Guam Hydrologic Survey (GHS)

&

Comprehensive Water Monitoring Program (CWMP)

FY 2007

Status Report

WATER AND ENVIRONMENTAL RESEARCH INSTITUTE
OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

October 2007

GUAM HYDROLOGIC SURVEY (GHS) AND COMPREHENSIVE WATER MONITORING PROGRAM (CMP)

FY 2007
STATUS REPORT

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Water & Environmental Research Institute of the Western Pacific
University of Guam

PROGRAM MISSION STATEMENT

The Guam Hydrologic Survey (GHS) and the Comprehensive Water Monitoring Program (CWMP) were created in 1998 by the 24th Guam Legislature under Public Laws No. 24-247 and 24-161 respectively. Both programs were created in response to Governor Carl Gutierrez' Vision 2001 initiative to maintain a sustainable supply of clean drinking water necessary to promote and ensure the economic growth and prosperity predicted for the island. The Water and Environmental Research Institute (WERI) was charged with administering the annual legislative appropriations necessary to drive these two programs and facilitate, direct and implement their primary objectives. Both programs are now an integral component of the WERI water resources research, information dissemination, education and training mission, both on Guam and throughout the region.

PROGRAM GOALS

The purpose of GHS is to consolidate Guam's hydrological data gathered over the years by local and federal government agencies and consultants, and to conduct research on water related issues of local importance. GHS also funds a diversity of water resource educational programs in various formats, including guest lectures and seminars at UOG and in the community, informational and training workshops for teachers and professionals from other government agencies, field trips and talks for schoolchildren, and the publication and distribution of educational posters, maps, and fact sheets.

The CWMP was created to collect data on: a) saltwater intrusion and water lens thickness in Guam's sole source aquifer in the northern part of the island and b) stream flow and other parameters associated with surface waters in the south. The program builds on studies previously undertaken by the US Geological Survey (USGS) that were abandoned several years earlier because of a discontinuance of matching funds from the Government of Guam. The CWMP annual appropriations from the Guam legislature have facilitated the collaborative reinstatement of these studies with USGS under their 50-50 Federal/State-Territory cost-sharing program for water resource monitoring.

The foresight of the Guam Legislature in creating these two very important programs deserves special mention here. Through their efforts and continued support, we have consolidated and interpreted several vital water resources databases for Guam and revitalized the USGS water monitoring program. Our understanding of the complex physical, chemical and biological processes that influence Guam's water resources has broadened considerably and the increase in graduate student research opportunities provided by the programs has substantially added to the number of highly trained water resources professionals entering the island's work force.

PROGRAM FUNDING AND FY'07 OBJECTIVES

The FY'07 appropriations for the GHS and CWMP programs were $204,200 and $173,948 respectively. A similar amount was received for FY'08. The information presented herein summarizes all GHS and CWMP program objectives and related activities undertaken in FY'07.

PROGRAM OBJECTIVES AND OUTCOMES FOR FY'07

GUAM HYDROLOGIC SURVEY (GHS)

In FY 2007, GHS provided funding to maintain the state of the art computer analysis and Geographic Information System (GIS) laboratory housed in WERI. Almost every water research project carried out by WERI involves a GIS analysis and mapping component. The GIS laboratory provides the required hardware and expertise in GIS analysis and serves as a data archive for GIS generated databases. WERI also works closely with various Government of Guam and Federal Agencies in sharing GIS data that becomes available.

Students in New Computer Analysis and GIS Laboratory

ARCMAP GIS Soft Ware

GHS provides limited stipends, tuition, and fees for research graduate students working on their MS degree in Environmental Science, several UOG undergraduate field and lab assistants, and partial summer salaries to WERI faculty advising those students. GHS funds the salary of a fulltime research associate charged with operating WERI's complex and sophisticated computer analysis and GIS facility.

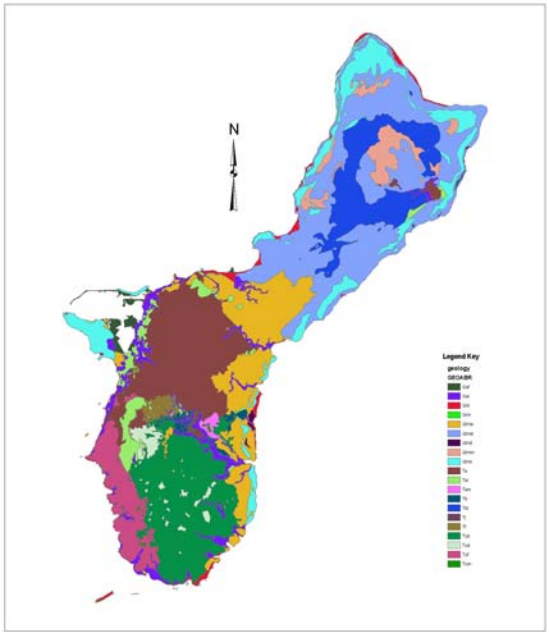
Research Projects Completed in FY07:

Four of seven highly significant projects either initiated or underway in FY06/07 have now been completed. Theses are: 1) an update of the geologic map of Guam; 2) a determination of background fluorescent materials in Guam's groundwater; 3) a heavy metal assessment of sediments and biota in the Lonfit River upstream and downstream of Ordot Dump, and 4) a digital annotated continuous aerial image of Guam's coast. A summary report for each project is given below.

1. *Updating the Geologic Map of Guam* (Total cost: $51,170)

Accurate knowledge of the origins, history, characteristics, and field relationships of the rock units and surface deposits of any given locale provides the essential basis for earth scientists to provide reliable and accurate scientific advice to developers, planners, engineers, resource managers, policy makers, and regulators, as well as other scientists in related disciplines. Geologic maps, in particular, support successful prospecting for mineral and groundwater resources; evaluation of geologic hazards; informed planning for the development and management of watersheds and agricultural land; the construction of airports, roads, aqueducts, and pipelines; and the development of safe and livable urban centers. Guam is fortunate that the US Geological Survey conducted a

comprehensive study of the island's geology in the 1950s and 1960s, which revealed the fundamental geological origins of Guam and produced a map that has been a valuable resource for the economic development of the island. Subsequent work by geologists with the benefit of the past 40 years of accumulated knowledge of regional geology, as well as new technology for dating rocks and conducting spatial analysis, however, has revealed some errors in the original map, shed new light on questions that were left unresolved, and resulted in some revision of the interpretations of the original study. Moreover, the emergence of new and better techniques for dating certain types of rocks, including cave deposits, has made it possible to obtain information on ages of rock units and related features that were not available to earlier workers.



Geological Map of Guam

This recently completed study has yielded an updated geologic map of Guam incorporating all of the revisions of the past 40 years as well as some new data on selected questions is in the final stages of production. The map has been published at two scales: a single 15-minute quadrangle and seven 7.5-minute quadrangles. These include more accurate and precise dates of the volcanic rocks, corrections to the limestone stratigraphy, and new information on post-emergence history of the limestone units, including ages of cave deposits, and post-emergence climate history of Guam. If additional funding and qualified student research assistants become available to extend this work, future studies will be conducted to resolve remaining questions relating to the ages, origins, and stratigraphic relationships of some of the volcanic units of southern Guam

2. *Determining Background Fluorescence in Guam's Groundwater* (Total cost: $79,799)

Dye trace studies are an effective and meaningful way to characterize groundwater transport within an aquifer. Such studies on Guam have revealed a highly-permeable, triple-porosity system in the Northern Guam Lens Aquifer. Results of a 2002 study conducted by David Moran and funded by the Guam Hydrological Survey (GHS) and the Guam Environmental Protection Agency (EPA) indicate that injected dyes carried by slow, diffuse flow through the bedrock matrix may discharge continuously over several months. These long term dye residuals have important implications when considering how to interpret the results of past and future dye trace studies.

True background fluorescence arises from overlapping spectra of other fluorescent materials, but contamination by the actual tracer material poses the most common threat. The tracer may be derived from off-site sources or it may mimic the spectra of another fluorescent material present.

Data Gathering for Background Fluorescence Study

This recently completed project revealed in detail the extant fluorescence in Guam's coastal waters, and provides the basis for reliable interpretation of future dye trace studies now only on Guam in other coastal areas of similar geology and climate. It supported an Environmental Science Masters thesis, and the findings will soon be published in a WERI technical report, and ultimately in the professional literature, as well.

3. *Heavy Metal Assessment of Sediments and Biota in the Lonfit River Upstream and Downstream of Ordot Dump* (Total cost: $57,306)

Guam's only civilian waste disposal facility is located just outside the village of Ordot in the center of the island. Ordot Dump as it is locally known has been in continuous use for over 50 years and has been operating at over capacity for almost 20 years. The western borders of the dump encroach on wetlands that drain into the Lonfit River. This rather picturesque stream converges with the Sigua River further downstream to form the Pago River, which in turn drains into Pago Bay on the eastern side of the island. Local residents fish all three rivers for food and the adjacent lands support a variety of agricultural activities including subsistence farming.

Unlike modern sanitary landfills, Ordot Dump is unlined and does not have a leachate retention system in place. As a result, streams of brown, foul smelling leachate intermittently flow from the perimeter of the dump and find their way into the Lonfit River valley below. Chemical characterization of the leachate streams has been attempted on a number of occasions since 1982. In each case, heavy metals have been identified as the contaminants of primary concern, both from an ecological and human health perspective. Specific elements flagged as exceeding toxicity thresholds include arsenic, chromium, copper, iron, lead, manganese, mercury, nickel, silver and zinc. Since these metals predominantly exist in particulate form, they were anticipated to be deposited in bottom sediments immediately downstream of the dump. Local residents have long expressed concern over

Aerial View of Ordot Dump

the impact of these contaminants on biotic resources within the watershed and are of the general opinion that all fish, shrimp and edible mollusks in the Lonfit and Pago Rivers are unfit for human consumption.

Lonfit River Downsteam of Ordot after Major Storm Event

This study examined the heavy metal content of sediments and biota from 15 sites within the Lonfit, Pago and Sigua Rivers. No significant difference were found between samples collected upstream or downstream of the dump suggesting the rivers are purged clean during high stream flow conditions. Certainly, metal profiles in both biotic and abiotic components analyzed were typical of relatively clean background conditions from a heavy metal pollution standpoint. This self cleansing mechanism was of considerable interest local regulators involved with implementing appropriate remediation strategies for the Ordot Dump once the facility is closed in 2008. A summary of the findings is soon to published in *Micronesica.*

4. ***Digital Annotated Continuous Aerial Image of Guam's Coast*** **(Total cost: $10,000)**
Practically any field-orientated research relies to some extent on aerial photography. At the very minimum, a researcher desires a high quality, high resolution view of his/her study site. More often, one desires a range of images covering a wider area of several different sites. While orthocorrected stereo images currently available for Guam are undoubtedly useful, they can be difficult to interpret, provide an unnatural perspective, lack aesthetic appeal necessary for data presentation , and fail to reveal many details not visible from directly overhead (e.g., cliff line geomorphology, height of vegetative cover etc.). They are also expensive to produce and are quickly outdated. On the other hand, oblique aerial images provide an inherently more natural perspective which human brain interprets without effort. They allow us to better visualize spatial relationships in a given area and can thus positively influence researchers' thinking, work and data quality. Oblique aerial photos are also inexpensive to obtain and easy to update. Finally they provide appealing material for publication and presentation of data. However, they do have three major drawbacks: high quality aerial photographs are often subject to copyright, data sets are incomplete as photographers tend to take pictures of interesting views rather than uninterrupted image arrays, and most importantly, they are extremely difficult to index and keep organized. By producing a comprehensive series of aerial views of the entire coastline of Guam, seen from a constant angle and elevation, and stitched together to a continuous digital file that is easy to browse, zoom in and out, manipulate and interpret, this project resolves all the shortcomings mentioned above.

Oblique Aerial Photograph of Northern Guam Coastline

The final product boasts an up-to–date, high resolution, full-color, copyright-free set of oblique aerials that avoids cumbersome indexing yet stays organized and is inherently easy to use. These high resolution photographs of the Guam coastline were shot from a small aircraft. They were taken at a continuous rate and steady angel, elevation and distance from the coastline over a period of several days. The hundreds of photographs were digitally stitched together into an uninterrupted, very long image of the entire coastline. Several version images (at different dpi resolution, jpg compression levels etc.) were made to ensure best suitability for different purposes (e.g., fast browsing, zooming in for detail, high quality printing). Layers of additional information was superimposed on the image to provide place names and ensure easy navigation, and can be turned on and off by the user. The built in annotations include the names of beaches, stretches of cliff line, bays, headlands, coastal points, offshore islets, reefs, river mouths, etc. and are provided in two versions: official U.S. toponymy and standard Chamorro orthography.

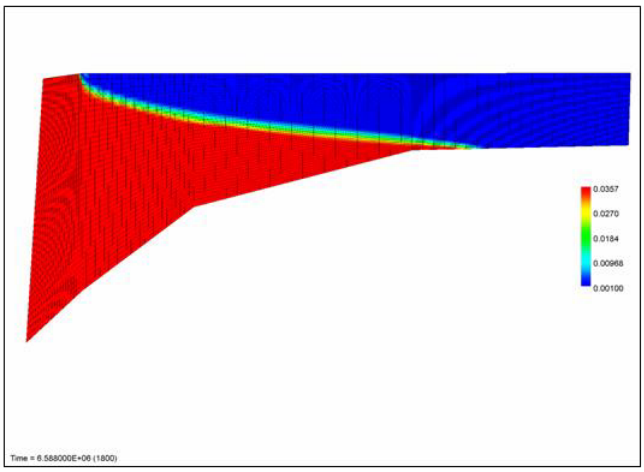
The end user simply needs to open the mage and scroll along the left and right to roll through aerial views of the coastline in clockwise and counter clockwise directions. This is an exceedingly easy and natural way to locate the necessary visual information, which can never become displaced or disorganized. Using Photoshop or any other similar software, the user can select various annotation layers (place names) to be displayed or not; can zoom in and out; can copy and paste any details; can save, print and modify any part of the image, etc. This up-to-date, extremely easy to use, annotated and organized set of copyright-free oblique aerial photographs is sure to become an irreplaceable resource to anyone doing field-related research in or near Guam's coastline.

The final product is presented as a digitally annotated continuous aerial image of the entire coastline of Guam. It is available on a single DVD containing the highest resolution (TIFF at 7 mega pixels) version of the image for greatest detail, several lower resolution/JPG compressed versions for quick browsing on different machines or online via WERI's website, and print-optimized 300 dpi PDF and web-optimized PDF versions of the same image. An attractively designed CMYK printer-ready poster-size PDF is also available. The product is currently being loaded onto the WERI web site and should be available for general viewing shortly.

Research Projects Initiated or Ongoing during FY07:
The three remaining projects which are poised on the brink of yield highly significant data are: 1) the development of a unified model for contaminant transport within the saturated zone of the northern Guam lens aquifer (Phase II), 2) the role of soil moisture in determining the evapotranspiration and aquifer recharge in northern Guam, and 3) recent hydrologic conditions on Guam. The significance and current status of each of these studies are outlined below.

1. ***Development of a Unified Model for Contaminant Transport Within the Saturated Zone of the Northern Guam Lens Aquifer, Phase II: Model Development, Testing, and Analysis*** **(Total cost to date: $104,592)**

The fresh water lens contained within the limestone plateau of northern Guam is the primary drinking water resource for the residents of Guam. Increasing demand for water resources is beginning to result in the degradation of water quality within portions of the Lens. In order to meet future water demand, while maintaining acceptable water quality, water resource managers must be provided with the most up-to-date estimates of sustainable yield available. Recent observational studies, preformed within the Lens, indicate that that the volume of freshwater stored within the lens is constantly changing due to changes in recharge volume and local sea level. The dynamic processes that regulate the Lens volume have not been fully accounted for in past estimates of Lens sustainable yield. Computer-based, groundwater flow and contaminant transport models may be used to investigate the effects of changing recharge volume and sea level. This ongoing project intends to develop, and test a three-dimensional finite-element groundwater flow and contaminant transport model for the Northern Guam Lens Aquifer. This model will then be used to estimate the volume of water that may be safely extracted from the lens.



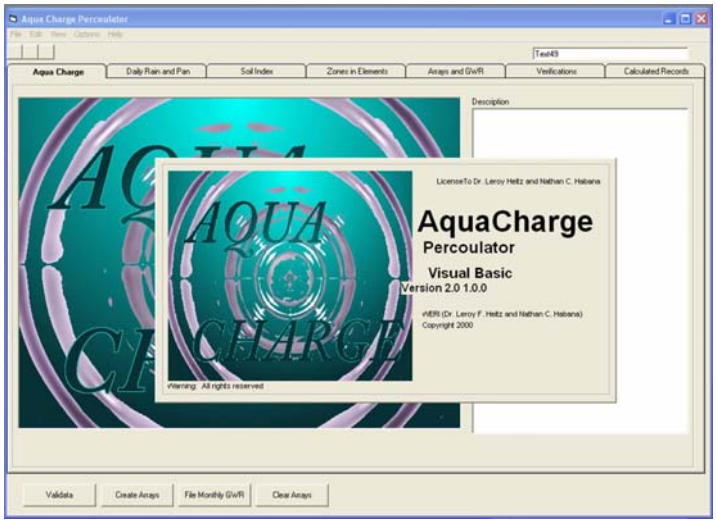
Simulated Cross Section of the Northern Guam Lens Aquifer

A computer-based, finite-element groundwater flow and contaminant transport model, similar to the USGS model SUTRA is currently under development. The two-dimensional version of this model is currently being used to evaluate estimates of recharge to the Northern Guam Lens Aquifer (figure 1). Once completed the three-dimensional model with be used to: 1) evaluate the effects of changing recharge and sea level on Lens volume, 2) estimate the maximum volume of water that maybe extracted from the lens while maintaining water quality, and 3) maximize aquifer development strategies.

2. *The Role of Soil Moisture in Determining the Evapotranspiration and Aquifer Recharge in Northern Guam* (Total cost to date: $75,893)

The northern Guam lens aquifer is arguably one of Guam's most valuable renewable resources. Currently, around 80% of the freshwater used on the island is extracted from this aquifer. In order to effectively manage this vital resource, it is essential to have a reliable estimate of its sustainable yield and where production wells would best be located.

In the early days of development of the northern Guam aquifer, well placement and development were rather easy. Almost all wells developed in the loosely defined aquifer boundaries produced high quality water at good flow rates. Now this situation has changed. As development approaches the sustainable yield of the aquifer, successful new well expansion has become more and more difficult.



The AquaCharge Model is Used to Assess Temporal and Spatial Evapotranspiration Variability across the Aquifer

A more in-depth understanding of net rainfall inputs or recharge to the aquifer, broad term aquifer hydraulics, and the impacts of mans developments above the aquifer is essential to sound management of the underlying groundwater system. More importantly, these improved understandings need to be brought together into a numerical model of the aquifer with which we can explore and optimize various aquifer development and protection scenarios.

This ongoing study is aimed at gaining an improved understanding of the spatial and time distribution of the rainfall that recharges the northern Guam aquifer system and the role that soil moisture has in determining these distributions. Any modeling and management efforts are severely hampered without a better understanding of this part of the aquifer hydrologic system.

In a previous study, we developed a computer program named AquaCharge. This program allows us to look at the spatial and time variability of evapotranspiration across the aquifer. Using this program, we are examining various relationships between evapotranspiration, pan evaporation, and soil moisture. In addition we are adding a component of the model to simulate the time lag and attenuation of the rainfall as it flows down through the soil and limestone materials before reaching the aquifer.

To date, the Geographic Information System (GIS) input files have been developed to match the requirements of the latest groundwater model used to simulate groundwater flow through the northern Guam aquifer system. GIS layers have been developed to describe the groundwater model mesh, soils conditions, and rain and evaporation gage

locations. These layers have been processed in the ArcView GIS program to provide the required input database files for processing by the Aquacharge model. The Aquacharge model has also been successfully modified to provide direct input to the groundwater model that is presently in use.

Later this year a previously developed routing routine will be added to the Aquacharge model to simulate the time delay and attenuation affect that is experienced as rainfall makes it was down to the aquifer system. Various routing parameters will be tested to match the response that is seen in the aquifer for different rainfall events. Next three sets of soil moisture vs. evapotranspiration effectiveness curves will be developed for each of the soil types in Northern Guam. The Aquacharge model will then apply to each set to a twenty-year record of daily rainfall and daily pan evaporation. The results of these runs will then be compared with each other and with previously used values of pan coefficients to formulate recommendations concerning which relationships lead to the most realistic recharge rates.

3. *Recent Hydrologic Conditions of Guam* (Total cost to date: $40,000)

Several agencies are responsible for developing and managing freshwater supplies on the island of Guam. Approximately 74 percent of the water produced on the island is provided by the Guam Waterworks Authority. The remainder is produced by the Air Force and Navy installations on Guam. Ground water supplies about 80 percent of the freshwater for the island's nearly 150,000 residents and one million visitors per year. In northern Guam, water is obtained from wells that tap the upper part of a fresh ground-water lens in an aquifer composed mainly of limestone. About 180 wells, nearly all in northern Guam, withdraw more than 35 million gallons per day of water with chloride concentrations ranging from less than 10 to almost 600 milligrams per liter. In southern Guam, the main source of freshwater is from surface water that runs off the weathered volcanic rocks that are exposed over much of the area. About 10 million gallons per day of freshwater is obtained using surface water sources in the Fena and Ugum watersheds. The island's freshwater resources are adequate to meet current needs, but future demands will eventually be higher owing to increases in population growth. Periodic summaries of recent hydrologic conditions are needed to evaluate the status of water resources and to quantify stresses on existing water supplies.

GWA Produces Approximately 74% of Guam's Drinking Water

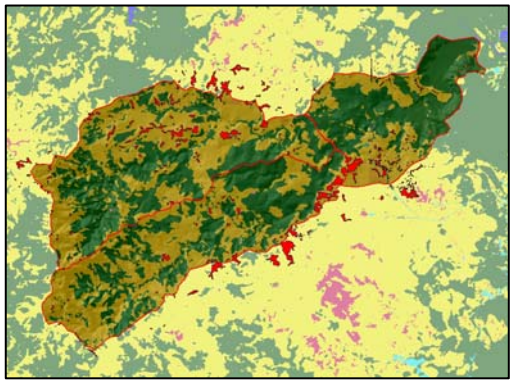
The primary objective of this recently initiated project is to create and maintain a set of dynamic web pages that present historic and recent hydrologic conditions on Guam. The hydrologic data will include selected rainfall records, water levels and transition-zone profiles in monitoring wells, pumping rates and chloride concentrations of municipal and military production wells, and selected streamflow records.

Available hydrologic data has been gathered from cooperating agencies and presented in simple graphical formats to show how recent hydrologic conditions compare to long-term trends. Sources of data include: 1) rainfall records from the National Weather Service and the U.S. Geological Survey; 2) continuous water-level records from the U.S. Geological Survey; 3) transition-zone profiles from the U.S. Geological Survey; 4) production well pumping rates and chloride concentrations from Guam Waterworks Authority, the U.S. Air Force, and the U.S. Navy, and 5) streamflow records from the U.S. Geological Survey.

The web pages created from this work will be updated quarterly as data becomes available from cooperating agencies. In addition, they have internet links to all of the cooperating agencies and to the historic and recent data compiled from the cooperating agencies. Data is released with the agreement of cooperating agencies.

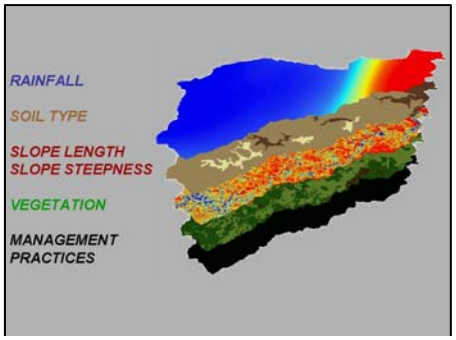
GHS Related Research Activities Funded by Other Sources

1. *Ugum River Watershed Study*: Phase I & II (independently funded by USGS and NOAA)



Map of Ugam Watershed Showing Watershed Boundaries

WERI investigators recently completed a watershed study of the Ugum River Basin. This river is particularly important to Guam since it is the major freshwater source for south Guam's drinking water supply. The study used streamflow and sediment data gathered under the Guam Monitoring Program and GIS data gathered under the Guam Hydrologic Survey to identify sources of non-point-source pollution in the Ugum basin. A companion study has developed strategies for modeling sediment production in the basin using GIS modeling techniques and the commercial software package ArcGIS®. In this particular study a method the Universal Soil Loss Equation (USLE) was used to calculate long-term average annual soil loss within the basin after considering such watershed characteristics as rainfall, soil types, slope, and vegetation cover. The GIS was used to store the USLE factors as individual digital layers and create a soil erosion potential map. The findings of these studies are available as WERI Technical Reports (Nos. 109 and 117) and can be



GIS Layers Used to Build Ugum Watershed Soil Erosion Model

downloaded from the WERI website: http://weriguam.org/home/index.htm.

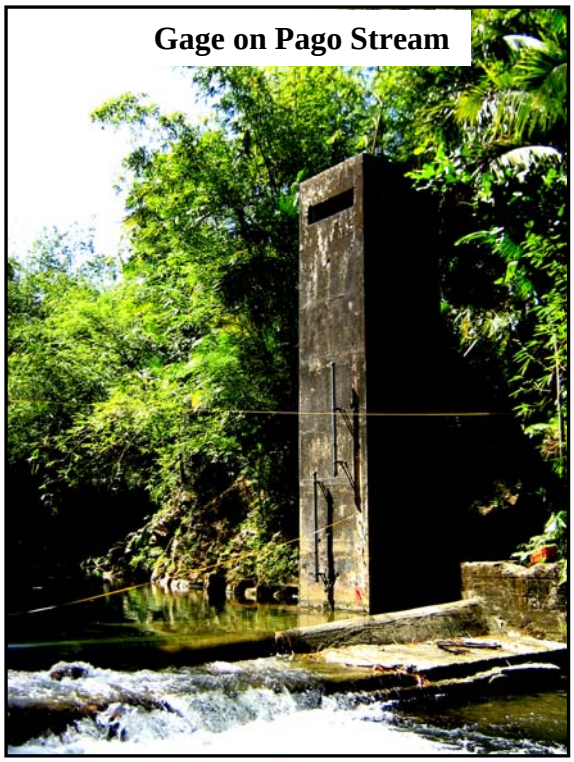
2. *Impact of Ordot Dump on Pago Bay* (independently funded by USGS and NOAA)
WERI investigators have recently completed a heavy metal assessment of biotic an abiotic components in Pago Bay. This study was seen as a logical extension of the GHS work undertaken in the Lonfit-Pago River system and was designed to explore the potential impact of the heavy metal enriched leachate discharges from Ordot Dump on this coral reef environment. It was jointly funded by grants from USGS (104-B) and NOAA. The findings of the study are available as a WERI Technical Report (No. 113, 63 pp. 22006) and can be downloaded via the WERI website.

Sediment Plume in Pago Bay Reef Channel after Storm Event

The study clearly showed that Pago Bay is not a permanent sink for sediment bound metal contaminants mobilized downstream from the Ordot Dump. Further, any contaminated sediments deposited in and around the river mouth, the reef channel and the southern half of the bay during a normal wet season, are re-suspended and flushed from the system by major storms (typhoons) that approach the eastern side of the island. Under such conditions, the reef channel serves as a conduit for their transportation and dispersion into offshore waters beyond the reef margin. Thus the climatic and topographic characteristics of the area conspire to provide an effective means of periodically flushing out pockets of contaminated sediments from the entire watershed into the ocean.

Comprehensive Water Monitoring Program (CWMP)

The United States Geological Survey (USGS) has monitored our island's water resources since 1951. Unfortunately, several years ago, they were forced to downsize this program because matching support from the Government of Guam was discontinued. This resulted in the abandonment of all deep monitoring wells needed to monitor saltwater intrusion in the north, and most of the stream gages in the south. Then in 1995, the USGS closed its field office at Naval Station, but continued to run a limited monitoring program (out of its Saipan and Honolulu offices).



Gage on Pago Stream

In August, 1998 the CWMP was made a permanent part of WERI's program when Governor Gutierrez signed PL 24-247. This resulted in the refurbishment of the deep monitor wells and a renewed program of water resource monitoring on Guam. The intent PL 24-161 was to restore, and then to expand, as needed, the discontinued monitoring program in order to help Guam manage and safeguard all of its freshwater resources, now and in the future. Under PL 24-161, WERI/UOG and the USGS entered into a memorandum of understanding to administer and fund this program on a 50/50 cost-sharing basis. The CWMP is a permanent investment in Guam's future.

Ugum Stream Sediment Sampler

In 2002, Typhoons Chataan and Pongsona produced record high streamflows in Guam. Unfortunately these record high flows caused severe damage to the entire stream gage network which included 12 recording stream gages and 2 crest-stage gages in operation at that time. During 2003 and 2004 all of the damaged sites were repaired and re-instrumented. During 2004 and 2005, two new sediment-monitoring stations were added to the surface water measurement sites. The 2005-2006 CWMP project funding was used to continue to gather the valuable data obtained from the stream gage sites. The current USGS program on Guam includes 8 stream gages, 2 crest-stage gages, 2 suspended sediment gages, and 7 rain gages. All of these sites, except for those in the Fena Watershed, are operated as part of the CWMP.

Deploying water level and salinity monitoring equipment into a well near Ghura-Dededo

The CWMP also operates the ground water monitoring program on Guam. This includes water level and salinity monitoring in 14 wells in the Northern Guam Aquifer, plus a tide gage for reference in Agana Harbor. These gages provide long-term information on the conditions of the aquifer and are used to assess the affects of pumpage and climate variability. Additionally, in 2004-05, high resolution measurement and recording of changes in conductivity (an indirect measurement of water salinity) and water level was measured at four well sites in a collaborative project between Guam EPA, WERI, and USGS . This data will be used in the development and calibration of a ground water flow model (SUTRA) that is being funded through a Guam Hydrologic Survey project.

The data collected under the CWMP is essential to the sustainable management of the surface and groundwater resources of Guam. This information can be downloaded directly from the USGS Pacific Islands Water Science Center Web Site at http://hi.water.usgs.gov/ or through the WERI website at http://weriguam.org/home/index.htm. In 2007, WERI and the USGS developed an updated web interface that dramatically improved access to hydrologic information about Guam, and summarizes recent hydrologic conditions on the island.

Locations of USGS monitoring stations on Guam

GHS PUBLICATIONS AND ASSOCIATED DOCUMENTS

Contractor, D.N. and J.W. Jenson (1999). Simulated Effect of Vadose Infiltration on Water Levels in the Northern Guam Lens Aquifer. *Water and Environmental Research Institute (WERI) Technical Report* No. 90, 18 pp.

Denton, G.R.W., M.C. Olsen and Y. Wen (2007). Solid Waste Disposal on Guam: The Impact of an Unsanitary Landfill on the Heavy Metal Status of Adjacent Community Representatives. *Micronesica* (in press).

Denton, G.R.W., W.C. Kelly III, H.R. Wood and Y. Wen (2006). Impact of Metal Enriched leachate from Ordot Dump on the Heavy Metal Status of Biotic and Abiotic Components in Pago Bay. *Water and Environmental Research Institute (WERI) Technical Report* No. 113, 63 pp.

Gamble, D. W., D. Taboroši, J.E. Mylroie, J.W. Jenson, J.L. Carew, J.M.U. Jocson, J.R. Mylroie and D.T. Vann (2003) The Use of Water Temperature to Characterize Groundwater Discharge of a Coastal Fracture on Guam, U.S.A.: *Journal of Coastal Research,* 19: 462-471.

Hoffman, S.M., J.W. Jenson, D. Moran, G.R.W Denton, H.R. Wood and L. Vacher (2007). A Qualitative Baseline Study of Background Fluorescence in Guam's Groundwater. *Water and Environmental Research Institute (WERI) Technical Report* in press

Jenson, J.W. and J.M.U. Jocson (1998). Hydrologic Data Collection for Guam. *Water and Environmental Research Institute (WERI) Technical Report* No. 83, 46 pp.

Jenson, J.W., T.M. Keel, J.E. Mylroie, J.R. Mylroie, K.W. Stafford, D. Taboroši, and C. Wexel (2004). Karst of the Mariana Islands, *Geological Society of America Special Publication* (in review).

Jocson, J.M.U., J.W. Jocson, and D.N. Contractor (1999). Numerical Modeling and Field Investigations of Infiltration, Recharge, and Discharge in the Northern Guam Lens Aquifer. *Water and Environmental Research Institute (WERI) Technical Report* No.88, 22 pp.

Jocson, J.M.U., J.W. Jenson and D.N. Contractor (2002). Recharge and Aquifer Response: Northern Guam Lens Aquifer, Guam, Mariana Islands. *Journal of Hydrology*, 260: 231-254.

Khosrowpanah, S., L.F. Heitz, Y. Wen and M. Park (2007). Developing a GIS-Based Soil Erosion Potential Model of the Ugum Watershed. *Water and Environmental Research Institute (WERI) Technical Report* No. 117. 98 pp.

Khosrowpanah, S. and J. Jocson (2005). Environmental Assessment for Non-Point Sources of Pollution for Ugum Watershed. *Water and Environmental Research Institute (WERI) Technical Report* No. 109, 53 pp.

Lander, M.A., J.W. Jenson and C. Beausoliel (2001). Responses of Well Water Levels on Northern Guam to Variations of Rainfall and Sea Level, *Water and Environmental Research Institute (WERI) Technical Report* No. 94, 36 pp.

Moran D. C. and J.W. Jenson (2004). Dye Trace of Groundwater Flow from Guam International Airport and Harmon Sink to Agana Bay and Tumon Bay, Guam. *Water and Environmental Research Institute (WERI) Technical Report* No. 97, 32 pp.

Mylroie, J.L. and J.W. Jenson, J.M.U. Jocson and M.A. Lander (1999). Karst Geology and Hydrology of Guam: A Preliminary Report. *Water and Environmental Research Institute (WERI) Technical Report* No. 89, 32 pp.

Mylroie, J.E., J.W. Jenson, D. Taborosi, J.M.U. Jocson, D.T. Vann and C. Wexel (2001) Karst Features of Guam. *Journal of Cave and Karst Studies,* 63: 9-22.

Quenga McDonald, M. (2002). Nitrate-Nitrogen Concentrations in the Northern Guam Lens and Potential Nitrogen Sources. *Water and Environmental Research Institute (WERI) Technical Report* No. 95, 37 pp.

Quenga McDonald, M. and J.W. Jenson (2003). Chloride History and Trends of Water Production Wells in the Northern Guam Aquifer. *Water and Environmental Research Institute (WERI) Technical Report* No. 98, 64 pp.

Taboroši, D., J.W. Jenson and J.E. Mylroie (2003). Zones of Enhanced Dissolution and Associated Cave Morphology in an Uplifted Carbonate Island Karst Aquifer, Northern Guam, Mariana Islands: *Speleogenesis and Evolution of Karst Aquifers*, 1: (4), 16 pp.

Taboroši, D., J.W. Jenson and J.E. Mylroie (2004), Karst features of Guam, Mariana Island, *Water and Environmental Research Institute (WERI) Technical Report* No. 104, 26 pp.

Taboroši, D., J.W. Jenson and J.E. Mylroie (2004). Karren Features in Island Karst: Guam, Mariana Islands, *Zeischrift fur Geomopholigie*, 48: 369-389.

Taboroši, D., J.W. Jenson J.E. Mylroie (2006). Karst features of Guam, Mariana Island, *Micronesica,* in press.

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Government of Guam
Fiscal Year 2009 Budget
Program Fiscal Summary

FUNCTION: EDUCATION & CULTURE
AGENCY: UNIVERSITY OF GUAM
PROGRAM: WATER AND ENVIRONMENTAL RESEARCH INSTITUTE (WERI)

Budget Account Allocation **FUND TITLE**	**Fund**	**FY2007** Actual Appropriation	Percent of Program	**FY2008** Authorized Appropriation	**FY2009** Current Service	Program Plan	Governor's Recommendation	**FY20010** Projected	**FY20011** Projected
General Fund Appropriation		$747,363		$848,919	$848,919	$964,372		$1,095,527	$1,244,519
Guam Hydrologic Survey (Local)		$204,200		$204,200	$204,200	$204,200		$204,200	$204,200
Guam Water Monitoring Project (Local)		$173,948		$173,948	$173,948	$173,948		$173,948	$173,948
Guam Water Monitoring Project (Federal)		$173,948		$173,948	$173,948	$173,948		$173,948	$173,948
USGS Water Institute Program (Federal)		$277,005		$277,005	$277,005	$277,005		$277,005	$277,005
ENSO Application Center (Federal, National Weather Service		$50,000		$50,000	$50,000	$50,000		$50,000	$50,000
Total Program Appropriations		$1,626,4646		$1,728,020	$1,728,020	$1,843,473		$1,974,628	$2,123,620
FTE Positions									
Performance Indicators	**TYPE**								
Projects Initiated	WKLD	15		15	15	16		16	16
Projects completed	WKLD	10		11	11	12		12	12
Technical Reports	WKLD	5		5	5	5		5	5
Journal Articles/Conference Proceedings.	WKLD	10		10	10	10		10	10
Workshops/Conference Presentations	WKLD	10		10	10	10		10	10