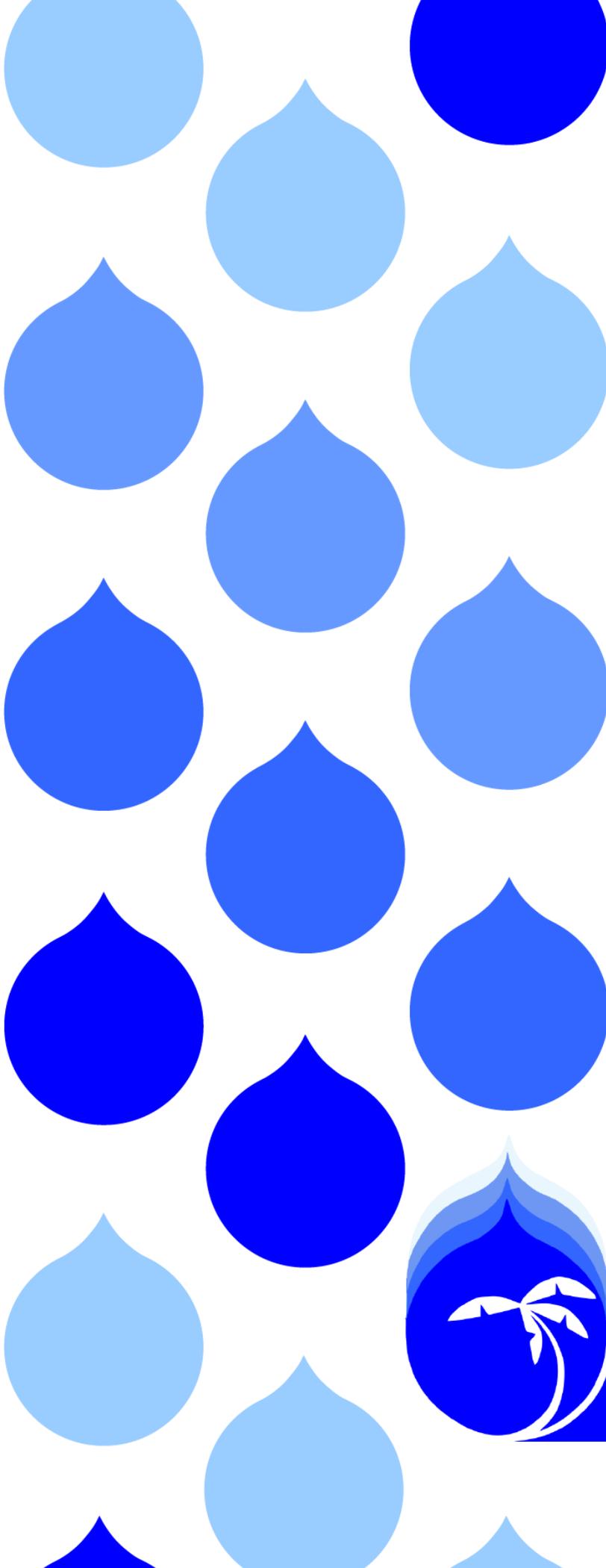


**Guam Hydrologic Survey
and
Comprehensive Water
Monitoring Program**

**FY 2018
Annual Report**



WERI

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

September 2018

**Guam Hydrologic Survey (GHS)
and
Comprehensive Water Monitoring Program (CWMP)**

**FY 2018
Annual Report**

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September 2018

Water & Environmental Research Institute of the Western Pacific

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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.

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.

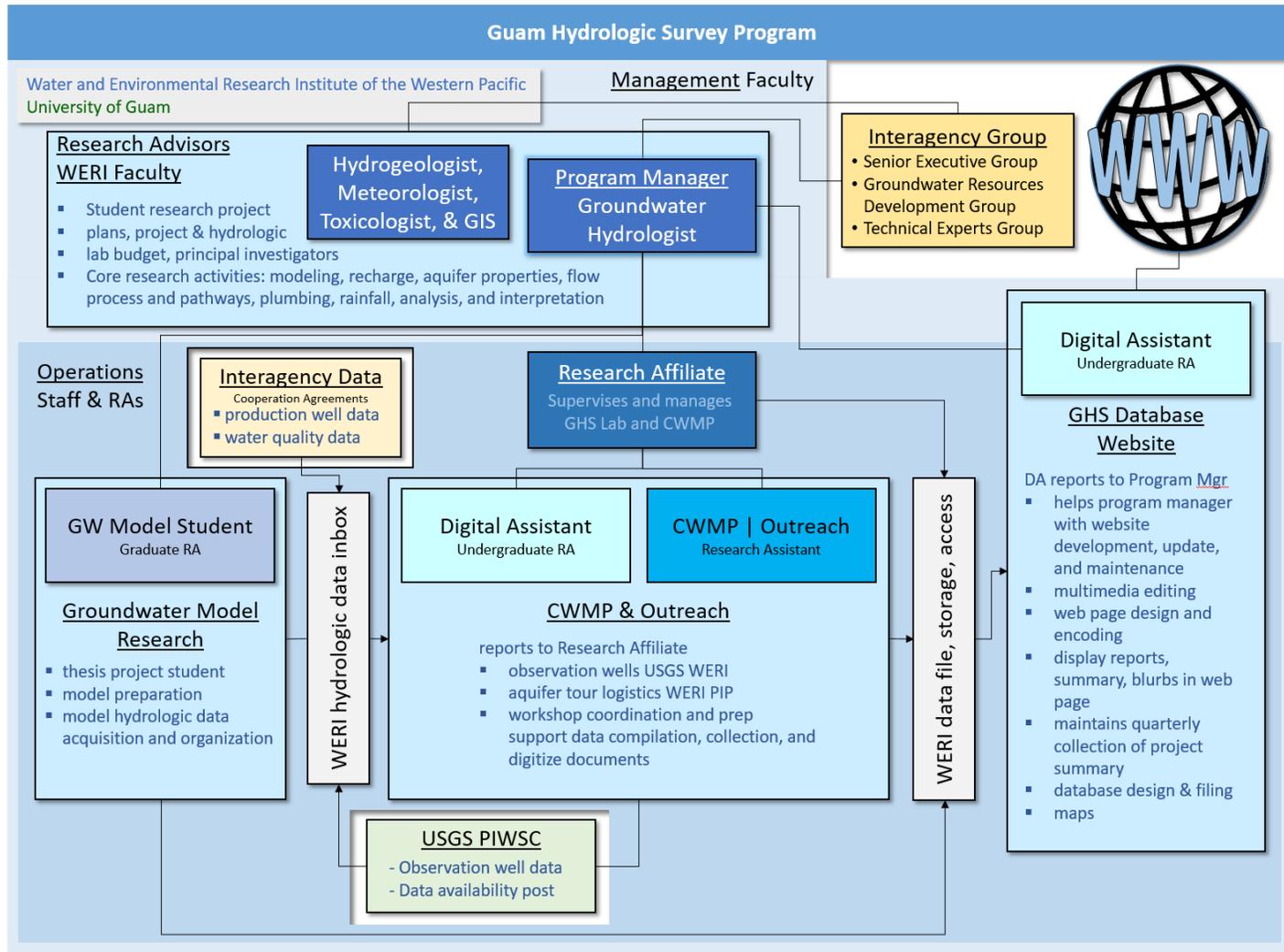
The foresight of the Guam Legislature in creating these two very important programs deserves special mention here. Through their efforts and continued support, we have consolidated and interpreted several vital water resources databases for Guam and revitalized the USGS water resources monitoring program. 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

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., \$192,309 and \$163,817 awarded for GHS and CWMP respectively. These shortfalls continued through FY'12. An additional 5% reduction was levied against each account by Governor Calvo in FY'12 and is continuing through FY'14. This reduces the 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'17.

GHS AND CWMP PROGRAM MANAGEMENT ORGANIZATION

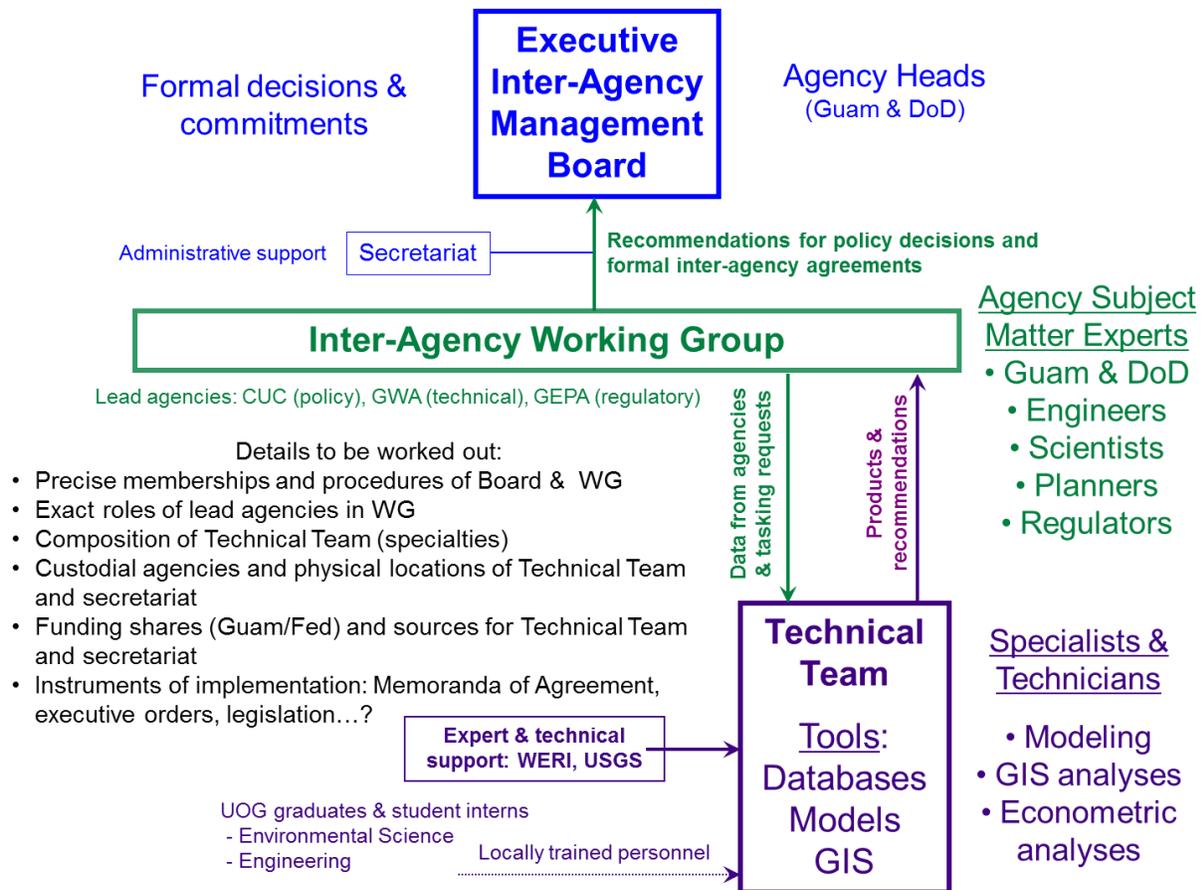
WERI organizes and integrates the GHS and CWMP programs to manage and execute the public law. The WERI personnel organizational chart of duties and responsibilities are shown below. WERI'S groundwater hydrologist is the program manager, supported by research advisors of hydrogeologist, meteorologist, toxicologist, and GIS expert. The research affiliate reports to the program manager, and is supported by a CWMP research assistant and digital assistant. Program manager has a digital assistant for the GHS website and a graduate research assistant for groundwater model research.



GROUNDWATER RESOURCES DEVELOPMENT GROUP AND TECHNICAL EXPERTS GROUP

WERI is also a member of the local water resource interagency organization called the Technical Experts Group (TEG) and the Groundwater Resource Development Group (GWRDG). The GHS and CWMP mandate requires interagency collaboration and cooperation, as written, “establish a direct working relationship with each organization collecting hydrologic data important to Guam, and maintain a permanent flow of new data from each organization to keep the data library up to date.” Attending local government and federal agencies are Guam Waterworks Authority, Guam Environmental Protection Agency, CUC, US Navy (NAVFAC, Marianas), USAF (CES), and USGS. Our interagency groups also include private consultants: Duenas Camacho and Associates, Allied Pacific Environmental Consultant (APEC), EA Engineering, Brown and Caldwell, and AECOM. Meetings are organized and held quarterly at Guam Waterworks Authority (Gloria B. Nelson Public Service Building), Fadian. Current discussion is the expansion of monitoring (observation) wells, see details in CWMP Research Projects section.

The interagency group is organized in the diagram below. It is formed of three groups: executive, working, working group, and the technical team.



PROGRAM ACTIVITIES FOR FY 2018

Guam Hydrologic Survey (GHS)

The GHS program management, WERI Director, and Research Affiliate has reorganized the program management to include undergraduate research assistant support. The undergraduate research assistants slot to be filled will assist the program management, supporting web development as GHS mandate part of data repository, access, and distribution. The Research Affiliate will utilize an undergraduate research assistant to manage data and field assistance.

The Guam Hydrologic Survey office and computer hydro-laboratory at WERI had been remodeled to improve GHS functionality. Designated storage space and work table has been built to organize and prepare valuable field equipment. Workstations and workspace have been configured properly for research assistants in the environmental science program. A Guam geologic rock display section was built to improve collection and organization of the island's rock inventory. This area is also designed as a small geology laboratory.

GHS provides limited stipends 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, and the salary of one full-time Research Affiliate is charged with operating and managing WERI's information database, the hydrology laboratory, and preparation and update of routine reports and presentations.

The program activities in this report begins with GHS Research Projects followed by CWMP Research Projects. The GHS section is organized into four sections: Northern Guam Lens Aquifer (NGLA) database, NGLA map series, Sustainable management, and Workshops.

1. GHS Research Projects

Research projects are grouped into four sections: database, maps, sustainable management, and outreach. The database organizes a borehole database, which is the basis of subsurface information, and a water resources library. It also includes the collection and organization of pertinent meteoric, hydrologic, and water quality data. The maps often summarize the data analysis, and it is truly an indispensable tool for water resource management. Sustainable management is a multi-faceted approach to quality sustainable water resource. The workshops provide training and outreach to our interagency partners.

1.1. Northern Guam Lens Aquifer database

The primary source of facts below the surface of the Northern Guam Lens Aquifer comes from borehole records. Technical Report 141, Bendixson et al., was a major feat in collecting and thoroughly organizing the subsurface factual information. It set a standard means of documenting and placing information in a most simple and logical arrangement. The filing system, table listing, and information categorization is easily updatable. Now, the database is

available on the internet for anyone to access (www.guamhydrologicsurvey.com, see also GHS CWMP Online section).



Drilling and drill logs

The Guam Hydrologic Survey mandates interagency cooperation with Guam Environmental Protection Agency (GEPA) such that new deep drillings into the aquifer will be properly and thoroughly documented/recorded and submitted the Guam Hydrologic Survey. The cooperation positions WERI to work closely with drillers in assessing the geology and hydrologic potentials in pursuit of optimal production wells. Downhole video is now being used to find the most productive porous media in the borehole to determine the best placement and screening recommendations.

One of the priorities of the PL24-247 is maintenance and routine update of the Guam hydrological database and routine trend analyses of the data. In response, is the ongoing project pertaining to the management and data analyses of the Northern Guam Aquifer Database.

GHS' NGLA Trilogy

WERI Technical Reports 141, 142, and 143, NGLA Trilogy, is a related set of essential NGLA management tools and reference. *Technical Report 141* provides a database of borehole and well data. In preparing the database, over 4,000 pages of documents were scanned and organized into individual electronic folders for each of the 525 wells documented so far. These include 20 exploratory wells, 115 observation/monitoring wells, 212 drinking water wells, 39 agricultural/industrial wells, and 104 stormwater management wells.

This database is now available online. Each well folder is hyperlinked to its corresponding record in a webpage converted Microsoft® Excel table and an online folder-file explorer like directory database. Documents within each folder contains key engineering and hydrogeological data.

The database is the primary data source for WERI's topographic map of the basement rock beneath the aquifer, *Technical Report 142, Topography of the Basement Rock beneath the Northern Guam Lens Aquifer and Its Implications for Groundwater Exploration and Development*. Creation of the map employed the latest data screening and spatial analysis techniques to evaluate 697 records, from which 173 control points were applied to the map. The new map updates the boundaries of the aquifer's six groundwater basins and provides for more accurate demarcation within each basin of its *basal zone*, where freshwater is underlain by saltwater, *para-basal zone*, where freshwater is underlain by basement rock below sea level, and *supra-basal zone*, where conduits and discontinuous patches of freshwater are underlain by basement rock above sea level. The new map also incorporates new insights regarding groundwater occurrence gained from the broad-ranging 2010 Exploratory Drilling Program funded by *Naval Facilities Engineering Command Pacific*. The report concludes with recommendations regarding groundwater exploration, aquifer development, and maintenance and

improvement of the basement map. This basement map is now called the Northern Guam Lens Aquifer Map (further details in the next section).

Production well quality concerning saltwater intrusion is a major limiter of water production quantity. McDonald, WERI Technical Report 98, 2003, reported the production-chloride analyses with respect to well design and construction. Simard, *WERI Technical Report 143*, 2015, third of the GHS trilogy, updated McDonald's chloride and production trend analysis to 2010, focusing on geologic and climatic factors that may be affecting well pumping and salinity levels. Similar to Bendixson's borehole database (BHDB) online folder file explorer system organization, Simard's work is also available online referred to as the CPDB (chloride and production database).

Lessons learned from rehabilitation of production wells

Currently, Guam Waterworks Authority produces 90% of the 45 MGD potable water from its main source, the Northern Guam Lens Aquifer. GWA manages 100 to 120 deep vertical production wells in this aquifer to meet the demand. However, many of these production wells are deteriorating from age with more than 50 years in operation, thus lifespan exceeded, and maintenance is no longer economically viable, quality and production may become degraded and unsustainable for these aging wells. USEPA, GEPA, GWA, and CUC had concurred to a plan of rehabilitating several aged wells. The rehabilitation plan was to drill and install new production wells next to selected wells within property bounds. This was determined considering historic performance of the wells, existing ease of access and available power utility, and the chance probability of replicating the performance of the old well nearby, using similar design specifications from the old well.



Production well (M-9) rehabilitation

The USEPA funding of the rehabilitation project yielded deep drilling and construction, with careful recording and documentation in tests and examination of seven new potential production wells. In the construction process, WERI served to contribute advice and recommendations, sharing GHS trilogy data from the Guam Hydrologic Survey website (www.guamhydrologicsurvey.com)

borehole database (WERI Technical Report

141), chloride and production database (WERI Technical Report 143), and the Northern Guam Lens Aquifer map (WERI Technical Report 142), working closely with the contractors (Allied Pacific Drilling Inc., APDI; AECOM) with exchange and examination of data. GEPA required the contractors to log and submit proper documentation, well video inspection, and well test (pump test production rate, water quality, drawdown) records. WERI, GWA, APDI, AECOM, and GEPA collaborated in recommending modification of plans such as deeper drilling to improve well production rate, quality (salinity < 250 mg/L), and mindful of production well hydrology (drawdown). The collaboration and interagency team work has proven to be the right approach in all endeavor for a successful outcome in the project. This experience has also brought about things we can improve upon for future production well expansion. WERI deems that it is undoubtedly necessary and highly valuable to compile, organize, and share the lessons learned from this interagency experience to further improve groundwater development on this island, and for other similar aquifers.

WERI will review data on seven abandoned production wells (D-3, 17, 18, 22A; M-9, 14; A-28) and organize the data according to hydrogeologic issues, contamination, and well construction. Necessary analysis will be conducted to categorize well development issues. Lastly, rehabilitation procedure in a manual and checklist, methods for use of available data, and proper expert group communications will be recommended.

Guam Geology Collection and Display

The GHS office laboratory at WERI has included geologic laboratory for basic testing, collection, inventory, reference, and display of Guam's rocks. WERI is collaborating with one of the island's most knowledgeable scientist of Guam geology, co-author of the Geologic Map and Sections of Guam, 2007, Dr. Randall. This laboratory is designed to do basic tests and identification analysis under microscope, chemical reaction, and ultraviolet light refraction. The collection shelves more than 50 rock collections from the U.S. (e.g., dolomite, quartz, obsidian, etc.). Dr. Randall will add his collection of prime sample rocks from Guam to add to the inventory. The display shelf organizes 27 rock units by geologic time order. The geologic laboratory is designed to store/shelve field samples, bucket collection, geologic equipment/tools (magnifiers, loupes, ultraviolet light, test chemicals), and geologic reference (literature/publication binder, text books, and geology books). This geologic rock laboratory will be available to the graduate studies environmental science program, outreach education and professional development (workshops), and UOG's Charter Day activities.

1.2. Northern Guam Lens Aquifer map series

By far the most important tool for successfully locating site for new wells that will deliver abundant high-quality water from the Northern Guam Lens Aquifer is an accurate and precise map of the aquifer's subsurface structure and hydrologic components. The updated mapping of the volcanic basement rock that forms the floor of the aquifer was a breakthrough to the developing the Northern Guam Lens Aquifer Map, Vann et al. 2014 (see GHS Trilogy, above). Other ideas have emerged to further improve the mapping of the NGLA.

The Northern Guam Lens Aquifer Map

The volcanic rock beneath the water-bearing limestone partitions the aquifer into semi-contiguous subterranean catchments, or *basins*. On the slopes of the basement rock standing above sea level, where the base of the aquifer thus lies above sea level, downward percolating fresh water becomes concentrated in basement valleys and at the base of the slopes, where it enters the lip of the fresh water lens. The rim of fresh water thus concentrated along the boundary of the volcanic basement and the water-table near sea level is underlain by volcanic rock rather than sea water. This *para-basal* water is thus fresher, thicker and much less vulnerable to salt-water contamination than the *basal* water downstream, which floats on the

the USGS Pacific Islands Water Science Center, in collaboration with WERI, has provided additional funding to update the database that supports the map. An accurate map of the basement topography is an essential prerequisite for building accurate and reliable groundwater models, which is one of the goals of the groundwater availability study.

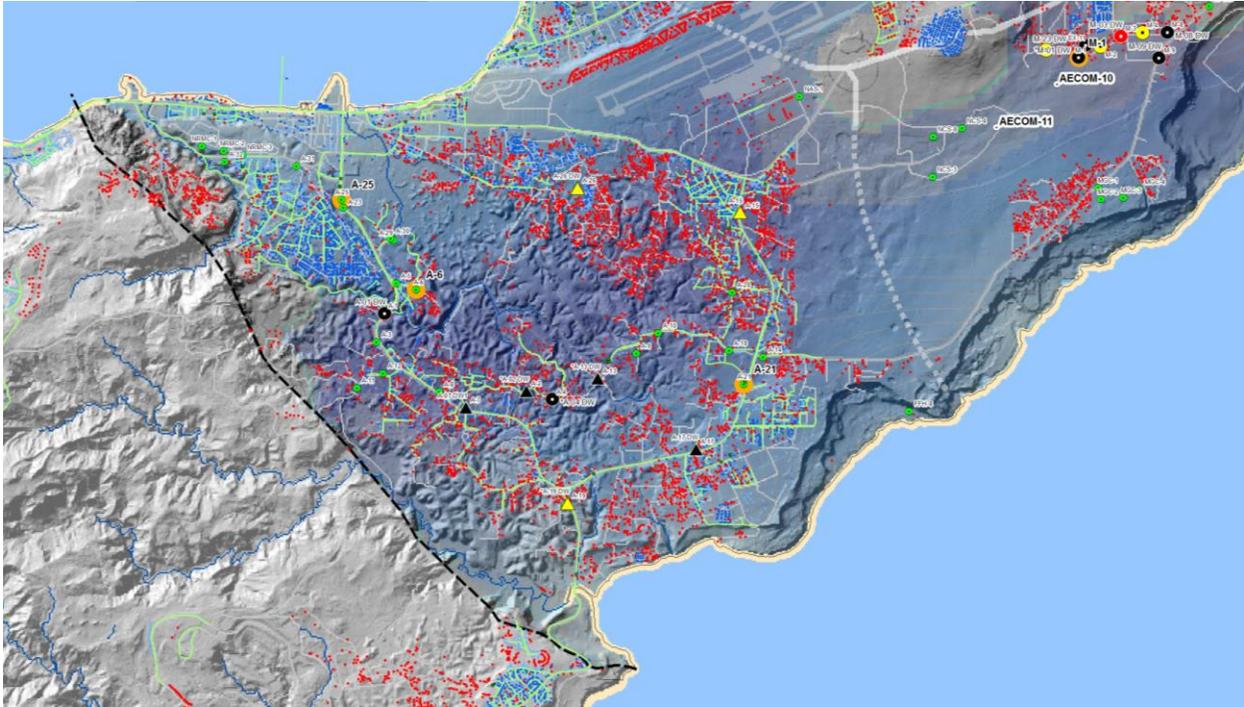
WERI anticipates publishing a revision of the 2017 NGLA map in 2019. The map consists of a set of superimposed map layers, revealing the basement topography in relation to aquifer geology, hillshade, and the locations of drinking water production wells and aquifer observation and monitoring wells. These maps will be available to other geologists and engineers in the public and private sectors, for which they will enhance the success and thereby reduce the cost of ongoing aquifer development. They will also be essential tools to environmental scientists, regulators, and policy-makers seeking to develop appropriate regulations for aquifer protection and sustainable management.

The Northern Guam Lens Aquifer is Guam's primary source of water, and if managed properly will continue to supply the island's daily water needs for generations to come. It is also a very complex hydrogeologic system. No simple technique or approach can characterize this aquifer. Rather, a multi-layer analysis is required to describe, model, and manage the groundwater system. The development of a series of hydrogeologic maps that captures each of the components—while also providing a means for showing their inter-relationships—is of basic and utmost importance for successful exploration, development, and management of the aquifer. The creation of an up-to-date map of the basement topography (also described in the section, The Northern Guam Lens Aquifer Database) has provided the first step toward an integrated, multi-layered hydrologic map. The new map includes not only updates of the boundaries of the aquifer's six groundwater basins, but also provides for more accurate and detailed demarcation within each basin of its three groundwater zones: basal, para-basal, and supra-basal. This year's update incorporates new insights gained from the 2010 Exploratory Drilling Program funded by *Naval Facilities Engineering Command Pacific* (AECOM Technical Services Inc., 2011), and the 2013 *Guam Groundwater Availability Study* (Gingerich, 2013; Gingerich and Jenson, 2010).

The new map specifically shows no-pumping simulation from the modeling study to estimate the water-table, hydraulic gradients, flow lines, and basin boundaries. The modeled lens geometry shows the estimated location of boundaries of the para-basal zone. Drill-logs and contours of supra-basal waters (ICF Technology, 1995) were also incorporated in the map. Occurrence of surface streams over the Hagåtña Basin and adjacent terrain were also included. Semi-transparent surface hill-shading provide a surface elevation perspective of the limestone plateau. Other hydrologic features that will be added to the current map or included in complementary maps in the series, include hydraulic conductivities, geologic features, soils, porosities, pumping effects, groundwater locality of sustainable limit supply, land cover, and rainfall distribution.

NGLA Maps: Wastewater Sources and Production Well Nitrates

Development over the NGLA is a concern of possible wastewater contamination. The aquifer's water resource in a durable karst plateau provides an economic access for development, but the residential and business wastewater discharged above it may be a threat to the freshwater



NGLA wells and wastewater system

resource. Increased and dense development must be accessed as it may intensify wastewater discharge.

The NGLA map and the layover of the wastewater system provides a useful assessment tool for contaminant transport. It was recently used in the initial assessment of PFOS contaminant source potential. The map may also be used to determine prioritization of sewer systems. The wastewater system map over the NGLA map helps planners strategize future development and reduce wastewater contamination.

NGLA Maps: Drone imagery of sinkholes - vadose fast recharge sites

The first complementary map, which will be published during the coming year, is a map of the sinkholes on the aquifer surface, which constitute its drainage system. Spatial analysis of LiDAR-based digital elevation model allows a precise determination of closed contour depressions on the limestone plateau.

Mapping these depressions and their relationships to other hydrologic and geologic features will be a major contribution to determining the distribution of recharge between fast vertical conduit flow channels and slow percolation through the bedrock. This is important to the refinement for accurately modeling aquifer recharge and potential contaminant entry and flow paths.

NGLA Maps: Drone imagery of watersheds, rivers, and streams

Proper management of a region's water resources requires water managers and water resources researchers to have accurate baseline information on the geomorphological and ecological health

of surface water streams in a region. It is also vital to have a detailed baseline knowledge of potential pollution sources in groundwater recharge areas. Along with this baseline information there is also a need for periodic sampling of water quality indicators to identify changes in the environmental health of streams and groundwater recharge areas. Studies such as surface and ground water supply studies, depend on this kind of long term variable information to develop the best management practices for a region's water resources.

In the past, the only means of visual monitoring of stream and groundwater recharge areas health was either with direct on-ground monitoring or the use of high altitude satellite imagery or LIDAR (Light Imaging, Detection, and Ranging) data. This imagery and data was typically accurate to about 0.5-meter resolution. Because of the expense of data gathering, these resources were not available at intervals that could be used for the continued monitoring of the environmental health of Guam's streams and recharge areas.

Recent advances in commercially available sUAS (Small Unmanned Aerial Systems) technology have made lower cost, highly accurate, sub- meter resolution aerial imagery available. Commercial sUAS drones fly at elevations less than 400 ft., capable of gathering high resolution data used for the development of georeferenced imagery on these low elevation flights. The photographs can be used as detailed high resolution individual photos of streams or groundwater recharge areas or can be composited into highly accurate georeferenced photos of various areas of study. Photogrammetric procedures allow foliage cover removal from the data to develop high resolution composite ground surface digital elevation models of areas of interest.

This project involves Five phases:

1. evaluating and choosing which sUAS drones, cameras and analysis software would be most appropriate for the stream and groundwater recharge study areas
2. choosing test stream reaches and groundwater recharge areas to develop the appropriate methodologies for carrying out the aerial data gathering missions
3. aerial data gathering and map development
4. developing a data management scheme for the imagery and other data gathered using the techniques developed by the project
5. continued imagery gathering and processing for various streams and recharge areas on Guam.

Federal Aviation Agency (FAA) no-fly zones, military restrictions, site accessibility, and ownership issues will determine which study areas will be selected. Commercial software such as LiMapper and Drone Deploy will be explored as a means of developing georeferenced imagery and digital elevation models of the areas of interest. The detailed georeferenced aerial data will provide baseline knowledge of the location, size, and potential pollution sources in groundwater recharge areas. In Southern Guam, drone data retrieved will accurately plot stream cross sections, determine erosion potential and possible sediment loading, and other sources of environmental contamination. Data management will use WERI's and the Island's Guam Hydrologic Survey website.

1.3. Sustainable Management of Guam’s Water Resource

Inter-agency Advisory and Cooperation Group

The sustainable management of water resources is complex that it is more than a hydrologic solution or determination. Ponce (2007) explains that “a holistic approach to groundwater sustainability considers the hydrological, ecological, socioeconomic, technological, cultural, institutional and legal aspects of groundwater utilization, seeking to establish a reasonable compromise between conflicting interests.” He concludes that “sustainability reflects resource conservation policy; the more conservative a policy, the more sustainable it is likely to be.”

WERI is also a member of the local water resource interagency organization called the Technical Experts Group (TEG) and the Groundwater Resource Development Group (GWRDG) established by the 16 July 2010 Memorandum of Understanding between the US Navy and Guam Waterworks Authority. The MOU provides an additional venue for meeting the GHS and CWMP mandates to “establish a direct working relationship with each organization collecting hydrologic data important to Guam and maintain a permanent flow of new data from each organization to keep the data library up to date.” Local and federal agencies that are party to or affected by the MOU include GWA, GEPA, CUC, US Navy (NAVFACMAR), USAF (36 CES), and USGS. Interagency groups also include private consultants: Duenas Camacho and Associates, Allied Pacific Environmental Consultant (APEC), EA Engineering, Brown and Caldwell, and AECOM. Meetings are organized and held quarterly at Guam Waterworks Authority (Gloria B. Nelson Public Service Building), Fadian. Current discussion is the expansion of monitoring (observation) wells, see details in CWMP Research Projects section. The interagency group organization formed of three groups: executive, working group, and the technical team.

The inter-agency group meets quarterly to discuss concerns, pool resources, share ideas, provide update, consult, and gain professional acquaintance and partnerships. Vangie Lujan of GWA hosts and organizes the group meetings. Here is a list of agencies in attendance:

Government of Guam:

- GWA – Guam Waterworks Authority
- GEPA – Guam Environmental Protection Agency
- GCUC – Guam Consolidated Commission on Utilities
- GBSP – Guam Bureau of Statistics and Plans
- GDPW – Guam Department of Public Works
- GPUC – Guam Public Utilities Commission
- NGSWCD – Northern Guam Soil Water Conservation District
- UOG – University of Guam
- GWK – Guam Water Kids
- WERI – Water and Environmental Research Institute of the Western Pacific

US Federal:

- USGS PIWSC – US Geologic Survey, Pacific Islands Water Science Center
- NAVFAC Marianas – Naval Facility Command Marianas, US Navy, Guam

Private Sector:

AECOM – Architecture, Engineering, Construction, Operations, and Management: Guam Expansion Project

APEC & APDI– Allied Pacific Environmental Consulting, Inc., Allied Pacific Drilling Inc.

B & C – Brown and Caldwell: Essential Ingredients®

DCA – Duenas, Camacho and Associates, Inc.

GHD – Gutteridge Haskins & Davey

IREI – Island Research and Educational Initiative

PCR – PCR Environmental, Inc.

Groundwater Model Explorations of Sustainable Yield: Phase IV

The Northern Guam Lens Aquifer (NGLA) provides 80% of Guam’s drinking water. The anticipated addition of US Marine Corps activities will require additional production, while ongoing economic growth will increase demand as well. Policy-makers and water managers have asked “what is the absolute maximum volume of water that could be sustainably withdrawn from the aquifer?” Answering such a question requires identifying (1) the natural limits on aquifer recharge, storage, and water quality imposed by climatic and geologic conditions, (2) , but doing it for an ideal production system, i.e., one that is constructed and operated so as to achieve the maximum possible production for a given standard of quality.

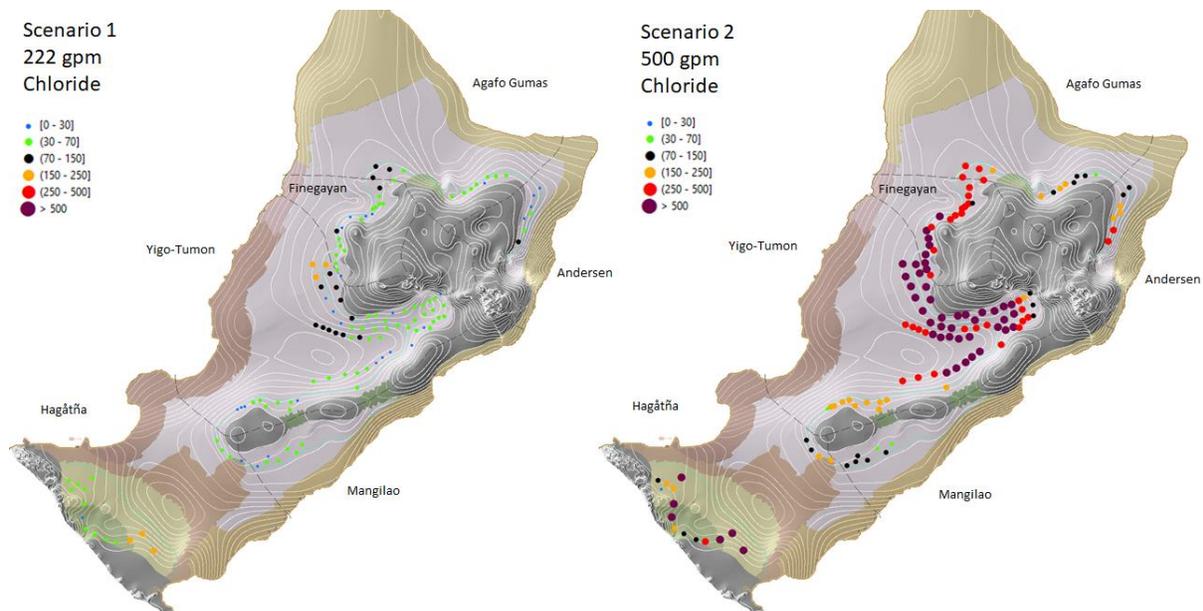
This study is therefore directed at estimating the maximum potential capacity of the NGLA, i.e., the capacity that ultimately could be achieved by an ideal production system, given what we currently know or must assume about the natural limiting conditions. Recent modeling has incorporated the current state of knowledge regarding natural conditions and constraints. The third phase model simulated maximum yield in the optimum boundary, less susceptible to saltwater up-draw, the parabasal zone. In the fourth phase, estimates of maximum potential capacity can now be made by exploring scenarios in which hypothetical well depths, expansion by addition of basal wells, and pumping rates are distributed so as to maximize the capacity for given upper limits of chloride. This fifth phase aims to refine the existing model, update the model boundary conditions and recalibrate to additional eight new observation wells and 10 new rehabilitated production wells. This study will thus help provide some estimates of the absolute upper limits of production that could, in principle, be achieved by an optimum system. These will provide ultimate baselines against which to make economic evaluations of future options for holistic sustainable management of the aquifer.

Methods: The principal investigators will continue to lead a research team composed of themselves, a WERI-based graduate research assistant (UOG environmental science MS candidate), working in collaboration with colleagues at the USGS Pacific Islands Water Science Center (PIWSC) to update the model. This will require preparation and reassembly of the data sets; identify new climatic phenomena and geologic features that are most likely to exert significant rainfall amount and intensity, infiltration rates, aquifer storage, groundwater flow, and groundwater salinity on northern Guam; and apply statistical, geospatial, and other analytical tools to identify,

characterize, and interpret past and present spatial patterns in rainfall, groundwater levels, specific conductivity, chloride concentrations, and production rates from existing wells within the NGLA. The team will recalibrate and test the model to existing, new observation wells, and rehabilitated wells.

Objectives: The objectives of the respective phases of this project are:

- (1) Data acquisition and literature review of published and emerging research on spatial and temporal distributions and trends of rainfall and salinity in the NGLA by WERI, USGS and others
- (2) Rebuild model parameters and mesh to the new information
- (3) Update temporal analysis and interpretation
- (4) Test the model
- (5) Run scenario simulations



Model results for a reconfigured well system

4. Outreach programs

Guam Hydrologic Survey provides outreach programs. WERI teams up with Guam Waterworks Authority, Guam Water Kids, UOG Professional and International Programs, for the NGLA Executive Tour and Technical Workshops.

Northern Guam Lens Aquifer Professional Tours

Early 2018, GHS Outreach provided four Northern Guam Lens Aquifer Professional Tours. The tours served two Executive Management and Legislature, Guam Water Kids and Guam Department of Education, and UOG Students. The Executive Management and Legislature tour held two sessions one week apart, inviting senators and representative staff, private sector heads,

UOG SVP and Board of Regents, and US Navy Captain Jones and staff representatives. The third tour was GHS and Guam Water Kids teamwork for Department of Education faculty and the School. Program Consultant, for teaching about our water resource. The final NGLA tour was to educate UOG Students – Geography and the School of Engineering’s Society of American Military Engineers. The tour begins with a virtual tour of the NGLA, a computer graphics 3-D hydrology of Guam that allows the audience to see by virtually flying into the aquifer freshwater lens and basement boundaries in the north and the surface water system in the south. It is then followed by a field trip experience of the geologic rocks that make up the aquifer components and an examination of its properties that allow water to move through.



NGLA Executive Tour. Dr. Jenson (WERI Director) at Channel 10, Mt. Alutom. The GHS outreach includes the NGLA Tour for executive leader representatives of the legislature, heads of private sector, and University of Guam. UOG SVP Dr. Enriquez examines the same rock type, Alutom, as the aquifer basement.

Northern Guam Lens Aquifer water resources workshop

The military buildup and ongoing economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam’s groundwater resources. Besides educating policy-makers and agency heads it is also essential that island water resource

professionals and educators be equipped with an accurate and up-to-date understanding of the essential characteristics of the island's aquifer and the factors that must be considered to frame and implement sustainable management practices. Professional people, including working-level technical professionals in the water resource industry, university instructors, and school teachers, have extremely limited time to engage in instructional opportunities. This proposal is for development and delivery of a series of short-course workshops to local water resource professionals and educators. It will include single-day intensive instruction in

- the Northern Guam Lens Aquifer database and development and use of basement map of northern Guam: and
- sinkholes and surface drainage of the aquifer, and salinity trends, patterns, and processes in the aquifer
- the NGLA Tour and 3-D virtual tour of the aquifer, and
- an introductory workshop in basic GIS, presented in six 2-hour sessions, for student researchers, faculty, and professionals working on groundwater and related problems.
- N-baseline report (Rouse et al.)
- Multi-layered NGLA maps (Yuming et al.)
- ENSO

Instruction and media organization will be supported by the GHS website containing the instructional materials plus additional references and links to other relevant and useful resources, and forums for maintaining continuing educational interaction and information-sharing. A new GHS website is underway to accommodate the course resources such as the NGLA database that will be useful for island water developers and managers.



Professional Guam Water Resources Workshop Series. The Northern Guam Soil Water Conservation District participated in the Fanuchanan 2017 workshop at WERI, UOG.

GHS Outreach Support of Guam Water Kids to the Department of Education

The Guam Hydrologic Survey Program and Guam Water Kids (GWK, funded by Triple J Motors) have more than a decade's worth of teamwork. The Guam Water Kids reaches Department of Education campuses teaching elementary students the value of our water resources and the importance of protecting it. Early 2018, Guam Water Kids and Guam

Hydrologic Survey provided a workshop for J.P. Torres High School Success Program. In one of the GWK workshops, GHS provided a demonstration of freshwater floating on saltwater in a porous media, lecture presentation of water occurrences throughout the island, and the virtual tour of the aquifer.



GHS and Guam Water Kids outreach to J.P. Torres High School Success Program.

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 1998, the CWMP was made a permanent part of WERI's program when Governor Gutierrez signed PL 24-161 and 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.

The loss of a hydrologic observation program has proven to be detrimental. Good hydrologic research studies and support for water management decision essentially require consistent and accurate data. Gaps in data limits a really good analysis and interpretation. This was experienced in the modeling of the NGLA (Gingerich 2013), where more information in the Agafa Gumas basin could have greatly improved the accuracy of the simulation. The interest and value is now well recognized in the GWRDG and TEG in preparation to the expansion of groundwater monitoring, the addition of eight new observation wells.

2. CWMP Research Projects

The CWMP program collects pertinent hydrologic data and applies analysis and interpretation. The analysis and interpretation is conducted in research projects that will contribute to the status our water resources and new findings. The CWMP program is organized into two components, the monitoring program and data analysis research.

2.1. Monitoring (observation) programs

The monitoring/observation program is improving. USGS-WERI continues to work as a team in collecting well hydrologic information. The GWRDG and TEG are also currently discussing and preparing for expansion of well observation, installation of eight new observation wells. WERI and GWA established cooperation in a Memorandum of Understanding, where GWA shares the monthly water production report and quarterly well water chloride concentration data. Wastewater-N data is now being logged in two production wells in the Yigo area.

Interagency cooperation agreements

Interagency cooperation and knowledge networking is very important and beneficial to our future of sustainably managing our water resources. GWA has a memorandum of understanding with WERI, an agreement to share their production, chloride, and other water quality data. The agreement further strengthens our long history partnership in all efforts to improve water production and wastewater management. Guam Environmental Protection Agency MOU with WERI is soon to follow.

USGS' PIWSC and WERI, observation wells data collection

The Comprehensive Water Monitoring Program yields observation well data. The appropriation and acquisition of USGS' Pacific Islands Water Science Center (PIWSC) and WERI services result in the collection of data for scientific research. It serves as the data source for accurately determining lens dynamics, lens profile terms and definitions, and response to communicative data such as rainfall and tidal signals. It is very useful for frequency analysis of the groundwater lens component position and even groundwater model calibration. The installation of new observation wells will expand the domain with more spatial and temporal data of the lens.

New Deep Observation Wells for the NGLA

The Department of Defense Office of Economic Adjustment (OEA) has granted \$3.7 million to the Guam Waterworks Authority (GWA) for constructing and testing seven new deep-monitor wells and rehabilitating twelve existing monitor wells in the NGLA. In January 2017, the GWA selected the engineering consulting firm Brown & Caldwell to lead the Program Management Office (PMO) for execution of the grant. The OEA grant provides critical infrastructure improvements needed to expand the Guam Comprehensive Water Monitoring Program prepared by the U.S. Geological Survey Pacific Islands Water Science Center (USGS) and the University of Guam Water and Environmental Research Institute of the Western Pacific (WERI). In support of the OEA-funded NGLA Monitoring System Expansion Project, WERI and USGS expand and deepen their collaborative work to analyze and interpret new data from the expanded monitoring system and thus provide GWA, GEPA, DoD, and other stakeholders—through an interagency framework—with independent, objective scientific information needed to make informed water-resource management decisions.

NGLA Monitoring System Expansion & Rehabilitation Project (MSERP) launched on October 2017 and will last until December 2020. This scope of work is divided into two tasks. Task 1 consists of (1) developing well-construction specifications for seven new deep-monitor wells and rehabilitating 12 existing monitor wells; and (2) defining sustainment requirements for the OEA-funded NGLA Monitoring System Expansion Project and associated expansion of the Guam Comprehensive Water Monitoring Program. Task 2 consists of geophysical logging of the seven new deep-monitor wells to evaluate aquifer properties, especially the characteristics of the water-bearing zones penetrated by the wells.

The role of the USGS and WERI work in Task 1 is to provide GWA and its contractors with technical assistance for constructing and testing new deep-monitor wells, rehabilitating existing monitor wells, and for defining sustainment requirements for the OEA-funded *NGLA Monitoring*

System Expansion Project and the associated expansion of the Guam Comprehensive Water Monitoring Program.

New deep-monitor well construction specifications and technical support: The USGS and WERI work with GWA’s the Program Management Office (PMO) to refine well-construction specifications for seven new deep-monitor wells. WERI provides technical support, including on-site support, before, during, and after construction of the new deep-monitor wells. The PMO will be responsible for ensuring that the driller constructs the wells as designed in the specifications and that the required timelines are met.

Existing-well rehabilitation specifications and technical support: The USGS and WERI will work with GWA’s PMO to refine well-rehabilitation specifications for 12 existing monitor wells. WERI will provide technical support, including on-site support, before, during, and after rehabilitation of the existing monitor wells. The PMO will be responsible for ensuring that the driller rehabilitates the wells as designed in the specifications and that the required timelines are met. The USGS will remove and reinstall water-level recording equipment before and after rehabilitation of existing monitor wells.

Sustainment requirements for the NGLA monitoring program: The USGS and WERI will work together to define permanent ongoing (post-construction) sustainment requirements for the OEA-funded NGLA MSERP and associated expansion of the Guam CWMP. This will include identifying monitoring parameters and frequencies, scheduling and implementing maintenance and recapitalization of the wells, and providing scientific support to include data collection and management, data interpretation, trend analyses, and periodic groundwater modeling updates. These actions are needed to ensure that the OEA-funded infrastructure investments are operated and maintained such that the infrastructure will continually yield high-quality data to support informed water-resource management decisions.

Major tasks and periods of activity

Tasks	2017	2018				2019				2020			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1:													
Well Specifications													
Sustainment requirements													
Technical support for well construction													
Water-level equipment removal and reinstall													
Task 2:													
Logistics and planning													
Geophysical logging and interpretation													
Report preparation and publication													

N-data collection: Phase II

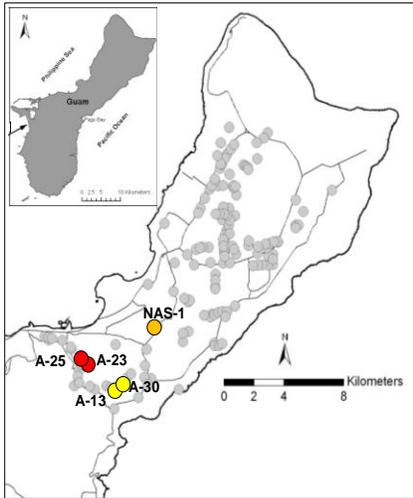
The Northern Guam Lens Aquifer (NGLA) is Guam’s primary source of freshwater for potable use. This porous limestone formation currently provides approximately 80% of the island’s municipal water supply. Aggressive production of groundwater has grown to 40 million gallons per day (mgd). With water demand rising and concerns over water quality increasing, proper

- transformation triggers, and study of groundwater contaminant transport.
- (2) Analysis of spatial time-series wastewater-N data at sites with rainfall and other possible influences such as pH, ORP, sewage discharge events, etc.
 - (3) Translation/interpretation of analysis such as increasing/decreasing trends, averages, and spatial distribution.
 - (4) Suggest/recommend development strategies to improve wastewater management.

2.2. Data analysis research

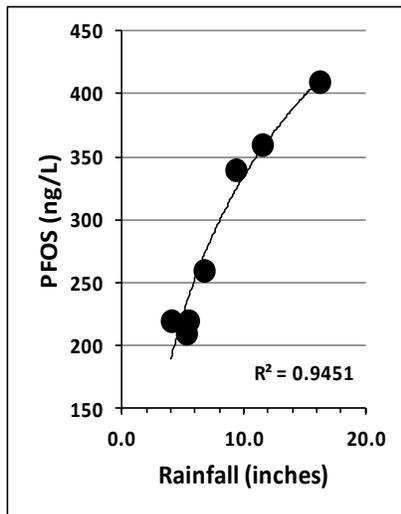
PFOS monitoring and trend analysis

The Guam Waterworks Authority (GWA) began monitoring PFOS in Guam’s groundwater in March 2015, in response to USEPA’s third Unregulated Contaminant Monitoring Rule, (UCMR3). Overall, five production wells were identified as PFOS contaminated and levels in two of them (A-23 and A-25) were consistently above the USEPA’s 70 ng/L benchmark. The highest PFOS levels occurred in well A-25 and ranged from 220-410 ng/L in March and September of 2015 respectively. Both A-23 and A-25 are currently offline as a



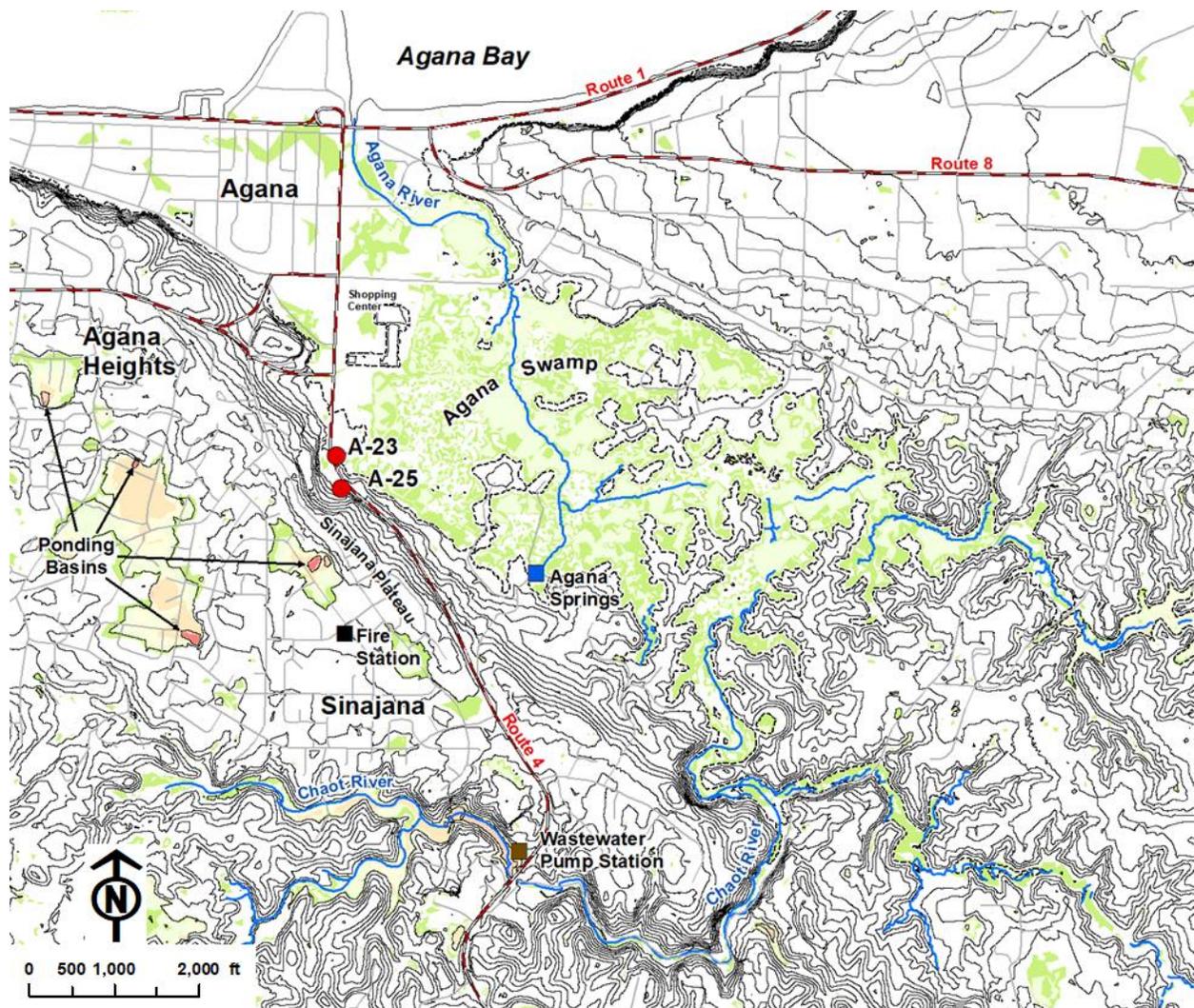
result of this contamination and may be retrofitted with GAC filters sometime in the future. Until then, all further monitoring of PFOS in both wells has ceased. WERI saw merit in continued monitoring and embarked upon a collaborative project with GWA to continue sampling well A-25 on a monthly basis as of June 2017. The study is currently ongoing and funded by awards made possible through the USGS 104-B Water Resources Research Institute Program and the Guam Hydrological Survey, with in-kind contributions from GWA.

GWA production wells with PFOS detections in the northern half of the island. Red and yellow circles indicate wells with PFOS levels consistently above and below 70 ng/L respectively. Orange circle indicates one exceedance to date.



All results acquired to date show a strong positive correlation between PFOS concentrations in well A-25 and monthly rainfall averaged over the three months prior to each sampling event. Interestingly, the delayed relationship between these two variables implies that the source(s) of PFOS contaminating A-25 may be located some considerable distance away from the well-head. Moreover, the fact that the highest PFOS value encountered at the peak of this year's wet season (September 2017: 340 ng/L) was approximately 20% less than that recorded in September 2015, suggests that some degree of PFOS attenuation is indeed occurring within the watershed.

Scatter-graph of PFOS data gathered to date from well A-25, plotted against monthly rainfall averaged over three months prior to each sampling event



The West Hagåtña Aquifer Basin maps the affected production wells A-23 and A-25 and investigation area in search of the source of PFOS.

On the strength of the data gathered thus far, it would seem prudent to continue the PFOS trend monitoring of well A-25 at least through one more wet/dry season cycle. Thereafter, pending further refinement of the time delay between rainfall and the PFOS concentrations encountered in the well, continued sampling could be scaled back to coincide with rainfall extremes that have occurred in previous months. The PFOS monitoring of A-25 will be continued on a monthly basis for an additional year in order to further understand the dynamics driving the system and ultimately implement science based, cost-effective management strategies to deal with the problem. This study is of considerable interest to GWA and the Guam EPA and also addresses several critical water resources research needs identified and/or reaffirmed at WERI's most recent Advisory Council Meeting with Guam stakeholders.

Lens dynamics

The limestone aquifer of northern Guam supplies more than 75% of the island's drinking water. As Guam prepares for more economic growth, the growing demand for water from the aquifer is a major concern. This research project will use historical groundwater hydrographic data and local meteorological data to study how the thickness, and hence the volume, of the freshwater lens in the Yigo-Tumon Basin responds to natural changes in recharge. The Yigo-Tumon Basin is the largest of the aquifer's six basins, supplying 18 mgd, or 56 % of the total production of 33 mgd from the NGLA (July 2016, GWA, Joe Garrido). Time-series data from the 35-year records for two salinity-profiling wells in the basin will be analyzed to gain insights into the timing, rates, and magnitudes of changes in lens thickness in response to seasonal, inter-annual, and episodic (storm) variations in rainfall. The study will thus help to identify the conditions and quantify associated parameters that determine the proportion of rainfall captured as recharge. Findings will support the development of effective sustainable management practices, including appropriate policy and management responses to storms and droughts. Improved understanding of observed lens dynamics will also help to improve the reliability of our groundwater models.

The quantity of groundwater available for extraction can be measured in terms of the freshwater lens thickness. Lens thickness can be measured directly from well salinity profiles and inferred indirectly from water levels. The lens thins or thickens in response to storage changes from recharge and water withdrawal (production).

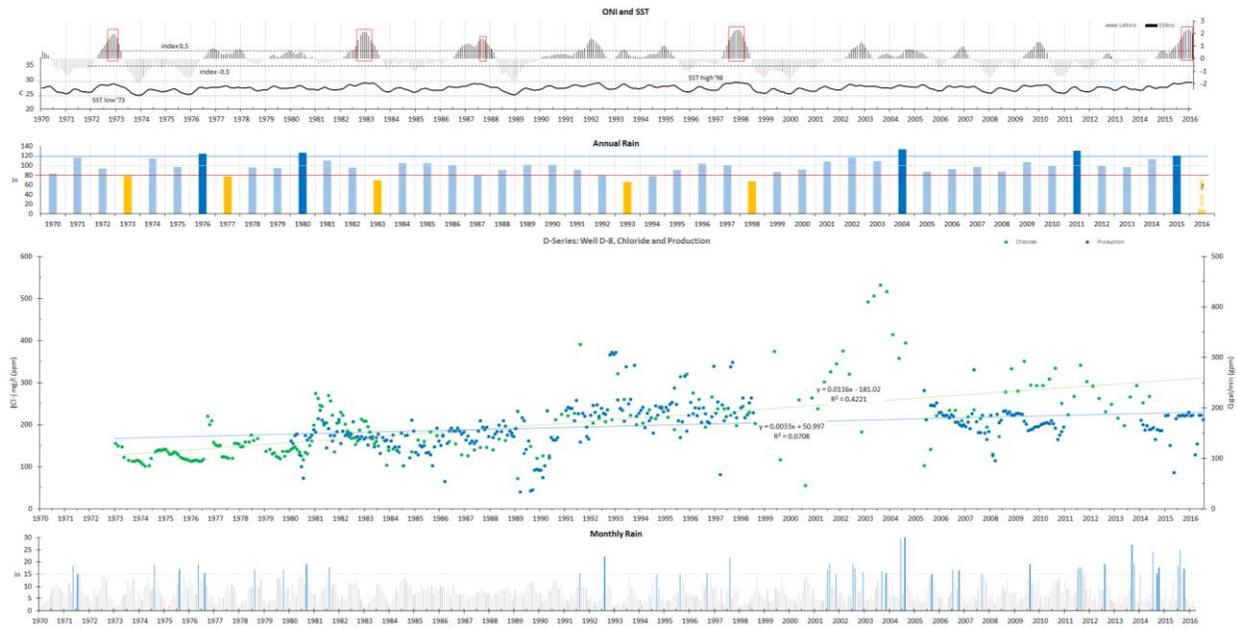
The amount of recharge that replenishes the aquifer depends primarily on seasonal and inter-annual changes in rainfall. Major storms account for only a few percent of total rainfall, but induce rapid responses in water levels and can thus have important immediate short-term effects on water quality. The timing and amounts of wet and dry season rainfalls are strongly influenced



by El Niño Southern Oscillation (ENSO) events and typhoons. Annual rainfall is reduced by as much as 50% during the year following strong El Niño (Lander 2016, personal communications). A strong El Niño (Oceanic Niño Index greater than 1.5) typically accompanied by a severe Micronesia wide drought, results in depletion of the freshwater lens, but the rate and magnitude of depletion has yet to be rigorously evaluated.

USGS deep observation data collection for CWMP

Production wells in the Northern Guam Lens Aquifer (NGLA) are susceptible to saltwater contamination. This project with the Guam Hydrologic Survey continues the process of



Rain, ONI and SST, chloride and production trend analysis, production well D-8.

updating the production well and chloride concentration database for the NGLA. Its purpose is to examine the Yigo-Tumon basin for historical trends and potential influences on salinity. The Yigo-Tumon basin accounts for over half (17 mgd) of the production of the total production (36 mgd) from the aquifer's six basins. The analysis focuses on natural climate cycles and their relationship to salinity. Chloride concentration in active wells determines extraction limits to municipal water production. Increasing demand may test sustainable limits of the aquifer. This project closely examines natural influence/causes of salinity in production wells in the Yigo-Tumon Basin. We aim to test the hypothesis that seasonality and the El Niño Southern Oscillation have a significant influence on the salinity in the wells.

The Yigo-Tumon basin dataset is of major interest due to the area's primacy in production volumes and demand. The knowledge gained from this work help to determine and suggest sustainable management practices for municipal water production the Yigo-Tumon basin. Understanding the NGLA response to the seasonal cycle will allow planners to plan new well configurations with greater confidence and to determine appropriate production rates for active wells with the overall goal to maximize production and better understand the risks associated with additional development in the Yigo-Tumon Basin.

There are multiple possible factors influencing the salinity in production wells beyond pumping. The daily tide, typhoons, the wet/dry seasonal cycle, and ENSO all exert their influence on the aquifer. Understanding these influences is critical to the continued sustainable management of a our groundwater resources.

GHS and CWMP Online – www.guamhydrologicsurvey.com

The GHS and CWMP online is a worldwide access of water resources information and database. The website's unified resource locator (url) or address is www.guamhydrologicsurvey.com. In the early days of the GHS program, hard copy environmental and water information was stored on the shelves and digital forms in hard drives in several computers managed by the Staff Hydrologist then at the hydrology laboratory at WERI. The GHS mandate requires the consolidation of pertinent Guam hydrologic data into a single computer-based library where information may easily be accessible. In 2010, WERI acquired a server station and developed an intranet of Information Technology tools and hydrologic information. The staff hydrologist then also developed an inhouse server network for each faculty, staff, and student, to store and transfer information. In 2016, the UOG President's program, Good to Great, aimed at expanding the university's capacity to make information available to at least interdepartmental level. The easiest solution for this was to create the Guam Hydrologic Survey website via world wide web server, that would reach the world.

Water and Environmental Research Institute of the Western Pacific | University of Guam | GWRDGTWG | Appreciation & Recognition

Guam Hydrologic Survey
Guam Public Law 74-247

Hafa Adai: Wed May 02 2018 16:33:18 ChST

Enter search keyword

Sustainable Management | Geology/Hydrology/Hydrogeology | Climate/Weather | Wastewater/Toxicology | Library | Data | Analysis and Interpretation | Projects | About GHS

Håfa adai (site development in progress)

Hello and welcome 😊

Jump to: Outreach | Sustainable Management | Annual Reports | Mission Goals Funding | GWRDGTWG | Charters Agreements

GHS Library Online >>

Our most valuable water resource is now online...

Fañomnåkan 2018: Guam Hydrologic Survey Outreach - NGLA Tour

Guam Hydrologic Survey Outreach provides the Northern Guam Lens Aquifer (NGLA) Tour to our policy makers, department executives, island development professionals, our children's educators, and college students. This outreach tour is about gaining a better understanding in our quest towards the sustainable management and development of our island's most valuable renewable resource, water. For more information, please call Ms. Norma Blas, 735-2685, nblas@triton.uog.edu.

2018 Tour Dates: UOG (SAME, GE, EV511) – 4/20
Guam Water Kids & Department of Education – 3/28 | Executive Tour – 3/9 & 3/16
Friday, April 20: Northern Guam Lens Aquifer (NGLA) Tour, for UOG Students

Water and Environmental Research Institute of the Western Pacific and Professional & International Programs, University of Guam, team up to host this year's **Guam Hydrologic Survey's NGLA Tour for UOG Students.**

Friday, April 20, the tour starts at **UOG, Annex A, Room 6, 8:00 AM**, for a 3-D virtual tour of the aquifer to take you for a dive into the freshwater lens. **8:30 AM**, we then **board the tour bus** for the field experience of the NGLA.

See the **itinerary map** of tour stopovers (1 – 6), below, starting and ending at (1) UOG, Annex A. Select site number icon for stop description. Plus, to view the map below in (entire browser window) Google Maps, select the box corners icon, right of the menu bar. To view the map legend below, select the left arrow panel icon, left of the menu bar.

Search Guam Hydrologic Survey

Search...

WERI UOG - NGLA Executive Tour 2017

Quick Reminders 2018

GWRDGTWG Meetings: Quarterly TBA
Evangeline Lujan
GWA Senior Regulatory Analyst
vangle@guamwaterworks.org
671-300-6887

Northern Guam Lens Aquifer Tour
Legislative & Senior Executive - March 9
Guam Water Kids & GDOE - March 28
SAME, EV511, GE - April 20
Contact Ms. Norma Blas 735-2685
nblas@triton.uog.edu

WERI Workshop
Session 1 - 9/2018
Session 2 - 9/2018
Contact Ms. Norma Blas 735-2685

WERI Advisory Council Meeting Schedule 2018
CNMI - 9/2018
FSM - 10/2018
Guam - 11/2018
Contact Ms. Norma Blas 735-2685
nblas@triton.uog.edu

GHS Research Affiliate: Dr. Barry Kim.
kimys@triton.uog.edu

Quick – Side Menu

Guam Hydrologic Survey website www.guamhydrologicsurvey.com

This website, in development progress, was first introduced in the GHS workshop, 2016, and the 2016 Guam Advisory Council Meeting and the American Water Works Association (Guam organization). The workshop trained the members of the Groundwater Resource Development Group and Technical Experts Group, and private consultants. It has also been proven to be a very useful source of information to assist in the rehabilitation of GWA wells in a teleconference with WERI and the contractors APEC and AECOM. The website contains the borehole database (WERI Technical Report 141), borehole database maps, chloride and production database (TR 142). AECOM has referenced the site in its reports. Soon, borehole videos of the rehabilitated wells will be available through the website.

The theme of the GHS website is sustainable management of the island's water resources. As we face the need for a successful new island development of expansion, upgrade, and rehabilitation, our island's teams of experts must work together. The GHS website will function as an easily accessible source of knowledge. Sustainable management of our utility water resources requires an understanding of the limitations of our water resources, with respect to all related aspects (e.g., social, economic, hydrologic, geologic). These together will help us determine the proper conservative policies.

GHS SPONSORED WERI RESEARCH PUBLICATIONS

Now available online:

<http://www.guamhydrologicsurvey.com/index.php/sustainable-management/ghs-sponsored-weri-publications/>

The screenshot displays the website for the Guam Hydrologic Survey. The header includes the organization's name, logo, and contact information. A navigation menu lists various categories such as Sustainable Management, Geology, and Wastewater. The main content area is titled "GHS Sponsored WERI Publications" and is organized by year, with sections for 2015 and 2014. Each year's section contains a list of publications with their titles, authors, and brief descriptions. On the right side of the page, there are several informational boxes: a search bar, a "WERI UOG - NGLA Executive Tour 2017" section with a photo, "Quick Reminders 2018" listing meetings and tours, and "WERI Workshop" and "WERI Advisory Council Meeting Schedule 2018" details.

Water and Environmental Research Institute of the Western Pacific University of Guam GWRDG/TWG Appreciation & Recognition

Hafa Adai: Wed May 02 2018 16:39:57 ChST

Guam Hydrologic Survey
Guam Public Law 24-247

Sustainable Management Geology|Hydrology|Hydrogeology Climate|Weather Wastewater|Toxicology Library Data Analysis and Interpretation Projects About GHS

GHS Sponsored WERI Publications

2015

Denton, G.R.W. C.A. Emborski, R. Masga, J.A. Stamer, 2015. Impact of WWII Dumpsites on Saipan (CNMI): Heavy Metal Status of Soils and Sediments. *Journal of Waste Management and Research*, (in review).

Khosrowpanah, S., Lander, M. A., Rouse, J.D., and Whitman, W.M.C. 2015. "Assessment of Turbidity in the Geus River Watershed in Southern Guam." *WERI Technical Report No. 156*, June 2015.

McCutcheon, A. L., Raymundo, L. J., Jenson, J. W., Prouty, N. G., Lander, M. A., and Randall, R. H., 2015, *Testing the Strontium/Calcium Proxy for Sea Surface Temperature Reconstruction in the Coral Porites lutea*, in Guam, Micronesia, University of Guam Marine Laboratory, Water & Environmental Research Institute of the Western Pacific. *UOGML Technical Report 152, WERI Technical Report 152*.

Rouse, J.D. "Development of Environmentally Sustainable Methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island." *WERI Technical Report No. 153*, February 2015.

Bendixson, V.M. (2013). "The Northern Guam Lens Aquifer Database." *WERI Technical Report No. 141*: 45.

Simard, C. A., Jenson, J.W., Lander, M.A., Manzanilla, R.M., Superales, D.G., Habana, N.C., 2015. *Salinity in the Northern Guam Lens Aquifer*, Water & Environmental Research Institute of the Western Pacific, WERI Technical Report 143

Simard, C. A., Jenson, J. W., and Lander, M. A., Analysis of Salinity in the Northern Guam Lens Aquifer, in *Proceedings Proceedings of the 16th Symposium on the Geology of the Bahamas and other Carbonate Regions*, Gerace Research Center, San Salvador Island, Bahamas, June 14-18, 2012 2015, in press.

Sfaelou, S.; Papadimitriou, C.A.; Manariotis, I.D.; Rouse, J.D.; Vakros, J.; Karapanagioti, H.K. "Treatment of Low-strength Municipal Wastewater Containing Phenanthrene Using Activated Sludge and Biofilm Process." *Desalination and Water Treatment*. 2015, pp. 1-11.

Wallace, C. D., Bailey, R. T., and Jenson, J. W., 2015, *Atoll Island Freshwater Resources: Modeling, Analysis, and Optimization*, *WERI Technical Report #155*, p. 147 p.

Wen, Y. and Chambers, D. (2015). Land Cover Change in Saipan, CNMI from 1978 to 2009, *International Journal of Research In Earth and Environmental Sciences (IJREES)*, Volume 3: Issue 4, pp 6.

2014

D.T. Vann, V.M. Bendixson, D.F. Roff, C.A. Simard, R.M. Schumann, N.C. Habana, and J.W. Jenson, (2014) *Topography of the Basement Rock beneath the Northern Guam Lens Aquifer and its Implications for Groundwater Exploration and Development*, Technical Report 143, WERI, UOG.

Bendixson, V.M., Jenson, J.W., and N.C. Habana (2014) *The Northern Guam Lens Aquifer Database w/ accompanying CD*. Technical Report 141, 2nd Edition, WERI, UOG.

Morrison, R.J., G.R.W. Denton, U. Bale Tamata and J. Grignon (2014). Anthropogenic Biogeochemical Impacts on Coral Reefs in the Pacific Islands – An Overview. *Deep-Sea Research II*, 6: 5-12

Denton, G.R.W. and C.M. Denton (2014). Regulatory Framework and Monitoring Strategies Adopted by GWA for the Sustainable Production of Safe Drinking Water from the Northern Guam Lens Aquifer. *Regional Islands Sustainability Conference*. Hyatt Regency. Tumon, Guam, April 15-16

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WERI UOG - NGLA Executive Tour 2017

Quick Reminders 2018

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GHS Research Affiliate: Dr. Barry Kim:
kimys@triton.uog.edu

GHS Sponsored WERI Publications available online

FY 2017 Expenditures for GHS and CWMP

Below is a composite summary of all expenditures lodged against the GHS account during FY'17. 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.

<u>Guam Hydrologic Survey Expenditures Summary for FY'17</u>	
<i>Category</i>	<i>Expenditure</i>
1. Salaries and Wages:	\$57,409.37
2. Fringe Benefits:	\$9,241.77
3. Tuition Fees	\$2,341.00
4. Supplies:	\$828.35
5. Computer Hardware/Software:	\$5,591.65
6. Equipment/Office Furniture:	\$12,248.75
7. Projects/Consultant Fees:	\$10,000.00
8. Postage/Long Distance Phone:	\$1,464.32
9. Printing:	\$4,068.08
10. Lab Remodeling:	\$8,666.00
11. Administrative Fees*:	\$18,359.40
Total FY'17 Expenditures:	\$130,191.69
Total FY'17 GHS Allotment Rec'd as of 12/17:	\$ 45,674.00
Balance:	-\$84,517.69
Total Approved GHS Budget Allotment for FY'17:	\$182,694.00
<i>Category</i>	<i>Expenditure</i>

GHS Comprehensive Monitoring Expenditure Summary for FY'17

<i>Category</i>	<i>Expenditure</i>
1. Projects/Consultant Fees:	\$153,729.00
2. Administrative Fees*:	\$ 15,562.60
<hr/>	
Total FY'17 Expenditures:	\$169,291.60
Total FY'17 GHS-CM Allotment Rec'd:	\$ 38,906.00
<hr/>	
Balance:	-\$130,385.60
 Total Approved GS-CM Budget Allotment for FY'17: \$155,626.00	

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

(BBMR PFS-1)

FUNCTION: EDUCATION & CULTURE
 AGENCY: UNIVERSITY OF GUAM
 PROGRAM: WATER AND ENVIRONMENTAL RESEARCH INSTITUTE (WERI)
 Fiscal Year 2017
 Program Fiscal Summary

Budget Account Allocation	Fund	FY2016		FY2017	FY2018			FY2019	FY2020
		Actual Appropriation	Percent of Program	Authorized Appropriation	Current Service	Program Plan	Governor's Recommendation	Projected	Projected
FUND TITLE									
General Fund Appropriation		\$998,000		\$1,003,500	\$1,003,500	\$1,154,473		\$1,154,473	\$1,269,920
Guam Hydrologic Survey (Local)		\$182,694		\$182,694	\$182,694	\$182,694		\$204,200	\$204,200
Guam Water Monitoring Project (Local)		\$155,626		\$155,626	\$155,626	\$155,626		\$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)		\$100,000		\$100,000	\$50,000	\$50,000		\$50,000	\$50,000
National Science Foundation (Federal)		\$164,335		\$59,875	\$164,335	\$59,875		\$0	\$0
National Park Service (Federal)		\$21,100		\$21,100	\$0	\$0		\$0	\$0
OEA-GWA - NGLA Monitoring Expansion Project		\$0		\$101,000	\$101,000	\$101,000		\$20,000	\$20,000
Total Program Appropriations		\$1,898,760		\$1,900,800	\$1,934,160	\$1,980,673		\$1,879,626	\$1,995,073