



Annual Summary of Activities

including

Guam Hydrologic Survey Activities



WERI

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

August 2021

Annual Summary of Activities

including Guam Hydrologic Survey activities

Edited by
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Dr. John W. Jenson, Director

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

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DIRECTOR'S MESSAGE

The Water & Environmental Research Institute of the Western Pacific (WERI) is one of 54 water research institutes established by U.S. Congressional legislation at each Land Grant University in the U.S. and in several territories. The Institute is now in its 45th year of operation.

WERI's mission is to seek solutions through research, teaching, and outreach programs, to issues and problems associated with the location, production, distribution, and management of freshwater resources. The Institute provides its regional stakeholders with technical expertise in water resources related fields spanning the entire natural water cycle and spectrum of human water use, including tropical climatology, surface water hydrology, rainfall catchment systems, groundwater modeling and management, and various aspects of water quality. WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the institute was created specifically to administer Department of Interior (US Geological Survey) money under Section 104 B of the National Institute of Water Research (NIWR) 104 B Program. WERI has responsibility for 104 B monies on Guam, in the Commonwealth of the Northern Mariana Islands (CNMI), and in the Federated States of Micronesia (FSM). The faculty and staff of WERI seek to improve economic conditions and quality of life for the citizens of Guam and its regional island partners.

In FY-2020 WERI faculty were involved as principal investigators and/or advisors on research, training and outreach projects with a combined budget of approximately \$2,406,901. Of this, \$277,005 was awarded through the Water Resources Research, Institute Program administered by USGS under 104 B, while \$309,009 was received as a special appropriation from the Guam Legislature. The remainder came from other Federal and Private Sources awarded directly to the Institute, or indirectly through local Government Agencies.

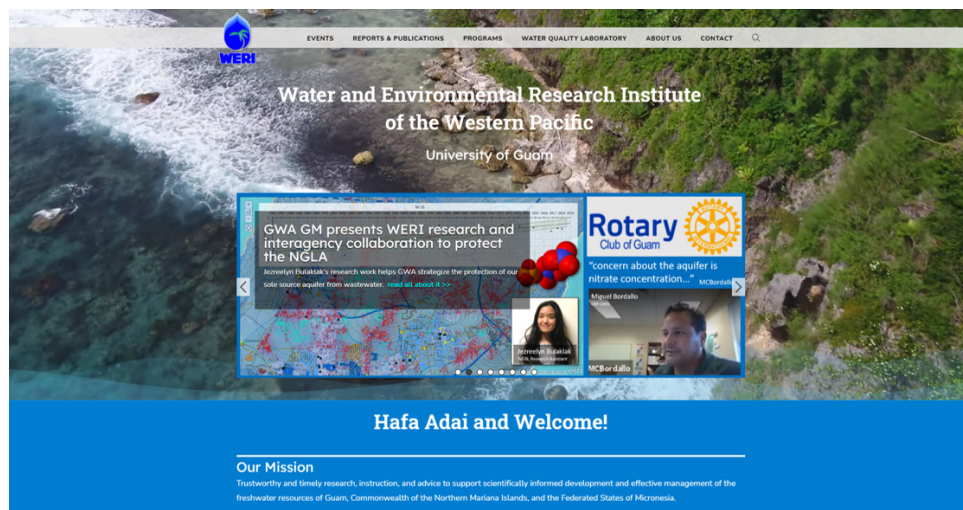
Currently, WERI has seven full-time research faculty, one of whom serves as Director on a rotational basis; one emeritus research faculty member; a water analysis laboratory manager, technician, and chemist; two office staff, as well as several graduate and undergraduate research assistants. WERI provides teaching and student advisement for the undergraduate Pre-Engineering and graduate Environmental Science Programs, and also provides community services to the university and public. WERI runs a state-of-the-art water quality laboratory that supports research and provides public service for water testing.

WERI faculty members have published refereed journal articles, technical reports, and conference proceedings. They have also given numerous professional presentations and training workshops. Following its 5-year evaluation, WERI was congratulated by the evaluation panel for continuing to promote an outstanding program appropriately focused in a programmatically separate way on the water problems of Guam, the CNMI and the FSM.

In August 2019, we were saddened by the loss of our colleague Dr. Joseph Rouse. In his memory, WERI established a scholarship to promote the values of professional competence and integrity in professional science and integrity Dr. Rouse epitomized. See page 26.

For more information on WERI's research and academic programs please visit us on the web at: <http://www.weri.uog.edu> or contact:

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MISSION

Trustworthy and timely research, instruction, and advice to support scientifically informed development and effective management of the freshwater resources of Guam, CNMI, and FSM.

WERI's mission flows from its federal and local mandates to conduct applied research and provide education, training, and scientific advice on the development and management of the fresh-water resources of Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and the Federated States of Micronesia (FSM). Research, teaching, and outreach focus on exploration, production, distribution, and management of local freshwater resources, but also extend to related basic scientific topics of region, national, and international scope. WERI trains new environmental scientists and fosters integrity in research and application of environmental science. WERI thus provides high quality graduate instruction and student research support. Under its Guam Hydrologic Survey (GHS) mandate, WERI maintains a hydrologic database for Guam and provides regular support to policy-makers and managers of Guam's water resources. WERI maintains essential laboratories, including a Water Quality Analysis Laboratory to support hydrologic and environmental research and meet public and commercial needs for water quality analyses on Guam and in the western Pacific region.

CORE VALUES

1. Reliable and honest science
2. Consultative decision-making and across-the board teamwork
3. Superb instruction and conscientious mentoring
4. Earnest service to the community and university
5. Sincere partnerships with public and professional agencies

VISION

WERI's vision is to remain the acknowledged local and regional source of choice for scientific and technical advice on water resource exploration, development, and management; and a nationally-ranked and internationally recognized center of excellence for research in its strategic specialties. To fulfill this vision, WERI will maintain broad expertise in the essential subdisciplines of scientific and engineering hydrology and leverage its expertise with strategic partnerships and collaborations.

Breadth of Expertise

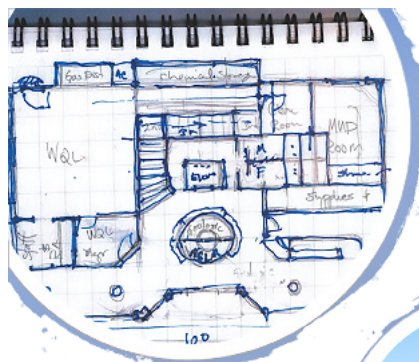
WERI seeks to maintain a portfolio of core expertise that spans the natural water cycle from meteorology through surface and groundwater hydrology, and essential water-use activities including exploration, development, and management; water quality protection and remediation; wastewater treatment and disposal; and related basic supporting fields, such as geospatial analysis, climatology, environmental chemistry, and microbiology.

Partnerships and Collaborations

WERI leverages its expertise on local geology and hydrology with national resources through active partnerships with the *USGS Pacific Islands Water Science Center* in Honolulu, Hawaii, with which it jointly administers the *USGS Groundwater and Streamflow Information Program* for Guam through the locally-funded *Guam Comprehensive Water Monitoring Program*, the *Guam Hydrologic Survey Program*, and - starting soon - the *One-Guam Aquifer Monitoring Program* in partnership with the Department of Defense's *Joint Region Marianas*. Local collaborative partners include the Guam Waterworks Authority and Guam Environmental Protection Agency, and Naval Facilities Engineering Command Marianas. WERI also has active external collaborations with researchers at other universities.



The Water Quality Laboratory supports WERI water quality research projects and operates as a semi-commercial laboratory that offers water quality testing. Testing services are categorized into three sections: microbiological, chemical, and physical tests.



In 2019, to support UOG's Para Hulo' strategy, WERI Director, Dr. Jenson, organized a WERI Building Team of WERI Faculty and Staff to work with RCUOG Executive Director Cathleen Moore-Linn to prepare the USED application. WERI also retained UOG Economist Dr. Rosanne Jones to advise on a business model for the Water Quality Laboratory. WERI team members for the Water Quality Laboratory former Laboratory Manager, Ms. Jennifer Cruz, and Laboratory Faculty Coordinator, Dr. Barry Kim. Ms. Cruz and Dr. Kim worked with Dr. Jones in evaluating the market and economic position and potential of the laboratory. WERI's Operations Manager for its Guam Hydrologic Survey Program, which utilizes its other laboratories, Dr. Nathan Habana, worked with Ms. Cruz, UOG Facility Maintenance, and Ms. Moore-Linn to design the functional requirements, floor plan, and estimate the cost of the building. Interim WERI Water Quality Laboratory Manager, Ms. Mallary Duenas, now joins the team to continue with Dr. Kim to incorporate the finer details to the laboratory as plans move forward. WERI administrative staff, Ms. Gema Payumo and Mr. Anthony Agustin have also been appointed to the team to focus on configuring and equipping the building for administrative and business support requirements.

Dr. John Jenson commented in an interview: "This is a classic success story for the value of long-term, strategic planning and the value of having an organizational culture that fosters and rewards teamwork. Our success in landing this grant actually has its immediate origins in the current president's Para Hulo initiative, and in the previous president's Good-to-Great initiative and his spearheading the creation of RCUOG: I recall the afternoon a couple of years ago when I was meeting as a member of the Para Hulo Infrastructure Committee, led by Dave Okada and Jim Hollyer. The subject of discussion was activities at the

university that might be constrained by lack of space or facilities, and which might otherwise be more productive, even revenue-generating. I pointed out that our water lab at WERI was a prime candidate and that WERI itself was spilling out of its building by the Marine Lab and into House 5 and containers proliferating around it in Dean's Circle.

WERI had acquired an additional faculty position in 2015 from the Good-to-Great initiative but had no more office space in its main building, so had to put its new faculty member in House 5—where my faculty office had been located since 2012. All on the Committee agreed that WERI was a good candidate, and then the Executive Director of RCUOG, Cathleen Moore-Linn volunteered, "I think I know how we can fund it!" The faculty and staff at WERI, especially our lab staff and lab faculty coordinator, Dr Barry Kim, drew up specific needs and helped to identify what the lab and WERI contribute to economic development and recovery for the USED application. The faculty member whose position WERI had gained from G2G and who had been initially placed in House 5, Dr Nate Habana, drew up the floor plans for new building, and we all worked with Cathleen and RCUOG to prepare and submit the proposal, which Cathleen shepherded through the process from beginning to end.

It is hard to imagine how this would have come about without the existence of RCUOG, the advent of G2G and Para Hulo, and the leadership of the specific people (whose names I mentioned) who led and staffed the initiatives, and, of course, the faculty and staff at WERI who do the high-quality work that has brought WERI the national recognition that made it eligible and competitive in the eyes of the granting agency, and which has driven the need for the new, bigger, and better facility in the first place."

GUAM HYDROLOGIC SURVEY PROGRAM

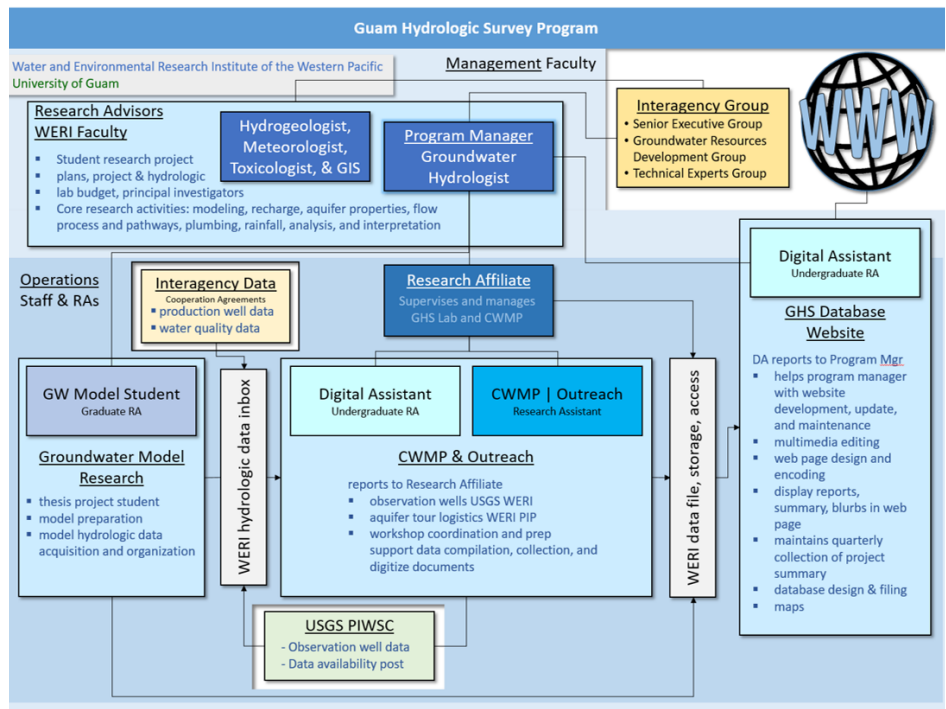
Dr. Nathan Habana, Operations Manager
Funded by Government of Guam

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. 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.

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 in 1998 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



Guam Hydrologic Survey and Comprehensive Water Monitoring Program Management.

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.

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.

One-Guam 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), created in the December 2016 MOU. 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, Consolidated Commission on Utilities (CCU), US Navy (NAVFAC, Marianas), US Air Force (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 Ongoing Research section.

Program Activities for FY 2021

The GHS program management, WERI Director, and Research Affiliate has reorganized the program management to include undergraduate research assistant support. The undergraduate research assistant's 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 was also designed as a small geology laboratory.

GHS provides limited stipends for research bygraduate 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.

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 are truly indispensable tools 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.

Outreach

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.



Executives from local and federal agencies, and visiting water resource researchers at the Professional Field Tour of the Northern Guam Lens Aquifer in March 2019.

COMPREHENSIVE WATER MONITORING PROGRAM

Dr. John Jenson, WERI &
Dr. John Hoffman, USGS
Funded by USGS and Government of
Guam

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 streamgages 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 Comprehensive

Water Monitoring Program (CWMP) was made a permanent part of WERI's program when Governor Gutierrez signed PL 24-161. 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 cost-sharing basis. The CWMP is a permanent investment in Guam's future.

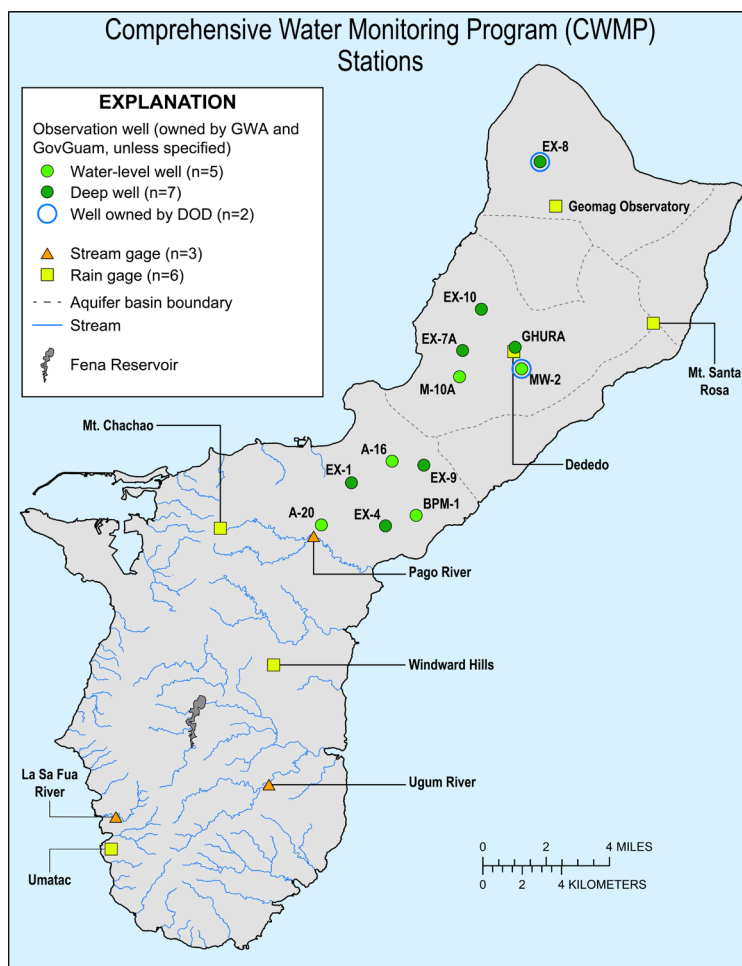
A well-designed long-term CWMP can save communities millions of dollars, and even human lives, by providing critical information for water supply,

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 streamgages, 8 rain gages, and 16 groundwater-monitoring wells 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 streamgages, 1 reservoir monitoring station, 8 continuous-recording groundwater-level-monitoring 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.

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 streamgages provide information needed by managers and engineers to properly manage the long-term sustainability of these water resources. Statistical analyses 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.





USGS stream gage along bank.

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 2022, the cost to operate a continuous-record streamgage will be \$24,515. 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 (\$10,675) and groundwater (\$7,725), 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>.



Instrumenting observation well with conductivity-temperature-depth sensor (sonde) to profile and record water level and salinity changes.

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 streamgages 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 streamgages to determine the level of financial aid from FEMA after storms. Currently, the WERI-USGS CWMP funds the operation of 3 streamgages at key locations in southern Guam.

Well Monitoring of the Northern Guam Lens 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 Niño 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



COMPLETED PROJECTS

Comprehensive Guam and CNMI WERI-Web-Based Rainfall Data Utility

Dr. Mark Lander

Funded by USGS and Pacific Islands
Climate Adaptation Science Center

Rainfall data for Rota, Tinian, Saipan and Guam were collected for archival and analysis. Rainfall data for Saipan presented several problems. Beginning in 2006, data for Saipan International Airport (SIA) archived at the National Climatic Data Center (NCDC) were ingested from the Automated Surface Observing System (ASOS). For many years (including the ASOS era), a NOAA-sponsored cooperative observer has been manually recording the daily (and monthly) rainfall at SIA. The ASOS rainfall data are always lower than the manually observed data (by 10-30% on the monthly tallies). There is also a trend of increasing shortfall in the ASOS data. For Guam, a time-consuming effort was undertaken to assemble a comprehensive archive of daily rainfall and temperature at Andersen Air Force Base (AAFB) and Guam International Airport Authority (GIAA). From the hundreds of thousands of hourly Meteorological Aerodrome Reports (METARs) at AAFB and GIAA during 1948 to present, the project PI filled in hundreds of missing days in the NCDC record for AAFB and GIAA. Problems in data archiving, effects of station moves, and failures of automated equipment were discovered. The complete daily and monthly climatic record for Guam and the CNMI is slowly being populated into a digital archive.

The enormity of the task (e.g., the need to cross-check official daily climate observations against the roughly 1 million hourly reports in the historical METAR record) was unanticipated and unabated. The problems discovered with the data are sufficient magnitude to substantially alter analyses of trends used for studies of climate change. The premier example of these is the completed archive for AAFB, in which hundreds of the daily climatic record and entries in the NCDC

publicly available Global Historical Climatological Network (GHCN) climate data were cross-checked using a massive archive of over 1-million aviation hourly airfield reports. Similar comprehensive spreadsheets for climate data for other stations on Guam and for stations on the islands of the CNMI are in various stages of construction, with continual updating for current conditions.

Hydrological Features and Analysis in the Finegayan Area

Dr. Yuming Wen

Funded by USGS

This project undertook an inventory of hydrogeological features in the Finegayan Basin, focusing on sinkholes, and exploring correlations between their proximities to relevant conditions, especially groundwater salinity, and how the proximities between features and conditions might relate to spatial and temporal variability of the conditions. The Hydrogeological features are identified and characterized from DEM and other mapped data, and include sinkholes, faults, changes in surface slope, and locations of groundwater zones (i.e. basal v. para-basal v. supra-

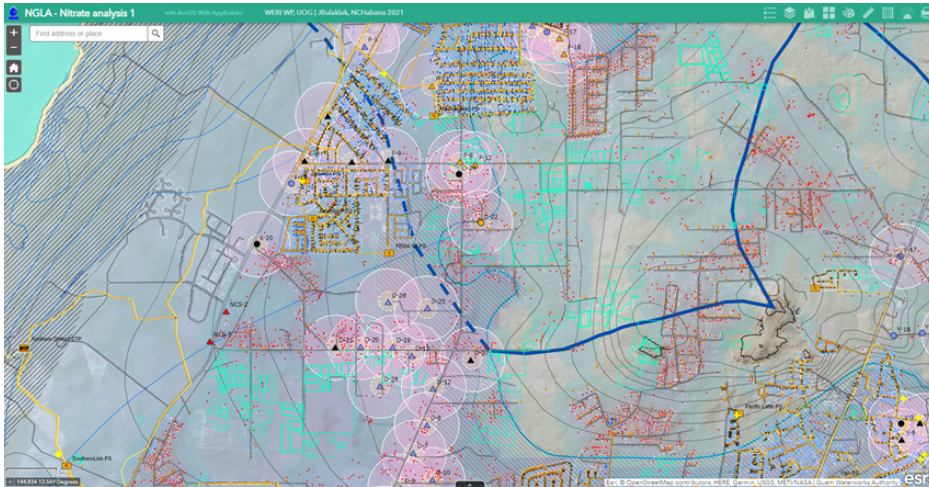
basal). Conditions of interest include groundwater salinity (as conductivity or chloride), turbidity, pH, and hardness at production wells; daily, monthly and annual precipitation; land-use zoning, land cover and land-cover change.

Analysis of salinity indicates that certain wells (F-10, F-6 and F-13) were consistently high in salinity, while other wells (F-19, F-4 and F-12) showed variable salinity. Additional work is required to explore the causes of variability, but one candidate hypothesis is proximity to concentrations of descending supra-basal water. Analyses of sinkhole-well proximity suggest that the water quality of wells may correlate with proximity to sinkholes to some degree, e.g., some high-salinity wells have substantially developed sinkholes within 150 m of them, but additional work is needed to identify relevant sinkhole characteristics. Regression of well production against chloride concentration shows mixed results—positive correlations in some cases, negative correlations in other cases. Additional work is needed to examine the attributes of some of the historical data more closely, and explore the influence of other factors, such as well depth and efficiency.



Tipping bucket rain gauge mounted above Jinapsan forest, northern Guam. Mergagan Point (right) and Pati Point, furthest in background. Photo courtesy of J. Jenson.

COMPLETED PROJECTS



Power Web MApp of the resulting analysis of Nitrate-N in production wells. This Web MApp product is currently being used by Guam Waterworks Authority to strategically develop the wastewater management system above the aquifer.

These values suggest that considerable nitrification and, potentially, denitrification were occurring. This exploratory project indicates that the chemical environment in this aquifer is complex

Development of GIS-based Imagery Database for Groundwater Recharge Areas and Key Reaches of Streams on Guam Phase II

Dr. Nathan Habana & Dr. Leroy Heitz
Funded by USGS

To effectively manage a region's water resources, water managers and water resources researchers must have accurate baseline data and subsequent time-series information on the geomorphological and ecological health of surface water streams and groundwater recharge areas. Recent advances in commercially available sUAS (Small Unmanned Aerial Systems) technology have made it possible to provide this baseline and follow-on time-series data with low cost, accurate, sub-meter-resolution aerial imagery. Phase II of this project began by installing at WERI an EOS Arrow Gold differential correction (RTK) base station and antenna system. The second step was calibration of the base station and extensive testing to confirm rover coordinates for ground

control points match coordinates used in base maps available in WERI's GIS system. The third step was development of georeferenced ortho-maps and digital elevation models of test areas in northern and southern Guam. The detailed georeferenced aerial data provide baseline information on location, size, and potential pollution sources in sinkholes located in the northern Guam groundwater recharge areas. In southern Guam, we can accurately



Profile line drawn through area of Jeff's Pirates Cove project. Ground control points (GCPs) and orthomosaic overlay the current satellite image of the river that outputs into Togcha Bay, Yona, Guam.

plot stream cross-sections, determine erosion potential and possible sediment loading, and identify other sources of environmental contamination. The final step will be development of a data management scheme for the imagery and other digital data gathered by the project. The data management scheme will be compatible with WERI's existing on-line water resources data retrieval system.

PFOS Trend Monitoring in Saipan Production Wells

Dr. Yong Sang Kim, Dr. Nathan Habana & Heidi Yelin
Funded by USGS

Perfluoroalkyl substances (PFAS) have received attention as emerging contaminants in drinking water sources. The US EPA UCMR3 result revealed that drinking water contamination by PFAS in Saipan is more prevalent than in the Continental U.S. The Commonwealth Utilities Corporation (CUC), the public water and utility agency in Saipan, had collected water samples from 24 drinking water entry points. As the result of PFAS analysis, PFOS was detected in 5 wells and reservoirs.

In particular, the production well IF-208, located within the Saipan International Airport (SIA) has been contaminated with PFOS in the range of 4900 ~ 7000 ng/L, a value that is one hundred times higher than the US EPA's lifetime health advisory concentration (70 ng/L).

As a preliminary step, 10 soil samples were collected for the analysis of UCMR3 PFAS. The Airport Rescue Firefighting Facility (ARFF) area in the SIA was selected as a sampling area because there was evidence of spraying firefighting foams for firefighter training. The result showed that all soil contained significant amounts of PFAS. The highest PFOS and PFOA concentrations detected were 6.57 ug/soil-kg, and 6.98 ug/soil-kg, respectively.

Significant amounts of PFHpA, PFNA, and PFHxS were also detected. Concentrations of PFHpA, PFNA, and PFHxS ranged 0.16 - 10.40 ug/soil-kg, 1.77 - 7.78 ug/soil-kg and 1.06 - 4.26 ug/soil-kg. PFBS was not detected in all soil samples. Distribution of these species is complex and poorly understood. Further investigations will be conducted to characterize the degree and distribution of PFAS contamination in this area.

Hydrologic Spatial Analysis of Basins and Suspect Sinkholes in the Northern Guam Lens Aquifer

Dr. Nathan Habana, Dr. Leroy Heitz & Dr. John Jenson

Funded by USGS and GHS

A concerning major pathway for contaminant transport into limestone aquifers is through sinkholes. The Northern Guam Lens Aquifer (NGLA) has a surface plateau formed from uplifted and tilted geologic formations of limestone bedrock. This aquifer is also the island's vital source of fresh water. It has a deep vadose zone (80-120 m) that filters much of the percolating infiltrated rainfall. However, during storms that often bring intense rainfall, infiltration



The Surface Hydrology of the Northern Guam Lens Aquifer. A snapshot of parts of Macheche, Adacao, and Mogfog. NGLA Sub-basins. Deep blue areas are surface depressions. Potential surface drainage are modeled by light blue lines, and catchment low points are medium blue.

rate is exceeded, and surface runoff occurs. The porous karst terrain on the plateau has surface depressions in a mesh of enclosed basins, basins within basins, and cascading basins. These basins serve as sites where surface runoff may pond and serve as cumulative and secondary sources of contaminants into the catchment low points. Some of these surface depressions have turned out to be sinkholes (collapsed and doline) and fractures that conduct or drain large volumes of runoff into the freshwater aquifer. Proper land development must take into consideration the pathways in which anthropogenic contaminants may be transported to water sources and drawn up in near production well drawdown zones or in down gradient production wells.

Guam Environmental Protection Agency (GEPA) is keen on regulating development over hydrologically significant sinkholes, fractures, and surface depressions. They require hydrogeological assessment and site inspection in these sensitive areas. However, initial assessment via existing maps of closed contour depressions used to determine potential sinkholes were derived from old topography and has proven to have major inaccuracies and limitations. The development of a new map using the latest lidar based digital elevation (1 m raster

resolution) and GIS hydrologic spatial analysis should greatly improve the island's stormwater management practices over the aquifer.

The map analysis provided by this project provides an important aquifer map series that will be used to assess groundwater protection zones. The need for an improved sinkhole analysis has been an important concern discussed in the WERI Guam Advisory Council Meetings.

(GWA) Production-Well Rehabilitation Assessment: Lessons Learned Report & Manual for Well Exploration and Development

Dr. Yong Sang Kim & Dr. John Jenson

Funded by USGS

GWA operates about 120 production wells, of which about 100 are on-line at any given time. Over the past few years, GWA has undertaken a systematic rehabilitation program for its non-performing (closed) wells. Investigation of these closed production wells showed there are three main categories for why the closed wells originally failed: 1) deterioration due to age; 2) contamination of water at the site; and 3) historically poor performance.

COMPLETED PROJECTS

Aging problems include broken or corroded well casing, stuck pumps from previous maintenance failures, and screen deteriorations. Contamination problems include saltwater contamination and the occurrence of contaminants originating from surface activities. The latter includes contamination by chlordane, PCEs and PFOS. Wells closed for chronic underperformance or mis-performance appear to have been installed in locations where geologic conditions produce large seasonal variations in local storage and water levels.

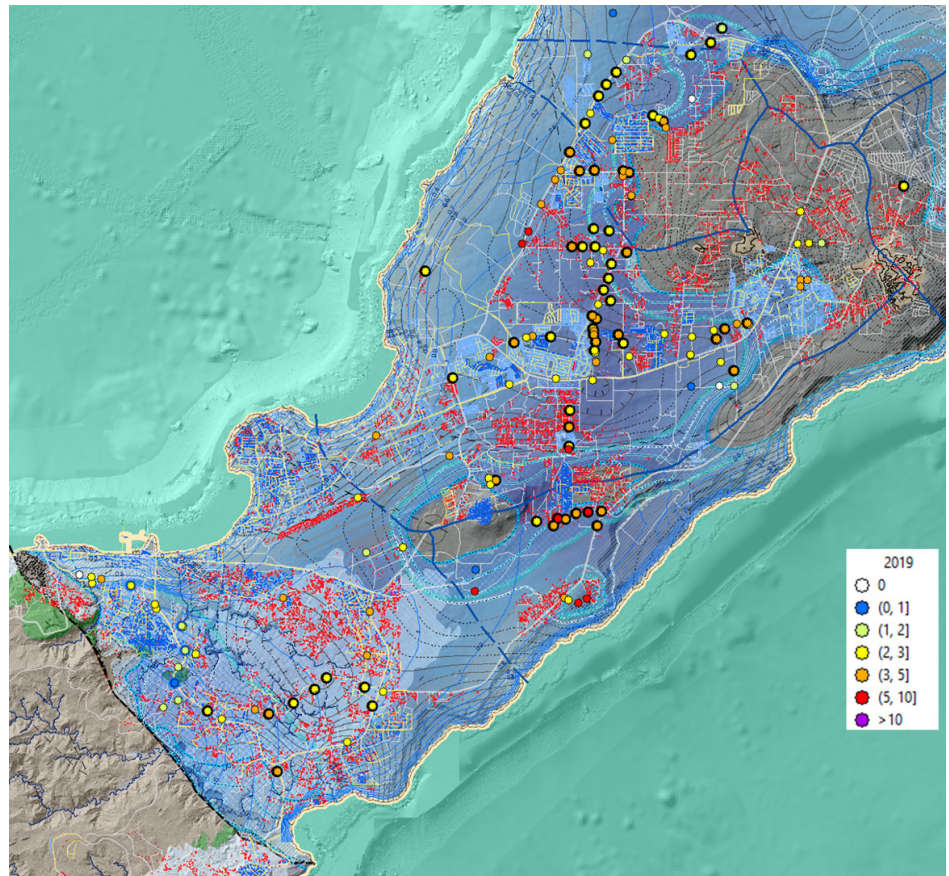
Drilling of adjacent replacement wells showed that well performance can vary greatly between identical boreholes located only a few tens of feet from one another—reflecting the high local-scale heterogeneity in the hydraulic properties of the Northern Guam Lens Aquifer (NGLA). Well rehabilitation data are being collected to prepare a Lessons Learned Report & Manual for Well Exploration and Development. This report will help local drillers better manage site selection, well installation, preventive maintenance, and rehabilitation.

Production Well Nitrate N-Trends in the Northern Guam Lens Aquifer

Jezryleen Bulaklak, Dr. Nathan Habana & Dr. John Jenson

Funded by USGS and GHS

Increased development over Guam's Principal Source Aquifer may be impacting the island's major water source with wastewater. Data analysis of nitrates in production wells reveal that more than half of the wells over the NGLA have an increasing nitrate trend. Sewer main systems have lagged and may have deteriorated, and wells near increased density of non sewerred homes seems to be impacted. GWA and GEPA are working closely with WERI, referring to the results of this project to strategically target areas that need immediate attention to reduce wastewater from entering the aquifer.



Nitrate concentrations as of January 2019 in mg/L. Yellow lines show existing sewerage systems. Red dots are mapped septic tanks. Aquifer basin boundaries, thick blue lines (solid and dashed) are hydrologically separate groundwater. Thin blue lines are the water-table contours. Groundwater flows from the interior of each basin toward the coast, perpendicular to the water-table contour lines.

Nitrate-N concentration above 2 ppm in utility water suggests contamination from some combination of sewer line leakage, septic tank effluent, agricultural animal waste, or fertilizer runoff from farms or golf courses. Preliminary inquiries 20 years ago suggested that potential reasons for increasing amounts of nitrate-N in production wells included increased numbers and densities of septic tanks in nearby areas. In this study, a trend analysis of nitrate-N data from 146 production wells from 1978 to 2019 was conducted to document changes since the previous study and help to prioritize intervention. The construction of nitrate-N time-series for each well, along with map series showing nitrate-N concentrations over time in each of the production wells provide a means for assessing

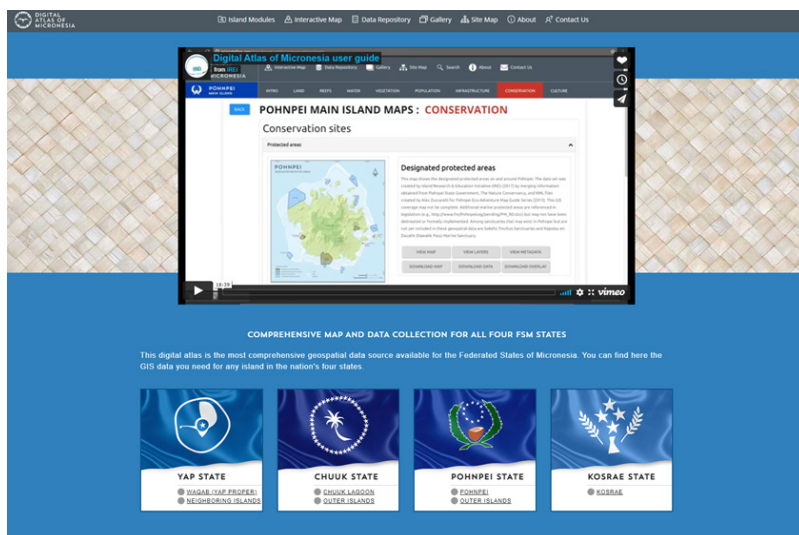
areas of concern and setting priorities for preventive and remedial actions. Results show that while initial records indicate background nitrate-N levels of about 2 ppm, concentrations have risen in 84 (58%) wells. Of these 84 wells, 66 (46%) exhibit steadily increasing trends across the entire record at values of 1.5 to 5.1 ppm, while 18 (12%) wells show increases up to about the year 2000, with the trend flattening thereafter to 2.9 to 5.4 ppm. Fifty-five wells (38%) exhibit no significant trend, and 7 (5%) show decreasing trends. Without interventions, nitrate-N concentrations are likely to rise in areas that see additional development. Results from this study may be used to inform effective management and regulation for aquifer protection.



Observing porosity and fracture features at Hawaiian Rock Quarry, Mangilao, Guam.



Observing volcanic outcrops of Umatac formation during a southern Guam field trip.



The Digital Atlas of Micronesia is an ongoing repository for geospatial data and interactive maps of islands in Micronesia.



RA, Matt Ziobro, and Dr. Nathan Habana gather GCP coordinates.



PFAS sampling in Agana Heights ponding basin.



Displacing drill cuttings via foam, CWMP well EX-7A.

ONGOING RESEARCH

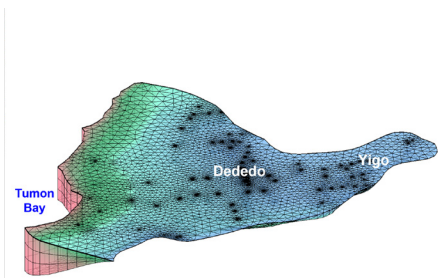
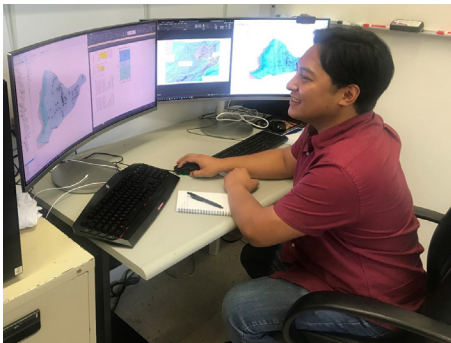
Development of the Groundwater Model of the Yigo-Tumon Basin, Northern Guam Lens Aquifer

Thomas Aguilo, Dr. Nathan Habana & Dr. John Jenson

Funded by USGS

MS Environmental Science Thesis

Guam has plans for major island growth and expansion well within the next 10 years, requiring more water from its principal source—the Northern Guam Lens Aquifer (NGLA). Developers will be looking for groundwater models to test aquifer capacity and placement of additional wells. Reliable groundwater models are very useful for determining aquifer development strategies that include optimum production well configuration and sustainable management of water resource. The Yigo-Tumon Basin, in the NGLA, is the most abundant source of utility



Graduate Research Assistant Thomas Aguilo, developing a 3-Dimensional groundwater model of our most abundant aquifer, the Yigo-Tumon Basin. This model will be used to recommend optimum well placement and water production development strategies.

water out of the 6 aquifer basins, where deep production wells extract about half of the total 42 MGD from the NGLA, which is about 90% of total water produced on the island. More than 20 years of NGLA research and data is available that can be used to develop a reliable groundwater model of the NGLA, starting with the Yigo-Tumon Basin. A new addition to NGLA research in 2019 is the time-series of phreatic profiles in three deep observation wells in this basin that present the spatially varied dynamic response to recharge, from which model results can be matched. And most recently accomplished, groundwater model assessment of the capacity of each basin's "sweet spot," the parabasal zone. Also, the advancement in groundwater modeling software and computer technology, integrating tested finite element code extensions (FEM Water), GIS capability, 3-D interface are available in Aquaveo® Groundwater Modeling Systems (GMS) that will be the selected model application, and that will run on WERI's fast computer.

A Comprehensive Review and Consolidation of Unpublished WERI Research on the NGLA Response to Variations of Sea Level and Rainfall

Dr. Mark Lander & Dr. John Jenson

Funded by USGS

Rainfall amounts on Guam are high. The average annual rainfall on the island is roughly 100 inches, with modest (10-15%) geographical variation (drier in the middle and on the central east coast, and wetter in the southern mountain region and in a stripe across the northern end). But, despite high average rainfall, there are large variations of rainfall at all time scales. Over the course of the year, there is typically a 6-month dry season during which only 30 inches of the annual 100 inches accrues. It is thought that very little of the dry season rainfall recharges the aquifer. The amount of annual rainfall also has large variation, primarily the result of forcing by the El Niño/Southern Oscillation (ENSO) phenomenon.

Annual rainfall amounts vary by a factor of three! (50 to 150 inches). Daily rainfall during a typhoon exceeds 7 inches in one hour and 30 inches in 24 hours.

In past WERI research efforts, evidence was found that on top of the immediate response of the water table to rainfall and variations to sea level, the water table of the NGLA responded at an 18-month lag to long-term surpluses and deficits of rainfall. An elegant method, outlined in 2009 (minimizing the hysteresis of modeled water table with respect to the observed water table), elucidated the response of the aquifer to rainfall input. The findings of this research were largely exploratory, with formal investigative follow-through pending. This project will consolidate and summarize these past findings with a formal rigor (data consolidation, updated data, further statistical analysis, clarification of the techniques, and a detailed discussion of the results).

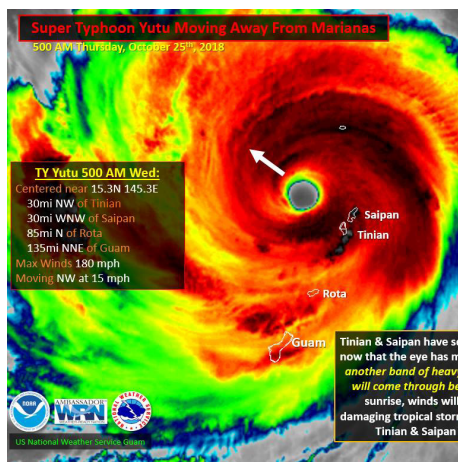
A Sustainable Plan for Stormwater Management and Flooding at Garapan, Saipan

Dr. Myeong-Ho Yeo & Dr. Mark Lander

Funded by USGS

Flooding is an overflow of a large amount of water beyond its normal limits. Floods are the most common and widespread of all weather-related natural disasters. Floods in the U.S. kill more people each year than other natural disasters. Average annual flood damages in the U.S. are more than 2.2 billion dollars a year. Furthermore, increasing trends in number of these natural disaster have been observed. Today flooding control including stormwater management has become a critical issue in civil and environmental engineering applications.

Stormwater management is originally intended for flood control and minimal water quality improvement. With stormwater runoff, four major problems begin to emerge; Flooding: excess stormwater increases the extent, severity, and frequency of



Screenshot of US National Weather Service October 25, 2018 posted on the USNWS social media showing the center of Super Typhoon Yutu. The strongest of eyewall winds had moved west of Saipan. Utilities and built infrastructure were heavily damaged. The island was without power and water for several months.

floods. Degraded water quality: stormwater carries a number of pollutants, nutrients, pathogens, and floating matters on streets. Erosion: increased stream volume and velocity exacerbate streambank erosion. Sewer overflows: increasing stormwater volumes contribute to combined sewer overflows.

Floods are a common occurrence in the lower Garapan area, Saipan. The relatively flat terrain in the target area causes lack of gradient, which prevents adequate drainage and the lack of drainage outlets. Thus, severe ponding problems are emerged from following moderate and heavy rainfalls. A flood prone zone includes an extensive number of residential structures, stores, and commercial establishments. Especially, the most critical area is located between the hotel resort area and the West Coast Highway. Due to frequent flooding over the area, it can be expected that the following offshore water quality, which caused by erosion and sewer overflows, and flooding damages. The objectives of the proposed project can be summarized as the followings;

1) To collect relevant base data, maps, aerial imagery; 2) To identify stormwater runoff flowing

characteristics; 3) To develop stormwater management model; 4) To suggest the Low Impact Development (LID); 5) To simulate the stormwater model for current and future weather conditions.

Identifying, Analyzing and Mapping Submarine Groundwater Discharge (SGD) with a Thermal Infrared (TIR) Sensor and Unmanned Aerial Vehicle (UAV)

Eliana Walker, Dr. John Jenson &

Dr. Romina King

Funded by NASA EPSCoR

MS Environmental Science Thesis

An autonomous aerial vehicle improved with a visual-thermal infrared gimble camera will be used to locate and quantify the plumes of freshwater discharging from the Northern Guam Lens Aquifer (NGLA), a sole-source karst limestone aquifer that comprises the northern half of the island and supplies over 90% of the island's drinking water. The Guam-based research team has already found and mapped numerous seeps and springs with discharges that can be evaluated to test the technology and the university's graduate environmental science program provides the human intellectual infrastructure of faculty and students who can conduct year-round fieldwork as well as laboratory analyses of GIS/remotely-sensed products and integrate the proposed work with previous and ongoing hydrological

and spatial analytical studies. Quantifying the aquifer's discharge provides a means of back-calculating its recharge, which comprises the limit to sustainable development for the island's groundwater – the overriding question for water resource managers in any jurisdiction.

Besides proving the application of this new technology, this project will also build regional technical capacity for water resource management using UAVs and remote sensors and help local natural resource managers in Pacific islands build more detailed and useful geospatial datasets of geographic conditions affecting water resources. Specifically, it will make the application of the technology (through separately-funded related projects) available to the Federated States of Micronesia (FSM), which still have little useful geospatial data by which to manage their water resources. It will also expand the nascent Geography Program at UOG and put in place a local system to monitor geospatial data and manage natural resources using regular UAS flights and data collection. Finally, beyond these terrestrial applications, the NGLA provides a terrestrial analogue to help NASA in their studies of karst landscapes and processes on other planets.

Thermal images were first acquired in the summer, when tide was the lowest-low (-1 ft) and weather was optimal for operating the UAV. For comparison, images were captured during sunny days in the rainy season.



Graduate Research Assistant Eliana Walker, preparing a drone to launch from a northwest study site along the coastline of Guam. The drone is equipped with a TIR camera, which has been capable of capturing thermal images of freshwater plumes flowing and seeping into the ocean. Photo courtesy of E. Walker.

ONGOING RESEARCH

Potential PFAS contamination sites near the GWA production well A-25.

Mallory Duenas, Dr. Yong Sang Kim & Dr. Gary Denton

Funded by NIEHS and USGS

MS Environmental Science Thesis

Perfluoroalkyl substances (PFAS) have recently received attention as emerging contaminants in drinking water. Recent UCMR3 results reveal three Guam Waterworks Authority production wells to be contaminated with perfluorooctanesulfonic acid (PFOS). One of these wells (NAS-1) is located inside of the former Naval Air Station at Tiyan, in the village of Barrigada. PFOS concentrations found in this well to date range from 67-110 ng/L. The two other wells (A-23 and A-25) are located in Hagatña, one of the oldest villages on Guam. PFOS concentrations determined in both of these wells to date are consistently above 70 ng/L with maximum levels occasionally exceeding 400 ng/L in well A-25. Both wells are currently off-line. Ongoing PFOS source studies have so far identified four potential contamination sites based on historical records and favorable hydrogeological properties of the surrounding area.



Groundwater production well A-25 in Hagatna. Photo courtesy of Y. Kim.

These sites include: 1) a defective wastewater pump station that leaked millions of gallons of wastewater into the Chaot River over a 25-year period, 2) Agana swamp which drains the Chaot River and where chronic illegal dumping has occurred since WWII, 3) neighboring ponding basins that direct stormwater into the underlying aquifer, and 4) a nearby air flight crash site.

The objective of this study is to conduct a preliminary assessment of PFAS contamination sites in Hagatna and Ordot-Chalan Pago regions.

Hydrological Features and Analysis in the Finegayan Area

Dr. Yuming Wen, Dr. John Jenson &

Dr. Nathan Habana

Funded by USGS

Guam Waterworks Authority (GWA) is the custodian of Guam's public water supply and is responsible for ensuring that it meets all appropriate standards as mandated under the Safe Drinking Water Act and Clean Water Act of US EPA. To this end, GWA regularly evaluates the physical, chemical and biological integrity of the island's drinking water in accordance with US EPA requirements. While the agency has maintained a considerable amount of monitoring data over the years, only values that approach or exceed the water quality standards are paid attention. The rest, which account for well over 99% of all monitoring data collected so far, falls well below critical thresholds of concern and is of little immediate interest or attention. As a consequence, these data are simply stored on file for reference purposes. They are just paid attention only when they need be used to identify subtle changes in contaminant abundances and distributions within the aquifer or changes for a long term basis.

Because of projected increase of population, and relocation of around 5000 marines from Okinawa to Gaum in the next few years, water quantity and quality, particularly groundwater quantity and quality will be crucial

to the sustainable development of resources and environment in Guam. Since the Finegayan area will be involved in lots of buildup activities due to relocation of marines, it's very important to evaluate whether the related activities will affect the quantity and quality of the water resources, especially groundwater resources. Concerning water quality problems in the northern Guam lens aquifer (NGLA), salinity is of serious consideration. Based on this concern, the project will focus on salinity problem in Finegayan. The foci of the project will aim to evaluate the patterns of salinity levels from individual wells and all wells in the basin in space and over time, and to analyze the trends of salinity change of individual wells and overall trends of salinity in the basin spatially and temporally.

Establishing Groundwater Protection Zones in Guam

Dr. Yuming Wen, Brian Bearden & Dr.

John Jenson

Funded by USGS

Guam is the largest (about 541.3 km²) and southernmost member of the Mariana Islands chain. It currently supports a local population of around 170,000 and receives over 1.5 million tourists annually. The relocation of around 5000 marines and their dependents in the next few years, and foreign labors hired to assist with buildup activities will impose impacts on water quantity and water quality in Guam.

Groundwater from a karst limestone aquifer in the northern Guam supplies local residents and tourists with approximately 90% of their daily water needs. While estimates of the aquifer's sustainable water resources remain adequate for the current population, there is serious concern that the projected population increase will severely compromise the island's drinking water supplies and have an unprecedented impact on water quality and quantity. The high porosity and rapid recharge characteristics of the northern Guam lens aquifer make it vulnerable to

contamination from urban runoff, chemical spills, effluents from septic tanks and sewage overflows.

Guam Waterworks Authority (GWA) is in charge of Guam's public water supply and ensures that it meets all appropriate standards as mandated under the Safe Drinking Water Act and Clean Water Act. While the agency has collected a considerable amount of monitoring data over the years, only values that approach or exceed the water quality standards are paid attention. Most of the data fall well below critical thresholds of concern and is paid little attention. However, these data may be useful for evaluation of changes of contaminants for a long term basis.

Since groundwater in the Northern Guam Lens Aquifer (NGLA) supplies local residents and tourists with about 90% daily water use, it's absolutely necessary to set up groundwater protection zones (GPZs) and make sure that water quality can be maintained so that the daily life of the people of the island will not be affected. The main purpose of the project will focus on a better way to create GPZs, particularly GPZs located in the parabasal zone in the NGLA. The existing GPZ boundary lines have been made available from the Guam Environmental Protection Agency (GEPA) for WERI to utilize and update.

Aerial Survey and Field Instrumentation for Investigation of Landslide Threat to a Tropical Watershed in Southern Guam

Dr. Ujwalkumar Patil, Dr. Mark Lander, Dr. John Jensen & Dr. Shahram

Khosrowpanah

Funded by GHS

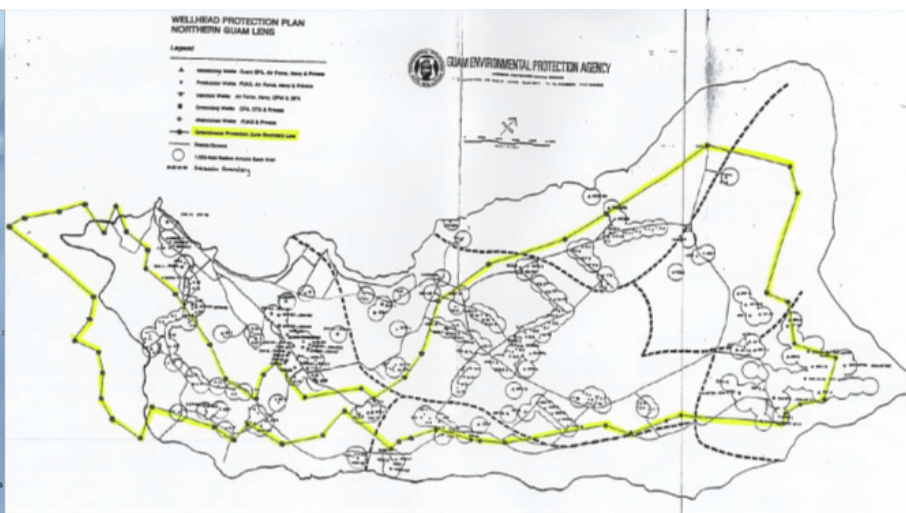
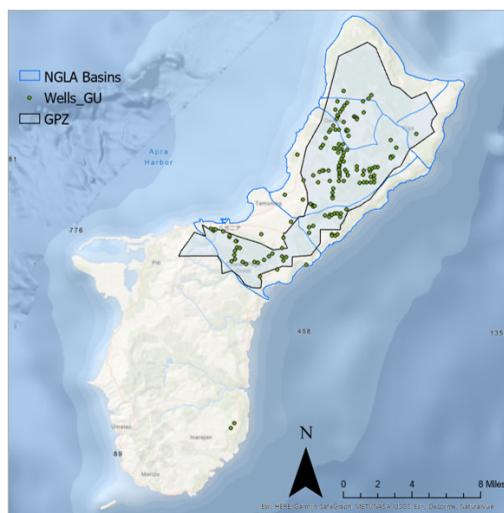
During 2019, the research team reviewed different watersheds in southern Guam and after much deliberation have identified 2 locations in Inarajan watershed, 2 locations along hillslopes of Fena Valley reservoir, and one location along Nimitz Hill Ridge in Piti-Asan watershed for this study. The PI and his research team has made several field visits to these sites and collected soil samples for lab studies as well as performed aerial and terrestrial photographic surveys to map the slope failures in these locations. One undergraduate engineering student from UOG's school of engineering has been hired on part-time basis to assist in lab testing and field assistance.

This research includes a one plus-year field monitoring study and will be followed by analyses of field data which will serve as an input of soil properties for slope stability analyses. Field instrumentation has been installed at Ija research station site in



Rainfall-induced slope failure in Fena Valley. Photo courtesy of U. Patil.

August 2019 and will be soon installed at Fena site. It will allow measuring the near-surface hydrologic response to assess the potential for landslides that mobilize into debris flow. It is our intent to capture a live shallow landslide event during monitoring period which will allow for identifying the triggering mechanism and modeling the safety factor changes. Shallow slope failure analyses will be presented and conclusions along with recommendations will be made to prevent future slope failures. Although we earlier planned monitoring of spatiotemporal soil



Boundary lines for the Groundwater Protection Zones (GPZs) will be updated into a digital tool from the existing Guam Environmental Protection Agency map, highlighted in yellow.

ONGOING RESEARCH

surface movement along the slopes, later with consultation with the Co-PI's we decided to not include this part and instead we included more site locations for field and lab studies. In next phase, we request to provide us with a budget to buy subscription to remote services to access data and for numerical analyses software for slope stability studies and purchase some supplementary field supplies. These measurements will be a valuable information which will enable us to hopefully capture "real time slope failure".

Northern Guam Lens Aquifer Monitoring System Expansion Rehabilitation Program (MSERP)

Dr. John Jenson & Kaylyn Bautista
Funded by Guam Waterworks Authority

The NGLA Monitoring System Expansion Rehabilitation Project (MSERP) launched on October 2017. 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 Rehabilitation Phase of MSERP is near completion. Well fences, concrete pads, and deteriorated surface casings were removed. New PVC well casings were coupled a few feet below the ground surface to the existing casings that were still in good, usable condition. A wellhead locking cap, new well pad, well enclosure, and where needed, security fencing were installed. Bollards were installed at wells that required protection from passing vehicles. The surrounding grounds were cleared to maintain easy access at each well site.

The Expansion Phase of MSERP will include USGS and WERI working with GWA's the Program Management Office (PMO) to provide 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.

Comprehensive Hydrological Database for Secure Water Resources in Tofol Watershed, Kosrae

Dr. Myeong-Ho Yeo & Dr. John Jenson
Funded by USGS

The management and allocation of water resources have always been considered as one of the most significant endeavors in human society since water plays a vital role in all natural and environmental systems of the Earth. Information on the variability in time and space of rainfall and on the resulting runoff characteristics is thus essential for the planning, design, and water resources management. For instance, daily/monthly precipitation time series are commonly used for the assessment of the available water resources in a region, and the extreme rainfall amount for a given return period is required for the estimation of flood for the design of hydraulic structures.

However, almost all river basins on the Federated States of Micronesia (FSM) do not have a network of rainfall and flow measurements to provide a sufficient record of observed data, estimating accurate hydrological responses. Rainfall records have been collected by various governments since 1985. Due to short or incomplete records, it is however impossible to be used for estimating the available water resources on the island. Consequently, characterizing watersheds on the island for the sustainable water supply was identified as a high priority concern at the Advisory Council Meeting for the FSM held in Kosrae Island in October 2019.

The water collected from surface water sources generally requires heavy treatment processes to reduce its turbidity, remove micro-organisms, and odor. Nevertheless, there is no one who was trained on water quality testing and sampling with not enough facilities. In addition, the Advisory Council Meeting 2019 requested a training course on ArcGIS for the development planning. To maintain



Groundwater observation well, M10A in Harmon, is one of ten wells that were proposed for in MSERP. The concrete pedestal and metal housing were removed, and a new well pad, metal enclosure, and security fence were built over the rehabilitated wellhead and surface casing.

the monitoring system consecutively and to test water quality at local sites, it has been recognized as a high priority work to conduct training courses. The proposed courses will cover the water quality test, the maintenance of the monitor systems, and to implement GIS data. They fall within the category of Research and Education/Professional Training Needs for the FSM, respectively. The operators for the measurement instruments do not require official certification, but training can be done by an instructor.

The immediate objectives of this phase are to set up the monitoring systems for daily rainfalls and stream flows on the island and to train personnel. The following works cover gathering the measured records and storing them for the public purposes. Building a database and/or website will be required for continuously providing the water resources information. From the information provided by this project, further research works will be suggested for the development of duration curve, the development of average and low flow, and the wastewater treatment plant design.

Hydrogeological Control on Submarine Groundwater Flow in Ayuyu Cave

Maria Jhonnie Villareal, Dr. John Jenson
& Dr. Romina King
Funded by NASA EPSCoR
MS Environmental Science Thesis

Characterizing karst features is integral to understanding groundwater movement in karst aquifers, which in turn assists scientists and water resource managers toward effective aquifer management. A USGS modeling study (Gingerich, 2013) of withdrawal and drought in the Northern Guam Lens Aquifer (NGLA) concluded a point that an estimated 163 million gallons per day (Mgal/day) discharges continuously along the northern coastline. 30.8 Mgal/day (20%) of that discharges along a single basin's coast (Finegayan Basin) on the northwest side of the island. Previous



WERI Director, Dr. John Jenson, and graduate Research Assistant, Maria Jhonnie Villareal, record ceiling, cave wall, and stalagmite observations and measurements in a chamber in Ayuyu Cave, at the northwest coast of Guam.

coastline projects observed a channel of freshwater discharge at a single cave, Ayuyu Cave, which measured 2.3 Mgal/day, 18% of the estimated 13 Mgal/day, the second largest area of freshwater discharge. This cave is hypothesized to be located at the edge of the Pugua Fault, an important geologic feature with potential to channel groundwater in Finegayan. Previous field work was conducted in a cenote on the fault surface.

Observations of the cave interior noted two sections of the cave - an enlarged chamber filled with tidal debris (trash, shell and coral fragments, and cave rubble), inner passages of detached cave formations from the walls and ceiling, and a brecciated zone with varying-sized conglomerate limestone bedrock pieces. The most significant progress was an unexplored passageway that lead to the discovery of a cave pool. Water samples indicate the pool is in the brackish zone of the lens (386 mg/L chloride). Water level loggers currently are logging temperature and pressure in the cave pool and in the chamber the pool is located. These

project aims to conduct an updated cave survey and produce a digital map of these new cave areas into 2D and 3D. Additional surveys need to be conducted on the fault surface at the cenote to characterize the position of Ayuyu Cave to the Pugua Fault. Project goals are to 1) further understand the geologic processes by which coastal karst aquifers transmit and discharge groundwater (particularly the Pugua Fault in the Finegayan Basin) and 2) improve existing models of groundwater storage and flow for coastal and island karst aquifers.



UOG President, Dr. Krise, caving with WERI researchers.

EDUCATION and OUTREACH

Digital Atlas of Chuuk - A Geospatial Map and Data Server for Resource Management

Dr. Myeong-Ho Yeo & Danko Taborosi
Funded by USGS

Chuuk Lagoon is one of the largest coral lagoons in the world. It is a semi-atoll and its barrier reef encompasses 18 high islands, all but one of which are inhabited. There are also many small, low-lying coral islands, one of which is inhabited. Chuuk Lagoon is the political and economic center of Chuuk State, the central and most populated state of the Federated States of Micronesia (FSM). The state capital, Weno, located in Chuuk Lagoon, is the largest and most densely populated urban area in the FSM. Chuuk Lagoon also acts as the administrative center for many outlying atolls scattered in the surrounding open ocean and can, thus, be viewed as the hub of commercial activity and economic development for the entire region of the Central Caroline islands. In addition, Chuuk is a part of a Small Island Developing State (SIDS) whose many low-lying yet densely-populated areas are at great risk of natural disasters and effects of climate change and sea-level rise. Sustainable development

and effective management of resources, especially in the context of improving resiliency to the effects of climate change and responding to the risk of natural disasters and ameliorating their effects, requires geospatial information of the physical, environmental, and anthropogenic components of the entire system. Such information must be accurate, up-to-date, mutually compatible, and readily available. Given the difficulties in locating and accessing such data in Micronesia, let alone verifying their quality and actually applying them in decision making, Chuuk has a great need for a unified, comprehensive, and user-friendly information management system.

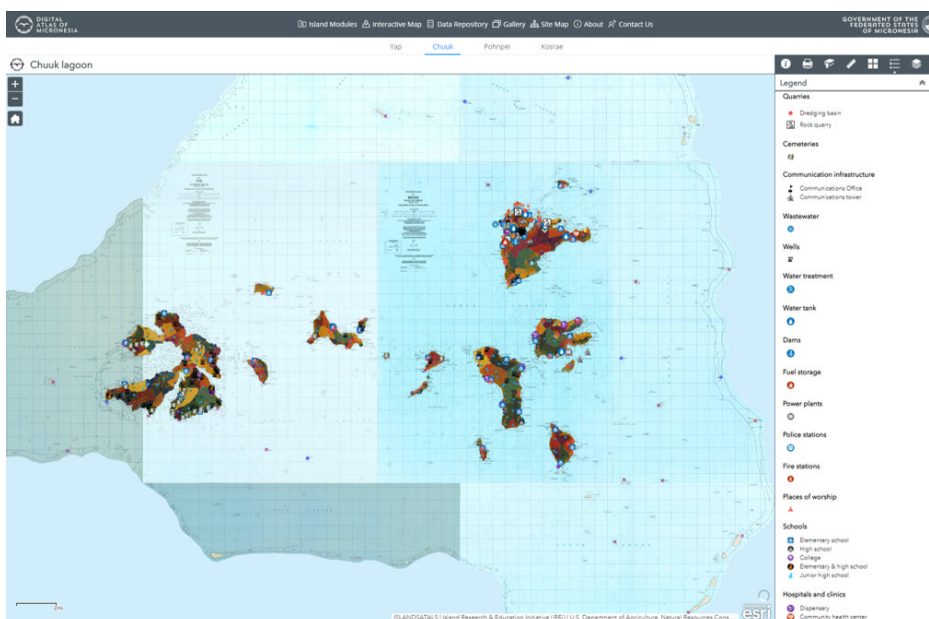
This geo-database for Chuuk will be established to incorporate all relevant physical, environmental, and infrastructural information and would include existing data (which would be inventoried and collected as part of this project) and any new data yet to be created, and become the mainstay for future collecting, digitizing, cataloguing, and distributing geospatial data on Chuuk. Therefore, the overall objective of the project proposed here is to create a robust, comprehensive, and versatile geospatial data server to support

all geospatial aspects of planning, disaster risk reduction and emergency response, resource management, sustainable development, research and modeling, conservation, and education on Chuuk. Based on experiences from Guam and the FSM (specifically Pohnpei, and results of comparable projects there, we plan to call the product proposed here the “Digital Atlas of Chuuk.” It will be a counterpart of the intensively used and highly successful “Digital Atlas of Northern Guam” and “Digital Atlas of Southern Guam” created in several stages between 2009 and 2013, and a sister product of the “Digital Atlas of Pohnpei”, “Digital Atlas of Yap”, and “Digital Atlas of Kosrae”, which were developed by iREI and WERI from 2016 until 2019.

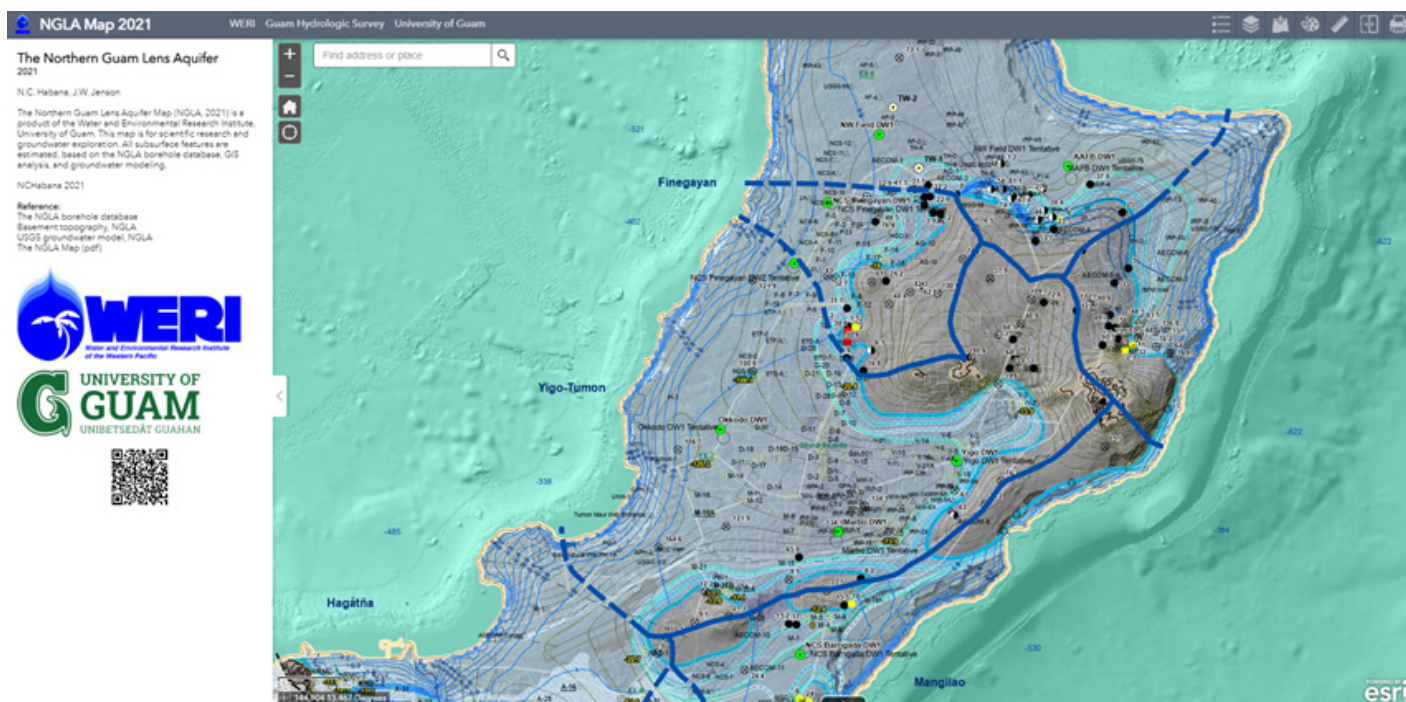
Guam Hydrologic Survey Website: Power Web MApps

Dr. Nathan Habana, Dannika Valerio & Glen Aguilar
Funded by GHS

The Guam Hydrologic Survey website is developing interagency tools in Power Web MApps. Power Web MApps will be accessed online, via web links and QR code in the GHS website. More than five major Northern Guam Lens Aquifer (NGLA) and Guam maps have been developed thus far, built of multi-layer spatial information that will be useful to strategic development and protection of our most valuable resource, the NGLA. The Power Web MApps we develop is powered by ESRI®, Arc GIS Online, so the server system is robust and reliable. It opens up a panel on the left that describes the map, authors, and links to database and literature resources. The top right hand corner line a set of common useful and easy to use app widgets such as legend, layers, add layers, draw, ruler, and print. These Web MApps may be accessed on any web browser, on a desktop computer or handheld devices. More Power Web MApps are underway, and organized from their interagency data source. Three Web MApps are already being used now by



A snapshot of the Interactive Map of Chuuk Lagoon. Selected layers shown are land, water, and infrastructure. The legend shows symbol descriptions.



Power Web MApp of the Northern Guam Lens Aquifer.

our interagency partners: GWA, GEPA, GDOE, and Kumision I Fino CHamoru. We see this as one of the best way to share our research products and data to the world, empower our island regulators and developers with good information, and help us all to focus more on strategic and smart planning, execution, and management. With this new technology, now, our valuable resource is in all of our hands.

Workshop Series on Guam Groundwater Resources

Dr. Yong Sang Kim & Dr. Nathan Habana

Funded by USGS and GHS

The military buildup and ongoing economic growth anticipated on Guam over the next decade have raised concerns regarding sustainable management of Guam's groundwater resources. Besides educating policymakers and agency heads, it is essential that island water resource professionals and educators be equipped with an accurate and up-to-date understanding of the island's aquifer and the factors that must be considered to frame and

implement sustainable management practices. Professional people in the water resources industry, from technicians to engineers, managers, agency heads, and policy-makers have extremely limited time to engage in professional development education opportunities. In FY 2019, WERI offered a two-day professional workshop on the Northern Guam Lens Aquifer (NGLA). It was held on 31 January and 7 February 2020. The affiliations of the participant included Guam EPA, Guam Bureau of Statistics and Plans, and private firms including EA Engineering, GHD, APDI, and AECOM.

The workshop covered WERI's aquifer database containing hydrogeological, engineering, and management data. The salinity histories of wells and the relations to well operation, construction, and location were also addressed. The workshop also introduced ongoing studies of salinity, PFOS, and nitrogen analyses, hydrologic modeling of groundwater production capacity, and concepts for sustainable management of the NGLA. Nine WERI faculty taught a total of nine sessions of the workshop. Four one-day professional tours of the

NGLA were planned in FY2019, but the tours were cancelled due to the COVID-19 pandemic.

Sand Filtration Training for Yap State Public Service Corporation (YSPSC)

Dr. MyeongHo Yeo & Ken Rekdahl
Funded by USGS

There are four independent water authorities in Yap: FSM-Yap State Public Service Corporation (YSPSC), Map Municipality Water Authority, Gagil-Tamil Water Authority, and Southern Water Authority. This four-day training incorporated in-class lectures and hands-on practice sessions as well as field trips. This training was the first training in which the different water authorities participated together. Operators from three water authorities, agents from Environmental Protection Agency (EPA), and the agents from the Project Management Office, Yap State, attended this training. Although the original training objective was to have been only slow sand filtration, participants advised the trainer that YSPSC has a rapid water treatment

EDUCATION and OUTREACH

system, and asked for instruction and advice on basic hydraulics, techniques, and equipment operation. The trainer therefore adjusted the curriculum to provide information and tools appropriate for current local conditions and resources.

The training thus included the following information and more: 1) introduction to water system hydraulics, from water sources to storage tanks to customers; the parts of pumps and how best to operate and maintain them; and 3) how to operate and maintain disinfection systems. This spontaneous course of instruction was very well received, and now is in constant demand. The success of the training is explicitly documented in the survey collected at the end: 69% marked it excellent, and 16% scored it very good. Regarding how applicable the training is to their work, 58% of the attendees said very applicable, and 21%, applicable. A certificate of the completion was given to each attendee, and was uniformly highly appreciated.

Guam Water Kids

Kaylyn Bautista & Dr. John Jenson

Funded by USGS

This year's Guam Water Kids program continued to build on the success of this well-received collaborative effort between WERI and K-12 educators in the local community. Activities included 1) a Guam Water Kids service-learning collaboration with two Guam Department of Education (GDOE) central district schools: Tiyan High School and P.C. Lujan Elementary School; and 2) presentations and activities at the Pay-Less (groceries stores) Summer Camp and University of Guam's 52nd Charter Day community outreach events. The primary goal achieved this year was building the partnership between officials and educators from GDOE, Tiyan, and P.C. Lujan Elementary School to implement the Guam Water Kids service-learning modules. Representatives from both schools acknowledged the limited off-the-shelf resources and materials available

to help visualize local geology, hydrology, and pollution sources in their classrooms. Teachers welcomed the program's assistance to motivate students to be productive citizens and good stewards of the environment. Timely communication and logistic deliberate logistical planning aided in the Tiyan-P.C. Lujan service learning success in October 2019, despite Super Typhoon Hagibis' passage over Guam the day before.



Visit the Guam Water Kids website (guamwaterkids.com) for handouts and videos to use in teaching about freshwater on Guam.

One notable success from this event is the quality of retention young students developed from the presentation of concise scientific explanations of local natural features and from subsequent hands-on activities. Several fifth-graders astounded the Tiyan High School ambassadors when they consistently answered content questions during the service learning visit. These students were also summer school participants received instruction over a span of three months—from a July summer presentation to the service-learning presentation in October. WERI and Guam Water Kids are preparing training kits for educators and students using local rocks, gravels, and sands.

Guam Water Kids plans to expand its videos, free downloadable handouts and activities collection to include new footage from around the island.

Educational information for students can be found in the forms of narrated

videos, flash cards, quizzes, and a link to the Guam Water Kids Facebook site for up-to-date media posts and announcements (<https://www.facebook.com/guamwaterkids/>).

Advisory Council Meetings

Dr. John Jenson

Funded by USGS

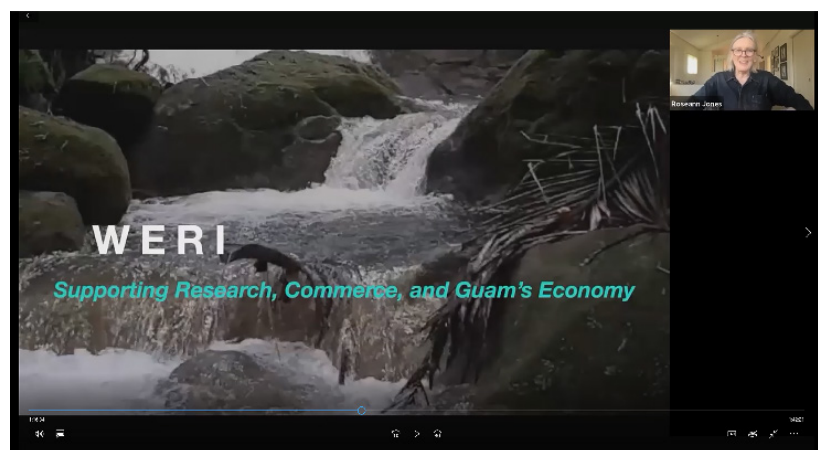
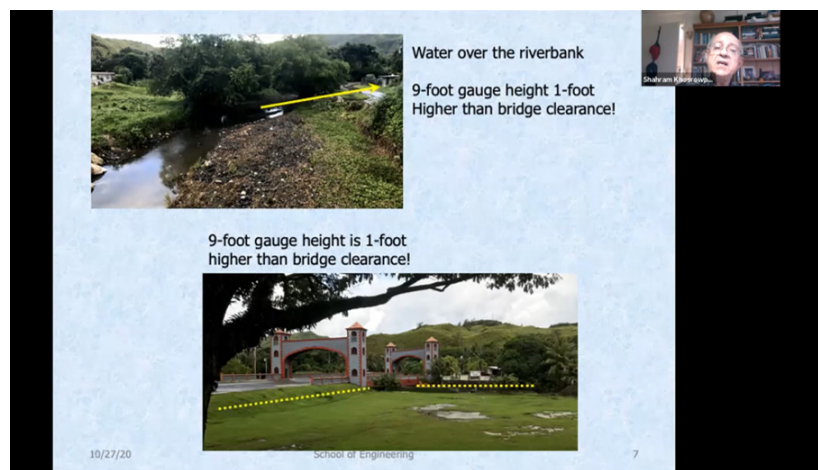
WERI's Three Advisory Councils. WERI maintains a separate advisory council for each of its three regional constituencies: 1) the US Territory of Guam, 2) the Federated States of Micronesia (FSM), and 3) the Commonwealth of the Northern Mariana Islands (CNMI).

Each council is built around a core of officials, managers, and technical experts from local agencies involved with water resources development, management, or regulation, who serve as more or less permanent members. Some have been formally appointed by their governments or agency heads. Others serve by invitation from WERI. The composition and appointment process for each council reflects the governmental and geographic conditions unique to each constituency.

The Guam Advisory Council core members include managers and technical experts from local agencies, and local offices of US federal agencies, including the local military civil engineering units and their contractors that deal with water resources. The core members of the councils for the CNMI and FSM include representatives from local government departments, as well as permanently-stationed employees of US federal agencies; United Nations, European Union and other international development aid agencies; Non-Governmental Organizations; and local colleges and schools.

WERI convened each council for a day-long virtual conference to review and update its agendas for research, information transfer, and educational projects. In addition to the core

members, people invited to the meetings include government officials, private sector engineers and planners, educators, students, and other scientific and professional colleagues involved in ongoing projects and programs. The morning agenda includes presentations on recently completed projects and ongoing projects. Following lunch, there are plenary and focus-group discussions on critical needs, after which each participant fills out a survey regarding directions of ongoing projects and prospective future projects. Meeting participants frequently observe that WERI Advisory Council meetings are the sole venue in which all of the water resources professionals on their island meet together in a single group. The meetings are thus valued as unique forums for professional information-sharing and networking. Throughout each year, WERI uses council mailing lists to provide updates and announcements for events of common interest, including WERI research presentations, professional workshops, and thesis defenses.



WERI's 2020 Advisory Council Meetings were virtually hosted by the University of Guam's Global Learning and Engagement Office (GLE). Participants joined in to view WERI's ongoing research projects and training, education and outreach programs.

UNIVERSITY OF GUAM PROGRAMS SUPPORTED BY WERI

Environmental Science Graduate Program

The Environmental Science Program is designed to provide students with an appreciation of the interdisciplinary nature of environmental problems that exist in the world today and prepare them for professional employment, teaching, or advanced studies in diverse areas of environmental science, or related disciplines. The program also serves working professionals in local schools, government agencies and the private sector who are seeking career advancement and/or professional enrichment, e.g., educators, regulators, administrators and planners.

The interdisciplinary focus of the program is intended to train students to identify and understand environmental problems and exercise sound judgment in effecting their remediation. This is accomplished through a careful blend of core courses and electives in an integrated teaching-research approach. Students are required to conduct a research project and document their study in thesis form. They are encouraged to present their findings in a variety of forums (e.g., society meetings, conferences, workshops, seminars, peer-reviewed journals, technical reports, newsletters and the local newspaper). Students also have the option to serve out an internship with a local environmental or engineering firm, or an appropriate

Government of Guam or Federal Government Agency. This permits them to gain professional problem solving skills in the environmental arena. Students who graduate from the MS program can, therefore, reasonably expect to enter professional employment in a variety of areas in the public and private sectors where an understanding of the complex interdisciplinary scientific, social, and political dimensions posed by environmental problems is increasingly necessary.

The Environmental Science Program strives to promote educational and service projects within island communities of the Western Pacific, and attract a broadly based group of scholars committed to seeking answers to the many environmental questions that are arising in developing island nations of the tropical Pacific Basin. Areas of faculty expertise center around three broad areas of concentration namely, biology-ecology, geosciences-engineering, and economics-management.

Further information may be obtained from the Environmental Science Program Chair, Dr. Romina King, phone: 735-2874, e-mail: roking@triton.uog.edu.

School of Engineering

Engineers are society's problem solvers. They take the theoretical ideas of the scientist and bring them into reality in today's world for the benefit of mankind. Engineers are involved in projects that vary from the design and construction of transportation systems to the planning of the space stations of the future. Nearly all aspects of our lives are touched by the projects worked on by people in the various engineering fields.

The School of Engineering at the University of Guam (UOG), which was established in 1989 (as the Pre-Engineering Program), parallels the curricula of the first two years of the engineering programs offered at major colleges and universities in the US and abroad. After completing the required coursework in this program, students transfer to other universities that offer degrees in engineering in order to complete their studies. In 2013, a cooperative agreement was signed with the Universities of Iowa, Mapua Institute of Technology (Manila, Philippines) for student and faculty exchange. The courses offered by the program at UOG have been accepted by these institutes. Therefore, it provides for an easy transfer of students, thus enabling them to complete their degree.

On October 29, 2009, the President of the University of Guam expressed his vision for establishing a four-year accredited engineering degree program to help meet current and growing demand for engineering expertise in Guam's private and public sectors. The anticipated rapid economic growth and development in our community and region over the next decade will produce an acute need for engineering talent to support new construction, repair and rehabilitation of aging infrastructure, development of natural resources, and environmental protection and preservation. It is therefore envisioned that the engineering curriculum will focus, at least initially, on civil and environmental engineering.

For more information about the Civil and Environmental Engineering Programs of the School of Engineering at the University of Guam, contact the Interim Dean, Dr. Shahram Khosrowpanah, phone: 671-735-2694, e-mail: khosrow@triton.uog.edu.





THE JOSEPH D. ROUSE SCHOLARSHIP FOR PROFESSIONAL EXCELLENCE AND INTEGRITY



The career of Dr. Joseph D. Rouse, Professor of Water Resources and Environmental Engineering and member of the faculty of the Water and Environmental Research Institute of the Western Pacific, University of Guam, from 2011 to 2019 epitomized the values of competence and integrity in professional science and engineering. Dr. Rouse's contributions to the University of Guam included leading its graduate Environmental Science Program, teaching and advising environmental science students in course work and thesis research, and voluntarily assisting the new School of Engineering in developing its curricula, recruiting its faculty, and securing accreditation. It is fitting, therefore, that the University establish this scholarship to honor Dr. Rouse's memory and preserve his legacy as a role model for new environmental scientists and engineers whose careers are beginning with their education and training at the University of Guam.

The scholarship shall be an endowed scholarship with a base of at least \$25,000 to produce an anticipated annual return of about \$1000. The award shall be given annually to a graduating environmental science or engineering student who has served as a graduate or undergraduate research assistant on a project that has produced results worthy of presentation at a professional conference or publication in the peer-reviewed professional literature; whose contributions to the project merit lead authorship or co-authorship of the presentation or report on the project; and whose academic performance and personal character exemplify the virtues of professional excellence and integrity that Dr. Rouse stood for. The award shall be used to support registration or travel to a professional conference, or publication costs of an article for a conference proceedings volume or a peer-reviewed professional journal.

The WERI faculty shall establish specific criteria for eligibility and selection based on the principles cited above. The WERI Director shall issue an annual call for nominations in February, which will invite the Environmental Science Program Executive Committee and School of Engineering Faculty to nominate worthy candidates by the end of March. The winner shall be selected by vote of the WERI faculty convened by the WERI Director by the end of April. The award will be presented by the WERI faculty at the University Awards Ceremony in May.

No more than one award shall be given each year, and no award shall be given unless at least one candidate is found who meets all of the criteria for top-quality research production and publication, outstanding academic performance, and exemplary personal character, as cited above.

CONTRIBUTIONS



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