodent map developed by Dumaliang and Khosrowpanah (1998) was used for the R-factor. The LS-factors were derived based on the digital elevation model (DEM). The K-factor was taken from the National Resource Conservation Service (NRCS) soil survey database (Young, 1988). The C-factor was assigned based on land cover as determined by overlay satellite imagery.

Kottermair, M. (2010) used GIS modeling to investigate dynamics of badlands at three different study sites in separate watersheds of southern Guam. A comparison of historical aerial images from 1946, 1994, and 2006 were evaluated in GIS. It was determined that badlands evolve both naturally and from human activities suggesting that the badland dynamics are extremely complex.

Khosrowpanah, S., Lander, M., Golabi, M., and S. Manibusan (2012) conducted a study on the hydrologic response of the Piti-Asan Watershed to development. They collected rainfall, streamflow, stream level, and turbidity readings in the Piti-Asan Watershed from 2011 through 2012. They also conducted a GIS-based erosion model and aerial surveys to identify major sources sedimentation and how they might be better managed.

Methodology

1. Field observations
   Field visitations were conducted on a weekly basis from December 2013 through December 2014, and are still on-going. During each visit, conditions that may contribute to erosion and sedimentation that were observed were documented. These conditions include vegetation types, badland locations, slope and topography, and fires or other human activities (Figure 9 and 10). In addition, aerial surveys were conducted to observe land coverage from above and identify areas with more potential susceptibility to erosion.

Figure 9. Badlands Atop the Pigua Ridge, Merizo (March 15, 2014)

Figure 10. Burned Savanna along the Geus Slopes (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 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 collection is on-going.

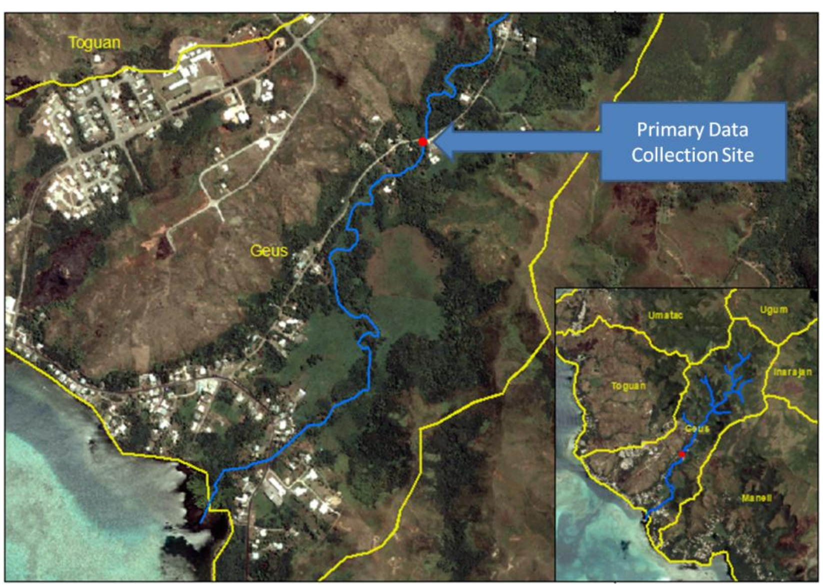

Figure 11. Location of Primary Data Collection Station

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. Water column height was calculated during data processing.

Figure 12. Installation of Data Loggers (January 15, 2014)

Figure 13. Field Download of Level Logger Data (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 Geus River (January 15, 2014)

Turbidity

Turbidity was measured two ways. An Analite NEP495P Turbidity Logging Probe was used 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 (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. The rain gauge uses two tipping buckets that collects water as it falls, recording each time the tipping buckets are activated representing a specific quantity.

3. Soil Sampling

Soil from seven locations was sampled and tested in the lab to identify the various soil types represented in the Geus Watershed. Samples were collected as composites from the sample locations selected based on exposed soil observations or supported vegetation types (Figure 16 and 17). 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 areas dominate.

Upon collection all samples were processed and analyzed at the University of Guam Soil Research and Testing 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.

Figure 16. Soil Sample Collection (June 3, 2014)

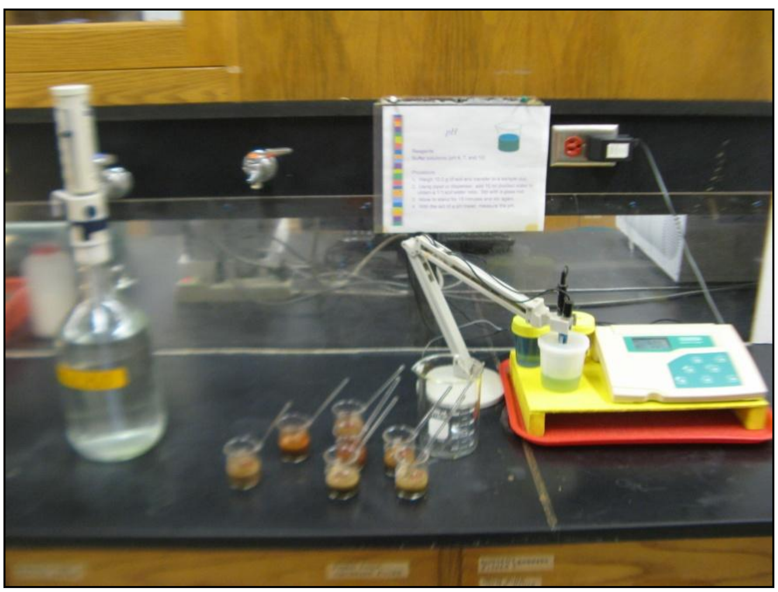

Figure 17. Laboratory Soil Analysis

4. GIS-RUSLE Model

The GIS-based soil erosion model developed by Park (2007) is based on the principles of the RUSLE (Renard et al, 1997). The RUSLE is a widely accepted method for estimating soil loss by statistical determination and calculation of several factors based on small field plot experiments. Combined with GIS, the RUSLE is can more accurately calculate soil loss using raster data files that can quickly assess a larger area as a grid. 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.

The GIS-based soil erosion model was applied to the Geus Watershed with the same data processing procedures as described by Park (2007) (Figure 18). 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.

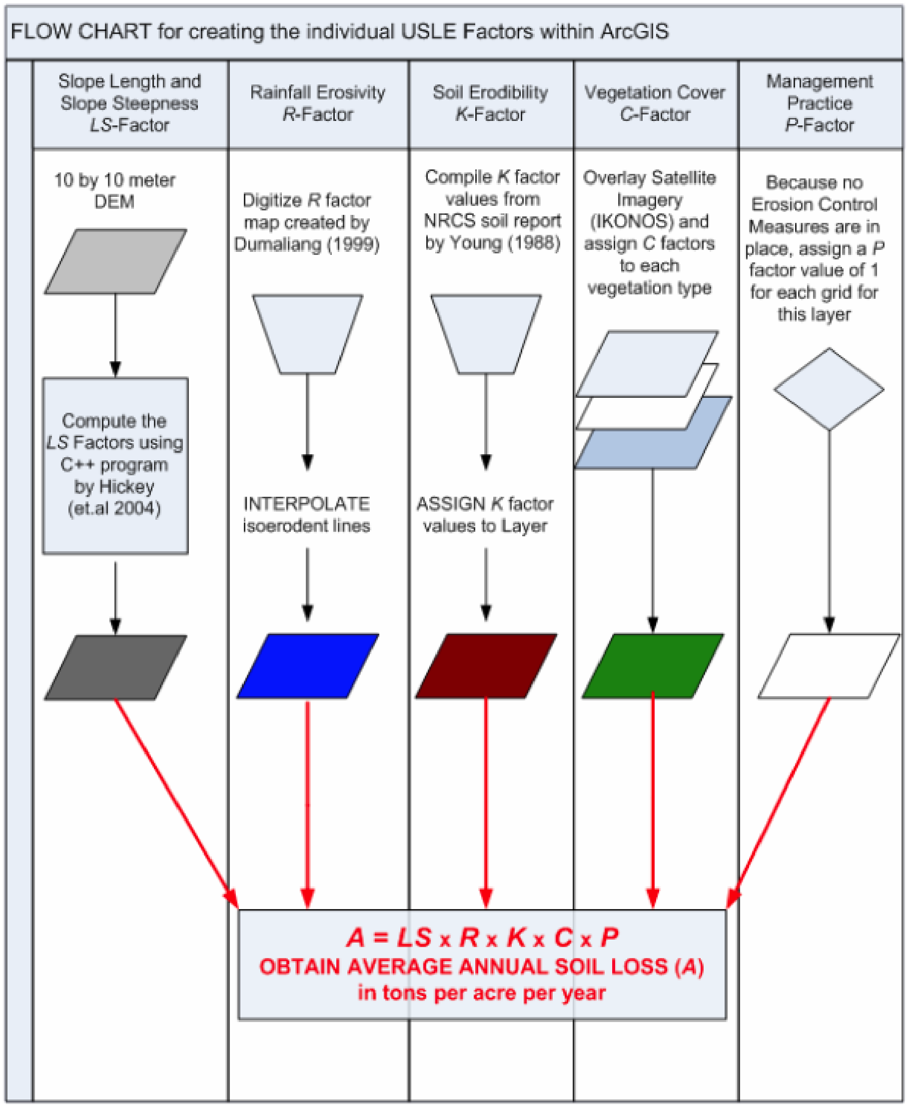

Figure 18. GIS-Based Erosion Model Flow Chart (Park, 2007)

Results and Discussion

Since data collection is still on-going, the current results are considered preliminary findings pending a more complete data set and thorough analysis for the final report. Hydrologic data collected was used to develop correlations between rainfall, stream level, stream flow, and turbidity (Figures 19, 20, and 21).

These correlations provide a better understanding of the dynamic behavior of the Geus Watershed. For example, the first graph (Figure 19) shows that rainfall of as much as one to two inches per day resulted in an increase in stream level on the order of one to two feet (baseline level during dry periods was about 0.35 feet). The maximum rainfall recorded was 7.27 inches on July 30, during Tropical Storm Halong. During this storm event the maximum stream level recorded was 7.0 feet at 2:05 am, and the duration was not longer than that 5-minute interval.

During that spike stream level was greater than six feet for 30 minutes, greater than five feet for 40 minutes, and greater than four feet for 70 minutes. Based on this data, the stream level doubled then came back down (from 3.5 to 7 feet) in less than an hour and a half. A similar pattern was exhibited in the turbidity data (Figures 20 and 21), which recorded a maximum concentration of 964.9 NTU from 2:15 am to 2:30 am on July 30. Turbidity above 900 NTUs lasted about an hour and a half, and significant differences were observed when stream level rose to greater than three feet. This storm event is one example that shows how dynamic the Geus Watershed is.

Based on the preliminary findings combined, it appears there is a strong correlation between stream level and rainfall in the Geus Watershed (Figure 19). In general, when more than one or two inches of rainfall occurred in a day, the stream level similarly increased. There also appeared to be a strong correlation between turbidity in the Geus River and rainfall (Figure 20). This observation is supported by overlaying stream level with stream turbidity (Figure 21). This is also important because it provides a baseline under current watershed conditions and helps predict how the watershed may respond to future developments.

The preliminary stage discharge curve is also presented below (Figure 22). The stage discharge curve will gain greater accuracy as more data under a range of flow regimes continues to be collected. This watershed management tool will provide an estimate of flow based on measured stream levels.

The results of the GIS-based erosion model are shown in Figure 23. The quantities of erosion listed (maximum of 1,141.56 tons/acre/year) is considered an estimate that could be further evaluated based on actual field studies. However, one thing that this data provides is an 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 23). The steep terrain at the back of the valley appears to also have some level of increased contribution to erosion based on this model.

Hydrologic data can also be useful for comparison with the same parameters measured at other watersheds of southern Guam. For the sake of this preliminary evaluation, when compared to turbidity readings from the Piti and Asan Watershed, the Geus Watershed turbidity appears to include much higher levels of suspended solids during rain events. During typical rain events turbidity in the Geus River rises to around 100 NTUs, slowly decreasing to 20 NTU or so. During tropical storm Halong (July 30, 2014) the turbidity peaked at almost 1,000 NTU. However, all of the highest turbidity readings collected were in-part because a turbidimeter was installed and logging data every 15-minutes. The highest turbidity recorded manually during site visits was 21 NTU. At the Piti and Asan Watersheds turbidity was only collected manually using the hand-held turbidimeter multiple times per week. The maximum turbidity readings observed were around 80 – 100 NTU following rain events (Manibusan, 2012). A more detailed analysis will be provided with a more complete dataset in the final report.

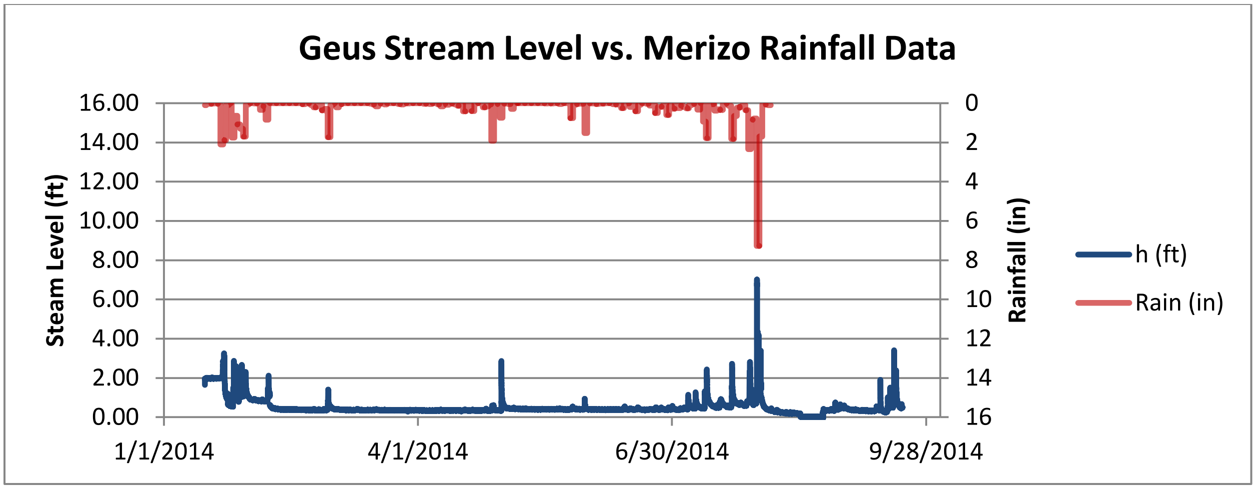

Figure 19. Geus Stream Level and Rainfall, Preliminary Data

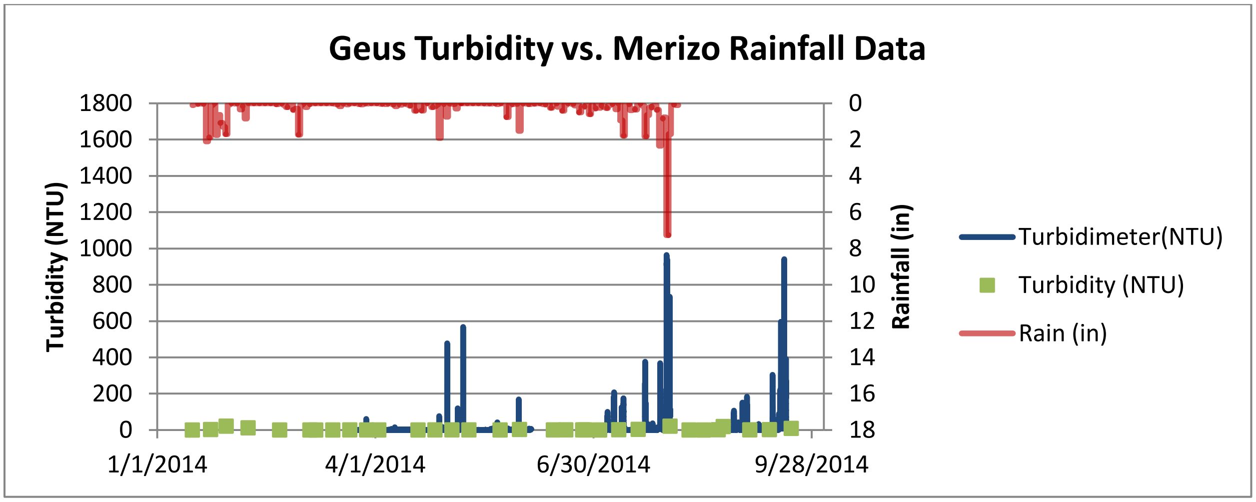

Figure 20. Geus Turbidity and Rainfall, Preliminary Data

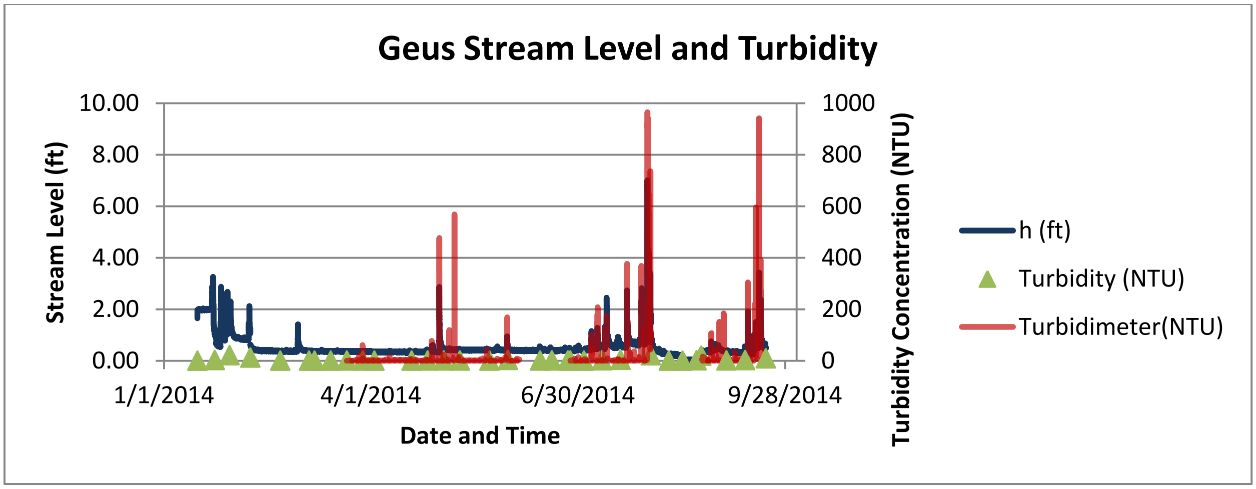

Figure 21. Geus Stream Level and Turbidity, Preliminary Data

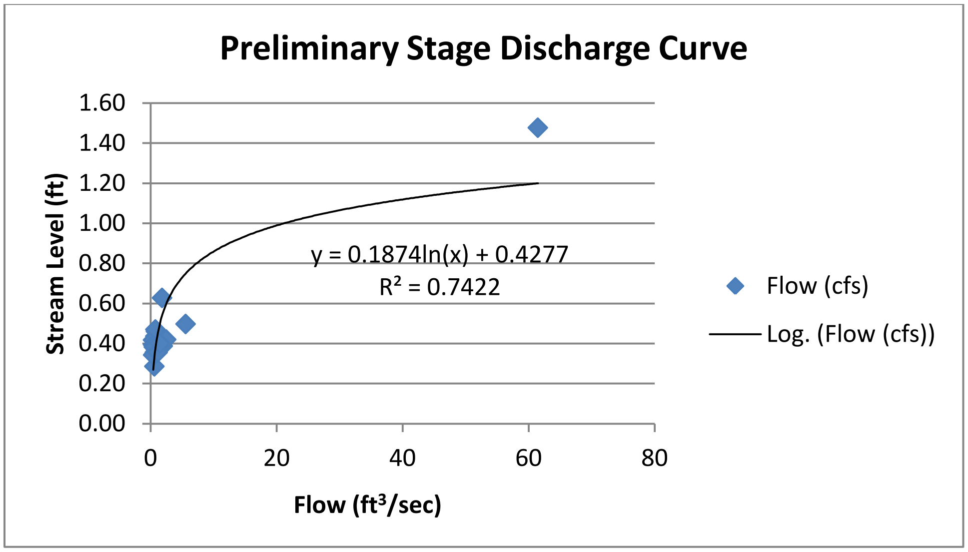

Figure 22. Preliminary Stage Discharge Curve for Geus River

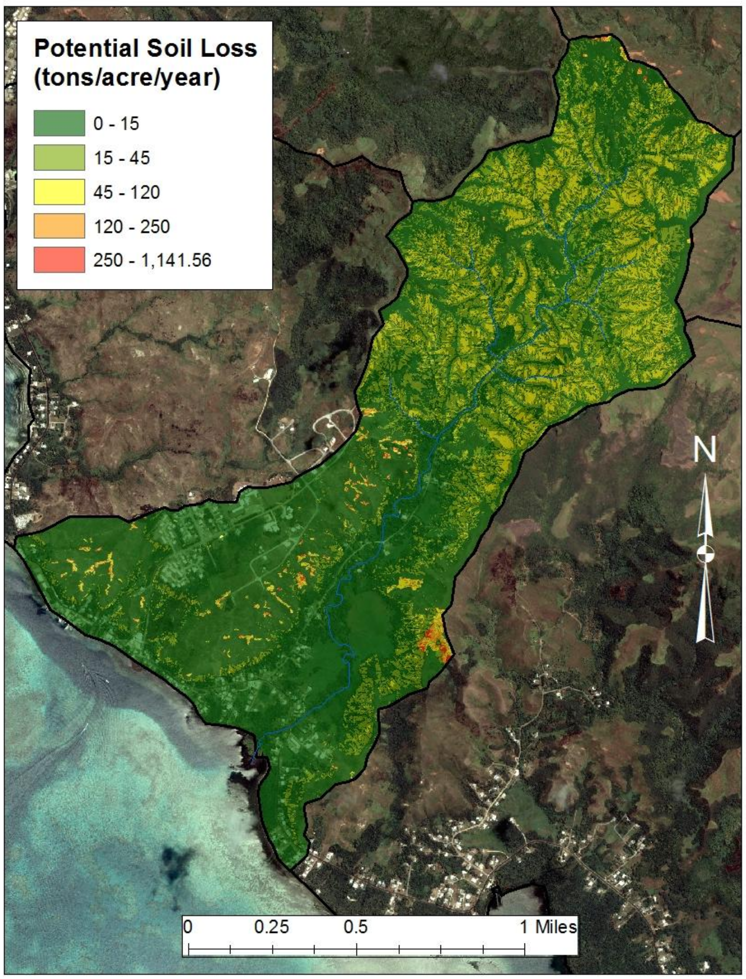

Figure 23. Preliminary Results of GIS-Based Erosion Model

Literature Cited

Burdick, D., V. Brown, J. Asher, M. Gawel, L. Goldman, A. Hall, J. Kenyon, T. Leberer, E. Lundblad, J. McIlwain, J. Miller, D. Minton, M. Nadon, N. Pioppi, L. Raymundo, B. Richards, R. Schroeder, P. Schupp, E. Smith, and B. Zgliczynski. 2008. The State of Coral Reef Ecosystems of Guam. Waddell, JE and AM Clarke, editors. 465-509.

Dumaliang, P., and S. Khosrowpanah. 1998. Soil Erosion in Micronesia. American Water Resources Association: Third International Symposium on Tropical Hydrology and Fifth Caribbean Islands Water Resources Congress, San Juan, Puerto Rico. July 12 – 16, 1998.

Dumaliang, P. 1998. M.S. thesis on The Determination of R-Factors for Southern Guam by accounting for Climate Variability. University of Guam. Mangilao, Guam. March 1998.

Golabi, M.H., C. Iyekar, and M. J. Denney. 2005a. Challenges and Actions Regarding the Rehabilitation of Degraded Lands: Case Study from the Pacific Island of Guam. Sociedade & Natureza, Uberlandia, Special Issue, 87-106. May 2009.

Golabi, M., C. Iyekar, D. Minton, C. L. Raulerson, and J. Chargualaf Drake. 2005. Watershed Management to Meet Water Quality Standards by Using the Vetiver System in Southern Guam. AU J.T. 9(1): 63-70. July 2005.

Khosrowpanah, S. and N. Scheman. 2003. Badland Erosion rates and Sources in a Tropical Watershed. Proceedings of 2003 Annual Conference, Soil and Water Conservation Society. Spokane, Washington. July 2003.

Khosrowpanah, S. and J. Jocson. 2005. Environmental Assessment for Non-Point Sources of Pollution for Ugum Watershed. Technical Report No. 109, Water and Environmental Research Institute, University of Guam. December 2005.

Khosrowpanah, S., L. Heitz, Y. Wen, and M. Park. 2007a. Developing a GIS-Based Soil Erosion Potential Model of the Ugum Watershed. Technical Report No. 117, Water and Environmental Research Institute, University of Guam. December 2007.

Khosrowpanah, S., Y. Wen, and L. Heitz. 2007b. Development of a digital watershed atlas for Guam. Technical Report No. 116, Water and Environmental Research Institute of the Western Pacific, University of Guam. 2007.

Khosrowpanah, S., M. Lander, M. Golabi, and S. Manibusan. 2012. A GIS-Based Watershed Management Plan for the Piti-Asan Watersheds. Technical Report No. 139, Water and Environmental Research Institute, University of Guam. October 2012.

Kottermair, M. 2010. MA thesis on Spatio-Temporal Dynamics of Badlands in Southern Guam: A Case Study of Selected Sites. University of Guam. Mangilao, Guam. November 2010.

Lander, M. A. and C. P. Guard. 2003. Creation of a 50-Year Rainfall Database, Annual Rainfall Climatology, and Annual Rainfall Distribution Map for Guam. Technical Report No. 102, Water and Environmental Research Institute, University of Guam. June 2003.

Manibusan, S. 2012. MA thesis on The Hydrologic Response of the Piti-Asan Watershed to Development. University of Guam. Mangilao, Guam. October 2012.

Minton, D. 2006. Fire, Erosion, and Sedimentation in the Asan-Piti Watershed and War in the Pacific NHP, Guam. Technical Report 150, Pacific Cooperative Studies Unit, University of Hawaii at Manoa. November 2006.

National Oceanic and Atmospheric Administration (NOAA). 2014. Press Release: NOAA Selects Manell-Geus Watershed on Guam as "Habitat Focus Area." Released February 5, 2014 via Pacific New Center Guam.

Park, M. H. 2007. M.S. thesis on Developing a GIS-Based Soil Erosion Potential Model for the Ugum Watershed. University of Guam. Mangilao, Guam.

Renard, K. G., G.R. Foster, D.K. McCool, and D.C. Yoder. 1997. Prediction soil erosion by water: A guide to conservation planning with the revised Universal Soil Loss Equation (RUSLE). USDA Agricultural Handbook 703.

Scheman, N., S. Khosrowpanah, M. Golabi, and L. Heitz. 2002. Identification of Erosion Processes and Sources of Exposed Patches in the La Sa Fua Watershed of Southern Guam. Technical Report No. 99, Water and Energy Research Institute, University of Guam. December 2002.

Siegrist, H. G., Jr., M. K. Reagan, R. H. Randall, J. W. Jenson & L. Masonic. 2008. Map: Generalized Geology of Guam, Mariana Islands. Funded by Water & Environmental Research Institute at the University of Guam through the Guam Hydrologic Survey Program.

Van Remortel, R., R. Maichle, and R. Hickey. 2004. Computing the RUSLE LS Factor based on Array-based Slope Length Processing of Digital Elevation Data Using a C++ Executable. Computers and Geosciences Volume 30. No. 9-10, pgs 1,043-1,053.

Young, F. J. 1988. A Soil Survey of the Territory of Guam. Soil Conservation Service, United States Department of Agriculture (USDA).