

**Guam Hydrologic
Survey
(GHS)**

&

**Comprehensive Water
Monitoring Program
(CWMP)**

FY 2006-2007

Status Report

WERI

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

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

FY 2006-2007
STATUS REPORT

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PREAMBLE

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.

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.

The FY'06 appropriations for the GHS and CWMP programs were \$204,200 and \$173,948 respectively. A similar amount was received for FY'07. The information presented herein summarizes all GHS and CWMP program related activities undertaken for FY'06 and the first quarter of FY'07.

RECENT PROGRAM INITIATIVES

GUAM HYDROLOGIC SURVEY (GHS)

In FY 2006 GHS provided funding to develop and staff a state of the art computer analysis and Geographic Information System (GIS) laboratory. Almost every water research project that is 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.

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 Activities:

Six projects initiated in FY 2006 are now entering their second year of development and are poised on the brink of yielding highly significant information. They are: 1) an update of the geologic map of Guam; 2) a determination of background fluorescent materials in Guam's groundwater; 3) the development of a unified model for contaminant transport within the saturated zone of the northern Guam lens aquifer; 4) a heavy metal assessment of sediments and biota in the Lonfit River upstream and downstream of Ordot Dump; 5) the role of soil moisture in determining the evapotranspiration and aquifer recharge in northern Guam, and 6) the development of a 3-dimensional groundwater model of the Northern Guam Lens using the US Geological Survey (USGS) SUTRA Model. Two additional projects so far approved in FY 2007 are: 7) a digital annotated continuous aerial image of Guam's coast, and 8) recent hydrologic conditions on Guam. The significance and current status of each of these studies are outlined below.

1. *Updating the Geologic Map of Guam* (\$42,885)

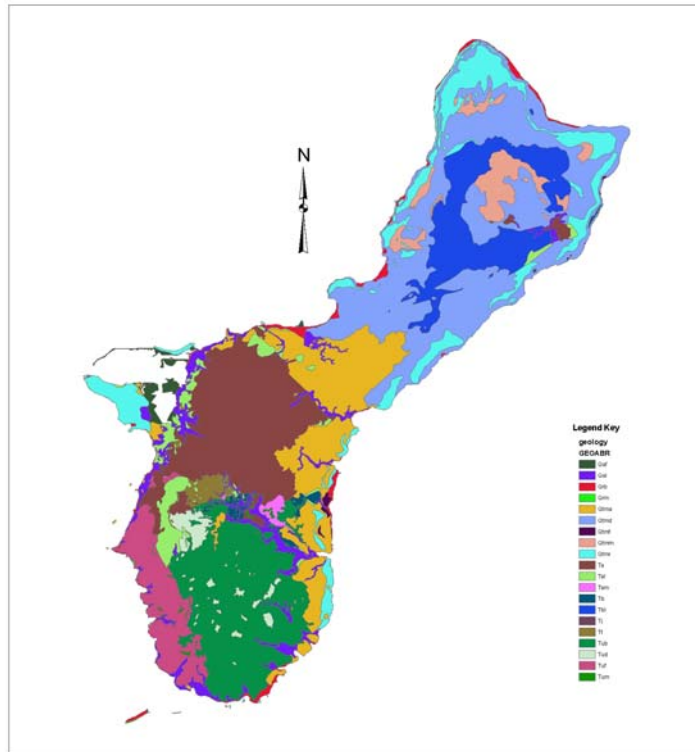
Accurate knowledge of the origins, history, characteristics, and field relationships of the rock units and surface deposits of any given locale provides the essential basis for earth scientists to provide reliable and accurate scientific advice to developers, planners, engineers, resource managers, policy 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



Students in New Computer Analysis and GIS Laboratory

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.

The study currently underway is consolidating the more recent information and focusing on new field and laboratory work in areas where important questions have emerged or remain unresolved. An updated geologic map of Guam incorporating all of the revisions



Geological Map of Guam

of the past 40 years as well as some new data on selected questions is in the final stages of production. The map includes 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. Additional studies will be conducted over the next two years to resolved questions relating to the ages, origins, and stratigraphic relationships of the volcanic units of southern Guam.

2. *Determining Background Fluorescence in Guam's Groundwater* (\$87,306)

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 project is currently conducting a comprehensive study of the nature of background fluorescent materials in the waters discharging along the western coast of Guam, from Agana Bay north to Double Reef. To date, several adsorptive carbon ‘bugs’ have been deployed and retrieved from strategic locations along this stretch of coastline. These are currently being extracted and analyzed to determine spatial and temporal changes in the qualitative characteristics of fluorescent materials present from the water column. The data will provide a better understanding of the types of interferences that can be expected in future dye trace surveys conducted in relatively remote sections of the island as well as in areas close to anthropogenic source of potential interference (e.g., harbors and marinas, storm water discharge points and sewer outfalls) and will facilitate the refinement of such studies. Laboratory based kinetic studies are also underway to assess the adsorptive and desorptive characteristics of the carbon ‘bugs’ in order to optimize sampling frequency.

3. Development of a Unified Model for Contaminant Transport within the Saturated Zone of the Northern Guam Lens Aquifer, Phase I: Energy & Water Balance Data Collection (\$62,439)

Guam’s primary source of drinking water is an aquifer in the northern half of the island. Commonly referred to as the northern Guam lens, this karst limestone system is especially susceptible to contamination from the ground surface. Little is known about the rates and processes by which infiltrating surface waters descend to and interact with the lens. It is not known, for example, how much of the rain that arrives during high-intensity events, such as thunderstorms and tropical cyclones, is actually taken into long term Lens storage. Because it is



Pit Toilets in Northern Guam are a Potential Source of Nitrate to the Underlying Aquifer

impossible to monitor and measure coastal discharge accurately, especially during and after heavy storms, there has been no quantitative data gathered on the volumes, and residence time of water that arrives at the water table after rainstorms. It has long been recognized however, that there are definitive differences in temperature between rainwater, groundwater, and seawater on Guam, as in similar tropical areas.

The current project is collecting temperature data from rainwater and the underlying lens to establish appropriate boundary conditions for a numerical phreatic transport model that will then be used to evaluate the heat and mass budgets for the water moving through it. The model will be used to calculate the quantities and rates at which recharge waters go into storage, transport, and discharge in response to rainfall events of different intensities under both wet- and dry-season conditions. The model will eventually provide a tool for obtaining accurate estimates of the mass flux of water-soluble contaminants, such as nitrate, that are carried to the lens by recharge.

4. *Heavy Metal Assessment of Sediments and Biota in the Lonfit River Upstream and Downstream of Ordot Dump (\$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.



Aerial View of Ordot Dump

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



Lonfit River Downstream of Dump

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 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.

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 2007.



Lonfit River Downstream of Ordot after Major Storm Event

5. The Role of Soil Moisture in Determining the Evapotranspiration and Aquifer Recharge in Northern Guam (\$26,815)

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 a knowledge of where production wells would best be located.

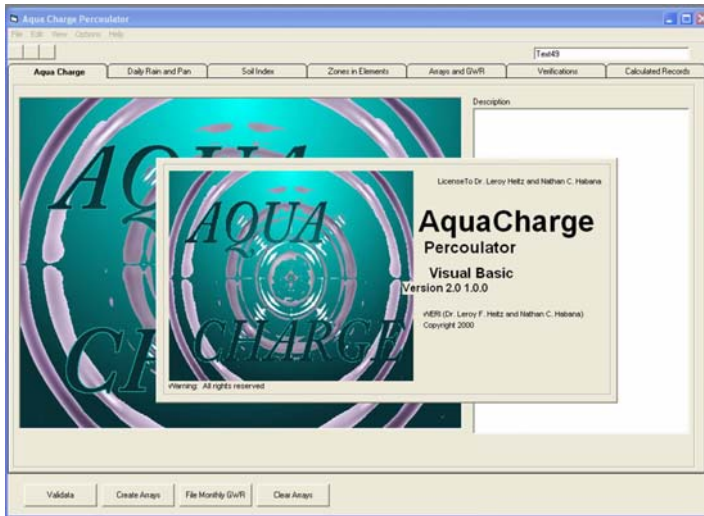
In the early days of development of the northern Guam aquifer, well placement and development were rather easy. Almost all wells developed in the loosely defined aquifer boundaries produced high quality water at good flow rates. Now this situation has changed. As development approaches the sustainable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

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 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.



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

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.

6. Development of a Three-Dimensional Groundwater Model of the Northern Guam Lens Using the US Geological Survey (USGS) SUTRA Model (\$62,439)

This research project reflects the continued concern for the health of the northern Guam lens aquifer, a karst limestone system that provides at least 40 million gallons per day of drinking water to the island. Within the aquifer, the Yigo-Tumon sub-basin is the

principal water-producing area and accounts for about 40% of the total production and probably as much of the remaining fresh water reserve. It is also the most heavily developed area, containing over half of the island's population, and nearly all of its civilian commercial and industrial activities.

The study currently underway is a collaborative effort between WERI, Guam EPA and the US Geological Survey (USGS). Previous and ongoing Guam Monitoring Program data collection has collected a significant amount of data on water table response to recharge events and lens thickness. Abundant data are therefore available with which to parameterize and test the model. The scope of the study is limited to the Yigo-Tumon Sub-basin, the most prolific and most heavily developed sub-basin in the lens. The basic objective of the current work is to ultimately prepare a 3-dimensional model that accurately simulates the response of the aquifer to historical monthly recharge and sea-level forcing.



**Graduate Student Working
With 3-D SUTRA Model**

This project will produce an improved understanding of the affect of short-term and medium-term environmental weather events on contamination, recharge, volume, and production on the lens. Long-term environmental weather events can be looked at in future studies with the same computer model and simulation procedures, which have been created for this project. To date, a 2-dimensional computer model has been created using the SUTRA and SSARR computer models. It contains both vadose and phreatic zones to more realistically portray the entire aquifer and will provide for better aquifer management by regulators and operators. The model has been validated using four historical typhoon events' data and one historical year's data for a wet and a dry season. The primary focus is on the affects of recharge (rainfall) and contamination (saltwater intrusion) on the lens volume and chloride profile. With this information a better plan to deal with extremes in weather cycles by looking at rainfall and sea level data can be created. The development of the 3-dimensional model is currently underway. Chloride profile data, soil information, pan evaporation data, and geologic properties of the aquifer are all being studied in great detail to develop the complex computer model system and simulation process. With the new data from this project, the management of northern lens water resources and the understanding of how the aquifer responds to recharge, pumping, and sea level changes will be significantly improved. Such knowledge will support more effective standards and regulations for current and future land use and aquifer production.

7. *Digital Annotated Continuous Aerial Image of Guam's Coast (\$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 orthorectified 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. This proposal is for a product that offers all the benefits of oblique aerial photography and resolves the three above-mentioned shortcomings. It will produce 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.

The aim is to produce an up-to-date, high resolution, full-color, copyright-free set of oblique aeriels that avoids cumbersome indexing yet stays organized and is inherently easy to use. It is proposed to make several flights around Guam (at different times to ensure most favorable sunlight in all areas) in a small aircraft, following the coastline and taking high resolution photographs at a continuous rate, and steady angle, elevation and distance from the shoreline. The hundreds of photographs would then be digitally stitched together as to appear as an uninterrupted, very long image of the entire coastline. Several version images (at different dpi resolution, jpg compression levels etc.) would need to be made to ensure best suitability for different purposes (e.g., fast browsing, zooming in for detail, high quality printing). Layers



Oblique Aerial Photograph of Northern Guam Coastline

of additional information would be superimposed on the image to provide place names and ensure easy navigation, and can be turned on and off by the user. The annotations are to include the names of beaches, stretches of cliff line, bays, headlands, coastal points, offshore islets, reefs, river mouths, etc. and would be provided in two versions: official U.S. toponymy and standard Chamorro orthography.

The end user simply needs to open the image 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 will be presented as a digitally annotated continuous aerial image of the entire coastline of Guam. It is delivered 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 will also be provided.

8. *Recent Hydrologic Conditions of Guam (\$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



**GWA Produces Approximately 74%
Guam's Drinking Water**

of recent hydrologic conditions are needed to evaluate the status of water resources and to quantify stresses on existing water supplies.

The primary objective of this 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.

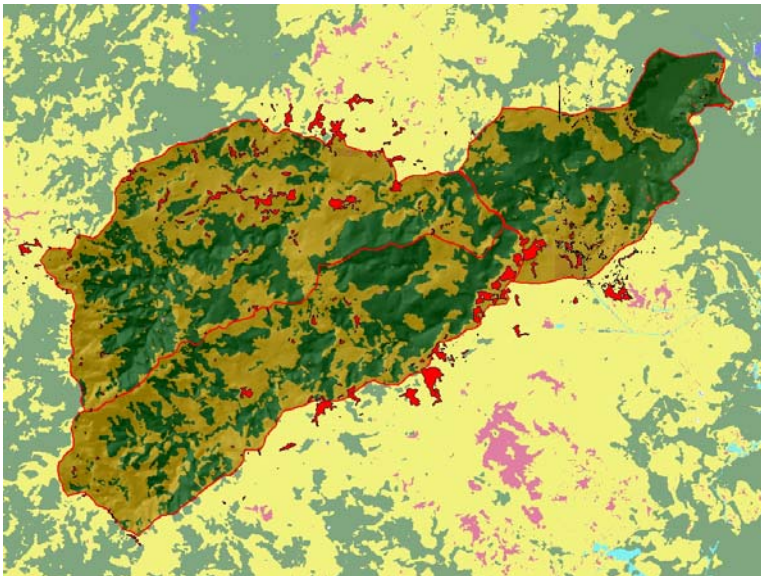
Available hydrologic data will be gathered from cooperating agencies and presented in simple graphical formats to show how recent hydrologic conditions compare to long-term trends. Possible sources of data include: 1) rainfall records from the National Weather Service and the U.S. Geological Survey; 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.

Once the web pages are created and made public, they will be updated about every three months with recent data provided by cooperating agencies responsible for collecting the data. In addition, the web pages will have internet links to all of the cooperating agencies and to the historic and recent data compiled from the cooperating agencies. Data only will be released with the agreement of cooperating agencies.

GHS Related Research Activities Funded by Other Sources

1. *Ugum River Watershed Study* (\$50,000; NOAA)

WERI investigators have recently undertaken a watershed study of the Ugum River



Map of Ugum Watershed Showing Watershed Boundaries, Badland Erosion and Vegetal Cover

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 just getting underway will be developing strategies for modeling sediment production in the basin using GIS modeling

techniques. The findings of the study are available as a WERI Technical Report (No. 109, 53 pp. 2005) and can be downloaded via the WERI website:

<http://weriguam.org/home/index.htm>.

2. Impact of Ordot Dump on Pago Bay (\$99,786; NOAA, USGS)

WERI investigators have recently completed a heavy metal assessment of biotic and 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:

<http://weriguam.org/home/index.htm>.



Pago Bay Showing Pago River Reef Channel at Southern End



Sediment Plume in Pago Bay Reef Channel after Storm Event

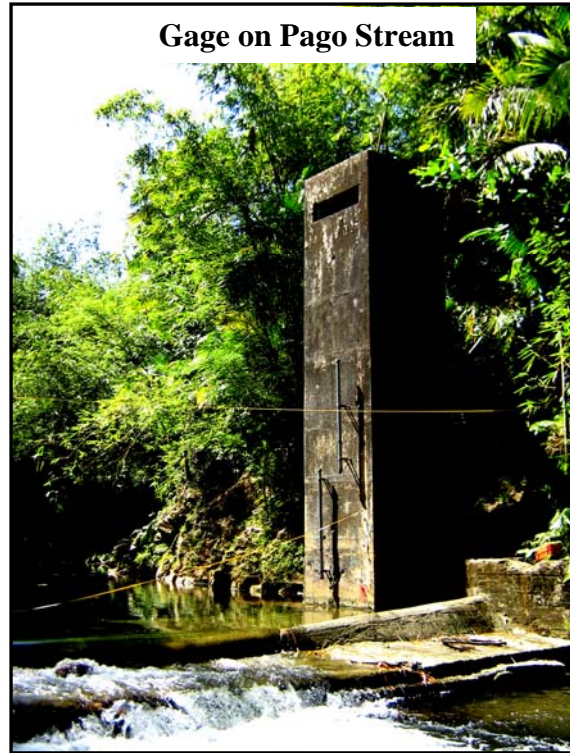
climatic and topographic characteristics of the area conspire to provide an effective means of periodically flushing out pockets of contaminated sediments from the entire watershed into the ocean.

The study clearly demonstrates that Pago Bay is not a permanent sink for sediment bound metal contaminants mobilized downstream from the Ordot Dump. It was therefore concluded that 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

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).

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.



Gage on Pago Stream



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.

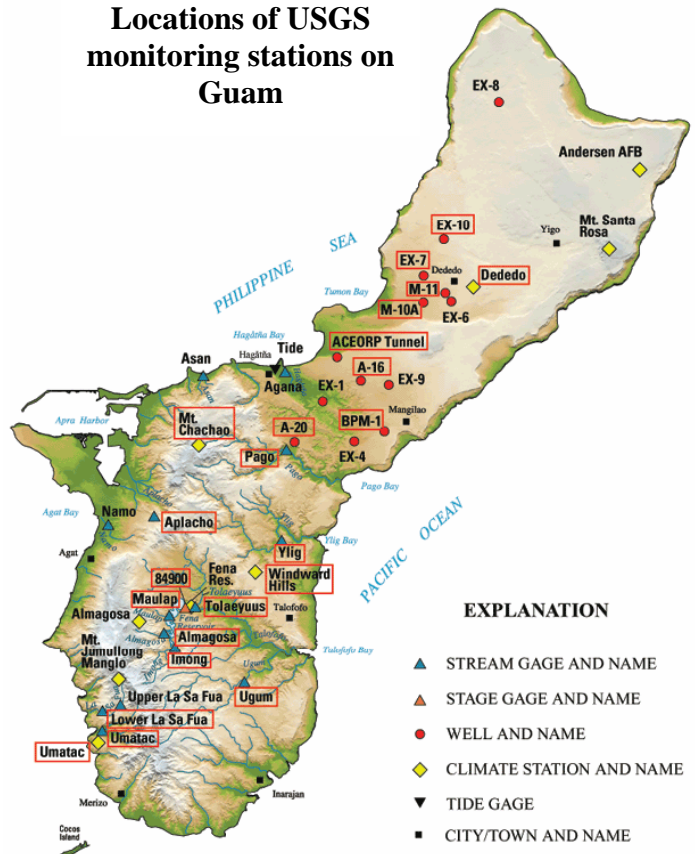


The CWMP also operates the ground water monitoring program on Guam. This includes water level and salinity monitoring in 14 wells in the Northern Guam Aquifer, plus a tide gage for reference in Agana Harbor. These gages provide long-term information on the conditions of the aquifer and are used to assess 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.

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

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 plan to develop an updated web interface that will improve access to hydrologic information about Guam, and summarize recent hydrologic conditions on our 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., 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.
- 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. 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.

- Myroie, 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.
- Myroie, 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. Myroie (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. Myroie (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. Myroie (2004). Karren Features in Island Karst: Guam, Mariana Islands, *Zeitschrift für Geomorphologie*, 48: 369-389.
- Taboroši, D., J.W. Jenson J.E. Myroie (2006). Karst features of Guam, Mariana Island, *Micronesica*, in press.