IDENTIFICATION OF EROSION PROCESSES AND SOURCES OF EXPOSED PATCHES IN THE LA SA FUA WATERSHED OF SOUTHERN GUAM

By

Nicole Scheman
Shahram Khosrowpanah
Mohammed Gollabi
Leroy Heitz

ABSTRACT

In Southern Guam, dramatic erosion processes are visibly evident. Areas of land overlying steeply sloping topography are eroding soils, leaving exposed patches of earth, or badlands. The objective of this study was to learn more about the specificity of erosion rates and sources from badlands in Southern Guam within the boundaries of the La Sa Fua watershed. Using quantitative evaluations from physical measurements and information from previous studies, a disparity was established between previously published estimated rates and measured sediment loss. Results indicated that badlands across the steepest slopes of the watershed contribute an average of 65.90 tons/acre/year in soil yield, as opposed to the 225.92 tons/acre/year calculated from the Revised Universal Soil Loss Equation (RUSLE). Comparatively, badlands from the lower lying, less steep area of the watershed averaged 13.70 tons/acre/year in sediment yield, as opposed to the 225.92 tons/acre/year calculated from the RUSLE model.

TABLE OF CONTENTS

Page

v

LIST OF FIGURES

LIST OF GRAPHS

LIST OF TABLES

INTRODUCTION

Soil erosion is the main source of sediment that pollutes streams and fills reservoirs, as well as degrades coral reefs (Elliot and Ward, 1995). Soil erosion is also a major contributor of non-point source pollution. "Non-point" source pollution refers to diffused or transported pollutants such as nutrients and pesticides. Erosion falls into two major categories: geological and accelerated erosion-the result of man-made or animal activities (Schwab et al., 1996). Geological erosion is the wearing away of Earth's surface by the forces of wind and water. For example in humid climates that support forests or grasslands, vegetation holds the soil in place and new soil continuously forms, offsetting all or part of the slow geologic erosion. Geologic erosion can also occur as landslides, which generally result from inherent geologic instability, but may also be triggered by heavy rainfall or earthquakes. Accelerated erosion is the result of human disturbance to the soil. Examples of accelerated erosion include the clearing of native woodlands, cultivating crops, the setting of fires and the use of overland recreational equipment.

Non-point source pollution from watersheds has adverse effects on downstream and ecosystem water quality (Cochrane and Flanagan, 1999), however the problem of erosion is often ignored by its subtle and imperceptible nature (Pimentel, 1993). In southern Guam, dramatic erosion processes are visibly evident in large, bare plots of earth that occur throughout watersheds in the southern half of the island. These areas of land along the steeply sloping topography, termed '*badlands*', are continually eroding soils, which leave exposed patches of earth. Erosion control practices have the potential to minimize the impact of land losses and sustain water quality. However, controlling erosion in watersheds is costly; therefore it is critical to identify the processes and sources of erosion before implementing watershed management practices.

The badlands of southern Guam (Figure 1) are located within the confines of several of Guam's most important watersheds, including the Ugum, Fena and La Sa Fua watersheds. The overall extent of the badlands on Guam and elsewhere is currently unknown. Badland association with non-point source pollution is not considered to be a

linear relationship, as the ratio of observed badland area to the total sediment yield for the small, southern watersheds is disproportionably smaller (NRCS, 2001). Meaning badlands account for approximately 1-10% of the total vegetation cover area in southern Guam, but contribute the highest proportion of predicted soil erosion.

Figure 1. Badlands in a southern Guam watershed.

1.1 Defining badlands

As described earlier, the term 'badlands' on Guam refers to pitted, sloping sites void of vegetation (NRCS, 1996). Young (1988) described badlands on Guam as actively eroding areas of very deep, well-drained saprolite derived from tuff and tuff breccia. Saprolites are weathered rocks, in this case volcanic in origin, whose original textures and structures are preserved despite replacement of the fresh minerals by clay (Carroll and Hathaway, 1963). Since badlands are exposed to the direct impact of overland flow, wind and rain, they are considered the effect of sheet and rill erosion. Sheet erosion occurs when rain falls faster than the soil can absorb it and carries off the soil particles. The resulting eroded soils appear as patches, or sheets, over ground surfaces. Rill erosion occurs when surface flow establishes paths. If the soil remains unprotected, some of the small paths give way to larger rills, or small eroding channels, where water flows through and detaches

soil form both the floor and sides of the channel. Given such direct impact from the elements, both wind and rain, and the moderately low permeability of badland soils, rapid runoff results in severe sheet and rill erosion patterns.

A recent estimate by Natural Resource Conservation Service (NRCS) on Guam says that, "… sediment delivery indicates that sheet and rill erosion contributes nearly 93% of the erosion and sediment in Fena Watershed." In deriving the percentage, the NRCS implemented the Universal Soil Loss Equation (USLE) for the purpose of predicting sheet and rill erosion as well as erosion in the badlands of Fena Watershed. The study also concluded that badlands, while contributing approximately 1% of the total surface area of Fena Watershed, are the greatest contributor to sediment in the reservoir on a per acre basis.

Badlands, or sheet and rill type erosion, are a significant source of sediment in the La Sa Fua watershed. From observation, badlands are currently increasing in number and size. The origins of badlands in southern Guam are believed related to grazing animals, forest clearing, annual wild- and set-fires, military activity and recreational vehicles. However, the rate of badland erosion is likely related to topographic slope, faulting and fractures, rainfall and position on slope (Simon et al., 1990).

1.2 Purpose of project

The primary objective of this study was to learn more about and document the specifics of erosion rates and sediment sources from badlands within the boundaries of the La Sa Fua watershed in southern Guam using quantitative evaluations from physical measurements and information from previous studies. The secondary objective of this study was to estimate and compare sediment yield from steep-slope and valley locale badlands in southern Guam by comparing direct measurements of badland erosion rates to predictions from the Revised Universal Soil Loss Equation (RUSLE) used in previous estimations for erosion rates. Direct measurements were made using erosion-pin arrays and suspended sediment sample collection. Information from previous studies was amassed from watershed assessments of southern Guam conducted by NRCS and a previous master's thesis from the University of Guam. The badlands for this project were chosen

based on a number of factors including surface area in relation to the total area of the La Sa Fua watershed, lack of potential disturbance, representation of badland morphology within the watershed and slope variables.

REVIEW OF LITERATURE

Tropical soil erosion has been studied extensively, but there is little information regarding the particular, patchy erosion phenomena that is visible in southern Guam. Additionally, little quantitative data have been collected on badland association with non-point source pollution in the form of sediment runoff and its impact on fringing coral reefs. The following references are utilized in this report for the purpose of erosion rate comparisons between southern Guam watersheds.

In 1996, the <u>Ugum Watershed Management Plan, Territory of Guam</u> was compiled by soil scientists and resource conservationists for the Natural Resource Conservation Service (NRCS, 1996). The report, which targeted local farmers, environmentalists and politicians on Guam, was intended as a watershed management plan including erosion control practices. The report concluded that badlands within the geographical boundaries of the Ugum watershed contributed 243 tons/acre of watershed/year in sediment yield. Results from the assessment were determined using the Universal Soil Loss Equation.

In 2001 NRCS prepared the <u>Fena Watershed Resource Assessment: Erosion and Sediment Identification for Critical Area Treatment</u> for the United States Navy (NRCS, 2001). The report concluded that badlands within the geographical boundaries of the Fena watershed, which includes Guam's largest surface water supply, Fena Reservoir, contributed 240 tons/acre of watershed/year in sediment yield. Results from the assessment were determined using the RUSLE method for determining a total sediment delivery ratio for the watershed.

In a University of Guam master's thesis, Dumaliang (1998) developed and determined empirically the rainfall-runoff erosivity factor, or R-factor, a rainfall erosion index. The soil erodibilty factor, or K-factor, is the soil-loss rate per erosion index unit for a specified soil, as measured on a standard plot, and was determined from the most recent <u>Soil Survey of the Territory of Guam</u> (Young, 1988). The 12-year-old survey was developed by the Soil Conservation Service (SCS) in order to classify Guam's soils into taxonomies as well as yield sample descriptions.

In 1997 a master's thesis from the University of Guam by Lewis assessed the basin sediment yield from slope retreat rates in the Taelayag River watershed empirically.

5

Completed during a single wet season, the total rainfall accumulation for the period of the study was only 52.9 in (134.4 cm).   The results estimated approximate sediment yield for badland erosion at 2.1 to 9.5 tons/acre/year, 96% less than the results published by the NRCS for both the Ugum and Fena watershed reports. The report, compiled over a four and half month period, stressed the need to measure erosion rates over a period of a year or more to determine a more accurate yield.

METHODOLOGY

To accomplish the objectives of this study it was necessary to utilize a field methodology for directly measuring soil erosion on hillslopes. Such methods were developed by K. Michael Nolan of the USGS for the purpose of measuring rates of hillslope erosion. These methods were described in a sediment-source data report for Lake Tahoe, California (Hill et al., 1990) and pioneered by Schumm (1954). Physical erosion measurements are based on fluctuations in the average land-surface altitude over time. Estimated soil erosion and sedimentation calculations, using the RUSLE, used established procedures developed by the Agricultural Research Service (ARS) and the Soil Conservation Service, present-day NRCS.

This study was conducted from August 9, 2001 to July 8, 2002, with experimental data gathered from July 17, 2000 to July 8, 2002 and rainfall data examined from 1992 to 2002. The experimental time frame was originally divided into annual site visits. Initial analysis showed that a more aggressive measurement schedule was going to be needed. Consequently, site visits were made every three months, and finally following Typhoon Chata'an (July 5, 2002). Each site visit took place over a 2-day period. Factors for use with the RUSLE method were measured and compared to field data from the experimental sites as well as previous assessments for badland erosion.

3.1 Test sites

The La Sa Fua watershed, Figure 2, is located in the southwestern half of Guam, north of the Umatac Village and south of Cetti Bay. It has a drainage area of 1.06 mi^2 (2.74 km^2), which includes the La Sa Fua River with tributaries from the Chagame River and Alatgue Springs. The watershed trends follow the length of the river for approximately 2.5 mi (4 km) in a westerly direction toward the coast, finally discharging at Fouha Bay. Its highest elevation, Mt. Jumullong Manglo, sits at 1,282 ft (393 m) above sea level. It is a largely undeveloped watershed with its heaviest traffic located along the western most edge following Route 2 at approximately 600 ft (183 m) above sea level (Figure 2). Due to its underdevelopment, the La Sa Fua watershed site was selected for qualifying and

quantifying badland erosional sources with sediment loads and suspended sediment at gage sites along the La Sa Fua River. The experimental plots were chosen based on surface area in relation to the La Sa Fua watershed, lack of potential disturbance, representation of badland morphology within the watershed and slope variance. The four test sites within the La Sa Fua watershed (Figure 3) selected for this project varied in shape and size, but remained representative of upland and low-lying badland and grassland locations within the watershed.

Two badland and two grassland sites were selected within the watershed. All sites were within the topographical boundaries of the drainage basin. All four sites represent typical badland and grassland sites at the highest and lowest elevations within the basin. Elevation for the steep-slope badland and grassland is approximately 1,100 ft (335 m). Elevation for the valley badland and grassland is approximately 400 ft (122 m). Relief within the steep-slope badland test site is approximately 40 ft (12 m) with slopes varying between 17 to 42 degrees. Relief within the valley badland and grassland test sites is less than 10 ft (3 m), with slopes varying between 15 to 19 degrees.

Test sites are listed in Table 1 and are further referred to by their project reference numbers hereafter. Each test site contained a minimum of 3 transects, or pin-array configurations (Figure 4), with 11 pin measurements, or stations, between each transect. Transects were numbered 1-10 based on the test site location. For instance, valley locale badland described as RC contained three configurations, RC1-1, RC1-2 and RC1-3. Therefore, RC1-1 contained 11 equally spaced stations numbered 0-1.0 and so forth for transects RC1-2 and RC1-3.

Figure 2. Local setting.
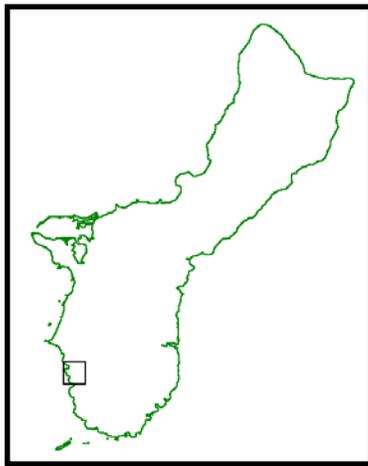
La Sa Fua watershed
stream gages

Mt   Jumullong
Manglo
Raingage

Valley test sites

Steep-slope test sites

La Sa Fua watershed
boundary

0.4   0   0.4 Miles

Figure 3. Test Sites (clockwise from left) BL, GL1, RC and GL3.

Figure 4. Sketch of pin-array configuration.
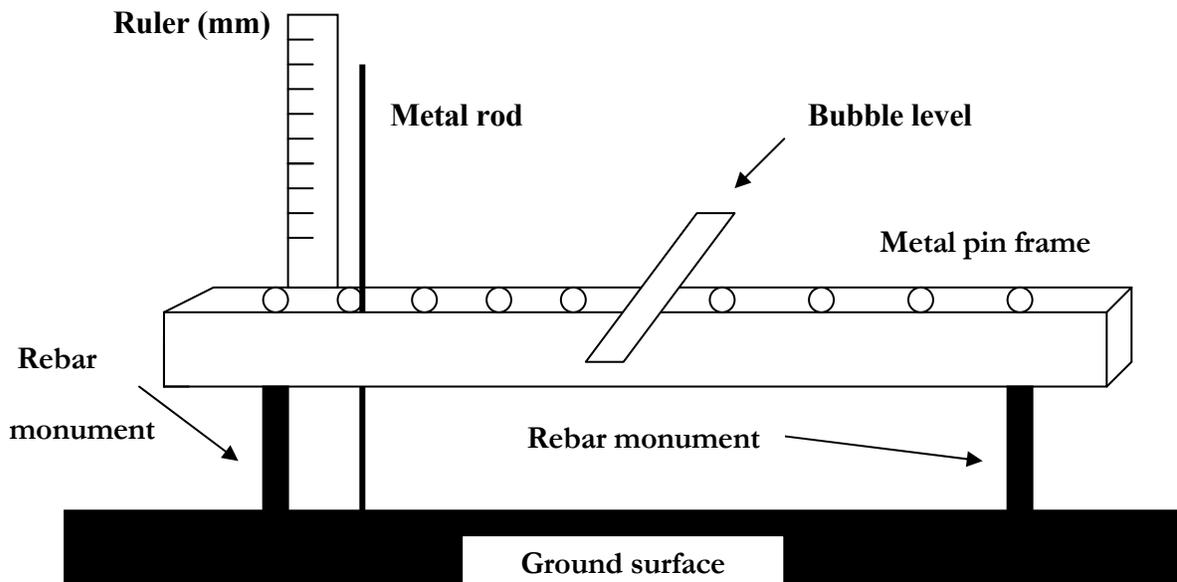
Test sites BL and RC lie on different members of the Umatac Formation. BL over the Bolanos Pyroclastic Member and RC over the Facpi Formation, which may account for differences in the color of the saprolites. RC is a former road cut and the older exposure.

3.2 Field methods

3.2.1 Site delineation

The boundaries for the test site perimeters were delineated and surveyed in July 2000. All site areas were observed and traversed on a regular basis to ensure a continued lack of disturbance and to observe any marked changes with regard to land surface. Stereophonic and orthographic photographs from December 16, 1966 and 1994 respectively, were utilized for delineation of the watershed boundary. The area of the drainage basin was further determined by overlaying the delineated boundary on a

topographic projection in the existing geo-referenced GIS database, which also insured that test site areas fell within the watershed.

3.2.2 Site yield

In order to determine the volume of sediment eroding over the site area, it was necessary to implement the USGS techniques for measuring hill-slope erosion. Transects were established with lengths of iron rebar (monuments) driven into the ground in pairs, forming meter wide experimental plots (see Figure 5).

Figure 5. Photograph of erosion-pin array technique.
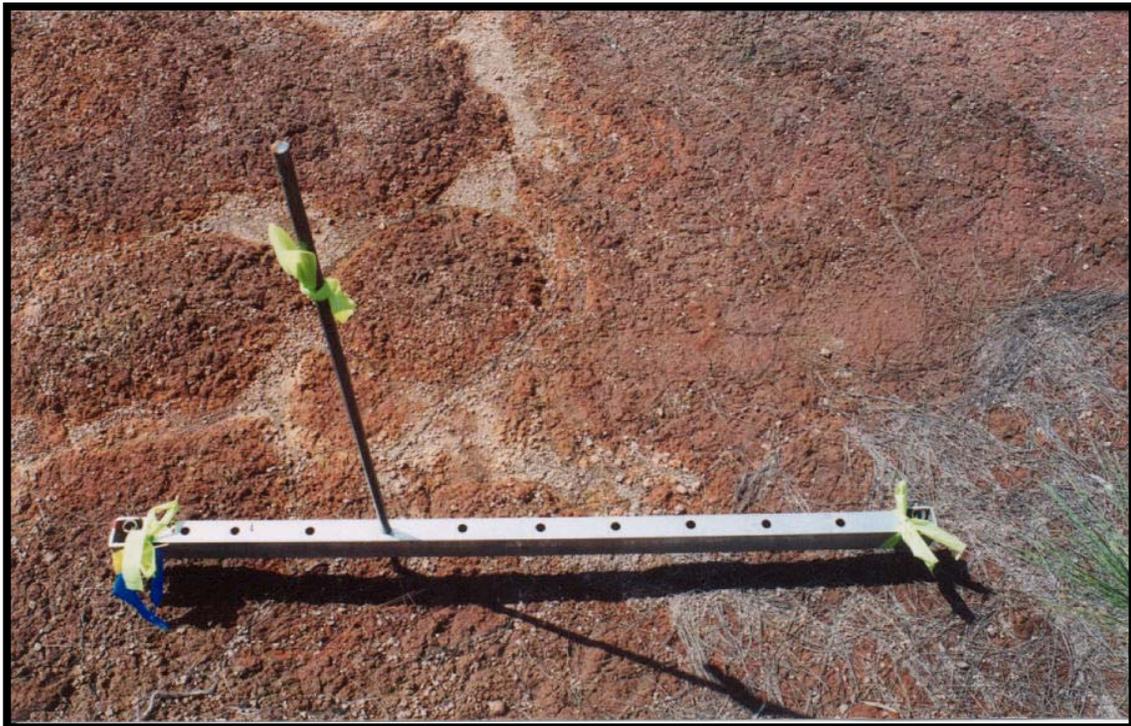
The transects were installed within the badland and grassland site areas typically in sets of three; however, in BL there was one set of three while the remaining arrays were more randomly placed to yield a more accurate overall measurement (Figure 6). The distribution of pin arrays insures measurement of soils re-deposited within the designated plot area. Only a fraction of the sediment is actually carried off the site since even the

highest energy storm events tend to relocate soils. With regard to the fallacies of experimental plots, Blaikie and Brookfield (1987) assert that, "…the complete removal of one 'unit' of soil may require several storm events over an extended period of time, but on the experimental soil-loss plot it would have needed only one such event".

Figure 6. Sketches of transects within test site boundaries.
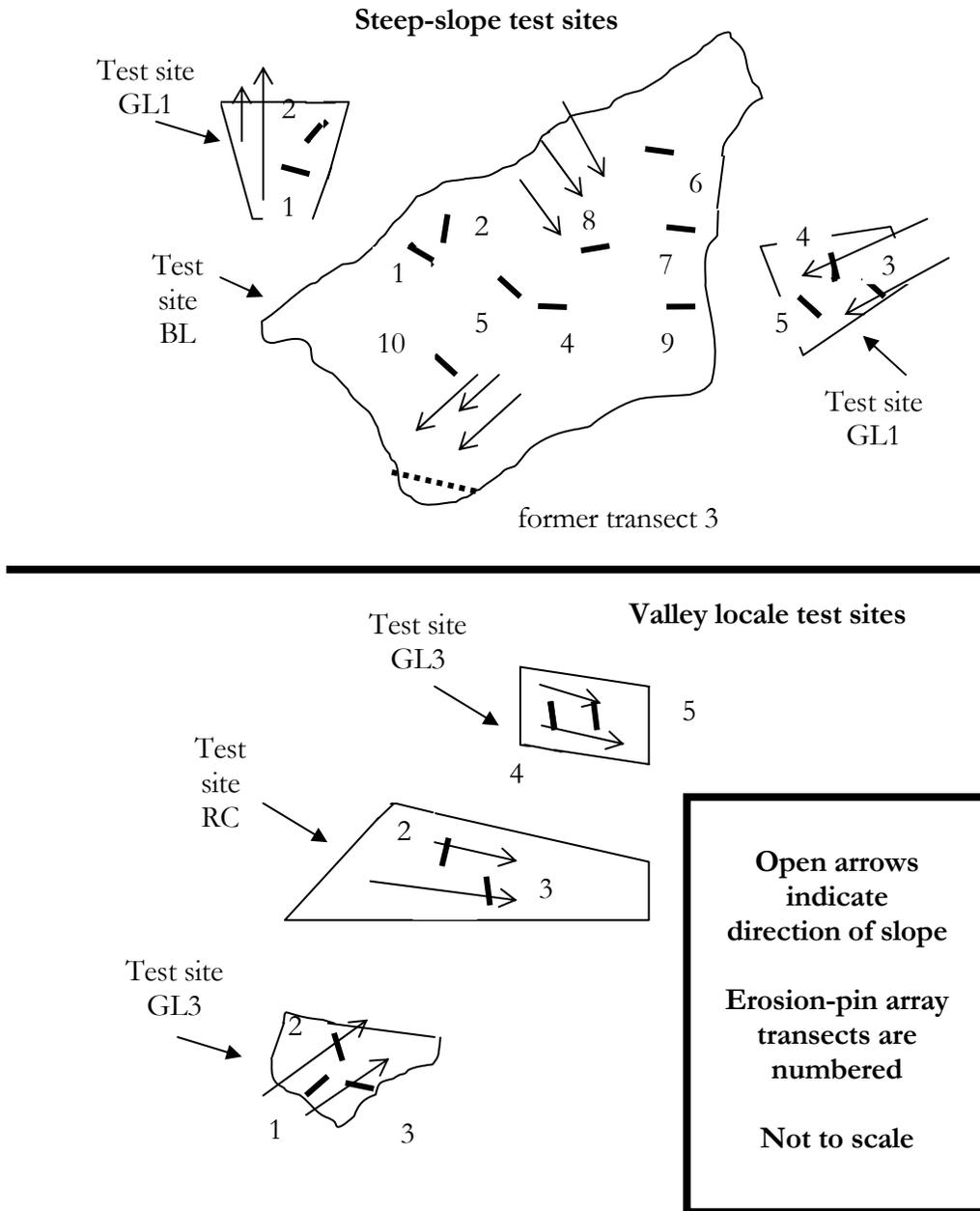
Blaikie and Brookfield's observations proved true for this experiment, as soil movement within each experimental test site was a process of relocation and not complete removal, with the greatest shifts following a typhoon event.

Transects were further offset so that no pair was directly down-slope of another transect at a single site. Changes in land-surface altitude were measured by placing a specially fabricated aluminum bracket between the two monuments of each pair (Figure 5) (Hill et al., 1990). This bracket was attached to the monuments at a consistent distance, 1.7 in. (3.8 cm), relative to the tops of the monuments. Each station was measured using a carpenter's (bubble) level in order to insure a flat surface, both horizontally and vertically. Offset between monuments was measured during each site visit and remained negligible despite three large magnitude (>5.0) earthquakes throughout the length of the study.

After establishing a level surface across the frame, a 21 in (53 cm) metal rod was dropped through each of the nine holes drilled across the length of the bracket. The height of the rod that remained above the bracket after the rod had contacted the soil surface was measured with a ruler. Measurement precision was 1 mm. As recommended by Lal (1994), many of the monuments were resurveyed to check for possible changes in altitude, possibly due to disturbance or tectonic activity, but changes were found to be negligible. Changes in average rod height above the bracket represented changes in the average land-surface altitude between erosion-pin array monuments. A decrease in rod height indicated lowering of the land surface. Average change for an erosion-pin array (Appendix IV) was considered positive if the net change was a decrease in rod height, that is, if the ground surface had been lowered between successive measurements (Hill et al., 1990).

Volume of sediment eroded within badland/grassland test sites was determined from the RUSLE model using field measurements for length and slope factors and compared with the predicted volume of eroded soil from the measured average surface altitude loss from the erosion-pin arrays. The annual rate of soil erosion, or weight of soil loss in tons/acre/year, for individual sites was ascertained for five months in calendar year 2001 and seven additional months in 2002, totaling 12 months of data (Appendix V). Annual erosion rates from badlands in the La Sa Fua watershed were compiled with erosion rates, as determined by the RUSLE model, and the empirically derived averages

(Appendix III). The badlands and other vegetation types within the watershed boundary were determined from 1994 orthographic photographs and the Topographic Map of Guam, Mariana Islands (USGS, 1978).

3.2.3 Rain gages

The purpose of precipitation analysis was to correlate sediment loss with rainfall. Dumaliang (1998) established an R-factor for Umatac Village in southern Guam, based on the National Weather Service (NWS) and USGS raingages, of 457 (dimensionless) during wet years and 412 during dry years, with an average annual R-factor of 426. For this project, rainfall data from two USGS raingages, the Mt. Jumullong Manglo and the Umatac Raingage, were utilized. Both gages are continuous recording stations housed in a protective, vertically emplaced, galvanized culvert. The raingage included a 4.0 ft (1.2 m) high and 1.0 ft (0.3 m) in diameter copper canister, a Leupold and Stevens GS-93 water level monitoring system (datalogger), a solar panel, 26 amp-hour battery and a voltage regulator. The datalogger was set to record rainfall at 30-minute intervals.

USGS rain gages, Umatac Raingage, located within the Umatac watershed boundary and Mt. Jumullong Manglo Raingage, located within the La Sa Fua watershed boundary, were used over the length of this project (July, 2000-July, 2002). The Umatac raingage is a continuous recording station that reads in 30-minute intervals and contains a complete monthly record from 1992-1997, 2000-2002. Mt. Jumullong Manglo is also a continuous recording station that reads in 30-minute intervals, but was not established until December 2000. The following graphs illustrate the monthly variance of rainfall accumulation and wet and dry seasonal trends, in Umatac Village.

Raw data for the graphs can be found in Appendix I. Along with the raw data is a comparison of monthly means and standard deviation between 1992 and 1997 with the monthly means and standard deviation for the period of this project, July 2000 through 2002. As monthly rainfall deviations greatly vary on Guam, averages between the months from one year to the next makes testing for normality of distribution unreliable. However, it is important to notice that average monthly rainfall accumulation for this project was within a range determined by previous years.
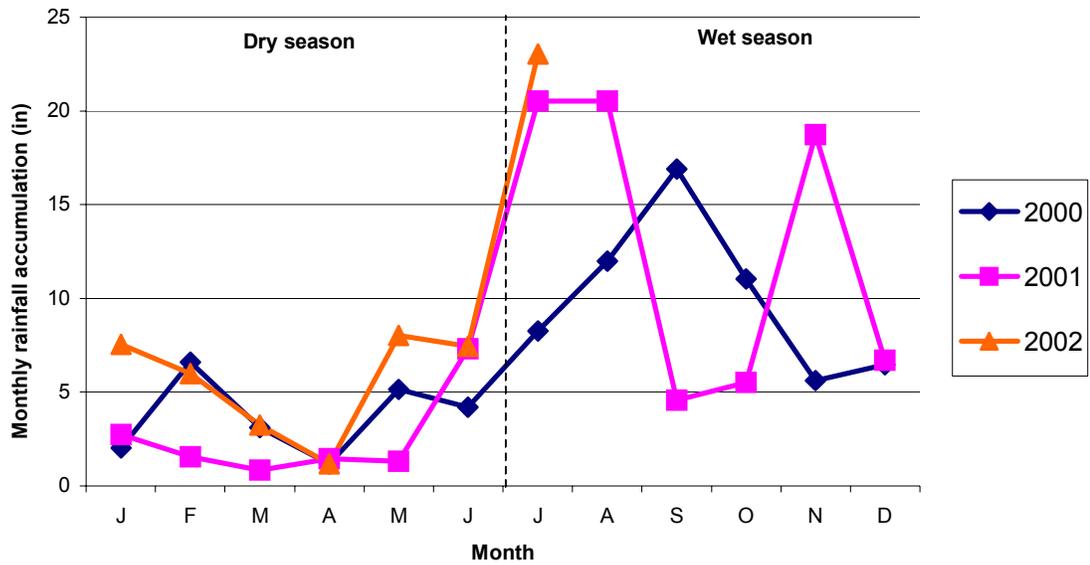
Graph 1. 2000-2002 monthly precipitation totals, Umatac Raingage, Guam.
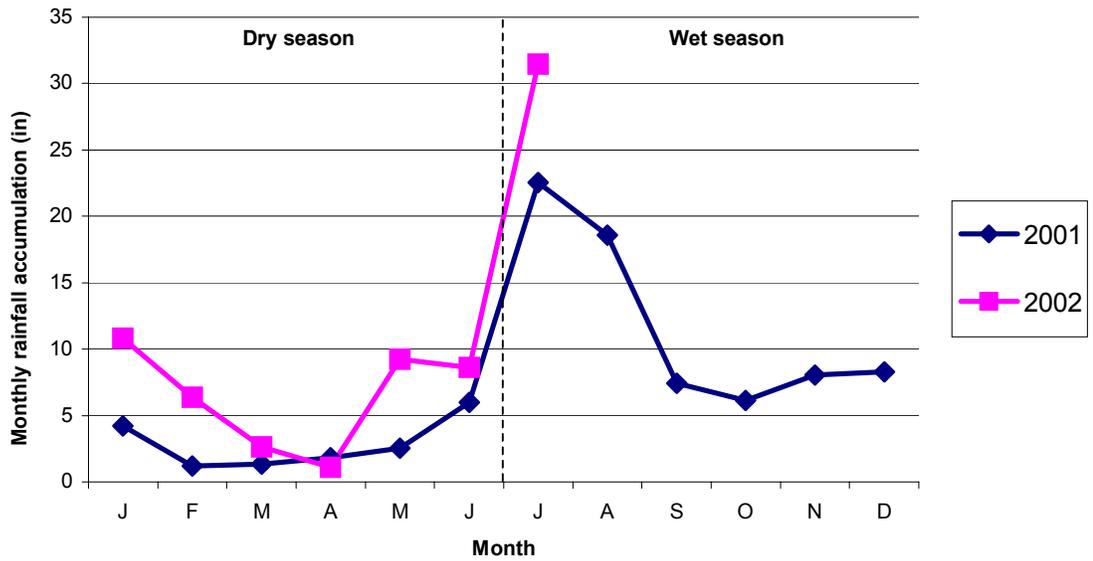
Graph 2. 2001-2002 monthly precipitation totals, Mt. Jumullong Manglo Raingage, Umatac, Guam.

3.3 Laboratory methods

3.3.1 Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is a mathematical erosion model designed to predict the longtime average annual soil loss (A) carried by runoff from specific field slopes. The expected erosion rate for a given site is a result of the combination of many physical and management coefficients expressed in an equation of the form

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

Where:

A = computed average soil loss per unit of area, expressed in ton $\cdot$ acre^{-1} $\cdot$ yr^{-1}, or metric tones $\cdot$ ha^{-1} $\cdot$ yr^{-1}.

R = rainfall-runoff erosivity factor (ft-tons-in/acre-hour).

K = soil erodibilty factor---the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot (, which is defined as a 72.6 ft. (22.1m) length of uniform 9% slope in continuous clean-tilled fallow.

L = slope length factor---the ratio of soil loss from the field slope length to soil loss from a 72.6 ft. (22.1 m) length under identical conditions

S = slope steepness factor---the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover management factor---the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = support practice factor---the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope (Renard et al., 1997).

RUSLE, like its predecessor the Universal Soil Loss Equation (USLE), guides in the making of methodical decisions in conservation and management planning, enables the planner to predict the average rate of soil erosion for various alternatives and provides specific guidelines for erosion control with manipulation of the C-factor. RUSLE users are cautioned that the model was not designed to predict sediment yield, sediment delivery, losses at various points on the slope (as this project will illustrate how losses greatly vary), or short-time fluctuations in influential variables.

The computed average rate for this project was based on an R-factor established by Dumaliang (1998), a K-factor from the Soil Survey of the Territory of Guam (Young, 1988), and field measurements in order to determine more precise L-and S-factors. Measuring and computing the L-and S-factors was executed since previous watershed management assessments acquired the factors based on slope approximations, and it was assumed the field data would add precision to the estimations. A surveying method that utilizes an optical measurement of distance, or stadia, was shot over transect plots. An attempt was made to survey as many transects over the same slope as possible, but as placement of the transects was not made in succession down-slope, several transects received separate L-and S-factors. Wind was the major limiting agent while surveying stadia readings hence the aerial photographs were used to confirm slope lengths.

The cover management, C-factor, for grassland sites with savanna vegetation as well as badlands, was determined using a standard USDA procedure (Soil Conservation Service, 1974a) for field computation of idle land, as first established by Wischmeier (1975) and Mutchler et al. (1982). The support practice, P-factor, was assigned a value of 1.0 as recommended for non-agricultural areas void of conservation practices.

3.3.2 Site determination-Geographic Information System (GIS)

A Geographic Information System (GIS) was utilized to determine the areas of the project test sites. Each feature (watershed boundary, vegetation cover and roads) was digitized into a database in the form of polygons (areas) or arcs (lines) using GIS software (ArcView® 3.2). GIS was further used to execute the percent cover of various vegetation areas along with the test sites. Surface cover for each site was categorized as savanna,

ravine forest, badland or wetland as estimated from the 1994 orthographic photographs. The GIS software provided a reference for the L- and S-factor surveys, calculation of slope within test sites, area calculation and allowed the author a more comprehensive scrutiny of the overall project area.

Control points around the perimeter of the test sites (see Figure 6) were recorded on the Trimble® Global Positioning Satellite (GPS) System. The control points recorded in the field were retrieved using GPS Pathfinder Office® software (version 2.8). The recovered data was differentially corrected using downloaded data from the web site, www.ngs.noaa.gov/CORS/Island/islands_guam.html. The corrected files were further converted to shape files in latitude/longitude coordinates. Finally the files were run over either a topographic projection or scaled aerial photograph of Guam.

3.3.3 Graphs

Microsoft Excel® spreadsheets were used to record and graph the data from the individual erosion-pin arrays, monthly rainfall fluctuations and comparison between erosion rates, surface water discharge, sedimentation rates and amount of rainfall. The data were formatted to create column and line graphs of each transect, illustrating intermittent fluctuations of surface altitude changes as well as monthly rainfall accumulations. Lines for each period were laid over the data points to allow patterns to be more easily recognized.

RESULTS AND DISCUSSION

4.1 Site parameters

Test site parameters are presented in Table 1 and are further described. Sediment yield results follow, and erosion-pin data for hillslope and valley sites per site can be found in Appendix IV.

Table 1. Site parameter summary.

Site Name	Area in acre (ft^2)	Composition	Average slope in degrees	Relief in ft. (m)
BL	0.22 (9,437.34)	Exposed saprolite (no vegetation)	30	40 (12)
GL1	.022 (971.28)	Savanna	21	10 (3)
RC	.027 (1,203.68)	Exposed saprolite (sparse vegetation)	19	12 (3.6)
GL3	.01 (550)	Savanna	15	6.5 (2)

4.1.1 Steep-slope badland (BL) test site

BL (Figures 7 through 10) is a large, variably hourglass-shaped depression with a large gully outlet. Figure 7 illustrates the bank erosion processes as well as the surface runoff potential for such upland volcanic soils and grasslands. Badlands soils in this area are classified as Akina series. The series covers approximately 31 percent of Guam's total land area. A soils test for the surface soils of this site indicated no organic content, 38 percent sand, 29 percent silt and 33 percent clay size material. Maximum elevation at this site approaches 1,100 ft (335 m) at the headwater end and lowers to approximately 1,060 ft (323 m) along the downstream end of the basin.

The entire site occupies 19,902.7 ft^2 (0.46 ac). The transects are located in the steepest section of the badland portion of the test site and occupy a 9,437.3 ft^2 (0.22 ac) section.

Figure 7. Steep-slope badland (BL) test site.

Graph 3. Rod height across a transect in the steep-slope badland (BL). Colored lines represent site visits.
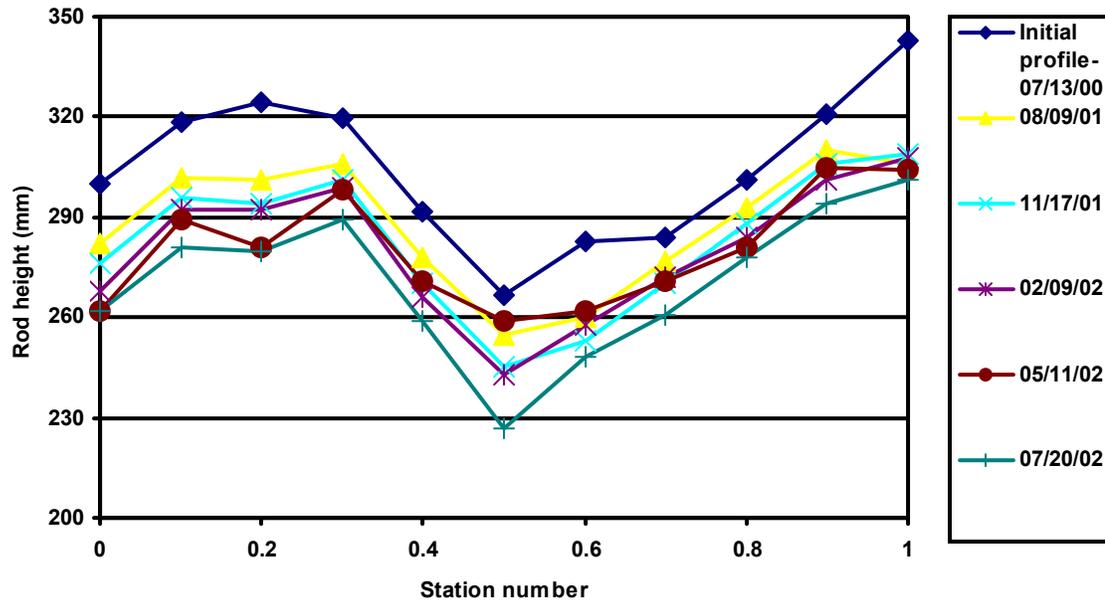
Graph 3 shows the typical, receding land-surface altitude between a single erosion-pin array configuration, located within the steep-slope badland test site. Six separate site visits were made over the length of the study. For the 2000-2001 field season, land-surface altitude loss between this transect, BL1-1, was 16.5 mm with minimal surface altitude gain experienced. The transect lies on an approximately 23-degree slope, and the graph shows no outliers in 24 months of data collection. Raw data for the changes in land-surface profiles can be found in Appendix V. Fluctuations in land-surface altitude between transects within individual test sites appear independent of site visits and dependent upon external factors, such as wet and dry season. Field measurements yielded the greatest difference between average, measured surface altitude losses for the steep-slope badland.

4.1.2 Steep-slope grassland (GL1) test site

GL1 is a large area adjacent to BL. Transects within the grassland fall on the down slope side north and south of BL. Figure 8 illustrates the extent to which foxtail grasses are present surrounding all the steep-slope badlands in the La Sa Fua watershed. The

significant slope (21 degrees) of this grassland and the resulting diminishing vegetation cover yielded indication that the vegetation is not appropriate for preventing this type of patchy erosion.   There is an Akina series soil horizon, the product of weathered marine-deposited volcanic rock or sandstone, usually a thin black soil composed of 60 to 80 percent clay size material. Soils tests for this site, at 4-6 in (10-15 cm) depth, yielded 8 percent organic content, 26 percent sand, 25 percent silt and 49 percent clay size material. Maximum elevation in this site approaches 1,100 ft (335 m) at the headwater end and lowers to approximately 1,090 ft (332 m) along the downstream end of the basin.

Since the sites are adjacent to BL, two transects (individual pin-arrays) were delineated to occupy 704 ft^2 (.016 ac) based on the extent of the slope, while three transects were delineated to occupy 267.3 ft^2 (.006 ac). Each grassland site was burned, the result of a set fire, between the 2000/2001 site visits.

Figure 8. Steep-slope grassland (GL1) test site.

The following graph, Graph 4, shows the typical, barely receding land-surface altitude between a single pin-array, located within the steep-slope grassland test site. Again, six separate site visits were made over the length of the study. There was consistent, though minimal, surface altitude gain over this approximately 15-degree slope, with negligible losses and no visible outliers in 24 months of data collection.

Graph 4. Rod height across a transect in the steep-slope grassland (GL1). Colored lines represent site visits.
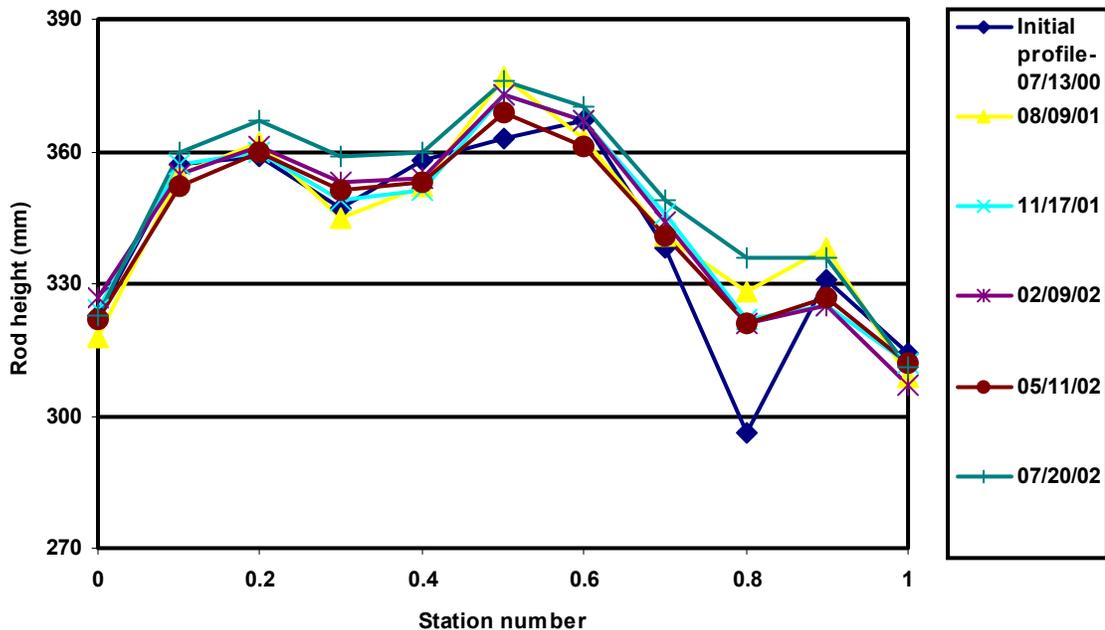
4.1.3 Valley badland (RC) test site

RC (Figure 9) is a medium-sized test site and former unpaved road cut. This one time jeep trail is possibly the cause of the erosion at this site. The figure illustrates the bank erosion processes in the flattest section of RC. Note the pale-colored surface horizon in the foxtail grass zone that follows the length of the site. Badlands soils in this area are also classified as Agfayan series. Soils tests for this site, at 4-6 in (10-15 cm) depth, yielded 2 percent organic content, 48 percent sand, 30 percent silt and 22 percent clay size material.

Note the lighter coloring of these bottomland soils as opposed to the deep red coloring of the highland soils of the same series. The pale RC soils are attributed to extreme weathering, drainage and the silty clay that helps classify this series. Maximum relief at this site approaches 412 ft (126 m) and lowers to approximately 400 ft (122 m) elevation toward the eastern, Chagame River tributary. The entire site occupies 1,203.68 ft^2 (.027 ac).

Figure 9. Valley badland (RC) test site.

The following graph, Graph 5, illustrates the atypical, advancing land-surface altitude between a single pin-array, this time located within the valley badland test site. Six separate site visits were made over the length of the study. This graph represents the variability of profiles within the badlands as slopes vary within each basin. This particular transect was located on a nearly flat surface (former road cut) beneath a small rise where the other two transects for this test site were emplaced. No outliers appeared within the

profile over the length of the study. It is interesting to note that the accumulation of sediment within this erosion-pin array was so extreme after 24 months, the rebar monuments, denoting stations 0 and 1, were nearly buried.

Graph 5. Rod height across a transect in the valley badland (RC). Colored lines represent site visits.
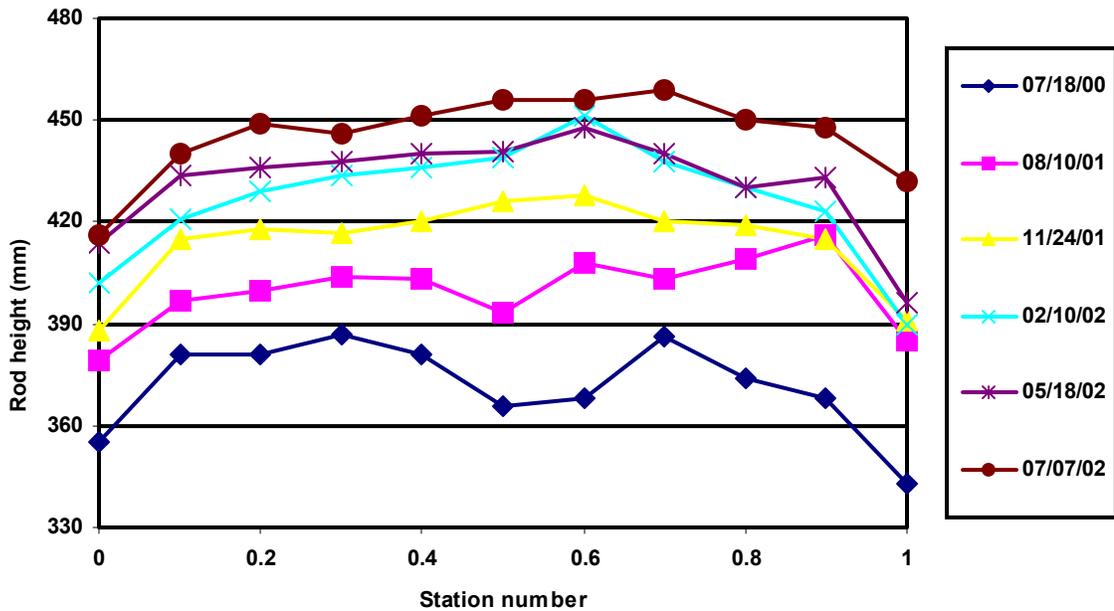
4.1.4 Valley grassland (GL3) test site

GL3 is composed of two medium-sized areas delineated by the comparable slope and size of RC. Transects within the grassland fall east of Route 2, but not adjacent to either side of RC. Figure 10 illustrates the extent to which foxtail and wild cane grasses are present in the valley as well as the steep-slope grasslands in the La Sa Fua watershed. The GL3 test site is not adjacent to RC because trees bound RC on the left side.   The lack of significant slope over valley grasslands, in combination with current vegetation, may be substantial for preventing patchy erosion. Again there is an Agfayan series soil horizon with 3 percent organic content, 40 percent sand, 22 percent silt and 38 percent clay size

material. Maximum relief at GL 3 approaches 406.5 ft (123 m) at the Route 2 facing end and lowers to approximately 400 ft (122 m0) along the downstream end of the basin. The entire site was delineated to occupy 550 ft^2 (.01 ac).

Figure 10. Vegetation cover over valley grassland (GL3) test site.

The following graph, Graph 6, shows the changeable land-surface altitude between a single erosion-pin array, located within the valley grassland test site. Again, six separate site visits were made over the length of the study. There was consistent surface altitude gain and loss over this approximately 23-degree slope, with no visible outliers in 24 months of data collection. Graph 6 represents what is commonly perceived to be the fluctuating landscape of soil profiles with savanna type vegetation.

Graph 6. Rod height across a transect in the valley grassland (GL3). Colored lines represent site visits.
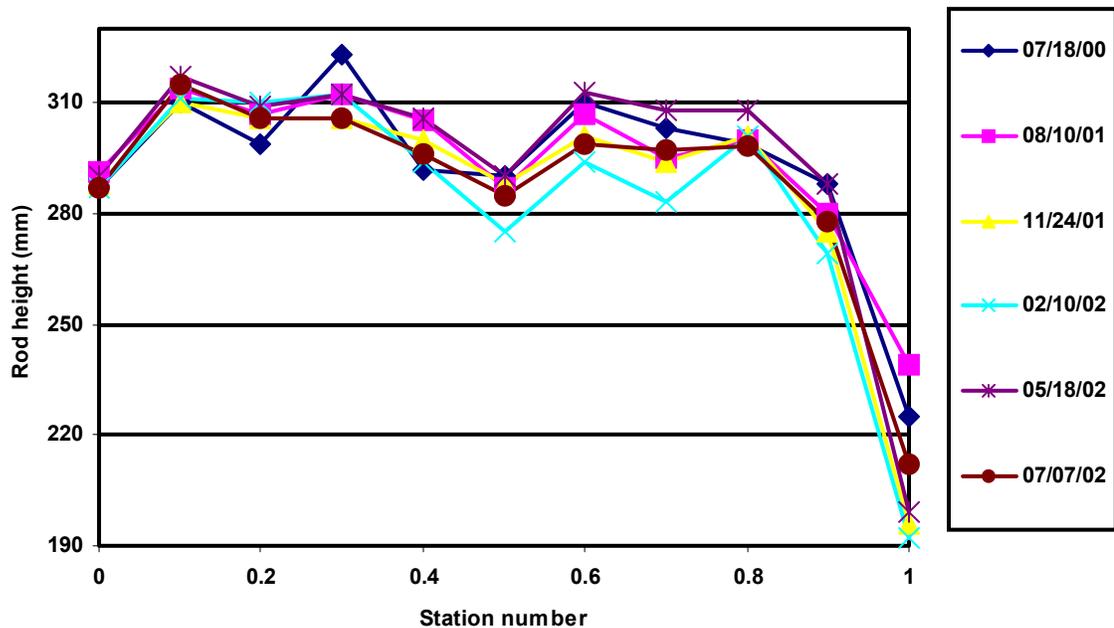
4.2 Test site comparison

Previous research and literature had indicated that soil losses from bare soils were directly proportional to rainfall intensity. Test sites however, proved more useful for comparison with seasonal variability than rainfall intensity. By comparing steep-slope and valley locale test sites, a connection could be drawn between the sediment yield over varying topographic/vegetative sites that constitute the southern highlands. Both test sites BL and RC experienced average surface altitude gains during the dry season on Guam. Both sites also experienced a greater average land-surface altitude loss during the rainy season on Guam. The steeper site exhibited proportionally greater loss between May and July 2002, a period which contained the July 5th storm event, Typhoon Chata'an. Similarly, test sites GL1 and GL3 experienced the greatest average surface altitude gains during the dry season on Guam. As expected, both grassland sites also experienced the

greatest profile losses during the wet season, but remained considerably more static than the badlands, with regard to surface altitude change, throughout the length of the study.

Between the badland test sites there is a definitive pattern of soil loss with precipitation accumulation. The steep-slope badland experienced increased erosion following the typhoon. Only the valley locale grassland test site exhibited a strong relationship between average patterns of losses or gains with seasonal variability. Differences between peak average losses or gains between the sites may be attributed to a number of factors including observed landslides, feral animals, rainfall run-off, the lag time between rainfall and soil infiltration, and the problematic nature of foxtail grasses with shallow root systems and clumping growth patterns. All were contributors to numerous single station outliers.

It is best concluded that such variability within a single badland test site indicates the movement of soil within the site from areas of higher slope to areas of lower slope. It may also be concluded that soil movement within a single grassland test site is less dependent upon monthly rainfall accumulation than badlands, but as dependent upon slope as the exposed surfaces.

While there were greater losses among individual transects within RC, average losses remained highest among BL. The following table exhibits such a range of surface altitude changes, as well as maximum and minimum changes, for each erosion-pin array (transect) between site visits for the 2000-2001 and 2001-2002 field seasons.

Table 2. **Test sites showing range of surface-altitude changes for transects and maximum/minimum single station changes between July 13, 2000 and July 20, 2002. * Negative numbers indicate an increase in surface-elevation.**

Site Name	Surface-altitude changes (mm) 2000-2001	Surface-altitude changes (mm) 2001-2002	Max. single station changes (mm) 2000-2001	Max. single station changes (mm) 2001-2002
BL	15-61.5	3-9	*-13-89	-144-168
GL1	-7-6	-5-3	-59-45	-61-46
RC	-28-37.5	-11.5-10.5	-48-75.5	-115-104
GL3	-11-19	-2-4.5	-37-35	-45-43

Average surface altitude drop varied between transects within each of the four test sites given the location, positioning and topographic relief beneath individual transects. For instance, the badland transect, denoted RC1-3, never experienced an average surface altitude drop within the entire span of the study, presumably since the positioning was located on the lowest and flattest section of the badland where runoff deposited the most soil.

In order to compare the average surface altitude drop within badland test sites with the amount of sediment lost, as predicted by the RUSLE model, it was necessary to convert the metric area measurements to a weight. For example, during the 2000-2001 field season, a single transect within BL experienced an average surface-altitude drop of 17 mm. Since:

$$\text{Bulk density} = \frac{\text{Weight}}{\text{Volume}}$$

 17 mm of surface altitude loss over transect BL1-1 (where bulk density was measured to be 0.55.g/cm^3) can be converted to 41.97 tons[†]/acre (see Appendix VI).

Bulk density measurements yielded an average of 0.55 g/cm^3 for the test sites. The following tables represents the conversion from a change in surface altitude in millimeters to a weight of soil loss in tons/acre/year, based on the average bulk density, for each transect within the badland and grassland test sites. Negative numbers indicate a gain in weight of soil loss and only occur in grassland test sites or badland transect RC1-3, where deposition of soil was the result of placement of the pin-array at the lowest topographic point within the site. Please note that the RUSLE model supports the U.S. standard short ton equal to 2,000 lbs. or 907,180 grams.

Table 3. Sediment yield from individual transects based on surface altitude loss for the 2000-2001 field season (negative numbers indicate gain).

Badland transect number	Average altitude change (mm)	Tons/acre	Grassland transect number	Average altitude change (mm)	Tons/acre
BL1-1	16.5	40.48	GL1-1	-3	-7.36
BL1-2	20	49.07	GL1-2	-1	-2.45
BL1-4	37	90.78	GL1-3	6	14.72
BL1-5	39.5	96.91	GL1-4	-1	-2.45
BL1-6	61.5	150.89	GL1-5	-7	-17.17
BL1-7	22	53.98	GL3-1	-3	-7.36
BL1-8	29	71.15	GL3-2	19	46.62
BL1-9	15	36.80	GL3-3	-1	-2.45
BL1-10	31	76.06	GL3-4	-3	-7.36
RC1-1	20	49.07	GL3-5	-11	-26.99
RC1-2	37.5	92.01			
RC1-3	-28	-68.70			

Table 3.1. Sediment yield from individual transects based on surface altitude loss for the 2001-2002 field season (negative numbers indicate gain).

Badland transect number	Average altitude change (mm)	Tons/acre	Grassland transect number	Average altitude change (mm)	Tons/acre
BL1-1	17	41.71	GL1-1	-1	-2.45
BL1-2	12	29.44	GL1-2	-6	-14.72
BL1-4	36	88.33	GL1-3	-15	-36.80
BL1-5	31	76.06	GL1-4	23	56.43
BL1-6	26	63.79	GL1-5	8	19.63
BL1-7	25	61.34	GL3-1	-9	-22.08
BL1-8	24	56.43	GL3-2	18	44.16
BL1-9	16	39.26	GL3-3	5	12.27
BL1-10	26	63.79	GL3-4	-2	-4.91
RC1-1	8	103.05	GL3-5	-9	-22.08
RC1-2	42	-112.86			
RC1-3	-46	19.63			

4.3 RUSLE comparison

Comparisons were made between the erosion rates generated from the model and the calculated sediment yield rates, deduced from empirical measurements on the slopes of each of the four test sites (see Table 4). Using the RUSLE without a field measurement, the equation predicted an average of 226 tons/ac/yr of sheet and rill erosion for the badlands, with 242 tons/ac/yr during wet years and 218 tons/ac/yr during dry years. By creating an L- and S-factor using field measurements for both the length and slope of the test sites, the RUSLE predicted between 144 and 193 tons/ac/yr of sheet and rill erosion for the test site badland, with 155 tons/ac/yr during dry years to 207 tons/ac/yr during wet years. The measured rates for the steep-slope badland (BL) produced between 29 and 151 tons/ac/yr. While the badland test site located at a lower elevation, under less relief and at a slope of approximately 19 degrees, exhibited more extreme variation, −113 to 103 tons/ac/yr.

The measured rates from the erosion-pin array technique, for both the steep-slope grassland (GL1) and valley grassland test site (GL3), averaged less than 1 ton/ac/yr. Both of these estimates were lower than estimates of 1.5 tons/acre/year provided by the RUSLE model. Using the measured L-and S-factors in the model, RUSLE averaged between 0.16 and 0.92 tons/acre/year. A larger lowland test site, allowing for an increased number of transects, might have skewed the range of estimates, or placed them in closer proximity to the steep-slope counterpart, though both weights were consistently low despite the typhoon.

SUMMARY AND RECOMMENDATIONS

5.1 Test site yield

The test site sediment yield results from the steep-slope, experimental sites were analyzed and compared to the valley counterparts by considering the surface cover area variables and weight of soil loss. Results within the test sites follow, succeeded by general site comparisons.

5.1.1 BL

Test site BL, a steep-slope badland, as shown in Figures 7 through 10, originally contained nine erosion-pin array transects and one rebar transect that spanned one of three small gullies that discharge overland water runoff from the entirety of the badland. However, the rebar transect, spanning the gully outlet, was lost in the second field season as the gully walls eroded beyond the emplacement of the rebar monuments. The remaining nine transects averaged an overall land-surface altitude loss between 15 and 61.5 mm of soil within a single erosion-pin array, for the 2000-2001 field season, and between 16 and 36 mm of soil loss for the 2001-2002 field season. Depth of soil loss was converted to an average weight of soil loss for the 2000-2001 field season and yielded between 36.80 and 150.89 tons/acre/year and between 29.44 and 88.33 tons/acre/year for the latter season. Maximum average losses were experienced between May and July 2002, while maximum average gains of surface altitude were experienced between February and May 2002.

The soil gains and losses appear to correspond with the wet and dry seasons on Guam. Note the comparable average losses in Graph 7 between May and July 2002, following Typhoon Chata'an, with the average profiles from August 2001. The August 2001 data were accumulated between site visits 11 months apart as opposed to the 2 months for the final profiles.   Outliers within the transects were visible over both years, and one landslide across transect BL1-10 between February and May 2002 accounted for a large shift in the trend toward both soil loss and gain.
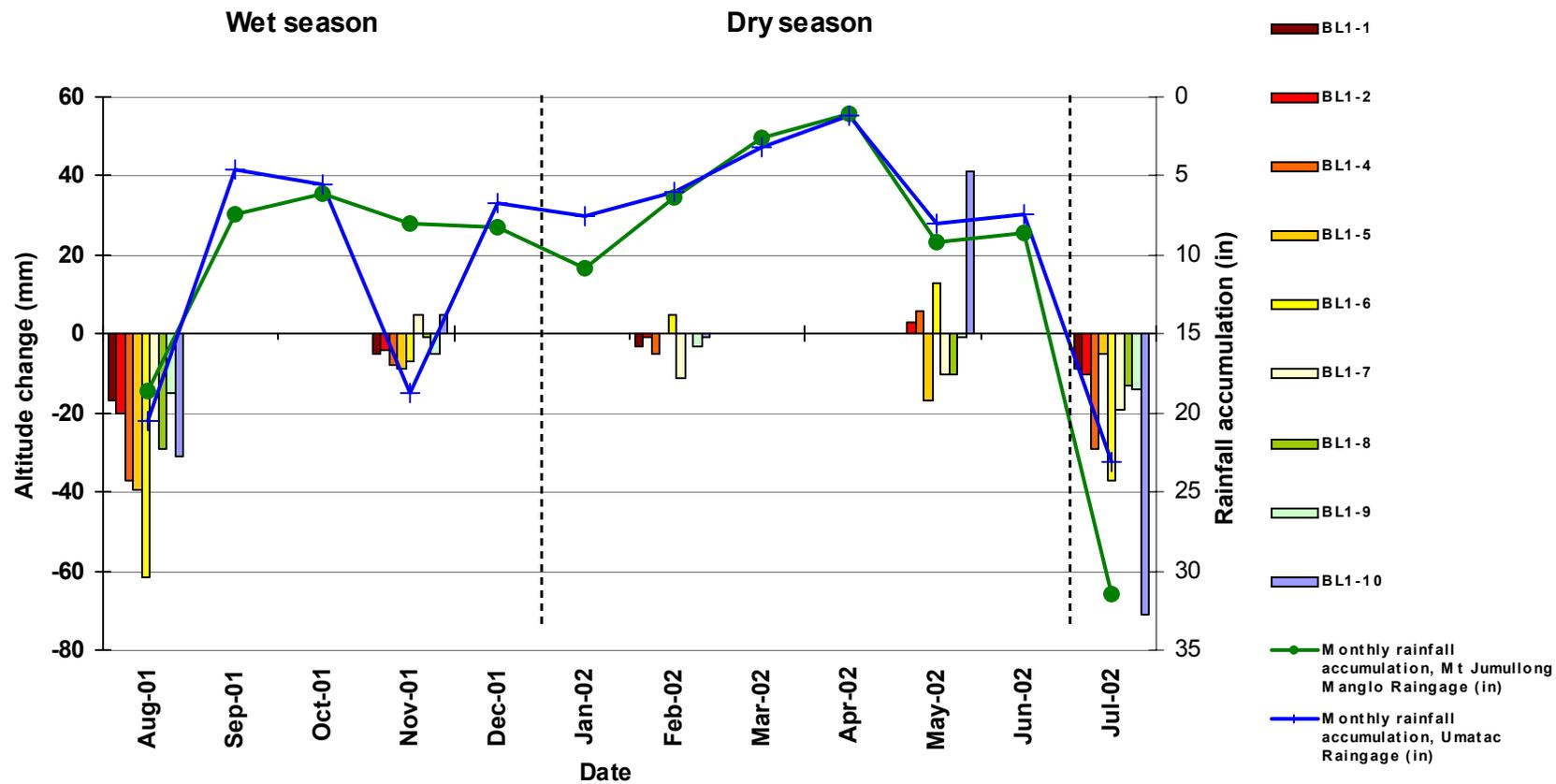
Graph 7. Average surface altitude change between transects for BL and monthly rainfall.

Graph 7 also illustrates the average surface altitude changes for each of the remaining nine transects over the 2001-2002 field season next to the monthly rainfall from the Mt. Jumullong Manglo and Umatac Raingages. The least amount of land-surface loss is experienced during the driest months, January through March.

The most compelling factor for average gains or losses in surface altitude was expected to be placement of transects. Transects placed along the steepest slopes (>30 degrees) within the basin were expected to experience more rapid losses, whereas those transects emplaced along the lesser slopes were expected to experience less rapid surface altitude losses. However, transects BL1-4, BL1-5, and BL1-6 which experienced the most loss (among both field seasons) were at comparable slopes with transects BL1-7, BL1-8 and BL1-9, which experienced less soil loss. In order to show the variability within each transect it was useful to record the maximum surface altitude loss or gain for a given station within a single erosion-pin array, which is shown in Table 2.

5.1.2 GL1

Test site GL1, a steep-slope grassland, as shown in Figures 4 and 8, retained the original five erosion-pin array transects throughout the length of the study. All but one of the transects averaged an overall surface altitude gain, between 1.5 and 7 mm of soil between a single transect, for the 2000-2001 field season, and between 1 and 15 mm for the 2001-2002 field season.   Surface altitude changes were converted to an average weight of soil loss for the 2000-2001 field season and yielded between -17.17 and 14.72 tons/acre/year, and -36.80 and 56.43 tons/acre/year (the negative indicates soil accumulation) for the latter season.

Two transects, GL1-4 and GL1-5, experienced an average loss in the second season. Maximum average losses were relatively uniform throughout the study, while maximum average gains of surface altitude were experienced between May and July 2002. Graph 8 shows the relative consistency between the changes across the land-surface profile and how the soil gains and losses do not appear to correspond with the rainfall seasons on Guam. Outliers between stations were visible over both years, and may be attributed to grazing feral animals disturbing the soil between the transects.
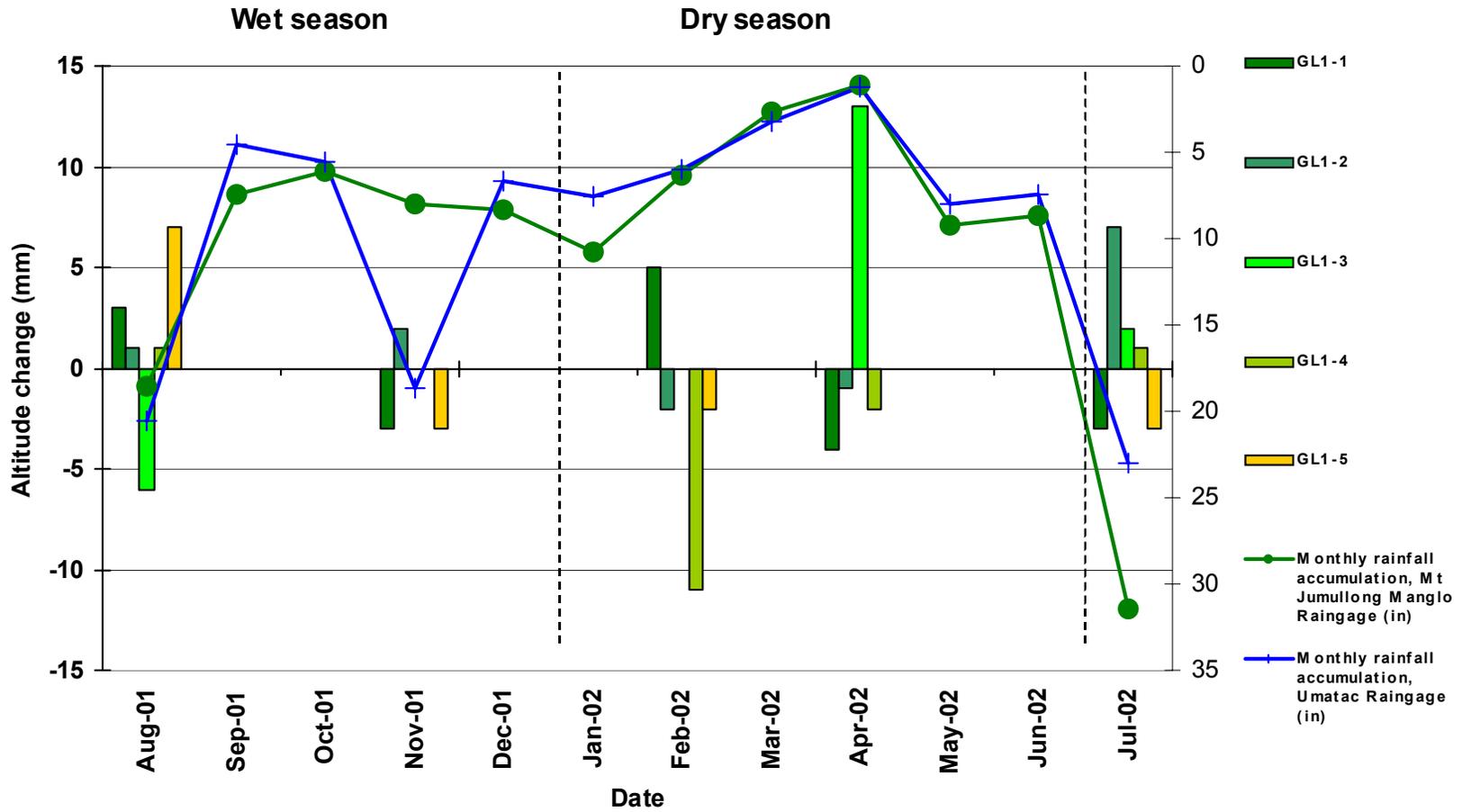
Graph 8. Average surface altitude change between transects for GL1 and monthly rainfall.

5.1.3 RC

Test site RC, a valley locale badland, as shown in Figures 4 and 9, retained all three of the original erosion-pin array transects. Of the three transects, two averaged an overall surface altitude loss, 8 and 42 mm for the 2001-2002 field season. Soil loss between each of the three transects was converted to an average weight of soil loss for the 2000-2001 field season, and yielded between –68.70 and 92.01 tons/acre/year, and between –112.82 and 103.05 tons/acre/year (the negative indicates an increasing rate) for the latter season.

Maximum average losses were experienced between August and November 2001, while maximum average gains of surface altitude were experienced between November 2001 and February 2002. Again there are comparable average losses between May and July 2002, following Typhoon Chata'an, with the average profiles from August 2001. Recall the August 2001 data were accumulated between site visits 11 months apart as opposed to the 2 months for the final profiles. Graph 9 illustrates how the soil gains and losses appear to correspond with the seasons on Guam, with the greatest average gains during the dry season and greatest average losses following the wet season. From the entire test site only one outlier ever appeared at a single station, in transect RC1-2, over the 24 months and did not affect the averages.
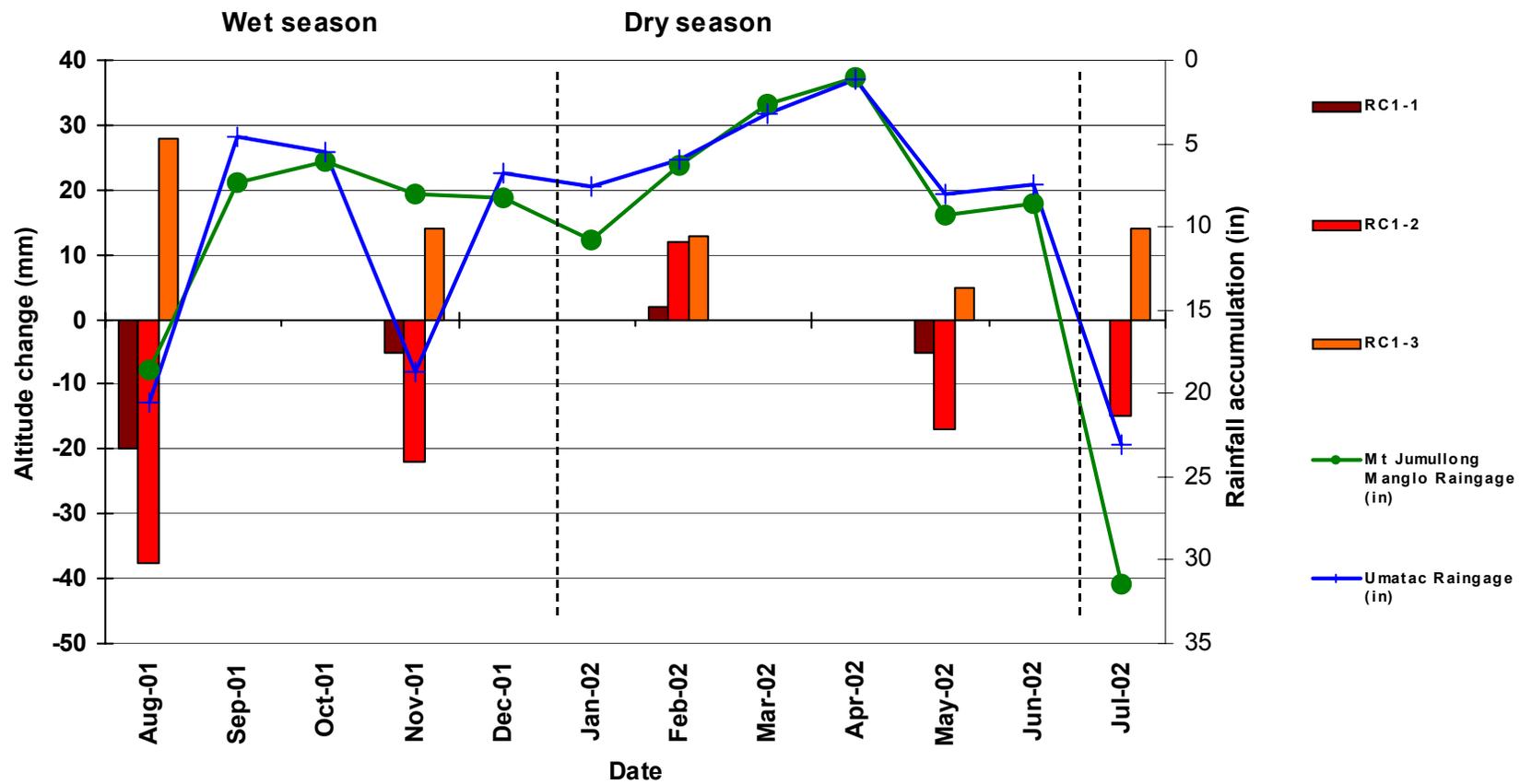
Graph 9. Average surface altitude change between transects for RC and monthly rainfall.

In the case of test site RC, average gains or losses in surface altitude were indisputably associated with the placement of transects. While the test site averaged a slope of 19 degrees, transect RC1-3 was emplaced on a nearly flat section of the site beneath the other two transects. At no point in the study did RC1-3 experience an average accumulation of soil or rise in land-surface altitude. In fact, over the entire length of the study, only a single station within RC1-3 experienced soil loss, a diminutive 3 mm.

5.1.4 GL3

Test site GL3, a valley locale grassland, as shown in Figure 10, also retained the original five erosion-pin array transects throughout the length of the study. Four of the five transects averaged an overall surface altitude gain, between 1 and 11 mm for the 2000-2001 field season. The converted weight of soil loss for the 2000-2001 field season yielded between –26.99 and 46.62 tons/acre/year. Three of the five transects experienced a gain in the 2001-2002 season, between 2 and 9 mm, contributing to a total weight of soil loss between –22.08 and 44.16 tons/acre/year. Like the steep-slope grassland, neither maximum average losses nor gains within the test site were relatively uniform throughout the study. However, unlike GL1, the average soil gains and losses do appear to correspond with the seasons on Guam, as shown in Graph 10. Four of the five transects experienced an average gain of surface altitude between the driest months, February to May 2002. Outliers never appeared between the years, but again fluctuations between the stations may be attributed to grazing feral animals disturbing the soil between the transects.
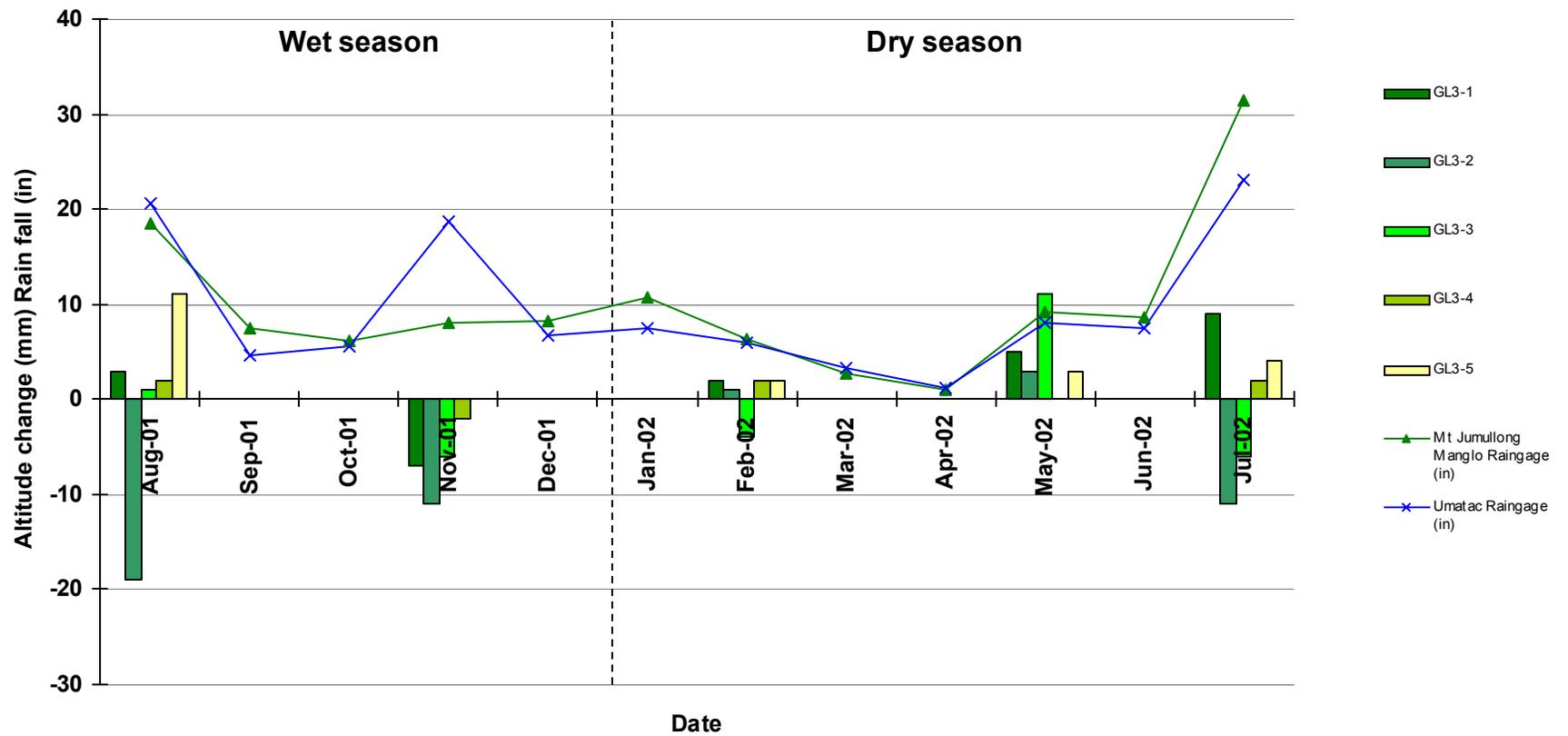
Graph 10. Average surface altitude change between transects for GL3 and monthly rainfall.

In agreement with the original conjecture, those test sites at lower altitudes with more moderate slopes experienced a lessened erosion rate, as compared to the steep-slope counterparts in either badlands or grasslands. Grasslands did not prove to be immune to heightened erosion rates resulting from increased rainfall amounts. This study concluded the bulk of sediment yield being generated from eroding steep-slope badlands appears following large storm events on Guam. While empirical measurements of stream channel and gully erosion were not undertaken over the course of this investigation, this type of erosion was observed to be the most active type in the La Sa Fua watershed.

5.2 RUSLE

The RUSLE method for predicting soil erosion measures the amount of potential sediment lost from the landscape profile represented by a particular RULSE computation, not the amount of sediment leaving a field or watershed. A landscape profile is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition like that on concave slopes, such as those in the La Sa Fua watershed. Soil loss is therefore inferred to be an average erosion rate for a landscape profile. Since erosion varies along the length of a slope, steepness factors into this variation and can become significant if steepness varies considerably from beginning to end of the slope length, where erosion at the end of the slope is approximately 1.5 times the average erosion for the length of the slope (NRCS, 1999).

Due to variability of slope length and steepness in the badlands of the La Sa Fua watershed, field measurements were accrued along lines within site areas to facilitate accurate data accumulation for length and slope factors. Recall the surveying techniques over transects for L-and S-factors described earlier. In most cases, length and slope measurements were taken directly through erosion-pin array transects, and encompassed more than one transect per measurement. The resulting slopes were labeled as 'plots' in Appendix III. For example, Plot A represents the length and slope of the plot area occupied by transect BL1-8, as it was measured through the erosion-pin array. The following list groups each plot with the corresponding transects: Plot B; BL1-6, BL1-7 and BL1-9, Plot

C; BL1-1 and BL1-2, Plot D; BL1-4 and BL1-5, Plot E; BL1-5 and BL1-10, Plot F; GL1-3 through 1-5, Plot G; GL1-1 and GL1-2, Plot H; GL3-1 through 3-5, Plot I; RC1-1 through 1-3. Site yield results (Table 4) exhibit annual values in tons/acre/year.

Table 4. Test site yield results in tons/acre/year.

Test Site	Method		
	RUSLE (from Renard et al., 1997) Erosion-pin technique	RUSLE using measured L-and S-factors	array
BL	225.92	163.56	65.90
GL1	1.49	.919	0.74
RC	225.92	119.55	13.70
GL3	1.49	0.16	0.98

Such extreme variation in erosion rates between adjoining plots may be explained by the difference in cover, C-factors between the two, C=0.45 for no appreciable canopy over 95+ percent of the surface area for a badland, and C=0.003 for tall grass, weeds or brushes with average drop fall height of less than 3 ft for 95+ percent of the surface area for the adjoining grassland (NRCS, 1999).

RUSLE estimates using the NRCS variables were consistently higher than RUSLE estimates using the empirically derived L- and S-factor, as well as measured values from the test sites. Despite revision of the isoerodent maps for Guam, RUSLE still does not appear to be a useful tool for predicting erosion within the confines of the small, southern watersheds on Guam, since the estimates remain consistently higher than those rates derived empirically.   Despite the relatively small surface area badlands contribute to the watershed, soil erosion rates from these patchy remnants are considerably larger than the savanna counterparts, likely creating a greater contribution to overall sediment loss.

5.3 Significance

      Several topographic and climatological factors appear to be contributing to the large patchy exposures called badlands in the southern highlands of Guam. As yet, observed badlands still constitute between one to five percent of the total cover area of the La Sa Fua watershed, but have proven rates of erosion faster than the surrounding vegetation types. Figures 11 and 12 illustrate the advancing surface area of badlands in southern Guam. Both photographs, taken one year apart from the highest point in the La Sa Fua watershed, span the adjoining Fena watershed. This type of time-series photography is most useful for explaining the need for erosion control to the general public as the increased quantity of badlands is dramatically presented in Figures 11 and 12.

      The problem of these expanding bodies comes when eroding soils enter the rivers and streams. Large plumes of sediment discharged over coral reefs and lagoons block light, essential for coral growth. Also, large plumes of sediment tend to clog freshwater reservoirs and disrupt pumping, as occurred in the Fena watershed following Typhoon Chata'an.   From this study and the Lewis (1997) study in the Taelayag watershed, it is evident that sediment yield from badlands are not as significant as current publications suggest. However, it is necessary to note that badlands on Guam have not exhibited natural recovery, as once the movement of water over exposed soils begins bare surface area only continues to grow. It is also necessary to note that results from this study cede that the bulk of suspended sediment in the La Sa Fua watershed is likely the product of gully and stream channel erosion. Bear in mind that large gullies, streams, even landslides can be the products of runoff from enlarged badland areas.

Figure 11. Badland coverage in adjoining Fena watershed, July 2001.

Figure 12. Badland coverage in adjoining Fena watershed, July 2002.

5.4 Recommendations

The primary objectives of this study were to learn more about the specificity of soil erosion rates and sources from badlands within the boundaries of the La Sa Fua watershed in southern Guam. The secondary objective of this study was to estimate and compare sediment yield from steep-slope and valley locale badlands in southern Guam by comparing direct measurements of badland erosion rates to predictions from the Revised Universal Soil Loss Equation (RUSLE) used in previous estimations for erosion rates.

The process of soil erosion and soil movement within a watershed is a complicated interdependent system of dependent variables, from the first drops of falling rain to the tiny accumulation of sediment particles that pass out the mouth of a river. Soil erosion remains the main source of sediment to pollute streams, fill reservoirs, and degrade coral reefs. As stated earlier, soil erosion is also a major contributor of non-point source pollution, which has adverse effects on downstream and ecosystem water quality in watersheds.

The information in this report is intended to add to the growing bank of knowledge about soil erosion in Guam's southern highlands. It is aimed to contribute to the site-specific problems of soil loss within the badlands and provide a comparison between mathematical and empirically derived rates of erosion. Additionally, it is intended to break down some of the complexities in determining sedimentation processes in a single watershed.

Badlands on Guam are visible from the surrounding vegetation by distinct red-colored saprolite clays. New and improved aerial photography, such as the IKONOS® imagery, provided by the National Oceanographic and Atmospheric Association (NOAA), will make observing and monitoring the expansion rate of badlands easier and more accurate. The erosion-pin array technique for measuring the land-surface altitude changes within and among the test sites proved highly useful, durable, economical and inconspicuous. In future field experiments, the author recommends dividing the plot areas into a definitive grid system of identical slope lengths for improved identification and mathematical manipulation. Since it is believed that stream channel and gully type erosion may account for the largest volume of sediment yield in the watershed, future research should include surveying stream channels and tributaries, turbidity measurements and

monitoring soil-creep rate. Also recommended is an analysis between suspended sediment concentrations and rainfall intensity, as to complete the overall picture of soil movement.

ACKNOWLEDGMENTS

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APPENDIX I. **Mt. Jumullong Manglo and Umatac Raingage data**.

Monthly rainfall totals (in) for Mt. Jumullong Manglo Raingage, Umatac, Guam.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2000							estab.	n/a	n/a	n/a	n/a	4.68
2001	4.2	1.2	1.32	1.8	2.52	6	22.56	18.6	7.4	6.12	8.04	8.28
2002	10.8	6.36	2.64	1.08	9.24	8.64	31.44	---	---	---	---	---

Monthly rainfall totals (in) for Umatac Raingage, Umatac, Guam.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1992	6.98	0.14	1.33	0.72	3.48	2.04	6.72	30	5.88	12.7	13.9	0.72
1993	0.96	2.76	0.6	0.36	2.76	0.84	6.84	18.7	14.4	7.32	7.2	4.80
1994	3.12	1.44	6.36	2.4	5.16	3.24	16.8	4.68	15.2	6.72	3.36	3.96
1995	2.64	1.2	0.84	0.84	4.92	8.4	8.4	13.2	15.4	14.3	7.68	3.12
1996	8.16	5.64	4.92	7.2	2.16	1.32	5.88	5.64	16.3	8.88	16.2	17.3
1997	12.24	2.16	1.68	7.2	1.80	12.12	13.44	37.8	9.24	15.12	5.99	7.32
2000	2.04	6.60	3.12	1.20	5.16	4.20	8.28	12	16.92	11.04	5.64	6.48
2001	2.76	1.56	0.84	1.44	1.32	7.32	20.52	20.52	4.56	5.52	18.72	6.72
2002	7.56	6	3.24	1.20	8.04	7.44	23.04	---	---	----	----	---

Umatac Raingage

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
92-97 mean	5.68	2.22	2.62	3.12	3.38	4.66	9.68	18.34	12.74	10.84	9.06	6.20
σ	4.22	1.90	2.41	3.24	1.41	4.57	4.42	13.33	4.19	3.66	4.93	5.85
00-02 mean	4.12	4.72	2.4	1.28	4.84	6.32	17.28	16.26	10.74	8.28	12.18	6.6
σ	3.00	2.75	1.35	0.14	3.37	1.84	7.90	6.02	8.74	3.90	9.25	0.17

Mt. Jumullong Manglo Raingage

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
00-02 mean	7.5	3.78	1.98	1.44	5.88	7.32	27	18.6	7.4	6.12	8.04	8.28
σ	4.67	3.65	0.93	0.51	4.75	1.87	6.28					

APPENDIX II. Geology of southern Guam (after Tracey et al, 1964 with revisions from Reagan and Meijer, 1984).

Rt. 6

Rt. 17

UOG

N

Map Legend

Major faults
Roads
Artificial fill
Beach deposits
Alluvium
Mariana limestone
Alifan limestone
Umatac Formation
Alutom Formation
Facpi Formation

3   0   3 Miles
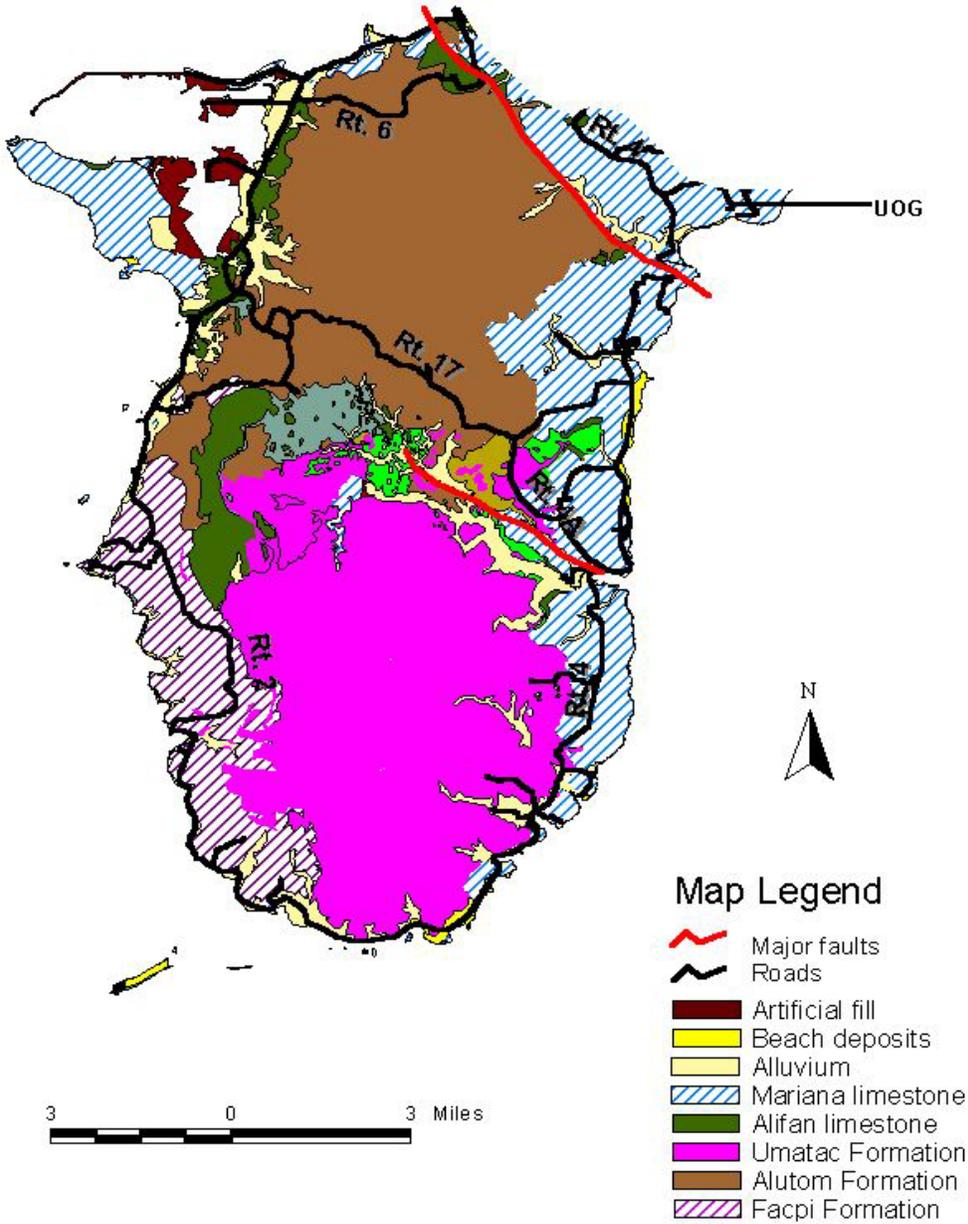
APPENDIX III continued. **RUSLE factors and results for Lines A-I.**

Plot	Spatial Average (tons/ac/yr)	Spatial Average (wet) (tons/ac/yr)	Spatial Average (dry) (tons/ac/yr)
A	164.5578	176.3654	158.9011
B	192.7174	206.5456	186.0927
C	154.5811	165.6729	149.2673
D	144.4649	154.8308	139.4989
E	161.4823	173.0693	155.9314
F	1.018861	1.091968	0.983838
G	0.819697	0.878513	0.79152
H	0.157174	0.168452	0.151771
I	119.545	128.1228	115.4357
Badlands	225.918	242.128	218.152
Grasslands	1.49	1.60	1.44

*Indicates S-factor = 3.0(sin θ) 0.8 + 0.56 for disturbed lands at slopes of up to 84%, with slope length less than 15ft.

**Indicates LS-factor for high ratio of rill to interrill erosion for horizontal slope length = 75 ft. and a slope of 40%.

† Indicates a LS-factor of low rill to interill erosion for horizontal slope length = 75 ft. and a slope of 40% (Renard et al., 1997)

APPENDIX IV. Erosion-pin data for hillslope and valley sites, La Sa Fua Watershed, Umatac Village, Guam, 2000-2002.

Erosion-pin array	Number of pins	Average altitude change (mm)	Maximum single station altitude change (mm) Increase	Decrease	Hill-slope angle (degrees)	Ground cover

July 13, 2000-August 8, 2001: 2 Site Visits

BL1-1	11	16.5	0	37	23	Bare
BL1-2	11	20	0	45	23	Bare
BL1-4	11	37	0	46	17-36	Bare
BL1-5	11	39.5	0	49	17-42	Bare
BL1-6	11	61.5	0	89	32	Bare
BL1-7	11	22	-13	34	32	Bare
BL1-8	11	29	0	39	36	Bare
BL1-9	11	15	0	18	32	Bare
BL1-10	11	31	0	40	42	Bare
GL1-1	11	-3	-16	10	21	Grass
GL1-2	11	-1.5	-32	6	21	Grass
GL1-3	11	6	-13.5	45	21	Grass
GL1-4	11	-1	-19	9	21	Grass
GL1-5	11	-7	-59	3.5	21	Grass
RC1-1	11	20	0	30	19	Bare
RC1-2	11	37.5	-7	75.5	19	Bare
RC1-3	11	-28	-48	0	19	Bare
GL3-1	11	-3	-28	19	15	Grass
GL3-2	11	19	-37	35	15	Grass
GL3-3	11	-1	-14	11	15	Grass
GL3-4	11	-2	-12	9	15	Grass
GL3-5	11	-11	-26	6	15	Grass

APPENDIX IV continued. Erosion-pin data for hillslope and valley sites, La Sa Fua Watershed, Umatac Village, Guam, 2000-2002

Erosion-pin array	Number of pins	Average altitude change (mm)	Standard deviation	Maximum single station altitude change (mm) Increase Decrease		Hill-slope angle (degrees)	Ground cover
BL1-1	11	4	4	-16	32	23	Bare
BL1-2	11	3	5	-13	23	23	Bare
BL1-4	11	9	15	-30	52	17-36	Bare
BL1-5	11	8	7	-12	27	17-42	Bare
BL1-6	11	6.5	22	-40	44	32	Bare
BL1-7	11	6	10.5	-21	33	32	Bare
BL1-8	11	6	6	-14	21	36	Bare
BL1-9	11	6	6	-8	15	32	Bare
BL1-10	11	6.5	47	-144	168	42	Bare
GL1-1	11	1	5	-20	17	21	Grass
GL1-2	11	-1.5	4	-15	13	21	Grass
GL1-3	11	-5	7	-61	46	21	Grass
GL1-4	11	3	5	-25	35	21	Grass
GL1-5	11	2	1	-10	20	21	Grass
RC1-1	11	2	3.5	-35	72	19	Bare
RC1-2	11	10.5	15	-115	104	19	Bare
RC1-3	11	-11.5	4	-36	3	19	Bare
GL3-1	11	-2	7	-29	36	15	Grass
GL3-2	11	4.5	7.5	-45	38	15	Grass
GL3-3	11	1	8	-25	43	15	Grass
GL3-4	11	-0.5	2	-11	13	15	Grass
GL3-5	11	-2	2	-43	38	15	Grass

August 8, 2001-July 20, 2002: 4 Site Visits

APPENDIX V. Change in land-surface profiles.

SUMMARY

BL1

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	18	6	8	6	0
0.1	16.5	6	4	3	8
0.2	23.5	7	2	11	1
0.3	13.5	5	2	1	9
0.4	13.5	8	4	-5	12
0.5	11.5	10	2	-16	32
0.6	22.5	7	-5	-4	14
0.7	7	7	-2	1	10
0.8	8	5	4	3	3
0.9	11	4	5	-4	11
1.0	37	-3	1	4	3

BL2

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	30	6	4	6	3
0.1	9	5	3	-1	5
0.2	13.5	2	-1	-4	12
0.3	48	5	-3	-7	18
0.4	44.5	2	-4	-9	17
0.5	8.5	6	-1	-2	9
0.6	18.5	12	0	0	9
0.7	13	6	4	-13	23
0.8	2	1	1	1	3
0.9	9.5	1	4	2	3
1.0	21	6	-4	3	0

APPENDIX V continued. Change in land-surface profiles (mm).

BL4

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	46	6	8	10	13
0.1	34	8	8	17	6
0.2	33.5	11	9	7	15
0.3	36	7	6	2	27
0.4	35	7	5	-3	29
0.5	40	7	3	-3	31
0.6	42.5	3	0	-8	37
0.7	36.5	15	-1	-11	33
0.8	42	10	0	-20	33
0.9	33	15	-5	-26	52
1.0	36	-9	20	-30	49

BL5

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	40	6	1	7	14
0.1	48	3	-1	5	15
0.2	46.5	4	2	9	9
0.3	48.5	6	-4	16	4
0.4	48	13	-10	13	10
0.5	39	11	-8	25	6
0.6	40.5	9	-1	18	4
0.7	39	9	0	19	6
0.8	43	10	-6	26	-1
0.9	41	6	1	25	-7
1.0	31	-9	26	27	-12

APPENDIX V continued. Change in land-surface profiles (mm).

BL6

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	23	3	3	-13	28
0.1	63	10	6	-8	28
0.2	42	36	3	-23	49
0.3	52.5	20	3	-16	41
0.4	88.5	-6	-16	-2	34
0.5	86	-40	10	1	32
0.6	82	-12	-3	-9	40
0.7	86	1	1	-22	44
0.8	71.5	-1	3	-23	40
0.9	7	9	-16	-18	44
1.0	77	7	2	-14	29

BL7

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	14	18	1	13	17
0.1	24	-11	16	7	12
0.2	24	0	12	1	14
0.3	33	-21	12	10	15
0.4	32	-13	2	7	24
0.5	34	-9	-4	8	20
0.6	25	0	-15	14	28
0.7	17	-5	-10	15	33
0.8	13	-12	-1	9	19
0.9	32	-7	-10	12	16
1.0	-13	3	17	4	20

APPENDIX V continued. Changes in land-surface profiles (mm).

BL8

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	19	12	-2	16	7
0.1	34	5	7	11	6
0.2	31	-2	2	7	14
0.3	31	2	0	3	21
0.4	32	-1	2	10	21
0.5	31	-2	3	15	17
0.6	31	-4	2	11	12
0.7	32	-10	5	17	6
0.8	39	-6	-2	5	14
0.9	33	-4	-5	8	15
1.0	4	16	-14	12	15

BL9

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	17	3	0	-4	14
0.1	14	5	3	5	6
0.2	15	3	3	5	7
0.3	17	3	1	4	4
0.4	18	5	2	1	6
0.5	15	4	4	4	4
0.6	16	3	4	5	4
0.7	12	11	-2	5	5
0.8	14	6	10	-2	2
0.9	14	12	5	-8	5
1.0	13	3	3	-5	15

APPENDIX V continued. Changes in land-surface profiles (mm).

BL10

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	30	0	1	-54	65
0.1	32	-8	6	-65	94
0.2	32	-9	6	-50	83
0.3	30	-13	7	-51	83
0.4	27	-2	2	-45	72
0.5	33	-11	9	-144	168
0.6	27	0	-1	-14	44
0.7	29	-4	-1	-15	48
0.8	34	-3	-8	-9	63
0.9	40	-2	-16	6	36
1.0	24	3	1	-5	22

GL1-1

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-16	-3	4	4	0
0.1	-3	8	1	-1	-3
0.2	0	11	-5	1	-2
0.3	3	3	-2	4	-8
0.4	10	0	-1	6	-12
0.5	-2	1	2	4	-3
0.6	-12	4	-10	2	7
0.7	2	1	-13	6	1
0.8	2	-6	-6	5	-6
0.9	-9	17	-20	9	-7
1.0	-3	-3	-9	0	1

APPENDIX V continued. Changes in land-surface profiles (mm).

GL1-2

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	5	-6	-3	5	-1
0.1	2	-2	2	3	-8
0.2	-3	2	-1	1	-7
0.3	2	-4	-4	2	-8
0.4	6	1	-3	1	-7
0.5	-14	4	0	4	-7
0.6	4	-4	0	6	-9
0.7	-3	-5	2	3	-8
0.8	-32	6	1	0	-15
0.9	-7	13	0	-2	-9
1.0	5	-3	5	-5	1

GL1-3

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-2		1	-15	-1
0.1	-13	**L**	14	-1	-13
0.2	45	**O**	46	-12	-13
0.3	9	**S**	-61	3	3
0.4	2	**T**	-13	-25	-12
0.5	21		7	-14	1
0.6	-6		-8	-20	-1
0.7	5		9	-43	33
0.8	2		3	-14	-3
0.9	-1		1	2	-1
1.0	-3		3	-1	-20

APPENDIX V continued. Changes in land-surface profiles (mm).

GL1-4

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	3	3	-25	10	-4
0.1	1	1	27	4	0
0.2	4	1	8	3	-6
0.3	0	0	1	6	-1
0.4	-6	3	35	-4	2
0.5	1	-2	30	0	0
0.6	-4	1	31	4	3
0.7	9	-3	-1	7	2
0.8	2	-1	-14	6	-1
0.9	3	-2	1	-1	-14
1.0	-19	3	20	-5	4

GL1-5

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	3	0	0	0	3
0.1	4	9	2	-7	-1
0.2	1	1	-1	-10	8
0.3	1	1	-5	-1	6
0.4	-12	1	4	3	-1
0.5	-59	0	1	1	-5
0.6	6	10	-1	0	2
0.7	-1	11	-1	6	20
0.8	3	-1	18	6	16
0.9	-12	0	1	1	-4
1.0	-9	0	4	-2	-3

APPENDIX V continued. Changes in land-surface profiles (mm).

RC1-1

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	30	15	-1	4	-35
0.1	29.5	19	-15	5	0
0.2	17	2	2	-5	2
0.3	9	3	0	5	-9
0.4	7.5	4	1	10	0
0.5	17	2	3	14	-7
0.6	29	2	0	8	-3
0.7	18	-1	-1	11	-6
0.8	22.5	3	-8	13	-13
0.9	26	14	-6	-1	-3
1.0	14	-9	5	-7	72

RC1-2

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	61	31	3	1	-4
0.1	68.5	31	6	8	24
0.2	75.5	30	-1	28	22
0.3	74	37	-4	30	12
0.4	17	28	-13	2	8
0.5	31	32	-14	10	20
0.6	52	28	-115	104	25
0.7	22.5	-1	4	-1	61
0.8	-6	5	-3	-4	3
0.9	-7	6	-3	-4	-9
1.0	28	13	7	7	8

APPENDIX V continued. Changes in land-surface profiles (mm).

RC1-3

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-24	-9	-14	-12	-2
0.1	-16	-18	-6	-13	-6
0.2	-19	-18	-11	-7	-13
0.3	-17	-13	-17	-4	-8
0.4	-22	-17	-16	-4	-11
0.5	-27	-33	-13	-2	-15
0.6	-40	-20	-23	3	-8
0.7	-17	-17	-18	-2	-19
0.8	-35	-10	-11	0	-20
0.9	-48	1	-8	-10	-15
1.0	-42	-6	1	-6	-36

GL3-1

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-6	0	2	0	-13
0.1	19	19	-15	-5	0
0.2	5	12	-11	-1	-9
0.3	-28	36	-8	-2	-29
0.4	8	27	-23	3	-15
0.5	2	6	0	-7	-7
0.6	13	-5	1	-8	-7
0.7	-28	4	9	-7	-7
0.8	-4	-23	24	-21	6
0.9	-8	2	-6	-8	-3
1.0	-6	3	2	4	-14

APPENDIX V continued. Changes in land-surface profiles (mm).

Gl3-2

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-5	27	7	-3	-3
0.1	-37	17	13	23	1
0.2	35	6	-5	-12	27
0.3	34	1	3	9	16
0.4	33	1	-5	2	23
0.5	23	14	-6	14	14
0.6	30	8	1	-10	9
0.7	13	14	2	-45	38
0.8	30	3	0	-19	8
0.9	17	8	-7	-11	-1
1.0	29	24	-19	20	-4

GL3-3

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-4	3	1	-3	3
0.1	-4	4	-1	-6	2
0.2	-8	1	-4	1	3
0.3	11	6	-6	0	6
0.4	-13	5	6	-12	10
0.5	3	-1	13	-15	5
0.6	3	6	7	-19	14
0.7	8	1	11	-25	11
0.8	-1	-1	0	-7	10
0.9	8	5	6	-19	10
1.0	-14	43	4	-7	-13

APPENDIX V continued. Changes in land-surface profiles (mm).

Gl3-4

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	4	-1	-3	-2	4
0.1	-12	13	-11	2	-2
0.2	-8	7	-5	-2	1
0.3	-4	5	7	-11	-5
0.4	-9	1	-4	3	2
0.5	3	-1	-8	7	-4
0.6	5.5	1	0	1	-5
0.7	-12	-3	1	4	-3
0.8	-8	6	-8	2	-7
0.9	9	3	1	1	-6
1.0					

GL3-5

Station No.	8/9/01	11/17/01	2/9/02	5/11/02	7/20/02
0	-8	6	-1	-1	-43
0.1	5.5	-1	9	-8	-5
0.2	-5	0	9	-1	-12
0.3	-26	-2	-3	-2	1
0.4	-18.5	-3	-3	-7	12
0.5	-12.5	3	-9	-3	3
0.6	-17.5	-11	4	-6	-14
0.7	-6.5	-5	-14	-2	-3
0.8	-24.5	-1	-3	0	-10
0.9	6	7	-11	4	-6
1.0	-2	12	2	-12	38

APPENDIX VI. Bulk density data.

BL	GL1	RC	GL3
Field weight	**Field weight**	**Field weight**	**Field weight**
31.8oz, 1.99lbs	31.3oz, 1.96lbs	37oz, 2.31lbs	35oz, 2.19lbs
902g	891g	1049g	992g
Dry weight	**Dry weight**	**Dry weight**	**Dry weight**
18.5oz, 1.16lbs	20oz, 1.25lbs	21.5oz, 1.34lbs	25.5oz, 1.59lbs
526g	567g	608g	721g
Moisture content	**Moisture content**	**Moisture content**	**Moisture content**
0.71	0.57	0.72	0.37
Volume	**Volume**	**Volume**	**Volume**
$42.41in^3$, $0.025ft^3$, $694.99cm^3$	$42.41in^3$, $0.025ft^3$, $694.99cm^3$	$42.41in^3$, $0.025ft^3$, $694.99cm^3$	$42.41in^3$, $0.025ft^3$, $694.99cm^3$
Bulk density	**Bulk density**	**Bulk density**	**Bulk density**
=0.93 g/ cm^3	**=0.73 g/ cm^3**	**=1.09 g/ cm^3**	**=0.54 g/ cm^3**

Formula:

moisture content = field weight/dry weight

bulk density = [(1-moisture content)*field weight]/volume

The bulk density, derived empirically from the steep-slope badland (BL) test site for the 2001-2002 field season, is 0.55 g/cm^3. Fo17 mm of land-surface altitude loss the formula is:

$$[.55\text{g/cm}^3]*[1\text{cm/10mm}]*[17\text{mm/1}]= 0.941 \text{ g/cm}^2$$

$$[0.941 \text{ g/cm}^2]*[929.03\text{cm}^2/1\text{ft}^2]= 873.95 \text{ g/ft}^2$$

$$[873.95 \text{ g/ft}^2]*[1\text{ton}^\dagger/907{,}180\text{g}]= 9.63 * 10^{-4} \text{ tons/ft}^2$$

$$[9.63 * 10^{-4} \text{ tons/ft}^2]*[43{,}560\text{ft}^2/\text{acre}]= 41.97 \text{ tons/acre}$$

[†]The RUSLE model supports the U.S. standard short ton = 2,000 lbs. or 907,180 grams.