A GIS- Based Watershed Management Plan for the Piti-Asan Watersheds

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ABSTRACT

The Piti-Asan Watershed is considered one of three "priority watersheds" (Kottermair, 2012), which contains several conservation areas and two large proposed developments. Within the Piti- Asan Watershed there was an estimated 2103 people during the 2000 census, which was estimated to have grown to 2454 by 2010. Furthermore, increased construction within the watershed and around the rest of the island is expected to occur as a result of the current population trends. These expected changes will have an effect on the dynamic hydrologic behavior of the watershed. Furthermore, sediment carried to the Piti and Asan Bay outlets from the watershed can adversely affect nearby coastal and marine communities.

This project performed an analysis of the potential impact of existing and proposed natural and human activities on the watershed behavior and suggested recommendations to manage such activities in order to reduce the impacts on the watershed. This study analyzed the hydrologic behavior of the Piti- Asan Watershed through measurements of rainfall, stream level, stream flow, and river turbidity over the course of one year. Estimates of erosion contribution by areas within the watershed were conducted using the GIS erosion model developed by Park (2007).

A correlation between the collected hydrologic data was made. The product of the research was a stage discharge curve for the Masso and Asan Rivers. The study determined the areas contributing the most potential erosion and the major causes of soil erosion in the Piti-Asan Watershed. Such causes of erosion included: erosive soils, poor vegetative soil cover, bank erosion, steep slopes, heavy rainfall events, improperly managed construction, and lack of erosion management on existing buildings. Management strategies to address these problems were suggested.

Introduction
Chapter 1

1.1 Location

The Piti-Asan Watershed is located along the western shore of central Guam (Figure 1). The boundary of the watershed, outlined in Figure 2, ranges from Adelup to the Piti Power Plant and inland to the ridgeline on Nimitz Hill with Sasa Valley Tank Farm to the South and encompasses only part of Piti and Asan Municipalities. According to a recent study by Kottermair (2012), the Piti-Asan Watershed is one of three "priority watersheds needing restoration in the Clean Water Action Plan."

As a priority watershed, the area requires baseline data for restoration efforts. Data required includes: a compilation of available historical data regarding the Piti-Asan Watershed, hydrologic field data to understand the dynamic behavior of the watershed, an estimate of potential impacts of human activity on the watershed dynamics, a stage discharge curve for the watershed rivers to aid in future study of the watershed, a model to estimate the potential soil erosion of the watershed system, and best management practices of the watershed system to aid in maximizing the effect and viability of future restoration efforts.

The current civilian population on Guam is around 181,000 and is expected to increase to 204,000 by 2020 (U.S. Census, 2012). In the Piti-Asan Watershed alone, there was an estimated 2,103 people in 2000, which was estimated to have grown to 2,454 by 2010 (Kottermair, 2012). With the impending population growth around the island, the population in the Piti-Asan Watershed area and other watersheds around the island are also expected to see a dramatic increase. Furthermore, increased construction activity is expected to occur as a result of the population influx. These expected changes in population and increase in construction in the Piti-Asan Watershed area will have an impact on the dynamic behavior of the watershed (i.e. increased sedimentation, increased risk of contamination, changes in stream flow). Sediment and other material carried to the Piti and Asan Bay outlets from the watershed can adversely affect coastal and marine communities because of a decline in water quality.

Figure 1: Piti-Asan Watershed (2012)

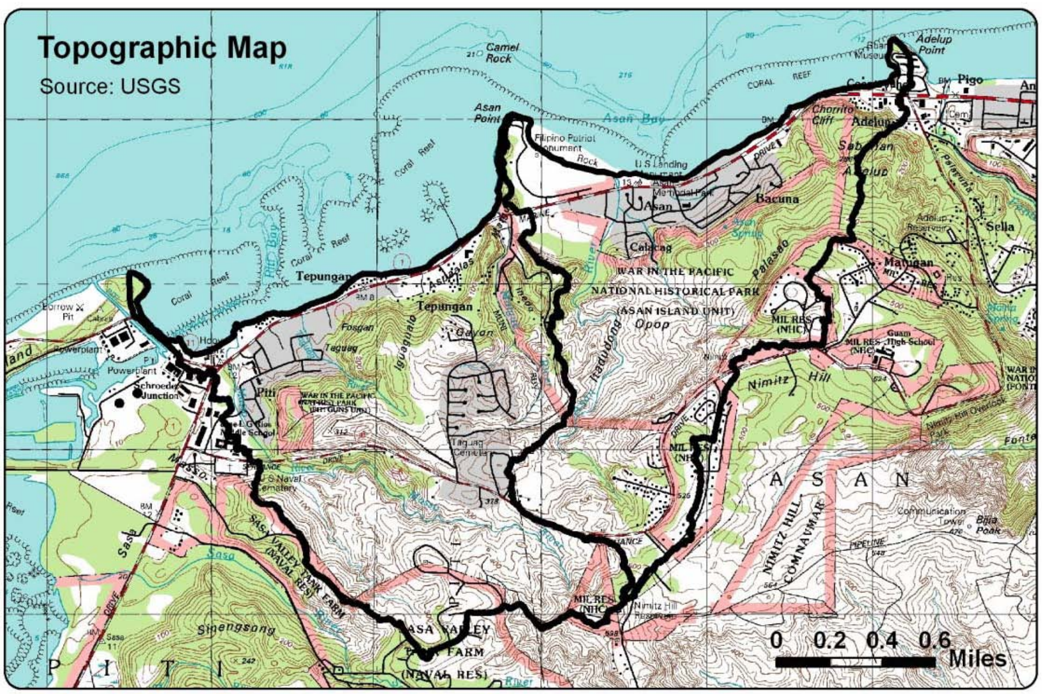

Figure 2: USGS Topographic Map (Kottermair, 2012)

The watershed area also contains many important conservation areas including the Masso Reservoir, parts of the War in the Pacific Memorial Park (i.e. Asan Beach Unit, Asan Inland Unit, and Piti Guns Unit), and The Piti Bomb Holes Preserve (Figure 3). The next bay south of the study site also contains the Sasa Bay Preserve. Each of the conservation areas located within the Piti-Asan Watershed feature some recreational activities. These facilities are normally used by both locals and tourists.

The Piti-Asan Watershed consists of two Sub-Watersheds: the Piti Watershed outlets flow into the Piti Bay and the Asan Watershed flows directly into the Asan Bay. Furthermore, the watershed is divided into several sub-basins identified in Figure 4. These sub-basins collect runoff which is deposited into their respective rivers. The major contributors of runoff to the Piti-Asan Watershed are the Asan River in the Asan sub-basin of the Asan Sub-Watershed and the Masso River in the Masso sub-basin of the Piti Sub-Watershed. Because the Masso and Asan Rivers are the two major rivers flowing through the Piti-Asan Watershed, they are the focus of the hydrologic study conducted.

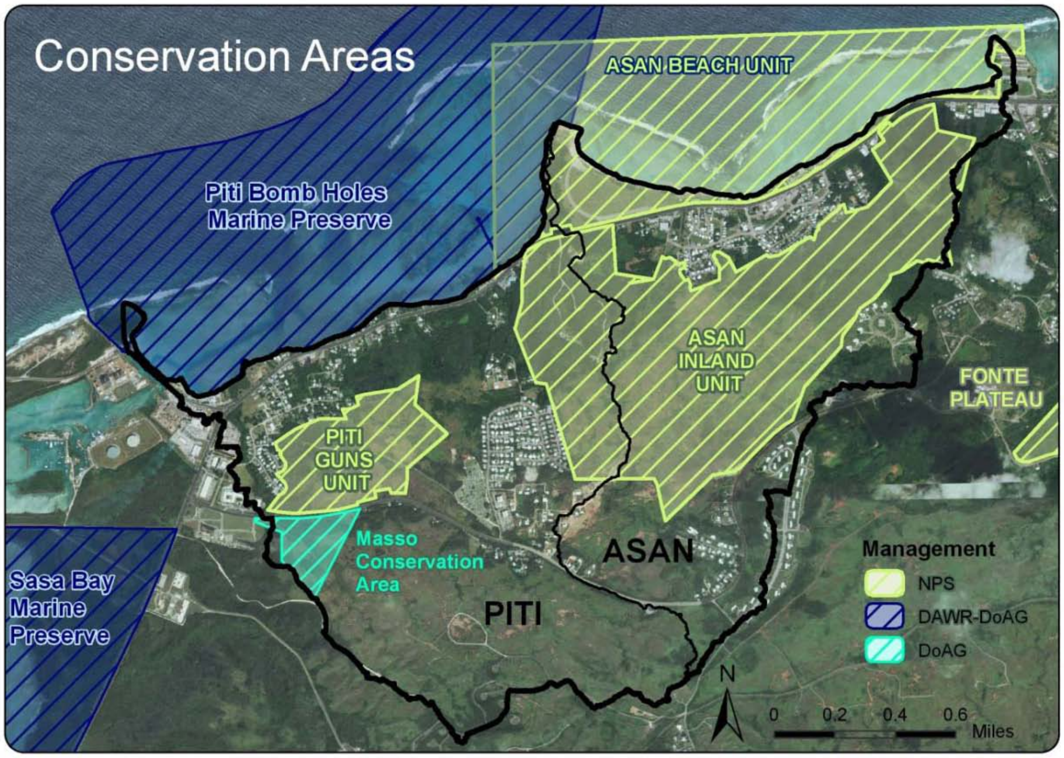

Figure 3: Piti-Asan Watershed Conservation Areas (Kottermair, 2012)

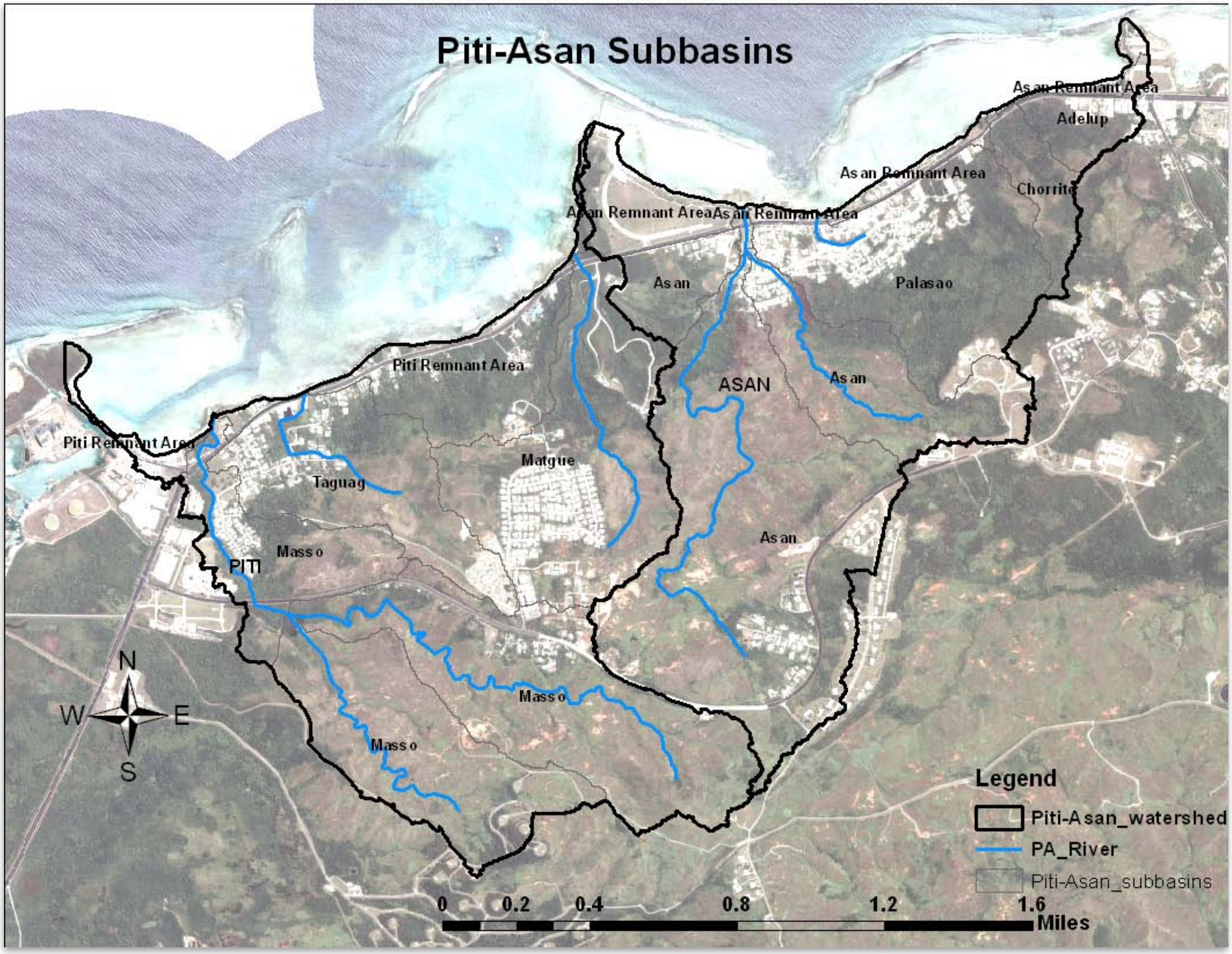

Figure 4. Piti-Asan Watershed Sub-basins

1.2 Climate

“Climate is a major factor controlling streamflow patterns and the shaping of landforms and vegetation communities (Gordon et al, 1992).”The rainfall gradients and the patterns on Guam are “strongly influenced by the northeast-southwest orientation of the island, the shape of the island, and the terrain of the island (Lander and Guard, 2003).” As such, the major rainfall patterns on Guam are “generally oriented north-northeast—south-southwest, with maxima and strong rainfall gradients located along the western and southern mountains.” Guam has two primary seasons: the wet season, which runs from July through December, and a dry season, which occurs from January through June (Lander 1994). “Nearly all extremely dry years on Guam occur during the year following an El Niño event (Lander and Guard, 2003).”

1.3 Geology

The Piti- Asan Watershed lies southeast of the Pago-Adelup fault, which divides the northern limestone and the southern volcanic uplands of Guam. The topography of the Piti- Asan Watershed, as seen inFigure 2, varies in elevation from sea level to 729 feet above sea level with slopes less that 15% along the coastal plain, but is steeper along the hillside. About 36% of watershed has slopes greater than 30% (Kottermair 2011). The majority of the watershed lies on the Alutom formation (Figure 3). The coastal plain of the watershed consists primarily of alluvium and beach deposits. The lower portion of the watershed consists of Mariana limestone while the higher elevations in the northeast are covered by Alifan limestone. The northeastern area of Nimitz Hill also contains many cave features, namely“fissures, sinkholes, pits, and shelter caves”(Taborosi, 2004).

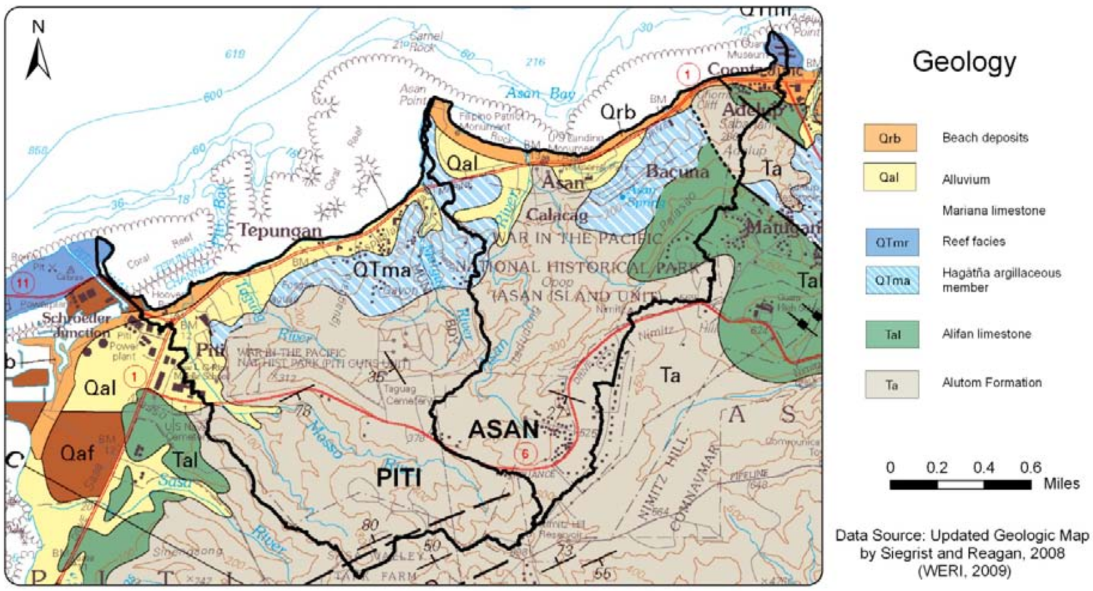

Figure 5. Geology Map (Kottermair 2011)

1.4 Soils

The most common soil types along the Asan-Piti watershed are the Agfayan-Akina and Akina-Badland complexes. The side slopes and ridge tops consist of Agfayan and Akina soils whereas flat areas consist of Inarajan type soils. The lower elevated areas of the watershed, which are underlain by limestone, consist of Pulantat clay and Ritidian-outcrop soils (Young, 1988).

Akina-Agfayan complex contains “very shallow to very deep, well drained, moderately steep to extremely steep soils; on strongly dissected mountains and plateaus (Young, 1988).” The Inarajan soils are often “[d]eep and very deep, somewhat poorly drained, level and nearly level soils; on valley bottoms and coastal plains.” The Inarajan variant is found“in the major valleys in the central and southern parts of Guam. It is also on coastal plains along the southern coast and extends from Agat to Piti on the western coast.” Pulantat clay is characterized by “[s]hallow, well drained, gently sloping to steep soils; on dissected plateaus and hills.” They are composed of clay and silty clay over argillaceous limestone.Ritidian–rock outcrop soils are “very shallow, well drained, gently sloping to extremelysteep soils, and Rock outcrop; on plateaus, mountains,and escarpments (Young, 1988).”

1.5 Vegetation

The Piti- Asan watershed area is dominated by forest and savanna, which covers roughly two-thirds of the watershed as represented in Figure 6(Kottermair, 2012).Roughly 21 percent of the watershed is developed, about half of which are comprised of impervious material.About eight percent consists of scrub and shrub vegetation and about one percent consists of wetland vegetation. The remaining two percent consists of bare land.

According to Wiles and Ritter (1993), Guam contains more wetlands and more wetland varieties than any of the other Marianas Islands. On Guam, all rivers and nearly all wetlands occur in the southern and central parts of the island. Wetland categories on Guam include: freshwater swamps with woody vegetation, natural freshwater marshes that are usually dominated by *Phragmites karka*, man-made freshwater wetlands (originally used as water containment for humans, cattle, and crop irrigation), and estuarine wetlands located in brackish water or tidal intrusion areas. Some factors affecting wetlands on the island include: the development of land, especially filling in of wetlands and poor planning, grassland fires, and pollution of which nearly half of the islands wetlands are affected (Wiles and Ritter, 1993).

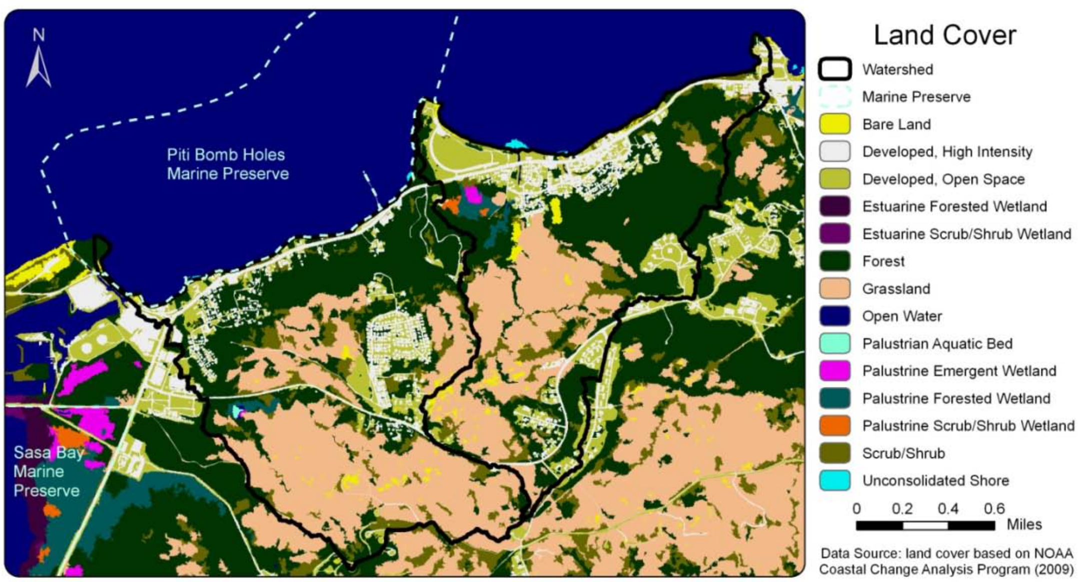

Figure 6. Piti- Asan Land Cover Map(Kottermair, 2012)

1.6 Land Use

The Piti-Asan Watershed is the drainage area for Piti Bay and Asan Bay. Several perennial and ephemeral rivers drain into the two bays. The watershed also contains the Masso Reservoir and the Asan Dam. The watershed boundaries used in this project were derived by Kottermair (2012).Limited stream flow data has been gathered historically for some of the rivers in the watershed area. There are also several points in the watershed where groundwater seeps to the surface. However, the Asan Spring is the only mapped spring, which was used as a pumping site by the Guam Waterworks Authority (GWA) from 1915 until 2003, when it was discontinued because of poor water quality, whichwere caused by high coliform bacteria levels. The coast of the Piti-Asan area is also considered a high flood zone area.

According to Wiles and Ritter (1993), the Masso Reservoir in Piti (Figure 7) is a man-made reservoir that is a common moorhen habitat. The reservoir was built by Navy around 1945 for drinking water use but abandoned due to siltation in 1951. Since then, the property was turned over to the Government of Guam. The Guam Department of Agriculture's Division of Aquatic and Wildlife Resources (DAWR) renovated in 1978 as a fishing area but the project was terminated in 1983 due to illegal fishing with chlorine (Wiles and Ritter, 1993). Most recently, DAWR has renovated the reservoir for recreational use including a fishing platform. The renovation project also included reforestation efforts and hiking trails surrounding the Masso Reservoir (Figure 7).

Figure 7: Masso Reservoir, Piti (August 16, 2012)

The Piti-Asan region was historically a fishing village during the Spanish occupation era and later developed into farming villages, which grew crops such as taro, rice, and sugarcane (Kottermair, 2012). Various land uses existing today include residential housing, conservation areas, commercial properties, and recreational facilities. Currently vacant private lots are also likely to be developed in the future.

One such planned development is a proposed 240 unit residential subdivision on a 25 acre lot on Nimitz Hill by JHP Development (Figure 8 and 9), which was rezoned from agricultural land (zone A) to a multi-family residential zone (R-2). This proposed development poses a risk of increased sedimentation due to proximity to the nearby Asan River and stream, which passes through the property as well as its uneven and partly steep sloping terrain (Kottermair, 2012). Other individual houses and business infrastructure are also expected in the area because of the increasing island population.

A second large scale planned development of 194 residential units comprised of 78 single-family homes and 116 condominium and townhouse units by Hanjin Heavy Industries & Construction Co., Ltd (DC&A, 2011). About 33 acres of land is undergoing a proposed zone change from agricultural zone (A) to a multifamily-residential zone (R-2). The proposed project site is located in Piti (Figure 8 and 10) and is adjacent to the Nimitz Estates subdivision on Nimitz Hill (DC&A, 2011). In addition to the major proposed developments by JHP Development and Hanjin Heavy Industries & Construction Co., Ltd other private homes are also being constructed within the Piti-Asan Watershed (Figure 11, 12, 13, and 14).

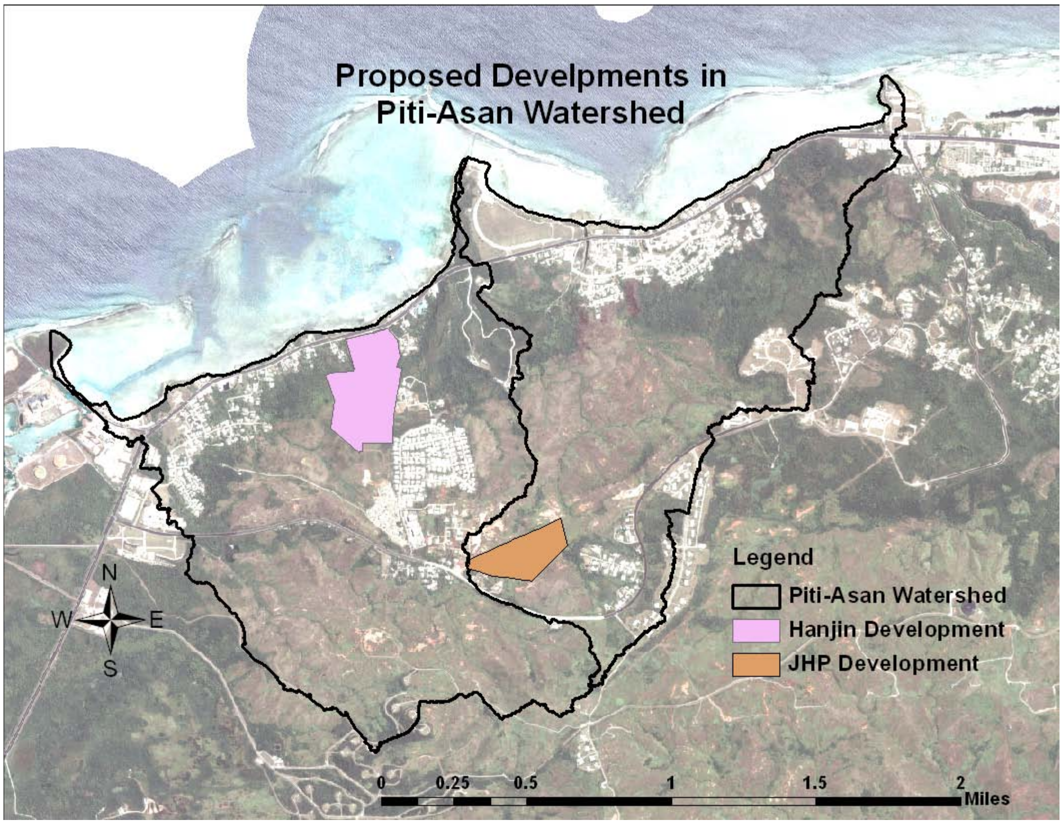

Figure 8: Map of Proposed Housing Development Sites

Figure 9: Site of Proposed JHP Development (August 16, 2012)

Figure 10: Site of Proposed Hanjin Development (August 16, 2012)

Figure 11: Piti-Asan Watershed Construction (June 20, 2012)

Figure 12: Piti-Asan Watershed Construction (June 20, 2012)

Figure 13. Aerial Image of a Clearing Site nearAsan River (July 12, 2012)

Figure 14: Clearing and Grading Near Asan River (March 12, 2012)

1.7 Objectives

This project aims to investigate the dynamic behavior of the watershed, to analyze the potential impact of several proposed human activities on the watershed behavior, to produce a stage discharge curve for the Piti and Asan Watershed systems, and to make recommendations on how to manage activities to minimize the negative impact of human activity on the Piti- Asan Watershed. The project also used the Piti- Asan Watershed erosion management plan as a model for other watersheds around the island.

The primary objective of this project is to investigate the dynamic behavior of the Piti- Asan Watershed under different scenarios.Hydrologic data was collected and combined with existing current and historical data pertaining to the Piti- Asan Watershed was modeled using the GIS erosion model developed by Park (2007) in order to understand the existing behavior of the watershed and to predict potential future behavior of the watershed based on proposed and existing development and natural watershed activity.The collected data and model predictions will allow future prediction of the watershed behavior based upon the various proposed activities. Using this knowledge, management strategies were developed to prevent damage to the watershed.

Review of Literature
Chapter 2

2.1 Guam Watershed Management

The Government of Guam's (GovGuam) Clean Water Action Plan for Guam (1998) aimed to achieve clean water through the encouragement of interagency collaboration to restore high priority watersheds on Guam. As part of this plan, the island was divided into 20 sub-watersheds, which were further subdivided into four categories based on national guidelines for prioritizing watershed management. The three "Category I" (highest priority) watersheds identified in 1999 were the Northern, Ugum, and Talofofo watersheds (GovGuam, 1998).

The Guam Comprehensive Watershed Planning Processwhich was developed in 2003 by the Guam Environmental Protection Agency (GEPA) and the Guam Bureau of Statistics and Plans – Guam Coastal Management Program (GCMP), established a framework for watershed stakeholders to develop watershed management plans which implement regulatory nonpoint source management measures. The implementation of such measures is desired in order to restore and protect Guam's water quality in watersheds. The planning framework cites two levels of organization: the community level, and territory or "state" level. Community level management includes goal setting and prioritizing of resources and stewardship promotion by individual watershed community stakeholders, while the state management level includes the overall management strategy for the island as well as determining the direction and priority-making for restoration of impaired watersheds. Components of the Comprehensive Watershed Management Approach include: Data collection and monitoring, Assessment prioritization, Strategy development, Watershed plan review and approval, and Implementation and evaluation. The document also recommended the development of a list of preferred practices to avoid duplication of efforts by the various stakeholders (GEPA and GCMP, 2003).

The Nature Conservancy (TNC, 2009) created a Draft Conservation Action Plan with the aim for Piti to become a model of a "community based, management driven, [and] environmentally friendly village with sustainable resources in harmony with the environment." This plan is part of an effort to: preserve and enhance water quality, native forest, coral reef ecosystem, and endangered species in the Piti watershed. The plan includes an analysis of conservation targets, current condition, ranked threats, potential strategies, and a capacity assessment in order to better direct efforts to improve conservation and reduce human impacts on the natural environment (TNC, 2009).

2.2 Piti- Asan Watershed Research

Past and present monitoring studies performed in the Piti- Asan Watershed Area include weekly beach monitoring by the Guam Environmental Protection Agency (GEPA), which tests water quality at Adelup Park, Asan Bay, Piti Bay, and Santos Memorial Park. Stream water testing was conducted by the Environmental Protection Agency (EPA) from 1975 through 1977, in 1997, and 1999. The National Park Service (NPS) has also been monitoring the Asan River since 2005 with eight fixed sites and eight temporary stations tested every year. The Guam Waterworks Authority (GWA) tests the groundwater quality within the watershed every year. USGS is currently conducting a two-year long rating curve analysis of flow in the Asan River that began in 2011.

Abotanical inventory study by Yoshioka in 2008 documented at least 90% of the plant taxa within the seven units of the War in the Pacific National HistoricalPark (Asan Beach, Asan Inland, Fonte Plateau, Piti Guns, Agat, Mount Chachao-Mount Tenjo, and Mount Alifan).As mentioned, the Asan Beach, Asan Inland, and Piti Guns Units of the War in the Pacific Memorial Park are all contained within the Piti- Asan Watershed. Within the seven park units, 392 plant taxa were identified, of which: 44% (173) of the plants are native to Guam and the Mariana Islands, 4% (15) are endemic and 40% (158) are indigenous. The field surveys of the plants were accompanied by collection of plant specimens, digital images, landscape images, and an addition of new records to NPSpecies (Yoshioka, 2008).

The reefs located within the War in the Pacific NHP are highly affected by numerous terrestrial activities. Of these activities, sedimentation is one of the most significant threats to the long-term health and persistence of the park reefs. Based on two 3-month deployments of recruitment plates at a single depth, the study conducted by Minton and Lundgren found only 16 coral recruits were observed on 384 plates totaling 30.04 m^2. The Coral Recruitment and Sedimentation paper concluded that there was no correlation between recruit density and the sediment collection rate that was observed. Furthermore, the settlement patterns of recruits on plates suggested that light, not sediments or predation, was the primary factor affecting settlement patterns on the reef. The paper concluded that “low recruitment rates and lower light availability as a result of sedimentation raises significant concerns about the long-term health and persistence of the coral reefs within the park (Minton and Lundgren, 2006).”

The project goal of the Masso Watershed Restoration Project was to reduce the amount of sedimentation released from the Masso watershed, which affects the Piti Marine Preserve area, and, in doing so, enhance the water quality. The plan for the project includes: tree planting of nitrogen fixing trees to increase forest vegetation, planting of a green belt as fire breaks, and ungulate fencing to reduce rooting, browsing and trampling by ungulates. Erosion pins were also used to monitor change in soil surface level over time within planted grasslands and badlands (Forestry & Resources Division, 2007).

The Vegetation Strategy for Southern Guam was written to recommend strategies for addressing watershed, wildfire, biodiversity and invasive species concerns problems in southern Guam. The primary long-term goal of the strategy is to reduce wildfire occurrences and to make Southern Guam into a more stable native community or a culturally and/or economically productive community that maintains natural ecosystem functions. Strategy recommendations include: shaded fuel breaks to separate grasslands, vegetation of badlands with bare soil, propagation of native species forest, and management of feral ungulates and invasive plants. The paper concluded that land ownership will be a large factor in the implementation of the management strategy and can become an impediment to the project goals (Bell et al., 2002).

The Guam Better Site Design Workshop Summary consists of a summary of the various ideas that were generated during a training workshop by the Center for Watershed Protection (CWP) and Horsley Witten Group (HW) on better site design (BSD) and storm water management. The purpose of the workshop was to introduce effective watershed planning, storm water management, and site design techniques that can be implemented island-wide. The workshop participants make several recommendations including demonstration sites of BSD practices and specifically BSD and management improvements in the Piti watershed area (CWP and HW, 2010).

2.3 Erosion and Sedimentation in Piti- Asan Watershed

According to Minton (2006), erosion and sedimentation are a major threat to Guam's terrestrial and aquatic habitats. Wildfire events in particular have been identified as a driver in the formation of savanna ecosystems. A fire, erosion, and sedimentation study was conducted because the interactions between erosion, sedimentation, and wildfire have been poorly investigated on Guam. Erosion and sediment close to the shoreline were identified as concerns for the long-term health and persistence of Guam's savannas and coral reef ecosystems. The study concluded that "effective watershed management is the only way to achieve long-term reductions in these environmental impacts."

Furthermore, the only way to fully address coastal sedimentation in Asan is to reduce soil erosion and soil transport through BMPs (Minton, 2006).

Golabi et al. (2005) measured runoff rate for different soil surface treatments, quantified sediment loss, and to evaluated the effectiveness of Vetiver grass on erosion and sediment loss and provided recommendations for restoration of the lands affected by erosion. The study plots included: natural vegetation, bare soil, controlled burn areas, and vetiver grass. Vetiver grass was concluded to be effective in reducing the sedimentation from sample plots and a potentially effective tool for reducing erosion within watershed systems on Guam (Golabi et al., 2005).

Sediment, nutrients, and other pollutants from many anthropogenic activities are detrimental to many coral reef ecosystems. The two primary activities that can impact the coral reef ecosystems are pollution and coastal land use/development. The purpose of the study was to determine ocean circulation patterns along the coast and sedimentation in the War in the Pacific Asan Unit and its coral reef ecosystem. The data collection included continuous measurements of winds, rainfall, river discharge, waves, currents, tides, and water properties (turbidity, temperature, salinity, and light) to analyze near shore circulation and circulation variability. The goals of the experiment were to understand the delivery of sediment to the bay and its residence time in the bay. The study found that turbidity was relatively low in the bay and was similar to other areas of west-central Guam. The study concluded that sedimentation in Asan Bay was primarily from erosion of the carbonate reef flat sediment and terrestrial sediment discharged from the Asan River (Storlazzi et al., 2009).

Light Detection and Ranging (LiDar) is a remote sensing technology used in a GIS databases to collect topographic data. LiDar was used in Kottermair's project to collect topographical data for the Piti- Asan watershed. The main project goal was to identify areas suitable for revegetation projects, which included non-forested, steep areas in government land that were close to rivers. The LiDar analysis found that 65% of public land near rivers has low vegetative cover and 41 % (35ha) has steep slopes, which are priority re-vegetation areas (Kottermair, 2009).

A study by Tsuda and Donalsdon (2004)assessed the cumulative and secondary impacts of three marine recreational activities, (i.e., Fish Eye underwater observatory in Piti, Seawalkers in Piti and Cocos Lagoon, and Scuba BOB (Breathing Observation Bubble) in Cocos Lagoon). The Fish Eye Underwater Observatory and Seawalker, Piti were analyzed as a single activity under the study because they occur within the same large sink. The project included: a survey of benthic algae, cyanobacteria, seagrasses and macroinvertebrates, a fish survey and a water quality analysis. Water analysis of the Piti site found no discernible pattern in physical and chemical data within and between zones was observed at the site. Benthic substrate and fish assemblage surveys found a significant difference between treatment and controls in the sinkhole, but not in seagrass or sand areas. The significant difference in the sink hole could have been related to the presence of the Fish Eye Observatory and Seawalker facility in the treatment sink hole, the greater development of coral compared with the control sink holes, or the fish feeding activities (Tsuda and Donaldson, 2004).

A feasibility study by Duenas, Camacho and Associates (DC&A, 2009) was conductedto analyze potential improvements to the Santos Memorial Park in Piti, Guam. The project included: assessing existing site conditions, developing feasible alternatives for storm water and other park improvements, and providing complete design services for the preparation of plans, specifications, and estimates needed to procure construction bids for improvements. The existing concrete structures within the site consist of two pavilions, a restroom facility, and a paved area once used as a basketball court. The planned construction included: a new parking lot, the repair and construction of pavilions, side lighting, repair of restrooms, and development of a nature trail. Two chief concerns of the project were the shoreline erosion caused by the ocean waves and the deposition of sediments by the Masso River into Piti Bay. These concerns wereexpected to be reduced by the Masso Reservoir Rehabilitation project and the Reforestation of the Cetti Bay Watershed project respectively (DC&A, 2009).

2.4 Land Cover in Southern Guam

AnUgum Watershed spatial distribution study measured the change of badlands over time through historical aerial images (Khosrowpanah et al., 2010).The badland changes over time were analyzed based on a 1946 historical aerial photo and a 2006 satellite image, which spanned a 60 year change.The study included a characterization of topographical variables of southern badlands through the use of the current satellite imagery and LiDar. The study found that badlands have expanded over time in southern Guam; however they have also shown the ability to recover (Khosrowpanah et al., 2010).

Soil erosion is the main source of sediment pollution to water bodies and of non-point source pollution. A study of the La Sa Fuawatershed analyzed the erosion rates and sources of sedimentation from badlands within the boundaries of the La Sa Fua watershed in southern Guam (Scheman et al., 2002). The study used the RUSLE model to estimate soil erosion and sedimentation rates. The results of the study found that badlands contributed more sediment than comparable sized savanna plots (Scheman et al., 2002).

Methodology
Chapter 3

3.1 Hydrologic Data

Hydrologic data was gathered in the two primary stream outlets (Figure 15) within the Piti-Asan watershed area: the Asan River and the Masso River. The hydrologic data was collected to develop a correlation with the amount of rainfall, stream water level, stream flow, and water turbidity. This correlation will assist in improving the understanding of the watershed's dynamic behavior through understanding the interaction between rainfall rates with stream output and sedimentation. An understanding of this correlation will aid in predicting future watershed behavior based upon projected development activities within the watershed. The hydrologic data that was collected includes turbidity, rainfall level, and stream level data. In collection of hydrologic data two rain gauges and four level loggers were installed throughout the Piti-Asan watershed for the duration of the one year study. Installation and collection of hydrologic data began on June 6, 2011 and continued through June 20, 2012. Stream flow measurements and turbidity sample collection was also performed at the fixed level logger locations (Figure 15).

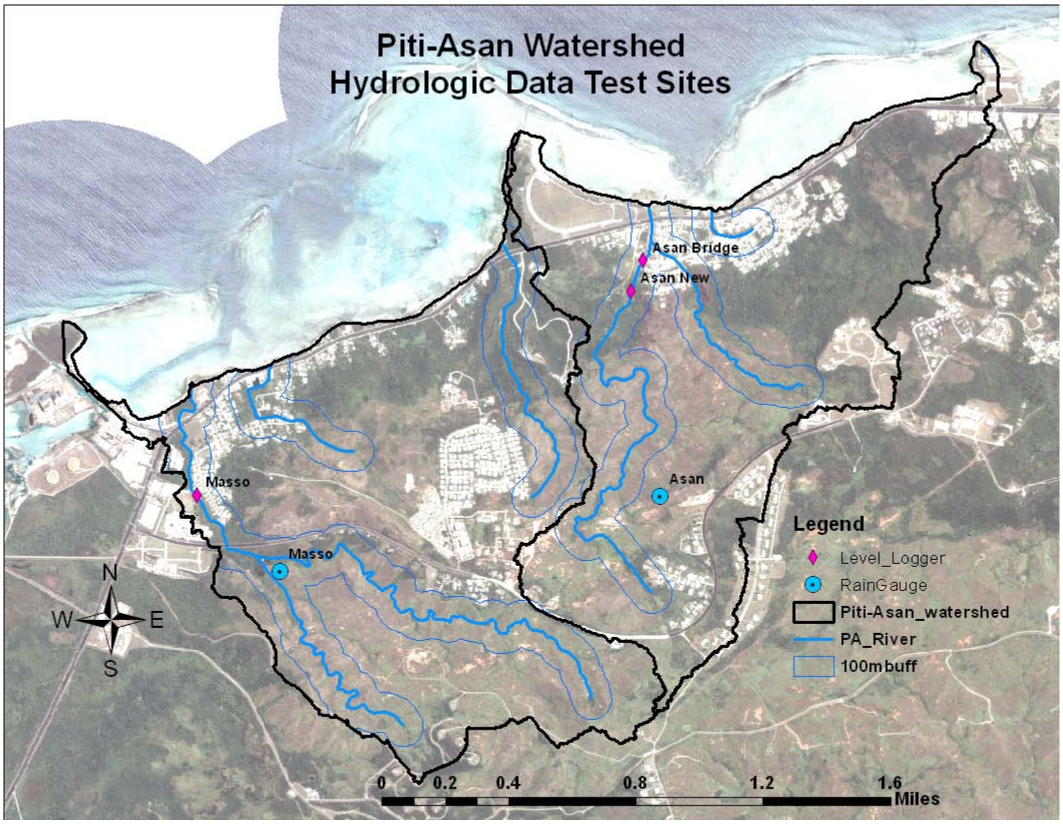

Figure 15:Hydrologic Data Sampling Sites

Rainfall Measurement

Rainfall was measured using two tipping bucket HoboWare® data logging rain gauges (Figure 16). The rain gauges were placed at two randomly selected sites around the Piti-Asan watershed. Site selection criteria included areas which were unobstructed by large vegetation, buildings, or any other large obstructions that could block rainfall to the rain gauges. Rain gauge sites were also chosen based on ease of access to the site and the risk of damage to the rain gauge by human activity.

Figure 16: Installation of the Asan Rain Gauge (June 9, 2011)

Turbidity Measurement

Turbidity measurements were made from water samples taken at the Masso River and Asan River. The turbidity level was measured biweekly using a portable Turbidimeter Measurement Device. Stream turbidity is a measure of the cloudiness of the water in terms of Nephelometric Turbidity Units (NTU), which indicates the amount of sediment carried in the stream. The turbidimeter is a device which measures the transmission of light reflected by particles through a solution. Turbidity was measured using using an OMEGA® handheld turbiditimeter. The turbidimeter measures the transmission of light reflected by particles through a solution of water. Turbidity measurements are useful in this study as an indicator of sediment in streams.

Stream Level Measurement

Water level was measured using four level loggers with one logger placed in each river to measure water pressure and one logger placed above the water surface and in the proximity of each river logger to measure the atmospheric pressure. The water level was measured regularly at 15 minute intervals using the two level loggers in the streams within the watershed. The recorded pressure of the in-stream loggers was compared against level loggers on land which measured atmospheric pressure. The atmospheric pressure was subtracted from the in-stream pressure to accurately calculate the water level of the streams based on pressure and temperature of the water level on the logger.

Flow Rate Measurement

Flow was measured weekly in the Masso and Asan Rivers using an electronic flow meter (Figure 17). Flow measurements were taken along transects running perpendicular to the flow direction at 0.5 foot increments from edge to edge of the river. Flow rate calculations included distance from the edge of the river, depth, and velocity as well as indications of the edge positions. The data was later input into a spreadsheet program, which calculated the flow output of the river based on the area and velocity measured at each increment.

Figure 17: Stream Flow Measurement in Masso River (March 12, 2012)

3.2 Soil Analysis

Soil composite samples were taken (Figure 18) and tested in the lab (Figure 19) to identify the various soil types represented in the Piti- Asan Watershed. A total of 17 composites were taken at the sites identified in Figure 18, which sampled the soil from depths of zero through 36 centimeters. Composite samples were ground and sifted through a two millimeter standard sieve. Sieved samples were analyzed for pH, texture, nutrients, and organic matter (Figure 20).All soil testing methodology was derived from the *Methods of Soil Analysis: Chemical and Microbiological Properties* text by Page et al (1982). This methodology has been adapted for use on Guam soils by the University of Guam Soil Research and Testing Laboratory.

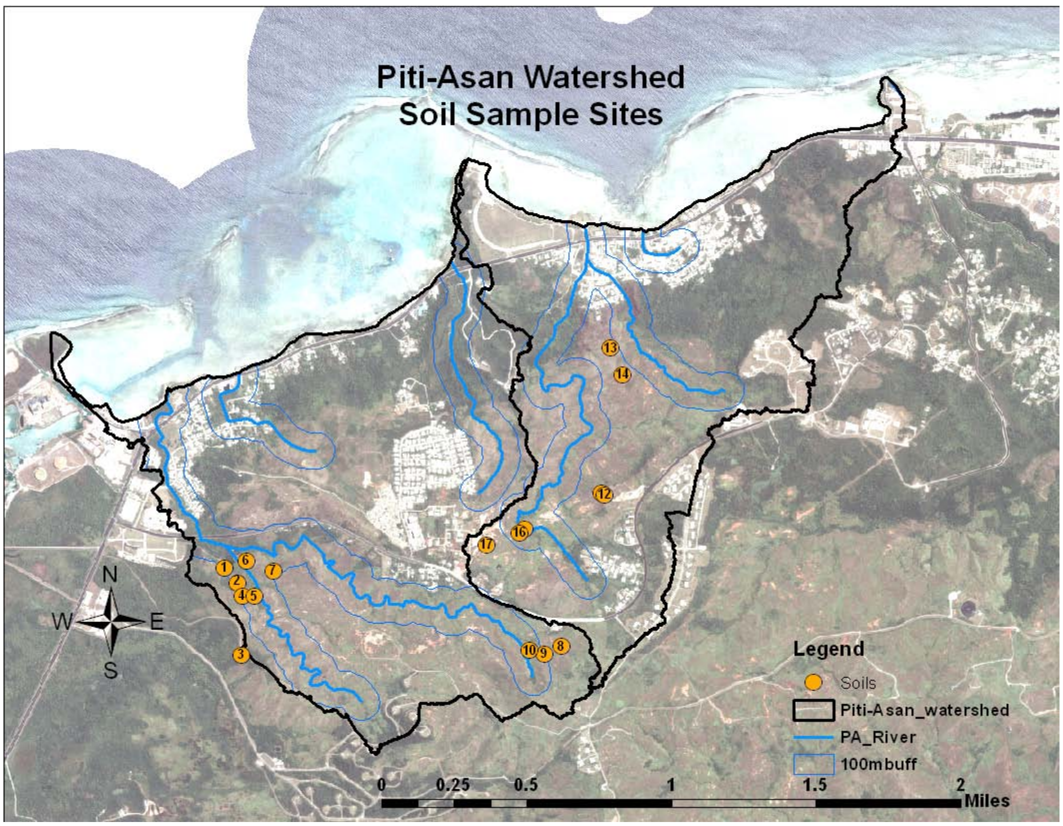

Figure 18. Soil Sampling Sites

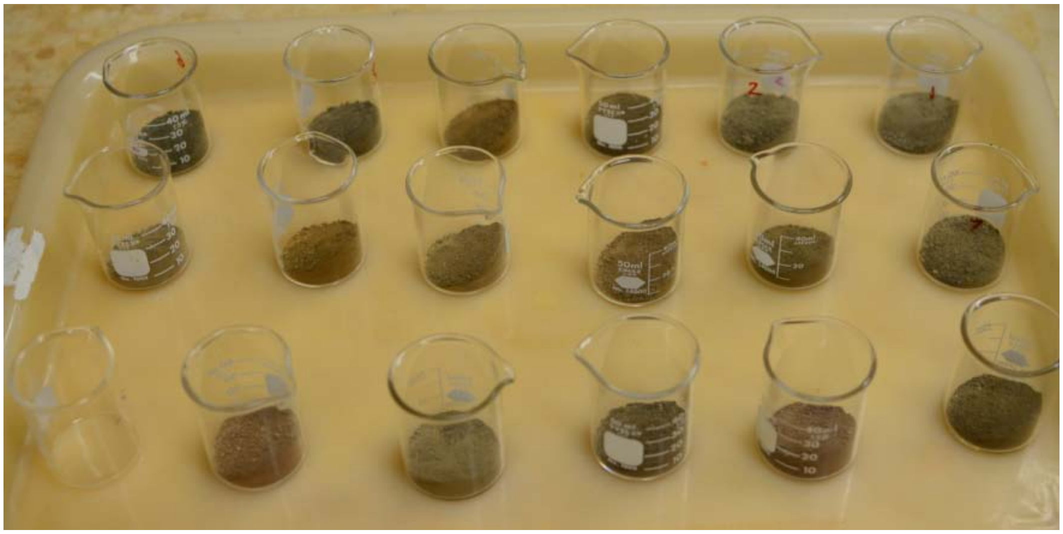

Figure 19. Soil Sample Analysis

Figure 20. Soil Organic Matter Analysis

3.3 GIS-USLE Model

The GIS-USLE model can measure the annual soil loss over a given area through combining Geographic Information Systems (GIS) with the Revised Universal Soil Loss Equation (RUSLE). The RUSLE is a revised version of the original Universal Soil Loss Equation (USLE), which was developed in 1965 by Walter Wischmer and Dwight Smith (Park et al, 2007).The model used was developed by Park (2007)in a study of Guam's Ugum Watershed.

The GIS-USLE model will be used to locate areas within the Piti- Asan watershed that contribute high levels of soil erosion and therefore detect significant areas of concern for implementing soil erosion practices. The USLE formula is described by acceptable soil loss (A), which is measured in tons/acre/year. The RUSLE formula is described by acceptable soil loss (A), which is measured in tons/acre/year. The formula is shown as:

$$A = R * K * LS * C * P$$

- Rainfall erosivity factor (R) accounts for the erosive power of rainfall.
- Soil erodibility factor (K) indicates the soil-loss rate for a given soil type.
- Slope length factor (L) is a ratio given the input of the erosivity over the length of a slope.
- Slope steepness factor (S) indicates the ratio of soil loss given a slope.
- Vegetative cover factor (C) accounts for the soil loss based on vegetative cover of the plot.
- Erosion control support practices factor (P) accounts for support practices that can be used to minimize soil loss on a plot such as through terracing, contour farming, strip cropping, or no-till farming.

Combined with GIS, the RUSLE is able to predict more quickly and accurately over a given area than through using the equations alone. GIS is used mainly to process and display data that contains a spatial component. The project will use vector and raster file formats. Vector file data contains “features defined by a point, line, or polygon” and are “useful for storing and representing discrete features such as buildings and roads. Raster file data are composed of a rectangular matrix of cells (Khosrowpanah et al, 2007).” The cells contain a specific width and height that is representative of a portion of the entire area of the raster as well as a value which “represents the phenomenon portrayed by the raster data set, such as category, magnitude, distance, or spectral value (Khosrowpanah et al, 2007).” USLE is represented in GIS through individual raster layers of for each of the USLE factors. Because of the overlap of the raster files and grid cells in each layer, the USLE can be computed by multiplying the USLE factors (Khosrowpanah et al, 2007).

3.4 Aerial Photography

Aerial photographs will be used to observe the land cover and vegetation of the watershed. Aerial images for this project were onboard a Cessna aircraft using a digital single lens reflex (DSLR) camera. The photographs will be taken for the observation through two flyovers by helicopter/ plane in order to observe the land cover of the Piti- AsanWatershed during both the rainy and dry seasons. Photos were also used to observe high erosion points and provide a better understanding of the overall vegetative coverof the watershed area.

Results and Discussion
Chapter 4

4.1 Expected Results

The results of the study predicted the behavior of the Piti- Asan watershed under the existing, natural conditions and with various proposed human activities. A correlation between rainfall, change in stream flow, stream level, and turbidity for the Masso and Asan Rivers has been found. Using a Geographic Information Systems (GIS) erosion-based model, soil testing, and aerial photographs, the areas of high erosion contribution and bank erosion sites have been identified. Recommendations for management strategies were made to reduce negative impacts on the watershed.

4.2 Hydrologic Data

The hydrologic data gathered in the course of the study from the Masso and Asan Rivers are shown in Figure 21 and 22 respectively. These included the rainfall collected for each watershed, stream level measured at 15 minute intervals, and the biweekly turbidity measurements. Figure 23 and 24 show the 15 minute rain and stream levels of the rivers during a single storm event.These figures are able to more clearly display the reaction time of water level to changes in rainfall.

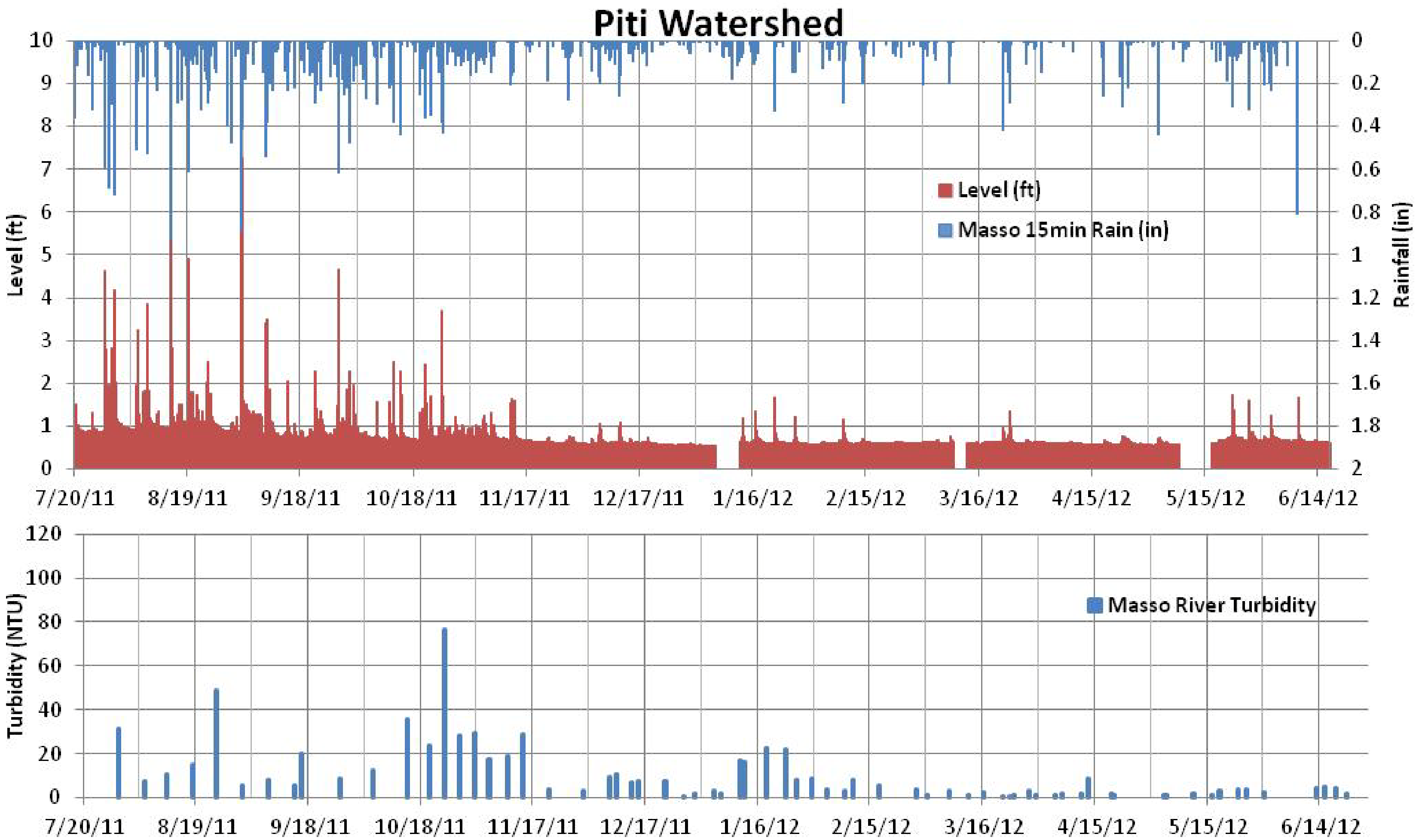

Figure 21: 15-minute Rainfall, River Level, and Flow to the Masso River

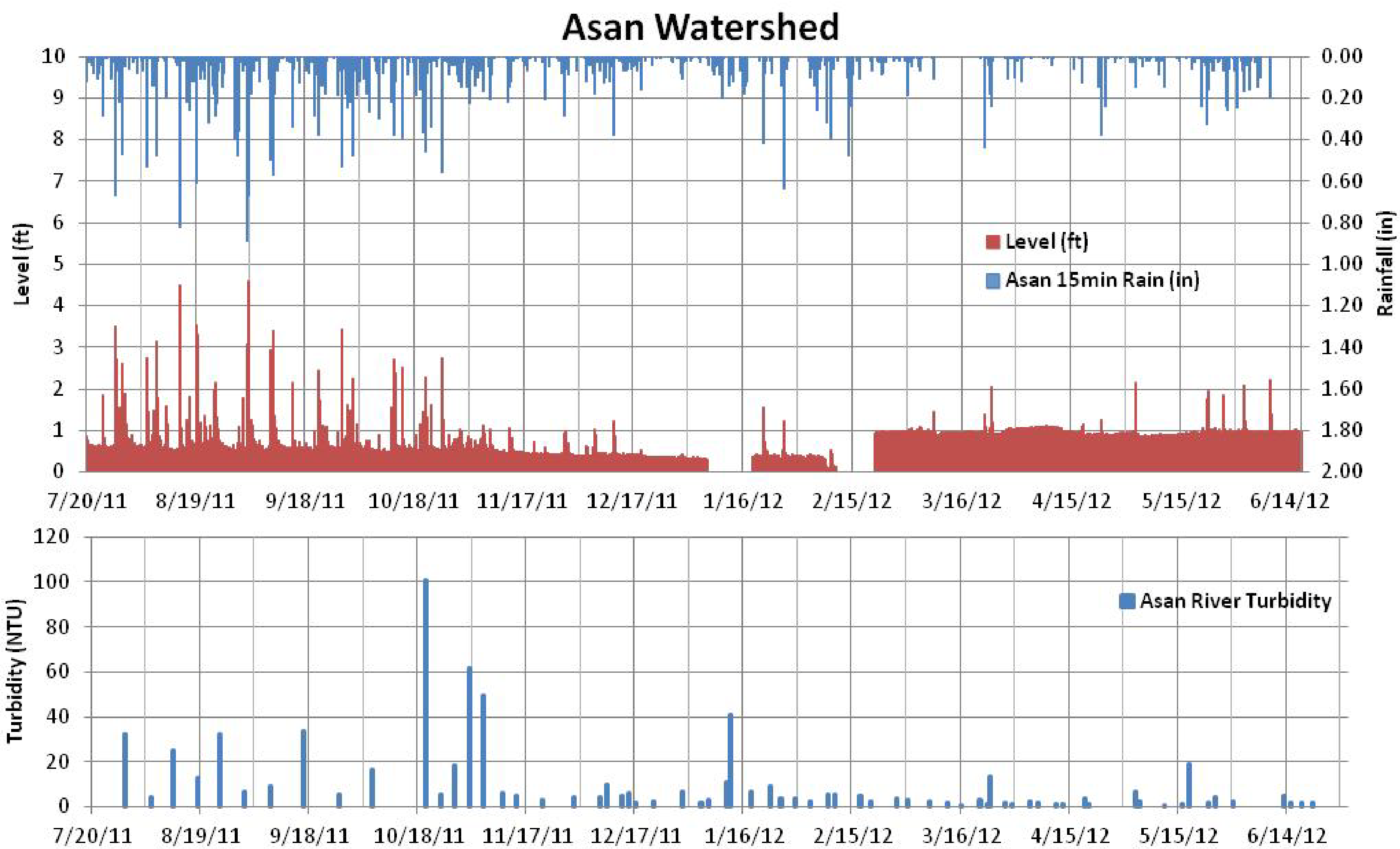

Figure 22: 15-minute Rainfall, River Level, and Flow to the Asan River

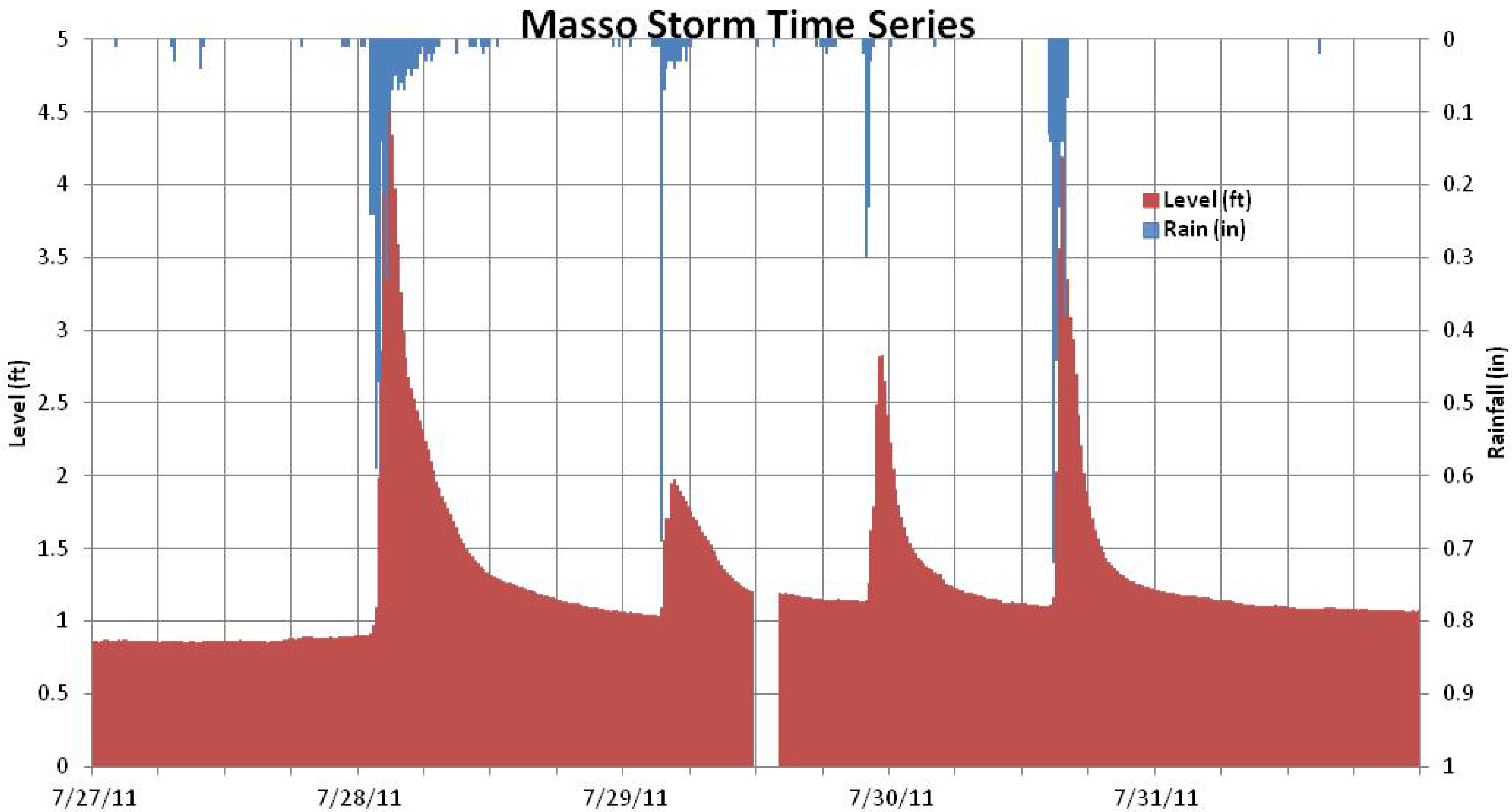

Figure 23: Masso Storm Event

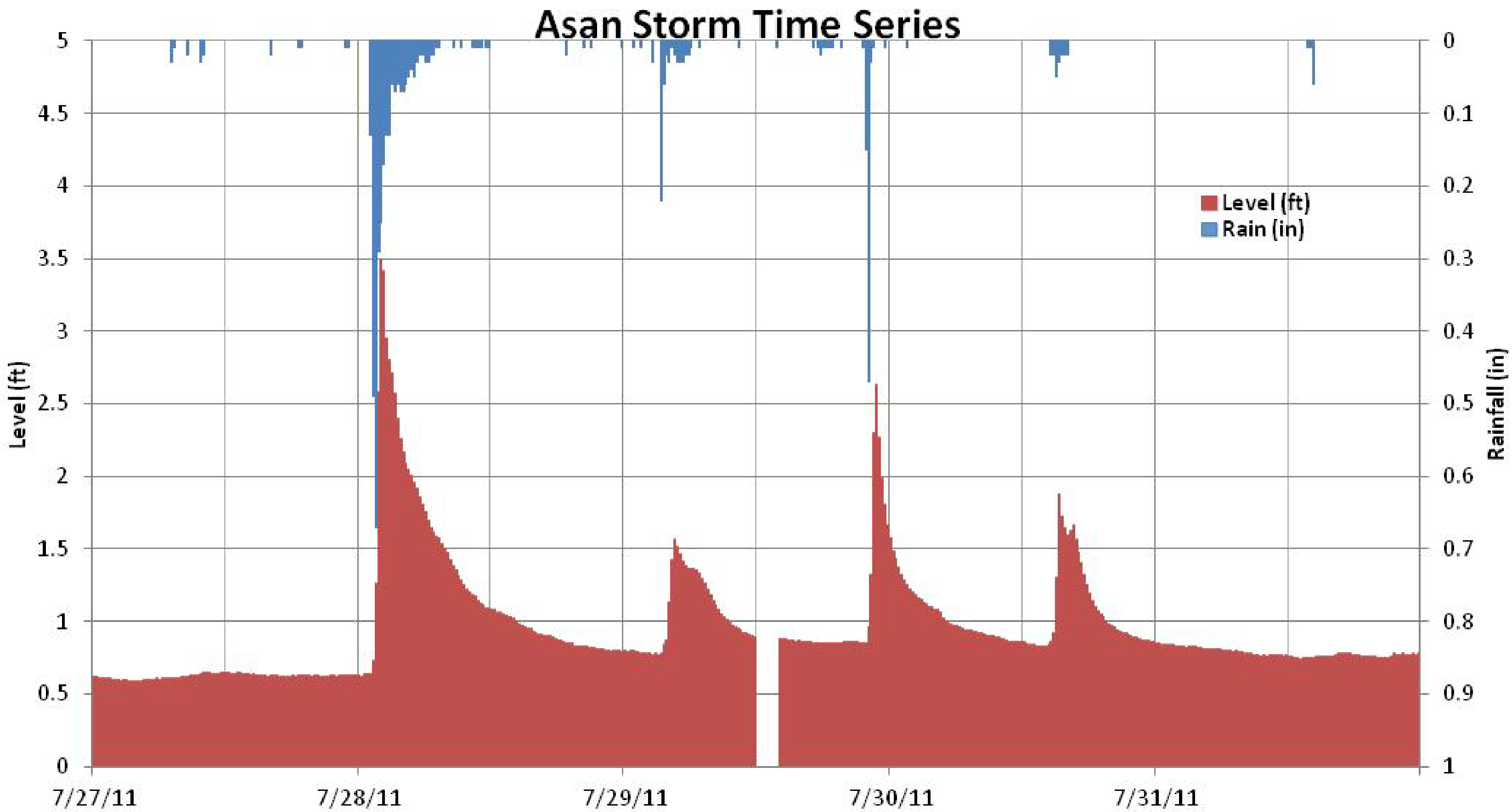

Figure 24: Asan River Storm Event

As observed by Figure 23, the reaction time of the Masso River's peak water level from peak during storm events was shown to have occurred within 45 minutes of the peak rainfall during large rainfall events when compared at 15 minute intervals. The Asan River's reaction time was shown in Figure 24 to have occurred within 30 minutes of peak rainfall during major storm events. This indicates that the water level of the Asan River is more reactive to rainfall events.

A gap in the rainfall data collected for the Piti- Asan Watershed (Figure 21 and 22) between August 19, 2011 and September 2, 2011, which occurred due to technical issues with the rain gauge shuttle. Rainfall data for this period was substituted using the National Weather Service's nearby weather station for that time period. Unfortunately, the largest rainfall event of the year recorded by the National Weather Service also coincided within that data gap.

In order to understand the amount of turbidity found within the rivers over time, a turbidity exceedance curve (Figure 25) was created. Figure 25 measures the percent of time that turbidity was equaled or exceeded for the given river. The measure at 100% therefore indicates the base turbidity level. An examination of the graphs leads to the belief that turbidity levels for the Masso River often exceeds the turbidity in Asan River.

The primary interest of the turbidity exceedence however, is in comparing the relative impacts of the sediment reaching the reef from the two watershed areas. In order to determine the relative measure of sediment load in the Masso and Asan Rivers, the following assumptions were made. First, turbidity is a relative measure of sediment load at a given point. Secondly, turbidity multiplied by the stream flow is defined as a flux rate (turbidity * flow = flux rate). In order to compare the two watersheds, the flux rate was divided by the watershed areas to produce an area weighted flux rate.Figure 26 illustrates the results of this measurement. Figure 26 takes into account both the amount of flow observed during turbidity measurements and relative sizes of the watershed by factoring watershed area. The product of this is an estimate of the frequency at which the relative sediment load (NTU*gpm/mi^2) exceeds a given value. The trends expressed by the relative sediment load duration curve seem to follow closely with the results ofFigure 25. The median value of the relative sediment load is about 2000 NTU*gpm/mi^2 for Masso River and 1140 NTU*gpm/mi^2 for the Asan River (Figure 25). The average relative sediment load is 11646 NTU*gpm/mi^2 for Masso River and 11201 NTU*gpm/mi^2 for Asan River.

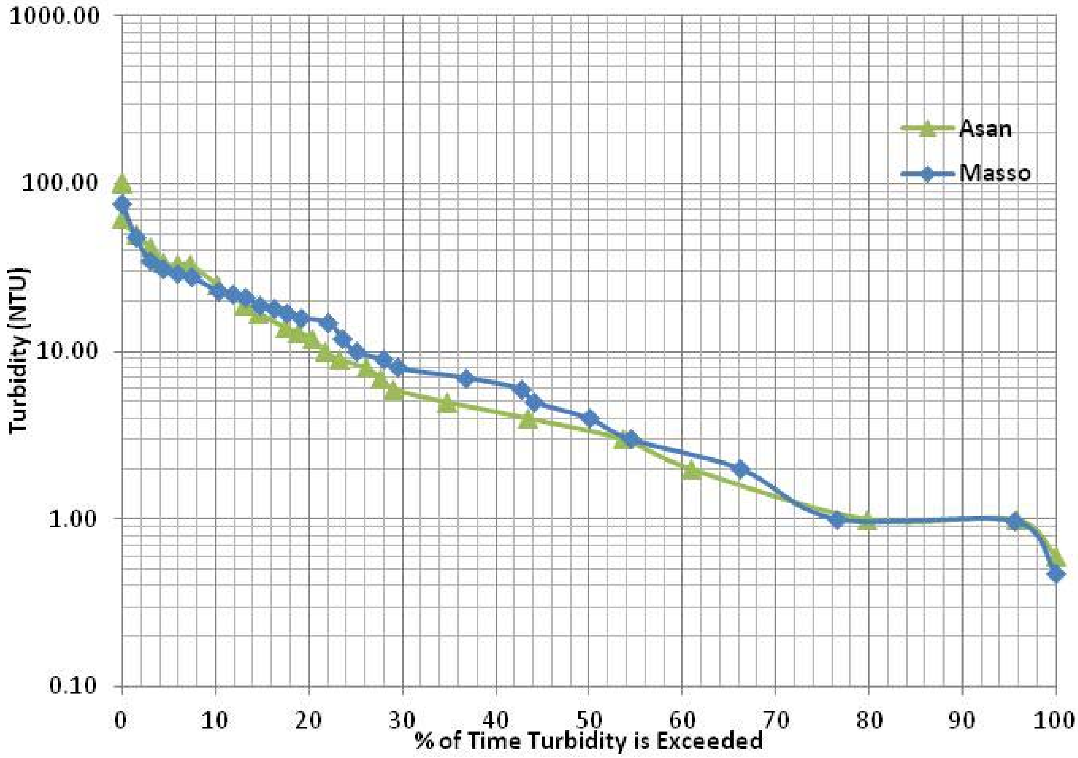

Figure 25: Turbidity duration for Masso and Asan Rivers

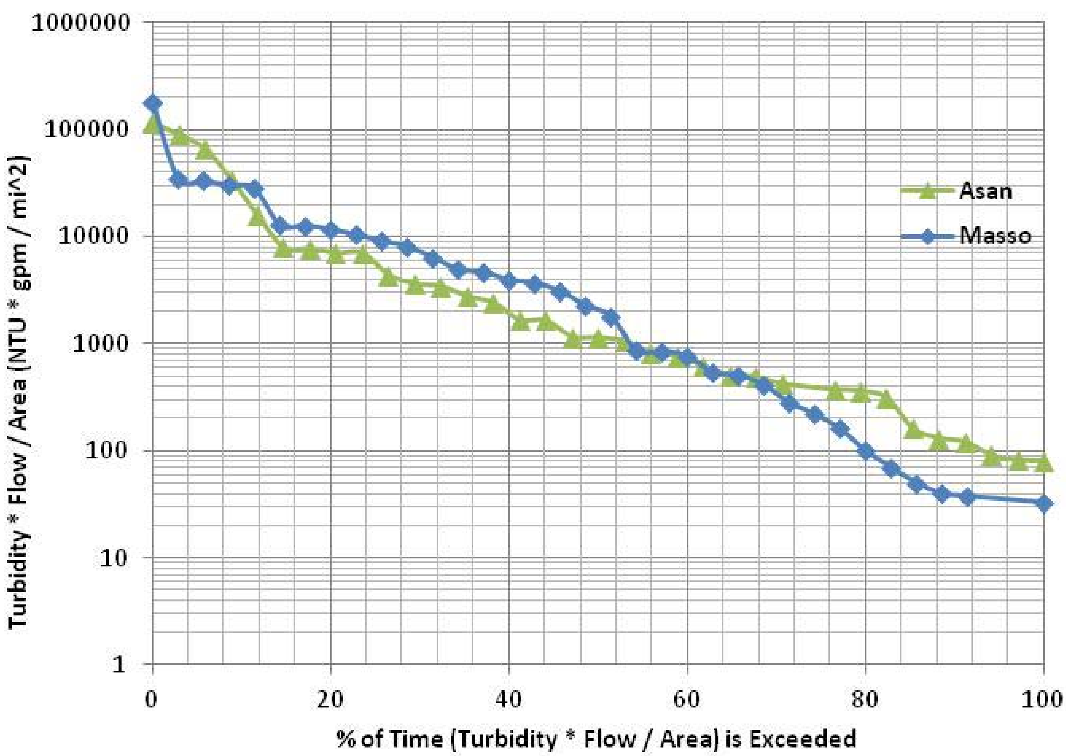

Figure 26: Relative sediment load duration curve for Piti and Asan Watersheds

The lower level of turbidity shown in Figure 25 and 26is influenced by the presence of the Masso Reservoir which is located less than a mile upstream from the Masso study site. Because of the reservoir's position downstream of most of the watershed area, much of the sediment is trapped and settled to the bottom of the reservoir before reaching the Masso study site during low rainfall events. During high rainfall events that cause more erosion however, the sediment carried by higher amounts of rainfall is not given time to settle in the reservoir before being carried to the study site and the river outlet.

A comparison of the measured flow and the area-adjusted turbidity for the Masso and Asan Rivers (Figure 27) shows that the Asan River is more reactive to changes in flow so that more turbidity per watershed area is produced by increases in stream flow than the Masso River. The turbidity measured within the Asan and Masso rivers (Figure 27) both reflect low overall turbidity levels, with the exception of major storm events, which produced large increases in the stream turbidity. This is caused by increased upland erosion during heavy rainfall events.

Figure 28 and 29 indicate the reaction of each stream level to changes in rainfall for the Masso and Asan Rivers respecitvely. As shown by Figure 28, the level change for the Masso River reacts within a short response time to large changes in rainfall. In contrast, Figure 29 shows that the Asan River responds with a lower change in river level overall within the 24 hours prior to rainfall events, which can be attributed partially to the widening that is occuring in the lower Asan River.

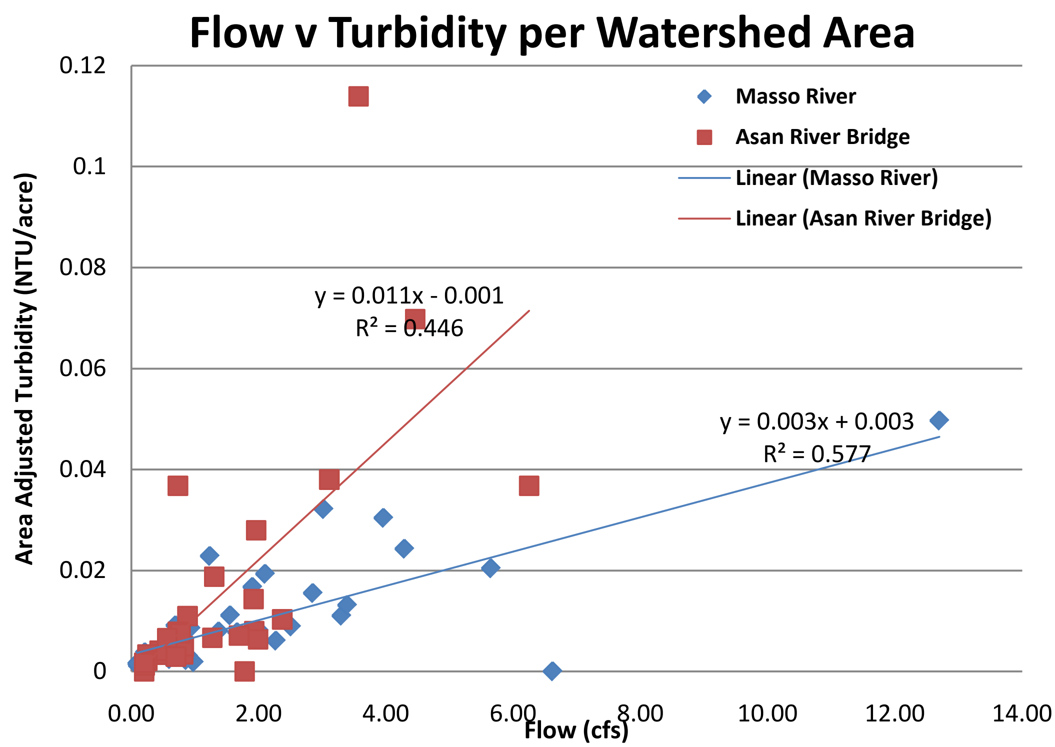

Figure 27: Flow versus Turbidity per Watershed Area of Asan and Masso Rivers

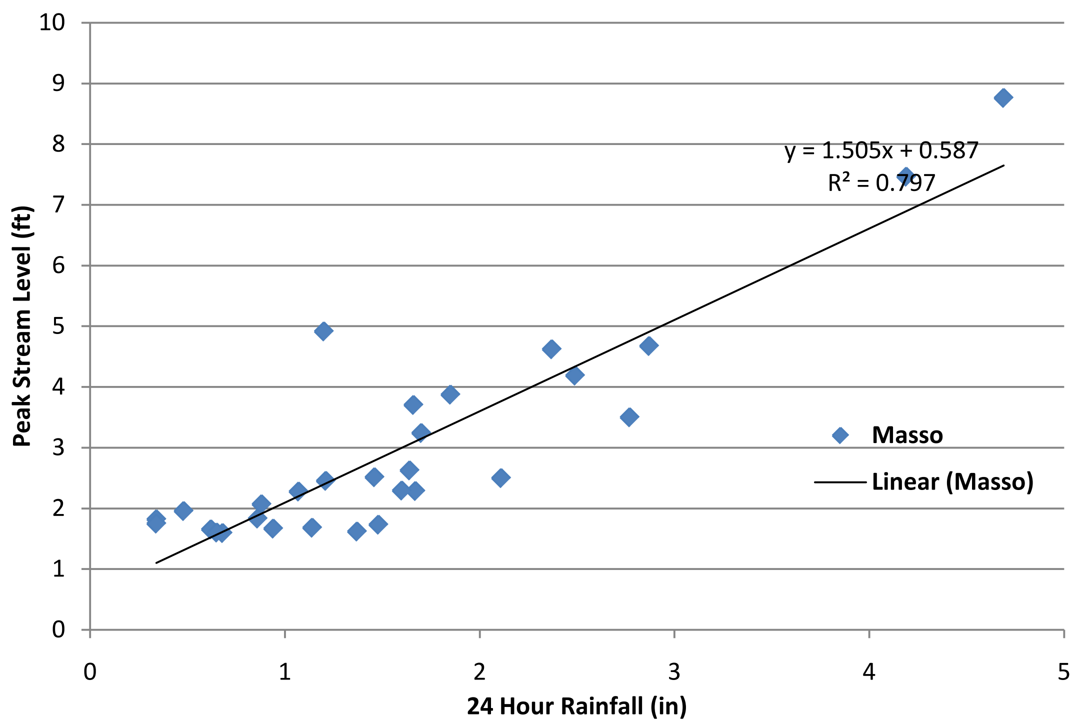

Figure 28: Rainfall versus Peak Stream Level in Masso River

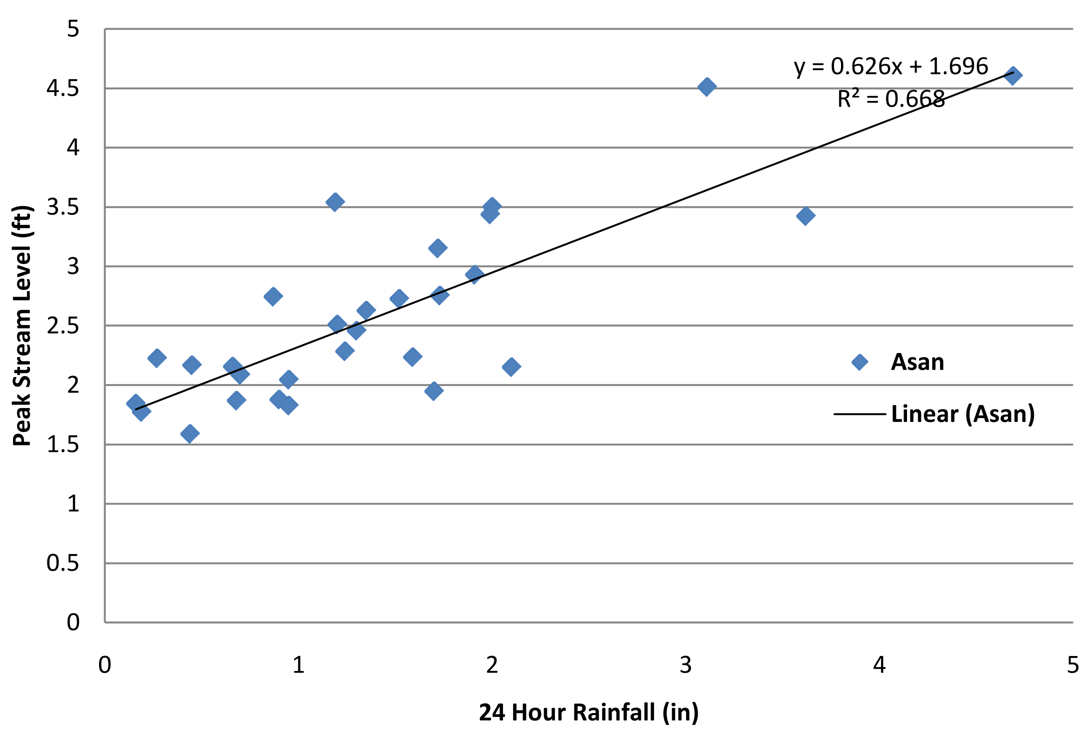

Figure 29: Rainfall versus Peak Stream Level in Asan River

4.3 Development of a Stage Discharge Curve for the Asan and Masso Rivers

A preliminary stage discharge curve was developed for the Masso River (Figure 30) and the Asan River (Figure 31), which are the two major stream outlets for the Piti- Asan Watershed. The stage discharge curve was developed from the weekly stream flow measurements conducted within the Masso and Asan Rivers and the stream level measured by the installed level loggers.

An accurate stage discharge curve should utilize several years' worth of water level and stream flow data. The development of an accurate stage discharge curve for the primary rivers of the watershed is essential to future management of the watershed because the stage dischargecurve removes the need for the weekly flow measurements of the watershed by providing ameasurement of flow level in the river.

The stage discharge curves developed for this study utilized only one-year of data collected. Therefore, this does not provide a fully accurate estimate of the flow and water level relationship of the Masso and Asan Rivers. However, the stage dischargecurve developed can serve as the basis for future hydrologic studies within the Piti- Asan Watershed. It is recommended that flow and level recordings of the Asan and Masso Rivers continue to be measured in order to obtain a more accurate estimate of the watershed behavior for future studies.

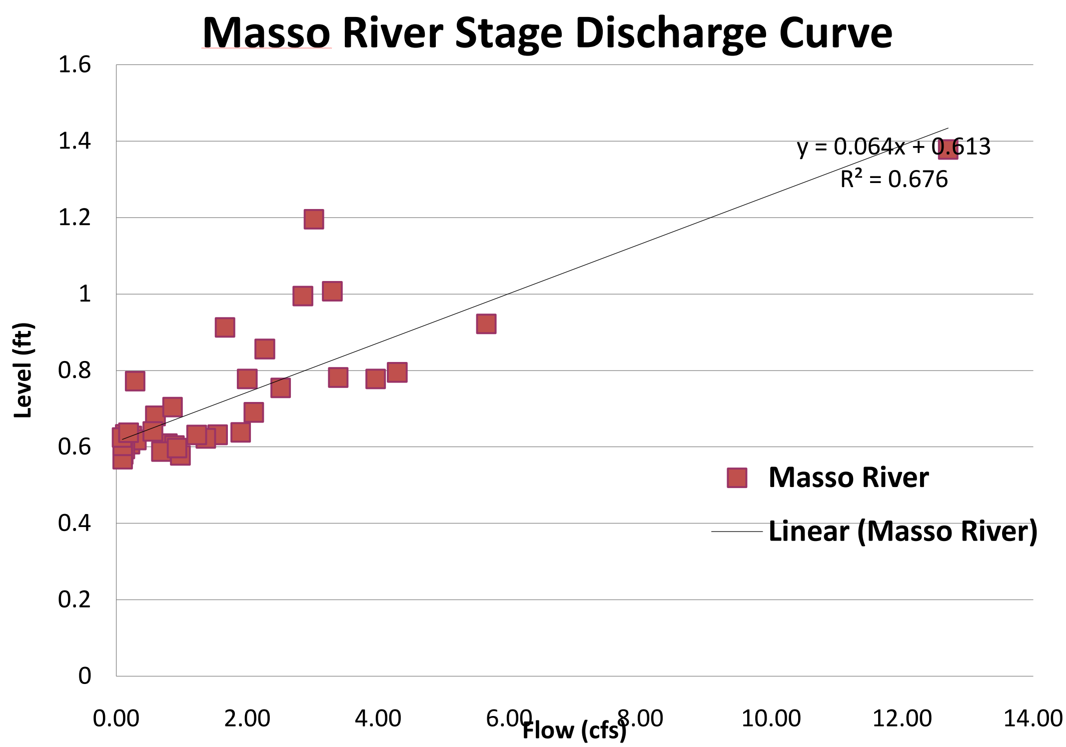

Figure 30: Masso River StageDischarge Curve

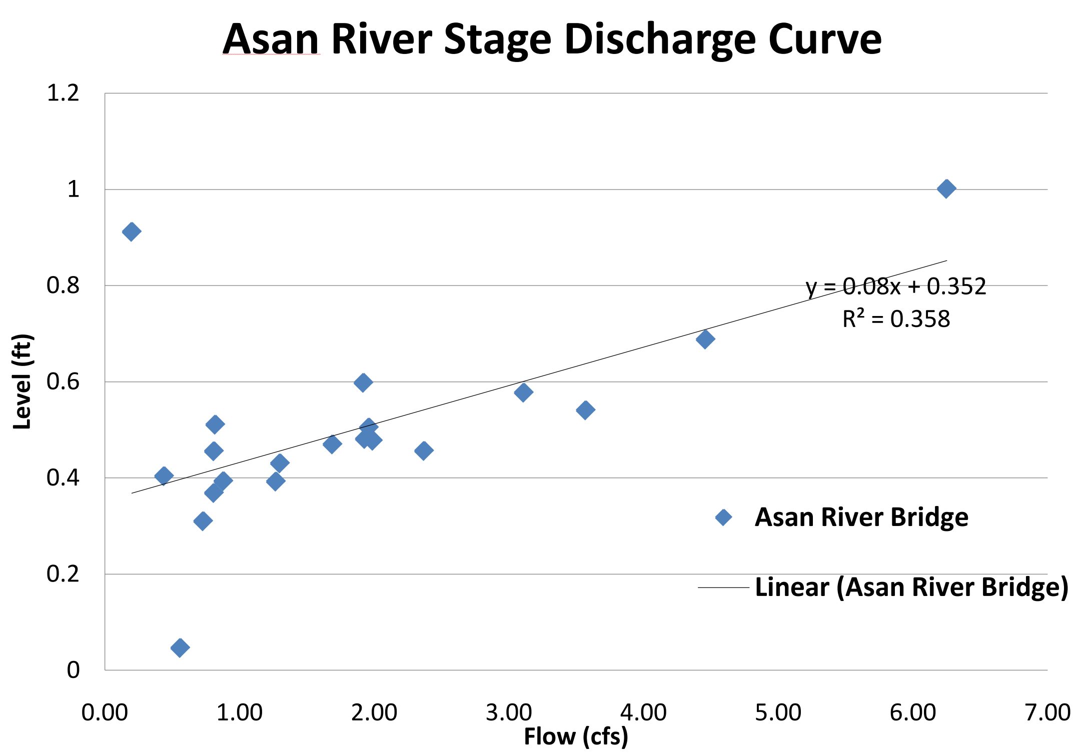

Figure 31: Asan River Stage Discharge Curve

4.4 Soil Composite Results

As shown by the results from the soils composites analyzed (Table 1), all samples displayed low pH levels and very low organic matter as compared to the soil reference for Guam developed by the University of Guam (UOG) Cooperative Extension Service (CES; 1980) and which was referenced as the ideal soil values. As shown inTable 1, both the high pH and low organic matter (OM) indicate that the soils are unable to sustain crops or large vegetation but instead can be prone to weedy species growth or bare soil. All of the soil composites also contained high levels of soluble magnesium (Mg), which was likely increased by the soil acidity. The large amount of magnesium can act as an indicator of soil toxicity (Golabi, Pers. Comm, 2012) and can also indicate high levels of aluminum in the soil, which is toxic to animals and most plant species.

The majority of the soils contained normal amounts of absorbable potassium (K). The soils samples also contained little to no absorbable phosphorus (P), which was unusual for the high acidity of the soils. The lack of absorbable phosphorous can be attributed to the very high levels of calcium (Ca) in the soil, which could have bound much of the phosphorus as calcium phosphate ($Ca_3 (PO_4)_2$) (Golabi, Pers. Comm, 2012). The majority of the soil composites are sandy clays and sandy clay loams. As such most of the soils have lower water retaining capacities and could be more prone to soil erosion during heavy rainfall.

Table 1. Soil Composite Test Results

	Site	Avg. pH	Color	% OM	Soil Texture	K ppm	Ca ppm	Mg ppm	P ppm
Masso	1	5.68	2.5Y 6/2	2.17	Sandy Clay	144	10326	3126	ND
	2	5.65	2.5Y 6/2	2.20	Sandy Clay Loam	146	17493	2563	0.473
	3	6.19	7.5YR 5/4	2.76	Sandy Clay to Clay	113	22370	1339	0.314
	4	6.20	7.5YR 6/4	1.55	Clay	81	13316	1566	1.279
	5	6.11	2.5Y 5/2	1.46	Sandy Clay Loam	71	14416	3201	ND
	6	6.02	2.5Y 5/2	1.08	Sandy Clay Loam	99	6140	3146	ND
	7	5.29	10YR 6/3	2.25	Sandy Clay	79	3775	6108	ND
	8	5.44	10YR 5/2	2.34	Sandy Clay	266	4828	4007	ND
	9	5.09	5YR 6/4	0.04	Sandy Clay Loam	91	1892	3105	ND
	10	5.18	5YR 6/6	0.92	Sandy Clay Loam	171	3181	3440	ND
Asan	11	5.90	5YR 6/6	0.04	Sandy Clay	79	2579	319	ND
	12	6.03	10YR 7/3	0.96	Sandy Clay Loam	63	5800	5206	ND
	13	5.90	10YR 5/2	2.84	Sandy Clay	109	4525	5787	ND
	14	5.65	2.5YR 5/4	0.13	Clay Loam	83	407	7519	ND
	15	5.62	10YR 5/2	3.50	Sandy Clay Loam	70	6050	2868	ND
	16	5.42	10YR 6/3	2.23	Sandy Clay Loam	76	1698	5992	ND
	17	5.28	5YR 6/4	0.20	Sandy Clay Loam	69	3015	1291	ND
Ideal*		**6.5**		**8**		**140**	**1500**	**150**	**50**

ND = Not Detected

*Ideal values adopted from University of Guam Cooperative Extension Service (1980)

4.5 Estimated Annual Soil Loss

The estimated soil loss from the Piti and Asan Watersheds (Figure 32) were calculated from the erosion model developed by Park (2007) using file layers at a resolution of 1m^2. The estimated soil loss from the Asan Watershed was 8.05 ton/acre/year and 5.15 tons/acre/yearfor the Piti Watershed.

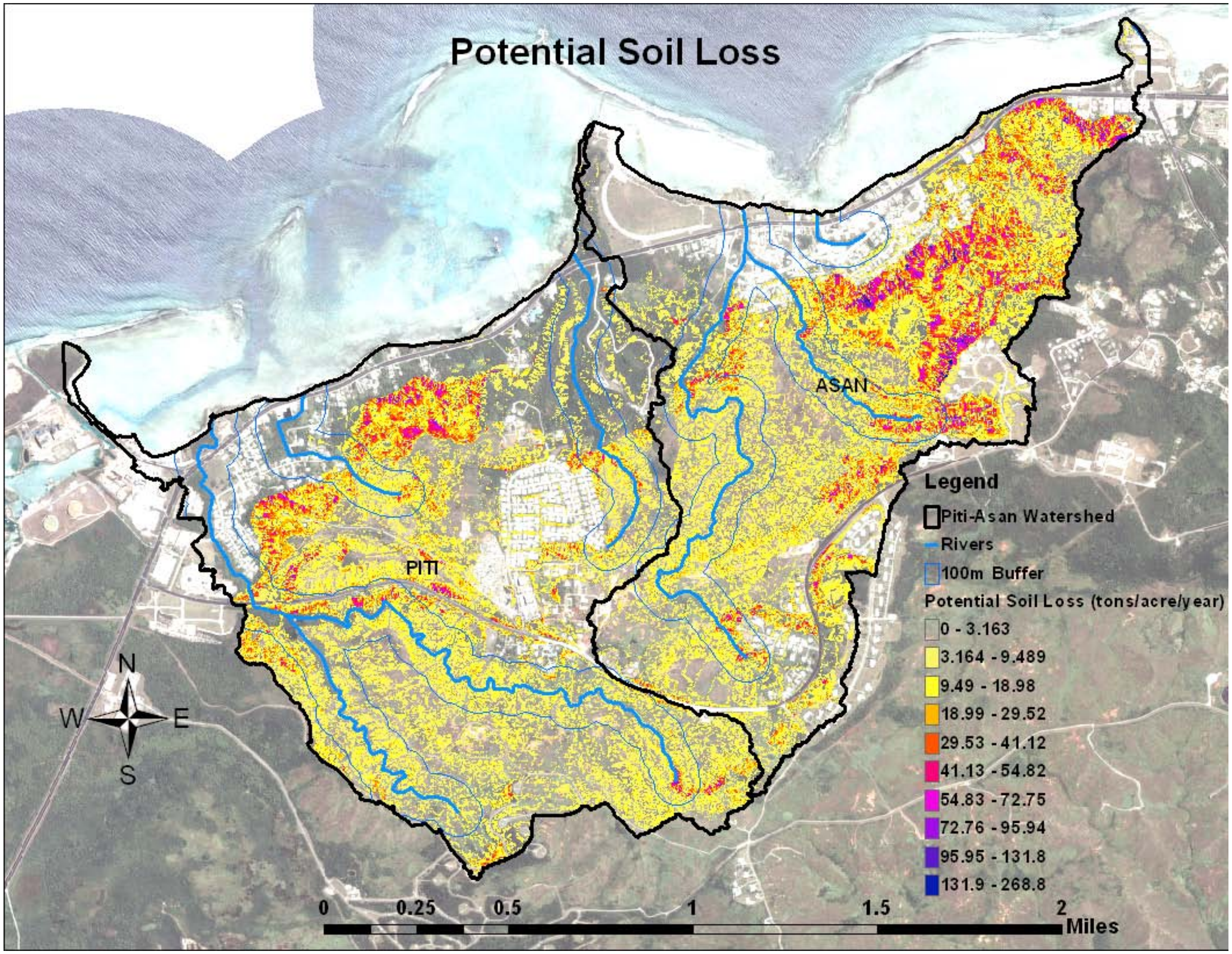

Figure 32: Estimated Soil Loss for the Piti- Asan Watershed

There are five named rivers and two unnamed tributaries located within the watershed (Figure 33). The two primary rivers flowing through the watershed as mentioned earlier are the Masso River in Piti and the Asan River in Asan. A 100 meter buffer zone (Figure 34) around the rivers feeding in to the Asan Bay and Piti Bay was created using the ArcGIS buffer tool. This buffer zone was used to estimate the amount of soil that has the potential to be deposited into the two bays because erosive sites located further away from river bodies can be less likely to deposit soil into water bodies as deposition sites. The estimated soil loss of the buffered 100-meter area within the Piti- Asan Watershed (Figure 34) is 4.57 tons/acre/year for Piti and 5.93 tons/acre/year for Asan.

Using the 100 meter buffer as a mask for the potential soil erosion from the Piti- Asan Watershed, the raster was clipped to display only the potential soil erosion from within 100 meters of nearby streams and rivers (Figure 34). The potential contribution of sediment from within the buffered area to the river outlet in the Piti and Asan Bays is the primary focus of the sites in which recommendations for erosion management practices in the watersheds.

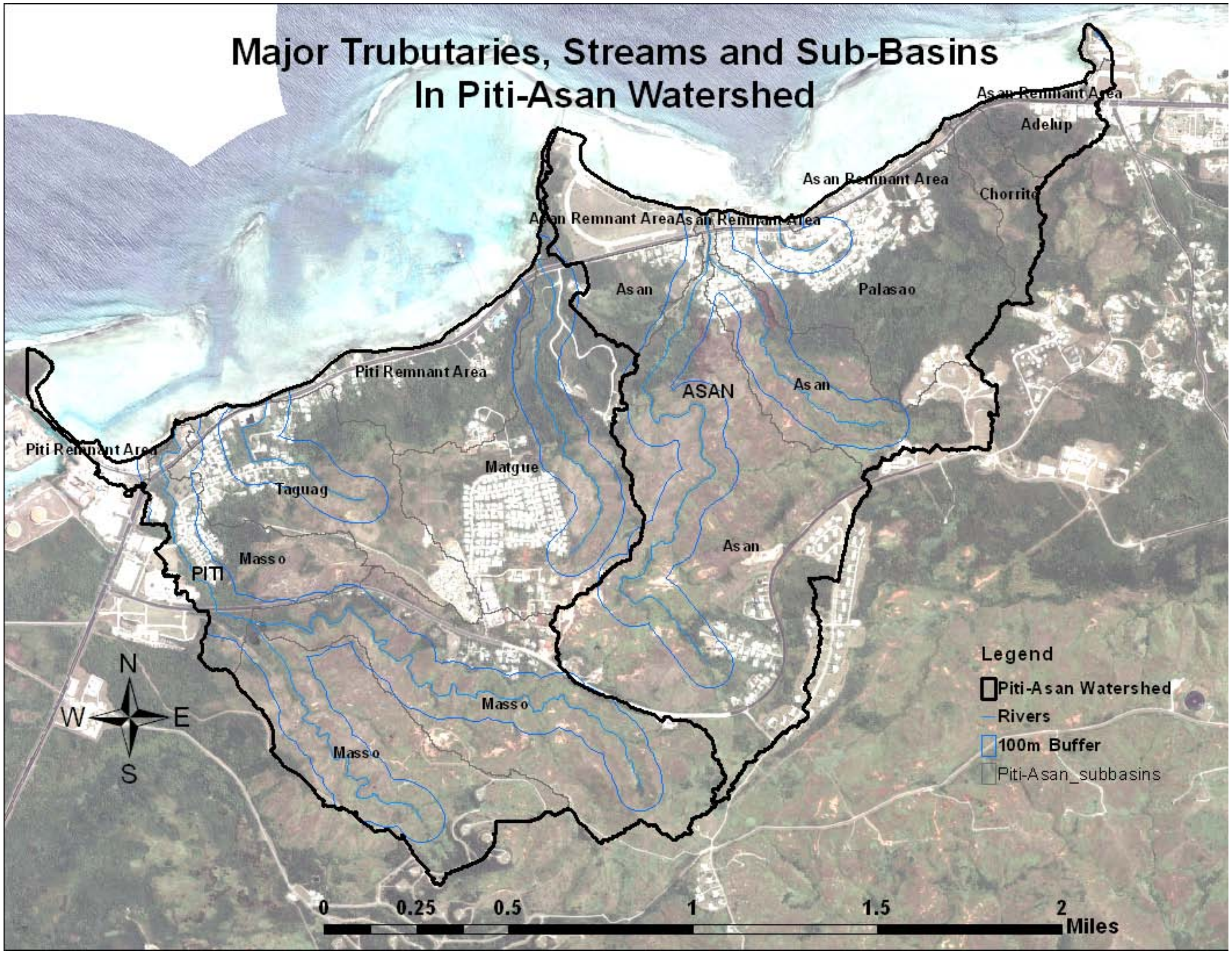

Figure 33: Major Tributaries, Streams, and Sub-basinsin the Piti- Asan Watershed

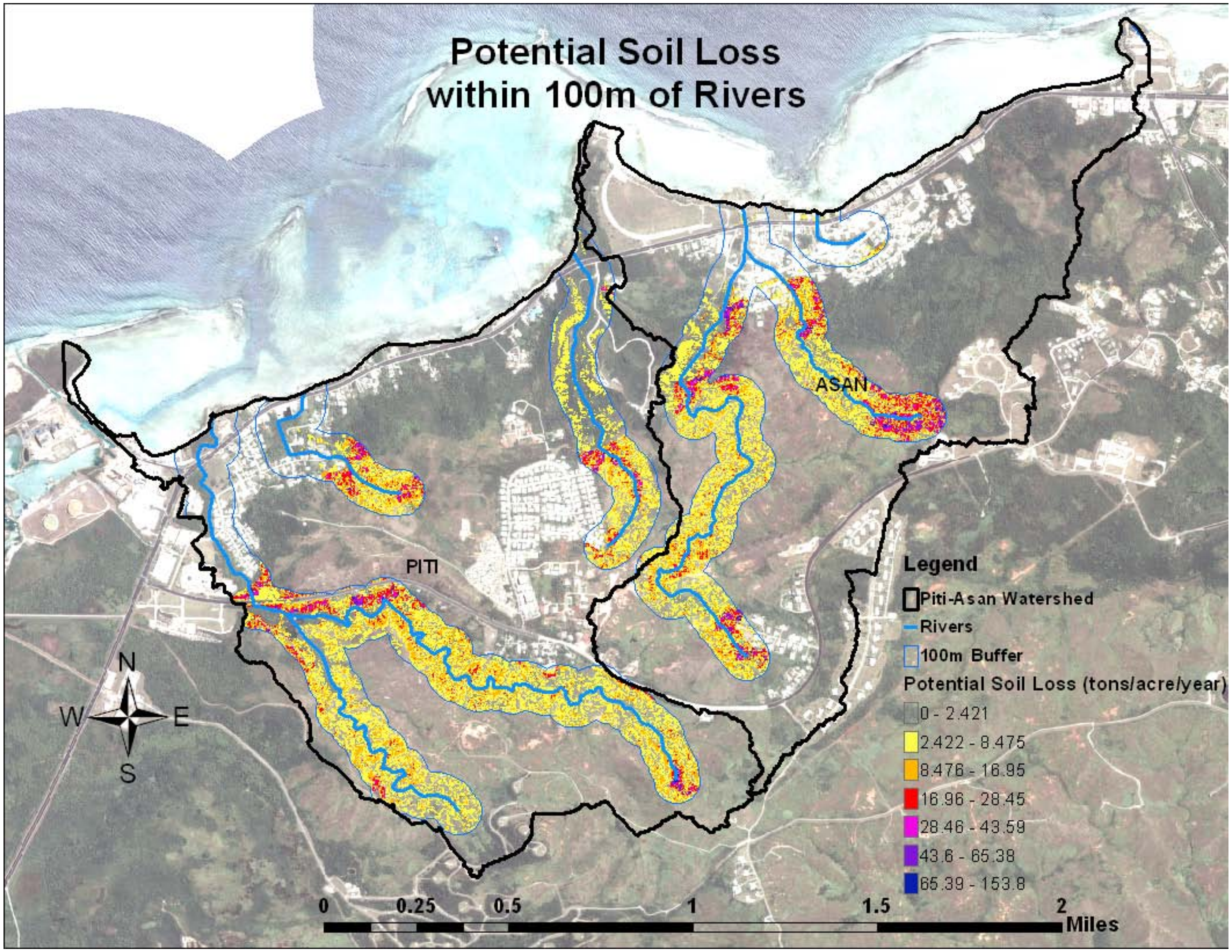

Figure 34: Estimated Soil Loss for Piti- Asan Watershed within 100m of Rivers

As mentioned earlier, there are two large proposed developments in the Piti-Asan Watershed, the Hanjin Development and the JHP Development (Figure 35). The impact of the proposed developments on soil erosion as shown in Figure 35 were estimated by making changes to the vegetative cover layer of the GIS erosion model. The boundary of proposed developed properties assumed a vegetative cover factor of 0.011, which assumes a cover if impervious material. The same proposed developments during construction activities assumed a vegetative cover factor of 0.45 that indicates a property with no vegetative cover or canopy cover.

Figure 36 illustrates the potential soil loss during construction of the proposed Hanjin Development. Figure 37 shows the projected erosion to the watershed with the proposed Hanjin Development with the assumption that proper erosion control practices are used to permanently stabilize soil on the site, especially along steep slopes. Table 2illustrates the change in the potential soil erosion within the 100-meter buffer zone for the Hanjin project.

It must be noted that although the model showed no change in the effect of the Hanjin development on the erosion within the buffer zone, the change of the property's surface from development activities such as clearing and leveling as well as from adding pavement or drainage systems will have some impact on the watershed. This is because the proposed developmentscan change the dynamic hydrologic behavior in terms of the directionality of flow on the property and areas surrounding the proposed development site.

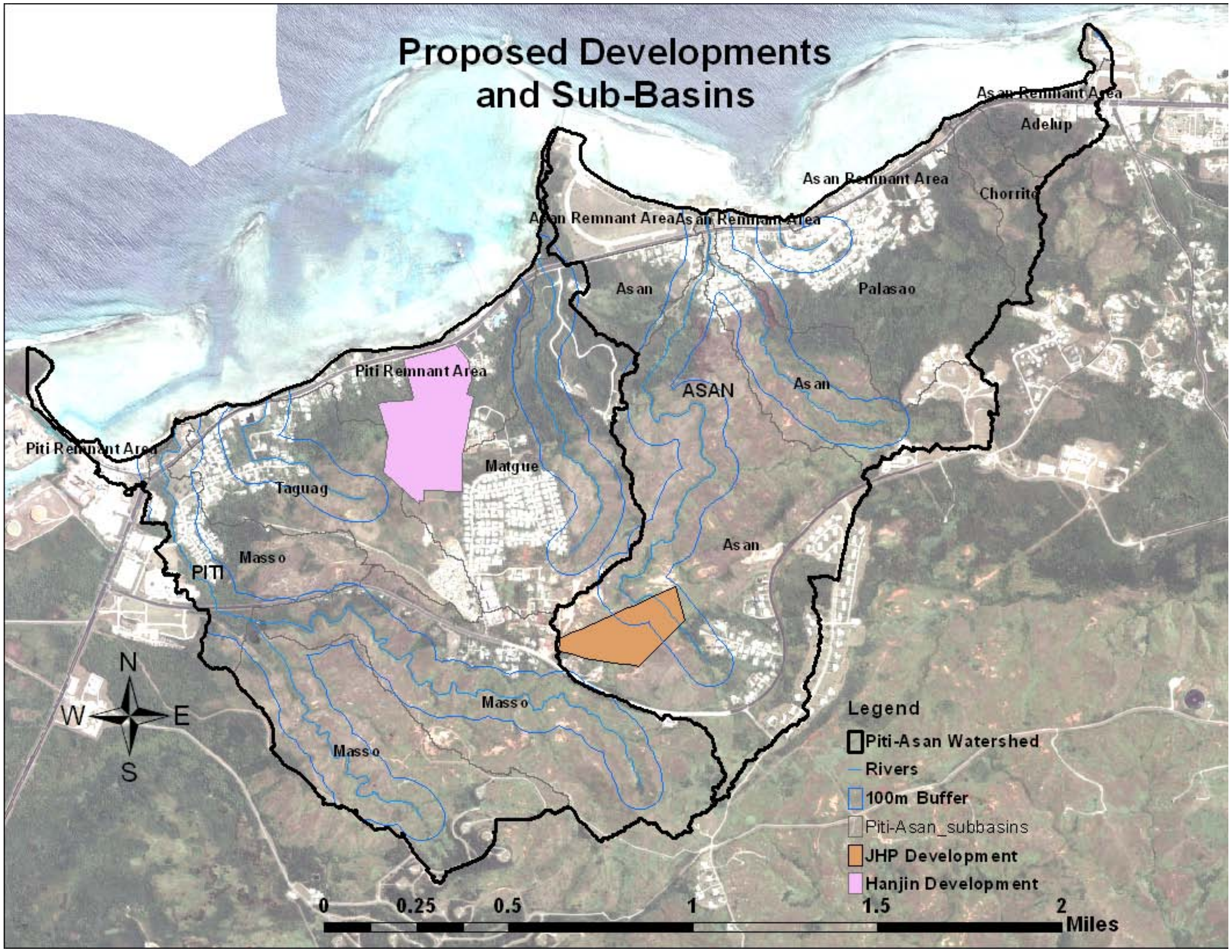

Figure 35. Proposed Developments in the Piti-Asan Watershed

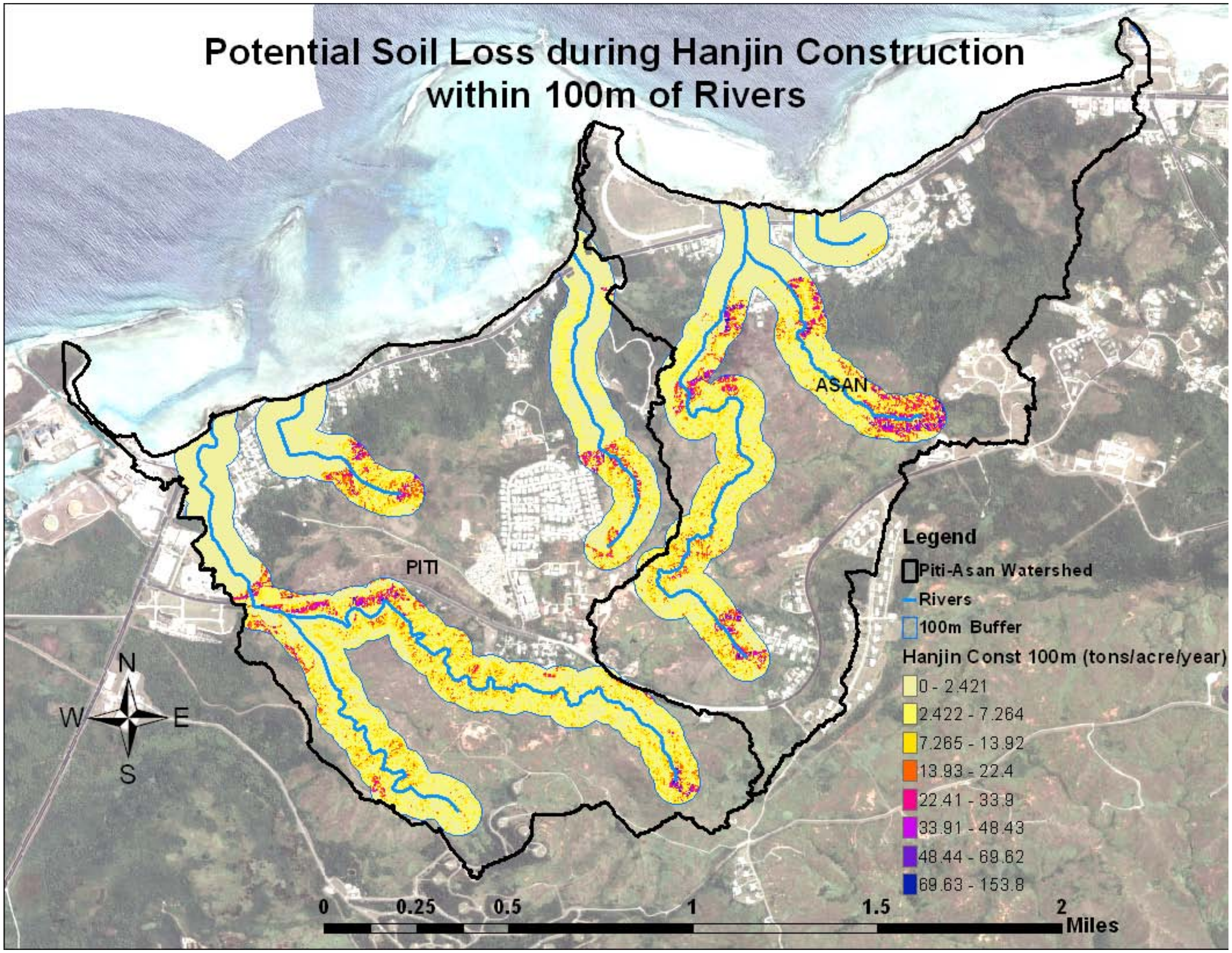

Figure 36. Soil Loss During Hanjin Construction within 100m of Rivers

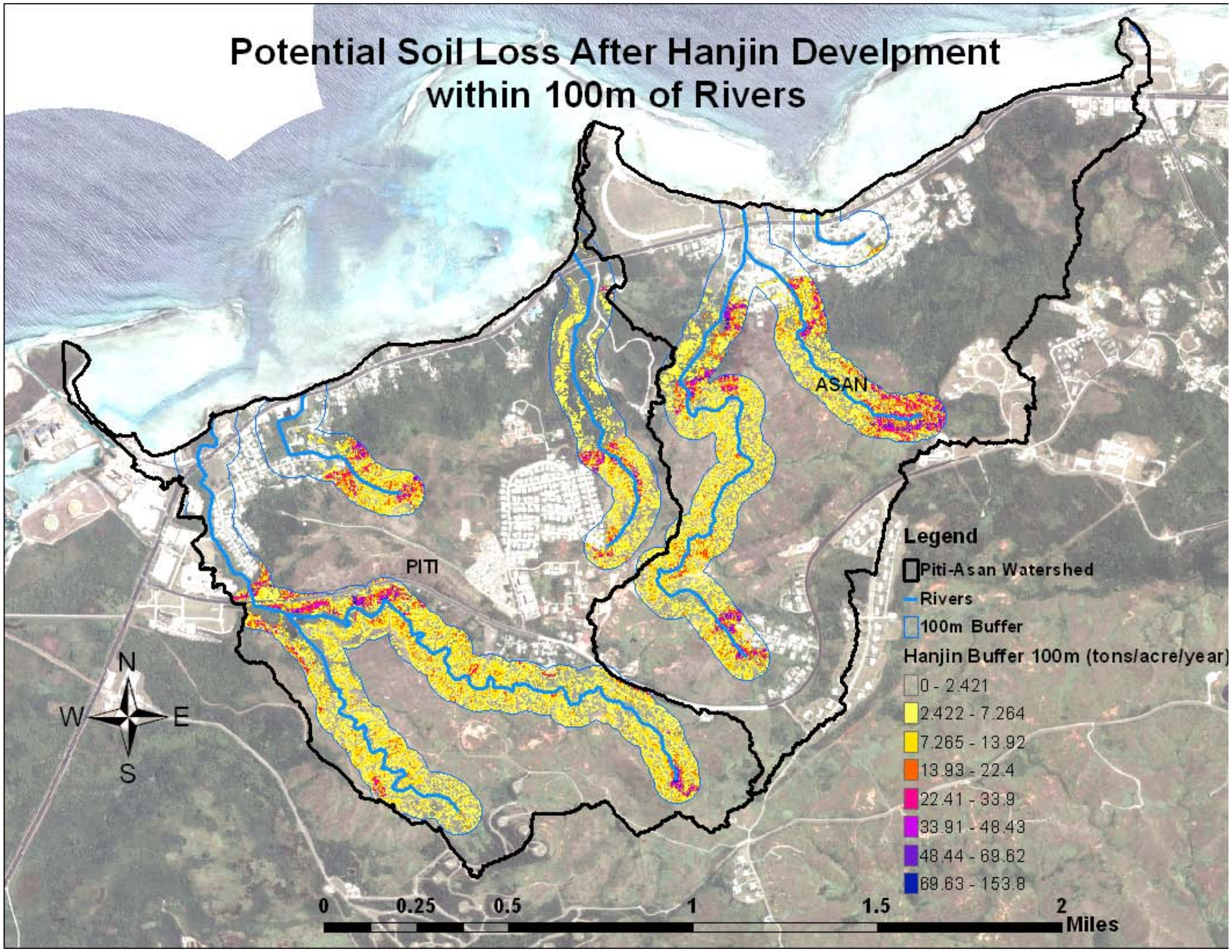

Figure 37. Estimated Soil Loss within 100m of Rivers with Hanjin Project

Table 2. Potential Change in Soil Loss from Development

Potential Soil Loss within 100m Buffer (tons/ acre / year)				
Site Description	Piti	% Change	Asan	% Change
Existing Condition	4.57		5.93	
Hanjin Developed	4.57	0	5.93	0
JHP Developed	4.57	0	5.89	-0.675

As previously stated, there is a section of the Asan River that flows directly through the proposed JHP Development property. As such, the JHP Development would require more attention to the management of erosion and sediment control (ESC) practices and other controls to minimize and mitigate for any environmental impacts of construction. Figure 38 illustrates the potential soil loss from the watershed during the construction of the proposed project. The figure illustrates that a large amount of potential soil loss would occur from the project during construction in comparison to the contribution from the rest of the watershed. This proposed development would cause a significant amount of soil erosion if proper soil barriers and other mitigation efforts to minimize soil loss from the property are not enforced and is why ESC practices during construction are important to reducing erosion and sedimentation in the watershed.

Figure 39 shows the potential soil loss with the JHP Development assuming permanent erosion controls are used and slopes are sufficiently stabilized along the stream banks and within the buffered areas. The JHP development property lot development of the lot in question would eventually cause a decrease in soil loss from that area as evidenced in Figure 40, which compares the final completed project with the current conditions and shows areas of negative change in erosion with the JHP Development. Furthermore, Table 2 illustrates that although the eventual change in potential soil loss within Asan Watershed would decline with the proposed JHP development, however there would be no significant change in potential soil loss to the watersheds.

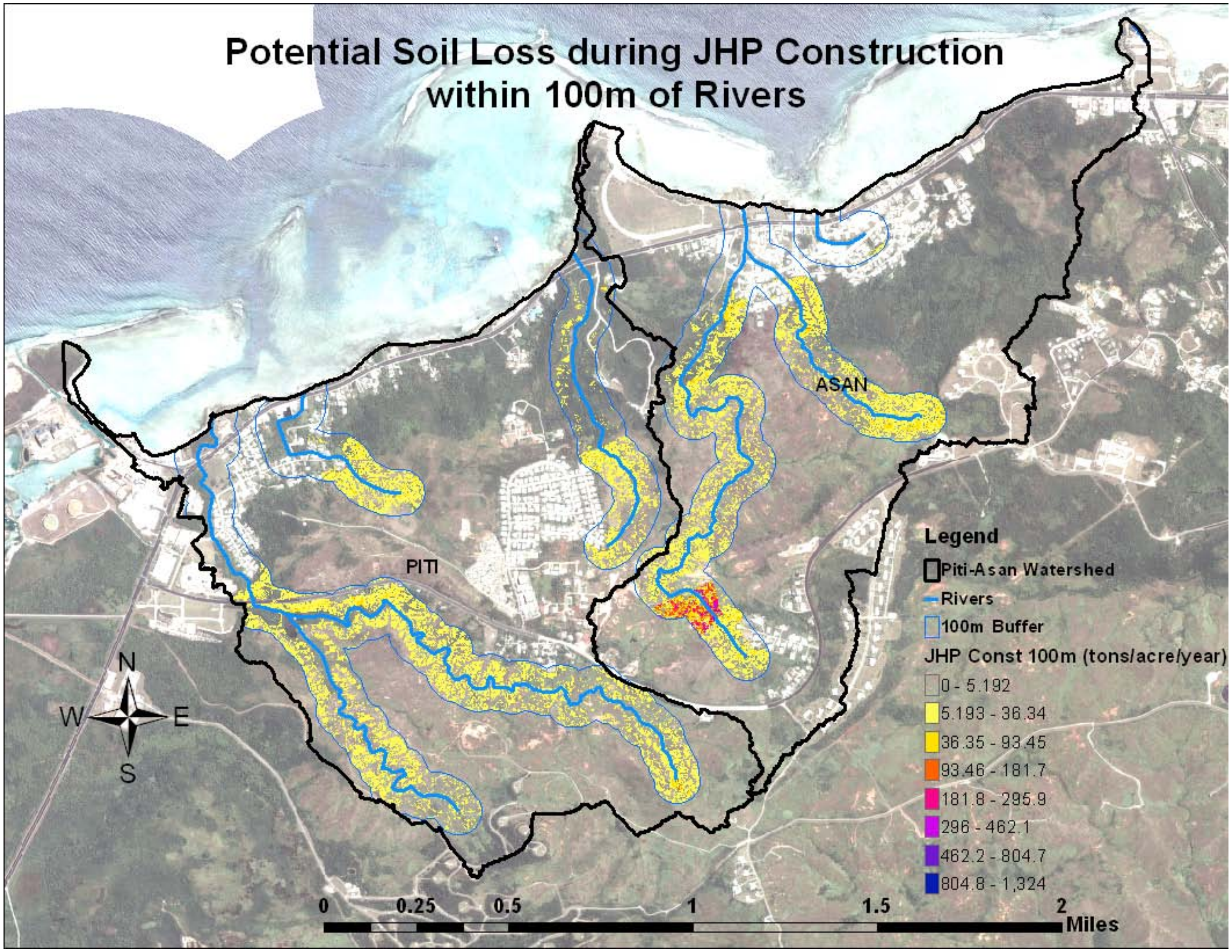

Figure 38. Estimated Soil Loss with JHP Development During Construction within 100m of Rivers

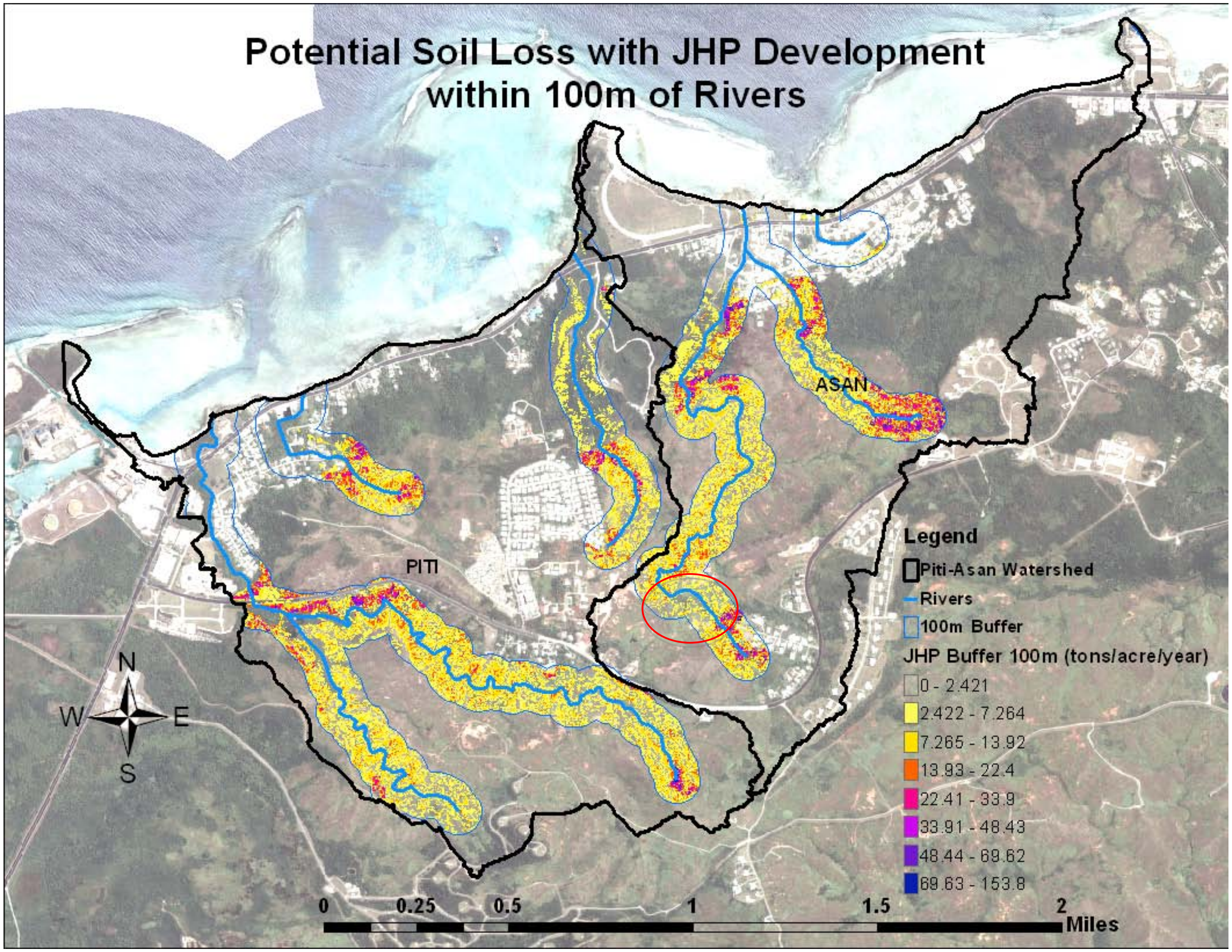

Figure 39: Estimated Soil Loss within 100m of Rivers with JHP Project

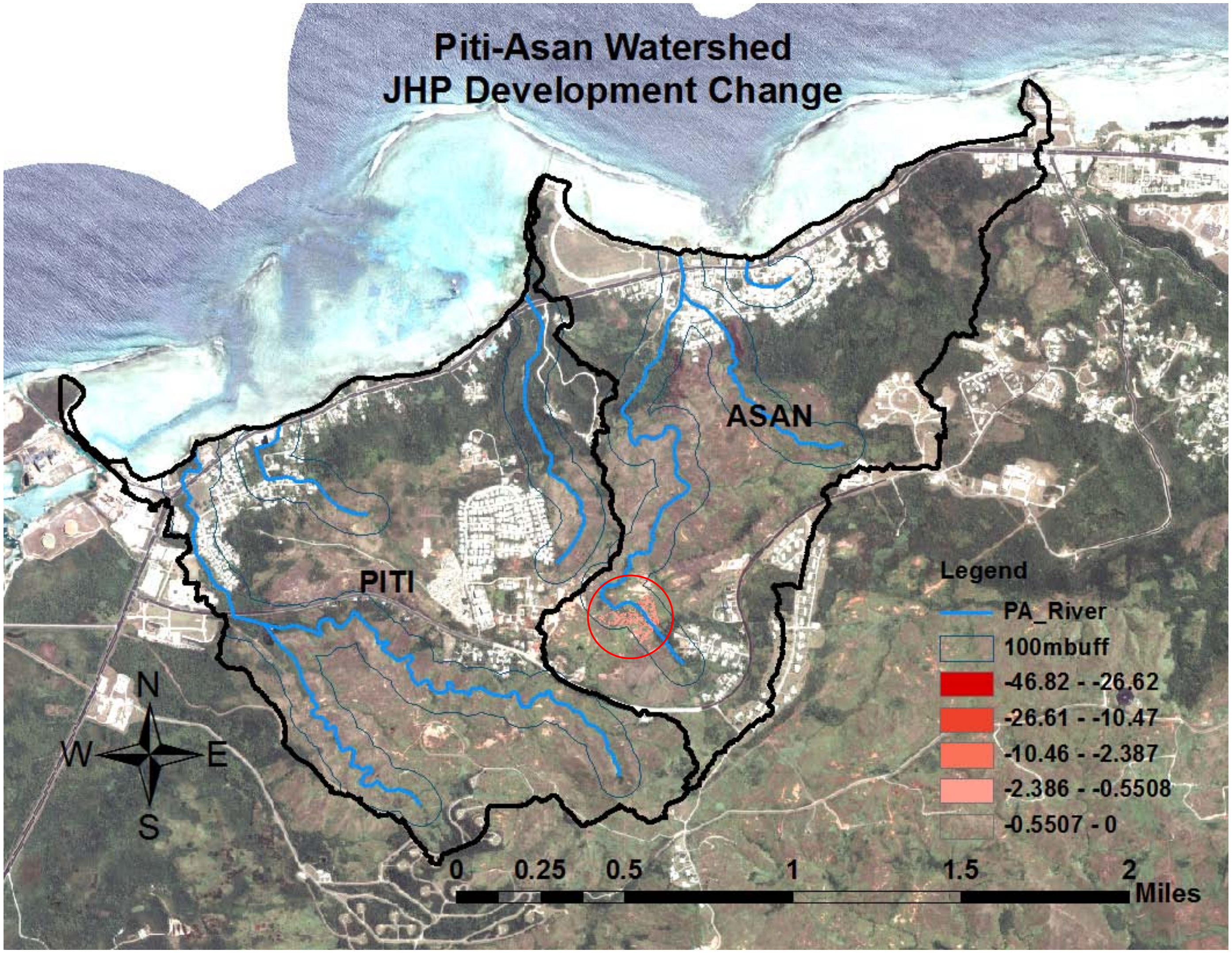

Figure 40: Estimated Soil Loss Change after Proposed JHP Development (tons/ acre/ year)

The Asan Watershed and Sub-basin is currently an area containing high levels of human activity. Aside from the housing already in existence and individual homes currently being constructed near the Asan River, there is also a major housing development being planned. The JHP Development Project is a large proposed housing project in which the Asan River flows directly through the property boundary. Because of the JHP Development's direct access to the Asan River, the proposed development will have a large impact on the Asan Watershed and must be well managed and monitored to minimize any impact on the environment.

Other activities within the Asan Watershed include uncontrolled clearing and grading activities, which have been observed within close proximity to the river (Figure 41). Such activity will result in additional contribution of inland soils into the Asan Bay. Although the soil in both watersheds is highly erosive, the increased activity within the Asan Watershed is accelerating the natural rate of erosion in the area. Without proper erosion control efforts surrounding existing housing and proposed development especially within 100 meters of the river, the outlets will be prone to increases in sedimentation from inland erosion.

Figure 41. Cleared Site for Construction without Mitigation Efforts and Located within Close Proximity of the Asan River

These proposed changes from the current conditions do not completely illustrate the potential change in soil loss to the watershed because it only accounted for land cover change based on change in land use. The changes in topography associated with leveling a property for development could increase the rate of soil erosion. This topographical change can impact the rest of the watershed in changing the dynamic hydrologic behavior of water flow throughout the system. Furthermore, flow through developed property to its former outlets downstream can be redirected not only by the change in elevation, but also by the addition of impervious surfaces which cause a rerouting of the flow to other areas within the watershed. Despite these issues, the GIS model does account for the potential soil loss changes and the soil loss change in comparison to the existing conditions.

The use of GIS in the production of the estimates of soil loss allow for the visual interpretation of areas most under need of erosion controls. Figure 42 was created using the existing conditions within the 100 meter river buffer so that the location of areas needing the most attention can be easily identified. One such area includes Figure 43, which shows a badland area and construction area located near the Asan River. The use of GIS enables the sites to be readily identified on a map and can aid in potential future erosion control efforts in the watershed by identifying possible areas of concentration for erosion control practices to be enforced.

The Masso Sub-basin is mostly a natural watershed environment. There is little development in the area except along the road. As a part of the development of the Masso Reservoir as a fishing area complete with a floating fishing platform on the reservoir. There have been efforts to reduce erosion and sedimentation into the reservoir to improve the reservoir's water quality for the game fish. There is not much data however regarding the state of the Masso Reservoir and the Masso River's sedimentation or hydrology prior to this project. There are some high erosion potential areas in the Masso River area identified by the 100 meter buffer in Figure 42.

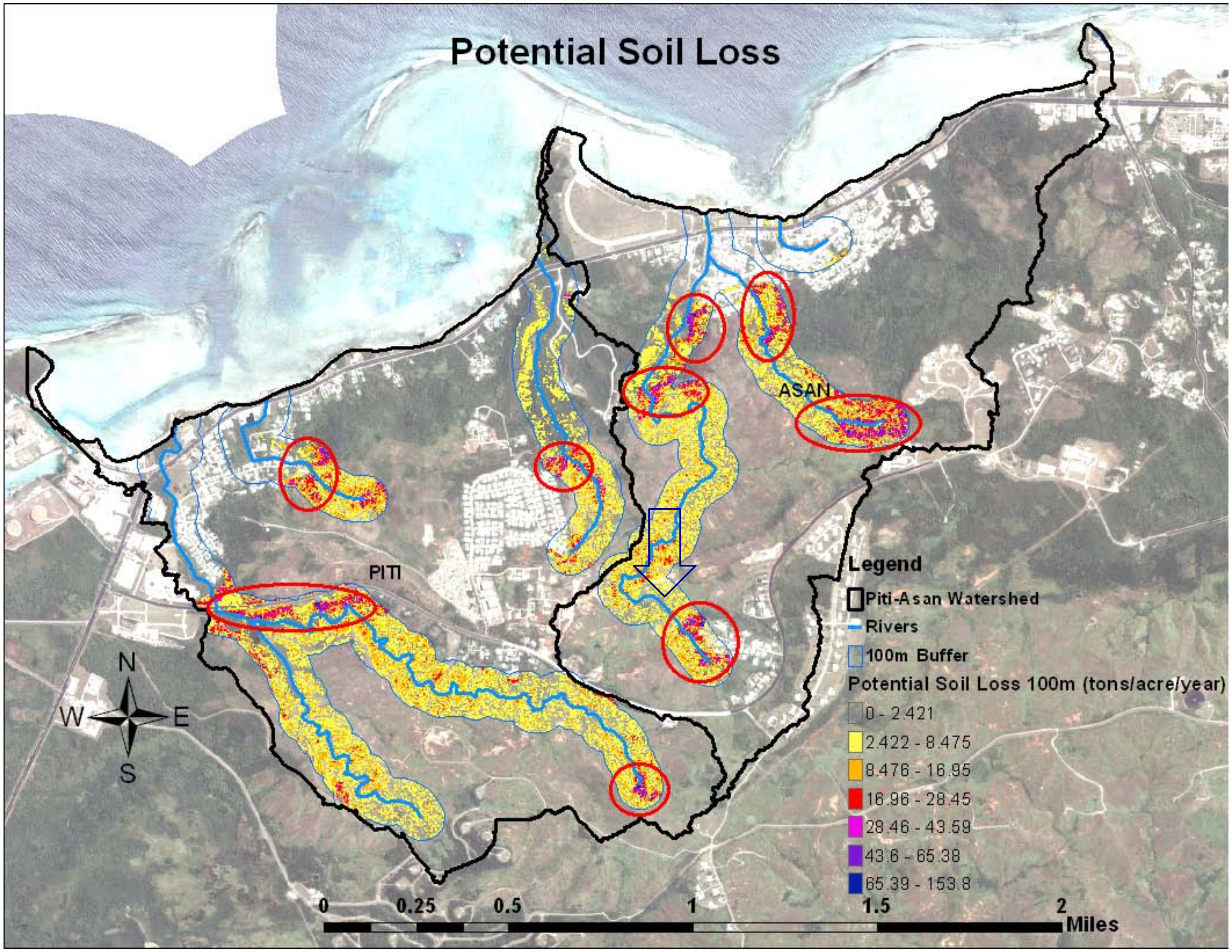

Figure 42: Piti- Asan Watershed High Sediment Contribution Areas

Figure 43: Sample Imagery of a High Erosion Contribution Area (June 20, 2012)

The steep slopes along the length of the river contribute to the high potential erosion areas near Masso River. There is one private lot (Figure 44) currently being developed along the Masso River that could be contributing to erosion and sedimentation within the Piti Watershed. However, the development is small compared to the developments being proposed in Asan.

The overall difference in turbidity observed within the Masso River and Asan River studies can be affected by differences in construction and development levels within the two watershed areas. The turbidity can also be influenced by the presence of the Masso Reservoir (Figure 45) located upstream of the Masso study site and its location downstream of a large length of the river. This location has been observed to collect sediment from upstream and can diminish the contribution of most of the sediment into the Piti Bay.

Figure 44: Masso Lot Construction (July 12, 2012)

Figure 45: Masso Reservoir (June 7, 2011)

Recommendations
Chapter 5

The major contributors of soil erosion within the Piti-Asan Watershed are both natural and human activity. Natural causes of soil erosion include highly erosive soils, poor vegetative soil protection, steep slopes, bank erosion, and heavy rainfall events. Human contributors include construction activities and the lack of erosion controls surrounding existing buildings, especially buildings along steep slopes. Areas identified to contribute high potential erosion, especially sites within the 100 meter buffer zone, should be prioritized and monitored. For future studies in the watershed it is also recommended that stream level and flow measurements continue to be collected in order to build upon the stage discharge curves created for the Masso and Asan Rivers.

An increase in the accuracy for future use of the GIS erosion model would also benefit from a more detailed vegetation map illustrating the dominant species of vegetation covering the site. This could be especially beneficial for high swordgrass (*Miscanthus floridulus*) covered areas, which can be more erosive than most other grass types and provide very little surface cover. As such the presence of high swordgrass may underestimate the potential soil loss in that area.

Slope stabilization using grass seeding (Figure 46), erosion blankets (Figure 47), or other slope stabilization methods to stabilize eroding sites, especially within 100 meters of river bodies, would minimize soil loss near river bodies. Some grasses identified as suitable for waterway or exposed soil stabilization include

> *Cynodon dactylon* (Bermuda grass), *Axonopus affinis* (carpet grass), *Eremochloa ophiuroides* (centipede grass), *Digitaria eriantha* (digit grass), *Paspalum hieronymii* (paspalum), *Stenotaphrum seundatum* (St. Augustine grass), *Chrysopogon zizanoides* (vetiver grass), and*Zoysia japonica* (zoysia grass) (Horsley Witten Group, 2012).

Seeding with other vegetation, such as the introduced*Acacia confusa,* may also be useful as it has been used for various other reforestation efforts in southern Guam including the Masso Reforestation Project (Guam Department of Agriculture Forestry & Soil Resources Division, 2007). Once *Acacia* has been established, planting with native tree species can eventually be performed to reforest with native vegetation.

Figure 46: Hydroseeding

Figure 47: Erosion Control Blankets

Seeding with hedgerows of vetiver grass (Figure 48) along high erosion potential areas can have the benefit of not only a reduction of sediment contribution to rivers, but also act as a form of filtration treatment to remove other pollutants carried by runoff (Truong et al, 2000). Commercially sterilizedvetiver is the preferred species to treat erosion on Guam. This type of vetiver is noninvasive because it does not produce fertile seeds and therefore does not pose a risk to outcompete native vegetation. Seeding of grasses improves slope stabilization and soil conditions so larger native vegetation can be reestablished in the area.

More stringent policies and enforcement of erosion control methods in construction and development, especially along river bodies could minimize water pollution contributed to water bodies during and after construction. Construction occurring within the watershed, especially near water bodies should be conducting erosion and sedimentation control (ESC) practices throughout the duration of construction projects.Figure 49shows one such site that should have ESC practices in place, but lacked any form of erosion control on site despite the close proximity to the Asan River. Some recommended construction practices include the proper use of silt fencing, compost socks, berms, swales, vetiver hedge rows, or temporary sediment traps.

Silt fencing is a frequently used erosion control practice on Guam and elsewhere that is often improperly installed or lacks proper maintenance, which limits its effectiveness in keeping sediment controlled. The use of compost socks or berms are alternatives to the use of silt fencing to control the flow of runoff around construction areas, but also require regular maintenance to maintain effectiveness. Compost socks are tubular mesh netting filled with compost and possibly also grass at prioritized sites could filter out sediment in runoff water and encourage filtration at high erosion potential sites.

ESC practices are recommended for existing structures. These suggestions should be especially enforced in areas prone to landslides and close to river bodies. This includes slope ESC for homes built on steep slopes (Figure 50). Stabilization of the mouth of the river bodies is also recommended to reduce erosion at river outlets.

Figure 48: Vetiver Grass Hedgerow

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Figure 49: Cleared Lot without ESC Measures near Asan River

Figure 50: Site for Suggested Soil Stabilization

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APPENDIX I
HISTORICAL DATA

Table 3. Masso River Historical Turbidity Data (Guam EPA)

DATE	STATION	TIME	pH	Rainfall	Temperature, air (^oC)	Temperature, water (^oC)	Total Solids (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
5/6/1997	APRM-1A	0950	7.90	none	NS	26.6	NS	2	1.97
6/3/1997	APRM-1A	0920	7.41	none	NS	29.3	NS	2	3.4
6/30/1997	APRM-1A	0945	7.42	none	NS	28.3	NS	15	26
8/25/1997	APRM-1A	1022	8.08	none	NS	28.8	160	10	23
12/1/1997	APRM-1A	1030	7.943	scattered	33.7	27.0	220	3.3	2.7
5/6/1997	APRM-1B	1005	7.59	none	NS	27.8	NS	4	2.84
6/3/1997	APRM-1B	0915	7.99	none	NS	27.7	NS	2	1.4
6/30/1997	APRM-1B	0930	7.77	none	NS	26.5	NS	20	20
8/25/1997	APRM-1B	1010	7.74	none	NS	26.1	140	10	15
12/1/1997	APRM-1B	1020	7.888	scattered	33.7	25.9	240	0	2.1
NS = Not Sampled									

Table 4: Asan River Historical Turbidity Data (Guam EPA)

DATE	STATION	TIME	pH	Rainfall	Temperature, air (°C)	Temperature, water (°C)	Total Solids (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
5/6/1997	ASRI-2	0920	8.23	none	NS	NS	NS	2	1.8
6/3/1997	ASRI-2	0900	8.30	none	NS	29.6	NS	2	3.4
6/30/1997	ASRI-2	0905	7.81	none	NS	28.8	NS	14	8.7
8/25/1997	ASRI-2	0948	7.57	none	NS	27.9	300	0	6.8
12/1/1997	ASRI-2	1000	7.954	scattered	33.7	27.0	280	3.3	2.5
5/6/1997	ASRI-3	0930	8.01	none	NS	27.4	NS	2	1.5
6/3/1997	ASRI-3	0905	8.04	none	NS	27.8	NS	2	1.1
6/30/1997	ASRI-3	0920	7.83	none	NS	27.4	NS	6	6.6
8/25/1997	ASRI-3	0956	7.78	none	NS	26.6	180	0	10.2
12/1/1997	ASRI-3	1005	7.892	scattered	33.7	25.4	230	3.3	1.5
NS = Not Sampled									

APPENDIX II
RUSLE FACTOR VALUE TABLES

Table 5: USLE C Factors (Soil Conservation Service, 1977)

Cover management, "C" factors for permanent pasture, rangeland, and idle land.

Vegetal Canopy		Cover That Contacts the Surface						
Type and Height of Raised Canopy[2]	Canopy Covers[3] %	Type[4]	Percent Ground Cover 0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush, 0.5 m (1.6 ft.) fall ht.	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, 2 m 6.6 ft. fall ht.	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable, low brush , 4 m (13.1 ft.) fall ht.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

[1]All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years.
[2]Average fall height of waterdrops from canopy to soil surface.
[3]Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a birds's-eye view).
[4]G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep. W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, and/or undecayed residue).

Table 6: Soil K Factor Values for Guam (NRCS, 2007)

HEL Frozen Soils List for Water Erosion Pre-1990
Island of Guam, Territory of Guam

Highly Erodible Land Classes:
Class 1 = HEL (Highly Erodible Land)
Class 2 = Potentially HEL
Class 3 = NHEL (Non-HEL)

Soil Map Unit Number	Soil Map Unit Name	K Factor	Soil Loss Tolerance (T) Value	HEL Class
1	Agfayan Clay, 15 to 30 percent slopes	0.2	1	1
2	Agfayan Clay, 30 to 60 percent slopes	0.2	1	1
3	Agfayan-Rock Outcrop Complex, 7 to 15 percent slopes	0.2	1	1
4	Agfayan-Rock Outcrop Complex, 15 to 30 percent slopes	0.2	1	1
5	Agfayan-Rock Outcrop Complex, 30 to 60 percent slopes	0.2	1	1
6	Agfayan-Akina Association, extremely steep	0.2	1	1
7	Agfayan-Akina-Rock Outcrop Association, extremely steep	0.2	1	1
8	Akina Silty Clay, 3 to 7 percent slopes	0.2	5	2
9	Akina Silty Clay 7 to 15 percent slopes	0.2	5	1
10	Akina Silty Clay, 15 to 30 percent slopes	0.2	5	1
11	Akina Silty Clay, 30 to 60 percent slopes	0.2	5	1
12	Akina-Agfayan Association, steep	0.2	5	1
13	Akina-Atate Silty Clays. 0 to 7 percent slopes	0.2	5	2
14	Akina-Atate Clays, 7 to 15 percent slopes	0.2	5	1
15	Akina-Atate Silty Clays, 15 to 30 percent slopes	0.2	5	1
16	Akina-Atate Silty Clays, 30 to 60 percent slopes	0.2	5	1
17	Akina-Atate Association, steep	0.2	5	1
18	Akina-Badland Complex, 7 to 15 percent slopes	0.2	5	1
19	Akina-Badland Complex, 15 to 30 percent slopes	0.2	5	1
20	Akina-Badland Complex, 30 to 60 percent slopes	0.2	5	1
21	Akina-Badland Association, steep	0.2	5	1
22	Akina-Urban Lands Complex, 0 to 7 percent slopes	0.2	5	2
23	Chacha Clay, 0 to 5 percent slopes	0.15	5	2
24	Chacha Variant Clay, 0 to 3 percent slopes	0.15	5	3
25	Guam Cobbly Clay Loam, 3 to 7 percent slopes	0.05	1	1
26	Guam Cobbly Clay Loam, 7 to 15 percent slopes	0.05	1	1
27	Guam-Saipan Complex, 0 to 7 percent slopes	0.05	1	2
28	Guam-Urban Land Complex, 0 to 3 percent slopes	0.05	1	2
29	Guam-Yigo Complex, 0 to 7 percent slopes	0.05	1	2
30	Inarajan Clay, 0 to 4 percent slopes	0.24	5	2
31	Inarajan Sandy Clay Loam, 0 to 3 percent slopes	0.17	5	3
32	Inarajan Cariant Mucky Clay, 0 to 3 percent sploes	0.28	5	3
33	Pulantat Clay, 3 to 7 percent slopes	0.24	1	1
34	Pulantat Clay, 7 to 15 percent slopes	0.24	1	1
35	Pulantat Clay, 15 to 30 percent slopes	0.24	1	1
36	Pulantat Clay, 30 to 60 percent slopes	0.24	1	1
37	Pulantat-Chacha Clays, 0 to 7 percent slopes	0.24	1	2
38	Pulantat-Chacha Clays, 7 to 15 percent slopes	0.24	1	2
39	Pulantat-Kagman Clays, 0 to 7 percent slopes	0.24	1	2
40	Pulantat-Kagman Clays, 7 to 15 percent slopes	0.24	1	2
41	Pulantat-Urban Land Complex, 0 to 7 percent slopes	0.24	1	2
42	Pulantat-Urban Land Complex, 7 to 15 percent slopes	0.24	1	1
43	Ritidian-Rock Outcrop Complex, 3 to 15 percent slopes	0.02	1	2
44	Ritidian-Rock Outcrop Complex, 15 to 60 percent slopes	0.02	1	1
45	Rock Outcrop-Ritidian Complex, 60 to 99 percent slopes	0.02	1	1
46	Sasalaguan Clay, 7 to 15 percent slopes	0.28	4	1
47	Shioya Loamy Sand, 0 to 5 percent slopes	0.15	5	2
48	Togcha-Akina Silty Clays, 3 to 7 percent slopes	0.15	5	2
49	Togcha-Akina Silty Clays, 7 to 15 percent slopes	0.15	5	2
50	Togcha-Ylig Complex, 3 to 7 percent slopes	0.15	5	2
51	Togcha-Ylig Complex, 7 to 15 percent slopes	0.15	5	2
52	Troposaprists, 0 to 1 perceent slopes	0.02	5	3
54	Ylgi Clay, 0 to 3 percent slopes	0.24	5	3
55	Ylgi Clay, 3 to 7 percent slopes	0.24	5	2