

Guam Hydrologic Survey and Comprehensive Water Monitoring Program

**FY 2023
Annual Report**

WERI

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

October 2023

Intentional Page

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

**FY 2023
Annual Report**

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Water & Environmental Research Institute
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Guam Public Laws 24-247 and 24-161

The Guam Hydrologic Survey (GHS) and the Comprehensive Water Monitoring Program (CWMP) were created in 1998 by the 24th Guam Legislature's enactment of 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 integral to the WERI water resources research, information dissemination, education, and training mission.

The foresight of the Guam Legislature in creating these two vital programs deserves special mention. Through their efforts and continued support, WERI advances in consolidating and interpreting several essential water resource information, constructing databases for Guam, and revitalizing the USGS water resource monitoring program. Our understanding of the complex physical, chemical, and biological processes that influence Guam's water resources has broadened, and the increase in graduate student research opportunities provided by the programs contributed to the number of highly trained water resource professionals in the island's workforce.

Guam Hydrologic Survey Program (GHS)

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. In addition, GHS also funds research assistants and associates who engage in CWMP activities, including fieldwork with USGS' observation well data collection, and phreatic groundwater and hydrologic data analyses.

For nearly 25 years, WERI has continued to operate and administer the GHS Program. The GHS and CWMP Annual Reports are now available online on the GHS website:

<https://guamhydrologicsurvey.uog.edu>

WERI serves numerous island agency partners through the GHS Program, attending legislative hearings, providing research findings, sharing hydrologic and geologic maps, and advising on water resource concerns. Through the GHS Program, reliable research-based information can be achieved. Therefore, the Guam Legislature, Guam Environmental Protection Agency (GEPA), Guam Waterworks Authority (GWA), NAVFAC Marianas, and the Groundwater Resources Development Group are more confident in determining management plans, actions, and regulations involving our water resources. WERI shared water research findings in the last five years and advised agencies on wastewater issues, aquifer capacity, hydrogeologic assessments, surface hydrology, and saltwater intrusion.

In addition, WERI provided GHS outreach to the Northern Guam Soil and Water Conservation District, GWA, the Legislature, Guam DOE, visiting universities, and the private sector with WERI's Virtual Tour into the Northern Guam Lens Aquifer. With the social distancing restrictions lifted and a new geologist on board, the GHS Program will resume the Northern Guam Lens Aquifer Site Tour in the next dry season.

Furthermore, WERI expands GHS interagency support through its online web products. Since developing the GHS website in 2016, WERI continues to manage and produce new hydrologic reports, presentations, maps, and databases. Most recently, WERI developed modern online data visualization tools—a new means of sharing hydrologic data through interactive maps and graphs, such as WERI Web MApps and MAppFx, which are discussed further in the information management section.

Comprehensive Water Monitoring Program (CWMP)

The CWMP is the core of essential water information, achieved through consistent measurements and analysis methods, with its collected data as the basis of reliable analysis. The CWMP was created to gather data on saltwater intrusion and water lens thickness in Guam's sole source aquifer in the northern part of the island. Stream flow data and other parameters associated with surface waters are collected in the south. Moreover, the program collects rainfall data for hydrologic, meteorologic, and climatologic studies. These are essential for determining sustainability assessments and water supply capacities.

The CWMP rehabilitated data collection assets that fell into disrepair. This allowed WERI-USGS to collect, organize, and manage hydrologic data from stream gages, rain gages, and observation wells. The CWMP appropriations from the Guam Legislature restored the Federal/State Territory cost-sharing program for water resource monitoring and reinvigorated the collaborative work between WERI and USGS.

With over 100 years of experience, USGS procedures ensure that data are reliably collected, analyzed, and widely available. Most data from USGS gages are readily accessible on the internet. As part of CWMP between WERI and the USGS, historical data and other hydrologic information for Guam are consolidated and made publicly available at:

<http://hi.water.usgs.gov>.

Government of Guam and USGS funds the CWMP. Additionally, the CWMP is funded through GHS, which employs research assistants and research associates to organize, analyze, and interpret CWMP field data. In that sense, CWMP is also an essential GHS project that processes and analyzes the collected data and conducts field investigations.

Organization and Operations

GHS and CWMP are organized by a program management team that involves the WERI Director and a support panel of WERI Faculty subject experts, the Program Coordinator, the Operations Manager, and the Program Advisor. The WERI GHS and CWMP Program continues to improve and may also change the internal organizational structure yearly to streamline operations

for internal use | WERI 2023



management, processes, and product output. The organization is also crucial for determining the program's resource requirements, project focus, and annual budget. The figure above is an internal WERI GHS and CWMP personnel and process diagram.

GHS analyzes water resource data for investigative research and the production of reports. WERI Faculty proposes GHS projects annually and selects a research assistant to conduct a GHS-related project. This opens opportunities for a research assistant to do a master's thesis through UOG's Environmental Science Program. GHS also has an Information Management team that oversees and develops both the WERI and GHS websites. The Operations Manager collects project summaries from faculty projects, CWMP projects and activities, and Information Management, and manages the organization and drafting of the GHS and CWMP Annual Reports.

Introduction

In this annual report, the Guam Hydrologic Survey (GHS) projects are organized by Information Management Projects and Guam Hydrologic Survey Research. The GHS Information Management projects are web development products of reports and data visualization, made available for use with interagency partners and anyone interested in Guam hydrologic information. The GHS research section is a collection of Guam water resources and hydrologic research projects. Completed research projects are published as technical report products. The results of technical reports may later be selected for a data visualization product. In both cases, a technical report is due and is made available as a downloadable PDF file on the GHS website. The Comprehensive Water Monitoring Program (CWMP) research section provides a summary report on activities related to well development, hydrogeologic field investigations, hydrologic data collection, data analysis reports, plans for exploration, and data preparation for online data visualization products. The last section is an overview and update on the agreement status of the One-Guam Water Resources Information Program (OGWRIP).

GHS Information Management

D.K.U. Valerio and N.C. Habana

The Guam Hydrologic Survey Information Management (GHS IM) develops the GHS website, which is the worldwide interface for accessing Guam's available hydrologic information. The secure GHS website address is:

<https://guamhydrologicsurvey.uog.edu/>

The website is part of the UOG web domain, and the UOG Web Team, Office of Information Technology, manages content and server security.

This section of the GHS Program addresses an accountable task in public law: disseminating Guam's pertinent hydrologic information. The GHS website is a modern and effective means of connecting with and delivering to clients. Additionally, the university's mission, the Good to Great (G2G) initiative in 2016, pursued the collection, organization, and transfer of "Big Data" through fast internet and service to interagency partners. Fortunately, WERI operations management was in position at this time and developed its intranet website, which was made available on the internet in a commercial (dot com) domain. In 2018, the GHS website was moved to an appropriate education domain (*.uog.edu) under UOG.

Today, WERI leads the island as the center for sharing and providing access to hydrologic information for local interagency partners and anyone's interest worldwide. The effectiveness can be measured from the responses and requests from interagency partners referring to the website content and calls for assistance with website use, navigation, and search. This website superiorly improved program management and reduced the need for printing. The GHS IM is operated by three personnel who manage, organize, design, develop, and code the website's interface and its developer platform (WordPress®), FTP. In 2023 and 2024, GHS Program online services will be expanded to include the One-Guam Water Resources Information Management

Program, wherein OGWRIP's pyramid structure pinnacle is information management and transfer. Fortunately, the GHS IM is ready for OGWRIP. In 2022 and 2023, GHS IM significantly improved website content with its new collection of online data visualization applications, such as WERI Web MApps and MAppFx, discussed in the following section.

GHS Website Content and Navigation

The GHS website stems from a modern version of the classic webpage design, including a traditional main menu bar of SOTA (State of the Aquifer) Reports, REO (Research Education and Outreach) Agendas, Sustainable Management, Groundwater | Hydrogeology, Hydrology, Climate | Weather, Wastewater | Toxicology, Library, and About GHS (see following figure). Each menu item has a dropdown list. A photo slider of essential content links on the home page is below the menu bar, followed by information on upcoming events, the latest news, sustainable management, annual reports, interagency partners, charters and agreements, and GHS and CWMP mission statements and goals. White papers and program reports are found in the REO Agendas and Sustainable Management tabs, respectively. The REO tab contains years of WERI white papers about REO. The Sustainable Management tab contains the Annual Reports, and unit organization and management of its operations. The following four tabs refer to components of the hydrologic cycle, beginning with groundwater and hydrogeology. Soon, a geology section will be a menu item. Each of these hydrological menus contains pertinent, recent, and significant published WERI research work based on technical reports, publications, maps, data visualization products, and databases. The GHS website is often presented at the Guam Advisory Council Meetings.



Guam Hydrologic Survey website homepage

In 2022, WERI's Water Resources Forum highlighted the upgraded website and navigated the site's features for several local interagency partners, including USGS-PIWSC, NWS-NOAA, and Brigham Young University. The forum also unveiled and demonstrated the use of WERI's new online data visualization products, which will be further discussed in the next section.

New Online Data Visualization Products

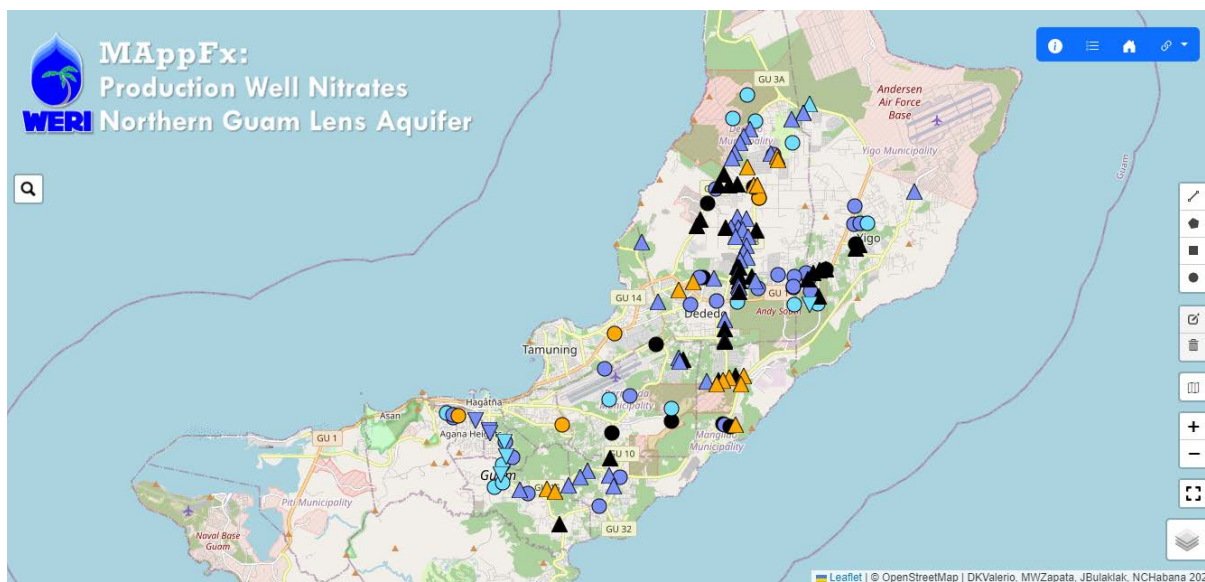
Data visualization is the current means for easy access to data that utilizes online interactive map and graph JavaScript libraries and JSON (JavaScript Object Notation) data forms. In collaboration with Brigham Young University (BYU), GHS IMs and researchers went to BYU's Engineering Department to receive training for developing data visualization products. Another data visualization product is from ESRI's ArcGIS Online to create interactive maps. The GHS program brought onto the GHS website two useful data visualization products: MAppFx and Web MApps. MAppFx is an online data visualization app with interactive maps and graphs, and Web MApps are interactive maps. The following are completed data visualization products with technical reports.

MAppFx: Production well nitrates Northern Guam Lens Aquifer

Valerio, D.K.U., Zapata, M.W., and Habana, N.C.

[Technical Report 180](#) | [Online Summary Report](#) | [MAppFx](#)

Numerous water resource researchers and agencies have long waited for an interactive database map that is straightforward for anyone to access, especially for deciding water source protection and production management. Interactive web maps and graphs are the modern means for access to online interactive hydrologic databases. This is possible through JavaScript and JS Libraries, which are available for developing interactive web applications. In this intent, an interactive online application, MAppFx, exhibits a map point and graph display feature (see figure below).



MAppFx: Production Well Nitrates Northern Guam Lens Aquifer

Recent research products of Guam production well nitrate trends and analysis were the selected datasets for developing this new interactive feature that expands the interagency web map products on the GHS website. The online summary report is in the dropdown list of the Wastewater|Toxicology tab of the GHS website. The product is an online map of Guam production wells as point trend symbols with well names that, upon selection, display a time graph of nitrate concentrations in a panel or over the map option.

The goal was to build MAppFx, an interactive map and graph web page interface. The map features production well nitrate concentrations sampled from Guam's deep aquifer production wells. The trends were based on an update and expanded statistical analysis to [McDonald 2002](#). The nitrate study produced a WERI [Scientific Advisory Report](#) and was published in the Guam Daily Post. It was documented to provide information for a legislative concern on wastewater discharge from septic systems or leaking/overflowing sewer lines into the aquifer. This map and graph product aims to share the information with agency partners, and anyone worldwide interested in obtaining the information in an easy-to-use and accessible platform. This information is most useful for on-demand records reference and research. MAppFx may also be used to replace extensive data in appendices in technical reports.

This data visualization product is the first of the MAppFx series, producing Technical Report 180 (link above). This product was first presented in the WERI Water Resources Forum 2022, followed by the UWCOWR/NIWR Conference (2023) in Colorado, the Northern Guam Soil and Water Conservation District (NGSWCD) Educator's Symposium (2023, [WERI News](#)), and most recently for Saipan's Bureau of Environmental and Coastal Quality (BECQ) and Commonwealth Utilities Corporation (CUC). BECQ and CUC expressed great interest and addressed production well security concerns. Furthermore, a MAppFx sample for CNMI nitrate data will be showcased in the next CNMI Advisory Council Meeting in November. This success may expand support for other islands in the Western Pacific. In December, WERI will showcase our MAppFx products at the National Groundwater Association's annual event, Groundwater Week, in Las Vegas.

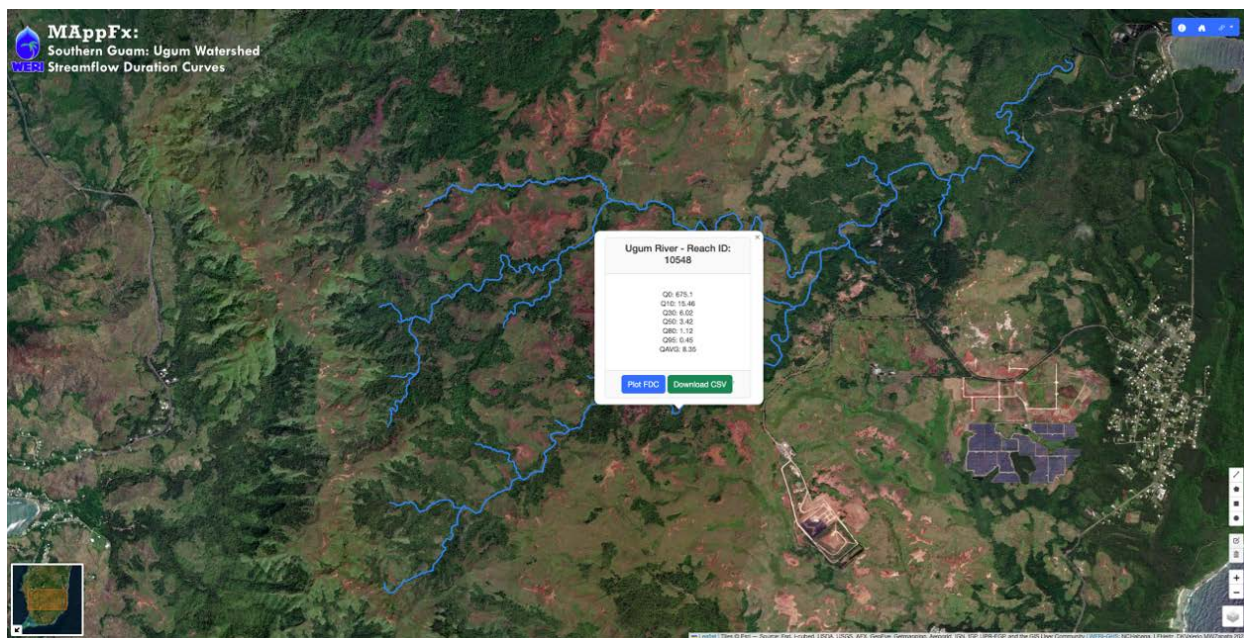
The success of MAppFx will pursue other interactive maps and time graph products of Guam's water resources, such as the observation well dynamics, chloride and production, rainfall hydrology, and other field surveys. The following product in line is the time series of chloride and production, and up for proposal for the next fiscal year is a geologic photo gallery and time series of Deep Observation Wells.

MAppFx: Southern Guam, Ugum Flow Duration Curves

N.C. Habana, L.F. Heitz, and D.K.U. Valerio

[Technical Report 181](#) | [Online Summary Report](#) | [MAppFx](#)

Guam hydrologic information of streamflow duration curves is the second WERI online data visualization interface and a MAppFx product. The online summary report is under the Hydrology tab on the GHS website. The streamflow duration curves of the Ugum River in the Ugum Watershed, Southern Guam, are the first phase of streamflow duration curves available online. The flow duration curves are based on WERI analysis research (



MAppFx: Southern Guam, Ugum Watershed Flow Duration Curves

Heitz and Khosrowpanah 2015). MAppFx is an intuitive data visualization interface that features a map of the Ugum River as a polyline of segments that, upon selection, opens the section of the river's flow duration curve (graph). This means of information transfer makes quick hydrologic reference of a select site along the river. The next phase updates the map to include all the flow duration curve segments from every mapped stream/river in Southern Guam.

While online data visualization is gaining popularity in the earth sciences, outreach is critical to ensure interagency partners and researchers have access, familiarization, and utility training for complete product success. WERI has already introduced an early development introduction of this product during a WERI Guam Hydrologic Forum in November 2022, which received feedback of amazement and gratitude. Other upcoming WERI-hosted venues will bring this product on stage to gain popularity and familiarization as a valuable data source for determining the feasibility of watershed development.

Web MApps: Surface Hydrology of the Northern Guam Lens Aquifer

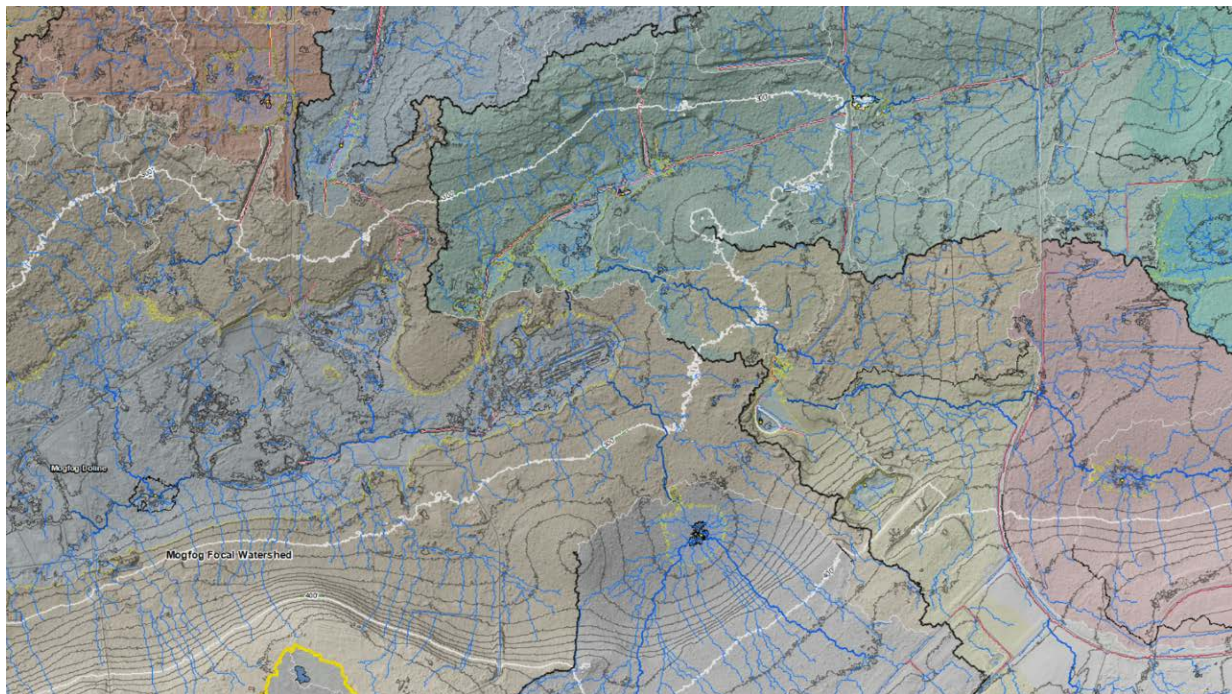
N.C. Habana, L.F. Heitz, and D.K.U. Valerio

Technical Report 175 | Hydrologic Web MApp

The mapping of the surface hydrology of the Northern Guam Lens Aquifer (NGLA) is integral to our efforts to protect our most valuable freshwater source. The NGLA is an uplifted island karst aquifer that exhibits a plateau of well-developed stormwater transfer and infiltration systems that effectively recharge the freshwater lens. However, as the island continues to develop above the sole source aquifer, there is an increased risk of loading stormwater runoff containing contaminants from anthropogenic activities that may transfer, accumulate, and infiltrate surface depressions of hydrologically significant sinkholes, transporting undesirable substances to the

water source. The risks could become greater if we are not careful and strategic with planning and development, and if we are not informed with a good set of surface hydrologic maps of the NGLA that can assist with strategic design. Furthermore, it is at the surface where we may only have the chance to do so. With an online map application such as WERI Hydrologic Web MApps, Guam Environmental Protection Agency, Guam Waterworks Authority, and developers can work towards determining strategic storm drain systems, mitigation, management, and protection of our precious sole source.

The surface hydrology maps of the NGLA are GIS hydrologic spatial analyses of Guam's 2012 LiDAR (bare-earth) based DEM, producing the highest precision hydrologic maps available to date. These computational processes produced features and imagery value rasters that are organized and made available for having useful hydrologic map references for our interagency partners (GEPA, GWA, and contractors) who have a stake in developing the aquifer. The hydrologic map products are advanced and go beyond identifying suspect sinkholes from closed contour depressions. The maps from this project are a comprehensive hydrologic analysis of the plateau basin. A plateau basin was discovered on the NGLA as a large stormwater catchment area containing tributary watersheds that may overflow and runoff stormwater. It cascades into its focal watershed, the lowest surface area in a plateau basin. The focal watershed is often a deep doline with the lowest ground surface point in a plateau basin. It receives terminal overflow runoff from tributary watersheds that infiltrate the surface through a fast flow route to the water source. To protect the water source, it is essential to map the surface hydrology, and identify storm catchment areas and runoff that may transfer potential anthropogenic contaminants to dolines, fast recharge areas. Sixty plateau basins were named based on several [historic maps of Guam](#) by the [Kumisión I Na'an Lugåt Guahan](#) (Guam Place Name Commission).



WERI Web MApp: Surface Hydrology of the NGLA, Phase II

The hydrologic map products were converted into an online map application, such as WERI Hydrologic Web MApps. The hydrologic Web MApp products are available on the GHS website in the Interagency Maps section under the Library tab.

A follow-up of *Web MApps: Surface Hydrology of the NGLA, Phase II*, technical report and Web MApp update is underway. The surface analysis of internal hydrologic features within fill areas or closed topographic surface depressions is completed. This phase II update develops the most comprehensive surface hydrologic map (see following figure). In addition, for 2024, the same GIS hydrologic analyses will be applied to produce the Surface Hydrology of Southern Guam, using the latest (2020) Guam, LiDAR-based DEM.

Other available WERI Web MApp products

N.C. Habana and D.K.U. Valerio

Interagency Maps

Web MApps have been a “game changer” for the GHS Program and interagency hydrologic map information requests, discussion points, and navigation. The online map application provides a set of layers and an intuitive map interface, reducing the need to learn the desktop application, meaning everyone can use the maps.



Water and Environmental Research Institute of the Western Pacific (WERI)

WERI research product maps are research-based and developed maps.



Surface Hydrology (LiDAR Imagery)

[VIEW MAP »](#)



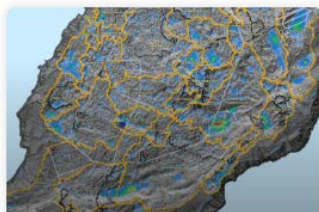
Production Salinity

[VIEW MAP »](#)



Northern Guam Terrain

[VIEW MAP »](#)



Surface Hydrology

[VIEW MAP »](#)



Nitrate-N and Sources

[VIEW MAP »](#)



NGLA Map

[VIEW MAP »](#)

More WERI Web MApps, GHS Online

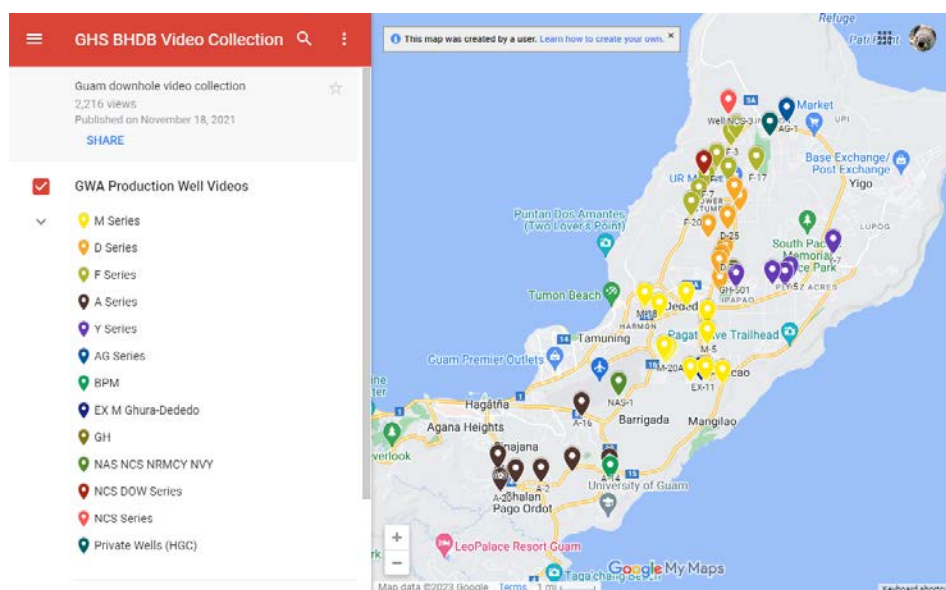
It has now developed to be organized as a collection of Web MApp products on the GHS Interagency Maps web page under the Library tab. The page is a growing platform with maps from WERI, Kumisión I Fino' CHAMORU, FEMA, and the Bureau of Statistics and Plans. The GHS IM team plans to expand the agency collection of Web MApps, including maps from GWA, GEPA, USGS, and GDLM. The WERI collection was borne of recent research work and continuing map production, such as the Northern Guam Lens Aquifer Map, surface hydrology and terrain analysis, and the map layer loaded nitrate-N and sources—the first WERI Web MApp. While mapping can be a security concern for some agencies, GHS IM coordinates with agency map sources and stakeholders to screen and scan the maps (especially the attributes) before making a Web MApp publicly available. These interactive map products have been shared, presented, and navigated for interagency peers in the WERI Water Resources Forum 2022, held at WERI and virtually online, and the NGSWCD Educator's Symposium (2023) at the Guam Museum. GWA management has expressed tremendous gratitude and amazement and makes excellent use of WERI Web MApps.

DOW Borehole and Production Well Videos

D.K.U. Valerio, M. Ziobro, and N.C. Habana

[Maps and Posters](#) | [Online Map and Video](#)

The Comprehensive Water Monitoring Program supported the installation of seven new deep observation wells (DOW), owned and maintained by Guam Waterworks Authority (GWA, on local government property) and the US Military (on military property). The CWMP public law requires recording downhole videos after drilling to capture the pore features for groundwater studies and Borehole database records. A video was given for processing, DOW NCSF 1, and is now available on the GHS website, on the web page *Maps & Posters*, found in the Library tab. The online map and link to the video also contain production wells casing downhole videos provided by GWA.



GHS Borehole and Well Casing Database Video Collection

Guam Hydrologic Survey Research

The Guam Hydrologic Survey allocates funding for research. Top priorities for chloride and production, nitrates, observation wells, and groundwater modeling reports are maintained. However, other pertinent hydrologic research work is welcome and available to WERI researchers and partners, which include climate/meteorologic phenomena studies, water quality, surface hydrology, and geology.

Water Quality

Water production is regulated by its maximum contaminant level (MCL) of contaminants, determined by USEPA. While all listed contaminants/undesirable solutes are monitored and regulated, the top three common GHS water quality observations are chloride, nitrates, and perfluoro alkyl substances (PFAS). Chloride is an undesirable solute for observing salinity, nitrates for wastewater, and PFAS (observed, not yet regulated) as a new emerging contaminant of concern. Studies look for trends, patterns, and changes that may give insight into the groundwater status, aquifer porosity, sources, influential forces, and mechanical aspects of a production well.

Chloride and Production Reports

H. Ko, Y. Wen, and J.W. Jenson

[Technical Report 178](#) and [Technical Report 177](#)

Frequent status and updates of production rate and chloride are top priorities in the GHS Program. Chloride from phreatic saltwater may be intrusive, updrawn by wells in a freshwater lens, and is also regulated by Guam EPA. Although salinity is not a contaminant, GEPA regulates pump rates that exceed 250 ppm of chloride. Chloride and production data are also crucial for groundwater flow model “calibration” or history matching. Recently, two technical reports, 178 and 177, were produced (see links above) for Yigo-Tumon and Finegayan Basins, respectively, and the following are the abstracts of the reports.

Technical Report 178, Abstract:

This study focuses on the geospatial-temporal analysis of patterns and trends of salinity in the Yigo-Tumon Basin. Using statistics in Microsoft Excel and ArcGIS, spatial and temporal trends of the increase or decrease of chloride concentrations are observed and analyzed. Of the wells in the Yigo-Tumon Basin, sixty-three are analyzed for this study. Fifty-three wells are in the basal groundwater zone, eight are in the para-basal zone, and two are in the supra-basal zone. Of all the wells analyzed in this basin, twenty-eight wells have passed the local MCL; of those twenty-eight, thirteen have passed the USEPA National Secondary Drinking Water Regulation Guideline. All wells in the Y-series have yet to pass the local MCL. Forty-seven of the sixty-three wells (74.6%) demonstrate a significant increasing trend, seven (11.1%) show a non-significant increasing trend, six (9.5%) exhibit a non-significant decreasing trend, and three (4.76%) demonstrate a significant decreasing trend.

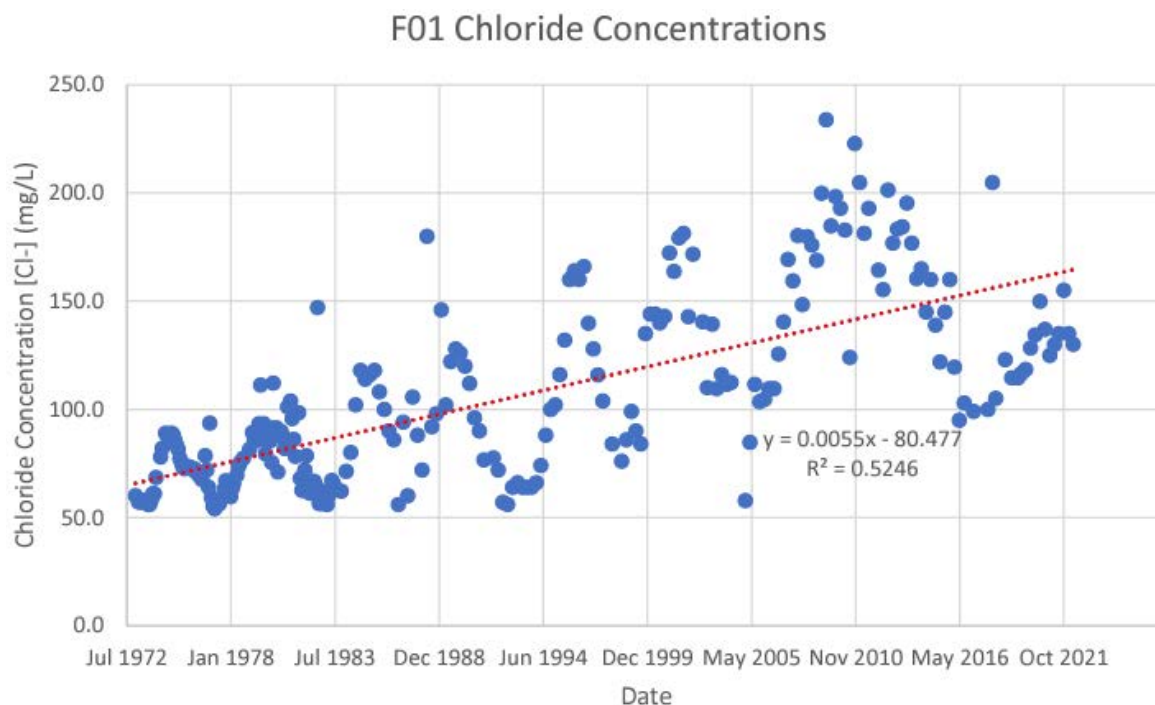
Temporal analysis not only gives the increasing or decreasing trends but allows for visualization of cyclical patterns. Across the basin, chloride concentrations are higher in more recent years. Spatial analysis will enable us to determine whether the wells are close to each other or whether other external factors affect chloride concentrations.

Technical Report 177, Abstract:

Finegayan Basin is one of six groundwater basins in the Northern Guam Lens Aquifer (NGLA), which supplies 90% of Guam's drinking water. It comprises 7% of the NGLA but supplies about 15% of total production from 15 wells operated by Guam Waterworks Authority (GWA) and three wells operated by Naval Facilities Engineering Command Marianas (NFM). This project sought to characterize historical patterns and trends in chloride concentration to provide a baseline for managing saltwater contamination.

This study focuses on the geospatial-temporal analysis of the patterns and trends of salinity in the Finegayan Basin. Using statistics in Microsoft Excel and ArcGIS, spatial and temporal trends of salinity levels measured by chloride concentrations are observed and analyzed. In Finegayan Basin, data is available for sixteen individual wells. Seven of the wells are basal wells, eight are parabasal wells, and one is in the supra-basal zone. The seven basal wells are F1 (see sample figure below), F02, F03, F04, F10, F11, and F13. The eight parabasal wells are D24, F08, F12, F15, F16, F17, F18 and HGC2. The one supra-basal well is D22A. Of all the wells analyzed in this basin, five exceed the MCL, and of those five, two exceed the USEPA National Secondary Drinking Water Regulation Guideline.

Temporal analysis not only indicates the increasing, decreasing, or stable trends but also demonstrates cyclical patterns. This may be due to El Nino to La Nina periods, usually lasting up



Chloride concentration history of Production Well F-1, Finegayan Aquifer Basin

to 6 years. Spatial analysis is applied to determine whether adjacent wells affect each other and whether the groundwater in the coinciding area has a trend of increased chloride levels so that appropriate inferences can be made.

Contaminants: Nitrates and PFAS in production wells

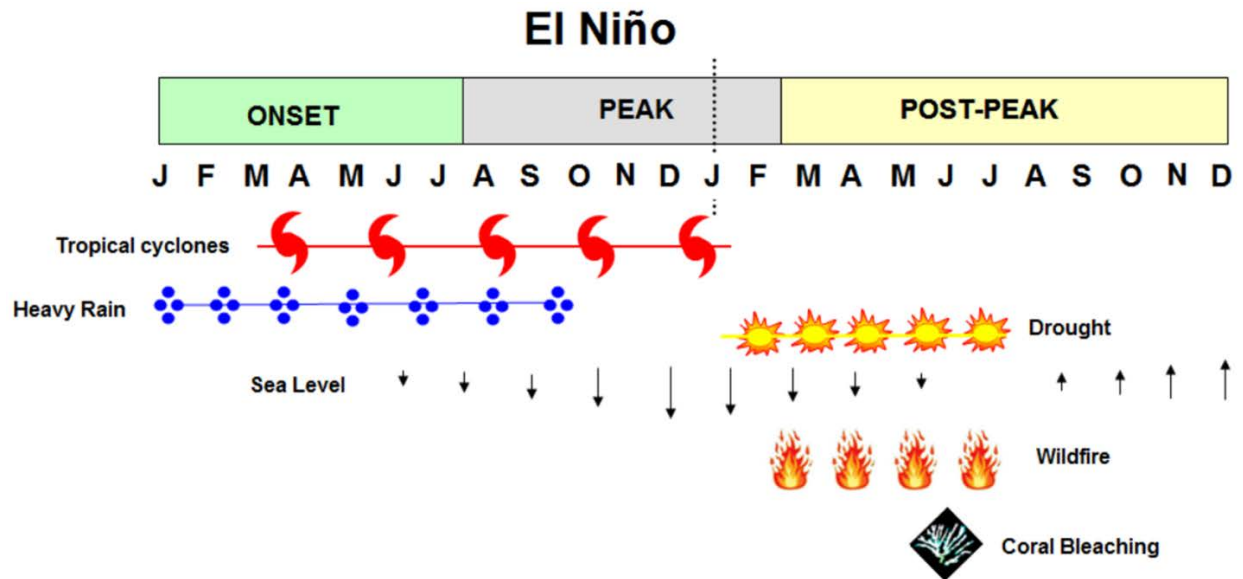
While all contaminants in water sources are a concern, nitrate-N (wastewater) and perfluoro alkyl substances (PFAS) are the top two observed. Development over the aquifer is a risk of contamination from anthropogenic sources. WERI research continues to obtain data from GWA and conduct statistical analysis to observe trends, especially pointing out increasing ones and wells surpassing nitrate-N MCL. Water production is regulated at or above ten ppm (USEPA MCL) of nitrate-N and observes PFAS (USEPA). PFAS and nitrate history reports are available on the GHS website in the Wastewater | Toxicology tab. The latest nitrate-N production well-trend product is MAppFx, mentioned in the information management section above. The PFAS study produced a master's thesis and a Master's, Mallary Duenas, from the UOG's Environmental Science Program in December 2022. Duenas is currently converting the thesis to a WERI technical report that will be available soon.

Regional and Local Climate

WERI is now searching for a new meteorologist to continue reporting on the State of the Climate, Guam, and producing weather and climate reports. The Climate | Weather tab on the GHS website has a 2015-2016 state-of-the-climate report that must be updated.

This year, 2023, has been very wet. In late May, Typhoon Mawar left the island in a state of disaster, with total rainfall of more than 20 in. Mawar reached Category 4 as it slowly passed through Guam, leaving the island wrecked and had the island living off the grid for months. In the aftermath, a FEMA representative visited WERI for advice on storm surge, coastal flooding, and flood maps. Also, the GHS program collaborated with the National Weather Service in an island flood study pursued by their summer intern, Owen Richardson, from Dartmouth University. WERI and NWS continued collecting and processing rainfall data from the Southern Mountain Rain Gage (SMRG), initially installed by the late WERI Meteorologist, Dr. Mark Lander. From late May to August, El Nino onset emerged unusually late, starting with Typhoon Mawar, followed by months of heavy rainfall. By September, rainfall surpassed 100 in. Furthermore, in October, a category one typhoon (Bolaven) brushed Guam with 20-40 mph winds and heavy rains as the storm passed through the Marianas. This abnormal El Nino delay is not clearly understood at this stage; however, more heavy rainfall and storms are expected in the following year, and 2024 may be an interesting year for climate and weather observation as El Niño peaks and post-peaks.

In the meantime, as WERI awaits a meteorologist, WERI GHS Research is preparing a proposal for the hydrologic analysis of rainfall, which is useful for studying and updating estimates of recharge that can be used in groundwater modeling. Rainfall and climate studies are also helpful for studying streamflow in Southern Guam and flood inundation, a research interest.

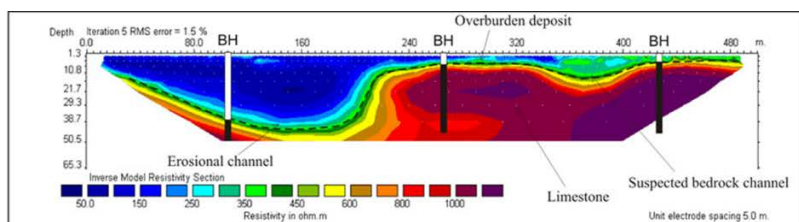


El Niño impact on Guam (Lander 2016)

Aquifer and Island Geology

B. Miklavič

WERI hired a new geologist in 2022, Dr. Blaž Miklavič, a specialist in karst, carbonate island karst geology, and hydrogeology. In 2022, Miklavič invited karst geology colleagues from Europe to present their research work in Australia. One of the highlights was Electrical Resistivity Tomography (ERT), a geologic instrument that can produce subsurface imagery, most useful for detecting voids, varying rock densities, and groundwater. In 2023, WERI procured an ERT through GHS and will use the technology to explore the aquifer subsurface. Such explorations may give us insight and verification of hydrologically significant sinkholes and faults. The technology may also help us refine the aquifer's freshwater "sweet spot," known as the parabasal zone, and even potentially high-yielding suprabasal groundwater. ERT would also be necessary for studying hydrologic boundaries and hydrogeologic features in the aquifer, which could improve the delineation of groundwater model boundaries and conditions. Miklavič completed ERT training in Germany last July and has begun testing and preparing the equipment for use on the NGLA.



Electrical Resistivity Tomography, subsurface imaging analysis example (from Terradat®)

Aquifer Development: Reassessing the Groundwater Protection Zones

N. Bravo, Y. Wen, J.W. Jenson, and B. Bearden

The Northern Guam Lens Study, CDM 1982, a collection of reports that include the Groundwater Management Program, stands as the milestone publication of Guam EPA, which helped establish water resources development regulations that are still used today. For example, establishing the groundwater protection zone for production wells 4,000 feet inland, aquifer basins, and the 40-foot well depth are standard GEPA regulations for production well construction. However, with improved maps of the Northern Guam Lens Aquifer, more development over the aquifer, production well quality concerns, water production demand, and questionable areas for development, stakeholders are considering a need for reassessment and refinements to the groundwater protection zones and their regulations. This item of top concern is now a master's thesis research project pursued by a UOG graduate student, Natalie Bravo. Bravo's team is now focusing on narrowing the assessment to protect the water source and wells, setting the limitations and boundaries to maintaining quality water, and recommending the best places to develop our island's water supply. This report may significantly impact determining regulations for development over the aquifer.

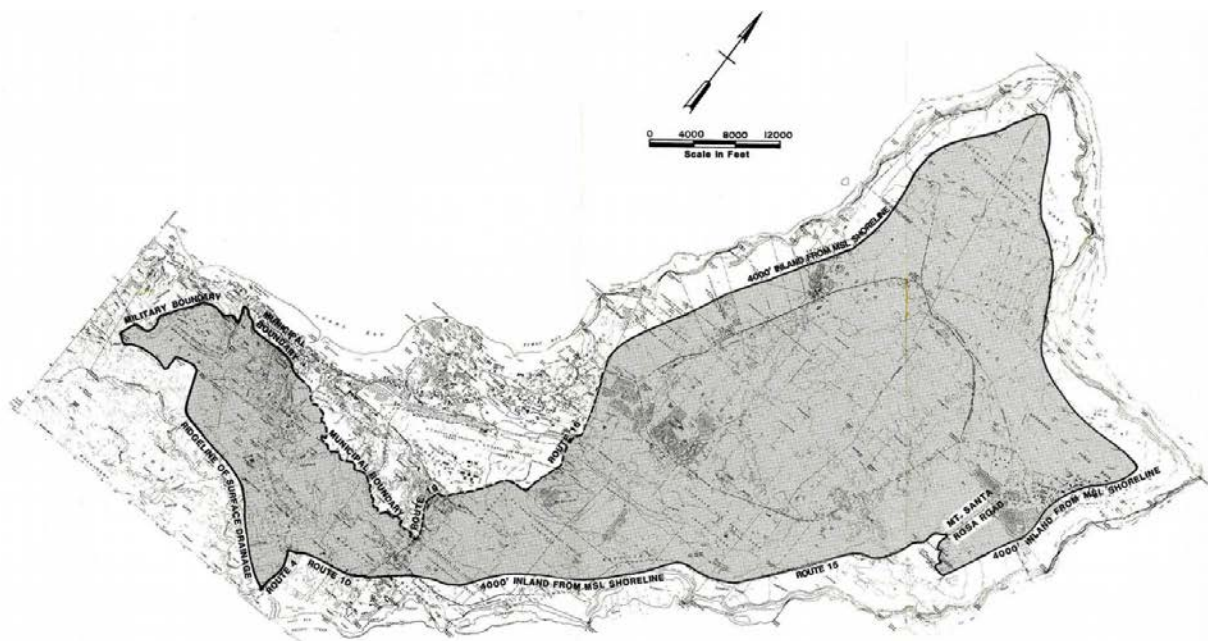


FIGURE 8-1
GROUNDWATER PROTECTION ZONE

Updating the Groundwater Protection Zone Map (Northern Guam Lens Study, CDM 1982)

Groundwater Modeling Research, Northern Guam Lens Aquifer

Groundwater modeling is a complex endeavor and process that requires a lot of hydrologic and geologic information, technical skills, conceptualization and perspectives, and various

contributing temporal and spatial hydrologic data analysis. Developing a comprehensive and reliable model of Guam's high-yielding aquifer requires detailed studies involving production well construction, operations, water quality, hydrology, meteorology, land cover, deep observation wells (CWMP), and hydrogeology. GHS research must do in-depth studies in production well salinity, nitrates, rainfall, recharge, geology, maintain a hydrologic database, and more to build the closest representation of the real aquifer. Groundwater models are extremely useful in helping make water resource management decisions, so componential research must be in place to build a useful groundwater model. Modeling is also the ultimate way of exploring sustainable production configurations.

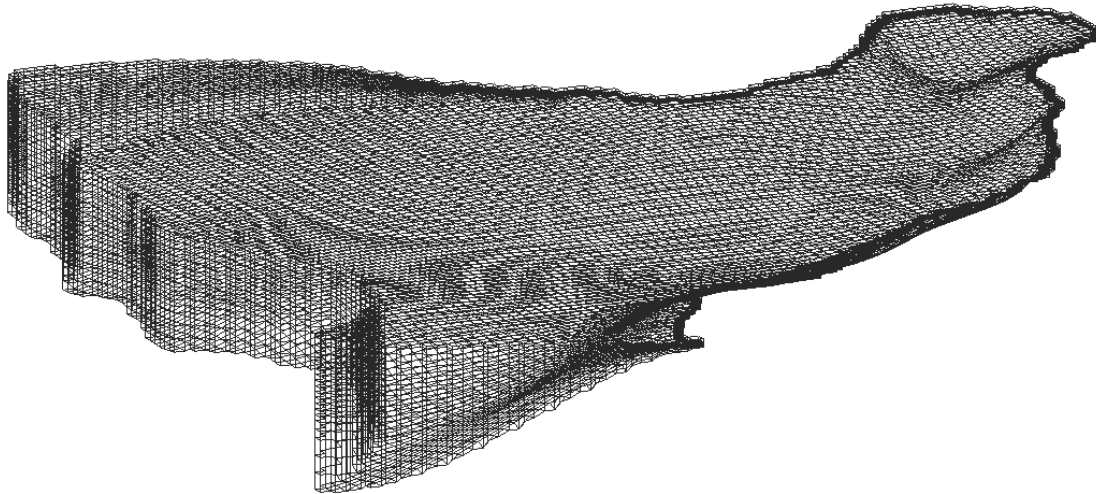
In the past five years, the WERI GHS Program has invested in collaboration with Aquaveo® (Provo, UT) Groundwater Modeling Systems (GMS), the world's leading groundwater model software developer and application service, to build the most reliable models of our sole source aquifer. WERI has undergone software use training in Aquaveo workshops and has received CEU certification. The GHS Groundwater Modeling Team Researcher and Research Assistants have learned to use the software and ensured proper use and review from Aquaveo technical support experts. The following sections summarize the modeling projects and progress with the phreatic model and nitrate-N solute transport projects.

Phreatic Model of Tomhom Aquifer Basin, with Strategic Well Relocation Scenario

J.A. Caasi, H. Tran, and N.C. Habana

WERI Groundwater Modeling team and [Aquaveo®](#) collaborated and developed a SEAWAT code flow model of the Tomhom Aquifer Basin using the Aquaveo [Groundwater Modeling System](#) (GMS). GMS is WERI's choice platform as it is the most advanced groundwater model application. GMS has a groundwater model preparation interface, various choices of codes/modes, a basic GIS working environment, and a 3-D post-process feature and display, all available in a single desktop application.

The purpose of developing this groundwater model was to test the [SEAWAT](#) code/mode for a 3-D freshwater lens and saltwater phreatic zone that will be used to support a GWA Master Plan of Production Well Relocation. Tomhom Aquifer is the largest in the NGLA and has the most production wells, producing about 20 MGD, half the total quantity of utility water produced from all the deep production wells in Guam. The completed and "calibrated" model, analysis, and application resulted in three poor-performing wells relocated to select areas in the parabasal zone. The selected area in the parabasal zone required an existing road, and the land property preferred was that of the Government of Guam. However, one well was relocated to a large private property, practicing a GWA-landowner agreement scenario. The team also examined a report from Superales et al., 2019 ([WERI TR 170](#)) to determine the parabasal area's sensitivity to salinity from increasing pump rates. Each relocated well was set to pump at 500 GPM. For the worse case observed and model-determined hydraulic conductivity from existing wells in the parabasal zone, the relocated wells maintained a steady state chloride concentration of 70 ppm, well below the 250-ppm regulation. This Tomhom Phreatic Model is



Tomhom aquifer, high-resolution phreatic model mesh, view of coast (left side) and trough (top right)

constructed on a high-resolution mesh grid and does not have code instabilities that result in negative chloride at the wells. The resulting flow model was then considered for use to develop the Swamp Road, nitrate-N, solute transport model (next section) in [MODFLOW USG](#) mode, using Voronoi Cells. The technical report draft is in progress and will be published soon.

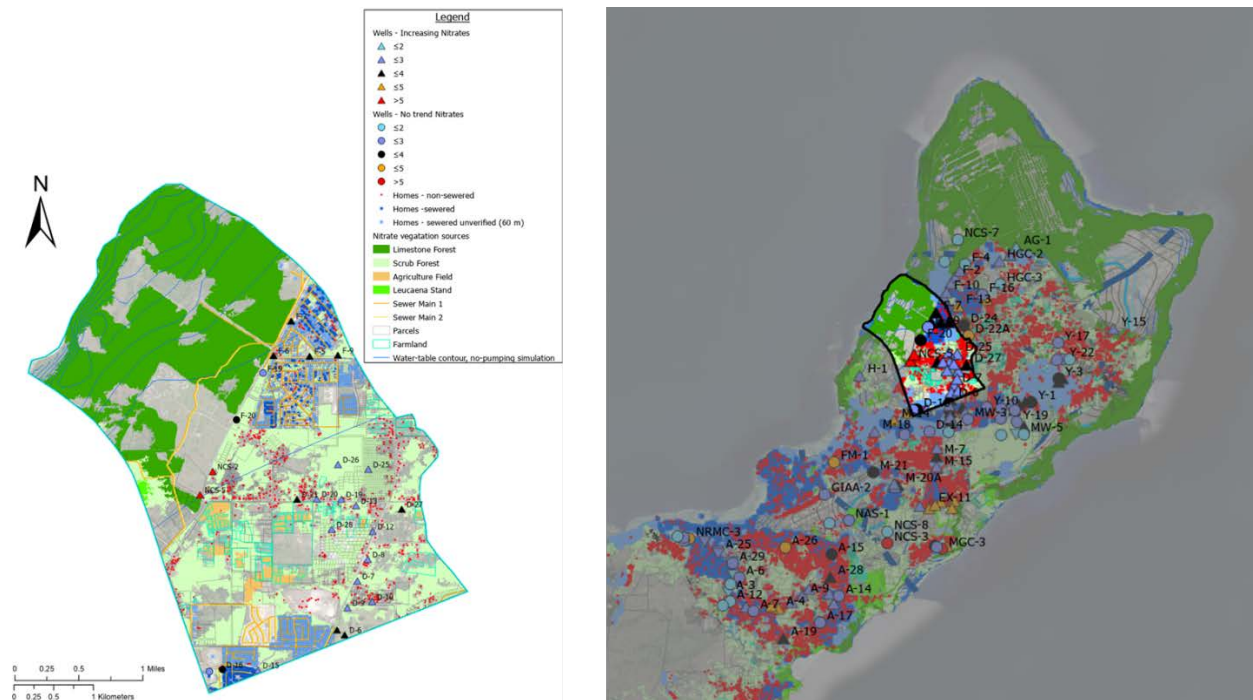
[Nitrate-N Solute Transport Model, Swamp Road Area](#)

A. Bautista, J.A. Caasi, T. Wood, and N.C. Habana

The first and most comprehensive 3-D solute transport model application, starting with the Swamp Road area in Dededo, is in progress. WERI GHS Modeling Team and Aquaveo® collaborate to develop a MODFLOW USG, nitrate-N solute transport model of the Swamp Road area, using GMS. The model scenario analysis was completed in August and a technical report is underway. Presentations are scheduled for the Guam Advisory Council Meeting (November) and the National Groundwater Association (NGWA) [Groundwater Week 2023](#) (December).

This model is the most complex and inclusive model ever developed for Guam, which includes nitrate-N sources from wastewater discharge (non-sewered), naturally from vegetation (legumes, “tangan-tangan”), and from agriculture (fertilizer, wastes). The spatial information of wastewater from non-sewered sources is from the GWA and WERI sewer status map (2006). The vegetation sources are from landcover analysis (Wen et al. 2009), and agricultural areas are from the Department of Land Management. The flow model component was from the SEAWAT model, the *Phreatic Model of the Tomhom Basin* (above).

The model forms a 3-D phreatic saltwater-freshwater lens that receives recharge on the water table and the lens toe and discharges to the coast. All active production wells (GWA data) are also placed in the model to simulate the source-to-well nitrate transport.



Swamp Road Domain and the multiple layer sources of nitrate-N

The model performed three scenarios:

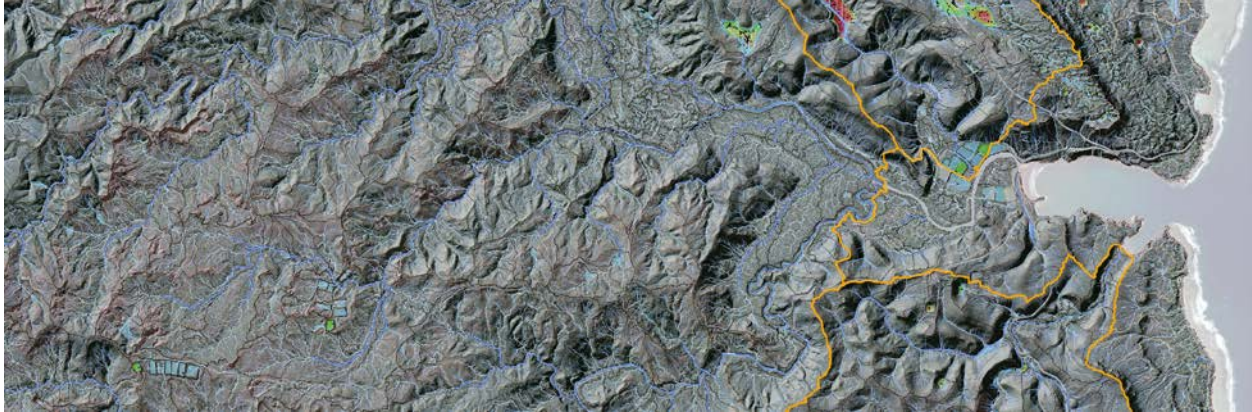
1. Nitrates from legumes and agricultural sources only, no production wells
2. Nitrates from legumes, agricultural, septic sources, no production wells
3. All sources and production wells

The results are available, and interpretations have been made. The team will also be ready for the presentation at the Guam Advisory Council Meeting in November and at the NGWA Groundwater Week conference in Nevada in December. The technical report is in preparation. In addition, Lemon and Wood of Aquaveo had expressed great interest in this model, mentioning that it is the most complex groundwater model they had ever been a part of developing. They requested to use this solute transport model as a workshop example and an exercise, and we agreed in response.

Surface Hydrology of Southern Guam

N.C. Habana, D.K.U. Valerio, and L.F. Heitz

Southern Guam hydrology is composed of watersheds with surface waters of streams, rivers, and reservoirs. With the success of developing the *Surface Hydrology of the Northern Guam Lens Aquifer*, [WERI TR 180](#), the GHS Hydrology Team decided to apply the same techniques in that project to Southern Guam. Using the latest Guam DEM (digital elevation model) 2020, the results are the most sophisticated, detailed, and comprehensive hydrologic map ever developed for Southern Guam. The following steps are to create its Web MApp on ArcGIS Online, finish the technical report, and post it on the GHS website. This work springs ideas for future research plans of recent great interest in flood inundation studies due to a very intense wet year brought



Web MApp: Surface Hydrology of Southern Guam (in progress)

on by the El Niño onset that included two typhoons. Flood zones will be identified and highlighted on the maps. In addition, a research proposal in December will aim to combine the surface hydrology maps of the south with the north using the latest 2020 DEM that will yield a Surface Hydrology Web MApp of Guam.

Comprehensive Water Monitoring Program Activities

The Comprehensive Water Monitoring Program is currently searching for a Research Associate, as CWMP is reorganizing to prepare for research workload expansion. Two Research Assistants have been recently hired and will work under the GHS Operations Manager as we search for a new CWMP Research Associate. Moreover, halfway through FY2023, WERI CWMP and GHS Operations cooperated and contributed as field support in the observation well data collection with USGS and participated in the location selection, discussions, and recommendations for developing new deep observation wells.

USGS-WERI Observation Well Data Collection

Todd Presley of USGS Pacific Islands Water Science Center (USGS-PIWSC) is the lead field hydrologist that collects Guam's observation well data quarterly through a USGS-WERI collaboration. WERI CWMP research assistants/associates accompanied and helped Presley in the field, visiting each observation well and logging conductivity to obtain the observation well's phreatic profile. Presley also managed the data logging of observation well water level. Other WERI research assistants also assisted and learned from Presley for research projects and hydrologic data collection experience. The data collection undergoes a data quality examination, noting each measurement as provisional or approved and made available on the [USGS' website](#).

New Deep Observation Wells

Previous CWMP and MSERP (Monitoring System Expansion Rehabilitation Project) Research Associate Jhonnie Villareal attended, observed, and recorded the drilling of the new observation wells and the rehabilitation of old observation wells. Villareal obtained the new deep observation well test data and Borehole videos that will soon be processed, edited, and uploaded onto the GHS website on the Borehole videos collection.

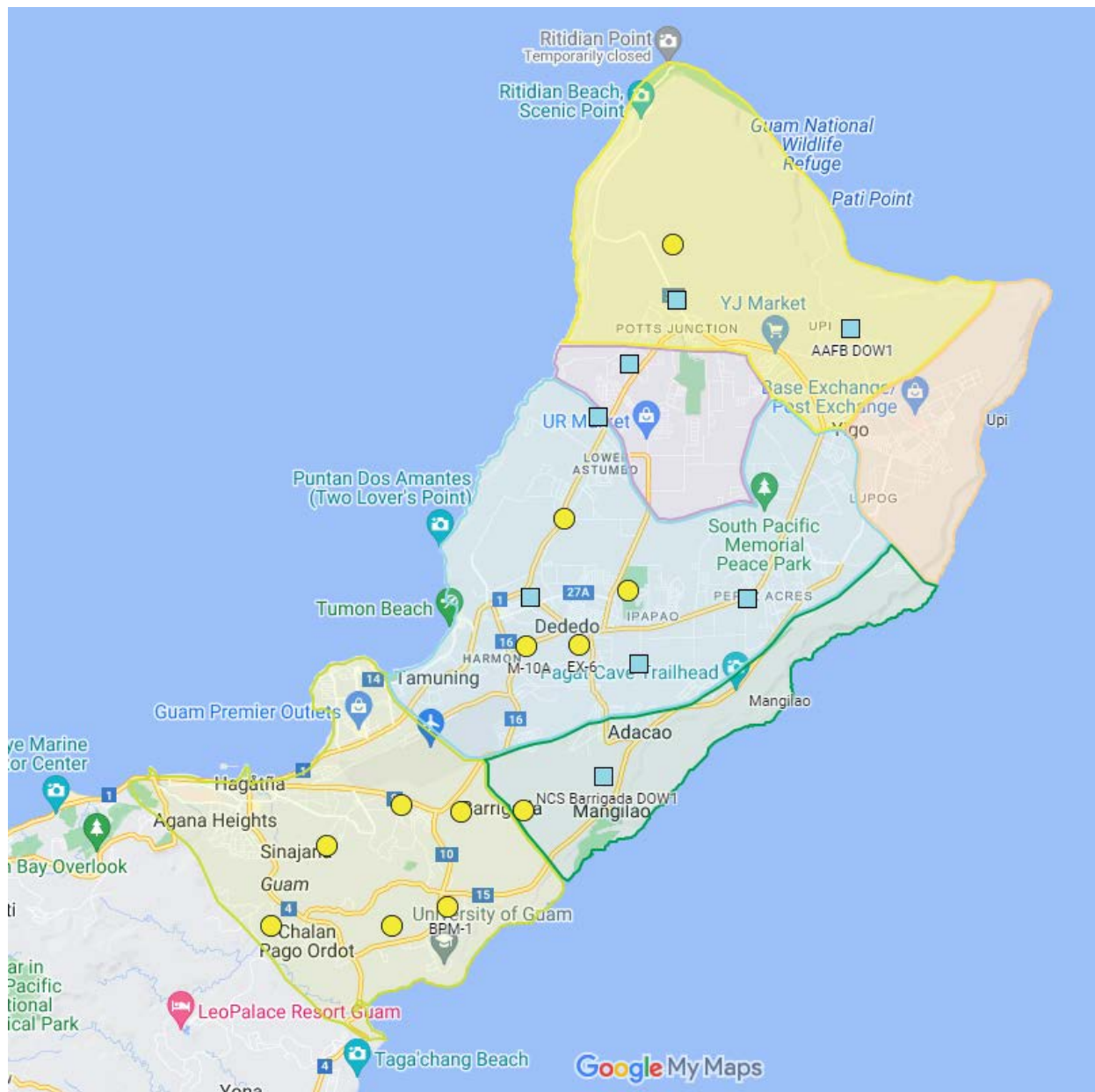


Bekah Dougher, collecting observation well data for CWMP, an essential program task

Additionally, Villareal attended technical meetings with GWA, NAVFACMAR, USGS-PIWSC, Brown and Caldwell, and Marianas Drilling, Inc. and participated in decisions, recommendations, and task management. For FY 2024 and with the new CWMP Research Assistants, the information Villareal noted and stored may be prepared for submission to WERI's Information Management team to be posted on the GHS website.

MApFx: Deep Observation Wells Northern Guam Lens Aquifer

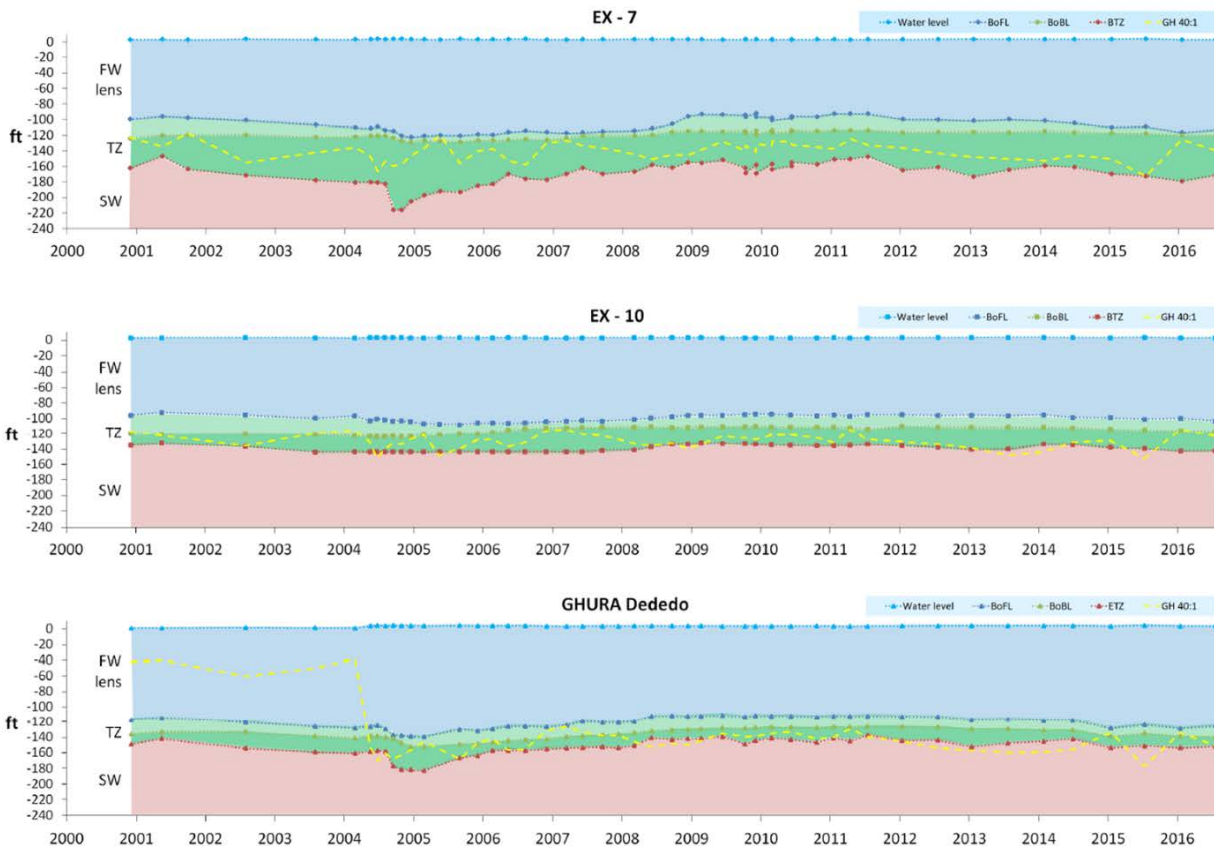
In 2019, a thesis project revolutionized how we look at freshwater lenses. Dougher et al. (2019) analyzed conductivity and depth data from three deep observation wells in the Tomhom Aquifer Basin: EX-7, M-10, and Ghura-Dededo. Dougher first defined the phreatic profile zones of freshwater, transition zones of saline and brackish, and saltwater. Data was then extracted from the three DOWs to graph the dynamics of the freshwater, transition zone, and saltwater. The



Monitoring System Expansion and Rehabilitation Program, seven new DOWs (light-blue square), and 12 observation wells for rehabilitation (yellow circle)

research won the Farvolden Scholarship in a poster presentation at the NGWA, Groundwater Week 2019 (Las Vegas), and Dougher received UOG's Presidential Thesis Award. The research is published, and a technical report is available on the GHS website. Dougher's work was later used to "calibrate" the Tomhom Phreatic Model (section above).

The GHS Information Management and CWMP Operations Manager plan to produce a MAppFx product out of WERI [Technical Report 168](#). CWMP Research-Digital Assistant Mary Snaer is assigned to the observation well data extraction task that will be converted into a JSON data format, which can be used in the MAppFx data visualization online interactive program. The



Phreatic salinity profile history ([Dougher et al. 2019](#))

project will be submitted as a GHS Research Proposal in December, and in the year after, the entire Guam DOW system will be on MAppFx.

One-Guam Water Resources Information Program

One-Guam Water Resources Information Program (OGWRIP) is an understanding and agreement of shared responsibilities between the Department of Defense (DOD) and the Government of Guam on managing the island's most valuable utility water source. DOD has been expanding its operations and facilities with the Marine Corps realignment, which raised concerns about utility water demand and the Island's Sole Source Aquifer ([FR-43](#)), the NGLA. The NGLA contains groundwater, with a freshwater lens that supplies 90% of the Island's utility water.

In 2020, Guam Waterworks Authority's (GWA) General Manager Miguel Bordallo and NAVFAC Marianas (NAVFACMAR) Navy Commanding Officer Captain Daniel Turner signed a One-Guam Water memorandum of understanding (MOU) that establishes "a stronger partnership and collaborative commitment to the improvement of its utility system" ([PNC 2020](#)). The MOU lays out an organizational structure, which includes scientifically informed advisement from the Island's technical experts on water resources, including the Water and Environmental Research Institute of the Western Pacific (WERI), University of Guam (UOG). In 2022, GWA, NAVFACMAR,



OGWRIP MOA signing (October 21, 2022): at the table, left to right, GWA GM Miguel Bordallo, US Navy CO Captain Troy Brown, Former UOG President Thomas Krise, USGS PIWSC Director John Hoffman; and on the podium, WERI Interim Director Ross Miller

UOG, and USGS signed memorandums of agreement ([MOA-GWA](#), [MOA-DOD](#)), bolstering One-Guam Water with OGWRIP, which funds water science research operations to be conducted and managed by WERI and USGS' (Hawaii) Pacific Islands Water Science Center (PIWSC).

WERI and PIWSC have been historic partners in collecting, organizing, and publishing Guam's observation well data partially funded through CWMP. Scientific data analysis and information transfer is done through the GHS Program. Major products from the collaboration were the NGLA groundwater flow model (Gingerich 2014, Superales et al. 2019), Borehole and production-chloride database, the NGLA Map, freshwater lens dynamics (Dougher et al. 2019), and the NGLA Tour. GWA and NAVFACMAR agree on the importance of scientific informed decisions and invest in the island's leading institutes on water resources.

The Island's increased demand for utility water supply has become a water source protection and sustainability concern, which calls for expanded observation, hydrologic analysis, and research. GWA and NAVFAC are now installing seven new deep observation wells (DOWs) in select locations in the NGLA. The GHS Program also expands to conduct data analysis and scientific research on our water resources.

WERI and interagency partners collaboratively organized an OGWRIP program that satisfies the MOA. A pyramid diagram of five sections assigns the operation and manning roles to conduct and report water science. Key program sectors are data collection and management, conducting scientific analyses and reports, and scientific information transfer management. WERI and USGS, from the data collection, will produce groundwater models in both localized areas and

the entire NGLA to simulate scenarios that will evaluate production capacity and contaminant transport. WERI will also be involved in water quality research, groundwater protection zones, surface hydrology, and climate studies. WERI's Information Management Team manages information transfer and develops online hydrologic products (MAppFx, Web MApps) and databases on the GHS website.

Dr. Miklavič is the new GHS-CWMP Operations Manager, and Dr. Habana is the GHS Program Advisor. Along with the WERI Director and Program Coordinator, Habana and Miklavič are coordinating with NAVFAC Marianas, Maria Lewis, and UOG Business Office, Wilfredo Magdalera and Merlita Azicate, in all efforts to finalize the OGWRIP Contract between NAVFAC Marianas and WERI-UOG, anticipated before the end of this year. Once finalized, the OGWRIP Program will be a 10-year contract to expand WERI GHS and CWMP operations, research projects, and resources.