Annual Summary of Activities



WERI

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

including Guam Hydrologic Survey activities

February 2020

Annual Summary of Activities

including Guam Hydrologic Survey activities

Edited by
Kaylyn K. Bautista

Reported by
Dr. John W. Jenson, Director

February 2020

Period of report: 1 Oct 2018 - 30 Sept 2019

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

TABLE OF CONTENTS

Director's Message 1

Mission 2

Vision 2

Core Values 2

2020-2025 Research Agenda 3

Guam Hydrologic Survey Program 4

Comprehensive Water Monitoring Program 6

Completed Projects 8

- PFOS Trend Monitoring in a Guam Drinking Water Production Well: Seasonal Influences 8
- Yigo-Tumon Basin Production Well Capacity Simulation 8
- Visualization of Salinity Patterns and Trends in the NGLA 9
- Guam Waterworks Authority (GWA) Production-Well Rehabilitation Assessment: Lessons Learned/Manual for Well Exploration and Development 10
- Impact of Stormwater from a Natural Wetland in American Memorial Park, Saipan, CNMI, on Receiving Waters and Resident Fisheries Resources 10
- Effects of Seawater on Nitrification in a Biofilm Treatment Process 11
- Determination of Rainfall Erosivity Factors to Selected Islands in CNMI 12
- Aerial Survey and Field Instrumentation for Investigation of Landslide Threat to Tropical Watershed in Southern Guam 12
- Dynamic Response of the Freshwater Lens to Natural Variations in Recharge, Northern Guam Lens Aquifer, Yigo-Tumon Basin 13

Ongoing Research 14

- Identifying, Analyzing and Mapping Submarine Groundwater Discharge (SGD) with a Thermal Infrared (TIR) Sensor and Unmanned Aerial Vehicle (UAV) 14
- Hydrogeological Control on Submarine Groundwater Flow in Ayuyu Cave 14
- Development of a GIS Based Imagery Database of Groundwater Recharge Areas and Key Reaches of Streams on Guam 15
- Phase-II of N-Baseline Data and Abatement Methods for the Northern Guam Lens Aquifer 16
- Three-Dimensional Finite-Element Groundwater Model of the Yigo-Tumon Basin, NGLA 16
- Potential PFAS Contamination Sites Near the GWA Production Well A-25 16
- PFOS Trend Monitoring in Saipan Production Wells 17
- Improvements to Sewage Treatment on Yap: Hydroponics and Composting of Waste Sludge 18
- Hydrological Features and Analysis in the Finegayan Area 18
- Water Use Data and Research in Guam 19
- Northern Guam Lens Aquifer Monitoring System Expansion Rehabilitation Program 19

Education and Outreach 20

- Digital Atlas of Yap - A Geospatial Map and Data Server for Resource Management 20
- Professional Workshop Series on Guam Groundwater Resources 20
- Comprehensive Guam and CNMI WERI-Web-Based Comprehensive Rainfall Data Utility 21
- Sand Filtration Training in Yap 22
- Advisory Council Meetings 22
- Virtual Tour and Professional Field Trip of the Northern Guam Lens Aquifer 23
- Guam Water Kids 23

University of Guam Programs 24

- Environmental Science Graduate Program
- School of Engineering

The Joseph D. Rouse Scholarship for Professional Excellence and Integrity 26

In Memoriam



Dr. Joseph D. Rouse

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 Marianas 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-2019 WERI faculty were involved as principal investigators and/or advisors on 24 research and training 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.

Over the last ten years, WERI faculty members have collectively published 72 refereed journal articles, 53 technical reports, and over 110 conference proceedings. They have also given numerous professional presentations and training workshops. Following its most recent 3-year evaluation, WERI was once again congratulated by the evaluation panel for continuing to promote an exemplary program appropriately focused in a programmatically separate way on the water problems of Guam, the CNMI and the FSM.

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

Dr. John W. Jenson, PhD
Director, WERI
jjenson@triton.uog.edu
303 University Dr.,
Mangilao, Guam 96913
Tel: 1-671-735-2685
Fax: 1-671-734-8890



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 in the next five years - 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. 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.

Guam

I. Aquifer research
- Baseline/core products: databases, map series
- Water availability: modeling, exploration, rehabilitation
- Water quality: salinity, sewage, chemical contaminants

II. Surface watershed research
- Baseline/core products: watershed imagery, maps
- Water availability: southern karst springs; stream flows
- Water quality

III. Water-use management: new USGS water-use database

IV. Training, education, outreach
- Website, State of the Aquifer Report, technical reports
- Workshops, Professional Aquifer Tour, Guam Water Kids

CNMI

I. Water availability
- Comprehensive Guam & CNMI rainfall

II. Water quality
- PFOS trends in Saipan

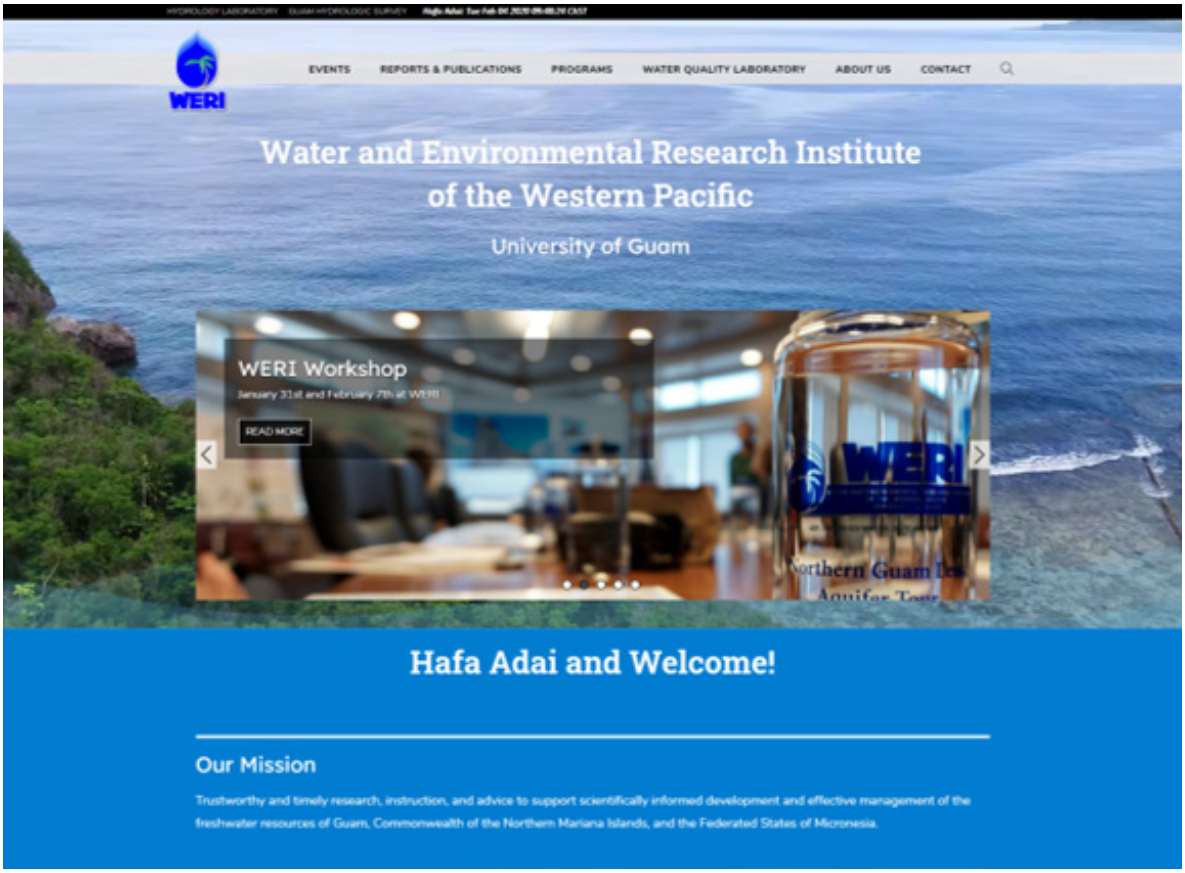
III. Stormwater management and planning

FSM

I. Yap
- Sand filtration training
- Wastewater treatment improvements

II. Kosrae
- Surface watershed research
- Baseline/core products: databases, maps
- Water availability: exploration

III. Education and outreach
- Yap Digital Atlas
- New education outreach for K-12
- Chuuk Digital Atlas
- Kosrae water resources training and outreach



Visit the WERI website for a new, user-friendly experience:
www.weri.uog.edu

GUAM HYDROLOGIC SURVEY PROGRAM

Dr. Nathan Habana

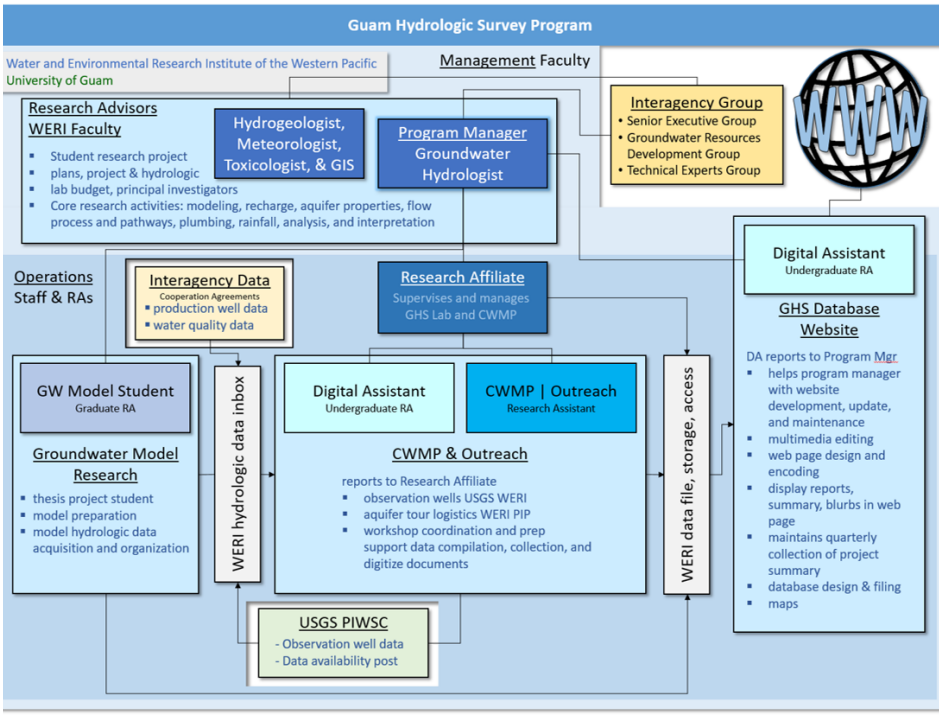
Funded by Government of Guam

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 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.



Guam Hydrologic Survey and Comprehensive Water Monitoring Program Management.

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, 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 2019

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 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.

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 and Stephen Anthony
Funded by USGS and GHS

The United States Geological Survey (USGS) has monitored our island's water resources since 1951. Unfortunately, during the 1990s they were forced to downsize this program because matching support from the Government of Guam was discontinued. This resulted in the abandonment of all deep monitoring wells needed to monitor saltwater intrusion in the north, and most of the stream gages in the south by the mid-1990s. In 1995, the USGS closed its field office at Naval Station, but continued to run a limited monitoring program (out of its Saipan and Honolulu offices). In August, 1998 the Comprehensive Water Monitoring Program (CWMP) was made a permanent part of WERI's program when Governor Gutierrez signed PL 24-247. This resulted in the refurbishment of the deep monitoring wells and a renewed program of water resource monitoring on Guam. The intent of PL 24-161 was to restore, and then to expand, as needed, the discontinued monitoring program in order to help Guam manage and safeguard all of its freshwater resources, now and in the future. Under PL 24-161, WERI/UOG and the USGS entered into a memorandum of understanding to administer and fund this program on a 50/50 cost-sharing basis. The CWMP is a permanent investment in Guam's future.

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



Locations of USGS monitoring stations on Guam.

Currently, USGS monitoring on Guam consists of 6 continuous-recording streamflow gages, 7 continuous-recording groundwater wells, 6 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 stream gages provide information needed by managers and engineers to properly manage the long-term sustainability of these water resources. Statistical analysis of long-term streamflow data are needed so the effects of abnormally wet or dry years can be understood and planned for. For example, USGS gages provide information that can be used to assess and manage the sustainability of surface water from the GWA Ugum Treatment Plant. Other gages, funded in cooperation with the U.S. Navy, are used to manage withdrawals from Fena Reservoir.



Flow in Pago Stream has been measured since 1951.

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

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 7 wells where water level is continuously measured and 6 wells where the thickness of the freshwater lens is measured biannually. Collectively, this information allows scientists at WERI, GEPA, GWA, and USGS to understand the flow of water through the aquifer and refine sustainability estimates of this resource. This information is used to understand how current levels of pumpage are affecting the aquifer and how future changes in climate and groundwater production may affect the sustainability of groundwater resources. Coupled with detailed geologic mapping and modern hydrologic tools such as groundwater flow models, information from this long-term program will be invaluable as additional water is needed to support increasing economic development on Guam.

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

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

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

In fiscal year 2019, the cost to operate a continuous-record streamflow gage will be $23,085. 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 ($10,085) and groundwater ($7,305), require less funding. With over 100 years of experience, USGS procedures ensure that data are reliably collected, analyzed, and publicly available

How can one get USGS water resource information?

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



WERI field assistant measures water levels in an observation well in the Northern Guam Lens Aquifer.



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

USGS
science for a changing world

COMPLETED PROJECTS

PFOS Trend Monitoring in a Guam Drinking Water Production Well: Seasonal Influences

Dr. Gary Denton, Dr. John Jenson, Dr. Mark Lander, and Carmen Sian Denton
Funded by USGS

Perfluorooctane sulfonate (PFOS) is a fully fluorinated anion that was once widely used in industry. It is very persistent and has substantial bioaccumulation and biomagnification properties, particularly in humans. PFOS is moderately water soluble (~600 mg/L) and has recently emerged as a drinking water contaminant of potential concern, having so far been detected in approximately 2% of public water systems across the Nation. In 2009, USEPA issued a provisional drinking water health advisory (HA) for PFOS of 200 ng/L. A final HA of 70 ng/L was promulgated in May 25, 2016 (Federal Register 2016).

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.

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. 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 2017'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.

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 dry/wet season cycle. Thereafter, pending further refinement of the time delay between rainfall and the PFOS concentration encountered in the well, continued sampling could be scaled back to coincide with rainfall extremes occurring in prior months. The proposal submitted herein therefore seeks funding to continue the PFOS monitoring of A-25 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.

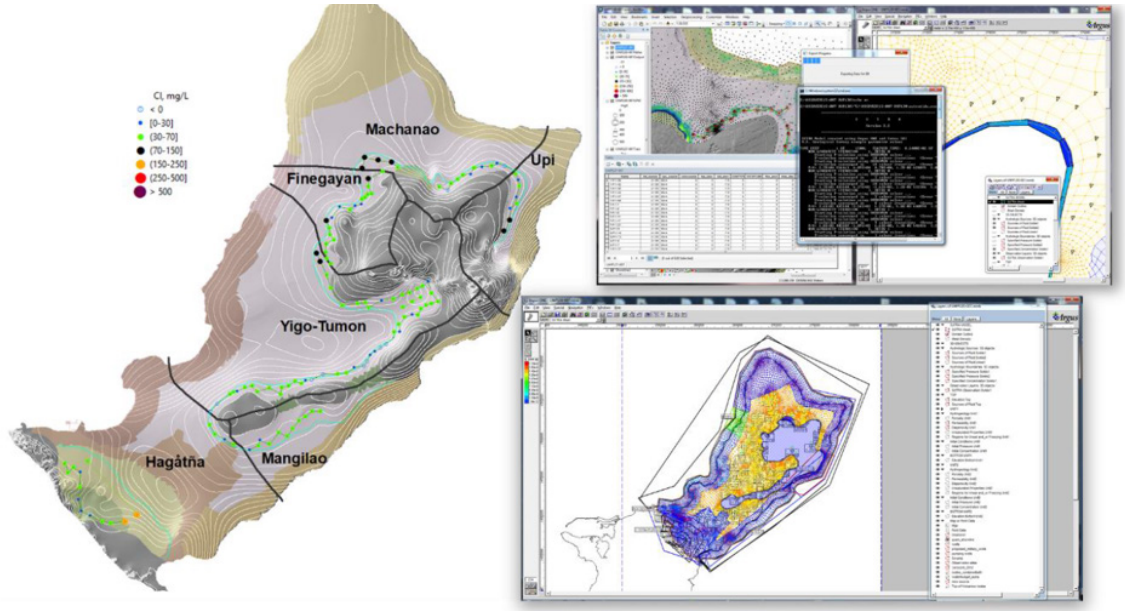


Well A-23 (bottom left) and A-25 (right of power line) are situated about 100 feet apart and located along Guam's Sinajana-Agana highway, Route 4.

Yigo-Tumon Basin Production Well Capacity Simulation

Daniel Superales, Dr. Nathan Habana, Dr. John Jenson, and Stephen Gingerich
Funded by GHS
MS Environmental Science Thesis
Dec '19

A numerical groundwater model of the Northern Guam Lens Aquifer was used to evaluate the potential capacity of the freshwater lens. 130 vertical wells were simulated within the parabasal zone, the portion of the freshwater lens that is supported by the volcanic basement rather than seawater, in successive average-pumping scenarios from 100 gpm to 500 gpm. Baseline simulation results produced about the same volume of freshwater as the observed system but with a lower overall production weighted average chloride concentration of 44 mg/L compared to 123 mg/L. Successive simulation results show that up to 89 million



Simulation of groundwater production wells situated in the parabasal zone of the six basins of the Northern Guam Lens Aquifer. Few wells (orange dots in Hagatna Basin) exceed the US EPA MCL 250 mg/L for drinking water at a maximum pump rate of 500 gallons per minute (gpm). Majority (blue and green dots) remained below the US EPA standard.

gallons per day can be extracted from the aquifer while maintaining the production weighted average chloride concentration at 250 mg/L, the safe drinking water guideline set by the Guam Environmental Protection Agency. These results show the advantage of focusing development of carbonate island karst aquifer on the parabasal zone.

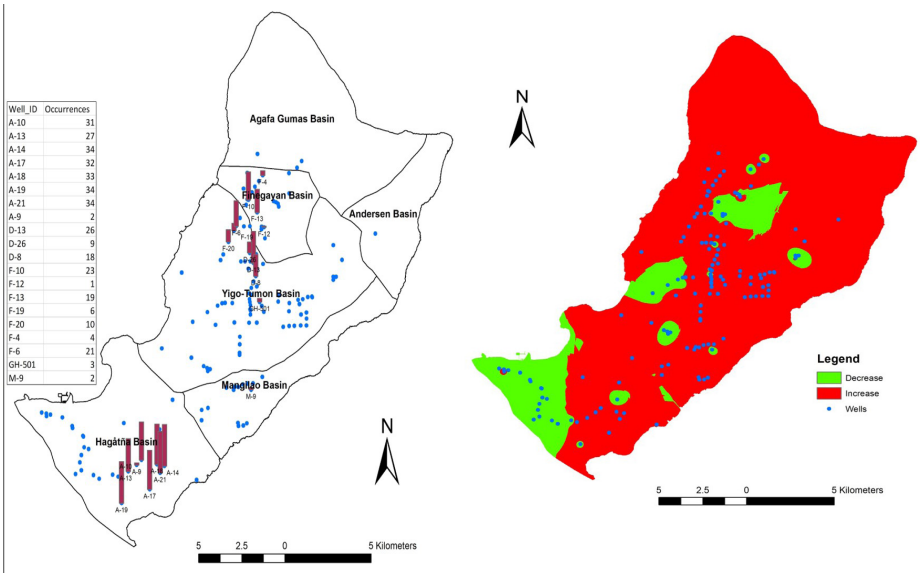
Visualization of Salinity Patterns and Trends in the NGLA

Dr. Yuming Wen, Dr. John Jenson,
Dr. Nathan Habana & Dr. Romina King
Funded by USGS

This project focused on processing, visualization and analysis of the patterns and trends of salinity from drinking wells in the Northern Guam Lens Aquifers (NGLA). Water quality data was available from Guam Waterworks Authority and GIS was utilized to process and analyze salinity data, and therefore locate wells with water quality problems with salinity. Since high level of salinity in drinking water poses risks to man's health, it is crucial to identify at-risk wells and archive them in a format that permits rapid visualization of spatial and temporal trends of salinity in the study area.

Based on the analysis of the salinity data, and visualization of the locations of the wells with salinity problems, conclusion can be made that most of well with salinity problems are located in Hagatna Basin and Yigo-Tumon Basin, and many located in Finegayan Basin though it is a small basin. Only Well M-9 located in Mangilao Basin was monitored with salinity problem. Changes of the trends of salinity can be achieved from time-series data.

Data analysis also determined that salinity levels increased between 2001 and 2009. This technique is especially useful for identifying and predicting subtle long-term trends (increases or decreases) in salinity levels within the aquifer when analyses of salinity data from different dates are provided. The analyses of salinity can provide local government agencies including Guam Waterworks Authority and Guam EPA which are interested in water contamination, particularly salinity.



(left) Problematic wells with salinity in the NGLA. Table shows well names and occurrences count of chloride. Blue dots are well locations, and maroon columns are cumulative occurrence count. (right) Salinity change in the NGLA between 2001-2009. Increasing trend of salinity was mapped as red shading. Decreasing trend was mapped as green.

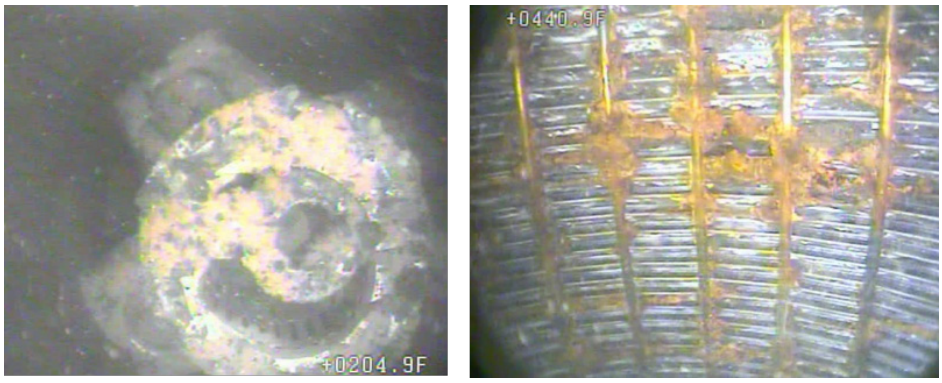
Guam Waterworks Authority (GWA) Production-Well Rehabilitation Assessment: Lessons Learned/Manual for Well Exploration and Development

Dr. Yong Sang Kim, Dr. Nathan Habana, and Dr. John Jenson
Funded by USGS

Currently, Guam Waterworks Authority (GWA) produces 90% of the 45 MGD potable water from its main source, the Northern Guam Lens Aquifer (NGLA). GWA is currently managing 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 40 years in operation, thus lifespan exceeded, maintenance is no longer economically viable, and production has become unsustainable. During the first project year (June 2018 – June 2019), main reasons why production wells had been shut down were analyzed based on the analysis of GWA production well data including 20 inactive wells. Classified main issues are: 1) aging, 2) contamination, and 3) water depletion. As of 2018, over 50% of production wells are over 40 years old. Main reasons why production wells had been shut down caused by an aging issue are classified as collapsed well casing, collapsed well screen and pump stuck in well casing. Four production wells have been taken offline due to exceeding maximum contaminant levels (MCL) of chlordane, tetrachloroethylene (PCE) and health advisory levels of perfluorooctanesulfonic acid (PFOS) regulated by US EPA.

- Chlordane : Well M-14, Yigo-Tumon, basal zone (since 1983)
- PCE : Well A-28, Hagatna, basal zone (since 2006)
- PFOS : Well A-23, A-25, Hagatna, para-basal zone (since 2017)

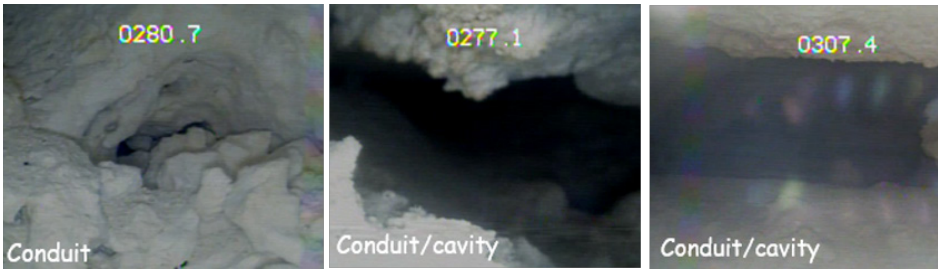
Two production wells have been shut down due to a water depletion issue. These two wells experienced pumped air during operation.



Over 50% of GWA production wells are over 40 years old. Main reasons why production wells have been shut down caused by an aging issue are classified as collapsed well casing, collapsed well screen and pump stuck in well casing.



Screenshots from a borehole drilled next to D-22 (low water production).



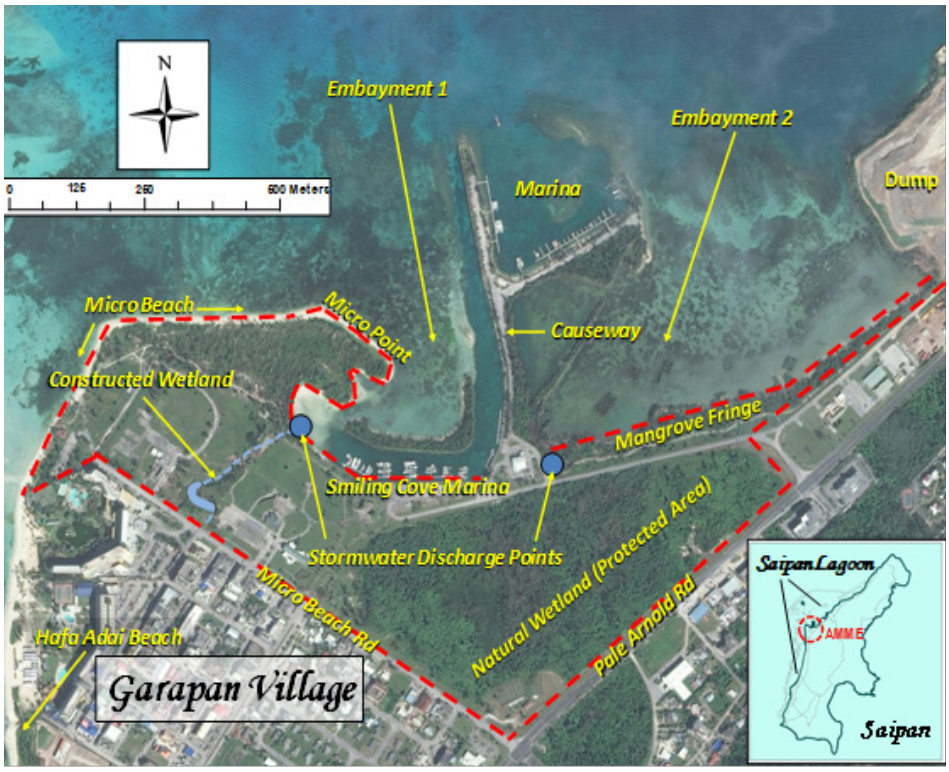
Screenshots from well D-18 (good water production).

Impact of Stormwater from a Natural Wetland in American Memorial Park, Saipan, CNMI, on Receiving Waters and Resident Fisheries Resources

Dr. Gary Denton
Funded by USGS

The American Memorial Park (AMME) in Saipan was established in 1978 to commemorate US soldiers and civilians killed on island during WWII. The land was occupied by the US Navy immediately after WWII and used as a motor pool and maintenance facility. It also served as a disposal site for unexploded ordnance and residual wartime munitions, as well as a general dumping ground for toxic chemicals and other hazardous wastes. Mercury levels in surface soils within the park commonly exceed 100 ng/g and are largely attributed to fulminated mercury released from surplus ammunitions detonated and/or buried on the property. Two wetlands currently exist within the park. One is natural while the other was created in the 1990s as part of a flood mitigation program for Garapan village. Both wetlands discharge excess stormwater into separate nearshore embayment (opposite page). Mercury levels in a popular table fish (*Lethrinus harak*) from each embayment were therefore of interest.

Overall, sixty fish were examined with fork lengths that ranged from 9.5-29.3 cm. Total mercury levels in their axial muscle ranged from 0.009-0.493 µg/g wet weight and were clearly size-dependent (coefficient: 0.705). Normalization of the log-transformed data to a 20-cm fish length yielded an average value of 0.097 µg/g (95% CL: 0.080-0.117 µg/g). Scatterplots of the datasets revealed no obvious mercury differences in fish between embayments. Since mercury levels in fish from clean waters typically range from 0.001-0.100 µg/g, the restricted consumption of *L. harak* from both embayments is advised for captured specimens exceeding 20 cm fork lengths.



American Memorial Park (AMME) in Garapan Village. Dashed red line indicates MME boundary. Blue plots indicated stormwater discharge points.

Effects of Seawater on Nitrification in a Biofilm Treatment Process

Lyuqin Liu, Dr. Yong Sang Kim, Dr. Yuming Wen, and Dr. Bulan Wu
Funded by Guam Waterworks Authority
MS Environmental Science Thesis
Dec '19

With growing populations in the coastal areas globally, the amount of freshwater resources has become an issue of increasing concern. In Guam, a multi-year drought could detrimentally impact the capacity of 90% of the freshwater resource coming from the Northern Guam Lens Aquifer. Using seawater for flushing toilets is a way to save freshwater in coastal areas. However, seawater can influence the efficiency of wastewater treatment if it directly flows into wastewater treatment plants.

The objective of this study was to evaluate the nitrification rate of wastewater under different salinity concentrations. To meet this objective, two conducting bench-scale, continuous-flow bioreactors using PVA-gel beads biocarrier were operated under the same conditions, such as temperature, pH, and dissolved oxygen, with the exception that seawater bioreactor influent was mixed with stepwise increasing sea salt. The performance of key nitrogen parameters (NH4+, NO3-, and NO2-) was monitored for the determination of nitrification rates and efficiencies.

In light brackish water (0% to 30% seawater), the salinity had no significant effect on the nitrification rate. In brackish water (30% to 80% seawater), the nitrification process was inhibited by the stepwise increasing salinity. In saline water (80% to 100% seawater), the transient decrease of nitrification was observed due to the inactivity of bacteria. After recovery time, the short-term effects of salt on nitrification in the biofilm treatment process were reversible, which could go back to original treatment efficiency.



Polyvinyl alcohol (PVA)-gel beads (left) have a porous microstructure that allows for microorganisms to enter and attach inside and outside the gel material, thus providing favorable retention and cultivation conditions. Salt biological reactor system (experimental) (right) indicated bacteria absorbed from suspended water.

COMPLETED PROJECTS

Determination of Rainfall Erosivity Factors to Selected Islands in CNMI.

Dr. Mark Lander
Funded by USGS

Last year we began a study of soil erosion and sedimentation in the islands of the CNMI. Specifically, we set out to develop Universal Soil Loss Equation (USLE) average annual rainfall factors (R factor) values for the islands of the CNMI in what hereafter will be called Phase 1 of the R factor study. On several trips to Saipan during 2017, we gathered available rainfall and storm data for Saipan, Tinian and Rota. Computation of the R factor requires detailed information about storms. A key parameter is the intensity (I) of the rainfall, usually at 15-minute intervals. There are many cases in which 15-minute rainfall data is not available, and methods for using hourly data exist. Rainfall intensities at time intervals greater than one hour are not recommended unless there is a very clear relationship between these and the 15-minute or hourly rainfall. On Saipan, there was only one source of hourly data: the Fisher-Porter rain gauge on Capitol Hill. The record is relative short, and does not contain data for typhoon passages.

For Phase 2 of this project, we proposed a thorough review and treatment of the rainfall data for computations of the R factor and other hydrological applications (e.g., return-period calculations) in the CNMI. The Saipan Fisher-Porter data needs to be carefully scrutinized and edited. For example, not all the hourly data in the raw data is truly hourly, but sometimes at a longer interval, but tallied in one hour. The other deficiency is the lack of typhoon captures. For this, we planned to use high-resolution rainfall captured in typhoons on Guam. Rain rates during typhoons are a factor of two higher than possible from any other storm type. Thus, to get her R factor correct, there must be a proper accounting for typhoon rainfall.

At the completion of Phase 2, a representative hourly rainfall time series was constructed to be used for the assessment of Saipan's R factor. It included the impact of typhoons. A comprehensive CNMI rainfall data base was developed to include all station meta-data, identification of possible data pitfalls and a strategy to properly account for typhoon rainfall. Major benefits of this project was the ability of various agencies dealing with soil erosion to identify areas of potentially high erosion. The rainfall data base was also informative for other hydrological applications such as the determination of rainfall return periods, and estimation of aquifer recharge.



Soil erosion and sedimentation are major sources of non-point pollution into streams, rivers, lakes, and onto reef systems. Understanding contributing factors requires organized baseline datasets and relevant models which can be calibrated and validated.

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

Dr. Ujwalkumar Patil, Dr. Shahram Khosrowpanah, Dr. Mark Lander and Dr. John Jenson
Funded by GHS

Tropical cyclones, common to the western Pacific islands including Guam, bring large amounts of rainfall within short durations, thereby triggering shallow slope failures and landslides. Accurate modeling of the slope failures resulting from heavy rainfall in mountainous basins requires spatial-temporal information of temperature and rainfall (meteorological and environmental factors); physical properties, degree of saturation, suction and shear strength parameters (geotechnical and hydrological properties) of soil. Conventional methods of slope stability analyses (saturated and dry soil) do not include the unsaturated soil properties and hence cannot accurately predict the rainfall-induced shallow slope failures. However, accurate seepage and slope stability analyses would require inclusion of unsaturated soil properties. This research project performed geotechnical investigations of shallow slope failures which included field instrumentation and lab testing in search of various factors that

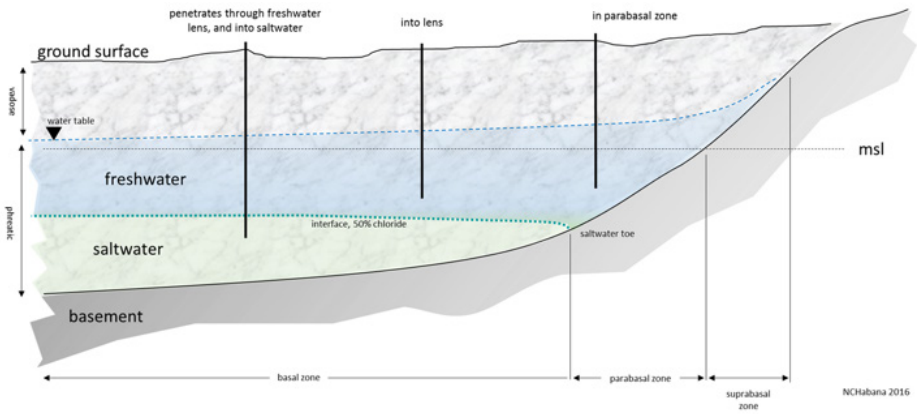




(left) Aerial photograph (from UAV) of rainfall-induced shallow slope failures in Inarajan, southern Guam. (above) Soil sampled for geotechnical, hydrologic, and shear strength properties.

triggered the shallow slope failures in southern Guam. Aerial photographs of slope failures in hard to reach mountainous terrain were obtained via UAV (Phantom 4 Pro).

Two sites are chosen for these studies. First area of study includes slopes in Inarajan watershed along route 4 and is to the North of Tinago river. Second study area Fena watershed. Rainfall induced shallow slope failures are prominent in the Inarajan watershed of southern Guam. Once the soft low-density topsoil layer supporting the grass/vegetation is lost from slope failure, it is very common that the land turns into badland. Badlands do not support new vegetation and hence the scars remain forever. Field validation and laboratory soil testing will aid in creating shallow slope failure and landslide predictions in a finite element model.



Well positions in the saturated (phreatic) zone of the Northern Guam Lens Aquifer. Deep observation wells intercept the saltwater zone, allowing sensors to collect measurements of chloride concentrations, and thus delineating the changes in thicknesses of the freshwater and saltwater layers.

Dynamic Response of the Freshwater Lens to Natural Variations in Recharge, Northern Guam Lens Aquifer, Yigo-Tumon Basin

Bekah Dougher, Dr. Nathan Habana, Dr. John Jenson, Dr. Mark Lander, Dr. Kevin Ho

Funded by GHS

MS Environmental Science Thesis

May '19

The limestone aquifer of northern Guam supplies more than 90% of the island's drinking water. 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 amount of recharge that replenishes the aquifer depends primarily on seasonal and inter-annual changes in rainfall as well as on evapotranspiration, rainfall intensity, and infiltration pathways.

Time series data were evaluated in order to determine lens response to recharge and drought. Lag time responses to variations in recharge were determined and can be used as an indicator of lens responsiveness. This project characterizes the response of the lens to natural climate variations, and documents lens and transition zone dynamics driven by both abundant recharge and extensive drought. It will provide an observational baseline against which the accuracy of past, present, and future modeling studies can be evaluated and by which future modeling studies can be reliably parameterized.



Several WERI faculty and graduate research assistants have been trained as a collaborative field team to complete drilling, borehole lithological logging, sample collection, and casing the boreholes. Pictured above is the WERI team drilling piezometer boreholes in the immediate vicinity of Santa Rita Springs catchment (concrete reservoir with corrugated tin roof).

ONGOING RESEARCH

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

Eliana Walker, Dr. John Jenson and 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.

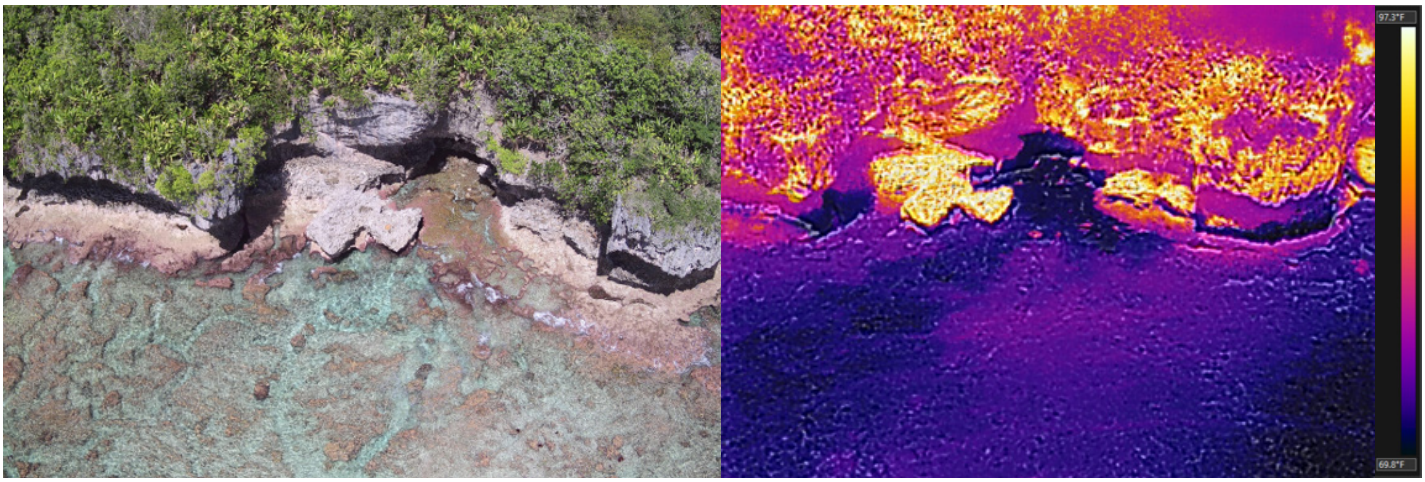
Besides proving the application of this new technology, this project will also build regional technical capacity for water resource management using UAVs and remote sensors and help local natural resource managers in Pacific islands build more detailed and useful geospatial datasets of geographic conditions 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.

Preliminary images (below) were acquired in the first week of summer field work, when tide was the lowest-low (-1 ft) and weather was optimal for operating the UAV.

Hydrogeological Control on Submarine Groundwater Flow in Ayuyu Cave

Maria Jhonnie Villareal, Dr. John Jenson and 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 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.



(left) Visual imagery from UAV of freshwater discharge site Ayuyu Cave. (right) Thermal infrared (TIR) of cave site during dry season low tide on May 8, 2019. Temperature ranged 97.3 to 68.7 degrees F. Freshwater discharge plume is dark blue shading from center of photo flowing toward the bottom left corner.

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.



Varying sizes of limestone conglomerates of the brecciated zone, near a newly discovered brackish cave pool in Ayuyu Cave. Other cave features not shown are detached cave formations in a cave passage above the cave pool. The cave will be mapped, tied to LiDAR imagery, and the Pugua Fault will be studied in its hydrogeologic contribution to the Finegayan Basin and coastal freshwater discharge.

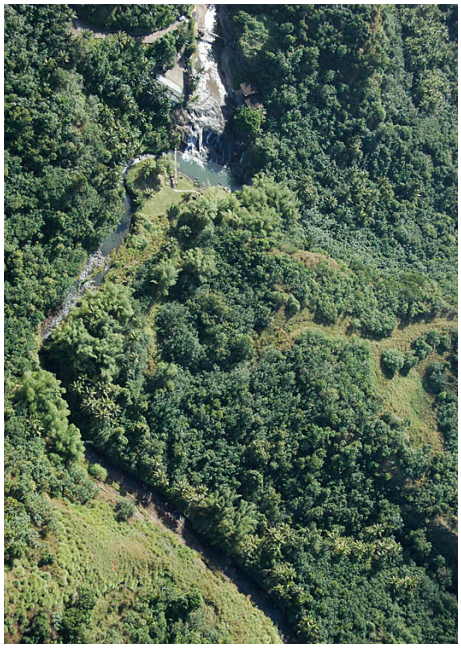
Development of a GIS Based Imagery Database of Groundwater Recharge Areas and Key Reaches of Streams on Guam

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

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.

Phase two will involve extensive testing of the WERI base station-GPS rover system to be certain that rover coordinates gathered using differential corrections from the base station match the coordinates of base maps used in WERI's GIS system. First, we will compare differentially corrected coordinates using the new base station with known locations on our GIS maps and surveyed locations on Guam. Once acceptable accuracy is established, we will fly Ground Control Point (GCP) missions at several locations around Guam. The Drone2Map software will apply the GCPs in order to develop accurately georeferenced photomosaic and digital elevation maps. These will be overlaid on our existing GIS base maps to be sure the desired accuracy is achieved.



Aerial image of Talofofo Falls and river, which discharges on the eastern side of Guam, at Talofofo Bay.

ONGOING RESEARCH

Phase-II of N-Baseline Data and Abatement Methods for the Northern Guam Lens Aquifer

Dr. Nathan Habana, Dr. Joseph Rouse, Dr. John Jenson, and Jezreelyn Bulaklak
Funded by USGS and GHS

This project responds to the critical needs expressed at the Advisory Council Meeting to conduct research on spatial and temporal trends in levels of contaminants in Guam's groundwater, as well as the need for continuous baseline studies on levels of nitrogenous compounds, etc. with respect to time and location. In addition, it addresses the need for evaluation of innovative wastewater treatment units as alternatives to conventional septic tanks for individual homes, commercial buildings, or hotels.

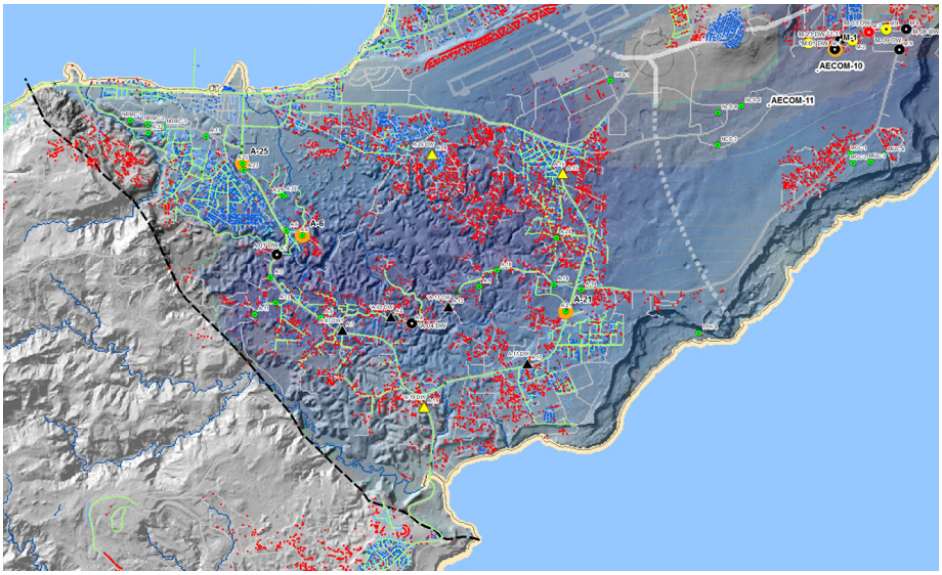
Civil and environmental engineering fieldwork will be incorporated in collecting effluent samples from package treatment plants in Northern Guam, which will be transported to the laboratory (at WERI, UOG) for water quality analyses. Computer analyses will be conducted to apply statistical analyses to the data, and trends and patterns may be overlaid onto the Northern Guam Lens Aquifer Map, a first in the series.

Three-Dimensional Finite-Element Groundwater Model of the Yigo-Tumon Basin, NGLA

Thomas Aguilo, Dr. Nathan Habana
Funded by GHS
MS Environmental Science Thesis

The Yigo-Tumon Basin is the largest, most developed, and most exploited of six basins fo the Northern Guam Lens Aquifer (NGLA). Previous models of the NGLA have been essential toward understanding and managing the aquifer. This project aims to create an updated model with modern software to further understanding of the NGLA. This model will be built using Aquaveo's Groundwater Modeling System (GMS) software and the FEMWATER mathematical model to incorporate data from production and observation wells with published values for regional hydraulic conductivity, recharge, and tidal attenuation. Aquaveo's GMS is at the forefront of groundwater modeling and allows users to build highly detailed models using common GIS objects - points, arcs, and polygons - and allowing models to be updated regularly as more information becomes available.

GMS is compatible with most groundwater numerical codes, including but not limited to MODFLOW-UGS, SEAWATER, and FEMWATER. The FEMWATER model will be used to simulate density-dependent flow and chloride transport and will be used to examine saltwater-freshwater dynamics and salinity intrusion. This model will be highly beneficial as a guide for future research endeavors and for improved water resource management and policy-making amid major island growth and expansion expected within the next 10 years. Furthermore, the Yigo-Tumon Basin is an appropriate pilot for the development of a model of the entire NGLA using this software.



NGLA water wells (light green circles with central black dot) and wastewater locations (red and blue clusters) at the proximity of the Pago-Adelup fault (black dashed line), which physiologically divides Guam to the northern limestone plateau and southern volcanic rise.

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

Dr. Yong Sang Kim, Dr. Gary Denton, and Mallary Duenas
Funded by NIEHS and USGS
MS Environmental Science Thesis

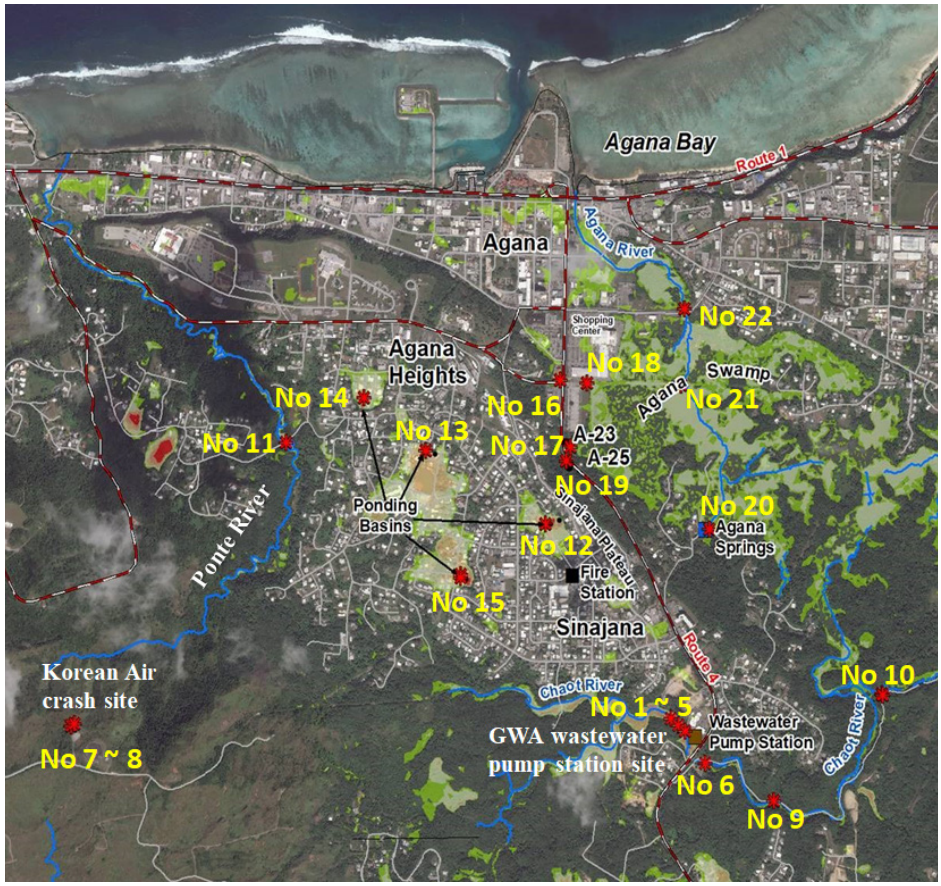
Perfluoroalkyl substances (PFAS) have recently received attention as emerging contaminants in drinking water. Recent UCMR3 results reveal three Guam Waterworks Authority production wells to be contaminated with perfluorooctanesulfonic acid (PFOS). One of these wells (NAS-1) is located inside of the former 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.

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.



Polyethylene tubes were deployed to collect water samples in rivers and ponding basins found with PFAS contamination. The passive samplers accumulate organic compounds by diffusion in both aqueous and atmospheric conditions.



22 water and soil sample sites were previously visited to investigate PFOS and PFAS source contamination.

PFOS Trend Monitoring in Saipan Production Wells

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

The third unregulated contaminant monitoring rule (UCMR3) test result revealed that drinking water contamination by PFAS in Saipan is more prevalent than in the US. The Commonwealth Utilities Corporation (CUC), a public 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 the 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). The Airport Rescue Firefighting Facility (ARFF) at the SIA is suspected as a major PFOS contamination area and a main source for groundwater contamination.

In June 2016, the CUC stopped using well IF-208 due to its high concentration of PFOS. the CUC has also bi-annually monitored PFOS in wells adjacent to well IF-208, and found varied concentrations: wells that had high PFOS in 2016 now have lower concentrations while wells with less than 40 ng/L PFOS have above 70 ng/L. There are several reasonable reasons: 1) PFOS has also affected other wells and reservoirs, but had not been detected from two sampling attempts under UCMR3 due to effects of rainfall and tide, which influence volume and flow of groundwater, and/or 2) groundwater pumping from wells changes in groundwater flower and PFOS concentration.

To understand the PFOS migration pattern in this area, 1) the PFOs contaminated site, ARFF, must be investigated, 2) regular PFOS monitoring from wells and reservoirs adjacent to the well IF-208 should be conducted, and 3) seasonal variation of PFOS concentration and its relationship between rainfall events should be analyzed. This research will help to identify PFOS migration pattern in groundwater and establish a proper remediation plan.

ONGOING RESEARCH

Improvements to Sewage Treatment on Yap: Hydroponics and Composting of Waste Sludge

Dr. Joseph Rouse, Dr. Hyun-Jong Hahm, Dr. Chris Yeo and Ken Rekdahl
Funded by USGS

In Yap, FSM, pilot testing was conducted at the municipal sewage treatment plant to assess the implementation of low-cost upgrades to enhance treatment. Incorporation of a bio-carrier medium was demonstrated to be helpful, but this is of limited value due to the relatively small amount of biofilm attached. Composting of the excess sludge, though, has progressed from pilot testing to a full-scale facility. Preliminary results have demonstrated that a Class-A compost suitable for public use is achievable, but more training is required to assure ongoing success. Progress on this project has been reported at four conferences, three of which were international, in addition to various Advisory Council Meetings in the western Pacific.

To further enhance sewage treatment, a hydroponics process is being considered. A local lily plant (*Eichornia crassipers*) has been shown to be compatible with the raw sewage and has already propagated in the treatment zone of the STP. Results of preliminary testing in the wet and dry seasons (below) indicate that the conditions are favorable for the lily plant, which is known to be sensitive to high salt concentrations. For comparison with this field data, the conductivity of seawater is 50,000 µS/cm and that of potable tap water would normally be less than 500 µS/cm.

It is interesting to note that the conductivity levels are much lower in the wet season because the saltwater content in the sewage is diluted by intrusion of rainwater into the collection lines. In the next phase of this project, further testing to quantify removals of organic and nitrogenous contaminants will be required to assess the use of the lily plants in conjunction with the existing biofilm process. In addition, sludge and compost materials will be tested for metals (e.g.: Cd, Hg, Pb, etc.) to address public safety concerns.

Further testing will be required to determine the benefit for removal or organic contaminants. Parallel to this, ongoing improvements to composting will be pursued by providing guidance for proper methods of hands-on technical operation and of effective managerial practices. Further venues for communicating the project's overall benefits to the people and natural environment of Yap will also be developed.



Propagation of local lily plant (*Eichornia crassipers*) at a sewage treatment plant in Yap, FSM.

Hydrological Features and Analysis in the Finegayan Area

Dr. Yuming Wen, Dr. John Jenson, and Dr. Nathan Habana
Funded by USGS

Guam Waterworks Authority (GWA), the custodian of Guam's public water supply, is responsible for ensuring it meets all appropriate standards as mandated under the Safe Drinking Water Act and Clean Water Act. 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 amassed 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 only when in fact they could and should be used to identify subtle changes in contaminant abundances and distributions within the aquifer or changes for a long term basis.

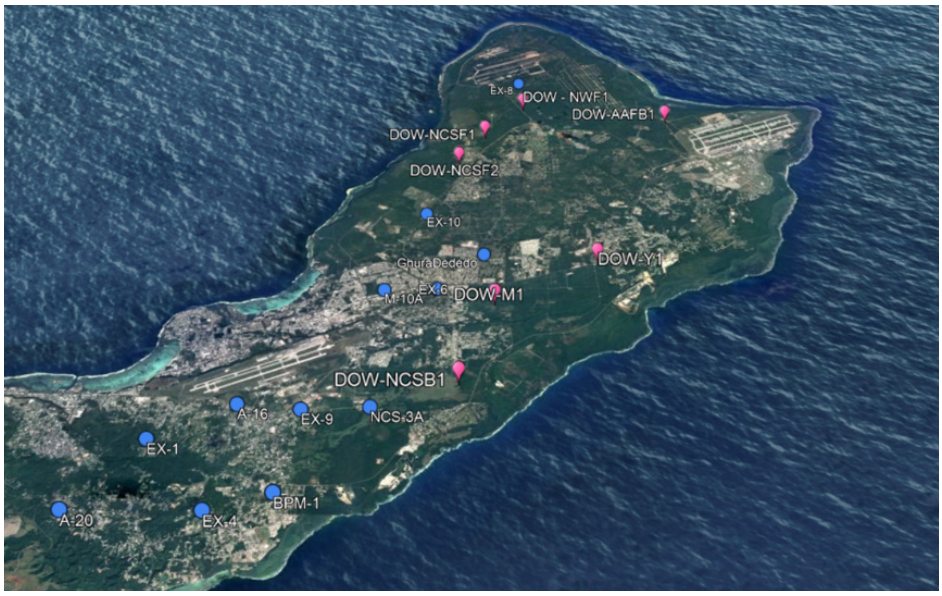
Since around 5000 marines will be relocated to Guam, particularly the Finegayan Area in the next few years, it's very important to evaluate whether relocation fo the marines and their dependents and related activities will affect the quantity and quality of the water resources, especially groundwater resources. Based on this concern, the project will focus on inventory of hydrological features and hydrological analysis in the Finegayan Area. The hydrological features in the Finegayan Area will be collected, processed and organized into a geospatial database so that the data can be utilized for further analyses and applications in the future. Hydrological features will be evaluation on whether they will have imposed impacts on water quantity and quality of groundwater resources in the Finegayan Area.

Water Use Data and Research in Guam

Dr. Yong Sang Kim
Funded by USGS

Ninety percent of Guam's 40 MGD of municipal water is produced from about 120 wells in its Northern Guam Lens Aquifer (NGLA)–the limestone bedrock aquifer beneath the uplifted plateau that covers the northern half of the island's 214 sq. mile surface and contains all its urban centers, including the tourist districts. Current production is estimated to be 14 to 17% of recharge but is constrained by increasing risks of drawing saltwater into the freshwater lens if new wells are set too close or too deep, pumped too hard, or placed in new locations that are vulnerable to saltwater contamination. Understanding the hydrogeological factors that determine where wells can best be placed; how they should be designed, built, and managed; and how water can be economically distributed from sources to customers is essential for effective water resources development. Stormwater and wastewater management also present increasing challenges for aquifer and coastal zone protection as urbanization continues and population grows.

On the volcanic upland of southern Guam, the US Navy's Facilities Engineering Command (NAVFAC) can produce up to 9 MGD of treated water from a surface reservoir. NAVFAC sells up to 3 MGD to the Guam Waterworks Authority to service the adjacent villages, except when the surplus is eliminated by drought. The reservoir is vulnerable to sedimentation from landslides in the watershed triggered by typhoons. Sediments and sewage releases carried by surface streams can threaten the health of reefs along the southern coast. Understanding how land use and other factors affect the quality and quantity of surface water resources in the south is thus also an essential component of water resources research, information transfer, and education programs on Guam. This project will analyze current water use data for Guam and compare it with baseline standard of USGS Water Use and Data Research (WUDR) and formulate a workable management plan whereby water use data can be readily comparable with other water use data from the United States.



Locations of observation wells scheduled to be rehabilitated (blue) and deep observation wells to be drilled (pink).

Northern Guam Lens Aquifer Monitoring System Expansion Rehabilitation Program

Dr. John Jenson, Dr. Nathan Habana, and 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.

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.

Digital Atlas of Yap – A Geospatial Map and Data Server for Resource Management

Dr. John Jenson, Danko Taborosi
Funded by USGS

The island of Yap is the westernmost high island in the Federated States of Micronesia (FSM) and the capital of Yap State, one of FSM's four federal units. In addition, Yap 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. Yap has a great need for a unified, comprehensive, and user-friendly information management system for geospatial data.

We propose to create a web-based digital repository and dissemination system for GIS and other geospatial data related to Yap. 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 Yap. Based on experiences from Guam and Pohnpei and results of comparable projects there, we plan to call the product proposed here the "Digital Atlas of Yap." 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", which was developed by iREi and WERI in 2016-17 and is scheduled to go on-line on February 28, 2017. Selected screenshots from the Digital Atlas of Pohnpei are included with this application. The Digital Atlas of Yap will be web-based, permanently on-line, and act both as a repository of relevant GIS data and geospatial resources in other formats, as well as a digital point-of-contact and information-sharing hub for anyone involved in resource management, engineering, research, and decision-making in Yap. The data will be cataloged, indexed, and maintained so that they are easily amendable and upgradeable. Whenever interested individuals and agencies access it, they will be accessing the most up-to-date versions. The system will also keep track of metadata, data sources, data ownership, data confidentiality, and any access restrictions that may be imposed on certain datasets by individual parties.

Finally, the data will be revised to fit a common projection, and also made available in non-GIS file formats usable by individuals who have no GIS experience or software, but do have needs and responsibilities in areas where geospatial data and analyses are beneficial. This will include a range of pre-designed maps, georeferenced image overlays, geo-PDFs, and KML files for use in Google Earth. This will ensure that the Atlas is not just a GIS-data hub, but truly the information gateway for nearly any activity with geospatial component.

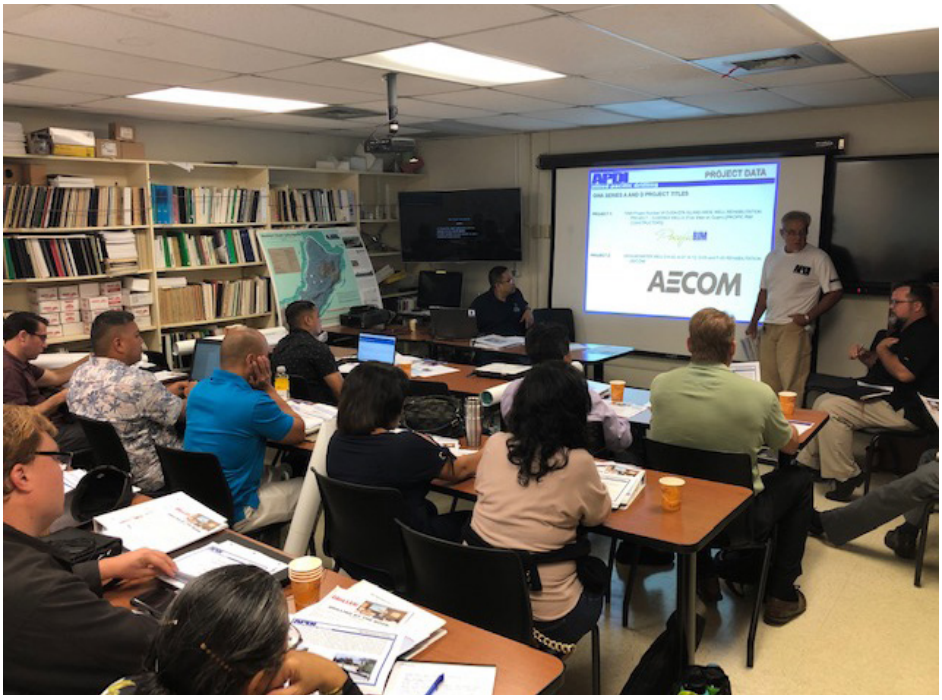


The atlas of Yap will be house on the Digital Atlas of Micronesia site upon completion.

Professional Workshop Series on Guam Groundwater Sources

Dr. Yong Sang Kim, Dr. Nathan Habana
Funded by USGS and GHS

The anticipated addition of new US Marine Corps facilities on Guam and the accompanying additional economic growth on the island will increase demand for drinking water as much as 10% beyond current production. To achieve and maintain sustainable management of the aquifer, it is essential that policy-makers, agency heads, water resource professionals, and island 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, however, have



WERI Professional Workshop Series featured short presentations and cross-talk forums between local water management agencies, private environmental firms, and WERI faculty and staff.

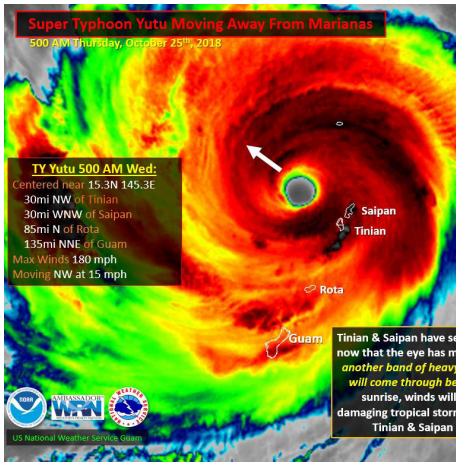
extremely limited time to engage in instructional opportunities. WERI will develop and deliver a series of short-course workshops and aquifer tour to local water resource professionals and educators. First, a two-day intensive workshop in 1) the Northern Guam Lens Aquifer Database and development and use of basement map of northern Guam: and 2) sinkholes and surface drainage of the aquifer, and salinity trends, patterns, and processes in the aquifer, and 3) production well rehabilitation in Guam and 4) an introductory workshop in basic GIS. The Aquifer field tour will involve a one-day intensive field trip to the Northern Guam Lens Aquifer, which will include a 3-D virtual tour of the aquifer. These workshop and field tour will be prepared for student researchers, faculty, policy makers and professionals working on groundwater and related problems. Instructional and media organization will be supported by Moodle websites 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 will accommodate the course resources such as the NGLA resources such as the NGLA database that will be useful for island water developers and managers.

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

Dr. Mark Lander
Funded by USGS

Rainfall and other climate data are required for studies of water quantity and water quality (WQ2) in our region. With the obvious importance of rainfall data, other climatic data with possible influence on WQ2 include (but not limited to): the typhoon distribution; local and regional sea level; the MAX and MIN temperature, and the effects of wind and amount of sunshine. A common request by local water resource managers (and outside environmental consulting businesses) involves acquiring storm data to assess return-period calculations for storm drain projects, stream-flow estimates, reservoir management, etc. Acquiring climate data for such projects is hampered by the multiplicity of sources, incomplete or missing data in official records, short periods of record, and an absence of metadata on recording sites.

This project will provide all local water resources managers, regulators, researchers and the public with:
1) a comprehensive collection of meteorological and hydrological data for Guam, Saipan, Tinian, and Rota;
2) a one-stop web site for accessing climatic and hydrologic data;
3) a presentation of derived products, such as recurrence intervals for storm-related parameters and high-quality graphics of data time series and derived products;
4) bounds and hard numbers describing rainfall distribution and impacts to be used as scenarios for modeling studies of island watersheds, groundwater and other sources of potable water;
5) a packaged seminar/outreach module (with study guides, a WERI technical report, and a PowerPoint presentation) dedicated to addressing the community need for reliable climatic and hydrologic data.



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.

EDUCATION and OUTREACH

Sand Filtration Training in Yap

Dr. Joseph Rouse, Charles Falmeyog, and Ken Rekdahl
Funded by USGS

Potable water quality is a serious issue for all utility agencies throughout the Western Pacific. The development of the modern water treatment systems and distribution networks for some of the more populated islands in this area started in 1970s. The slow, sand filtration plant used on the main island in Yap State is such on system, for which maintenance of a well-trained operational staff is an on-going challenge. Furthermore, recent turnovers in staff have heightened their concern that training is urgently needed.

This training is designed for 15 participants, and will have two parts. During class work, students will learn about the principal for water treatment including the equipment and accessories involved. Field training will include hands-on use with equipment as well as following a regimented reporting. The sessions were designed for operation and maintenance personnel working at the Yap State Public Services Corporation (YSPSC). The benefit will be assured quality of potable water and better management of one of Yap Island's most valuable resources, its water. Since the water systems in the other states are similar to the one in Yap, this training would also be meaningful to employees from the other states.



Wastewater treatment in Yap.



WERI's 2019 Guam Advisory Council Meeting, held at the Dusit Thani hotel.

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 convenes each council annually for a day-long 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 and submits 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.

Virtual Tour and Professional Field Trip of the Northern Guam Lens Aquifer

Dr. John Jenson, Dr. Nathan Habana, and Dr. Yong Sang Kim
Funded by USGS and GHS

WERI Information Transfer projects include a one-day tour of Guam's principal aquifer with offerings tailored variously for policy-makers, agency heads, water resources engineers and other professionals, school teachers, and students from high-school through graduate level. The physical tour is preceded by a big-screen, GIS-based 3-D graphical virtual tour of the aquifer. The *Virtual Tour of the NGLA* is a computer graphics 3-D hydrology of Guam that allows the audience to understand hard-to-visualize concepts and features not accessible on the physical tour (*Professional Tour of the NGLA*), and virtually fly through the subterranean boundaries between fresh water, salt water, limestone bedrock, and volcanic basement rock.

Relationships to the aquifer's actual water production wells, urban areas, roadways, sewer lines, and septic tanks are also highlighted. Developed originally to support the physical tour, the virtual tour is also now presented for classroom instruction and at workshops and public presentations independent of the physical tour. Plans are in place to make it available as an interactive web-based educational resource and to develop a version for younger audiences.



Executive members of federal and local agencies explore the varying porosity features (matrix, fractures, and faults) in the core of the NGLA (Barrigada Limestone) at the Department of Public Works Quarry.

Guam Water Kids

Arretta Ann Card, Kaylyn Bautista, and Dr. John Jenson
Funded by Ford Motor Company, USGS and RCUOG

The Guam Water Kids Program provide classroom and online resources for K-12 teachers and students for instruction on the origin and sustainable management of fresh water resources of Guam and the Northern Mariana Islands. Topics include: *Why Fresh Water is Important*, *Where Guam's Fresh Water Comes From*, *The Water Cycle*, and *What Kids Can Do*. Joint funding from the US Geologic Survey and Ford Motor Company's Global Giving Grant covered the development of educational materials; instructional workshops for teachers; presentations at public, private, and military schools; and interactive websites at: http://www.guamwaterkids.com.



High school students facilitated a hands-on aquifer contamination demonstration to 5th graders.



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/).

Guam Water Kids has provided three Educator workshops and three Professional Tours of the NGLA catered to science teachers and other interested educators; provided orientation and mentoring for high school level educators and students to learn about freshwater and to have an organized experience in sharing this information with younger students; and provided community materials at outreach events.

UNIVERSITY OF GUAM PROGRAMS

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.

UNIVERSITY OF GUAM
UNIBETSEDÅT GUÅHAN



Northwest coastline field work with thermal infrared.



Composting for sewage treatment plant in Yap.



WERI ranked in the top 12 Outstanding water resource research institutes by the USGS for the 2011 to 2015 evaluation period.



Measuring slope failures along volcanic ridges.



Surveying passageways in a coastal cave.

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 its 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. A commensurate award may thus 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. 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.

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.

CONTRIBUTIONS

The University of Guam Endowment Foundation
303 University Drive, Mangilao, GU 96913
Ph : +1-671-735-2956/7
SUPPORTUOG.ORG