# Report for 2004GU36B: Refining the R-factor and Developing Rainfall Distribution Maps for the Island of Pohnpei

There are no reported publications resulting from this project.

Report Follows

**Project Title:**

Refining the R-factor and Developing Rainfall Distribution Maps for the Island of Pohnpei

**Problem and Research Objectives**

Lack of accurate rainfall data is a common problem throughout Micronesia, making it very difficult for water resources professionals to initiate studies such as watershed management, soil erosion reduction, identifying potential land sliding areas and so on. The slope failure at Sokehs in 1997 that killed 19 people, and the slope failures in Chuuk during tropical cyclone Chata'an in 2002 that killed 47 people are the examples of the need for information on rainfall distribution (e.g., Short-term extremes, and threshold conditions for flooding and slope failures).

The United States Department of Agriculture Natural Resources Conservation Service (USDA/NRCS) has implemented several programs to help manage and reduce soil erosion on the islands. These programs require accurate estimates of annual soil erosion, which is calculated using the Revised Universal Soil Loss Equation (RUSLE). The Universal Soil Loss Equation (USLE) and its updated revision the Revised Universal Soil Loss Equation (RUSLE) are the equations used most commonly to predict soil erosion rates and soil losses in the tropical pacific. In tropical environments, climate, or specifically the volume and intensity of rainfall, is the most significant cause of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R or rainfall erosivity factor. It is important to have an accurate rainfall record with high time resolution (e.g., 15-minute duration) for calculating R-factor.

The objective of this research project were:

(1) Accurate assessment of the spatial distribution of rainfall on Pohnpei (e.g., isohyets of annual mean rainfall),

(2) some preliminary estimates of the magnitudes of extreme short-term rainfall rates;,

(3) an understanding of the general character of the rainfall (e.g., hourly distribution and month-to-month variability),

(4) develop Rainfall erosivity factor (R-factor) for island of Pohnpei and,

(5) identify the areas having a high potential for a land slide.

**Methodology**

The Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994) for Pohnpei Island predicts that the interior highlands receive much more rain than the coastal perimeter (Fig. 1). The PRISM model indicates that the annual rainfall in the mountainous center of Pohnpei is over twice that of the coastal perimeter. This is an enormous amount of rainfall (~300 inches per year) for the interior, and represents tremendous gradients of mean annual rainfall on this relatively small – 12-mile diameter – roughly circular island. In addition, to be able to use the PRISM prediction for locating the areas that have potential for land sliding requires calculating the rainfall erosivity factor. The calculation requires having an accurate continuous rainfall record of each storm that might cause the landslide.

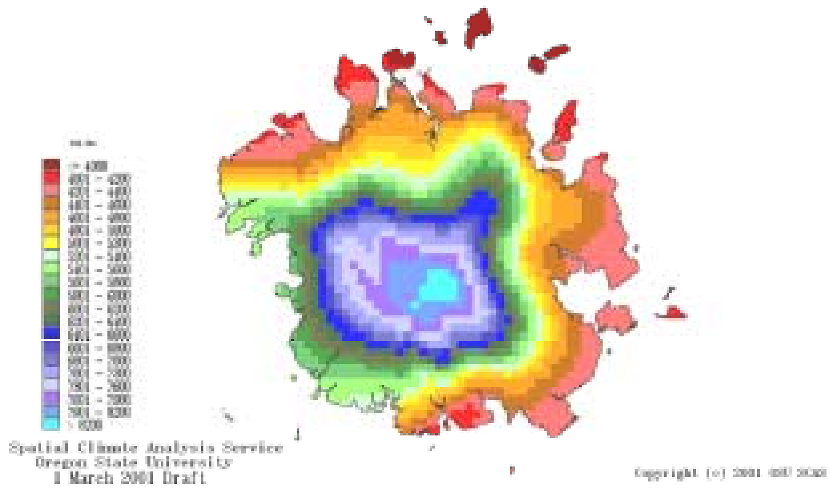



Figure 1. **PRISM**, estimated mean annual precipitation for island of Pohnpei.

The researchers at WERI with the help of Conservation Society of Pohnpei (CSP) installed a transect of manual and electronic rain gages extending from the coast to the highlands of the island. Figure 2 shows the location of WERI and WSO rain gages. Since rainfall is so heavy on Pohnpei (nearly 20 inches per month), simple manual rain gauges that consist of a 56-inch tall 6-inch diameter PVC cylinder capped by a funnel with a debris screen were constructed (Fig. 3a). These are cheap, easy to install and to maintain. Although not highly accurate, these crude manual gauges may be able to accurately measure the differences between rainfalls among the sites. One of the manual rain gauges was collocated with existing accurate recording stations at the WSO Pohnpei. Tipping bucket rain gauges with data loggers were set up at three of the transect sites (Madolenimw Mayor's Office, Nihpit, and Nahna Laud) (Fig. 3b). These allowed a calibration and validation of the rain collected by the manual gages. Two of the manual rain gauges were collocated with WERI/CSP electronic rain gauges at the College of the FSM, and on top of Nahna Laud. Additional electronic rain gauges were placed at the Airport and the College. Manual rain gauges were also placed at the Airport, the College, at a site (Mahnd) along the mountain transect between the Mayor's Office and Nihpit.

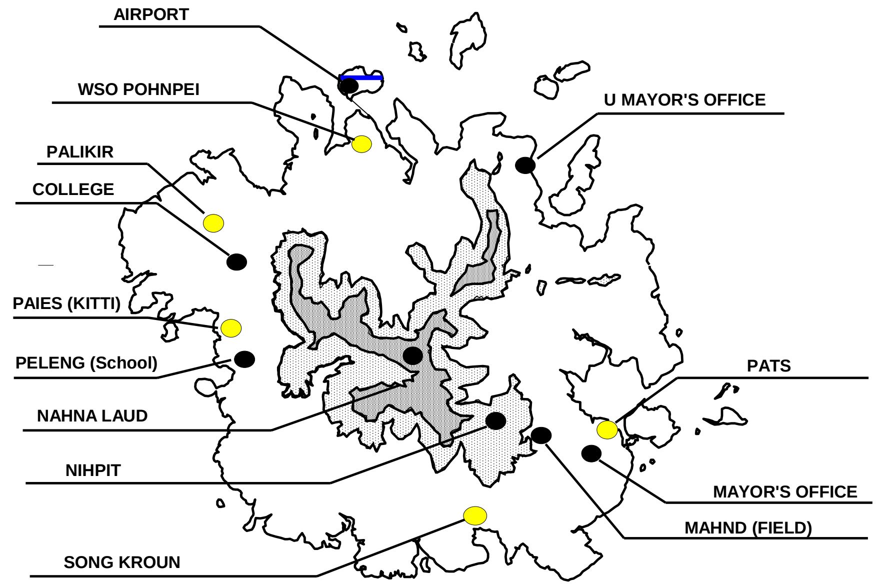
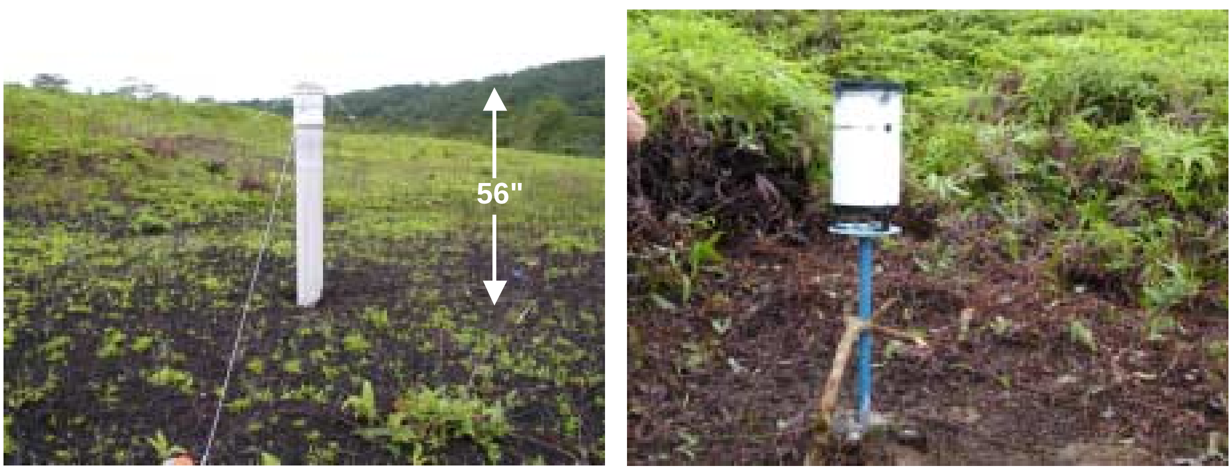



Figure 2. Locations of the raingages, black dots are WERI\CSP network, yellow dots are WSO raingages.




a b

**Figure 3.** (a) A view of the specially designed 56-inch PVC pipe rain gage assembled in the field at the Mahnd site on Pohnpei Island. (b) A view of the recording tipping bucket rain gage assembled in the field at the Nihpit site on Pohnpei Island.

The top of Nahna Laud was the selected site in the central highlands where two rain gages were set up near one another – one in an open area, and another under the canopy of the rainforest – to assess the impact of fog drip on the water budget of the island. The central highlands of Pohnpei are of sufficient height (~2,000 – 2,600 ft) to often be enshrouded in fog. Deposition of cloud droplets onto leaves, and subsequent coalescence and drip, may enhance the total water budget substantially. This so-called fog-drip is responsible for a substantial portion of the water budget on portions of the islands of Hawaii. An electronic gage is required at this site to determine the times when it is actually raining at the open-area location. The percent of time the highlands are enshrouded in cloud is itself an unknown.

The WERI project investigators traveled to Pohnpei at least once every three months to perform maintenance on the gages and to collect the data. Personnel at the Pohnpei CSP were contracted to perform readings of the rain gauges and routine maintenance.

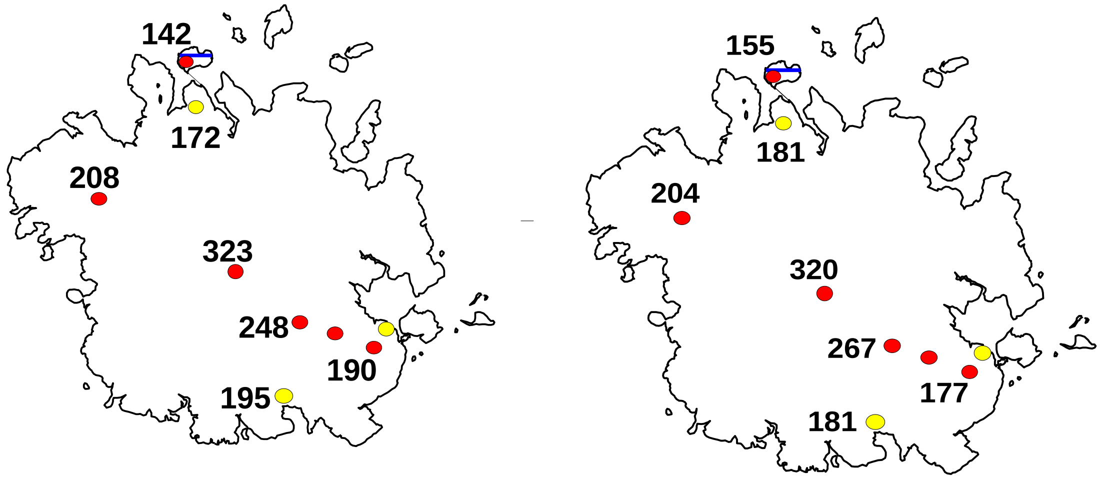
Before field installation, all rain gage equipment was evaluated by setting up a test site at the UOG campus where there already exists a dense network of manual and electronic rain gages: Several 4-inch plastic manual gages, two Qualimetrics tipping bucket rain gages with data logger, a National Weather Service (NWS) HANDAR station that contains a tipping bucket rain gage, and a NWS standard 8-inch brass manual rain gage.

## Principal Findings and Significance

SPATIAL DISTRIBUTION OF ANNUAL RAINFALL

According to measurements obtained by the WERI/CSP network, the distribution of rainfall on the island of Pohnpei is strongly affected by the topography, and the annual rainfall totals among recording stations on Pohnpei differed by more than 150 inches. The region in the vicinity of Pohnpei’s international airport (Figure 4) received the lowest annual total of 142 inches. The highest measured annual rainfall of 323 inches occurred in the central highlands. The western side of the island is wetter than its eastern side.

The annual rainfall measured on Pohnpei during the first year of operation of the WERI/CSP rain gage network compares favorably with the **PRISM** estimates of mean annual rainfall (Figure 5). Because of this favorable comparison, we feel that the **PRISM** maps are probably the best available estimate of the spatial distribution of the average annual rainfall at this time.




**MEASURED JULY 2003 – JULY 2004**

**PRISM ESTIMATE OF MEAN ANNUAL RAINFALL**

Figure 4. Rainfall measured on Pohnpei (left panel) during the first year of operation of the WERI/CSP raingages network, and the mean annual rainfall as estimated by the **PRISM** techniques (right panel).

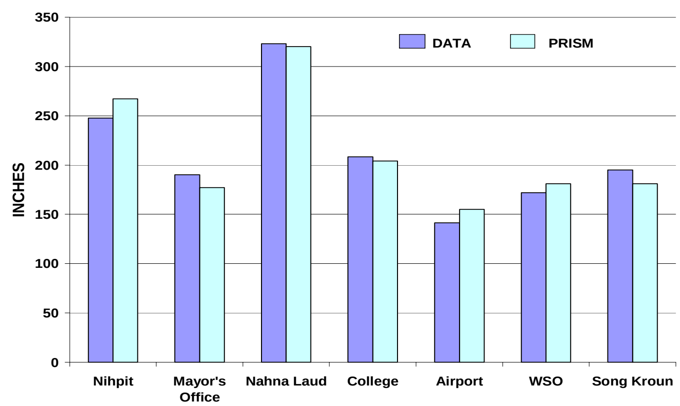



Figure 5. Comparison of measured rainfall to **PRISM** at selected sites on the island of Pohnpei.

## HOURLY DISTRIBUTION OF DAILY RAINFALL

Throughout much of the tropical Pacific there is a tendency for more rainfall to occur in the morning hours. Ruprecht and Gray (1976) analyzed 13 years of cloud clusters over the tropical western Pacific and found that over twice as much rain fell on small islands from morning (0700 to 1200L) clusters as from evening (1900 to 2400L) clusters. The heaviest rain fell when it was part of an organized weather system and when diurnal variation was most pronounced. Fu et al. (1990) used satellite infrared images over the tropical Pacific to confirm and refine these findings. Deep convective cloudiness was greatest around 0700L and least around 1900L. The morning rainfall maximum associated with western Pacific cloud clusters and the early morning instability in the trade winds both originate from the nocturnal radiational cooling of cloud tops. An analysis of the fraction of the rainfall accumulated during each hour of the day shows that there is a tendency for most rainfall to occur between local midnight and sunrise than during other hours, with an absolute minimum in net long-term accumulations contributed during the evening hours (Fig. 6). At most small islands and atolls of Micronesia such as Wake, Majuro and Chuuk, the hourly distribution of rainfall is that which is found to be typical over the open-ocean. This is not the case at Pohnpei, where the island topography distorts the hourly rainfall distribution. The hourly rainfall distribution is more complicated on the larger islands such as Pohnpei, Hawaii, and Guam. On mountainous islands such as Pohnpei and on the Hawaiian Islands, the large diurnal variations in rainfall (not necessarily synchronous with typical open-ocean variations) are driven by mountain- and sea-breeze circulations. Indeed, from personal experience on Pohnpei, during the summer months (May through October) when the winds are light, there is a strong tendency for heavy showers to develop over the mountains by noon. This is confirmed by the WERI/CSP rain gage atop Nahna Laud (Fig. 7). The interior early afternoon showers rain-out and die by evening. At almost all islands, there is an evening minimum of rainfall. ***Pohnpei's extreme amount of rain in the interior appears to derive from day-time convection over the mountains, and not from orographically enhanced rainfall as winds pass over the high terrain (as on many of the Hawaiian Islands).***

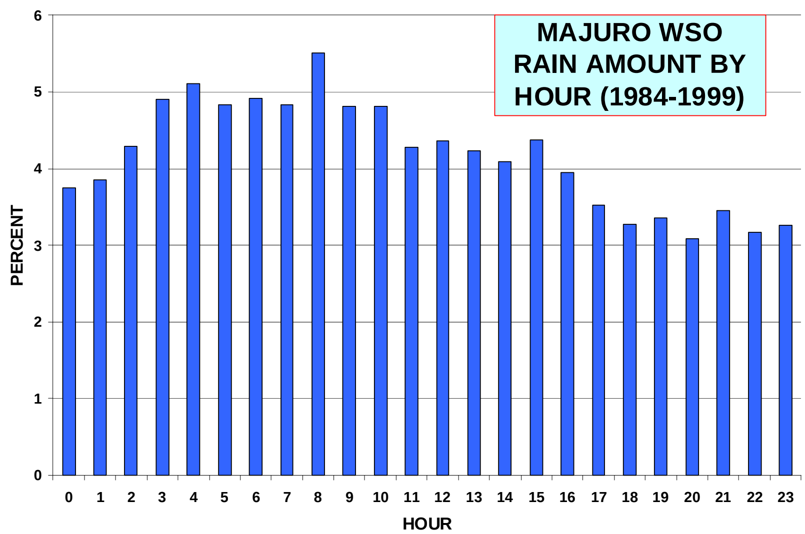



**Figure 6.** Example of the typical hourly distribution of rainfall in the tropical Pacific Ocean. The example chosen is Majuro Atoll.

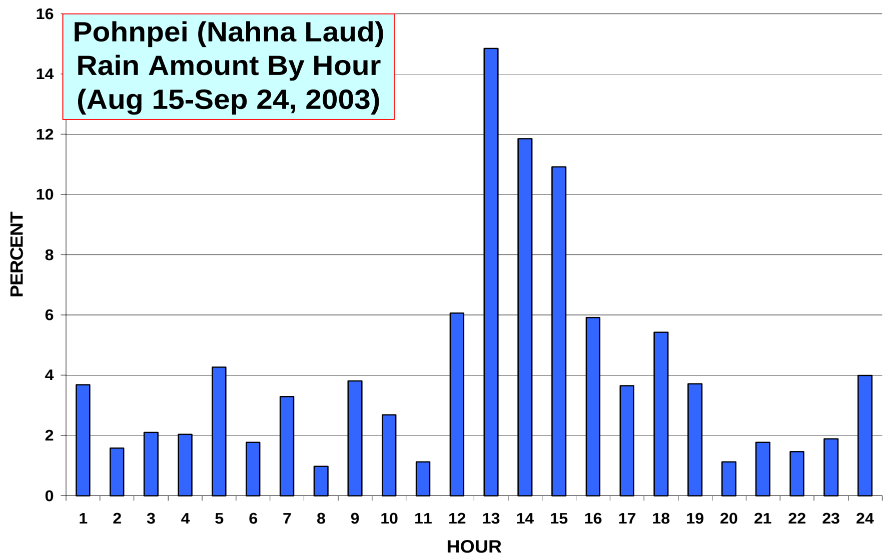



**Figure 7**. Preliminary data from the Nahna Laud site shows a sharp concentration of rainfall in the four hours of local noon through 4 PM in the afternoon. Convection induced by daily heating in light wind conditions allows for the build-up of thunderstorms nearly every day in Pohnpei's interior.

RETURN PERIODS OF SHORT-TERM HIGH-INTENSITY RAINFALL EVENTS

Since the rainfall records on Pohnpei are so short and/or incomplete, calculations of return periods of extreme rain events may only be crudely estimated. The more complete record of rainfall on Guam allows for a comparison by proxy. Guam, however, experiences direct hits by full-fledged typhoon far more frequently than does Pohnpei. Return-period calculations for Guam's peak annual 24-hour rainfall yield a mixed distribution, with typhoons causing all daily rainfall events in excess of 10 inches. A return-period analysis of the extreme 24-hour rain rates and extreme 1-hour rain rates using Pohnpei's shorter and more incomplete record is shown in Figure 8. Charts of intensity-duration-frequency (IDF) for Pohnpei (Fig. 9 and Table 1) can be derived from extrapolation.

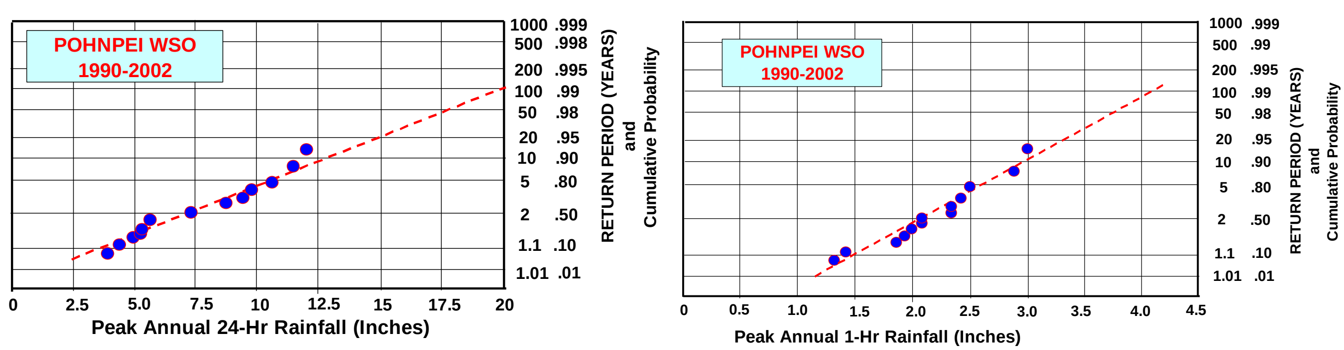



**Figure 8.** **(a)** Method-of-moments (ranking method) computations of 24-hour return period extreme rainfall events (left), and 1-hour return periods (right) using Pohnpei WSO data.

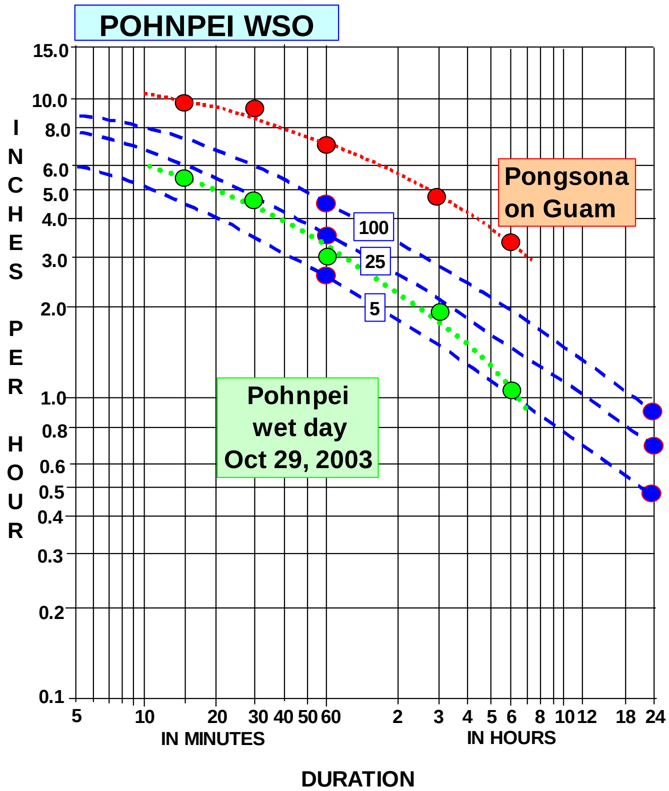



**Figure 9**. Intensity-Duration-Frequency (IDF) chart of selected return periods at the Pohnpei WSO (blue dots connected by blue dashed lines). For comparison, the IDF values measured during Typhoon Pongsona on Guam (red dots connected by red dotted line) are shown. Also, the highest IDF values measured within the past 9 months by the newly installed WERI/CSP rain gauge network on Pohnpei have been plotted (green dots connected by green dotted line). The Pohnpei event was fairly typical island-wide convection in a tropical disturbance.

**TABLE 1**. Charts of Pohnpei Rainfall Intensity-Duration-Frequency (IDF). Top panel is total rainfall, and the bottom panel is normalized to rainfall in inches per hour for the indicated return-period and duration.

| Return Period | RAINFALL (Inches) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 Minutes | 30 Minutes | 45 Minutes | 60 Minutes (1 Hour) | 120 Minutes (2 hrs) | 180 Minutes (3 hrs) | 360 Minutes (6 Hrs) | 720 Minutes (12 Hrs) | 1440 Minutes (24 Hrs) |
| $X_{100}$ | 2.13 | 3.00 | 3.98 | 4.60 | 6.60 | 8.55 | 11.70 | 15.60 | 20.40 |
| $X_{25}$ | 1.98 | 2.43 | 3.00 | 3.70 | 5.50 | 6.30 | 9.60 | 12.60 | 16.08 |
| $X_5$ | 1.48 | 1.85 | 2.12 | 2.70 | 3.90 | 5.10 | 6.60 | 7.92 | 11.76 |

| Return Period | RAINFALL INTENSITY (Inches/Hour) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 Minutes | 30 Minutes | 45 Minutes | 60 Minutes (1 Hour) | 120 Minutes (2 hrs) | 180 Minutes (3 hrs) | 360 Minutes (6 Hrs) | 720 Minutes (12 Hrs) | 1440 Minutes (24 Hrs) |
| $X_{100}$ | 8.50 | 6.00 | 5.30 | 4.60 | 3.30 | 2.85 | 1.90 | 1.25 | 0.85 |
| $X_{25}$ | 7.90 | 4.85 | 4.00 | 3.70 | 2.75 | 2.10 | 1.60 | 1.05 | 0.67 |
| $X_5$ | 5.90 | 3.70 | 2.95 | 2.70 | 1.90 | 1.70 | 1.10 | 0.67 | 0.49 |

## SPATIAL DISTRIBUTION OF RAINFALL EROSIVITY FACTOR

The Universal Soil Loss Equation (USLE) and its updated revision the Revised Universal Soil Loss Equation (RUSLE) are the equations used most commonly to predict soil erosion rates and soil losses in the tropical pacific. The five major factors used in USLE and RUSLE to predict soil erosion rates: 1) climate, largely rainfall, 2) soil, its inherent resistance to slaking, dispersion and its water intake and transmission rates, 3) topography, particularly steepness and length of slope, 4) plant cover, and 5) practice factor. Of these, the plant cover, practice and topographic factors are considered management parameters. In contrast, the climate factors and the soil characteristics are normally beyond manipulation by man. In tropical environments, climate or specifically the volume and intensity of rainfall are the most significant cause of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R or rainfall erosivity factor. The numerical value used for the R-factor in the soil loss equation must quantify the raindrop impact effect and must also provide relative information on the amount and rate of runoff likely to be associated with the rainfall regimes (Lal, 1994). The storm erosion index or Storm $EI_{30}$, derived by Wischmeier appears to meet these requirements better than any other of the many rainfall parameters. The relationship is expressed by the equation (Lal, 1994),

$$Storm\ EI_{30} = \left\{ \sum 1099 \cdot \left[ 1 - 0.72 \cdot Exp\left( -1.27 \cdot I_r \right) \right] \cdot R_r \right\} \cdot I_{30}$$

Where $I_r$ is the rainfall intensity (inch/hour) for a 30-minutes interval during the storm, $R_r$ is the rainfall amount (inch) during this same time interval. These values are input into the equation shown above for each time interval of the storm. The sum of the computed values is called the storm energy or E value. The E value is multiplied by the $I_{30,}$ which is the maximum 30-minute intensity during the storm. The product is called the Storm $EI_{30.}$ It is expressed in hundreds of foot-ton inches per acre-hour (Lal, 1994). The sum of the storm $EI_{30}$ values for a given period is a numerical measure of the erosive potential of the rainfall within the period. The average annual total of the storm $EI_{30}$ values in a particular locality is the rainfall erosion index (R-factor) for that locality (Lal, 1994). To calculate the Storm Erosivity $EI_{30}$, requires having 30-minute duration rainfall intensity. The annual storm erosion index (R-factor) was calculated for each raingage site. In order to determine the R-factors at un-gauged sites, a correlation of R-factors versus average rainfall was determined as shown in Figure 10.

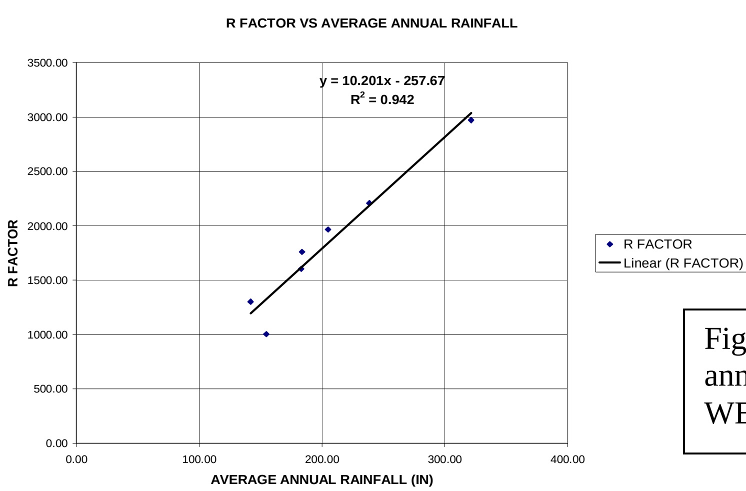



Figure 10. Linear trend of average annual rainfall and R-factor from WERI/CSP raingages.

The next step was to develop a GIS implementation of the average annual rainfall versus R-factor correlation. This required having a spatial distribution of average rainfall as a starting point. The **PRISM** data (Figure 2) was used for the annual rainfall distribution. The **PRISM** map was scanned and the digital files were geo-referenced to the Pohnpei's base map. Rainfall contours were developed from the scanned image. Next a geo-referenced rainfall Triangulated Irregular Networks (TIN) and appropriate average rainfall grid file and rainfall contours were developed as shown in Fig. 11.

The spatial distribution of R-factor was developed by applying the R-factor versus average annual rainfall correlation to each of the cells in the average annual rainfall map. R-value contours were next developed from the girded values and are shown in Fig. 12.

In order to develop maps of high erosion potential or land slides we developed a modified version of the USLE using only the R factor and slope factor components. The modified equation does not predict the amount of sediment production, but it indicated the areas where high potential for erosion exist. It does not account for plant coverage, management practices, and soil types. Using a spatially comparable digital elevation model (DEM) we developed a girded slope distribution map for the entire island of Pohnpei.

We applied the following relationship between the slope and length as expressed by (V. Novotny and Chesters 1981) to each of the girded slope values to obtain a new grid of the spatial distribution of the USLE slope factor.

$$LS = L^{1/2}\left(0.0138 + 0.00974 \cdot S + 0.00138 \cdot S^2\right)$$

Where L is the length in meters from the point of the origin overland flow (length of each cell), S is the average slope (%) over the runoff length. The final step was to spatially multiply the USLE slope factor by the previously obtained girded map of the R-factor. The resulting erosions potential map is shown in Fig. 13.

Figure 11. Average annual rainfall distribution map for Pohnpei Island.

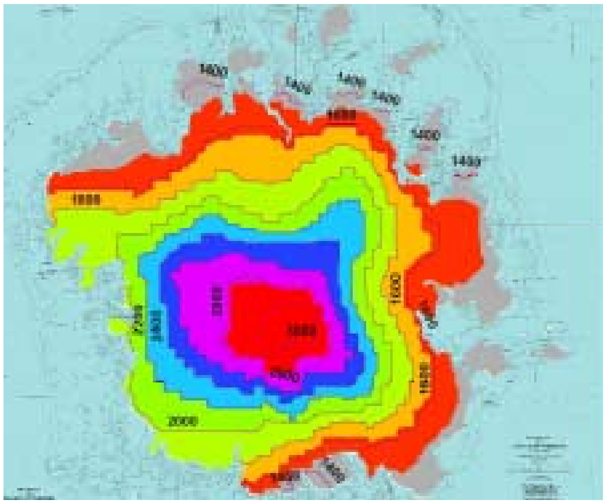


Figure 12. R-factor distribution map for Pohnpei Island.

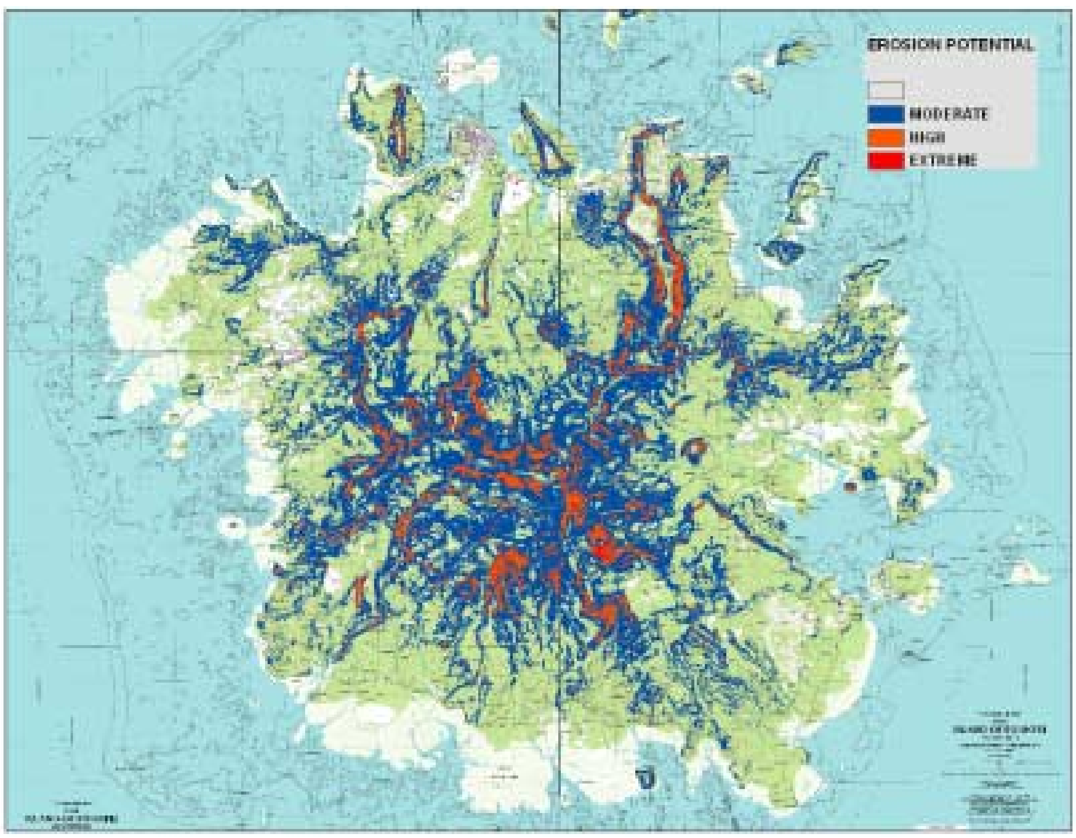



Figure 13. Areas with high erosion potential, Pohnpei Island.

**Summary of Findings**

The Preliminary results of the measured rainfall for the island of Pohnpei indicated that: (1) the distribution of rainfall on Pohnpei is affected by the topography, and the measured annual rainfall totals among recording stations on Pohnpei differ by over 150 inches; (2) Pohnpei's international airport received the lowest annual total of 142 inches. The highest measured annual total of 323 inches occurred on top of Nahna Laud in the highland rainforest of Pohnpei's interior; and (3) earlier charts of Pohnpei's mean annual rainfall using **PRISM** were comparable to the values measured at the WERI/CSP raingages.

The resulting erosion potential maps are a good first order identification of areas that bear close monitoring for high erosion potential and possible landslide activities. As more long term data is available, improvements on the existing annual rainfall distribution and the relationship between annual rainfall and calculated R-factor will be made. These improvements can be easily implemented within the existing GIS structure developed for this project. The preliminary maps that developed by this project will allow governmental managers to warn private citizens of possible high risk development areas and to developed management strategy to minimize the impact of soil erosion and land slide areas and watershed protection plan.

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