

**Guam Hydrologic
Survey
(GHS)**

&

**Comprehensive Water
Monitoring Program
(CWMP)**

**FY 2011
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 2011
STATUS REPORT

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Director

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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. 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 variety 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 saltwater intrusion and water lens thickness in Guam's sole source aquifer in the northern part of the island and 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 resources 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 in the island's work force.

PROGRAM FUNDING AND FY'11 OBJECTIVES

GHS and CWMP appropriations written into each public law are \$204,200 and \$173,948 respectively. Local budgetary constraints saw a 6% reduction in funding support for both programs in FY'09, i.e., \$192,307 and \$163,817 awarded for GHS and CWMP respectively. These shortfalls continued through FY'11. An additional 5% reduction was levied against each account by Governor Calvo for FY'12 reducing total awards to \$182,694 for GHS and \$155,626 for CWMP. The information presented herein summarizes all GHS and CWMP program objectives and related activities undertaken in FY'11.

PROGRAM OUTCOMES FOR FY'11

GUAM HYDROLOGIC SURVEY (GHS)

In FY'11, GHS provided funding the continued maintenance, repair and upgrading of instrumentation in the WERI *Computer Analysis and Geographic Information System (CA-GIS) Laboratory*. 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 become available.



Graduate students in WERI CA-GIS Laboratory

GHS provides limited stipends and tuition fees for research by graduate students working on their MS degree in Environmental Science and partial summer salaries to WERI faculty advising those students. It also pays for undergraduate field and lab assistants working on water resources projects on Guam. Finally, GHS funds the salary of one full-time research associate charged with operating WERI's complex and sophisticated computer analysis and GIS facility.

GHS Sponsored Research Projects Completed in FY'11:

With anthropogenically induced global warming now at the forefront of climate change research, WERI has focused on Guam's caves and corals to unlock climatic secrets of the past for this part of the world. Three such studies sponsored wholly, or in part by GHS funding are described below.

1. *Reconstructing the Climate History of Guam*

Stalagmites and water samples from a cave on northern Guam are providing clues to how the climate of Guam and the surrounding region evolved over the past 28,000 years. Stalagmites were initially collected by WERI researchers in April 2005. Laboratory work on the stalagmite has been underway for the past four years by collaborators at the Jackson School of Geosciences at the University of Texas-Austin. The initial results are consistent with results from other islands in the Pacific and suggest, among other things, that the regional climate was much drier some 5000-6000 years ago. The western Pacific Ocean plays an important, but still poorly understood role in



WERI collects cave drip water for chemical analysis

global climate. Results of this study will not only help to understand and predict longer-term climate trends for Guam, but for the entire western Pacific region. This study is thus an ongoing long-term study, which is now being linked to similar collaborative regional studies, one of which is now sponsored by the National Science Foundation. Besides extending the current work on Guam for another two years it has also extended the same investigation to the Philippines and Borneo. As these investigations continue to progress, Guam and the surrounding region will gain an increasingly reliable understanding of long-term climate cycles and weather-related events that control the hydrologic cycle and water resources of the islands in the region.

2. *Reconstructing the Wet-Dry Cycles and Sea Level History of Guam*

Initial funding by the Guam Hydrologic Survey gave WERI faculty and graduate students the means to begin collecting chemical data (from dripwaters, cave air, and stalagmites) each month, beginning more than three years ago, from a specially instrumented cave on northern Guam. Funding by the GHS enabled progress that attracted additional sponsorship from the National Science Foundation for what has evolved into a detailed hydrologic and paleoclimatic study in collaboration with geochemists at the University of Texas-Austin. Modern rainwater, cave dripwater, and cave stalagmite chemistry from northern Guam are used to reconstruct climatic history prior to the instrumental record. The cave records obtained so far for the past 160 years indicate the existence of droughts of decadal length, when rainfall is estimated to be ~4 cm/month less than average. Evidence from cave records also indicate



WERI research assistant, recording drip rates at one of the study sites in Jinapsan Cave.



WERI research assistant inspects Guam cave site for climate research project

that century-length dry conditions may have prevailed on Guam from about 5,000-6,000 years ago. Understanding the past pattern of wet and dry climatic shifts on Guam will provide a basis for more reliable diagnosis or prediction of current and future climatic conditions and trends. The results from the caves on Guam will also help to better understand the paleoclimate signal in the ongoing research in the Western Pacific and East Asia.

Related work on the adjacent fossil reef platform deposited some 120,000 years ago when the ocean stood some 6 to 8 meters higher is also enabling WERI researchers to get a better understanding of the history of sea level changes around Guam and of the rates of evolution for the systems of caves that are part of the

natural “plumbing” of Guam’s aquifer. Work to date has produced several manuscripts that are currently in press or in review, and has attracted the attention of climate researchers worldwide. The caves on Guam that are the subjects of these studies are the only tropical caves in the world to date from which monthly data have been and are being collected. Moreover, because of Guam’s location at the edge of the West Pacific Warm Pool, the history of the climate in this region is of particular interest to researchers studying natural global climate change. The results from this study are therefore not only of local value for determining the natural conditions that affect Guam’s and the region’s water resources, but also the history of global climate.

3. *Reconstructing the Modern Sea Temperature and Rainfall Drought History of Guam*

The purpose of this project was to determine whether the coral in Guam’s Apra Harbor are recording the rhythm and strength of past El Niño events and/or multi-decadal climate cycles. In summer, 2010, WERI researchers extracted coral cores in using a uniquely designed pneumatic drill. A specimen analyzed at the geochemical laboratory at the University of Texas, in the fall of 2010 produced a record of local climate trends for past 60 years on Guam, which will enable WERI researchers and their colleagues at the University of Texas to match the historical record with the coral record, thereby gaining a reliable means for accurately interpreting prehistoric coral records. The work to date has produced successful M.Sci. thesis in the University of Guam’s Environmental Science Program,



***Porites* coral heads such as the one shown here are extremely slow growing and store critical data related to Guam’s past climate**



WERI research assistant, and support team remove a 1m carbonate core from living *Porites* coral head for analysis

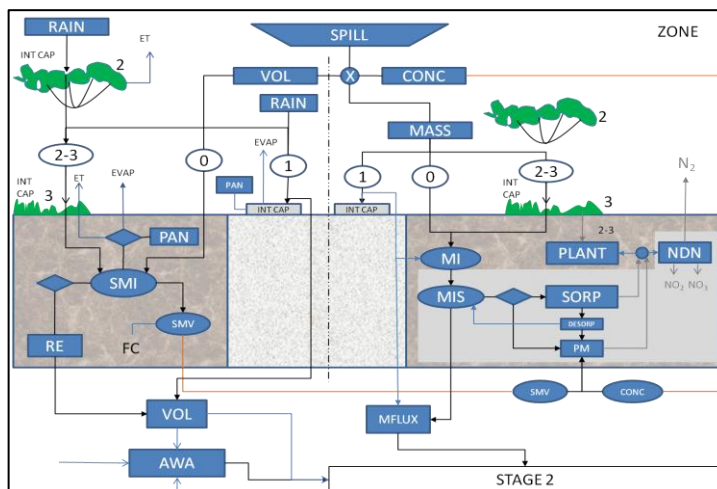
two WERI technical reports. A manuscript for a peer-reviewed climatological journal is underway. Results from such studies of coral on Guam are of particular value because they can be compared with the cave stalagmite record from northern Guam, for which initial, exploratory research was funded by Guam Hydrological Survey 2008. Understanding the past long-term cycles and trends on Guam will allow us to predict and model the future climate trends with much greater confidence, most especially the natural cycles of storminess and drought, which determine the long-term availability of fresh water resources, not only on Guam, but in the surrounding region of the western Pacific.

GHS Sponsored Research Projects Ongoing in FY'11:

Three ongoing research projects sponsored wholly or in part by GHS and are on the brink of that yielding significant data are: 1) the development of a management plan for the Piti-Asan watershed, 2) advanced subsurface archives via Arc Hydro Groundwater®, and 3) spatio-temporal analysis of groundwater quality on Guam. The significance and current status of each of these studies are outlined below.

1. *Development of Vadose Contaminant Transport Model for Northern Guam*

This is GHS-sponsored project that began as MSci thesis in the University of Guam's Environmental Science Program and which now forms the basis for a PhD dissertation at Mapua University, Philippines, in collaboration with WERI. The transport of wastewater nitrogen from septic tanks and sewage spills percolating through the deep karst vadose is a complex process. First, the karst system's spatially varied hydrogeology, possessing triple porosity, poses a challenge to modelers to simulating accurate recharge. Second, the role of the nature of biochemical process of nitrification and loss of wastewater nitrogen through sorption is undergoing detailed study. To handle the delivery of moisture through 200 feet deep limestone bedrock to the water table, we harness the capabilities of a recharge program called AQUA CHARGE. AQUA CHARGE is being redesigned to include impervious zones, improving the accounting of moisture infiltration, and wastewater nitrogen mass transport to the water table. The wastewater nitrogen transport model moves along with either moisture bulk flow or from home or business utility. The lag and attenuation of recharge as well as the nitrogen cycle process is simulated using a hydrology technique called routing. In its lifecycle, nitrogen transformation, sorption and biochemical process rates are inserted into the routing process. This program will simulate the fate, transport, and effects of wastewater infiltration in our groundwater system.



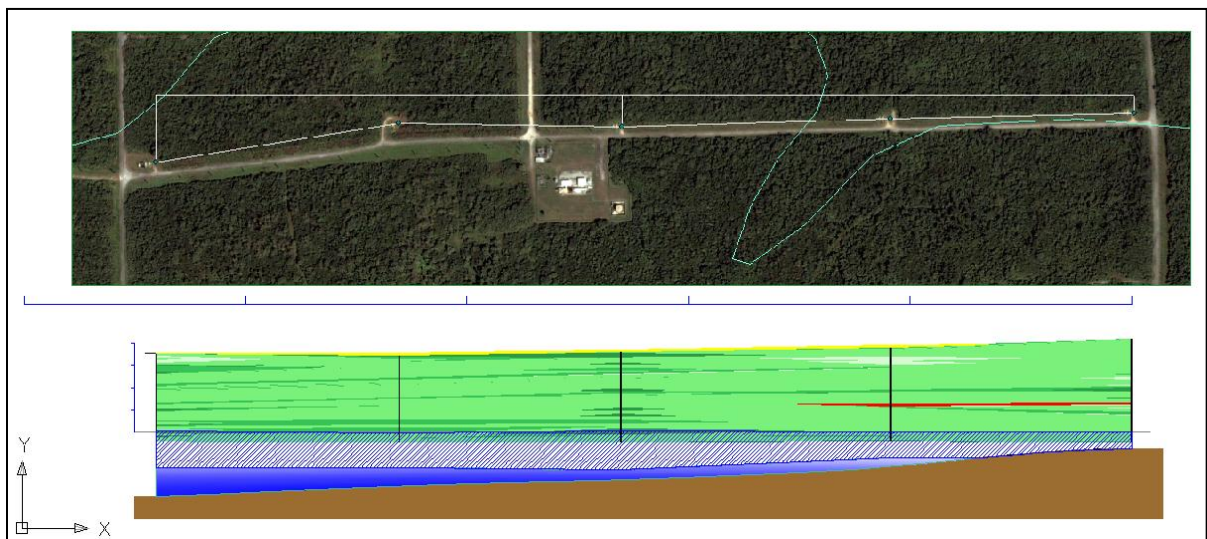
Flow chart showing modeling considerations for tracking movement of nitrogen from a sewage spill into Guam's aquifer

Stage 1 is a comprehensive conceptual model, programming flow diagram, to account for moisture and mass of contaminant at the surface and soil zone. Stage 2 uses routing to simulate the hysteresis bulk flow and transport of contaminants. The 2nd stage is shown above and is currently undergoing development to include the biochemical processes of nitrification and loss or retardation due to sorption.

2. *Advanced Subsurface Archives via Arc Hydro Groundwater®*

This is an ongoing project, which derives from the GHS Database, and will be added to it. It will serve as a model for similar work to be undertaken at various other locations around the aquifer. Aquaveo's Arc Hydro Groundwater® (AHGW, www.aquaveo.com) is an ESRI® Geographic Information System extension. It is an advanced software technology that builds upon borehole data, developing visual maps for accessing subsurface features. Such features of this software allows the development of geo-volumes (3-D block diagrams), cross-sections/stratigraphs, and fence diagrams, all mapped in both 2-D and 3-D. This tool gives explorers visual insight of the sub-surface in a quick and most useful way of determining well exploitation investments. It is also the state of the art means to manage the Guam Hydrologic Survey.

The scanning of hydrogeologic data and literature for Guam is moving along and the collection of borehole records database organization is taking shape through diligent efforts of research assistants. With AHGW, we take this organization of information to a new and improved level of data management through the forefront of technology using advanced software. AHGW has two application tools: Groundwater Analyst and Subsurface Analyst. Both applications build upon borehole records. The applications allow the development of cross-sections/profiles/ stratigraphs from boreholes or from existing scanned images. The scanned images may be transformed to digitized cross-section using XS2D. Cross-sections may also be built using a cross-section builder interpolating between gaps of nearby borehole data. The borehole data may also be used to build geo-volumes or block diagrams. The buildup and conversion of our database into useful subsurface maps and visual diagrams will prove to be a valuable tool for studies and consultations.

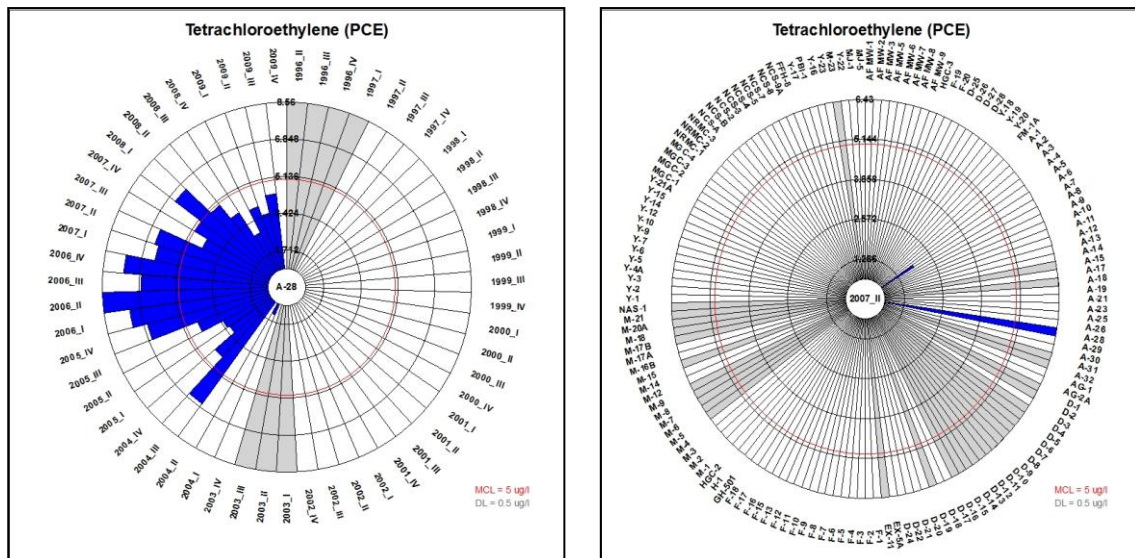


Cross-section of MW well series near Andes South, Yigo, provides a scale profile of the subsurface. Borehole derived profiles throughout Guam may be loaded onto AHGW subsurface analyst for ease of access.

3. *Spatio-Temporal Analysis of Groundwater Quality on Guam*

Since 1996, the Guam Waterworks Authority (GWA) has regularly monitored Guam's groundwater for all contaminants listed under the Safe Drinking Water Act. A substantial bank of data now exists from which certain space- and time-dependant trends are emerging. The 1996-2009 water quality data gathered by GWA has now been converted to GIS format for further processing and analysis. GIS can be applied to identify vulnerable wells within the aquifer for contaminants of critical concern.

A Visual Basic for Applications (VBA) based GIS model has been established to visualize the ground water quality data in space and time. The model can be applied to create clock diagram graphics which can be utilized to visualize water quality data, and identify deficient wells with contaminants more straightforward. The model can be employed to represent any contaminant in any well temporally, and any contaminant for all wells in any specific time. The two preliminary clock diagram graphics shown below illustrate the ease with which contaminant profiles for any well or group of wells can be evaluated over space and time. This user friendly method will provide GWA with a quick and convenient tool that allows them to readily identify potential problematic wells at a glance.



Application of Clock Diagram Graphics for identifying temporal and spatial changes in Guam's groundwater quality. LH clock diagram shows changes in PCE levels in GWA's well A-28 over time. RH diagram shows PCE values recorded during the 2nd quarter of 2007 for multiple wells. Blue bars = detects; grey bars = non-detects; colorless bars = no data; MCL = maximum contaminant level; DL = detection limit

Since the GIS model runs on ESRI ArcGIS for Desktop, and ESRI will discontinue support for VBA-based applications in new versions of ArcGIS, a Python-based GIS model for visualization and analysis of ground water quality data is suggested for further research. The advantage of Python-based GIS model is that people will not worry about discontinuation of support from third parties since Python is free to use.

SUMMARY OF FY'11 EXPENDITURES FOR GHS APPROPRIATION

Below is a composite summary of all expenditures lodged against the GHS account during FY'11. As in past years, budgetary shortfalls arising out of austerity measures implemented by the Guam Legislature have so far been covered by carryover funds from GHS allotments received in previous years. As these reserves are limited they cannot be expected to sustain the program at its current high rate of activity for too much longer. This notwithstanding, we gratefully acknowledge the Guam Legislature for their continued interest in and support of the GHS program and all associated water resources related research, education and training activities carried out at WERI.

Expenditure Summary for FY'11

<i>Category</i>	<i>Expenditure</i>
1. Salaries and Wages:	\$117,613.22
2. Fringe Benefits:	\$8,436.93
3. Tuition Fees	\$18,105.00
4. Supplies:	\$903.86
5. Computer Hardware/Software:	\$1,500.00
6. Equipment:	\$1,518.99
7. Consultant Fees:	\$54,350.00
8. Postage/Long Distance Phone:	\$972.89
9. Printing:	\$81.00
10. Subscription/Dues:	\$194.00
11. Administrative Fees*:	\$19,230.90
Total FY'11 Expenditures:	\$222,906.79
Total FY'11 GHS Allotment Rec'd:	\$186,542.16
Balance:	<u>-\$36,364.63</u>

* University of Guam cost sharing administrative fee of 10% levied against all special appropriations received from the Guam Legislature

COMPREHENSIVE WATER MONITORING PROGRAM (CWMP)

The United States Geological Survey (USGS) has monitored our island's water resources since 1951. Unfortunately, during the 1990s 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 by the mid-1990s. 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 monitoring wells and a renewed program of water resource monitoring on Guam. The intent of 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.

A well-designed long-term CWMP can save communities millions of dollars, and even human lives, by providing critical information for water-supply, culvert and bridge design, delineating flood-hazard areas, and tracking effects of climate change. The USGS started a water-resource monitoring program in Guam in 1951 with installation of stream gages at Pago, Lonfit, and Tolaeyuus and a rain gage near Fena dam. At the same time, measurements of discharge from Almagosa Springs and water levels in Fena Reservoir started. Since 1951 about 22 continuous streamflow, 8 rain, and 16 groundwater monitoring stations have been operated, providing reliable information on the water resources and hydrologic hazards of Guam.

Currently, USGS monitoring on Guam consists of 6 continuous-recording streamflow gages, 8 continuous-recording groundwater wells, 7 groundwater wells where the thickness of the freshwater lens is measured, and 8 continuous-recording rain gages. From a broad perspective, the program provides long-term information on the hydrologic cycle of Guam so that its water resources can be understood and sustainably managed. The bulk of the monitoring stations on Guam are funded as part of a Joint Funding Agreement between the USGS and WERI.



Locations of USGS monitoring stations on Guam

Stream Gages for Water Availability and Flood Planning in Southern Guam

Most freshwater used in southern Guam comes either from streamflow or wells that withdraw water from near the banks of streams. Data from USGS stream gages provide information needed by managers and engineers to properly manage the long-term sustainability of these water resources. Statistical analysis of long-term streamflow data are needed so the effects of abnormally wet or dry years can be understood and planned for. For example, USGS gages provide information that can be used to assess and manage the sustainability of surface water from the GWA Ugum Treatment Plant. Other gages, funded in cooperation with the U.S. Navy, are used to manage withdrawals from Fena Reservoir.

Long-term streamflow information is needed for flood planning. This information is used to delineate flood zones, estimate the magnitude of floods and frequency with which they could be expected to occur, and design bridges and culverts. For example, information from 11 stream gages and 3 other sites was used to assess the flood peak magnitude and recurrence interval following Typhoon Chata'an in 2002. FEMA uses information from USGS stream gages to determine the level of financial aid from FEMA after storms. Currently, the WERI-USGS CWMP funds the operation of 3 stream gages at key locations in southern Guam.



Flow in Pago Stream has been measured since 1951

Well Monitoring of the Northern Guam Lens Aquifer



WERI field assistant measures water levels in the Northern Guam Aquifer

Monitoring wells operated as part of the USGS-WERI CWMP provide information to assess the health and sustainability of the Northern Guam Lens Aquifer. This aquifer is the most important source of freshwater on the island. Currently, the program includes 8 wells where water level is continuously measured and 7 wells where the thickness of the freshwater lens is measured biannually. Collectively, this information allows scientists at WERI, GEPA, GWA, and USGS to understand the flow of water through the aquifer and refine sustainability estimates of this resource. This information is used to understand how current levels of pumpage are affecting the aquifer and how future changes in climate and groundwater production may affect the sustainability of groundwater resources. Coupled with detailed geologic mapping and modern hydrologic tools such as groundwater flow models, information from this long-term program will be invaluable as additional water is needed to support increasing economic development on Guam.

Rainfall Data to Estimate Water Supply Recharge and Flood-Water Distribution

The USGS currently operates 8 rain gages on Guam, 6 of which are funded by the WERI-USGS CWMP. Rainfall data are fundamental to understanding the water supply and threats from flooding. Information from these gages is used to evaluate the extent of drought during El Nino events and the severity of flooding during typhoons. Information from rain gages is also essential in determining how much freshwater infiltrates past the ground surface to reach the water table. This water, known as recharge, is the source of freshwater in the Northern Guam Lens Aquifer and only by measuring rainfall can its abundance be accurately estimated.

What does it cost to operate a stream flow and other gages?

In fiscal year 2012, the cost to operate a continuous-record streamflow gage will be \$25,200. This includes all operation and maintenance, site visits, field data collection, data analysis, and computation of the flow record. Gage operations are frequently reviewed and upgraded as improvements become available. Other gages, such as rainfall (\$12,100) and groundwater (\$7,500), require less funding. With over 100 years of experience, USGS procedures ensure that data are reliably collected, analyzed, and publicly available

How can one get USGS water resource information?

Most data from USGS gages are readily available on the internet. As part of CWMP between WERI and the USGS, historic data and other hydrologic information for Guam are consolidated and made publicly available at: <http://hi.water.usgs.gov>.

WERI RESEARCH PUBLICATIONS ARISING FROM GHS SPONSORED PROGRAMS

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- Denton, G.R.W. and Sian-Denton C.M. Groundwater Monitoring on Guam (2010): Management Responses to Recent Water Quality Violations, *Journal of Groundwater Monitoring and Remediation* Spring 2010: 127-133.

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- Khosrowpanah, S., Y. Wen, and M. Kottermair (2010). Spatial Distribution of Badlands in the Ugum Watershed: Characterization and Temporal Analysis. *Water and Environmental Research Institute (WERI) Technical Report*, No. 126: 29 pp
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(BBMR PFS-1)

Government of Guam
Fiscal Year 2012 Budget
Program Fiscal Summary

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

Budget Account Allocation		FY2010		FY2011	FY2012				
FUND TITLE	Fund	Actual Appropriation	Percent of Program	Authorized Appropriation	Current Service	Program Plan	Governor's Recommendation	FY2013 Projected	FY2014 Projected
General Fund Appropriation		\$850,036		\$982,453	\$982,453	\$1,008,850		\$1,036,038	\$1,064,043
Guam Hydrologic Survey (Local)		\$192,307		\$182,694	\$182,694	\$182,694		\$190,810	\$204,200
Guam Water Monitoring Project (Local)		\$158,902		\$155,626	\$155,626	\$155,626		\$162,540	\$173,948
Guam Water Monitoring Project (Federal)		\$139,020		\$155,626	\$155,626	\$155,626		\$162,540	\$173,948
USGS Water Institute Program (Federal)		\$277,005		\$277,005	\$277,005	\$277,005		\$277,005	\$277,005
USGS Supplemental Program (Federal)		\$79,979		\$104,942	\$104,942				
ENSO Application Center (Federal, National Weather Service		\$259,248		\$259,248	\$259,248	\$259,248		\$259,248	\$259,248
National Science Foundation (Federal)				\$56,891	\$52,619	\$52,619		\$54,023	
GWUDI Program (Local)						\$69,219		\$69,219	
Total Program Appropriations		\$1,956,497		\$2,174,485	\$2,174,485	\$2,160,887		\$2,211,423	\$2,152,392
Performance Indicators	Type								
Undergraduate Courses Taught	WKLD	3		5	3	3		3	3
Graduate Courses Taught	WKLD	10		10	8	8		8	8
Thesis Committees served (chaired)	WKLD	21(11)		16(8)	15(9)	15(9)		15(9)	15(9)
Projects Initiated	WKLD	15		14	12	12		12	12
Projects completed	WKLD	11		12	12	12		12	12
Technical Reports	WKLD	10		4	5	5		5	5
Journal Articles/Conference Proceedings.	WKLD	17		17	10	10		10	10
Professional Presentations	WKLD	12		12	10	10		10	10
Workshops/Conference Presentations	WKLD	3		3	2	2		2	2

