Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2003

Introduction

The Water & Environmental Research Institute of the Western Pacific or WERI is one of 55 similar water research institutes set up by U.S. Congressional legislation at each Land Grant University in the United States and in several territories. The institute is now in its 29th year of operation.

WERIs mission is to seek solutions through research, teaching, and outreach programs, to issues and problems associated with the location, production, distribution, and management of freshwater resources. WERI provides technical expertise, and conducts vigorous research and both undergraduate and graduate teaching programs aimed at improving economic conditions and the quality of life for citizens of Guam and regional island nations. WERI also runs a state of the technology water analytical laboratory and geographical information systems facility.

WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the institute was created specifically to administer Department of Interior (US Geological Survey) money under Section 104-B of the National Institute of Water Research (NIWR) 104-B Program. WERI has responsibility for 104-B money on Guam, in the Commonwealth of the Northern Mariana Islands (CNMI) and in the Federated States of Micronesia (FSM). In the 2003-2004 period, WERI faculty were involved as Principal Investigators on twenty (20) research and training projects. Funding sources for these projects included US Geological Survey, US Weather Service, NASA, local agencies such as Guam Environmental Protection Agency, Guam Bureau of Planning, Commonwealth Utility Corporation, CNMI and direct appropriations from the Guam legislature.

Currently WERI has a fulltime director who is also a UOG faculty member, four regular research faculty, one adjunct research faculty, a water analysis laboratory manager and technician, a GIS and network administrator, two office staff, as well as three graduate research students who are completing their MS degree in the UOG Environmental Sciences program. During the 2003-2004 interval, WERI faculty and staff taught eight graduate courses and four undergraduate courses in the Environmental Science MS program and the undergraduate pre-engineering curriculums respectively. Currently WERI faculty members serve as committee members on, or chairs on ten MS research theses in the Environmental Sciences and Biology graduate programs.

Following is a list of non USGS Funded Projects carried out by the Institute during the period 2003-2004:

NATIONAL SCIENCE FOUNDATION Collaborative Research: Testing and Constitutive Modeling of Fine Grained Tills Deposited by the Laurentide Ice Sheet

NASA Ground Based Radar Rainfall Estimation Project: Guam TRMM Validation

NATIONAL WEATHER SERVICE Pacific ENSO Applications Center

GUAM ENVIRONMENTAL PROTECTION AGENCY

Development of Strategies for the Reduction of Nitrate Contributions from Septic Tanks into the Northern Guam Aquifer

GUAM BUREAU OF STATISTICS AND PLANS

Development of Assessment Strategies for the Reduction of Nitrate Contributions from Septic Tanks to Streams and Coastal Water of Southern Guam

GUAM PUBLIC WORKS

Tumon Bay Environmental Study

DIRECT LOCAL FUNDING

Guam Hydrologic Survey

Water Resources Monitoring Program In Cooperation with Hawaii District, USGS

COMMONWEALTH UTILITY CORPORATION, CNMI

Hydraulic Modeling of Saipans Water Distribution System

Research Program

The Water and Environmental Research Institute (WERI) Advisory Council is the body, which determines research goals and priorities for WERI in general and the USGS 104B program in particular. The Research Advisory Council (RAC) for Guam consists of representatives from all Guam governmental agencies involved with water resources development or regulation, members of U.S. Federal agencies, military organizations on Guam that deal with water resources issues and members of the university research community. The RAC for the Federated States of Micronesia and the Commonwealth of the Northern Mariana Islands consist of representatives from various government departments that deal with water resources, representatives from local colleges, private sector engineers, environmentalists, and planners.

WERI held RAC meetings in August thru October 2002. Twenty four (24) people attended the Guam meeting, twenty five (25) people attended the CNMI meeting and ten (10) people attended the FSM meeting. The RAC groups examined the previous years research priorities and discussed changes to keep the listings up to date.

In early October, a Request for Proposals (RFP) was sent out by e- mail to the three regions: Guam, CNMI, and FSM. RFPs were sent to all regular members of the three RACs as well as to several agencies, institutions, and individuals that had expressed interest during the previous year. Each request for proposal included: a) 104-B proposal guidelines, b) an example of a well-written 104-B proposal, and c) the list of critical water resource needs for each of the regions.

Eleven (11) proposals, three (3) for Guam, Two (2) for the FSM, and six (6) for the CNMI were submitted. Review panels were selected for each of the regions. These panels were made up of researchers not submitting proposals or from others highly regarded in the water resources area of each of the regions. The submitted proposals were e-mailed to the members of the appropriate review panels. Each panel member had the list of critical needs and a scoring procedure that had been agreed upon at earlier RAC meetings. They were advised to work independently. Following a three-week interval, reviews were returned to WERI and re-evaluated by the Director. The Director made no changes to the individual ratings by the review panel members. The Director chose the two highest rated projects from each of the regions and two highly rated projects for CNMI to be submitted for funding.

Inventory and Evaluation of Karst Features Relating to Past and Present Groundwater Flow on Rota, Commonwealth of the Northern Mariana Islands (CNMI), in Terms of the Carbonate Island Karst Model

Basic Information

Title:	Inventory and Evaluation of Karst Features Relating to Past and Present Groundwater Flow on Rota, Commonwealth of the Northern Mariana Islands (CNMI), in Terms of the Carbonate Island Karst Model
Project Number:	2003GU18B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	NA
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Climatological Processes
Descriptors:	Groundwater, Island Karst, Carbonate Island Aquifers
Principal Investigators:	john jenson

Publication

PROJECT SYNOPSIS REPORT

Project Title: Inventory of Karst Features Relating to Past and Present Groundwater Flow in Rota CNMI, in terms of the Carbonate Island Karst Model.

Problem and Research Objectives

On uplifted limestone-covered islands, such as Rota, which rely on their limestone aquifers for most of their potable water, the karst features that develop in the limestone are important entry points, transport routes, and discharge points for groundwater. Understanding the relative sizes, distribution, and inter-relationships between the sinkholes, caves, and karst springs and seeps that control water entry and movement through the aquifer is therefore fundamental to formulating appropriate aquifer management practices to support sustainable economic development.

Rota is about 12 miles (20 km) long and 5 miles (8 km) wide at the widest point, and supports a population of about 2500. The entire island surface is covered by uplifted limestone, except for the 2.5-mile (4 km) scarp along the southernmost flank of the island, where the volcanic core is exposed. Currently, almost all of the island's potable water is produced from springs that emerge along the face of the scarp at the contact between the limestone and the underlying volcaniclastic basement. Protecting the watersheds that supply these springs must be given high priority to maintain water quality.

Future aquifer development will require a better understanding of the occurrence of water in the rest of the aquifer. Effective aquifer management and future development requires a more detailed understanding of the aquifer, specifically, the processes and pathways by which fresh water enters and is stored and transported through it. Experience on similar but more developed islands, such has Guam, has shown that his type of information will be needed in increasing detail by hydrogeologists, engineers, and planners to support reliable determinations of what types of extraction techniques are most appropriate, what levels of production are sustainable, and what sorts of land use and regulatory strategies are necessary or appropriate for protecting water quality.

The central objective of this study was to make a comprehensive survey of the island's major karst features, examine their relationships to the fundamental geologic units and hydrologic conditions (*e.g.*, past sea levels), and lay the groundwork for composing a systematic conceptual model of the island's aquifer units in terms of the Carbonate Island Karst Model. The project also provided the necessary reconnaissance of the island from which more detailed subsequent studies, such as the one recently concluded on Guam, may be successfully undertaken under separate funding.

Specific objectives of the project included the following: (1) Prepare maps of the key features of the karst drainage systems, to include fields of closed depressions, stream insurgences (groundwater entry points) and resurgences (groundwater exit points), and coastal springs and seeps. (2) Prepare preliminary maps of the limestone units in terms of their field characteristics and recognizable or inferred hydrogeologic attributes, showing relationships to cave systems and coastal discharge features, and boundaries of inferred groundwater drainage basins. (3) Identify and survey selected major caves, and prepare maps of representative caves.

Methodology

The study employed the classical methods of geological field investigation, including an exhaustive search and analysis of the previous work and existing literature, and exploration and mapping of selected features above ground and underground. WERI has robust GIS capabilities and access to digital elevation models, which were employed to produce state-of-the-art maps. Field investigations were coordinated with the USGS office in Saipan and the CNMI Department of Environmental Quality and Department of Historical Preservation. Both provided assistance in helping the field team to gain access where needed.

Most of the fieldwork took place during May-June 2003, when weather and sea-level conditions are most conducive to success. The principal investigator, Dr. Jenson, retained Dr. John Mylroie to join the field team for approximately 10 days of fieldwork on Rota. Mr. Robert Carruth, USGS hydrogeologist at the USGS Saipan Field Station, collaborated with the field team.

Dr. Jenson also employed and supervised a graduate research assistant to participate in fieldwork and conduct an exhaustive literature and data search. The search assembled not only the historical scientific and engineering publications related to the island, but also numerous drilling logs, aquifer test results, planning documents, environmental studies and meteorological data related to the island as well. Many such documents were found archived at the University of Guam's Micronesian Area Research Center. Much unpublished data were located in the field offices of the USGS and Commonwealth Utility Corporation on Saipan and Rota. All of this data was catalogued and put into a database to support the maps and diagrams that were produced from the field study. The reports and maps produced from the project were a result of synthesis of the analysis of existing work and the fieldwork undertaken during the summer of 2003.

Principal Findings and Significance

The immediate results of the study were a set of maps of the karst features of the island and a report describing their relationships to one another along with the implications for groundwater management. The first major benefit of these results was a more detailed and specific understanding of hydrologic processes that govern the catchment, storage, transport, and discharge of water from Rota's aquifer. Such understanding will directly support water resource development and management by providing basic information about the response of the aquifer to recharge and contamination and thus the vulnerability of the aquifer and its coastal discharge zones to contamination.

Second, the results of this work will support continuing development of the Carbonate Island Karst Model (CIKM), a general conceptual model of carbonate island karst that has recently been refined to include results from observations on Guam. The CIKM is currently being applied to Saipan and Tinian. Incorporating observations from Rota into the CIKM has helped to further refine the conceptual model itself. In particular, Rota is unique in that while it is relatively small and compact, it is also a composite island, *i.e.*, one on which the volcanic basement is exposed at the surface. The CIKM predicts that for small islands, their relatively large perimeter-to-surface catchment ratio likely precludes the development of significant conduit transport and discharge. On the other hand, it also predicts that composite islands should tend to exhibit stream caves along the basement contact, reflecting pathways established at former as well as present sea levels. Because Rota possesses a spectacular set of caves apparently fed by water that accumulates on the flank of the volcanic core and is thence concentrated in pathways that converge on flowing caves, observations on Rota have provided important new insights that will help to refine the CIKM.

The more complete and accurate conceptual model will provide hydrologists working on other uplifted carbonate islands with a means for more reliable estimates of sustainable yield and more accurate predictions of aquifer response to proposed land-use or regulatory strategies.

Development of Annual Rainfall Distribution Map for Island of Pohnpei State, Federated State of Micronesia

Basic Information

Title:	Development of Annual Rainfall Distribution Map for Island of Pohnpei State, Federated State of Micronesia
Project Number:	2003GU19B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	NA
Research Category:	Climate and Hydrologic Processes
Focus Category:	Non Point Pollution, Hydrology, Management and Planning
Descriptors:	RAINFALL, INTENSITY-DURATION-FREQUENCY (IDF), ISOHYETS, TROPICAL RAINFOREST, VALIDATION OF PRISM
Principal Investigators:	Mark Lander, Shahram Khosrowpanah

Publication

1. Mark A. Lander and S. Khosrowpanah, 2004, A rainfall climatology for Pohnpei Island, Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, 56 pp

PROJECT SYNOPSIS REPORT

Project Title: A rainfall climatology for Pohnpei Island

Problem and Research Objectives

Pohnpei Island is a "high" volcanic island, having a rugged, mountainous interior with some peaks as high as 2600 feet. It measures about thirteen miles across and is roughly circular in shape. It is the largest and tallest island in the FSM. The interior peaks get plenty of rainfall annually and this creates more than 40 rivers that feed the lush upper rain forest. A coral reef surrounds the island, forming a protected lagoon. There are few beaches on Pohnpei — the coast is surrounded by mangrove swamps. Several smaller islets and atolls, many of them inhabited, lie nearby and are included in the State of Pohnpei. The world-famous Nan Madol islet complex is located on the southeast coast of Madolenihmw municipality on Pohnpei Island (Fig. 1). The ruins at Nan Madol consist of 92 man-made islets covering an area of approximately 200 acres. The most spectacular of the islets have remains of sea walls, tombs and other structures built of large columnar basalt stones, brought to Nan Madol from other parts of Pohnpei.

The island of Pohnpei (6.9N 158.2E) lies about halfway between Hawaii and the Philippines in the recently formed country of the Federated States of Micronesia (FSM) (fig. 2). Pohnpei State is made up of one large volcanic island and six inhabited atolls, with most of its 133 square miles on Pohnpei Island. Its population is 34,486 (census 2000). Pohnpei State is the national capital of the FSM and site of the Community College of Micronesia. Pohnpei is a beautiful and fertile island with much local agriculture and a growing tourism industry. The main town on the island is Kolonia, on the north side.

The mountainous islands of the Pacific are seeing increased activity in development and agriculture. In addition, surface water is being increasingly tapped as a source of potable water and for hydroelectric generation. The soils of these islands are for the most part extremely thin and very easily eroded. Episodes of high rainfall events make the islands very susceptible to erosion and slope failures (such as the slope failure at Sokehs in 1997 that killed 30 people, and the slope failures at Chuuk during tropical cyclone Chata'an in 2002). The United States Department of Agriculture Natural Resources Conservation Service (USDA/NRCS) has implemented several programs to help manage and reduce erosion on the islands. These programs require accurate estimates of annual 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 most significant cause of high soil erosion rates (Foster et al., 1982). This factor is identified in the USLE and RUSLE as the R factor, or rainfall erosivity factor. It is important to have an accurate rainfall record with resolved 15-minute duration (or lower) for calculating the R factor.

Annual rainfall maps for most of the islands of Micronesia are incomplete, inaccurate, and/or non-existent for many areas. Estimated annual rainfall for Pohnpei prepared by the Spatial Climate Analysis Service, Oregon State University using the Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994) (Fig. 2) depicts rain in the central highlands that is estimated to be nearly twice that of the rain along the coast. This project will measure the influence of elevation on rainfall at Pohnpei Island.

Some problems that the local and Federal agencies face are:

(1) The USDA/NRCS requires the adaptation of RUSLE to selected Pacific Islands, which include: Guam, CNMI (Saipan, Tinian, Rota), Palau (Babeldaob), American Samoa (Tuitula), and Pohnpei. Success depends on the calculation of accurate R-factors, which depends directly on the accuracy of the values of annual rainfall for specific locations.
(2) USDA/NRCS needs an accurate annual rainfall maps for the indicated islands.
(3) Local water managers need accurate rainfall maps for purposes of development of infrastructure for storage and distribution of surface water.
(4) Disaster managers need accurate rainfall maps to better understand the processes that lead to slope failure, and local stream flooding.
(5) The optimal design of hydroelectric power plants requires an accurate knowledge of the annual and short-term distribution of rainfall.

This research project yielded a description of the weather and climate of Pohnpei to include: general rainfall statistics, a summary of the annual distribution of rainfall; an examination of the return periods of short-term high-intensity rainfall events; the effects of ENSO on the climate and weather of Pohnpei; a summary of tropical cyclones affecting the island; and, an examination of inter-annual and inter-decadal variations in mean annual rainfall.

Figure 1. The crowning achievement of Nan Madol is the royal mortuary islet of Nandauwas. Here, walls of 18 to 25 feet high surround a central tomb enclosure within the main courtyard. An impressive portal (shown here) marks the entry into the mortuary enclosure of Nandauwas. The second entryway in Nandauwas leads to the inner courtyard and central tomb, where the remains of the deceased *saudeleur* and, later, the *nahnmwarki* were interred.

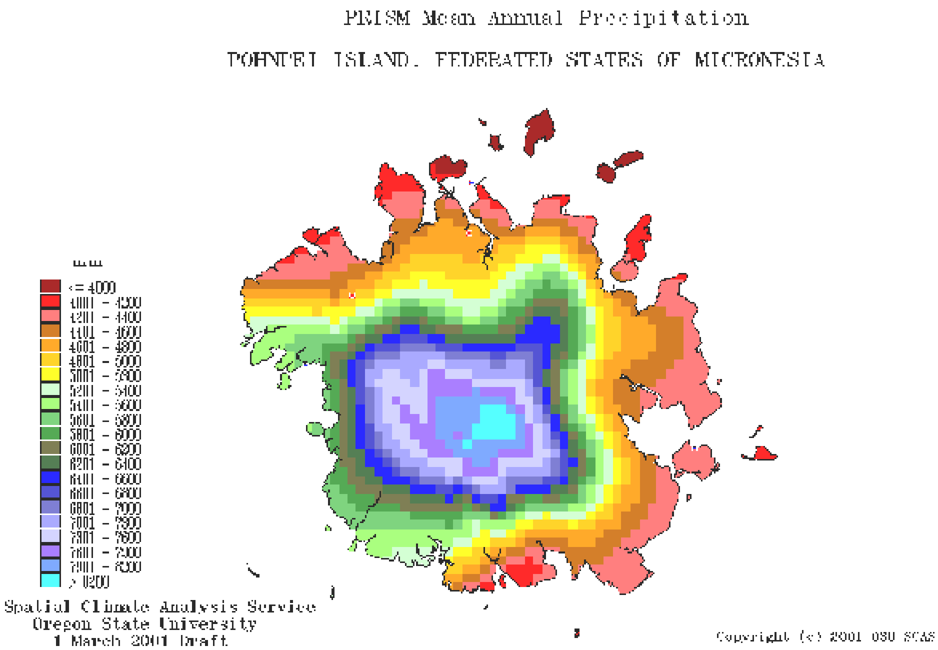


Figure 2. Estimated annual rainfall for Pohnpei prepared by the Spatial Climate Analysis Service, Oregon State University using the Precipitation-elevation Regression Independent Slopes Model (PRISM) analysis (Daly, et al. 1994). Note that the rain in the central highlands is estimated to be nearly twice that of the rain along the coast.

Methodology

There are very few locations on Pohnpei where rainfall has been measured in a consistent manner for any appreciable length of time. A continuous 30-year daily rainfall record is often considered sufficient to compute baseline monthly and annual averages, and to make accurate estimations of the recurrence intervals of heavy rainfall events. Monthly data for the WSO exists for the period 1954 to present. Hourly rainfall data from Fischer-Porter type recording rain gauges is available for Pohnpei at two locations: the WSO and the Hospital (near the current WSO). These gauges record rainfall at .10 inch increments. They are somewhat difficult to maintain, so the records from these gauges are often piecemeal. They are, however, the only sources of data for estimates of return-periods of short-term (e.g., hourly and 3-hourly) rainfall events. Monthly rainfall is available from several locations during the Japanese period of record (1926-1937).

All of the historical rainfall readings acquired on Pohnpei are from stations located along the coastal perimeter of the island. No sites have ever been located in the rain forests of the mountainous interior of the island. There are meteorological reasons why the interior highlands should receive more rain than the coastal perimeter of the island including the ascent of moist air over the mountains (the typical mechanism for the distribution of heavy rainfall in the higher elevations of the Hawaiian Islands), and inland convection driven by daytime heating of the island. Also, there is evidence that the western side of the island is wetter than the eastern side of the island. Personal observation confirms that, as on Guam and other tropical islands, daytime convection forms and/or advects downwind of the island in the form of an island could plume. On Guam this manifests in a concentration of thunderstorm activity offshore to the west of the island in east wind conditions, and to the northeast of the island when the southwest monsoonal winds are blowing. Lightning observed after sunset on Pohnpei during travels there by the project investigators has a strong preference for the western side or offshore of the western side of the island in conditions of easterly wind flow. Winds on Pohnpei can become westerly, especially during El Niño, but the project investigators have not been on Pohnpei during such times.

The methodology used in 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. 2). 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 order to investigate the rainfall differences between the highlands and the coastal regions of Pohnpei (that are currently depicted to differ by a factor of two for annual rainfall), a transect of manual and electronic rain gages was set up extending from the coast to the highlands of the island. Figure 4 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. 5a). 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 rainfall 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. 5b). 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.

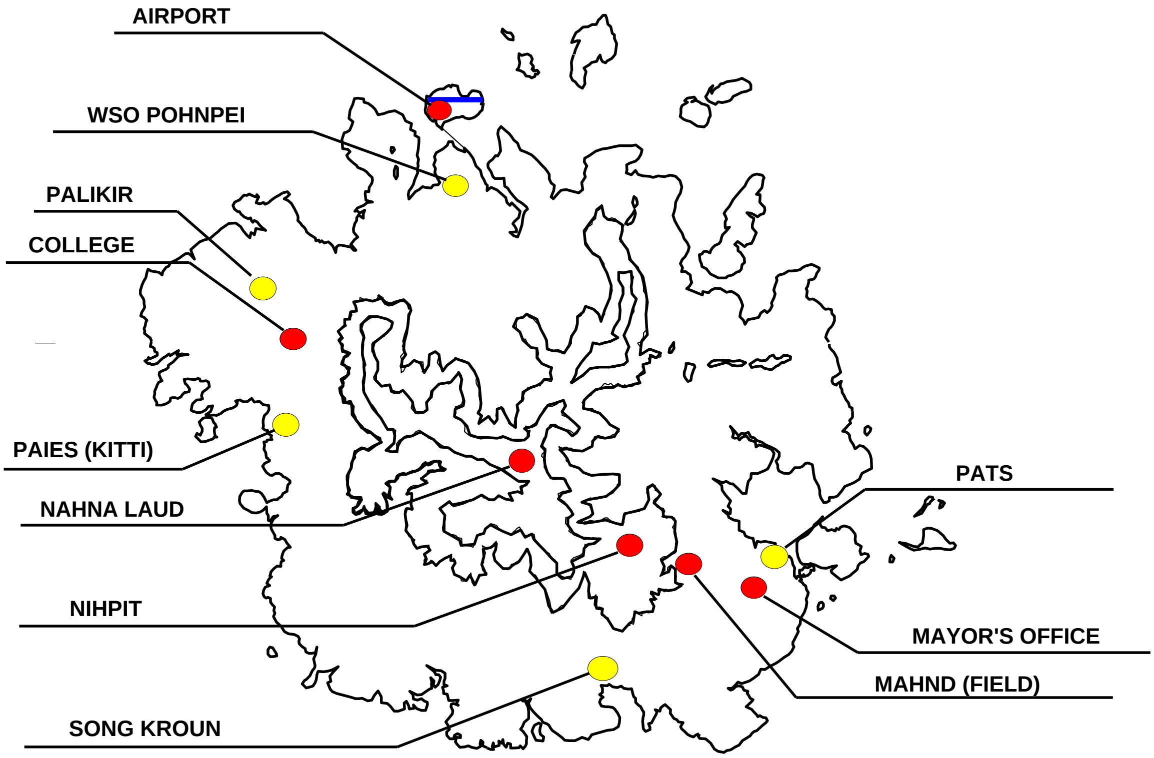


Figure 4. Stations on the island of Pohnpei where there are records of rainfall. Red dots are WERI Network installed in June 2003. Yellow dots are National Weather Service rain gauges. Half-tone shading indicates elevation: light gray $\geq$ 250 m; dark gray $\geq$ 500 m.

Figure 5. (a) A view of the specially designed 56-inch PVC pipe rain gage assembled in the field at the Mahnd site on Pohpei 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. A project currently funded by the USGS is attempting to quantify the importance of fog drip to ecosystem hydrology and water resources in tropical mountain cloud forests on East Maui, Hawaii, where there is evidence that fog drip is substantial (Juvik, J.O. and P.C. Ekern, 1978). The investigators on the Maui project are measuring the amounts of water input from fog by analyzing for stable isotope composition. Previous work (Ingraham and Matthews, 1995) has shown that rain and fog have unique isotopic signatures, so that stable isotopes of water can be used to track the fog water through the hydrologic cycle.

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. An estimate of the contribution of fog-drip to the water budget of the highlands will be obtained from a careful analysis of the data from the dual open-area/canopy site. Satellite imagery will be monitored, and observations from the WSO archived, to help determine the precipitation event type, and the presence or absence of cloud cover over the highlands (probably only during daylight hours).

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

This research project yielded a description of the weather and climate of Pohnpei to include: general rainfall statistics, a summary of the annual distribution of rainfall, an examination of the return periods of short-term high-intensity rainfall events; the effects of ENSO on the climate and weather of Pohnpei; a summary of tropical cyclones affecting the island; and, an examination of inter-annual and inter-decadal variations in mean annual rainfall.

Unlike the islands of Guam, Saipan, Kwajalein and other islands further to the north, the island of Pohnpei does not experience a pronounced wet season and a dry season. The driest months are January and February and the wettest months are April and May. Pohnpei's mean monthly rainfall is nearly uniform at 16-17 inches per month from May through December, then drops to its lowest value of just over 10 inches in February and rises to its peak value of nearly 20 inches in May. For most of the year the, the *mean* wind is from an easterly direction. Pohnpei is in the doldrums; that is, along the axis of the intertropical convergence zone (ITCZ). Winds are generally light, but can become fairly brisk trade winds in the winter and spring. During the spring through fall months, Pohnpei can experience episodes of brisk monsoonal winds from a westerly direction (the more-so in El Niño years).

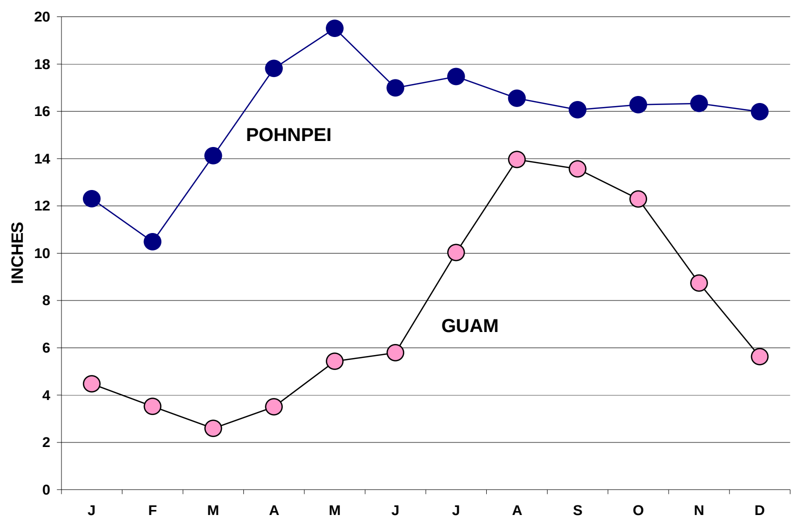


Figure 6. Monthly mean rainfall at WSO Pohnpei and at Guam's Andersen Air Force Base (in inches). Note that Pohnpei receives much more rainfall than at Guam in every month of the year, and has only two months (January and February) of relatively drier conditions, compared to the sharpy drier and prolonged "Dry Season" on Guam

On the large scale, there is an east-west zone of maximum annual rainfall from 4-8°N across Micronesia. The amounts drop off steadily as one progresses northward (where the dry season becomes more prolonged). The islands of Kosrae and Pohnpei experience at least 160 inches of rain annually, with no appreciable wet or dry seasons. A bit further north at Chuuk and at Palau, the over-water annual rainfall is approximately 140 inches; falling to 120 inches at Yap, 100 inches at Guam, and to 80 inches at Saipan. North and east from Saipan, the region is dominated by the mid-Pacific subtropical high pressure area and its accompanying trade winds, and the annual rain decreases to values around 40 inches (Fig. 7).

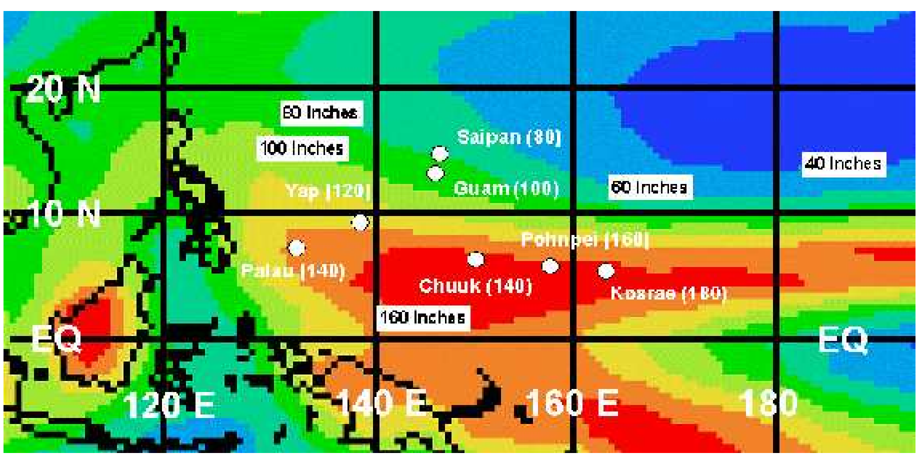


Figure 7. Mean annual over-water rainfall in Micronesia. Colors indicate rainfall pattern (amounts as labeled: red = 160 inches per year, orange = 140, yellow = 120, light green = 100, dark green = 80, teal = 60, light blue = 40, and within the blue there is a bit less than 40 inches of annual rainfall). Mean annual over-water rainfall at selected islands is indicated. Image adapted from figure on website URL http://orbit35i.nesdis.noaa.gov/arad/gpcp/

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. This is true at the Pohnpei rain gage at the Hospital site for only the winter months and year-round at other small islands and atolls of Micronesia such as Majuro and Chuuk. During the summer at the Pohnpei Hospital most of the rain tends to fall in the early afternoon. 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, during the summer months when the winds are light, there is a strong tendency for heavy showers to develop over the mountains by noon (Fig. 8). These 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).***

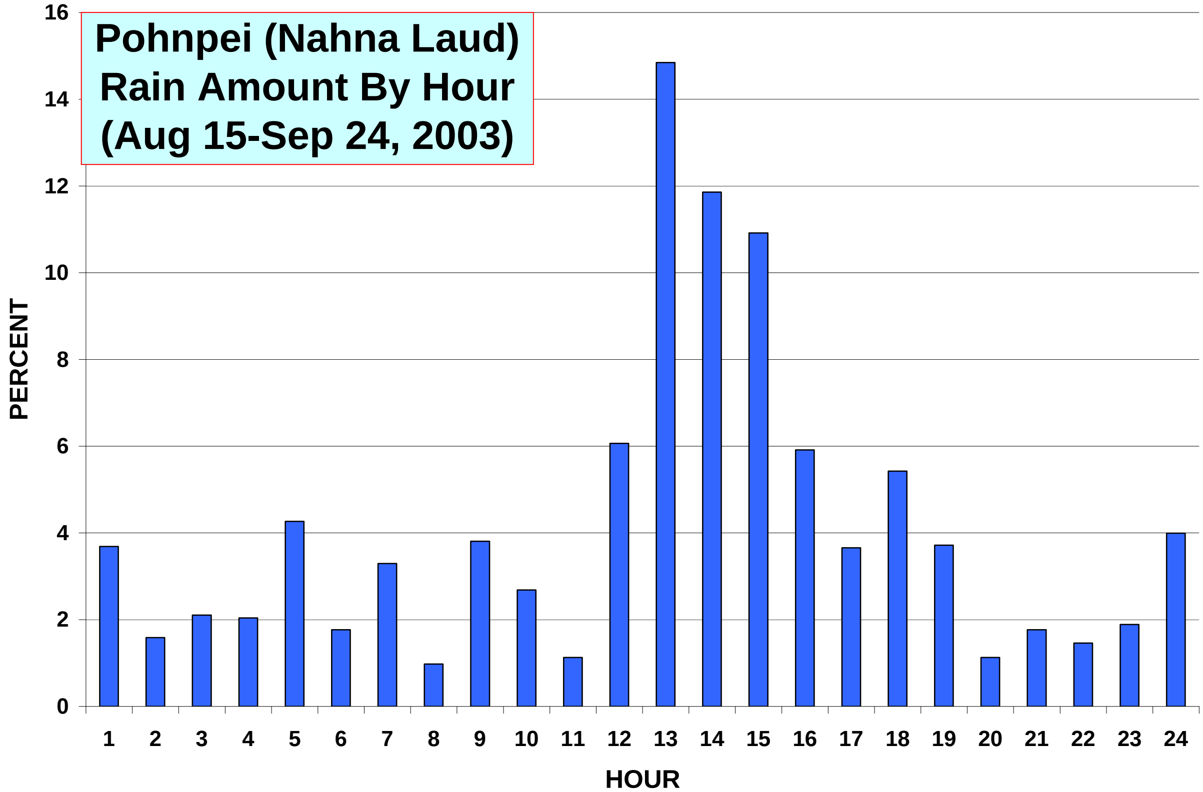


Figure 8. Preliminary data from the Nahna Laud site shows a sharp concentration of rain fall in the three hours from local noon to 3 PM in the afternoon. Convection induced by daily heating in light wind conditions allows for the build-up of thunderstorms nearly every day in Pohnpei's interior.

Historical records suggest that the annual mean rainfall on Pohnpei differs substantially across the island, and is heaviest in the interior of the island. While no rainfall measurements have ever been obtained in the interior highlands of the island (until the WERI transect was set-up in June 2003), the distribution of rainfall at existing locations on the perimeter of the island suggested that existence of sharp rainfall gradients as one ascended into the interior. The PRISM analysis using the historical rain fall records from Pohnpei yielded estimates of rainfall in the interior that were over twice the value of the rainfall along the north coast. The first 9-months of rain readings from the WERI-CSP network have revealed that this estimate is quite realistic.

The distribution of rainfall on the island of Pohnpei is affected by the topography, and the mean annual rainfall totals among recording stations on Pohnpei may differ by more than 100 inches! The region in the vicinity of Pohnpei's international airport receives the lowest annual total of about 120 inches. The highest annual average of approximately 300 inches (2300 mm) probably occurs in the central highlands. The western side of the island is wetter than its eastern side.

In order to arrive at an annual rainfall distribution chart for Pohnpei, the rainfall at recording stations was first compared to simultaneous readings at Nahna Laud – the wettest among all of Pohnpei's rain recording sites. Normalizing the stations to Nahna Laud (where Nahna Laud = 1.00) resulted in the distribution of Fig. 9.

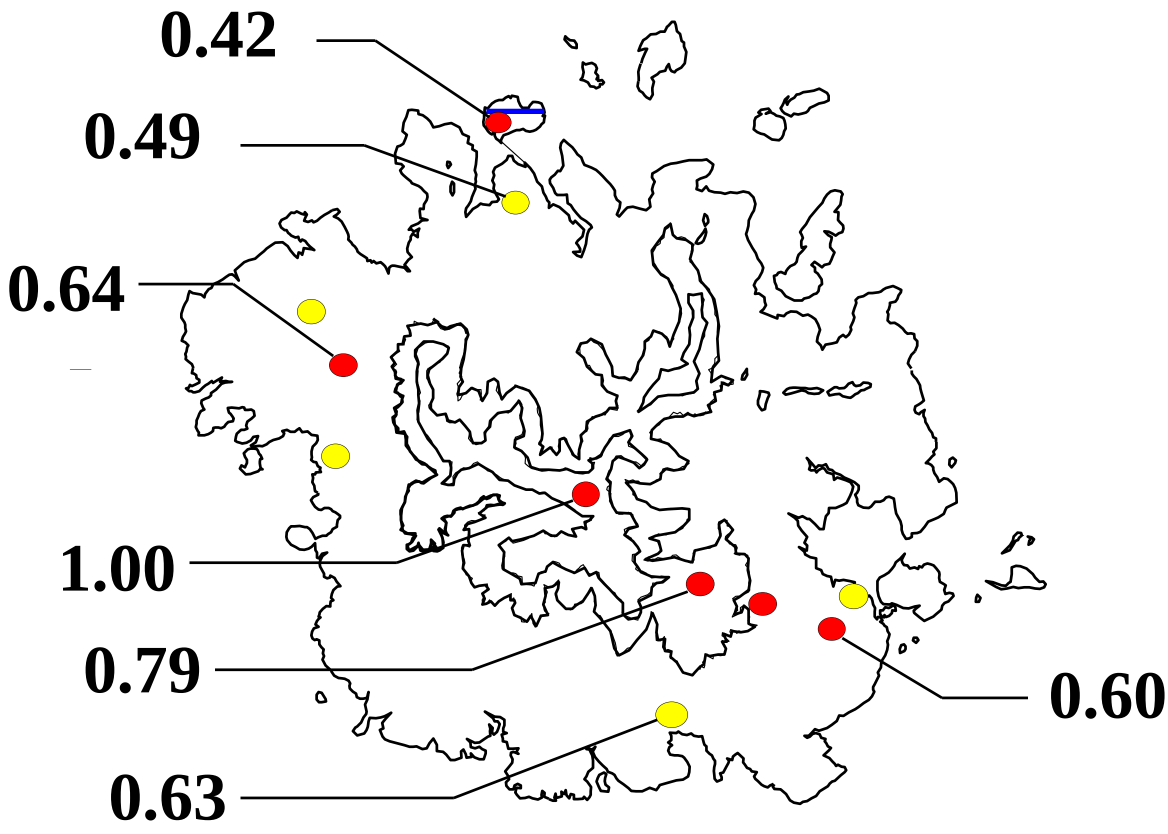


Figure 9. Rainfall at several sites on Pohnpei normalized to the rainfall at Nahna Laud, where the annual rainfall at Nahna Laud = 1.00.

The next step was to convert the percentages in Fig. 9 to rainfall in inches per year. This process resulted in the annual rainfall map shown in Fig. 10.

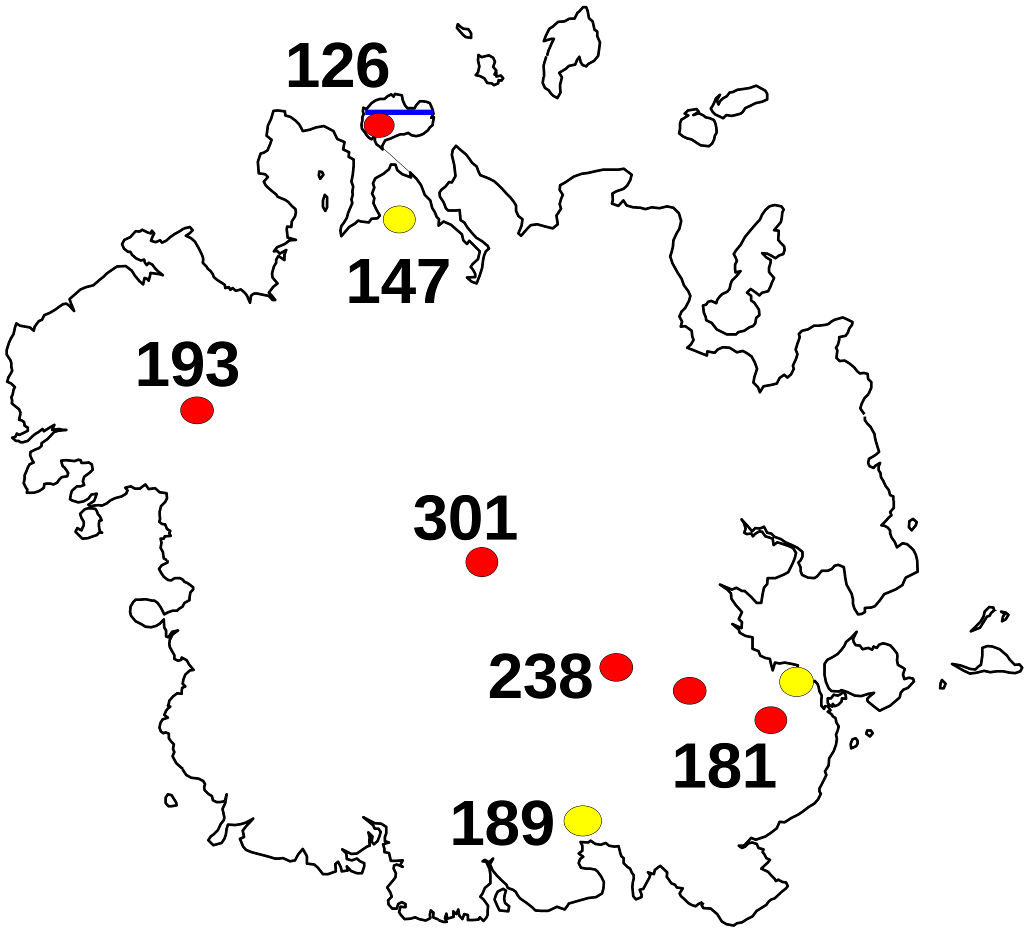


Figure 10. Mean annual rainfall at selected sites on the island of Pohnpei.

The extrapolated mean-annual rainfall from the 9-month inter-comparison of the WERI/CSP network (Fig. 10) compares favorably with the PRISM estimates of mean annual rainfall (Figs. 11 and 12).

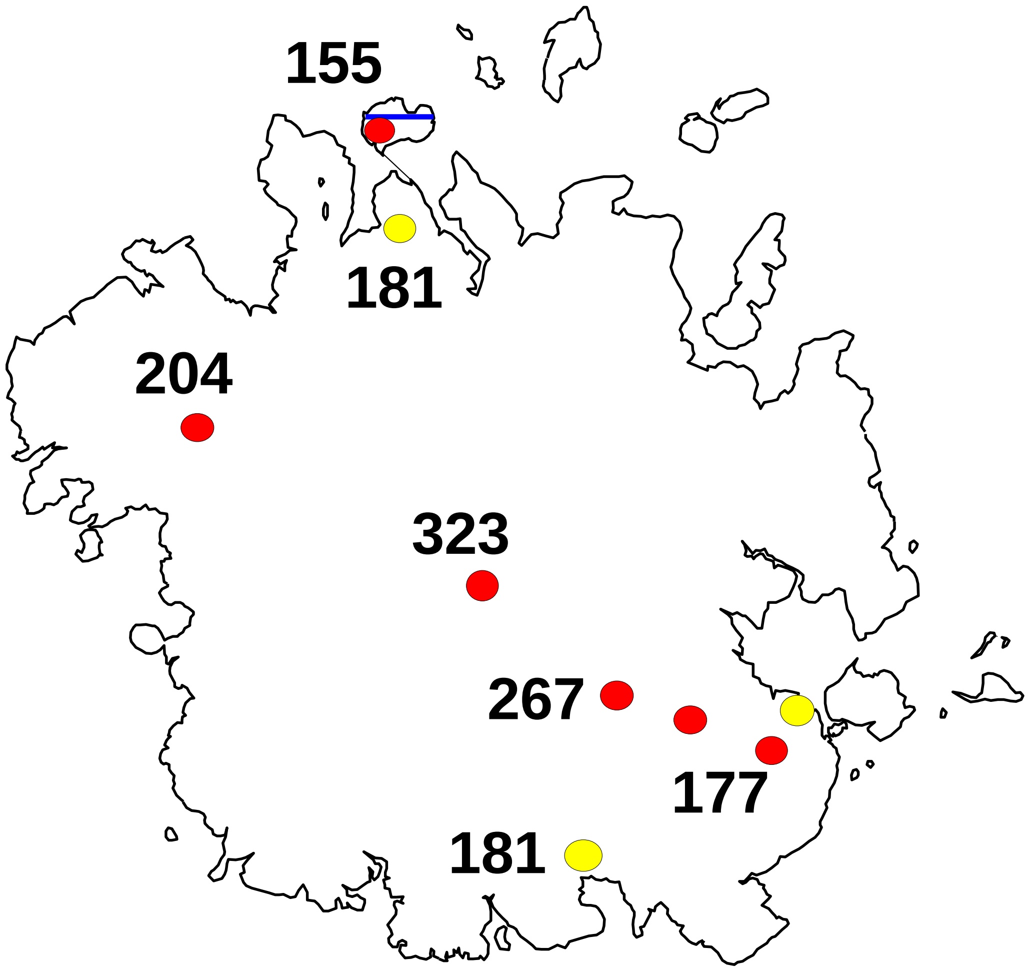


Figure 11. Contours of mean annual rainfall based on the PRISM analysis at selected sites on the island of Pohnpei.

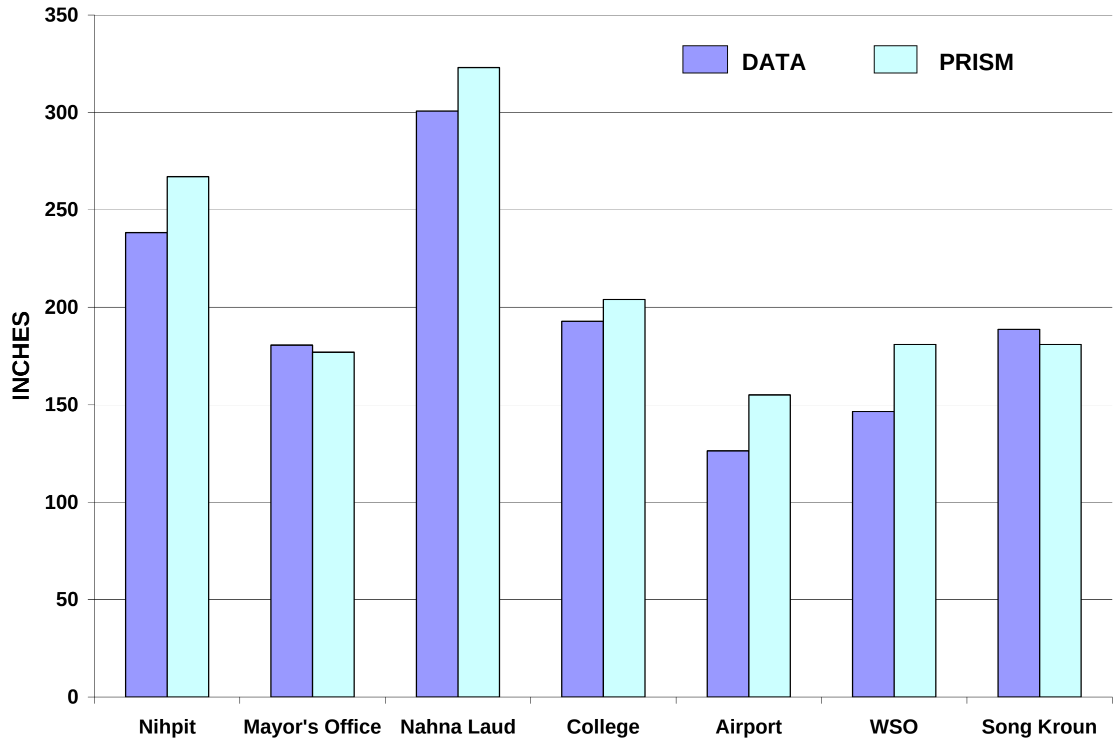


Figure 12. Comparison of measured mean annual rainfall those obtained from the PRISM analysis at selected sites on the island of Pohnpei.

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 rain gauge in the open area determines the times when it is actually raining. The rain gauge under the forest canopy continues to receive water from residual drip, and/or cloud-droplet deposition onto leaves. One of the problems with the site is the dwarf nature of the rain forest at high elevation. There are lots of shrubs and low trees across much of the summit area. Nevertheless, a rain gage was placed under the forest canopy at a site approximately 300 ft away from the gauge in the clearing in a small crater at the top of Nahna Laud. Analysis of the data is inconclusive. There are times, such as in Fig. 14, when it is clear that the rain gauge under the forest canopy continues to receive water for hours after the rain ceases in the clearing. Assuming the first hour or so to be residual drip, one can see from Fig. 13 that approximately .01 inches of rain accumulates every two hours. There is no way to know what portion of this is from the deposition of cloud liquid water onto the leaves. If this rate were continuous, there would be an accumulation of .12 inches of rain per day from this source which amounts to 14% of the net accumulation at the clearing.

A 14% increase over the open-area rainfall may therefore be considered an upper limit for fog drip accumulation, but this result in not trusted. In order to get a better picture of the contribution of fog drip at this site, the WERI/CSP team has proposed to set up a special fog-drip collector designed by Juvik.

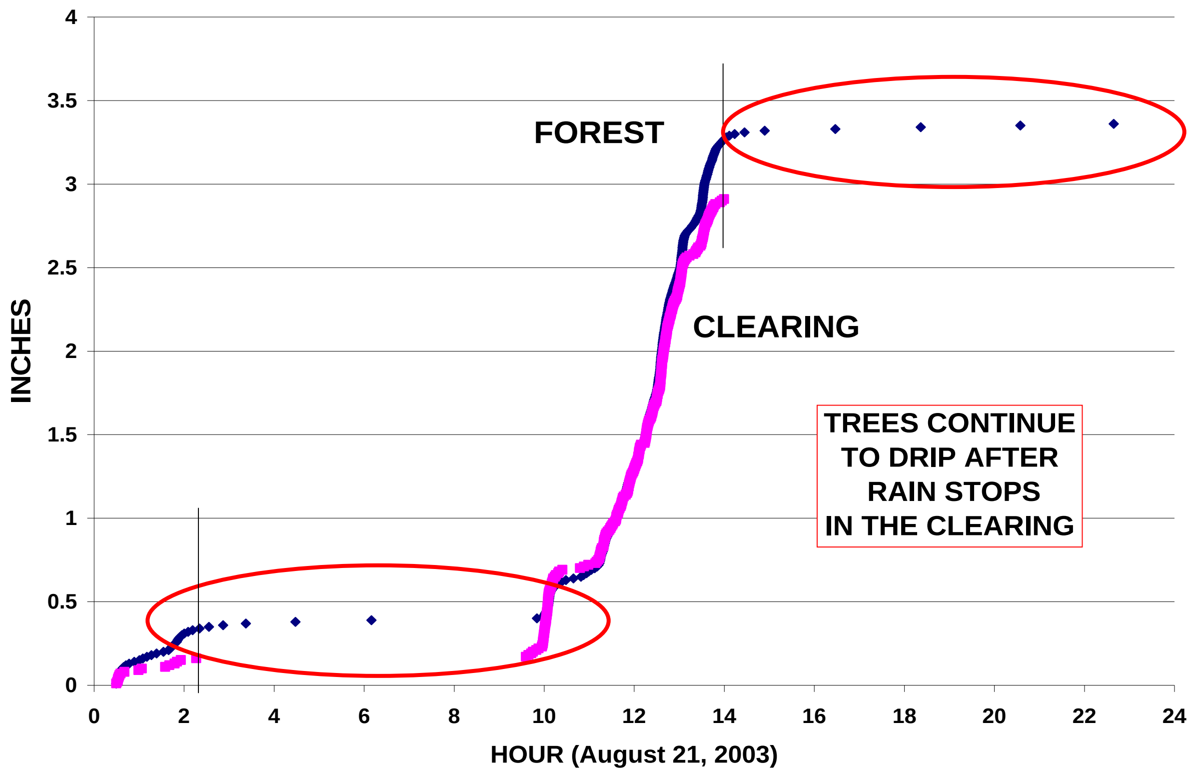
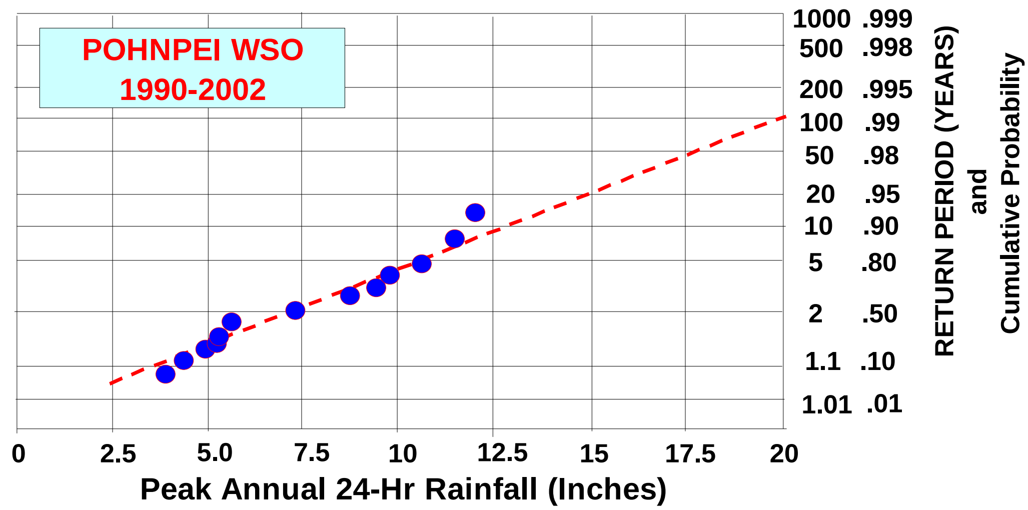


Figure 13. Rainfall on August 21, 2003 at two sites on Nahna Laud: one in a clearing, and the other under the canopy of the rainforest at a site located about 300 feet from the clearing. Each dot indicates an increment of .01 inch of rain. Note the continuation of rain accumulation at the canopy site after the rain stops in the clearing.

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. A similar return-period analysis of the extreme 24-hour rain rates using Pohnpei's shorter and more incomplete record (Fig. 14a,b), and extreme 1-hour rain rates (Fig 15 a,b). A chart of rainfall intensity-duration-frequency was constructed (Fig. 16).



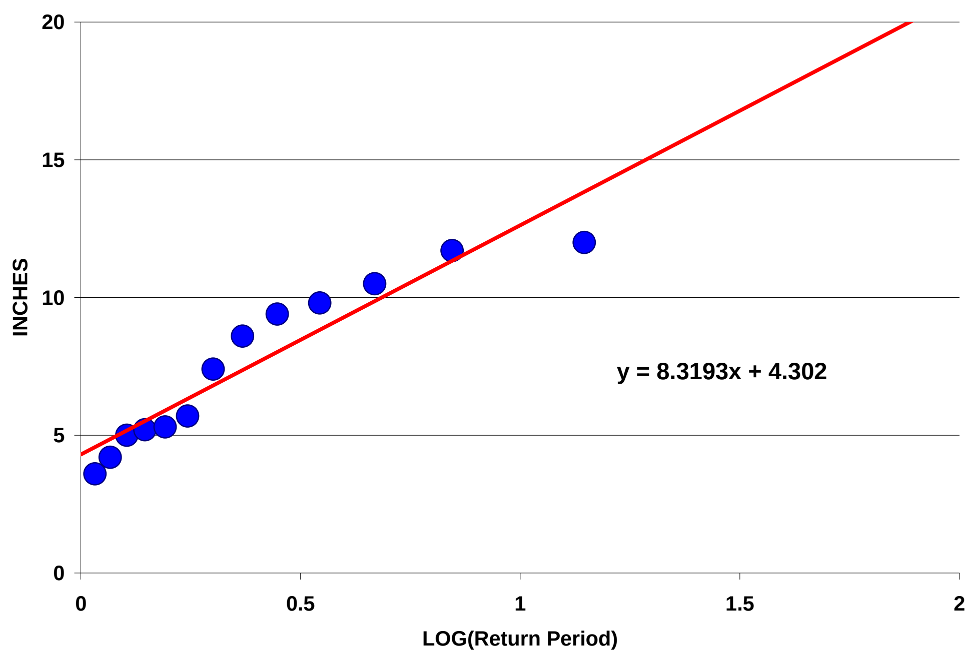
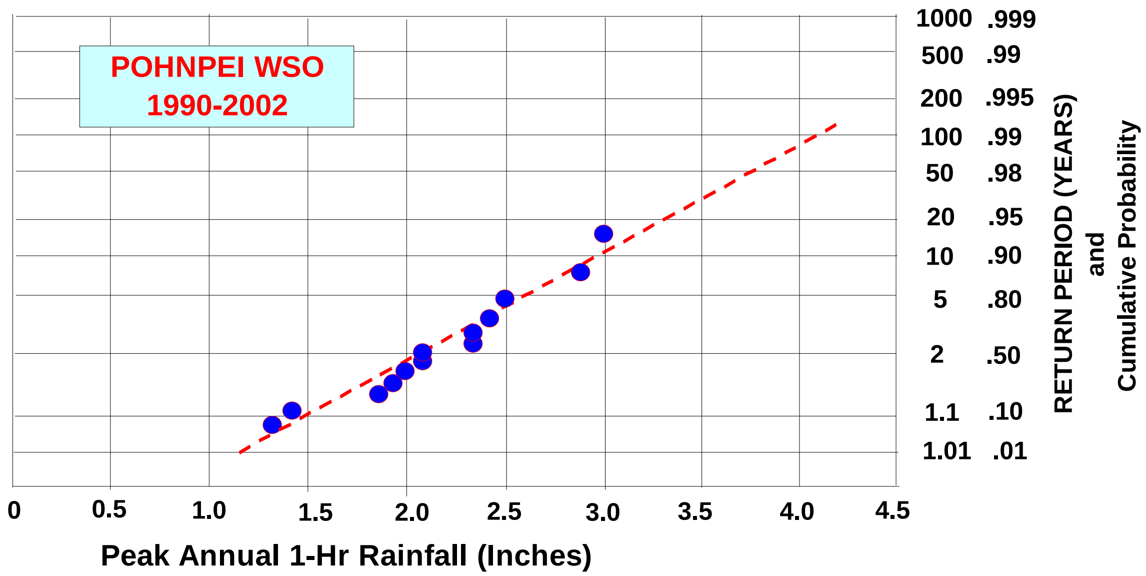


Figure 14. (a) Method-of-moments (ranking method) computations of 24-hour return period extreme rainfall events using Pohnpei WSO data. **(b)** Peak annual 24-hour rainfall at Pohnpei WSO versus the log of the estimated return period from the ranking method.



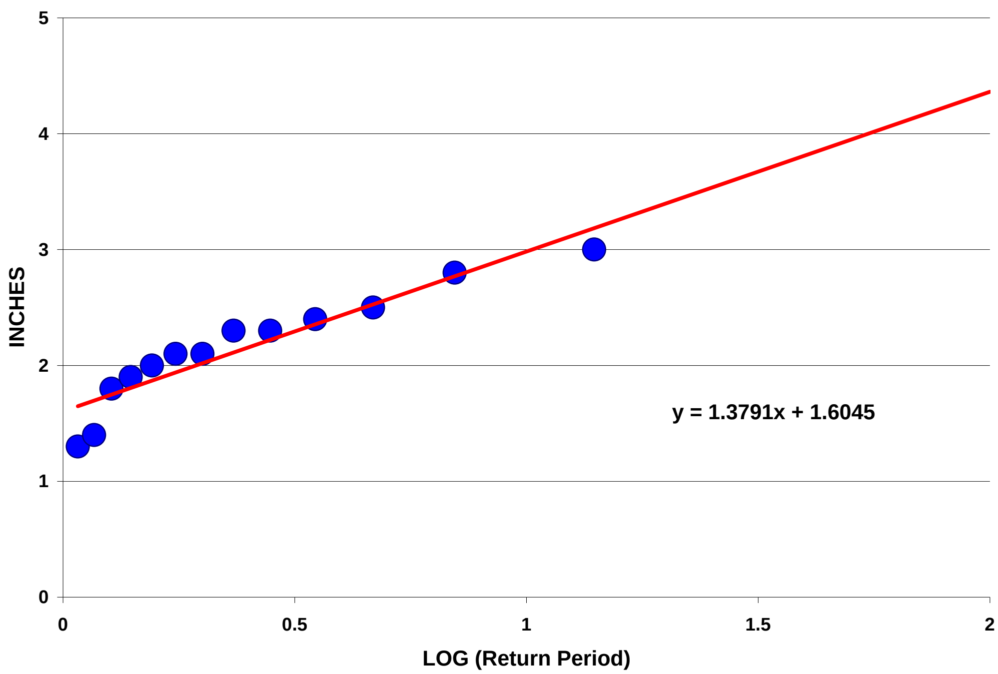


Figure 15. (a) Method-of-moments (ranking method) computations of 1-hour return period extreme rainfall events using Pohnpei WSO data. **(b)** Peak annual 1-hour rainfall at Pohnpei WSO versus the log of the estimated return period from the ranking method.

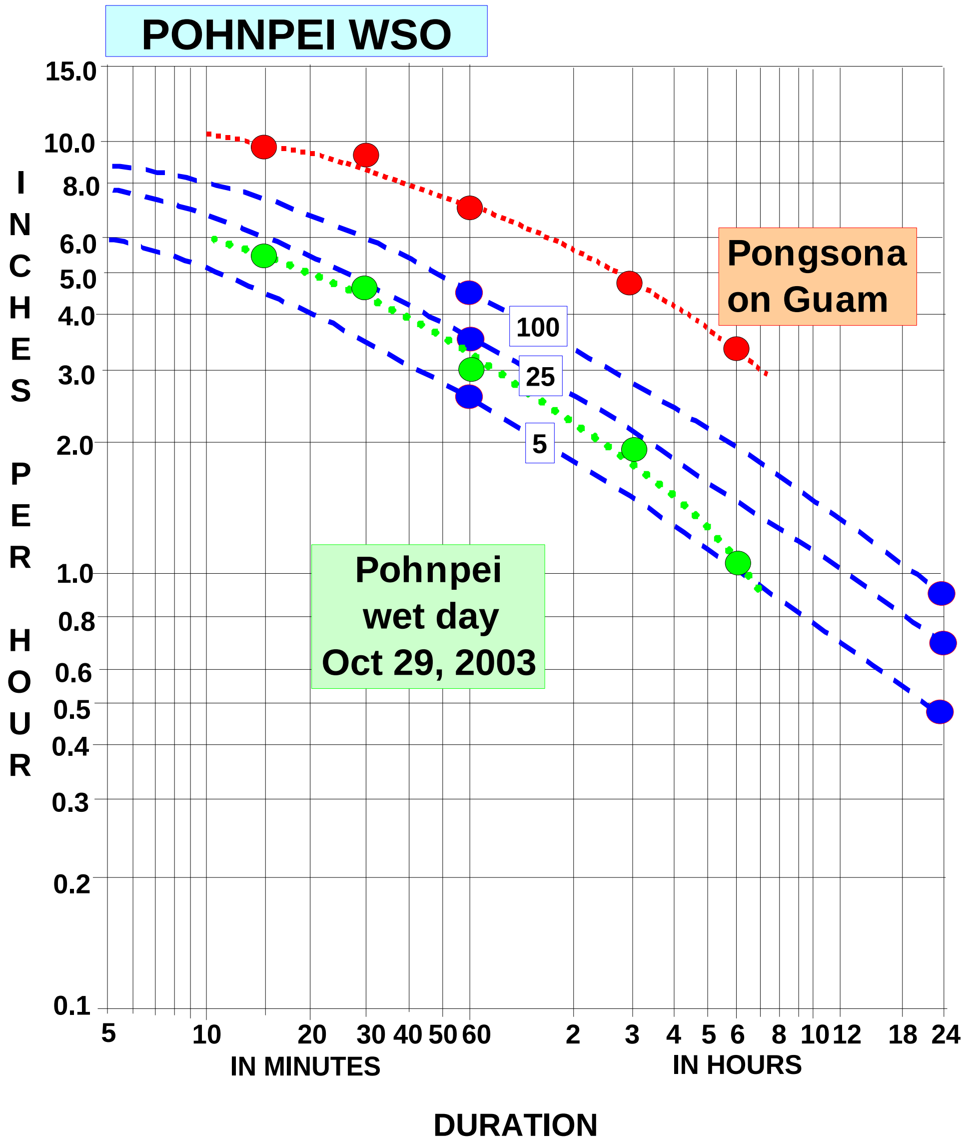


Figure 16. Intensity-Duration-Frequency (IDF) chart of selected return periods at the Pohnpei WSO (blue dots connected by blue dashed lines). For comparison, the IDF values measured during Typhoon Pongsona on Guam (red dots connected by red dotted line) are shown. Also, the highest IDF values measured 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 a fairly typical afternoon thunderstorms.

Nearly all extremely dry years on Pohnpei occur during the year following an El Niño event (Fig. 17). The driest year on record in Pohnpei and throughout most of Micronesia occurred in 1998 (the follow-on year to the major El Niño of 1997). Some El Niño years are very wet depending upon the behavior of typhoons and the monsoon trough. Most La Niña years and non-ENSO years are near normal to slightly above normal (unless they are the year following an El Niño; then, they are dry).

On Pohnpei, persistent dryness tends to become established in the fall of the El Niño year (unless a late-season tropical cyclone makes affects the island. Deleterious effects of drought (e.g., desiccation of grasslands and forests, draw-down of streamflow and well-heads, and wildfires) are exacerbated by extreme dryness and extension of drier than normal conditions for several months.

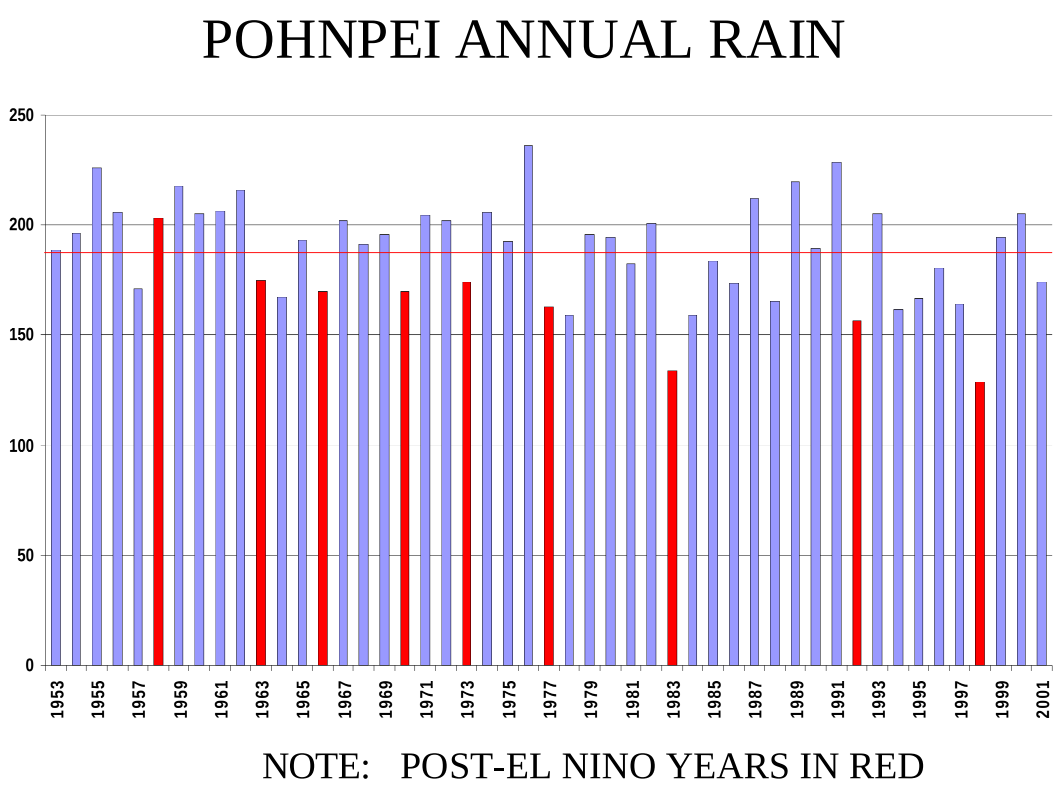


Fig. 17. Time series of annual rainfall at the Pohnpei Weather Service Observatory (WSO). Most post-El Niño years (red bars) are dry.

During an El Niño year, the mean sea level drops across most of Micronesia. Typically, the sea level in the region of Pohnpei falls to its lowest value in December of the El Niño year, then quickly recovers by the spring of the year following El Niño (Fig. 18). During La Niña, the sea level is elevated above its normal value. During the major El Niño of 1997, the sea level fell approximately 1 foot below its long-term average, and during the La Niña years that followed (1998-2001), the sea level rose to levels nearly 1 foot above its long-term average. The net difference of the sea level between the El Niño minimum in December 1997 and the La Niña high stands of the sea level during the summers of 1999, 2000, and 2001 was approximately 2 feet. This is substantial, considering that the normal range between the daily high and low astronomical tide is on the order of 4 feet! On the question of long-term sea-level rise due to global warming, it must be pointed out that the long-term rise of sea level due to large-scale global climate change is estimated to be on the order of 4 or 5 inches per century. The ENSO changes in sea level of 2 feet over the course of a year or two are enormous compared to this, and make it difficult to retrieve the long-term signal.

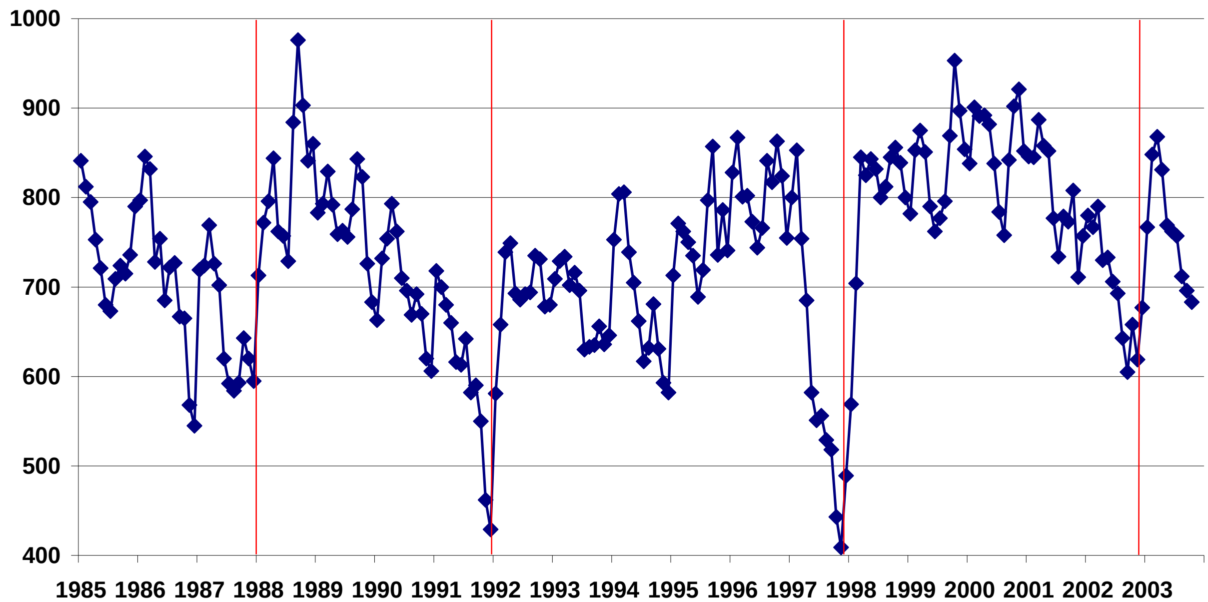


Figure 18. The record of monthly mean sea level at Pohnpei for the period 1985-2004. These changes in sea level are highly coherent across the region from Yap to Guam, Chuuk, Pohnpei, and Kosrae. Note the low sea level at the end of El Niño years (1987, 1991, 1997, and 2002) and the high sea level in the summers of La Niña years (1988, 1994, 1996, and 1998-2001).

The ENSO cycle has a profound effect on the distribution of tropical cyclones in the western North Pacific basin. The total number of tropical cyclones in the basin is not so much affected as is the formation region of the tropical cyclones. During El Niño, the formation region of tropical cyclones extends eastward into the eastern Caroline Islands and the Marshall Islands (see Fig. 19). During the year following an El Niño year, the formation region of tropical cyclones retracts to the west. This results in an increased risk of a typhoon for Pohnpei during El Niño years, and a decreased risk during the year following El Niño and during La Niña years. On Pohnpei, the risk of having typhoon force winds of 65 kt or greater is 1 year in 10 for El Niño years, and approximately 1 year in 50 for non-El Niño years. Pohnpei has not had a strike by a typhoon (65 kt wind on island) since Typhoon Lola in 1986 (an El Niño year, by the way).

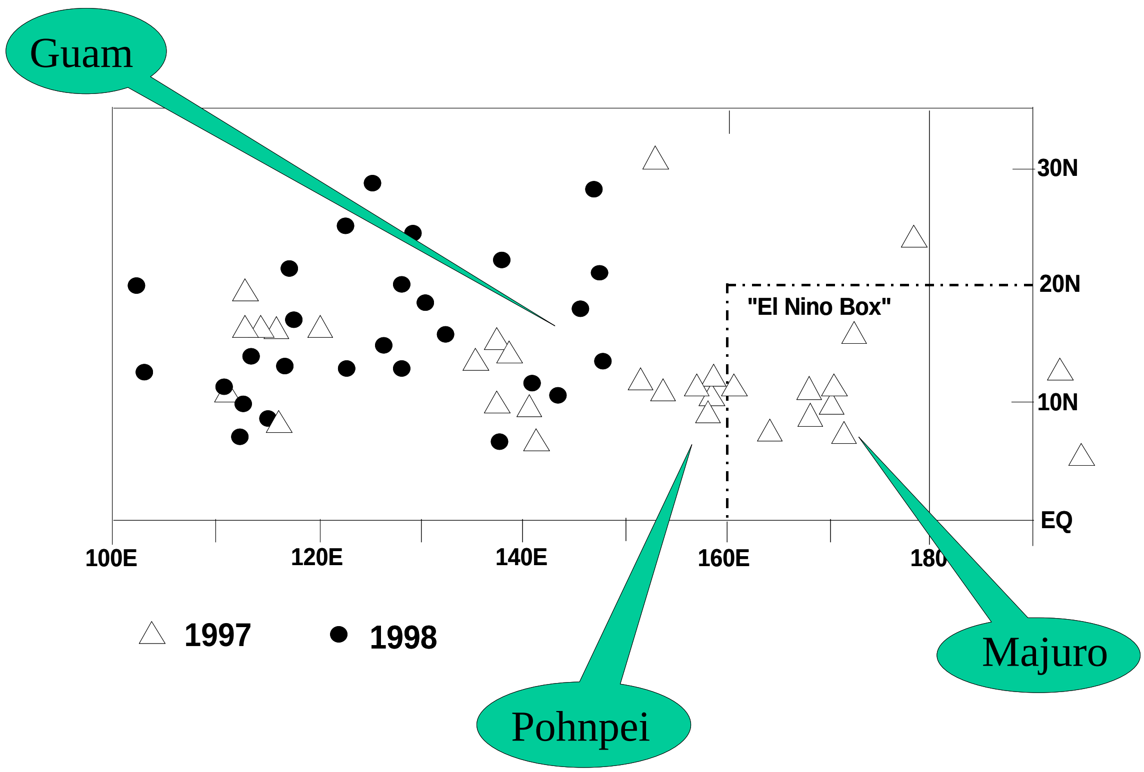


Figure 19. The formation locations for all western Pacific basin tropical cyclones during the El Niño year of 1997 (black dots) and the El Niño follow-on year of 1998 (gray triangles). Note the enormous difference in the formation region (especially in the area designated as the, “El Niño box”). Formation is defined as that point along the JTWC best-track that the tropical cyclone attained an intensity of 25 kt.

Typhoons rarely hit Pohnpei; more often they are spawned in central and eastern Micronesia and sent north-westward towards Guam. Every several years or so on average, a mildly damaging tropical storm or depression will affect Pohnpei island. The western North Pacific is the most active tropical cyclone basin in the world. On average, 28 tropical storms and typhoons occur annually (this compares to about 10 for the North Atlantic Basin). Of the annual average of 28 tropical cyclones of tropical storm intensity or higher, 18 become typhoons, and 4 become super typhoons. Another distinguishing feature of the western North Pacific basin is that tropical cyclones, although most common in late summer and autumn, can occur at any time of the year, whereas over other basins, off-season occurrences are rare. The main TC season for the western North Pacific extends from mid-May through mid-December. For the basin as a whole, tropical cyclones are least likely during the month of February. The highest frequency of occurrence of typhoons in the western North Pacific is in an area just to the northeast of Luzon in the Philippine Sea (Fig. 20) where there are, on average, five passages of a tropical storm or typhoon per 5-degree latitude-longitude square per year. In the region of Pohnpei, the frequency of tropical cyclones of tropical storm intensity or higher is less than one per 5-degree latitude-longitude square per year. The frequency of tropical cyclones passing Pohnpei is less than one every three years within 75 n mi. (Fig. 21), with a sharp gradient that features almost no tropical storms south of 5° N to over 1 tropical storm or typhoon passing within 75 n mi of locations several hundred miles to the north and west of Pohnpei. The distribution of tropical cyclone tracks passing Pohnpei appears to be random (Fig. 22) with a very sharp north-south gradient.

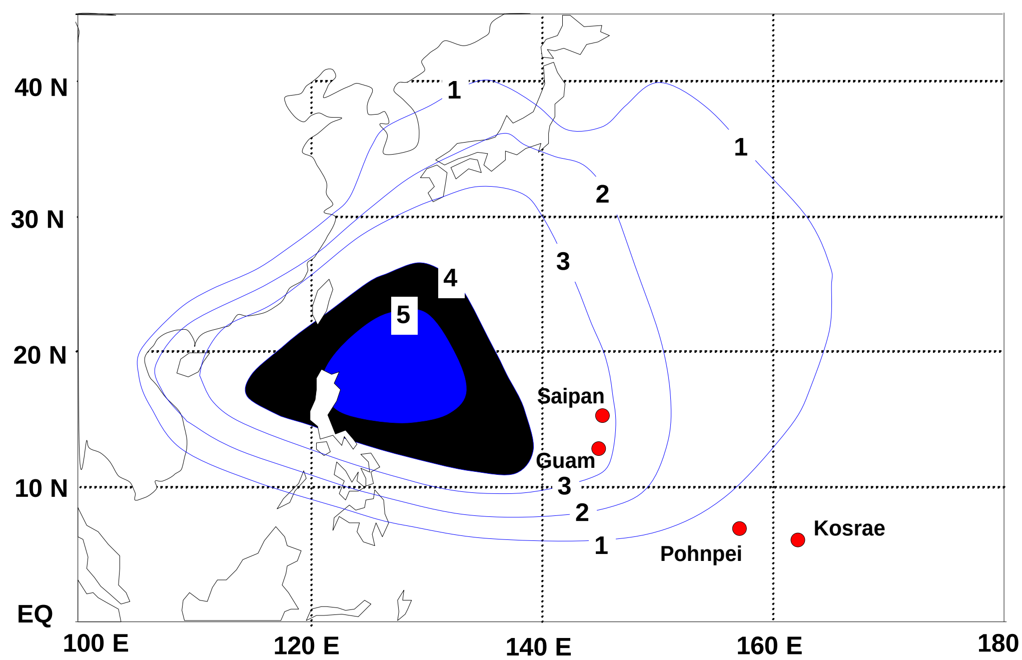


Figure 20. Mean annual number of tropical storms and typhoons traversing 5-degreee latitude by 5-degree longitude squares (adapted from Crutcher and Quayle 1974).

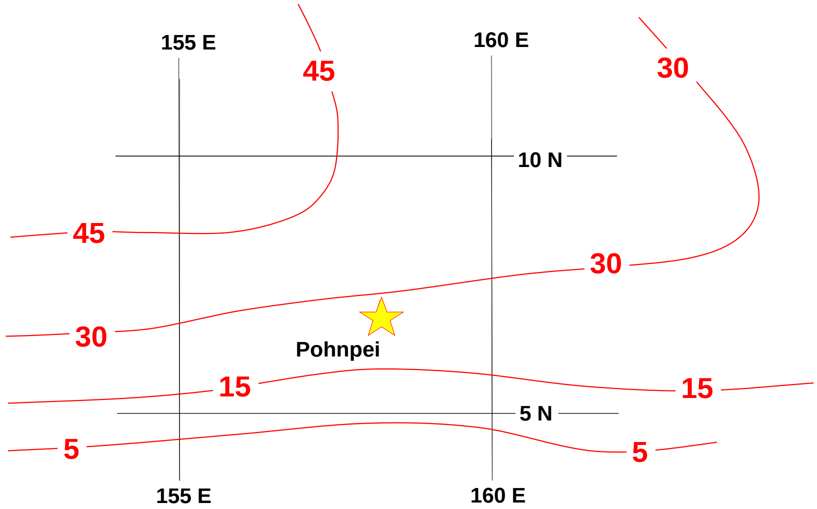


Figure 21. Number of tropical storms and typhoons per 100 years passing within 75 n mi of any map location. (Created from JTWC best-track data 1970-99.)

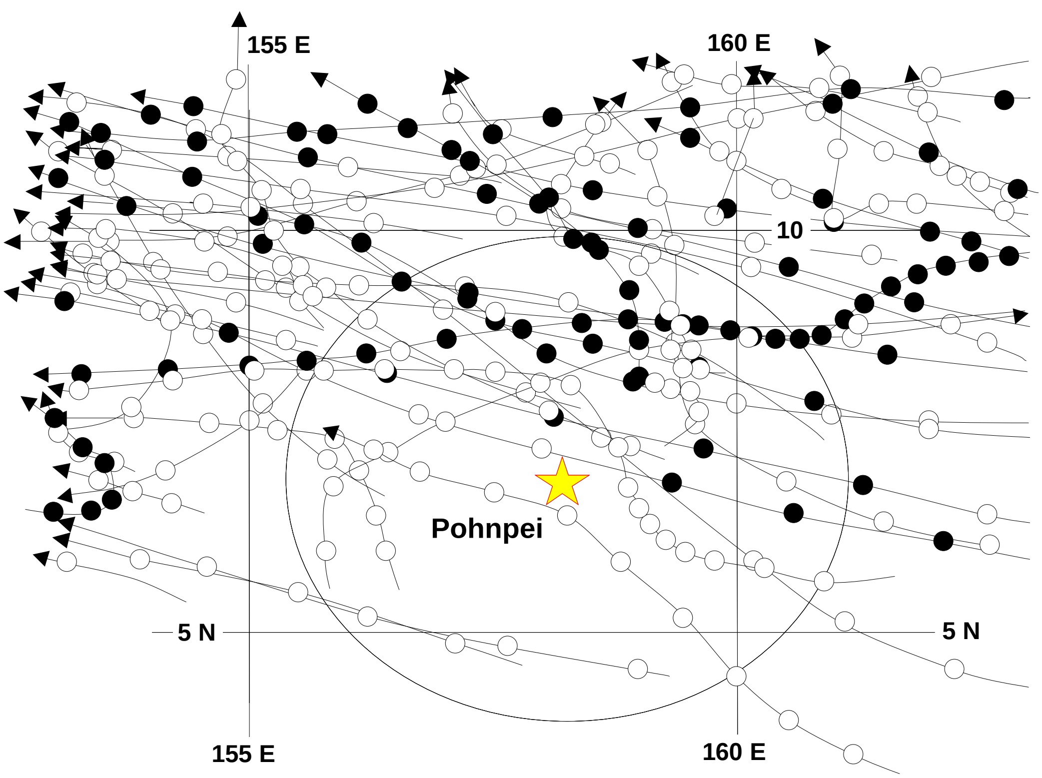


Figure 22. All tropical cyclone positions at six-hour intervals from the JTWC best-track archive. (a) The 1970's, (b), the 1980's, (c) the 1990's , and (d) the period 1970-1999. Open circles indicate tropical storm intensity, black dots indicate typhoon positions, star is the location of Pohnpei and the circle has a radius of 180 n mi from Pohnpei.

There is intense pressure on the scientific community to predict the long-term fate of earth's climate (e.g., global warming); and further, to show the impact of such long-term climate change at regional scales (e.g., the tropical Pacific islands, Antarctica, and the world's grain belt). It has been suggested by some (e.g., Morrissey and Graham 1996) that the hydrologic cycle of the western Pacific may change in a warmer world in a manner that would see tropical islands in the northwest part of the basin (e.g., Yap, Palau, Guam and the CNMI) become drier while islands of the central equatorial and South Pacific (e.g., Kiribati southeastward through the Society Islands) become wetter. As research continues on the problem of long-term climate change, attention has recently been focused on climate fluctuations at periods of one to several decades. These inter-decadal climate variations are troubling because they may mask, or may be mistaken for, longer-term climate changes. A plethora of local and regional climate patterns have been defined, for example: the Pacific Decadal Oscillation (PDO) (Minobe 1997), the North Atlantic Oscillation (NAO) (Uppenbrink 1999), and the Southern Oscillation. Nearly all of these have prominent inter-decadal variations. Any projections of a change in the hydrologic cycle in the western Pacific in a warmer world must take account of the presence of susbstantial inter-decadal variations of rainfall, as observed on Pohnpei and throughout Micronesia.

The 50-year record allowed some assessment of inter-decadal variations in Pohnpei's rainfall. The 1950s was a very dry decade, as indicated by the sharp downward slope of the running accumulations of rainfall anomalies shown in Fig. 23. The late 1960s to the mid-1970s were slightly drier than the long-term average, while the 1980s through the early 1990s were drier than the long-term average. The period 1960-65 was very wet as indicated by the sharp rise of the running accumulation of the rainfall anomalies. Superimposed on the long-term rise and fall of the integrated rainfall are sharp peaks and troughs that are primarily associated with ENSO: the period from the end of the El Niño year through the year following El Niño tends to be very dry.

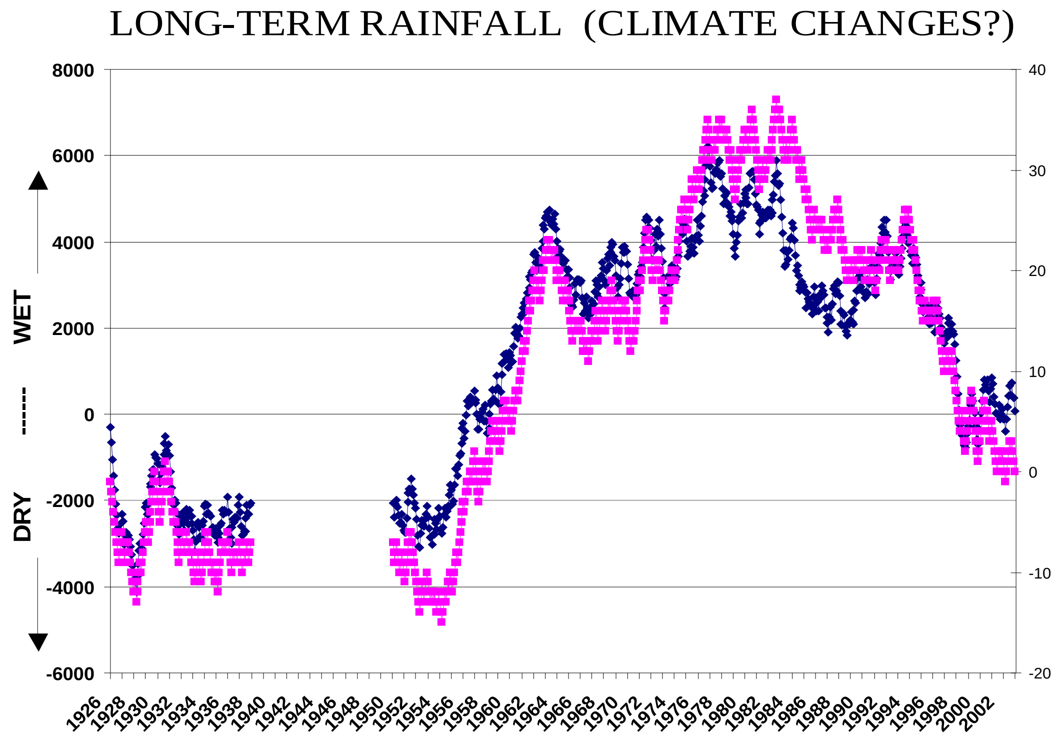


Figure 23. Running accumulations of the rank (lowest month = -305, highest month = +306) of each month's rainfall for the period 1954 to 2000 (annual cycle not removed). Complete records were available from Andersen AFB, Guam, and the constructed time series of the SIA. Prominent features include the extreme dryness of the 1950's, a very wet period in the 1960's, and recent overall dryness in the 1990's. Recent short-term prominent rainfall fluctuations include relative dryness from late 1992 through 1995, and a wet period during 1996 and 1997, followed by the driest year of record: 1998. These sharp short-term fluctuations are related to El Niño

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Groundwater Infiltration and Recharge in the Northern Guam Lens Aquifer as a Function of Spatial and Temporal Distribution of Rainfall

Basic Information

Title:	Groundwater Infiltration and Recharge in the Northern Guam Lens Aquifer as a Function of Spatial and Temporal Distribution of Rainfall
Project Number:	2003GU20B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
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Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quantity, Hydrology, Climatological Processes
Descriptors:	Wellhead Variations, Time-lag response, Climate, Data Analysis, Rainfall
Principal Investigators:	Mark Lander

Publication

PROJECT SYNOPSIS REPORT

Project Title: Groundwater Infiltration and Recharge in the Northern Guam Lens Aquifer as a Function of Spatial and Temporal Distribution of Rainfall

Problem and Research Objectives

Groundwater is the most important source of Guam's drinking water. Nearly 40 million gallons per day (mgd) are currently extracted from the thin lens-shaped body of fresh water that floats atop the seawater that permeates the limestone beneath it. Current environmental regulations on water production are based on the sustainable yield estimates from the 1982 Northern Guam Lens Study (CDM, 1982), which totaled to 59 mgd. Later estimates by J.F. Mink (Mink, 1991), based on well responses predicted by a computer model totaled to 70-80 mgd. Accurate assessment of the sustainable yield of the aquifer is crucial for effective planning and management of Guam's groundwater resources. The sustainable limit for withdrawal of groundwater on Guam is the amount that can be withdrawn by current technology without inducing salt-water intrusion into the wells. Pumping rates and well density must therefore be limited to amounts that do not cause salt water beneath the lens intercept the intakes of production wells. On the other hand, over-conservative limits to water production will constrain economic development by inhibiting development of new production and driving up costs.

Guam is characterized by one of the highest levels of rainfall variability in the world, with the highest annual rainfall nearly three times the lowest rainfall. This makes the region susceptible to droughts and floods, in addition to the large typhoon risk that threatens the island. This high rainfall variability directly affects ground and surface water supplies, water quality, erosion, pollution from run-off, and local flooding. Rainfall on Guam also has extreme short-term temporal and spatial variations depending upon large-scale weather patterns. When Guam is within the doldrum trough of summer, local thunderstorms may deposit upwards of 100 mm in one hour over an area as small as a few square kilometers, while the rest of the island gets little or no rainfall. When the island is within strong monsoonal southwest wind flow, or in the periphery of a tropical cyclone, similar peak hourly rain rates are possible, but the spatial distribution is larger. Nearly every location on the island receives a substantial amount of rain (although spatial variations may still be large – for example: a peak 24 hour amount of 200 mm may occur over the central part of the island with minima of 100 mm at other island locations). The direct passage of the core of a tropical cyclone over the island is responsible for all historical 24-hour rainfall totals of more than 250 mm. Tropical cyclone core rainfall has a larger spatial distribution and can result in extreme amounts island-wide. In the year 2002, Guam experienced two typhoons – Chataan in July, and Pongsona in December – that each yielded 20 inches of rainfall in 24 hours over much of the island. The July typhoon produced short-term (one and three-hour) rainfall totals of 6.5 and 13 inches respectively that were near or over the 100-year return period.

To make accurate estimates of sustainable yield, groundwater hydrologists need to know the amount of water that infiltrates to the lens from the surface at slow enough rates for the lens to capture and retain it for sufficient time for it to be extracted by pumping.

The ultimate objective of this project was to develop a set of statistical models incorporating the key variables for predicting the recharge that is actually captured by various parts of the fresh water lens. A second objective was to gain a more thorough understanding of the long-term average rainfall distribution on Guam (complementing a companion project undertaken by WERI meteorologists). These objectives will provided baseline information for identifying deviations from the average distribution that have measurable impacts on the aquifer, and implications for a water management plan.

Methodology

We imported historical data into a spreadsheet program from which we graphed rainfall and well levels as a function of time at several different scales. Since 30-minute records were available for several USGS observation wells and rain gages and hourly data were available for NWS gages (and for target rain events from NEXRAD), we were able to resolve the rainfall intensity and well-level responses into hourly intervals, and daily means, as well as monthly, seasonal, and annual means. We selected specific wells and nearby rain gages for focused study. For several wells, the time lags of response to variations of rainfall were estimated. Data was also available to extend the analysis to years prior to and following previous periods of study. Also, data from some other wells not looked at in the original study were available for analysis.

Since there is a well-documented 50-year record of rainfall collected by the NWS and the Air Force for northern Guam and almost 20 years of hydrographic data from several USGS observation wells installed during the NGLS, we had ample data from which to work. The project PI and graduate student worked with NWS, Guam EPA, and USGS scientists, most specifically with the USGS Field Team in the Marianas, led by R. Carruth. Much of the data was transferred readily over the internet. With the help of Dr. Lander, the graduate student lead the statistical analysis of the wellhead and meteorological data.

Principal Findings and Significance

From the proposed study, we gained a further corroboration of the time lags at which water moves through, and is stored in the Northern Guam Lens Aquifer. Statistics and graphs from this project provided a means for inferring the proportion of water from a given storm that is actually captured in long-term storage by the lens and is thus available for extraction by pumping. We now have produced a set of statistical models that will predict, to a known degree of accuracy, the proportion of rainfall that is retained in short and long-term storage. Using this information, hydrologists will now be able to make wellhead predictions based on known rainfall variations and known storage parameters. The nearly two-year lag in the response of the wellheads to long-term surpluses and deficits of rainfall allow for long-term prediction of wellheads. These could be especially useful if rainfall variations due to EL Niño could be accurately anticipated (as they were in 1998 and again in 2002).

Results from this project have provided insight into how much recharge is associated with different weather phenomena on Guam – how much, for example, is contributed by local thunderstorms, monsoonal rains, tropical storms, and typhoons respectively. This improvement in our understanding of rainfall-recharge relationships has enabled us to make more accurate and precise estimates of recharge, and therefore sustainable yield, to be made for designated well fields and sectors of production in the aquifer. By gaining insight into how a given well responds to different intensities of rainfall, we can also infer the contribution of surface conditions, most especially the contributions of sinkholes, retention basins, and other natural and artificial surface features that modify infiltration rates. This understanding can now provide a basis for determining appropriate environmental and land use regulations and stormwater management practices over the aquifer.

Explore the Operational Effectiveness of Saipans Existing Slow Sand Filter and Develop Recommendations to improve Operation of the Filter Plant

Basic Information

Title:	Explore the Operational Effectiveness of Saipans Existing Slow Sand Filter and Develop Recommendations to improve Operation of the Filter Plant
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End Date:	2/29/2004
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Congressional District:	NA
Research Category:	Engineering
Focus Category:	Treatment, Water Supply, Surface Water
Descriptors:	Streams, Water Quality Control, Slow Sand Filter
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publication

PROJECT SYNOPSIS REPORT

Project Title: Exploring the Operational Effectiveness of Saipan's Existing Slow Sand Filter and Develop Recommendations to improve Operation of the Filter Plant.

Problem and Research Objectives

The Saipan slow sand filter facilities were originally constructed in 1984 and they were rehabilitated in 1992: The system includes: a) a 20 million gallon storage reservoir catching direct rainwater runoff from Saipan International Airport (Isley Field), b) a pumping station next to the rainwater catchment reservoir that delivers water to the filters through an 8 inch PVC pipe, c) two parallel slow sand filters that are constructed of concrete and each measure 100 feet by 35 feet and, d) a nearby reservoir that stores finished water from the filter.

The rainwater reservoir is a 20 MG concrete lined earthen reservoir that serves as a collection point for runoff from the airport runways. There are two vertical turbine type pumps next to the reservoir that are sized to supply the maximum slow sand filter output of 700 gpm with both pumps operating. The original design allows for the pumps to be controlled manually or automatically. Due to break down of the automatic switches, the pumps are operated manually.

The slow sand filter units consist of two 100 feet long by 35 feet wide by 12 feet deep concrete structures connected by a common center wall. Each unit was designed to process water at a maximum rate of 350 gpm. The equipment provided at the slow sand filter site includes inlet piping, filter sand and under drain system, outlet piping, and filter controls such as valves and level sensors for measuring and controlling the water level in the filters. Water enters each of the filters via an 8-inch water main from the rainwater catchments pump station. The inlet flow is controlled separately to each filter by a gate valve. Each filter's sand and under drain system includes a 4 foot depth fine sand bed that is lying on a drain system that consists of 6-inch PVC well screen laterally spaced at 4 feet off a central 8-inch diameter header. The outlet piping from each filter consists of an automatic butterfly valve for outlet flow control, a flow meter to provide the control signal to the butterfly valve, and sampling taps for water quality measurement. There is a 4-inch diameter cross connection at the discharge end of the filters tapping into the filters just above the sand layer. A level sensing probe is mounted in a standpipe that is tied to the center of this pipe. The probe senses the level in the filters and controls the pump operation at the rainwater pump station thus maintaining the water level in the filter. As mentioned earlier, the automatic control doesn't work and the pumps are manually turned off and on. There are also piezometers on the outlet face of each of the filters. The piezometers measure the water level and pressure upstream and downstream of the filter media. Presently these piezometers are not working and they need to be replaced.

According to the Commonwealth Utility Commission (CUC), the Saipan slow sand filters have not been able to deliver the design flow, which is 350 gpm since 1993. A recent flow measurement indicates that the filters are delivering 50 to 60 gpm, which is 17 % of the design flow of 350 gpm. In addition, Department of Environmental Quality (DEQ) does not have a record of data that shows how effective the filters are in removing bacteria and turbidity.

The objective of this project was to monitor the quality and the quantity of the water that is being produced by the Saipan Slow Sand Filters, and then to make recommendations on how to improve the system operation in order to increase the finished outflow from the plant.

Methodology

The methods that were proposed were: a) filter preparation which included draining the filters, scraping the top layer of the filter media, and replacing all the valves and flow controls, b) monitoring and testing the filter out flow for turbidity and bacteria removal, and c) evaluating the filter performance and providing recommendations of filter operation, filter scraping time, and controlling the inflow/outflow to the filters.

During the filter preparation phase, the filtration media was tested using sieve analysis to determine the size distribution of the sand. The results of the sieve analysis for both filters are shown in Table 1 and a graphical representation of the size distribution of the sieve analyses are shown in Figure 1. This analysis technique allows for determination of the d_{10} and d_{60} of the sand. The d represents the diameter of particles passing through a given sieve size. The d_{10} (effective grain size) is determined by the sieve size that 10 percent of a sample (by weight) passes through during a sieve test. The d_{60} represents the particle size that 60 percent of a sample (by weight) passes through in a sieve test. Combining these two values as a ratio of d_{60}/d_{10} allows for determination of the uniformity coefficient (UC) of the material. The recommended effective grain size (d_{10}) for slow sand filter is 0.15 mm – 0.30 mm (0.006 in – 0.012 in) with UC value < 5 (preferably <3).

Table 1. Sieve analysis for Saipan's Slow Sand Filters No. 1 and 2

Sieve Size	Opening passed through (in)	Opening passed through (mm)	Filter No. 1 %	Filter No. 2 %
No. 10	0.078	2	99.25	97.7
No. 16	0.046	1.18	46.25	44.7
No. 18	0.039	1	15.25	16.08
No. 35	0.019	0.5	1.75	2.28
No. 60	0.009	0.25	1.25	1.78
No. 120	0.0045	0.125	1.1	1.58
No. 230	0.0025	0.063	1.04	1.5

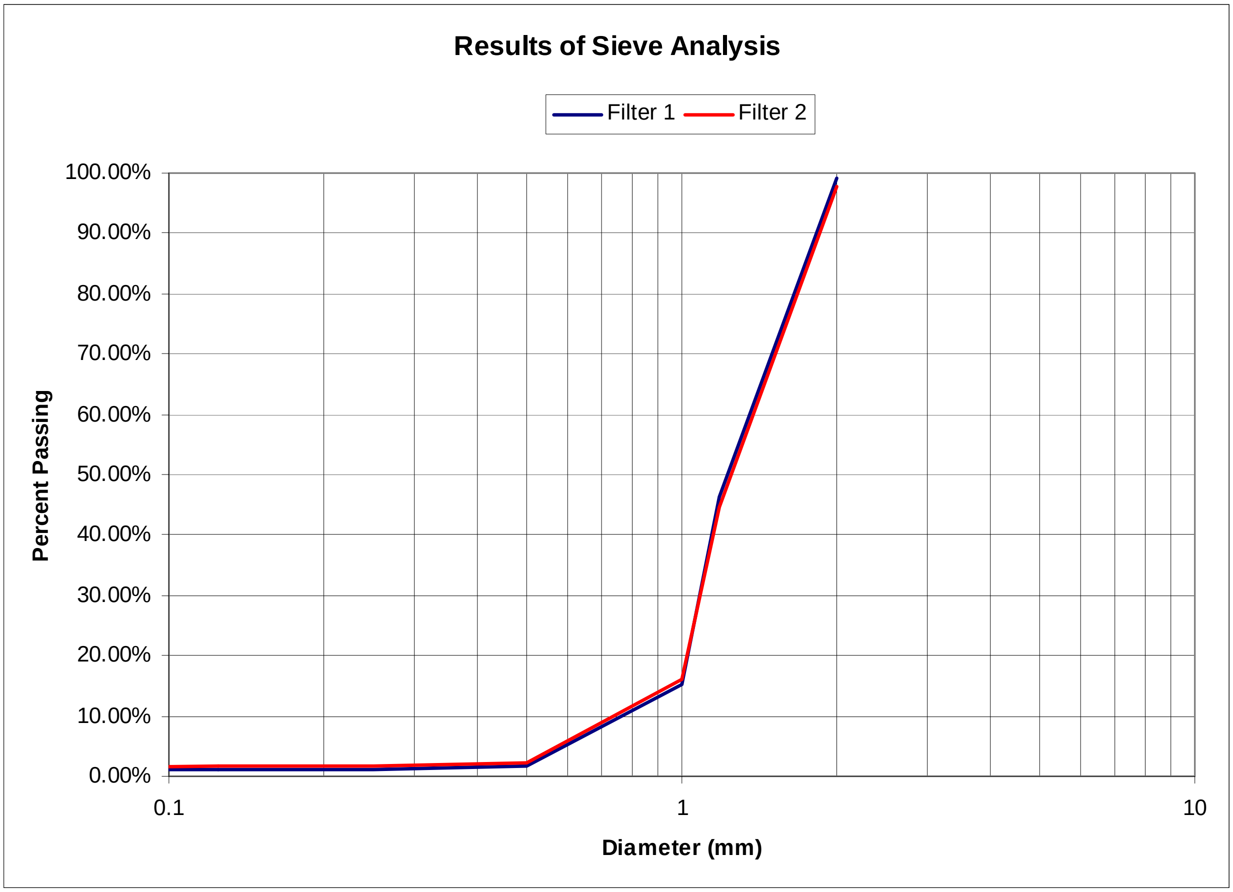

Figure 1. Size distribution curves from sieve analysis of filter 1 and 2 of Saipan Slow Sand Filter

Principal Findings and Significance

The Slow Sand Filter bed media plays the main role in microbial, viral, and sediment removal. Particulate removal in slow sand filtration is considered a passive process, differing from rapid sand filtration in that chemical pre-treatment of inflow is generally not performed and back flushing (pressurized flow reversal) is not used for cleaning the filter media. In rapid sand systems, filtration requires flocculation to coagulate particles contained in the inflow, coupled with back flushing every 1-2 days to dislodge coagulated particles trapped in the media. In contrast, slow sand water purification depends upon two passive removal mechanisms: 1) biological and 2) physical-chemical; neither of which is well understood. Removals attributed to biological activity within the filter media are absent in rapid sand filters, due to the aforementioned processes that prevent establishment of biological communities within the filtration media.

The sand media for slow sand filters should follow design criteria such as the effective size of the sand d_{10} should be in the range of 0.15 mm – 0.3 mm (0.006 in – 0.012 in) and the Uniformity Coefficient (UC) that is UC = $d60/d_{10}$ should be in the range of less than 5 and preferably less than 3. The UC is a reflection of the degree of variation in particles sizes. A lower UC indicates more uniformity in particle size, which generally results in a higher porosity, assuming the particles are uniform in shape. A higher UC indicates greater variation in particle sizes and usually indicates reduced porosity, as the voids created by larger particles fill with smaller sizes. These characteristics of uniformity coefficients serve as guidelines for determining porosity, however, the geometry of the sand particles has a considerable impact on the degree of sorting and hence, porosity of the media.

Table 2 shows effective size d10 and d60 and UC of the bed media of the Saipan Slow Sand Filter. The graphical representation of the size distribution of the sieve analyses for filter one and two are shown in Figure 1. The graph provides a means for obtaining the diameters of various percentages (10%, 60% etc.) of particles passing through a particular sieve. For comparison, the lower and higher limits of the size distribution for slow sand filter has been plotted in Figure 2. These limits were obtained from a slow sand filter web page. According to this figure the sand size distribution of the Saipan slow sand filter is far out of the range considered as acceptable for slow sand filters. We did a plot of a typical sand size distribution for rapid sand filter that is shown in Figure 1. The sand size distribution for rapid sand filter were also obtained from the rapid sand filter web sites.

The significant finding of this project is that: a) the sand bed media that are currently in place at the Saipan's Slow sand filter are not following the design specifications for slow sand filter bed media requirement, b) the bed media are more appropriate for rapid sand filters. Probably during the system rehabilitation in 1992, the original sand bed media was replaced by media suitable for rapid sand filters. We strongly recommended that the filter bed media be replaced with media that follows the recommended sand size distribution for slow sand filtration technology.

Table 2. Comparison of d10, d60, and UC for Saipan's Slow Sand Filter 1 and 2

Filter Media	d10 (Size of percent passing – mm)	d60 (size of percent passing – mm)	Uniformity coefficient (UC) d60/d10
Filter 1	0.85	1.52	1.76
Filter 2	0.84	1.52	1.76

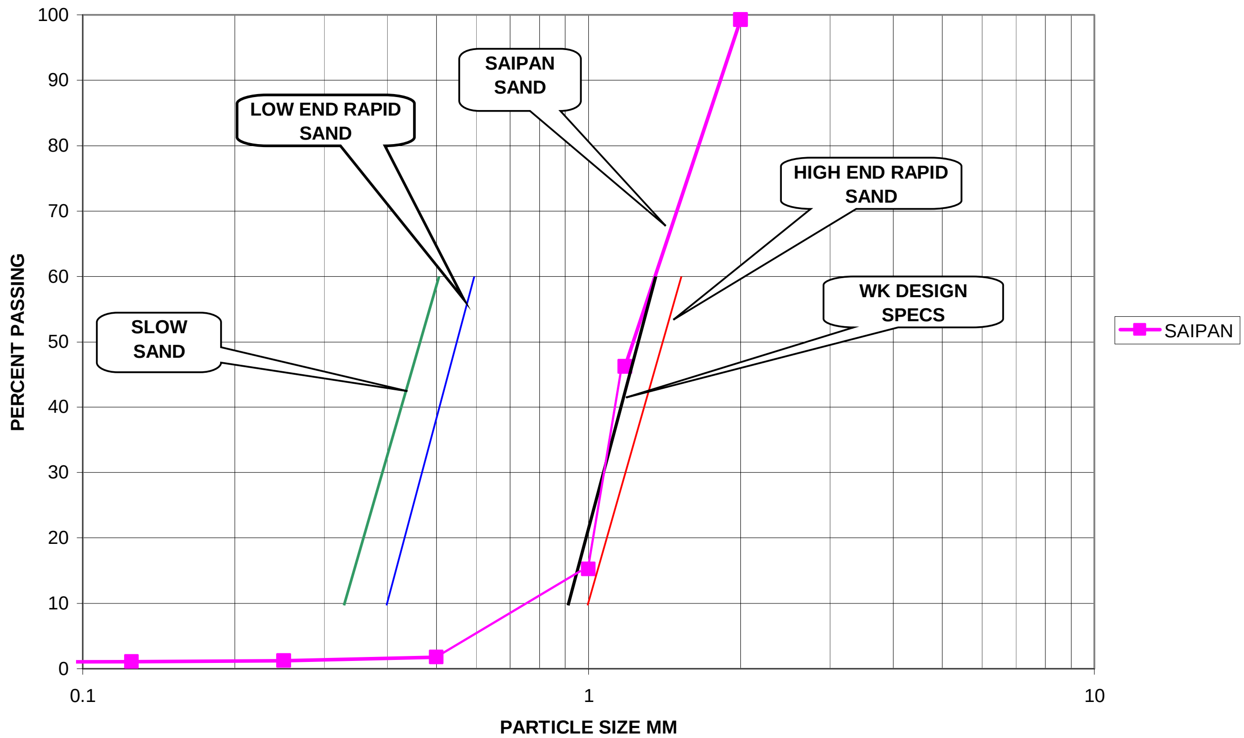

Figure 2. Comparison of Size distribution curves from sieve analysis of filter 1 and 2 of Saipan Slow Sand Filter with Rapid Sand Filtration.

Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer Outfalls

Basic Information

Title:	Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer Outfalls
Project Number:	2003GU22B
Start Date:	3/1/2003
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Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Non Point Pollution
Descriptors:	Bioindicators, Heavy Metals, PCBs, Pesticides, Tropical Coastal Waters
Principal Investigators:	Gary Denton, Peter Houk, Harold Wood

Publication

PROJECT SYNOPSIS REPORT

Project Title: Persistent Pollutants in Biotic Components of Tanapag Lagoon, Saipan, with Emphasis on Areas Impacted by Streams, Storm Water Runoff and Sewer

Problem and Research Objectives

Tanapag Lagoon borders the western shore of central Saipan. It harbors a rich diversity of marine life and supports a variety of commercial and recreational activities. Over the last quarter century, Tanapag Lagoon has become heavily impacted by the activities of man. Primary sources of anthropogenic disturbance in these waters include a power station and commercial port (Saipan Harbor), two small boat marinas, a sewer outfall, several garment factories, auto and boat repair shops, wood shops, government vehicle maintenance yards, a commercial laundry, and an acetylene gas producer. There are also a number of old military dumps and disposal sites in the area as well as a municipal dump that has served as the island's only solid waste disposal site for the last 50 years. Several streams and storm drains empty into the lagoon during the rainy season and provide a mode of transport into the ocean for any land-based contaminants. Overflows from sewer lines are also commonplace at this time of the year and the whole area is inundated by storm water runoff during periods of prolonged wet weather. The effects of these perturbations on the indigenous biota within the lagoon are largely unknown. Likewise, fundamental data describing the abundance and distribution of persistent and potentially toxic pollutants within the system is also lacking. Mindful of these shortcomings, a contaminant assessment of surface sediments within Tanapag Lagoon was recently completed.

The study reported here examined contaminants of potential concern (heavy metals, PCB, and pesticides) in biotic components of the lagoon and was seen as a logical extension of the work already completed. The primary objectives of the study were to establish a reliable contaminant database with which future findings can be compared and evaluated; identify 'hotspots' and delineate areas of contaminant enrichment within the study area, and assess the degree of biotic contamination in Tanapag Lagoon by reference to levels reported for similar and related species from clean and polluted environments in tropical regions from elsewhere in the world, including Guam. Potential health risks (if any) associated with the long-term consumption of edible resources surveyed are also being evaluated.

Methodology

The study focused on dominant organisms inhabiting the shallow nearshore waters of the lagoon with emphasis on groups with high bioindicator potential that were either sessile or are restricted in their movement e.g., algae, seagrasses, seacucumbers, bivalves and juvenile fish. Representatives of these were collected from 12 intertidal sites between Muchot Point and San Roque village in the southern and northern ends of the lagoon respectively (Fig. 1). Sites 1-9 were impacted by land-based sources of contamination of one sort or another while sites 10-12 were not and served as useful reference sites. A list of all the animals and plants collected for analysis at each site are presented in Table 1. Surface sediments (top 2 cm) were also collected for analysis from each location.

Figure 1: Map of northern Saipan showing biota sampling sites 1-12

The fish were captured by cast-net at high tide tide. All other organisms were hand picked off bottom substrates by wading through the shallows at low tide. A small aluminum rake was used to recover the bivalves from sediments in which they were buried. All samples were cleaned of conspicuous surface debris immediately upon collection. The algae, seagrasses, seacucumbers and bivalves were transported to the laboratory in clean seawater while the fish were immediately placed on ice.

In the laboratory, the algae, seagrasses and seacucumbers were processed immediately; the latter samples being separated into body wall and hemal tissue. Only the youngest portions of the algae and seagrasses were taken for analysis, as these were relatively free of epiphytic growth and adhering sediments and minimized variations in contaminant concentrations associated with growth. The bivalves were held in clean seawater for an additional 24 hours to clear their gut contents and were subsequently analyzed whole. All samples were stored at -20^{0}C until required for analysis. Those required for metal analysis were stored in acid cleaned polypropylene vials while those for PCB and pesticide analysis were individually wrapped in aluminum foil and sealed in Ziploc® bags prior to freezing.

To date, all samples have been analyzed for heavy metals. The PCB and pesticide analyses are currently underway. Analytical protocols are as previously described in Denton *et al.* (1997, 1999, 2000).

Flora and Fauna Sampled During Present Study

Species	Sites											
	1	2	3	4	5	6	7	8	9	10	11	12
ALGAE:												
Acanthophora spicifera	x	x	x	x					x	x		
Dictyota bartayresiana											x	
Gracilaria salicornia					x	x		x	x			
***Padina* sp.**		x	x	x			x		x	x	x	x
Sargassum polycystum											x	
SEAGRASS:												
Enhalus uninervis	x	x		x	x	x	x	x	x			
Halodule					x				x	x	x	
SEA CUCUMBERS:												
Bohadschia argus								x				
Bohadschia mormorata			x	x	x	x						
Holothuria atra	x	x	x	x	x	x	x	x	x	x	x	x
Holothuria hilla						x						
BIVALVES:												
Asaphia violascens		x										
Atactodea striata	x						x		x	x	x	x
Ctena bella	x											
Gafrarium pectinatum		x	x		x	x						
Quidnipagus palatum		x	x		x	x						
FISH:												
Caranx sexfasciatus	x	x		x		x	x					
Gerres argyrus	x	x	x	x	x	x	x	x				
Mulloides vanicolensis	x	x	x	x		x	x	x	x	x	x	x
Valamugil engeli	x	x	x	x	x	x						

Table 1. A list of all the animals and plants sampled from Tanapag Lagoon

Principal Findings and Significance

Sediments:

Sediment analysis revealed distinct copper, lead and zinc enrichment around the SW edge of the Puerto Rico dump (site 2), the area between the Seaplane Ramps (site 4) and immediately adjacent to the power plant and DPW maintenance yard (site 5). Sediments collected near dump were also noticeably enriched with silver, cadmium, chromium, mercury and nickel (Table 2). Elevated mercury concentrations were also evident in sediments from the mouth of Saddock Dogas (site 8), a small stream south of Tanapag village that receives drainage from an old military dumpsite ~1 km inland. Metal levels at all other sites were unremarkable and indicative of relatively mild impaction from surface runoff and stream discharges in the area.

Biota:

From Table 1, it can be seen that not all species chosen for analysis were available at all sites of interest. Those that were most widely represented were the brown alga, *Padina* sp., the seagrass, *Enhalus uninervis,* the seacucumber, *Holothuria atra*, the bivalves, *Atactodea striata* (sandy shores), *Gafrarium pectinatum* and *Quidnipagus palatum* (muddy shores), and the goatfish *Mulloides vanicolensis.* Consequently, only data summaries for these organisms are presented here.

Site	Location	Concentration (µg/g dry weight)							
		Ag	Cd	Cr	Cu	Hg*	Ni	Pb	Zn
1	Micro Beach	<0.20	0.20	3.27	0.50	3.70	<0.20	0.65	2.42
2	Peurto Rico Dump (SW side)	0.75	1.69	17.5	102	74.7	11.9	158	358
3	Echo Bay (S end)	<0.21	0.31	2.56	6.76	18.1	<0.20	3.19	7.39
4	Sea Plane Ramps	<0.15	0.23	2.83	39.8	23.0	0.89	17.7	84.0
5	Power Plant (N side)	<0.16	0.32	4.61	5.34	24.2	0.94	21.3	26.4
6	Lower Base Drainage Channel	<0.1	0.24	2.43	1.34	10.9	0.46	1.78	6.00
7	Tanapag 1 (Saddock As Agatan)	<0.17	0.17	3.08	4.70	6.90	0.85	0.84	15.1
8	Tanapag 2 (Saddock Dogas)	<1.18	0.18	3.67	5.79	50.2	1.16	1.33	18.5
9	Tanapag 3 (Bobo Achugao)	<0.17	0.17	1.42	4.80	3.28	0.25	4.07	12.1
10	Plumaria Hotel Beach (N end)	<1.18	0.18	2.78	2.53	4.37	0.26	2.19	12.0
11	San Roque Cemetary (Hotel Desalin Stream)	<0.15	0.22	1.71	0.60	2.38	0.22	1.08	3.73
12	Pau Pau Beach Park	<0.18	0.27	1.52	2.70	3.31	0.44	1.16	4.49

* mercury concentrations expressed as ng/g dry weight

Table 2: Heavy metals in sediments from Tanapag Lagoon, Saipan (2003)

Table 3 summarizes the range of heavy metal concentrations found in the most common and widespread biota sampled throughout the study area. As fish generally have relatively poor bioindicator capabilities for heavy metals, other than mercury, only the latter element was examined in this group. Moreover, only fish axial muscle was analyzed since this represents the tissues most commonly consumed by man.

Specimen	Tissue	Total Sites	Concentration (µg/g dry wt.)							
			Ag	Cd	Cr	Cu	Hg*	Ni	Pb	Zn
ALGAE										
Padina	yound frond	8	<0.09 - 0.29	<0.11 - 1.72	<0.30 - 1.43	1.3 - 25.3	0.41 - 6.44	0.9 - 1.65	<0.27 - 14.7	10.6 - 107
SEAGRASS										
Enhalus uninervis	young leaf	8	all <0.20	0.15 - 0.60	<0.30 - 0.87	1.03 - 49.5	0.37 - 3.18	0.60 - 2.34	<0.22 - 2.05	20.5 -32.9
SEACUCUMBER										
Holothuria atra	body wall	12	all <0.13	all <0.12	<0.28 - 0.66	0.96 - 3.10	0.45 - 4.54	<0.12 - 0.45	<0.15 - 2.07	13.1 - 24.1
	hemal system	12	<0.7 - 0.25	<.08 - 1.3	<0.26 - 4.99	2.8 - 11.2	5.53 - 63.2	<0.12 - 0.77	<0.11 - 6.33	29.8 - 287
BIVALVE										
Atactodea stiata	whole flesh	6	<0.14 - 5.08	0.08 - 5.45	<0.52 - 6.56	7.35 - 20.2	15.3 - 23.8	2.01 - 4.76	<0.39 - 3.14	71.8 - 147
Gafrarium pectinatum	whole flesh	4	<0.14 - 0.62	0.69 - 1.79	0.58 - 1.31	6.69 - 35.3	9.91 - 23.3	10.6 - 14.1	7.97 - 54.2	42.3 - 63.2
Quidnipagus palatum	whole flesh	4	0.32 - 19.8	0.17 - 1.4	4.81 - 10.6	14.7 - 1876	44.3 - 111	7.30 - 13.1	9.01 - 148	305 - 1027
FISH										
Mulloides vanicolensis	axial muscle	11	-	-	-	-	<0.5 - 43.2	-	-	-

* all mercury data expressed as ng/g wet weight; dashes indicate no data

Table 3: Heavy metals in selected marine organisms from Tanapag Lagoon, Saipan (2003)

While the different organism displayed widely differing affinities for the various elements examined, the bivalves and seacucumbers generally mirrored the metal distribution profiles demonstrated by sediments, particularly for copper, lead and zinc. This is to be expected as these organisms derive their metal load primarily through the ingestion of sediments and suspended particulates. The algae and seagrasses, on the other hand, are unique in that they largely reflect the soluble metal fraction and, as such provide a useful means of determining the biologically available fraction of metals in the water column rather than in the sediments. Consequently metal distribution profiles portrayed by algae and seagrasses are frequently quite different than those demonstrated by sediment ingesters like bivalves and seacucumbers. Metal profiles depicted by *Padina* provide a good example of this. For example, specimens collected from Seaplane Ramps contained approximately ten times more copper, three times more lead and five times more zinc than those near the dump (site 2). Sediments, on the other hand, were appreciably higher in all three metals at the latter site. Thus, *Padina* is telling us that dissolved levels of copper, lead and zinc are relatively high in the water column around the seaplane ramps compared to with the dump. As the former area serves as a dry dock facility, it is likely that *Padina* is 'seeing' soluble contributions associated with boat maintenance and repair activities, and possibly antifouling paints. It is also noteworthy the same three metals were relatively enriched in *Padina* from Echo Bay (site 3) in sharp contrast to the picture presented by sediment from this area. Again, the relatively high incidence of boat maintenance and repair activities at this location is the most likely explanation for this.

Like *Padina*, the seagrass, *Halodule uninervis*, also appears to be a very sensitive indicator of dissolved copper with levels approaching 50 µg/g in samples collected from the Seaplane Ramp area compared with only ~8 µg/g near the dump. Lead levels were also marginally higher in samples from the former site (2.05 µg/g vs. 0.71 µg/g) while zinc was similar at both sites (29.0 µg/g vs. 32.6 µg/g). It is possible that seagrasses have some regulatory capability for the latter element

As expected, mercury levels in the juvenile fish examined were all very low. A project is currently underway to determine levels of this element (and other contaminants) in larger specimens popularly taken for food from further offshore in the lagoon.

Where possible, the data gathered from the current work were compared with levels found in similar and related species from tropical waters elsewhere in the world. Several examples are cited in Table 4 for specimens collected from Guam and within the Australian Great Barrier Reef province. From such comparisons, a preliminary appraisal of the degree of heavy metal contamination exhibited by the biotic resources from within Tanapag Lagoon is possible. Clearly, there is significant copper, lead and zinc enrichment in sediments from the southern portion of Tanapag Lagoon. Biologically available levels of all three metals are also notably increased in this region. Copper is probably the element of greatest concern followed by lead and then zinc.

Species	Location	Ag	Cd	Cr	Cu	Ni	Pb	Zn	Hg[a]	Reference
BROWN ALGAE:										
Padina australis	Gt. Barrier Reef, Australia	nd	0.4-0.6	nd	2.0-3.0	1.0-1.4	<0.9-5.0	3.8-9.5	0.001-0.004	Denton & Burdon-Jones 1986a
Padina commersonni	Singapore coastal waters	nd	0.4-0.6	2.9-6.5	3.8-7.3	4.0-6.5	4.3-7.9	20.7-50.1	<0.01[b]	Bok & Keong 1976
Padina gymnospora	Puerto Rico	nd	nd	nd	nd	23.0-32.0	nd	nd	nd	Stevenson & Ufret 1966
Padina tenuis	Penang Island, Malaysia	nd	7.1	25.6	5.7	nd	17.1	45.5	1.025[b]	Sivalingam, 1978, 1980
Padina tenuis	Townsville coastal waters, Australia	<0.1-0.4	0.2-1.4	1.4-10.0	1.4-5.1	0.7-8.4	<0.3-6.2	3.7-30	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	Goa coastal waters, India	nd	nd	nd	3.2-7.9	8.0-18.3	3.0-28.3	4.5-11.7	nd	Agadi *et al.* 1978
Padina tetrostromatica	" " " "	nd	nd	nd	8.7-20.1	nd	nd	20.2-31.5	nd	Zingde *et al.* 1976
Padina tetrostromatica	Townsville coastal waters, Australia	<0.1-0.4	0.2-1.2	1.6-8.3	2.0-9.7	0.9-4.0	1.1-4.9	5.5-25.7	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	Townsville Harbor (lower reaches)	<0.1-0.4	0.2-0.6	2.1-9.9	4.4-11.1	0.7-5.6	2.0-10.2	67.2-166	nd	Burdon-Jones *et al.* 1982
Padina tetrostromatica	" " (upper reaches)	<0.1	<0.4	31.5	58.9	13.1	108	440	nd	Burdon-Jones et al.1975
Padina sp.	Israeli coast	nd	nd	nd	nd	nd	nd	nd	0.065[b]	Hornung *et al.* 1981
Padina sp.	Penang Island, Malaysia	nd	nd	nd	nd	nd	nd	nd	0.100[b]	Sivalingam 1980
Padina sp.	Lizard Island, Great Barrier Reef	nd	0.2	nd	2.2	1.1	<0.74	5.9	0.002	Denton & Burdon-Jones 1986a
Padina sp.	Agana Boat Basin, Guam	0.89	0.3	0.68	1.53	1.18	0.46	11	<0.002	Denton *et al.* 1999
Padina sp.	Apra Harbor, Guam	<0.1-<0.1	0.2-0.5	1.3-3.0	2.6-36.6	1.1-3.2	2.6-6.5	45.1-192	0.007-0.026	Denton *et al.* 1999
Padina sp.	Agat Marina, Guam	<0.1	<0.1	2.7	4.1	2.9	<0.25	18.7	<0.002	Denton *et al.* 1999
Padina sp.	Merizo Pier, Guam	<0.1	<0.1	14.1	27.2	2.28	8.07	78.3	0.003	Denton *et al.* 1999
SEAGRASSES:										
Halodule uninervis	Cleveland Bay, Townsville, Australia	<0.3	0.5	1.6	2.7	0.7	7	11.0	nd	Denton *et al.* 1980
Zostera capricornia	Upstart Bay, N Queensland, Australia	<0.2	0.2	0.9	3	0.6	0.4	18.0	nd	Denton *et al.* 1980
Zostera capricornia	Shoalwater Bay, N. Queensland, Australia	<0.2	0.2	1.9	2.8	1.8	0.4	14.0	nd	Denton *et al.* 1980
SEA CUCUMBERS:										
Holothuria sp. (whole)	Japanese waters	nd	nd	nd	1.9[c]	nd	14.4[c]	8.7[c]	nd	Matsumoto 1964
Holothuria sp. (whole)	Townsville coastal waters, Australia	all <0.2	<0.2	<0.3-6.3	<0.3-3.5	all <0.5	<0.4-3.8	13.9-39.4	nd	Denton, unpublished data
Holothuria atra. (muscle)	Agana Boat Basin, Guam	0.2	0.1	<0.1	1.4	<0.2	<0.4	12.6	0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " " "	0.7	0.12	3.1	6.4	<0.4	<0.72	117	0.091	Denton *et al.* 1999
Holothuria atra. (muscle)	Apra Harbor, Guam	all <0.1	<0.1-0.1	<0.1-0.3	0.7-1.2	<0.2	all <0.3	15.5-17.9	0.007-0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	4.9	0.26	8.6	5.19	<0.5	<0.8	180	0.088	Denton *et al.* 1999
Holothuria atra. (muscle)	Agat Marina, Guam	<0.2	<0.1-0.1	<0.1-<0.2	1.3-1.7	<0.2-<0.3	<0.4-<0.6	15.4-17.0	0.022-0.014	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	<0.2	0.1	0.9	3.7	<0.3	<0.5	141	0.072	Denton *et al.* 1999
Holothuria atra. (muscle)	Merizo Pier, Guam	<0.1	0.1	<0.2	2.5	<0.2	<0.4	21.2	0.008	Denton *et al.* 1999
Holothuria atra. (hemal)	" " "	<0.1	0.1	2.9	3.8	<0.2	<0.3	253	0.016	Denton *et al.* 1999
BIVALVES:										
Atactodea striata	Magnetic Island, N. Queensland, Australia	0.8	1.1	1.8	13	2.4	2.0	138	nd	Burdon-Jones et al.1975
Gafrarium tumidum	" " " "	5.7	0.3	1.6	7.1	11.9	3.1	68.8	nd	Burdon-Jones et al.1975
Gafrarium tumidum	Red Rock Bay, Townsville, Australia	5.3	0.3	0.6	7.7	14.5	5.1	26.3	nd	Burdon-Jones et al.1975
FISH (Muscle)										
50 spp.	Great Barrier Reef, Australia	nd	all <0.1	nd	0.47-2.4	all <0.5	all <0.7	4.3-41.8	<0.002-1.9	Denton & Burdon-Jones 1986c
8 spp.	Agana Boat Basin, Guam	all <0.2	all <0.1	<0.1-0.6	0.3-0.8	all <0.4	all <0.9	8.4-48.9	0.009-0.165	Denton *et al.* 1999
17 spp.	Apra Harbor, Guam	<0.1-0.2	all <0.1	all <0.5	0.5-7.8	all <0.4	all <0.8	8.3-34.2	0.012-0.660	Denton *et al.* 1999
6 spp.	Agat Marine, Guam	all <0.2	all <0.1	all <0.3	0.3-0.9	all <0.4	all <0.8	11.5-24.3	0.003-0.214	Denton *et al.* 1999
10 spp.	Merizo Pier, Guam	<0.1-0.3	all <0.1	<0.1-0.5	0.3-0.8	<0.2-<0.7	<0.4-<1.3	9.6-24.3	0.011-0.066	Denton *et al.* 1999

a = Hg determined as ug/g wet weight; b = Hg determined as ug/g dry weight; c = metal determined on a wet weight basis; nd = no data

Table 4: Heavy metals in marine organisms (µg/g dry wt.) from other parts of the world

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Improving Weno Water Distribution System Using Geographic Information System and Hydraulic Modeling Techniques

Basic Information

Title:	Improving Weno Water Distribution System Using Geographic Information System and Hydraulic Modeling Techniques
Project Number:	2003GU24B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	NA
Research Category:	Engineering
Focus Category:	Water Supply, Models, Management and Planning
Descriptors:	Water Distribution System, Geographic Information Systems, Water System Modeling
Principal Investigators:	Leroy F. Heitz, Shahram Khosrowpanah

Publication

PROJECT SYNOPSIS REPORT

Project Title:
Improving Weno Water Distribution System Using Geographic Information System and Hydraulic Modeling Techniques.

Problem and Research Objectives
Water hours and low delivery pressure have long been a part of the daily lives of the people in the Micronesia Islands. The problems with delivery of adequate supplies of water to the customers at appropriate pressure have become more and more of a challenge to Public Utilities through out these islands. Parts of these problems are due to phenomenal growth rate occurring in the island centers. This is particular true on the island of Weno in Chuuk State, Federated States of Micronesia (FSM).

Over the years the Chuuk Public Utility Commission's (CPUC) water distributions system has grown without adequate documentation as to the extent and size of supply and transmission resources and where these resources are located. Just recently several new wells were added to the CPUC's water supply. As built drawings of various portions of the system are non-existent and there is no comprehensive system map available that could be used as a base point for development of a hydraulic model of the system.
The effective management of a utility requires up-to-date information on the physical resources available to the utility manger and how these resources work together to provide the customer with the utility mandated service. Modern and effective water utility management requires the use of Geographic Information Systems (GIS) and computerized hydraulic models of the distribution system to accomplish these management goals. Presently the expertise to use such up to date computer management techniques is unavailable at CPUC.

The objectives of this project were to:

1. Gather data on the complete physical and hydraulic description of the Weno water distribution system.
2. Develop a digital description of the system using the information developed in objective 1.
3. Develop a hydraulic model of the system using the information developed in objectives 1 and 2, and translate this model into a ArcGIS Database of system components.
4. Provide information on the quality of water being pumped from new Asian Development (ADB) funded wells and throughout the distribution system.

Methodology
This proposed project was divided into four phases.

Phase I. Gather complete physical and hydraulic description of the Weno water distribution system
The importance of this phase of the project cannot be overemphasized. It was impossible to develop either a GIS Utility management system or a system wide hydraulic network model until a complete physical description of the water system was available. This was a combined effort between CPUC's operation and engineering staffs and WERI researchers. For this phase all the information that describes the Weno water system such as system maps, as built drawings, and system operation was collected. Researchers used differential Global Positioning System (GPS) techniques to gather location information on system components not included on as-built drawings.

Phase II. Development of GIS based Utility Management System
Upon the completion of the data-gathering phase WERI developed a series of digital maps describing CPUC's water system. The maps were developed in AutoCAD format The maps and accompanying database files were presented to CPUC for verification by the engineering and operations divisions. Corrections were made to any inconsistencies found in the review. The database consisted of the following items:

1. Physical and location description of the pumps, pipes, valves and miscellaneous fittings in the system were gathered. Element attributes recorded includee size, pipe length and diameter, materials, and connectivity to other components of the system. Such parameters as date of installation and condition of the component were added wherever available.
2. A complete physical and location description on all sources of water was gathered. For sources such as wells, all information about the components of the pumping and disinfections systems and their location with respect to the distribution system were added to the digital database.

Phase III. Develop Hydraulic Network Model of the CPUC Water Transmission System
Phase III involved the development of a hydraulic network model of the CPUC system using Haestad Methods Cybernet model. This Windows based model is relatively easy to use and very sophisticated in its capability to model complex looped piping systems. Input data for the model were input from digital AutoCAD maps and the data bases developed in Phase II of the project using the Haestad WaterCAD model running inside the AutoCAD program. The AutoCAD data was then translated exported into ArcGIS shape file format along with the accompanying database files for the attributes of all of the hydraulic elements of the system.

Phase IV. Water Quality Analysis
As part of this study and at the request of Mr. Robert Hadley, Assistant Secretary of Infrastructure Federated States of Micronesia, National Government, samples of water were taken from the Chuuk Public Utility Corporation (CPUC) water distribution system on Weno Island. These samples were analyzed on site and at WERI's water quality analysis laboratory at the University of Guam.

Principal Findings and Significance

Phase I, II and III involved gathering data, providing a geometric description of the water system components in to AutoCAD drawing program, and providing the data required for the development of a hydraulic water distribution system model using the Haestad WaterCAD for AutoCAD program. Figure 1 and 2 shows the system map of the entire Weno water distribution system as represented in the model. Figure 3 provides a detailed close up description of the system located around the Chuuk State Hospital. Table 1 provides the data used to describe the water storage tanks in the system. Table 2 provides the data describing the wells and well pumps in the system. The water distribution system model is completely operational and ready for use by engineers and water mangers seeking to optimize the water system operation.

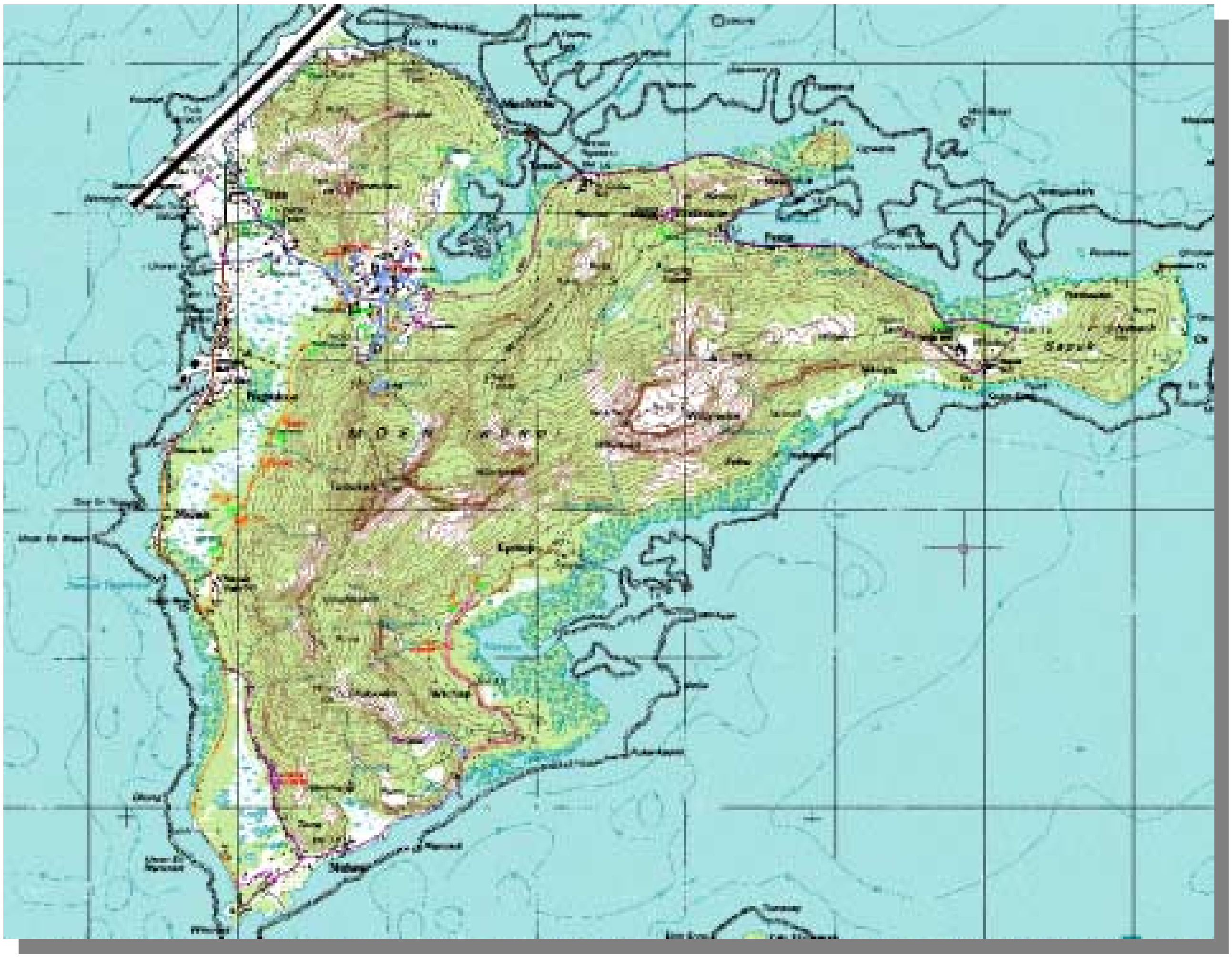


Figure 1 Weno, Chuuk Water Distribution System with USGS Topographic Map Background

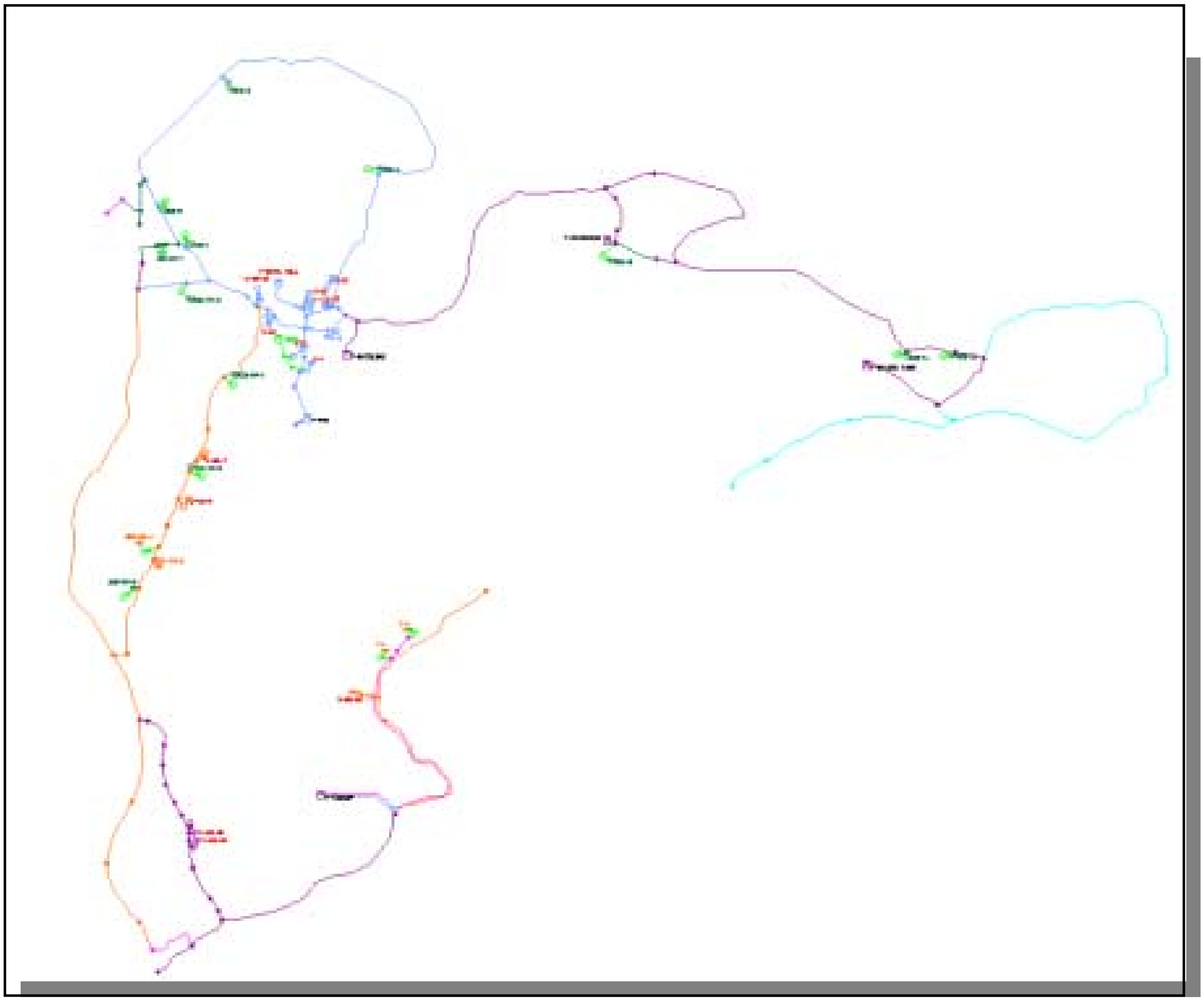


Figure 2 Weno, Chuuk Water Distribution System

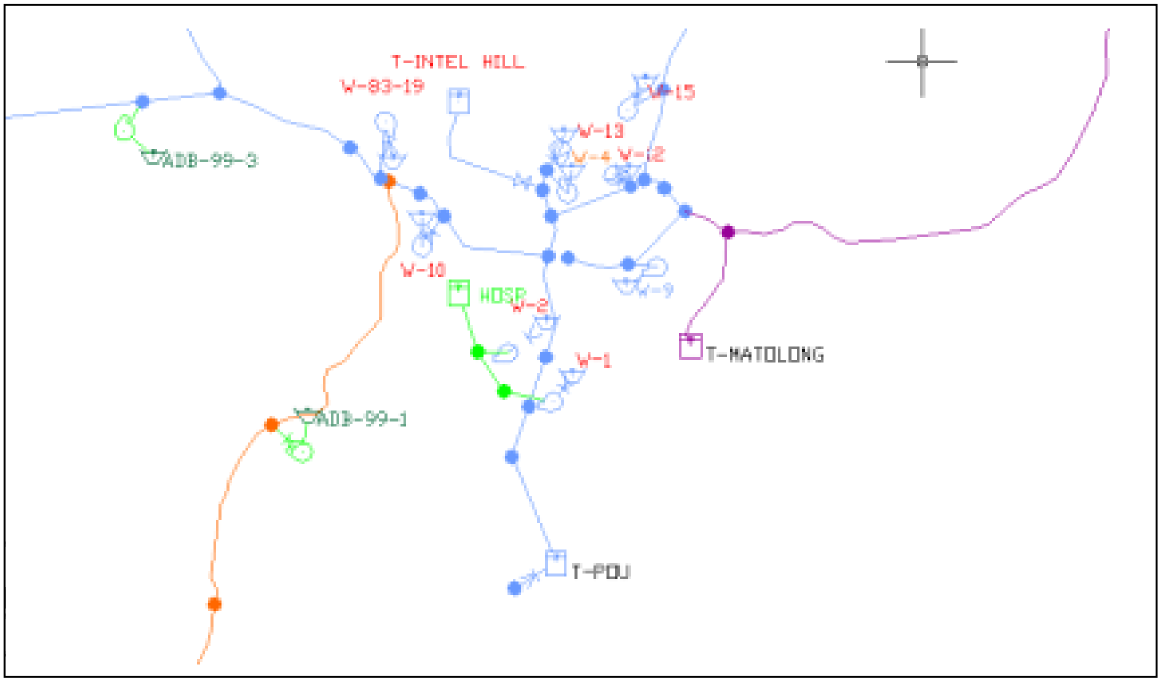


Figure 3 Details of Weno, Chuuk Water Distribution System near the Chuuk State Hospital

	Label	Total Volume (gal)	Tank Diameter (ft)	Base Elevation (ft)	Maximum Level (ft)	Minimum Elevation (ft)	Maximum Elevation (ft)
T-XAVIER TANK	T-XAVIER TANK	999,915.98	75.32	217.00	30.00	217.00	247.00
T-POU	T-POU	999,945.62	65.23	219.00	40.00	219.00	259.00
T-WICHAP	T-WICHAP	999,963.25	72.93	157.00	32.00	157.00	189.00
T-INTEL HILL	T-INTEL HILL	999,892.79	70.75	156.00	34.00	156.00	190.00
T-MATOLONG	T-MATOLONG	1,999,961.09	100.06	156.00	34.00	156.00	190.00
T-PENIESENE	T-PENIESENE	1,000,079.98	77.97	158.00	28.00	158.00	186.00
HOSP	HOSP	0.00	10.00	0.00	0.00	0.00	0.00

Table 1 Description of Tanks in the Weno, Chuuk Water Distribution System

Label	Pump Definition	Elevation (ft)	Label	Pump Definition	Elevation (ft)
PMP-83-22	60S30-5	0.00	PMP-14	60S75-13	0.00
PMP-83-30	60S30-5	0.00	PMP-16	60S20-4	0.00
PMP-TH-5	60S30-5	0.00	PMP-17	60S75-13	0.00
PMP-TH-9	60S50-9	0.00	PMP-18	60S50-9	0.00
PMP-83-7	60S30-5	0.00	PMP-20	60S50-9	0.00
PMP-10	60S30-5	0.00	PMP-21	60S75-13	0.00
PMP-83-19	60S50-9	0.00	PMP-22	60S50-9	0.00
PMP-15	60S30-5	0.00	PMP-23	60S75-13	0.00
PMP-2	60S50-9	0.00	PMP-24	60S75-13	0.00
PMP-1	60S50-9	0.00	PMP-25	60S50-9	0.00
PMP-12	60S50-9	0.00	PMP-26	60S50-9	0.00
PMP-13	60S30-5	0.00	PMP-27	60S20-4	0.00
PMP-7	60S30-5	0.00	PMP-28	60S30-5	0.00
PMP-83-25	60S30-5	0.00	PMP-29	Default Pump De	0.00
PMP-19	60S30-5	0.00	PMP-30	Default Pump De	0.00

Table 2 Well Pump Descriptions

As part of this study, samples of water were taken from the Chuuk Public Utility Corporation (CPUC) water distribution system on Weno Island. Water samples were taken from the newly constructed Asian Development Bank (ADB) funded wells, the older existing wells, from points in the distribution system, and at the Pou water treatment facility. Sampling points are shown in Figure 4.

Physical parameters such as pH, Conductivity, Residual Chlorine and Turbidity were measured at the time the samples were taken, bottles of water were also collected for bacterial and additional chemical analysis. The samples were analyzed for total coliform and *E. coli*. Water samples were taken back to the WERI facility for testing for Nox, PO4-P, Chloride, Calcium, Magnesium, Total Hardness, Iron, Manganese, and Sulfate. A complete listing of all of the analysis results is available in a WERI special report titled "Water Quality Testing Chuuk Public Utility Corporation, Chuuk State, Federated States Of Micronesia (FSM)" by Dr. Leroy F. Heitz and Mr. Harold Wood.

In general the chemical quality of water coming from the wells and the surface water treatment plant is good. Of concern are the chloride levels in Wells ADB 99-3 and ADB 99-4. Both of these sites also had relatively high conductivities. It would be good if the well withdrawal rates were reduced until the chloride levels and conductivities were more in line with the other wells in the system.

The most serious problems are bacterial in nature. Virtually all of the source waters had indicator bacteria total coliform counts greater that zero and many of the sites tested positive for E. coli.

Few of the ADB-Well chlorination systems were operating and none of the existing wells (pre-ADB wells) have chlorination systems at all. This means that only a small number of distribution system customers are being delivered safe potable water. It is recommended that all wells be provided with chlorinators and that adequate supplies of chlorination chemicals be maintained to keep all of these chlorinators operating on a 24 hour 7 day a week basis. Until the entire system is chlorinated the public should be notified that the water must be treated by boiling, home chlorination or some other means in order to make it safe for consumption.

The CPUC should purchase an inexpensive electronic chlorine residual meter and tests should be made on at least a weekly basis both at the well sites and in the distribution system to be sure that adequate Chlorine residuals are being maintained through out the distribution system. After the entire system is chlorinated, additional studies should be made to determine if the water is receiving adequate chlorine contact time before being delivered to customers.

Figure 4. Water Sampling Sites in the Weno, Chuuk Water Distribution system

Speciation Studies of Arsenic in Guam Waters.

Basic Information

Title:	Speciation Studies of Arsenic in Guam Waters.
Project Number:	2003GU26B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Water Quality, Toxic Substances, Non Point Pollution
Descriptors:	Arsenic speciation, arsenic, spring water
Principal Investigators:	Maika Vuki

Publication

1. Maika Vuki, 2004, Arsenic Speciation Study in Guam Waters, Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam 96923, (in preparation)
2. Maika Vuki, 2004, Arsenic Speciation Study in Guam Waters, in College of Liberal Arts and Social Science 25th Annual Research Conference Abstracts, University of Guam, p7.

PROJECT SYNOPSIS REPORT

Project Title: Speciation Studies of Arsenic in Guam Waters

Problem and Research Objectives

The toxicity of arsenic has received both national and international significance over the past 10 years because of it proven carcinogenic properties. High levels of arsenic are often closely associated with areas having high arsenic content in soils and rocks. However, more concern is now centered on manmade impact on arsenic levels in the environment. Some of common uses of arsenic are wood preservatives, pesticide, metal extraction in mining. The most vulnerable systems to be affected are water and air where human are susceptible to contamination. In the U.S. more than 700 sites for drinking water out of the 1300 National Priority sites has been reported to have high arsenic levels. The growing concern of high arsenic levels in ground water in the U.S. has lead to the reduction of the maximum safety limit to 10 part per billion (ppb) in drinking water in 2001.

Arsenic occurs in several forms the environment. Inorganic species, namely arsenite As(III) and arsenate As(V) usually predominate in ground waters and acid mine drains. However, organoarsenicals can often be significance in surface waters, especially when they have been impacted by human activities. The two common organic form of arsenic are monomethyl arsenate and dimethyl arsenate. Two main sources of organic arsenic are come from animal feed supplement and herbicide. As(III) is the most toxic of all the species of arsenic and the conversion between the different forms are possible given the right conditions. Very little is known is known on the fate of these compounds once distributed in the environment.

For the island of Guam, the levels of arsenic in ground water wells are generally low. However, some recent data show significant levels of arsenic in spring waters along Tumon Bay on the northern part of the island. From the nine stations that were studied in Tumon Bay in 2001, arsenic levels ranged from 16 ppb to 100 ppb with the average of 37 ppb. These levels are clearly high and warrant further investigation. Guam’s major industry is tourism and Tumon Bay in the main tourist hub where most hotels are located. The high level of arsenic in the spring water poses a serious threat to holiday makers that rely heavily on its beach and water for recreation. All the springs on Tumon Bay discharge directly into the bay.

The objectives are

i. To investigate the levels of Arsenic in Tumon Bay, the connecting freshwater wells on Guam and other potential sites during the wet and dry season.
ii. To conduct speciation studies of arsenic to ascertain the levels of the different forms of As both organic and inorganic.
iii. To conduct speciation study on the sediments and biota samples
iv. To conduct an interlaboratory validation exercise laboratory
v. To correlate the levels of arsenic to the likely sources and sinks.

Methodology

The first part of the project was to verify the levels previously reported form the two studies along the established sites. The hydride generation method with atomic absorption spectroscopy was used and this method has a detection limit of 1ppb. The method has four pretreatment regimes for the water sample to differentiate the four arsenic species; As(III), As(V), MMA, and DMA. Two pretreatment methods were considered first in this study to determine the levels of inorganic arsenic species, As(III) and As(V). These two forms of arsenic are known to be the major source of toxicity.

Water samples from the 10 sites along Tumon Bay were collected during the dry and wet season. Sampling protocol followed standard method. Samples were acidified with concentrated hydrochloric acid. Replicate samples together with field blanks were collected at the 10 stations for quality assurance. Measurement for pH, dissolved oxygen, salinity, and temperature were conducted at each site.

Water samples were filtered in the laboratory stored under 4^0C in the laboratory before analysis.

The arsenic levels were measured using atomic absorption spectrometry coupled with the hydride generation technique. Three Research Assistants were employed to assist in the laboratory and field activities.

Principal Findings and Significance

Result obtained in this study is shown in Table 1.0. Almost all the values were below 1ppb level. Arsenic levels reported by Guam EPA in 2001 ranges from 16ppb to 100ppb with 37ppb as the average. It is clear that Guam EPA values in 2001 were significantly high. However, a follow up study by Guam EPA in 2002 along the same sites reported on much lower values. The levels of arsenic reported in 2001 along the same locations were much lower and appears to be in agreement with data from this study. The arsenic levels in the Guam spring water are low but further analysis needs to be conducted to confirm the results from this study.

Table 1.0. Levels of inorganic arsenic in Tumon Bay Springs.

Tumon Bay Samples			
		Concentration ug/L	
Sample	**Spring Location**	**July 7, 2003**	**July 29, 2003**
TB1	Hilton On-Site Spring	0.6	0.2
TB2	Hilton On-Shore Spring (Dup.)	0.4	0.2
TB3	Marriott On-Shore Spring	0.4	0.2
TB4	Reef On-Shore Spring	0.4	0.3
TB5	Westin On-Shore Spring	0.6	0.3
TB6	Outrigger Off-Shore Spring	0.6	0.3
TB7	Hyatt Off-Shore Spring	0.4	0.3
TB8	Wet Willie's On-Shore Spring	0.4	0.2
TB9	Gun Beach On-Shore Spring (Background)	0.4	0.4
TB10	Gun Beach Rock Ledge On-Shore Spring	0.4	0.4
TB11 (Exp. Blank)	Blank	0.4	0.2
TB2SP(10)	Hilton On-Shore Spring (Spiked)	9.8	NA
TB9SP(5)	Gunbeach On-Shore Spring (Spiked)	5.8	NA
Std. 5	Calibration standard	Na	4.9
Std. 10	Calibration standard	NA	9.1

Rainwater And Dry Litter Waste Management: An Alternative Water Conservation System In Swine Operations

Basic Information

Title:	Rainwater And Dry Litter Waste Management: An Alternative Water Conservation System In Swine Operations
Project Number:	2003GU13B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	NA
Research Category:	Water Quality
Focus Category:	Agriculture, Water Supply, Management and Planning
Descriptors:	Water Conservation SystemDry Litter SystemRainwater Catchments System
Principal Investigators:	Allan Sabaldica, Lawerence Duponcheel

Publication

PROJECT SYNOPSIS REPORT

Project Title

Rainwater and Dry Litter Waste Management: An Alternative Water Conservation System in Swine Operations

Problem and Research Objectives

Tinian's livestock industry posed two emerging problems not only to farmer/ranchers but also to the whole community. The first one is on animal waste concerning Water Quality issues. Majority of the Tinian farmer/ranchers are located in and around two ridgelines that converge into the same valley where runoff is funneled into the Maui well which is the sole source of drinking water. Presently, hog farmers use the spray-out waste management system that simply deposits solid wastes behind the pens to seep into the ground over time, thereby increasing the risk of water acquifer contamination. Imagine the amount of manure produced per animal and the amount of pollutants it can contribute not only to drinking water but also to coastal water if animal waste were not properly managed. These pollutants can possibly bring diseases in humans and kill aquatic organisms. And secondly, the water supply in farm areas has been a longtime problem in Tinian because of a limited distribution system and high end-user water cost. Ranchers then transport water everyday so as not to affect the animal performance that will eventually affect the animal production.

The objectives of this project were to demonstrate to the public the suitability of the dry litter waste management and rainwater catchments system in swine operations as a method of water conservation. This was accomplished by combining dry litter waste management systems that decreases the need for copious amounts of water and simultaneously reduces the risk of water acquifer contamination by greatly reducing the rate of animal waste seepage into the ground and rainwater catchments systems that decrease the negative impacts to swine production on water security issues by monitoring the water consumption in relation to water collection and application of the *roofrain* spreadsheet in computation of storage tanks, gutter system and roofing size.

Methodology

Project Location/Facility/Pen slope. The Tinian CREES swine experimental pen was renovated by providing PVC gutters (one side only near to Dry Litter system) and water catchments that are all based on the computed water tank storage requirements, gutter system and roof size (see Table 1). The pens were divided into 4 treatment pens and 4 control pens. Each of which consists of 3 of 3x6 and 1 of 6x8 production pen. The treatment pen floors were provided with a 12 % slope that was enough to encourage gravitational flow of dry litter/animal waste into the renovated pen gutter and the control pens with zero slopes. Drinking water was made available to treatment pigs through nipples that are directly connected to a pipe coming from the storage tank located near the pen. Initially, water was provided in the tank. Water collected from rain and water consumed were monitored on a weekly basis using the water gauge installed outside the tank. Due to limited rainfall, any additional water given was recorded. Monthly cleaning of tank storage and or sludge removal was done using a hose.

Carbon materials such as coconut husks were chipped and provided bi-weekly as litter beddings. Bulk-density determinations, total carbon added, and discharged in the pens was recorded to provide farmers with an estimate of local carbon materials needed per pig. Litter beddings were collected and composted regularly (monthly). Wet litter bedding were regularly removed and put in a compost bins. Mixing of litter beddings were done also regularly to further promote composting.

Animal Performance. Treatment pigs were deprived of the usual spray-out system. Control pigs undergo the usual and conventional spray-out and water rationing. Animal health differences as well as animal performance were recorded. Both treatment and control pigs were given with the same food ration.

Principal Findings and Significance

A. Dry Litter Waste Management System:

Pen slope and Carbon Material Interaction:

A twelve percent (12%) slope was provided to Treatment pens. Each pen was initially loaded with coconut husk at about six inches thickness every week. The carbon-nutrient mix needs to flow out of the pens in order to achieve the second benefit of the system (compost). Regular mixing of litter and removal of the wet litter beddings were done when necessary. Shredded coconut husks alone tend to mat down and clog the system for a period of one month. To prevent the litter material to clog the system, a tree trimming were added in two treatment pens. This will provide good aeration and maintain the dryness Shredded coconut litter was also tested to control pens and revealed less significant. It promotes clogging and matting down thus promoting frequency in maintenance and bacterial proliferation. Better decomposition was observed with tree trimmings. When the manure-dry-litter mixture was ready (light, dry and odorless), they were transferred to a composting bin for further composting process. It is recommended that carbon sources be secured by long- term contracts. Pen slopes are the key to the Dry Litter system. It was found out that the decision on pen slope is dependent on the type and availability of the carbon resource.

Building materials. CREES Experimental pen walls are made up of concrete blocks that showed poor results to dry litter system. It only showed that pen of this type prevents air movements around the pens. It is therefore advised to use other materials like mesh-wire or cyclone wire walling for this purpose. This will also decrease investment cost. More roofing was provided to all the pens to maintain the dryness. Roofing gutters was provided to divert the rain from the pens and to collect water for drinking purpose. Pen gutters on the other hand was given ample space for dry litter to accumulate and decompose. A widened pen gutter is advised to help the farmers on the maintenance part.

The data below is showing the size of Tinian Experimental area (roofing's and gutters) and the theoretical value of water that it can capture. A 250-gallon fiberglass water tank was used in the project.

Table 1. Specification/Computation for the Tinian Ag Experimental Pen

Roofing size	
Length	33 ft
Width	20 ft
Gutter (half of the roofing size)	10 ft
Theoretical value on water that can capture	200 gallons of water per inch of rain

B. Rainwater Catchments System:

Rainwater is irregular in Tinian; therefore, we allocated an initial 100 gallons that is enough to sustain the drinking requirement of 7 weaners and 3 growers for 10-12 days. Unfortunately, there were instances that the water has been used up before the rain comes. And not enough water was being collected due to leakages present brought about the overlying trees around the roofing's. It is advised that the entire roof area must be guttered to maximize the water collection and tree branches must be cleared in order to maximize the potential water catchments area.

Table 2. Water Collection Results and Assessment

This research is still ongoing for more data recording. Below are water requirement values for each stage of pigs.

The table below shows the average rainfall in Tinian, however, there were months within a year that is really lower than 3 inches. This is not enough to supply an average of 10-15 pigs (grower-finisher) in a month. To include the amount of water that is loss thru evaporation, run-off and recharge.

Table 2.1 Tinian Water Supply

Tinian Water Cycle (inches per year)	
Rainfall	82”
Evaporation	46”
Run-off	6”
Recharge	30”

Table2.2. Overall water usage for piggery

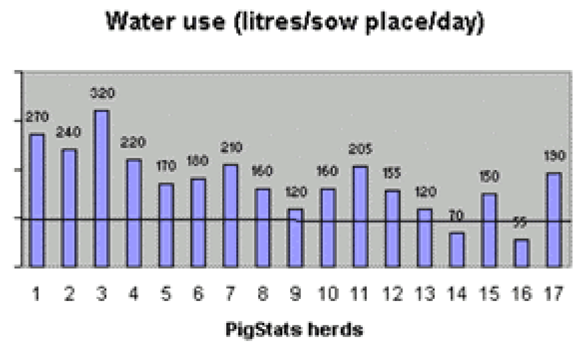
Stage	Liters/day*
Weaners	3
Growers	5
Finishers	6
Dry Sows	11

Lactating Sows	17

**Average/daily consumption for individual pigs can vary 50% from the average*

	Liters / sow place / day*
Drinking water only*	55 liters/sow/day
Wash down water	20 day/sow/day
Total water	75 day/sow/day

**Allowing 50% spillage*



The Roof rain spreadsheet was made available to all livestock clients that need consultation on the possible rainwater catchments designs and size requirements.

The water tank was cleaned in a regular quarterly basis. However, due to the presence of tree branches all over the pens, which contributed to water leakages, it also posed problems to water quality. It is also advised to take precautionary measures in order to prevent rat entry to water tank. Regular sludge and Leaf/ organic decomposition removal must be done to prevent animal health problems. So far, no deleterious effects on the animals were observed.

C. Animal Performance

A total of 10 animals were used in two trials to evaluate the suitability of rainwater catchments and the effects of pen slope and carbon interaction on the performance of weaners and growers. A 12 % slopes and two carbon materials were evaluated. Due to the herd size, only five animals were evaluated per trial. Control pen (with zero slope) was immediately stopped in order to prevent further animal health problems. Dry Litter in control pens tend to mat down or compacted that resulted in clogging the system, moisture build-up, bacterial proliferation and odor and flies problem. A different slope is advice depending on the type of the dry litter to be used. There was no difference in animal performance between the treatment and control. However the overall performance, compared to the treatment, may have been lower due to the slightly wetter conditions. It is recommended that a hog panel must be used instead of concrete blocks to allow good ventilation. In general, the effects of slope and carbon material on the growth performance of the animals are minimal. Based on the Pork Industry Handbook performance guidelines, weight gains and feed conversion matched the profile for good to excellent production. No animal injury was observed with all carbon resource used in the trials.

D. Outreach and Technology Transfer

The Project Investigator and the collaborators presented and disseminated information about the Rainwater catchments and the Modified Dry Litter system at advisory council meetings, workshops, invited conferences and training programs during the project period from 2003-2004. Technology transfer opportunities included regional (Republic of Palau, Yap State and Marshall Islands (3) and national (CNMI and Guam) (4) presentations; as well as exposure in state newspapers (2 articles) and national periodicals (2articles).

The Rain Water and Dry Litter Management System projects have made and are making many impacts in the way people and farmers view the concept of waste management. We are trying to shift paradigms in our outreach efforts; changing keywords such as waste to nutrient, liability to assets, expense to revenue and storage to utilization.

With this concept, United State Environmental Protection Agency (US EPA) granted NMC-CREES under the same Project Director a $70,000 budget to develop more demonstration sites in the western region (FSM, Palau, Guam and CNMI) to further promote and develop an Alternative Waste Management System in view of Water Quality and Water conservation in swine operations. Dry Litter demo sites are already set up in Rota islands, Tinian and Saipan. USDA-NRCS under Environmental Quality Incentive Program (EQIP) was also offering this kind of system for funding.

Information Transfer Program

Information Mangement

Basic Information

Title:	Information Mangement
Project Number:	2003GU16B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Hydrology, Management and Planning
Descriptors:	Water Resources Management, Climatic Data, Rainfall Data
Principal Investigators:	Leroy F. Heitz

Publication

INFORMATION MANAGEMENT

WERI's mission involves maintaining and providing water resources related data to researchers, water resources managers, educators and the general population of the islands of the Western Pacific. This project was used to provide funding to maintain subscriptions to a wide variety of data sources dealing with meteorology, climatology and hydrologic data. These resources are maintained at WERI and made available to researchers, water managers, educators and the general public throughout the region. Communication and information exchange between experts in the area of water resources is vital to the improvements in the wise use of this resource.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2003GU17B
Start Date:	3/1/2003
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, Water Supply
Descriptors:	Water Resources Education, Information Transfer
Principal Investigators:	Leroy F. Heitz

Publication

WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied geographically and by education level. It is important that WERI make this information available in a very widely distributed form.

This project funded the design, layout and printing of four technical completion reports resulting from USGS funded research projects. One hundred (100) hard copies of each report were printed and the reports were prepared for publication on WERI's Web page and entered into WERI's on-line searchable Technical Reports Data Base.

WERI's Web page, shown below, is located at http://weriguam.org/home/index.htm, and is the Institute's focus for Information Transfer/ Dissemination.

WERI Web Page

It is very important that WERI's Web page be updated and optimized on a regular basis. To provide this a professional web maintenance firm was contracted to provide maintenance to the WERI Web page on a regular basis. This year the firm also worked on finishing up digitizing all old WERI technical completion report finalized a database search engine for accessing the technical completion reports on line.

Because of Guam's remote location it is difficult and quite costly for researchers to present their findings at technical conferences and symposiums. This project funded a portion of off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past 104-B research projects.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	5	0	0	0	5
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	9	0	0	0	9

Notable Awards and Achievements

Publications from Prior Projects

1. 2000GU10B ("Erosion and Sedimentation Processes in Southern Guam") - Water Resources Research Institute Reports - Scheman, Nicole; Shahram Khosrowpanah, Mohammad Golabi,and Leroy Heitz, 2002, Identification of Erosion Processses and Sources of Exposed Patches in the Lasa Fua Watershed of Southern Guam, Water and Environemntal Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, Technical Report 99, 70pp
2. 2001GU1342B ("Development of Monthly and Seasonal Rainfall Climatologies and Distribution Maps for Guam") - Water Resources Research Institute Reports - Lander, Mark; Charles Guard, Mohammad Creation of a 50-year Rainfall Database, Annual Rainfall Climatology, and Annual Rainfall Distribution Map for Guam, Water and Environemntal Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, Technical Report Number 102, 26pp
3. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Water Resources Research Institute Reports - Stafford, Kevin; John E. Mylroie, John Jenson, 2002, Karst Geology and Hydrology of Tinian and Rota (Luta), CNMI A Preliminary Report, Water and Environemntal Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, Technical Report Number 96, 70pp