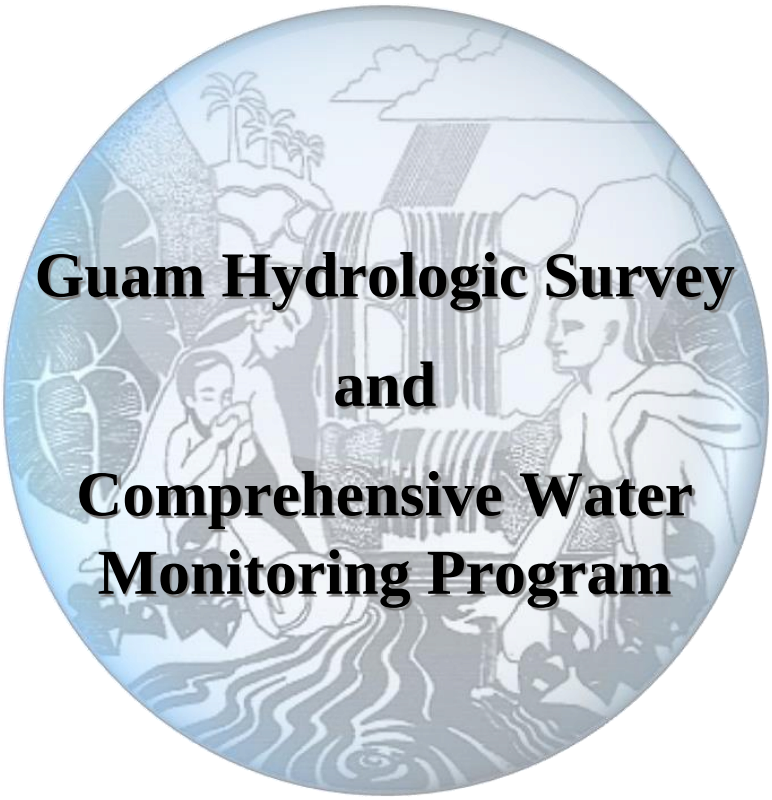

Guam Hydrologic Survey and Comprehensive Water Monitoring Program

FY 2017
Annual Report

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

February 2017

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

FY 2017
Annual Report

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Water & Environmental Research Institute of the Western Pacific
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PROGRAM MISSION STATEMENT

The Guam Hydrologic Survey (GHS) and the Comprehensive Water Monitoring Program (CWMP) were created in 1998 by the 24th Guam Legislature under Public Laws No. 24-247 and 24-161, respectively. The Water and Environmental Research Institute (WERI) was charged with administering the annual legislative appropriations to drive these two programs and facilitate, direct, and implement their objectives. Both programs are now an integral component of water resources research, information dissemination, education and training on Guam.

PROGRAM GOALS

The Guam Hydrologic Survey consolidates and archives new and historical hydrological data collected by local and federal government agencies and private consultants, and conducts research on water-related issues of local importance. GHS also funds a variety of water resource educational programs, including guest lectures and seminars at UOG and in the community, informational and training workshops for teachers and other professionals, 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 northern aquifer, and stream flow for surface waters in the south. The program builds on studies previously undertaken by the US Geological Survey (USGS) that had been abandoned in the 1990s because of a discontinuance of matching funds from the Government of Guam. The CWMP annual appropriations from the Guam legislature restored the program in 1998 and since then have facilitated the collaborative reinstatement of these studies with USGS under their 50-50 Federal/State-Territory cost-sharing program for water resource monitoring.

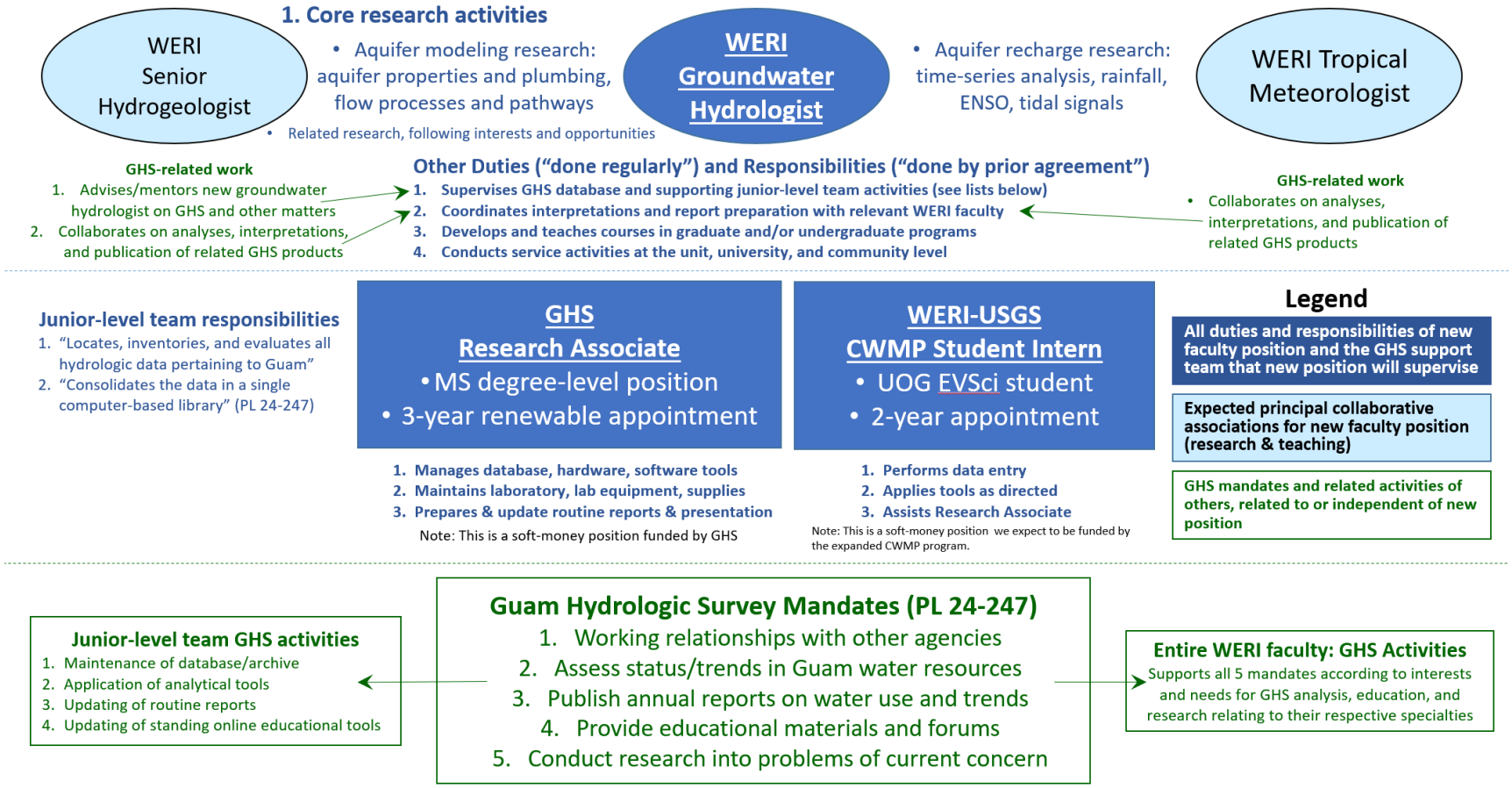
The foresight of the Guam Legislature in creating these two very important programs deserves special mention here. With the continued support of the Legislature, we now maintain several vital water resources databases for Guam and collect essential water resource data in collaboration with the USGS. 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 has substantially added to the number of highly trained water resources professionals in the island's technical work force.

PROGRAM FUNDING

The information presented herein summarizes GHS and CWMP program objectives and activities for FY16. GHS and CWMP requests for FY2016 were $204,200 and $173,948, respectively, which would have brought funding back to the nominal historical norm. Local government budgetary constraints in FY2009 drove a 6% reduction in funding at that time, which set the allocations at $192,309 for GHS and $163,817 for CWMP. These shortfalls continued through FY2012, when an additional 5% reduction was levied against each account by Governor Calvo. This reduced the total allotment to $182,694 for GHS and $155,626 for CWMP, which has continued through FY2016. The approved allotments for FY2016 were thus $182,694 and $155,626, respectively. As of the end of FY2016, the GHS had received $149,252, and CWMP $155,626.

GHS AND CWMP PROGRAM MANAGEMENT ORGANIZATION

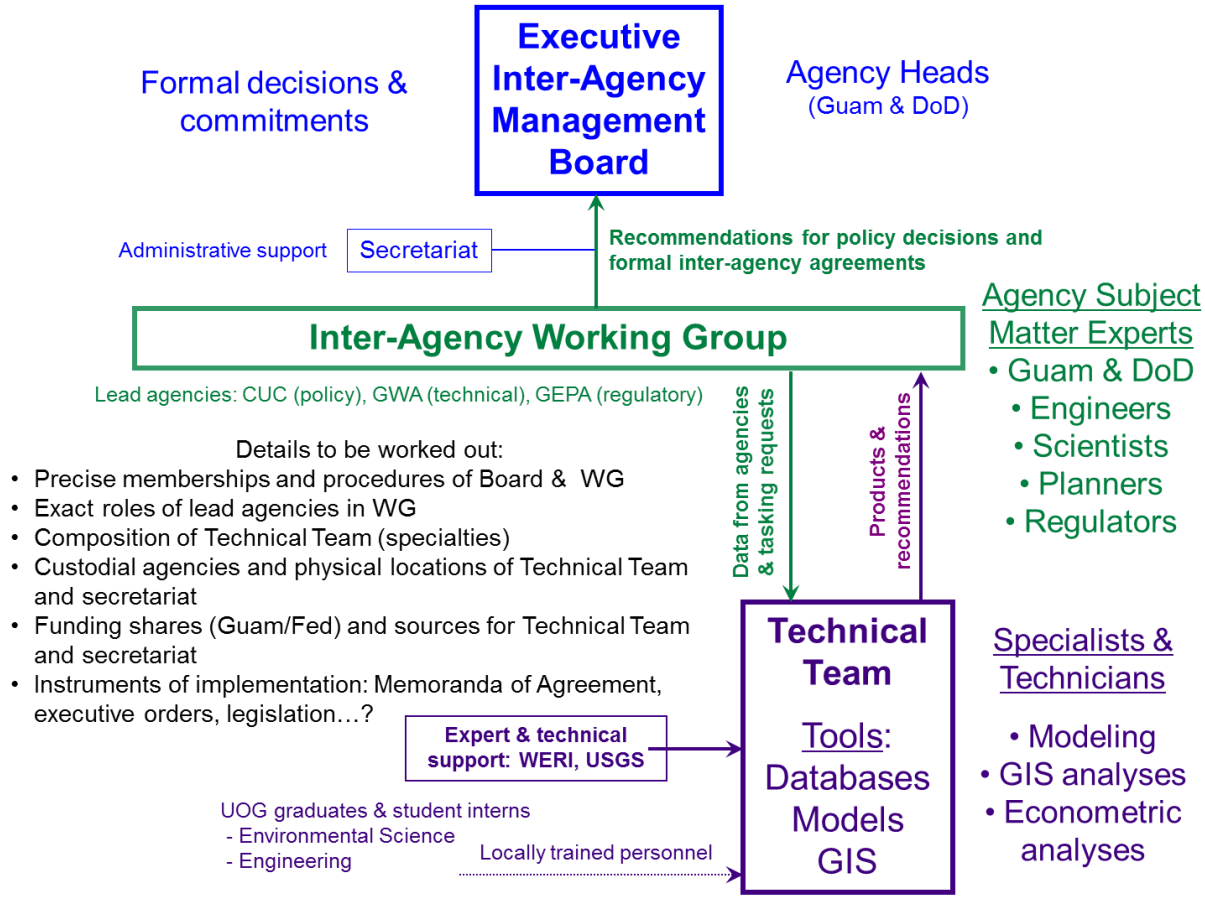
WERI organizes and integrates the GHS and CWMP programs to manage and execute the public law. Below is WERI's GHS organizational chart. The WERI groundwater hydrologist is the program manager, who with technical advice and assistance from the senior hydrogeologist and tropical meteorologist, prepares and manages the program's research agenda. GHS funds provide salary for a dedicated research associate, who reports to the program manager and is supported by a CWMP student intern. (This position is currently supported by separate funding.)



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) establish by the 16 July 2010 Memorandum of Understanding between the US Navy and Guam Waterworks Authority (Appendix I). The MOU provides an additional venue for meeting the GHS and CWMP mandates to "establish a direct working relationship with each organization collecting hydrologic data important to Guam, and maintain a permanent flow of new data from each organization to keep the data library up to date." Local and federal agencies that are party to or affected by the MOU include Guam Waterworks Authority, Guam Environmental Protection Agency, CUC, US Navy (NAVFACMAR), USAF (36 CES), and USGS. Interagency groups also include private consultants: Duenas Camacho and Associates, Allied Pacific Environmental Consultant (APEC), EA Engineering, Brown and Caldwell, and AECOM. Meetings are organized and held quarterly at Guam Waterworks Authority (Gloria B. Nelson Public Service Building), Fadian. Current discussion is the expansion of monitoring (observation) wells, see details in CWMP Research Projects section.

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



PROGRAM ACTIVITIES FOR FY 2017

Guam Hydrologic Survey (GHS)

The GHS program management team has hired a new full-time GHS Research Associate, beginning 1 May 2017. The Research Associate is charged with operating and managing WERI's information database, the hydrology laboratory, and preparation and update of routine reports and presentations. During the next year, one of his primary tasks will be to assist the Program Manager in further developing and enhancing the online GHS hydrologic database and library.

GHS provides limited stipends for research by graduate students working on their MS degree in Environmental Science, and partial summer research salaries to WERI faculty advising those students or carrying out research on their own. It also supports undergraduate field and laboratory assistants working on water resources projects on Guam.

The program activities in this report begin with GHS Research Projects followed by CWMP Research Projects. The GHS section is organized into four sections: NGLA database, NGLA map series, Sustainable management, and Workshops.

GHS Research Projects

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

1. Northern Guam Lens Aquifer database

Drilling and drill logs

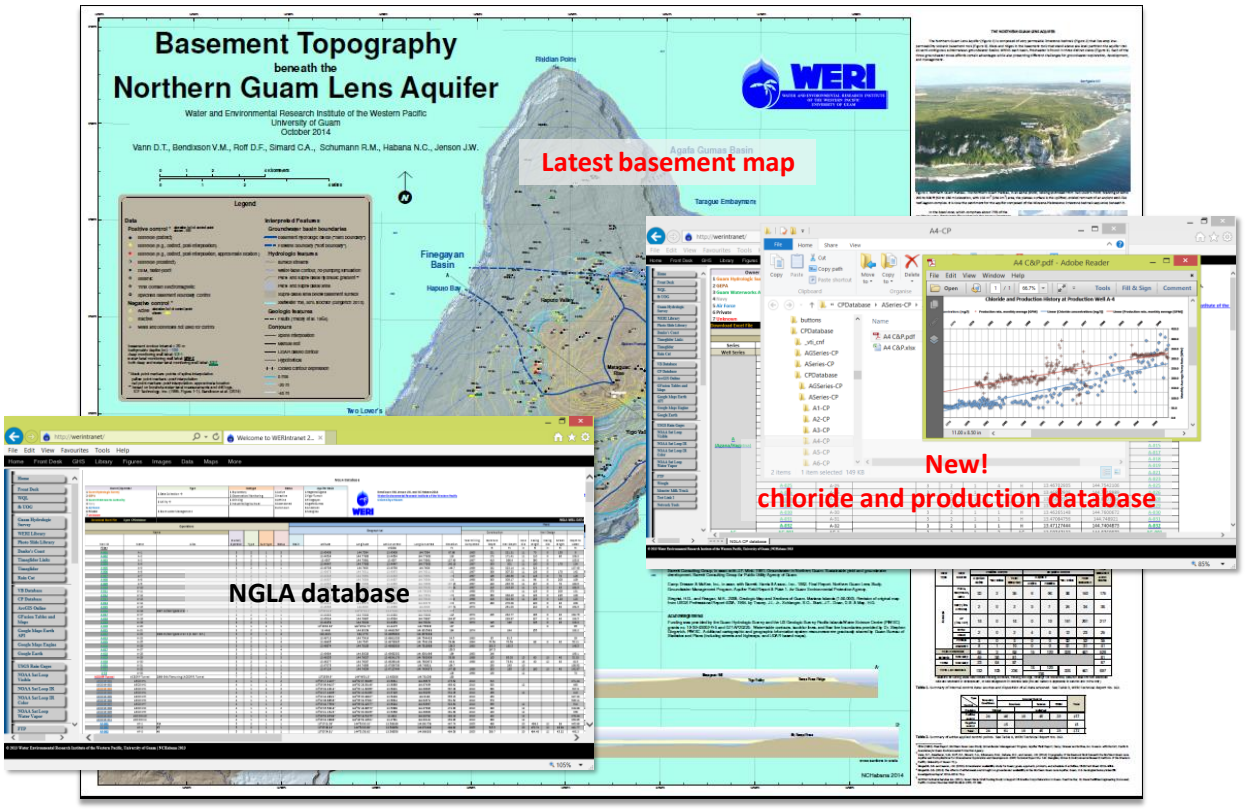
The primary source of facts below the surface of the Northern Guam Lens Aquifer comes from borehole records. Technical Report 141, Bendixson et al. (2013) laid the foundation for efficient and productive aquifer research by collecting and thoroughly organizing the subsurface factual information. It established a standard for documenting and placing information in a simple and logical arrangement. The filing system and table listing and information categorization are now set and are easily updatable. The database, which was once available only in the WERI intranet system, is now available on the internet for the professional community to access (see GHS CWMP Online section).

The enabling legislation for the Guam Hydrologic Survey (PL 24-247) mandates interagency cooperation with the Guam Environmental Protection Agency such that new deep drillings into the aquifer will be properly and thoroughly documented/recorded and submitted the Guam

Hydrologic Survey. The cooperation positions WERI to work closely with drillers in assessing the geology and hydrologic potentials in pursuit of optimal production wells. Downhole video is now being used to find the most productive zones in the borehole to determine optimal screen design and placement.

PL 24-247 also mandates routine maintenance and update of the Guam Hydrological Database and routine trend analyses of the data. The prime responsibilities of WERI's GHS Research Associate therefore include management of the database and preparation of the analyses from the Northern Guam Aquifer Database.

WERI Technical Report 141 is thus the first of a set of three related technical reports that provide basic information essential for successful development and management of the NGLA. In preparing the database over 4,000 pages of documents were scanned and organized into



The NGLA Trilogy: Technical Reports 141 (aquifer borehole database), 142 (aquifer map), and 143 (aquifer salinity database).

individual electronic folders for each of the 525 wells documented so far. These include 20 exploratory wells, 115 observation/monitoring wells, 212 drinking water wells, 39 agricultural/industrial wells, and 104 storm water management wells. Each well folder is electronically linked to its corresponding record in a Microsoft Excel® spreadsheet and webpage, which contains key engineering and hydrogeological data. To organize, classify, and relate the enormous amount of disparate data required development of a classification system for the data. The technical report is thus designed as a user's manual for the database, providing a detailed

description of the indexing system, along with definitions and conventions adopted or devised; data complexities, nuances, limitations; and assumptions and choices made in interpreting and classifying data.

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

GHS Support of Rehabilitation of GWA wells

GWA is currently rehabilitating 10 wells that have long been out of service for various reasons:

- A Series wells: A-02, A-07, A-12
- D Series well: D-03, D-5, D-18
- F Series wells: F-17, F-18
- M Series wells: M-09

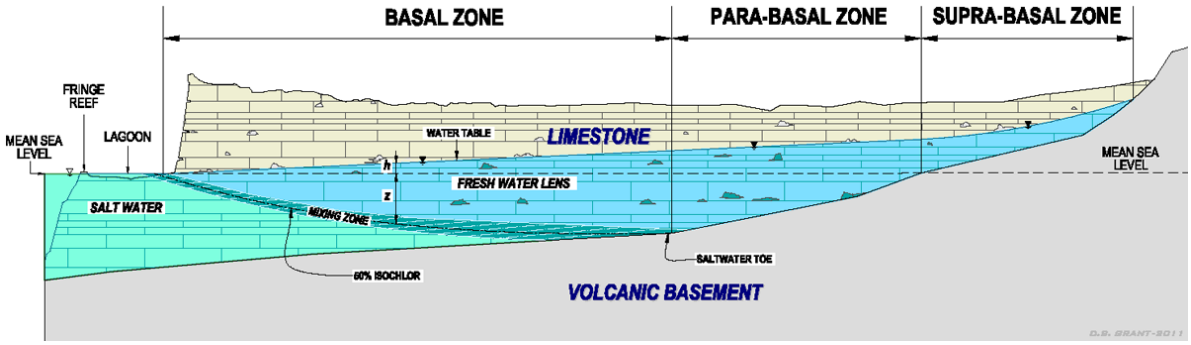
The well rehabilitation program plan is to install newly drilled wells at the same facility, generally less than 20 feet from the original borehole. Valuable new information on aquifer properties and well design is being gathered, and new approaches to drill logging, geologic and hydrologic evaluation are being practiced. Video logs of the borehole records will now be available and accessible in GHS aquifer database. Borehole records (documents, drill logs, pump tests, videos, and geologic descriptions) will now be available online for the professional community to access. During the preparation stage, the borehole database online was instrumental in bringing together WERI scientists, GWA engineers, the drillers, and supporting engineering consultants and to assess and interpret subsurface information, helping promote the success of the well rehabilitation program.

2. Northern Guam Lens Aquifer map set

By far the most important tool for successfully locating new wells that will deliver sufficient volumes of high-quality water from the Northern Guam Lens Aquifer is an accurate and precise set of maps on which basic data can be assembled. The updated mapping of the volcanic basement rock that forms the floor of the aquifer (Vann et al., 2014) was a major breakthrough for developing the Northern Guam Lens Aquifer Map.

The Northern Guam Lens Aquifer Map

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



Volcanic basement beneath limestone aquifer defines three groundwater zones: 1) the basal zone, where the fresh water lens is underlain by sea water, 2) the para-basal zone, where the fresh water is underlain by the volcanic rock, and 3) the supra-basal zone, where the fresh water moving down-slope toward the para-basal zone is lies above sea level.

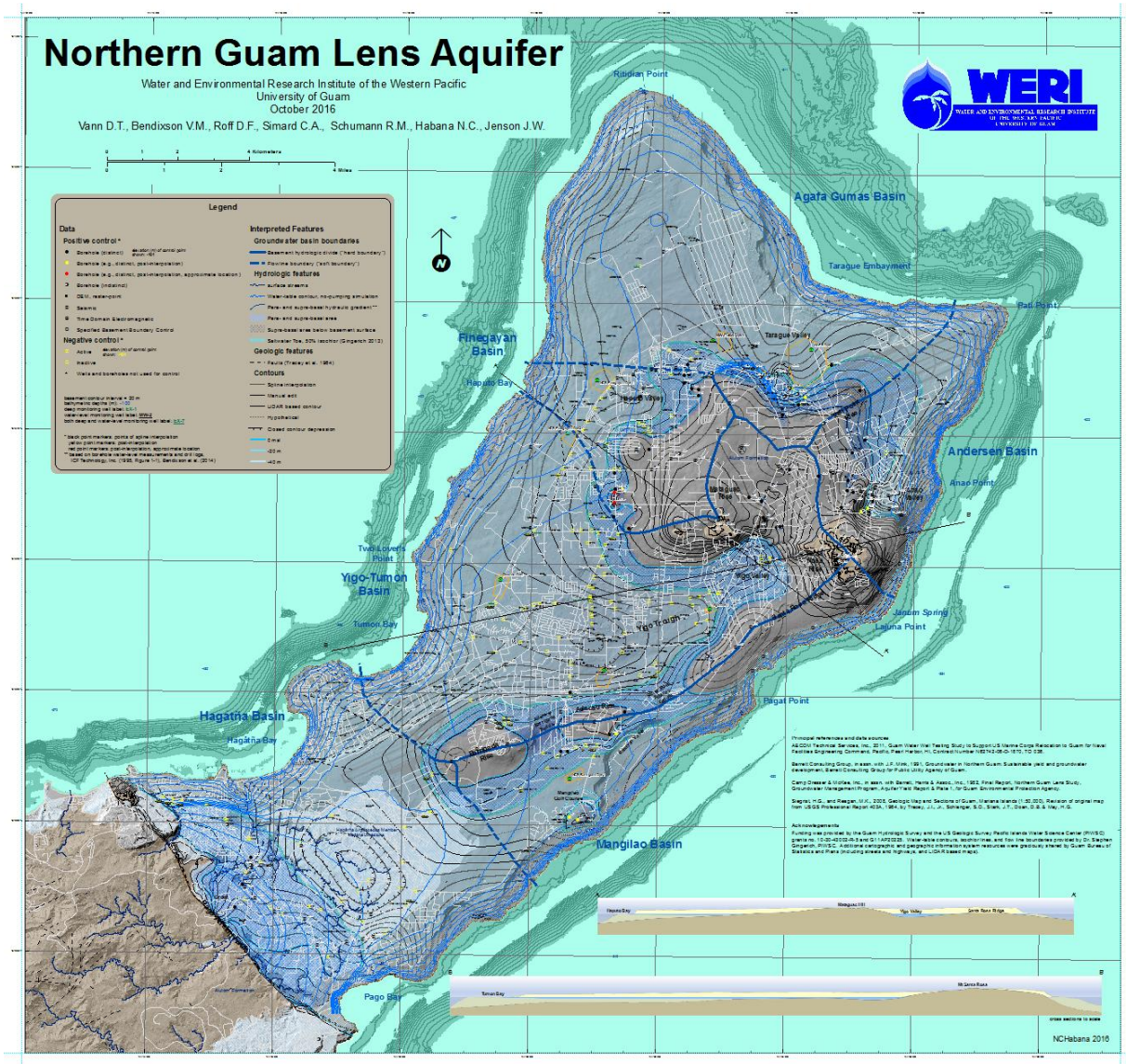
Outcrop on the summit of Mt Alutom, which gives its name to the entire unit of basement rock beneath the limestone plateau of northern Guam.

underlying sea water and becomes progressively thinner and saltier until it discharges at coastal springs and seeps. Water flowing down the flank of the volcanic slopes above sea level, designated *supra-basal* water, is the freshest of the water in the aquifer and is completely invulnerable to contamination by sea water. The first detailed map of the basement topography was produced as part of the 1982 Northern Guam Lens Study. Beginning in 1998, with the establishment of the Guam Hydrologic Survey by the 24th Legislature, WERI began updating and revising the 1982 map based on new data and insights acquired by exploratory drilling, the emplacement of new monitoring wells, and other data obtained incidental to ongoing local aquifer development and military installation environmental remediation projects.

Most recently, the exploratory drilling program undertaken by the US Navy in 2010 in support of the anticipated military build-up provided additional new control on the elevation of the basement in crucial locations. Moreover, the new Guam Groundwater Availability Study led by the USGS Pacific Islands Water Science Center, in collaboration with WERI,

provided additional funding to update the database that supports the map. An accurate map of the basement topography is an essential prerequisite for building accurate and reliable groundwater models, which is one of the goals of the groundwater availability study.

WERI first published the updated basement map in 2014, along with WERI Technical Report 142, which describes the supporting data, explains how the data were interpreted in developing the map, and highlights the map's strengths and limitations. The aquifer map is actually a composite set of maps, which shows the basement topography as a component of aquifer geology, along with surface topography and structural features, and the locations of drinking-water production wells and aquifer observation and monitoring wells. The map is available on line and an essential tool for environmental scientists, hydrogeologists, engineers, regulators, and policy-makers for protection and sustainable management of the aquifer.



Northern Guam Lens Aquifer map.

Ongoing and planned work on the hydrologic map set of the Northern Guam Lens Aquifer

The Northern Guam Lens Aquifer is Guam's primary source of freshwater, and if managed properly will continue to supply the island's daily water needs for generations to come. It is also a very complex hydrogeologic system. No single map can characterize this aquifer. Rather, a multi-layer analysis is required to describe, model, and manage the groundwater system. The development of a set of hydrogeologic maps that captures each of the components—while also providing a means for showing their inter-relationships—is of basic and utmost importance for successful exploration, development, and management of the aquifer.

The creation of an up-to-date map of the basement topography (as described above) has provided the first step toward an integrated, multi-layered hydrologic map. The current map includes not only updates of the boundaries of the aquifer's six groundwater basins, but also provides for more accurate and detailed demarcation within each basin of its three groundwater zones: basal, para-basal, and supra-basal. The 2013 update incorporated new insights gained from the 2010 Exploratory Drilling Program funded by *Naval Facilities Engineering Command Pacific* (AECOM Technical Services Inc., 2011), and the 2013 *Guam Groundwater Availability Study* (Gingerich, 2013; Gingerich and Jenson, 2010).

The 2013 update also shows no-pumping water-table simulation from the modeling study to estimate the phreatic surface, hydraulic gradients, flow lines, and basin boundaries. The modeled lens geometry shows the estimated location of boundaries of the para-basal zone. Drill-logs and contours of supra-basal waters (ICF Technology, 1995) were also incorporated in the map. Occurrence of surface streams over the Hagåtña Basin and adjacent terrain were also included. Semi-transparent surface hill-shading provides a surface elevation perspective of the limestone plateau. Other hydrologic features that can be added to the current map or included in complementary maps in the set include hydraulic conductivities, geologic features, soils, porosities, pumping effects, land cover, and rainfall distribution. Priority is being given to the following, as research funding becomes available:

1. Sinkholes and closed contour depressions

The first priority is a map of the sinkholes on the aquifer surface, which are elements of its natural surface drainage system. Spatial analysis of LiDAR-based digital elevation model allows a precise determination of closed contour depressions on the limestone plateau.

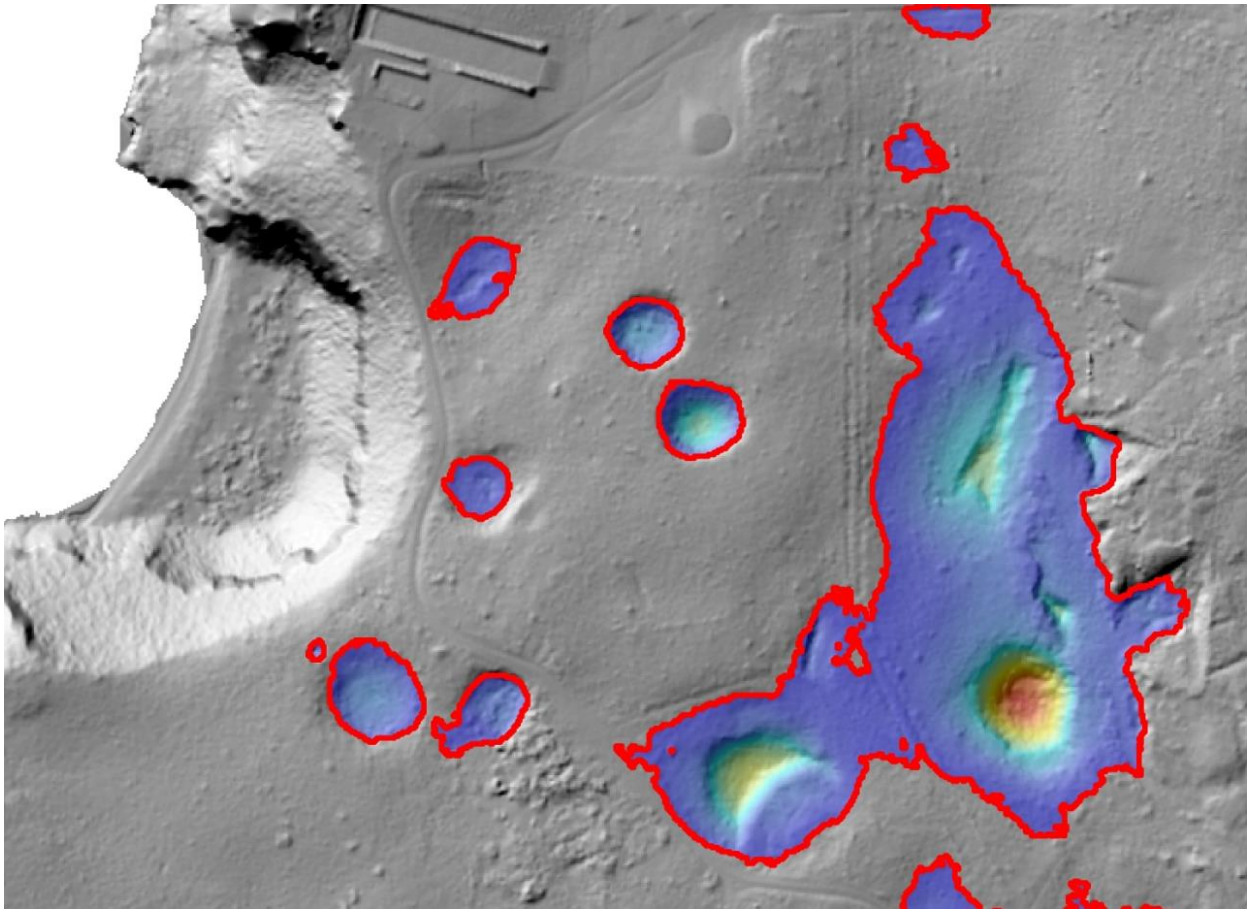
Mapping these depressions and their relationships to other hydrologic and geologic features will be a major contribution to determining the distribution of recharge between fast vertical conduit flow channels and slow percolation through the bedrock. This is important for accurately modeling aquifer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

2. Wastewater system

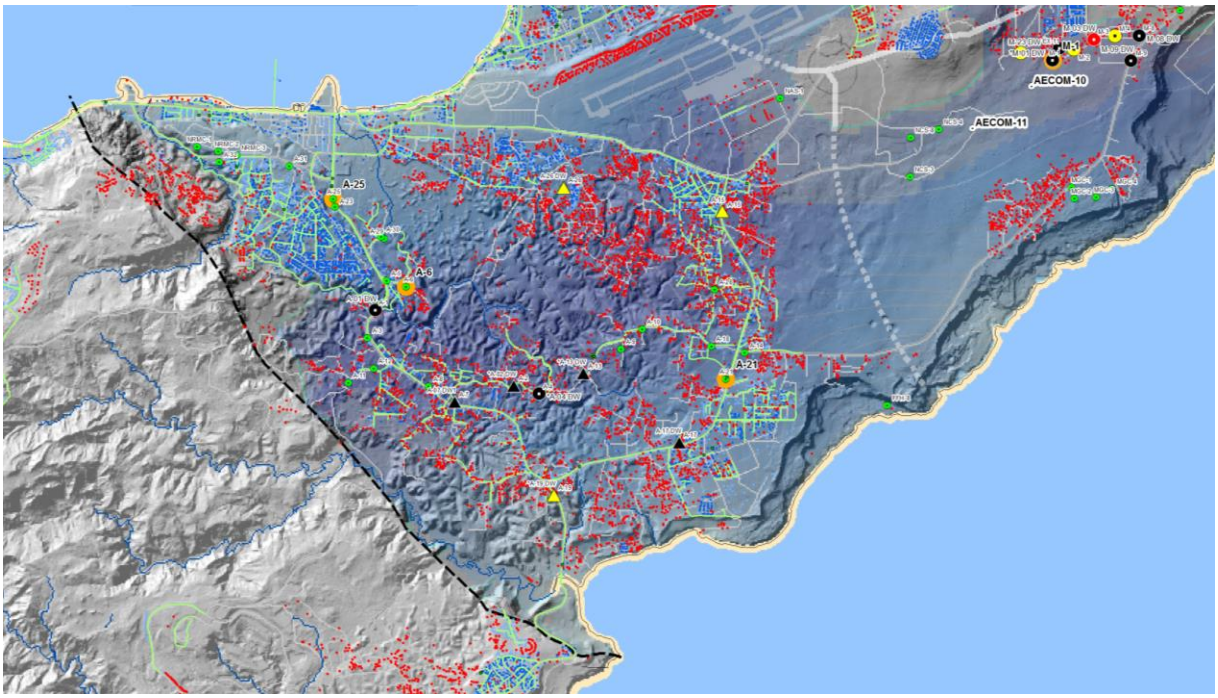
Development on the surface of the NGLA is raising concerns over possible wastewater contamination, as residential and business wastewater discharged at the surface and near-surface

may be a threat to the freshwater lens below. Increased and denser development may intensify wastewater discharge.

The NGLA map and the layover of the wastewater system provides a useful assessment tool for contaminant transport. It was recently used in the initial assessment of PFOS (Perfluorooctane-sulfonic acid) contaminant source potential. The map may also be useful to determine prioritization of sewer systems. The wastewater system map over the NGLA map will help planners manage future development and reduce wastewater contamination.



LiDAR image of sinkholes and surface depressions (Haputo Bay area).



Septic tanks and sewer lines, with location of wells also shown.

3. Sustainable Management of Guam's Water Resources

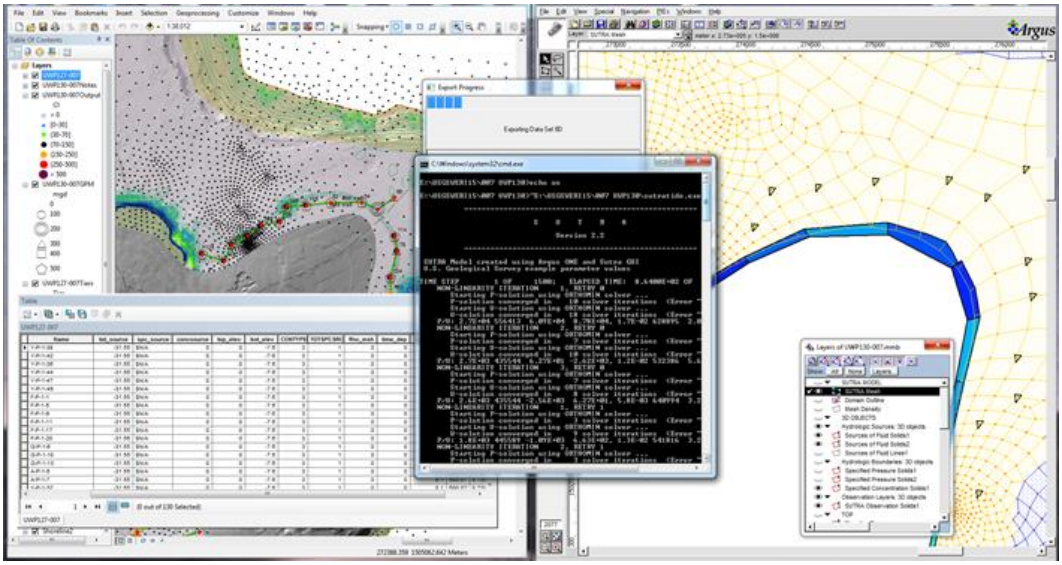
The Northern Guam Lens Aquifer (NGLA) provides 90% of Guam's drinking water. The anticipated addition of US Marine Corps activities will require additional production, while ongoing economic growth will increase demand as well. Policy-makers and water managers have begun asking "what is the absolute *maximum* volume of water that could be sustainably withdrawn from the aquifer?" Answering such a question requires identifying (1) the *natural limits* on aquifer recharge, storage, and water quality imposed by climatic and geologic conditions, (2) , but doing it *for an ideal production system*, i.e., one that is constructed and operated so as to achieve the maximum possible production for a given standard of quality.

Assessing the natural limits on aquifer production

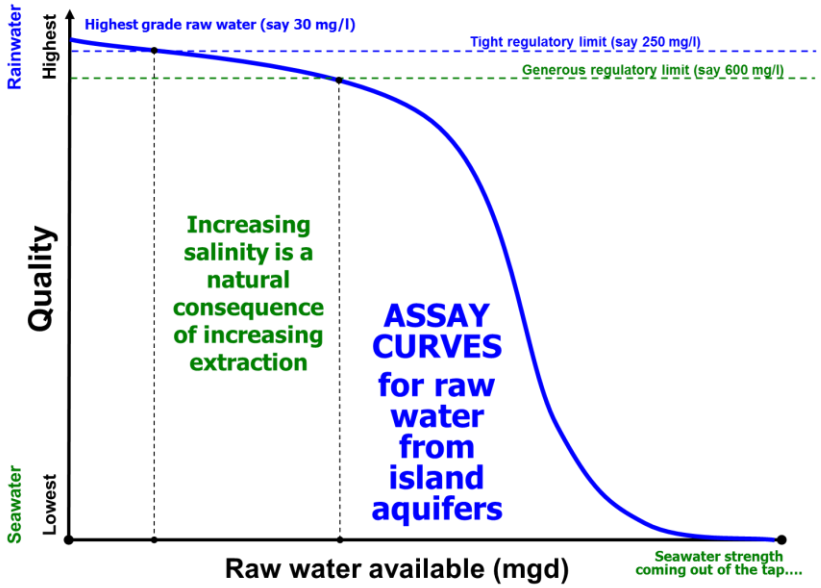
This study is directed at estimating the *maximum potential capacity* of the NGLA, i.e., the capacity that ultimately *could* be achieved by an ideal production system, given what we currently know or must assume about the natural limiting conditions. Recent modeling has incorporated the current state of knowledge regarding natural conditions and constraints. The current phase of the modeling project simulates maximum yield from the para-basal zone—the optimum location in the aquifer. In the next phase, estimates of maximum potential capacity can be made by exploring scenarios to evaluate the effects of changes in well depths, addition of new wells, and changes in pumping rates. This study will thus help provide some estimates of the absolute upper limits of production that could, in principle, be achieved by an optimum system. These will provide ultimate baselines against which to make economic evaluations of future options for holistic sustainable management of the aquifer.

Upper limits to production, however, must be measured in terms of the quality of groundwater associate with a given production target, however. In island aquifers, the salinity of the water increases

(thus the quality decreases) as production increases. The ongoing modeling study is thus directed at quantifying the trade-off between quantity and quality, which can ultimately be expressed as an *assay function* or *assay curve*. One of the objectives of the modeling study is thus to identify the assay curves for hypothetical alternative future production systems.



Numerical modeling to simulate effects of different extraction systems.



Notional assay curve for a coastal/island aquifer.

3. GHS Workshop Series

The military buildup and ongoing economic growth anticipated on Guam over the next decade has raised concerns regarding sustainable management of Guam's groundwater resources. Besides educating policy-makers and agency heads, it is also essential that island water resource professionals and educators be equipped with an accurate and up-to-date understanding of the essential characteristics of the island's aquifer and the factors that must be considered to frame and implement sustainable management practices. Professional people, including working-level technical professionals in the water resources industry, university instructors, and school teachers, have extremely limited time to engage in instructional opportunities. The GHS has thus developed a series of short-course workshops for local water resource professionals and educators. Instructional content can be tailored to specific audiences, but can include the following:

- the NGLA database, and development and use of the aquifer map set
- sinkholes and surface drainage of the aquifer
- salinity trends, patterns, and processes in the aquifer
- the 3-D virtual tour and professional field trip of the NGLA
- an introductory workshop in basic GIS
- ENSO

Instruction and media organization is supported by the GHS website containing the instructional materials plus additional references and links to other relevant and useful resources, and forums for maintaining continuing educational interaction and information-sharing.

Comprehensive Water Monitoring Program (CWMP)

The United States Geological Survey (USGS) has monitored Guam'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 US Naval Base Guam, but continued to run a limited monitoring program (out of its Saipan and Honolulu offices).

In August, 1998 the CWMP was made a permanent part of WERI's program when the legislature enacted PL 24-247. This resulted in the refurbishment of the deep monitoring wells and a renewed program of water resource monitoring on Guam. The intent of PL 24-161 was to restore, and then to expand, as needed, the discontinued monitoring program in order to help Guam manage and safeguard all of its freshwater resources, now and in the future. Under PL 24-161, WERI/UOG and the USGS entered into a memorandum of understanding to administer and fund this program on a 50/50 cost-sharing basis. The CWMP is a permanent investment in Guam's future.

The loss of a hydrologic observation program has proven to be detrimental. Good hydrologic research studies and support for water management decision essentially require consistent and accurate data. Gaps in data can limits a really good analysis and interpretation. This was experienced in the modeling of the NGLA (Gingerich 2013), where more information in the

Agafa Gumas basin could have greatly improved the accuracy of the simulation. The interest and value is now well recognized in the preparation for the expansion of groundwater monitoring with the addition of eight new observation wells (Appendix II).

CWMP Research Projects

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

1. Monitoring (observation) programs

The monitoring/observation program is improving. USGS-WERI continues to work as a team in collecting well hydrologic information. The Guam Water Resources Development Group and the Technical Experts Group are also currently discussing and preparing for installation of eight new observation wells. WERI and Guam Waterworks Authority (GWA) established cooperation in a Memorandum of Understanding, where GWA shares the monthly water production report and quarterly well water chloride concentration data. Wastewater-nitrogen data are now being logged in two production wells in the Yigo area.

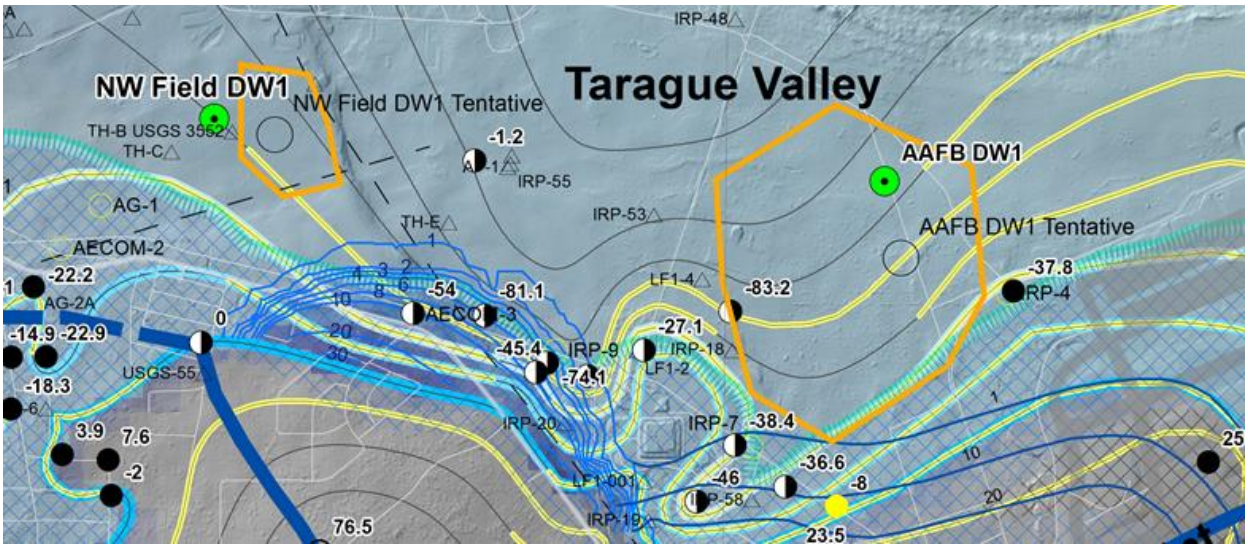
Interagency cooperation agreements

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

New Deep Observation Wells for the NGLA

In August 2016, the Guam Water Resources Development Group and Technical Experts Group agreed to stand up a field team to visit the tentative sites (marked by open circles in the maps below) within the general locations (marked by orange polygons) proposed by WERI and USGS for each of the eight new deep observation wells to be installed in the aquifer, and designate at each location a suitable site at which to drill each well (green circles with black dots).

The team was led by WERI Senior Hydrogeologist, Dr. John Jenson, and included technical staff and consultants from Guam Waterworks Authority (GWA), Naval Facilities Engineering Command Marianas (NAVFACMAR), and the 36th Civil Engineering Squadron (36 CEV) Environmental Flight. Team members received training on Munitions and Explosives of Concern (MEC) on 13 Oct and 16 Nov 2016, and deployed to the field on 28, 29, and 30 Nov, and 20 Dec 2016. The report (Appendix II) was prepared and submitted to GWA, NAVFACMAR, and 36 CEV, with considerations and recommendations for each selected site.



Sites for proposed new wells, NW Field DW1 and AAFB DW1, in the Andersen and Agafa Gumas Aquifer Basins.

Name	Latitude	Longitude
NW Field DW1	13.590759	144.880434
AAFB DW1	13.588623	144.906147
NCS Finegayan DW2	13.566813	144.842522
NCS Finegayan DW1	13.580353	144.850237
NCS Barrigada DW1	13.478581	144.843912
Marbo DW1	13.506319	144.852678
Yigo DW1	13.522250	144.880164
Okkodo DW1	13.529377	144.825345

GPS coordinates of the designated well sites.

Nitrogen-Baseline data

Preliminary inquiries have suggested that contaminants from anthropogenic sources are showing up in the NGLA. Much more baseline data are needed, though, to determine if the problem is greater in zones with sewer collection lines or in zones that rely on household septic tanks. Furthermore, from the current data it is not known if ammonium and nitrate levels in the environment are changing with time. Results do show, though, that ammonium is nearly absent in the groundwater, indicating that biologically induced nitrification is occurring in the environment. The presence of low levels of nitrate corroborate this, though there is no clear indication yet that denitrification is occurring. It is essential that these issues be studied before actions are taken to extend sewer collection lines or even build new wastewater plants in Northern Guam. In addition, the effectiveness of septic tanks is also an issue of concern. As an alternative to traditional septic tanks, consideration is increasingly given to use of single-family prefabricated, packaged treatment units. These units could serve to reduce the potential of contamination reaching the water table, and indeed test results of effluent from a prefab-unit on island show far cleaner discharge as compared to a conventional septic tank. Further comparative testing is to be conducted.

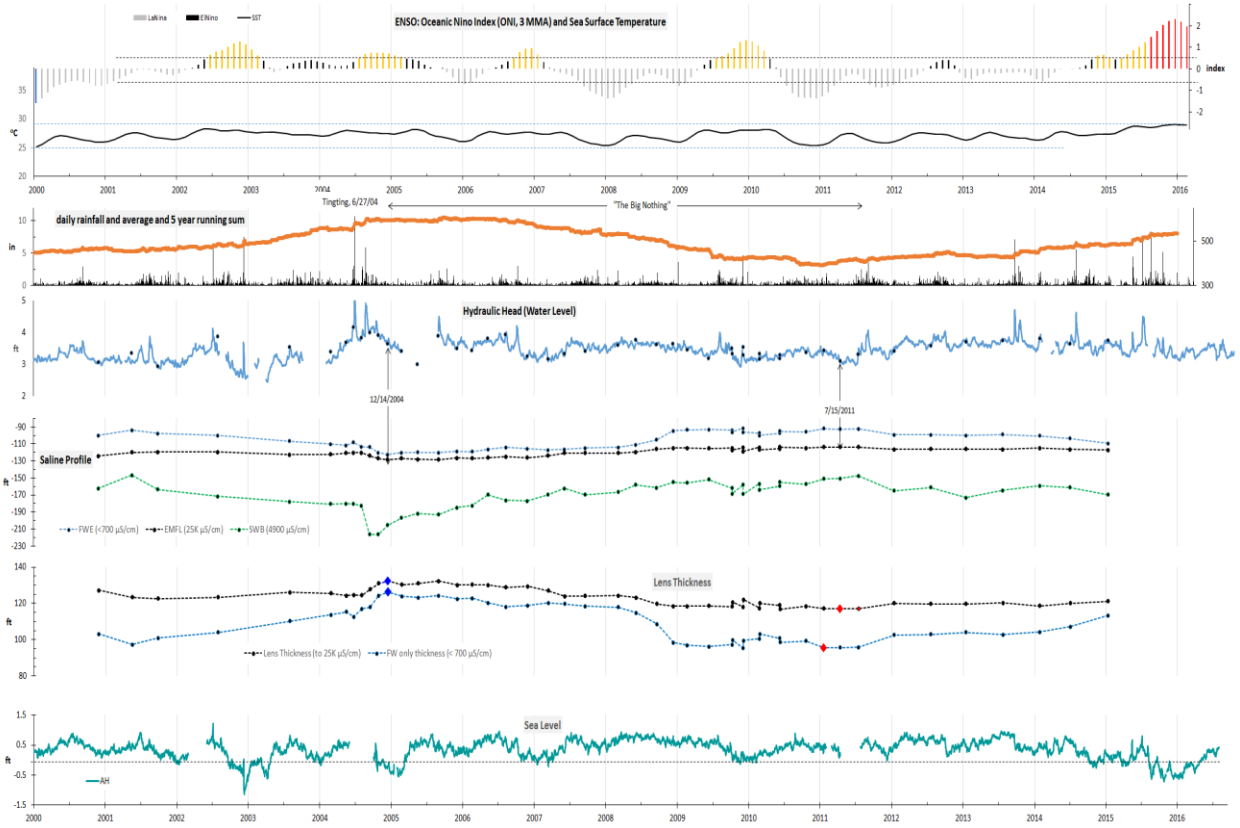
Hourly nitrate-N and ammonium-N data at Well Y-3

2. Data analysis research

Freshwater lens responses to recharge

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

The quantity of groundwater available for extraction can be measured in terms of the freshwater lens thickness. Lens thickness can be measured directly from well salinity profiles and inferred

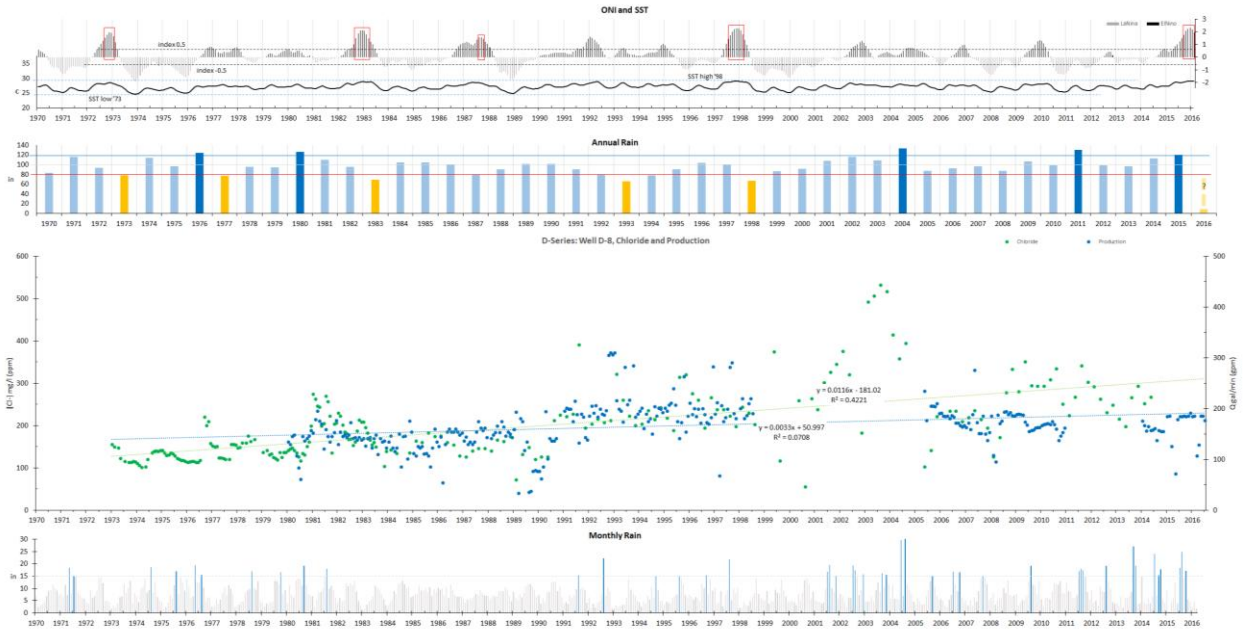


Multi-variable time series analysis of lens thickness, observation Well EX-7

indirectly from water levels. The lens thins or thickens in response to storage changes from recharge and water withdrawal (production). The amount of recharge that replenishes the aquifer depends primarily on seasonal and inter-annual changes in rainfall. This project is evaluating how the volume of water stored in the freshwater lens responds seasonal changes in rainfall, isolated storms, and El Niño Southern Oscillation (ENSO) events and typhoons.

Salinity trends in the Yigo-Tumon Basin

This project with the Guam Hydrologic Survey continues the process of updating the production well and chloride concentration database for the NGLA. Its purpose is to examine the Yigo-Tumon basin for historical trends and potential influences on salinity. The Yigo-Tumon basin accounts for over half (17 mgd) of the production of the total production (36 mgd) from the aquifer's six basins. The analysis focuses on natural influence/causes of salinity in production wells in the Yigo-Tumon Basin. We aim, in particular, to test the hypothesis that seasonality and the El Nino Southern Oscillation have a significant influence on the salinity in the wells.



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

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

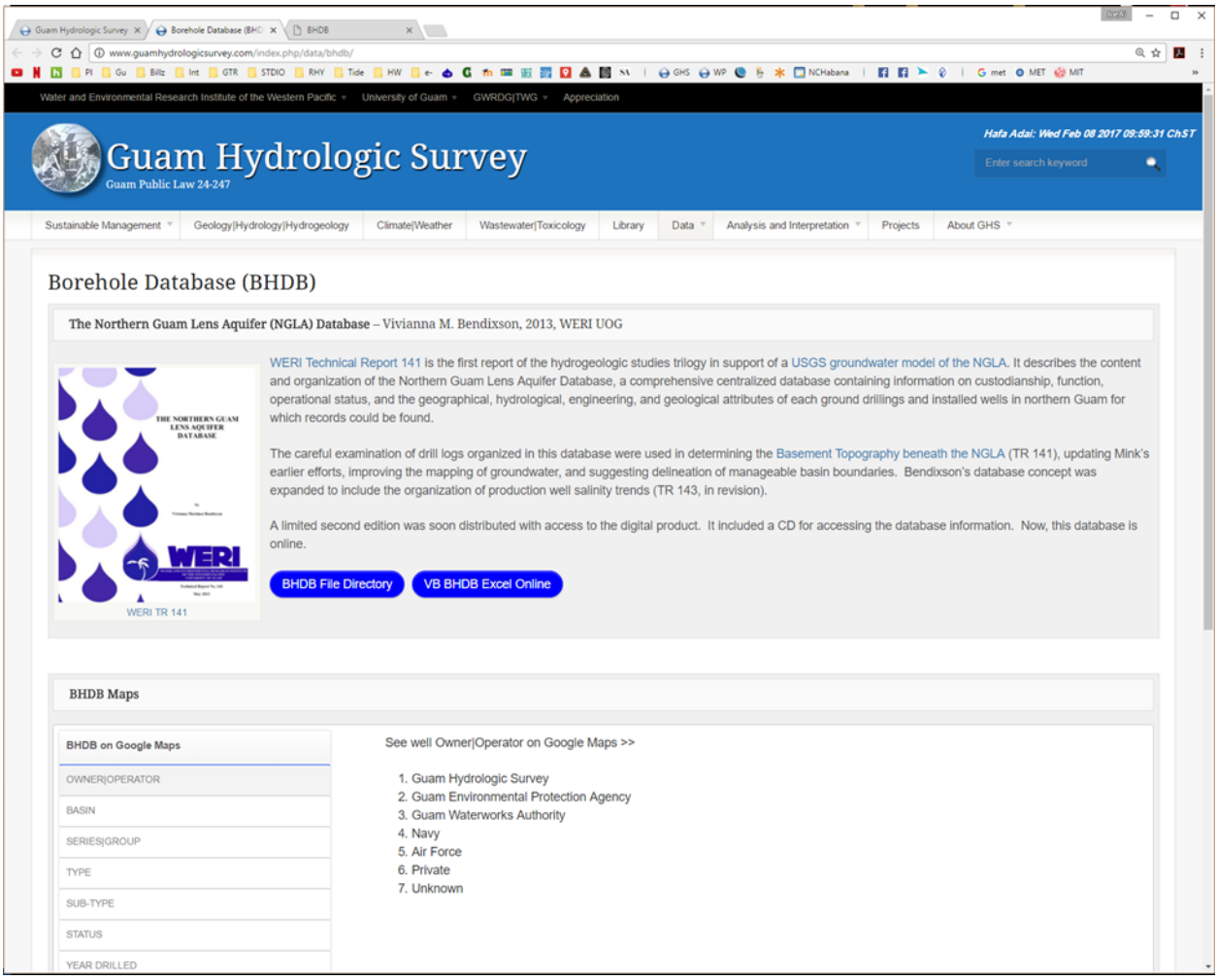
GHS and CWMP Online

Development of the Guam Hydrologic Survey website is ongoing. The GHS mandate requires the consolidation of pertinent Guam hydrologic data into a single computer-based library where information may easily be accessible. WERI is now in position to make hydrologic data access even easier by developing the GHS website (www.guamhydrologicsurvey.com).

The current website was first introduced in the 2016 GHS workshop, the 2016 Guam Advisory Council Meeting, and the 2016 American Water Works Association (Guam sub-chapter) meeting. The workshop trained the members of the Groundwater Resource Development Group Technical Experts Group, and private consultants. It has also been proven to be a very useful source of information to assist in the rehabilitation of GWA wells in a teleconference with WERI and local engineering consulting firms. The website contains the borehole database (WERI Technical Report 141), aquifer map (Technical Report #142), and chloride and production database (Technical Report 143). AECOM and other firms have referenced the site in its reports. Soon, borehole videos of the rehabilitated wells will be available through the website.

The GHS website is continually being refined to make the information in it accessible and easy to understand and interpret. As demand for freshwater grows, sustainable management will

require not only more detailed knowledge of the geologic and hydrogeologic properties of the aquifer and infrastructure, but also deeper understanding the economic and social constraints on the location and technologies for development, as well as conservation. Future development of the database will thus include information and links to primary sources of information on such aspects as supporting infrastructure (e.g., roads and power lines), water use, and land use.



Guam Hydrologic Survey website www.guamhydrologicsurvey.com

SUMMARY OF FY'16 EXPENDITURES FOR GUAM HYDROLOGIC SURVEY APPROPRIATION

Below is a composite summary of all expenditures lodged against the GHS account during FY'16. As in past years, budgetary shortfalls arising out of austerity measures implemented by the Guam Legislature have so far been covered by carryover funds from GHS allotments received in previous years. As these reserves are limited they cannot be expected to sustain the program at its current high rate of activity for too much longer. This notwithstanding, we gratefully acknowledge the Guam Legislature for their continued interest in and support of the GHS program and all associated water resources related research, education and training activities carried out at WERI.

Guam Hydrologic Survey Expenditures Summary for FY'16

Category		*Expenditure*
1.	**Salaries and Wages:**	**$44,787.00**
2.	**Fringe Benefits:**	**$2,946.75**
3.	**Tuition Fees**	**$0.00**
4.	**Supplies:**	**$13,100.85**
5.	**Computer Hardware/Software:**	**$2,555.00**
6.	**Equipment/Office Furniture:**	**$21,116.69**
7.	**Projects/Consultant Fees:**	**$5,102.40**
8.	**Postage/Long Distance Phone:**	**$1,941.00**
9.	**Printing:**	**$0.00**
10.	**Utilities/Subscription/Dues:**	**$0.00**
11.	**Administrative Fees*:**	**$18,269.40**
12.	**Miscellaneous :**	**$1,624.00**
Total FY'16 Expenditures:		**$111,443.54**
Total FY'16 GHS Allotment Rec'd as of 9/16:		**$149,252.00**
Balance:		**$37,808.46**
Total Approved GHS Budget Allotment for FY'16:		**$182,694.00**

GHS Comprehensive Monitoring Expenditure Summary for FY'16

Category	*Expenditure*
1. Projects/Consultant Fees:	**$149,252.00**
2. Administrative Fees*:	**$15,562.60**
Total FY'16 Expenditures:	**$164,814.60**
Total FY'16 GHS-CM Allotment Rec'd:	**$155,626.00**
Balance:	**-$9,188.60**

Total Approved GS-CM Budget Allotment for FY'16: $155,626.00

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

(BBMR PFS-1)

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

Government of Guam
Fiscal Year 2016 Budget
Program Fiscal Summary

Budget Account Allocation / FUND TITLE	Fund	FY2015 Actual Appropriation	FY2015 Percent of Program	FY2016 Authorized Appropriation	FY2017 Current Service	FY2017 Program Plan	FY2017 Governor's Recommendation	FY2018 Projected	FY2019 Projected
General Fund Appropriation		$941,847		$941,847	$941,847	$1,049,521		$1,154,473	$1,269,920
Guam Hydrologic Survey (Local)		$182,694		$182,694	$182,694	$182,694		$204,200	$204,200
Guam Water Monitoring Project (Local)		$155,626		$155,626	$155,626	$155,626		$173,948	$173,948
USGS Water Institute Program (Federal)		$277,005		$277,005	$277,005	$277,005		$277,005	$277,005
ENSO Application Center (Federal, National Weather Service)		$100,000		$100,000	$100,000	$100,000		$100,000	$100,000
National Science Foundation (Federal)		$164,335		$164,335	$164,335	$59,875		$0	$0
National Park Service (Federal)		$21,100		$21,100	$21,100	$21,100		$21,100	$36,816
Total Program Appropriations		**$1,842,607**		**$1,842,607**	**$1,842,607**	**$1,845,821**		**$1,930,726**	**$2,061,889**

I. PARTIES

Parties to this Memorandum of Understanding (MOU) are the United States Navy and the Guam Waterworks Authority (GWA).

II. PURPOSE

It is the desire of the Parties that through joint planning and cooperation the requirements to meet the water and waste water needs expected from the proposed military buildup on Guam can be met in a manner that is mutually beneficial and maximizes the effectiveness of the overall Department of Defense (DoD) and GWA utility systems. The purpose of this MOU is to establish objectives and a framework for further discussions relating to the implementation of utility service solutions devised to address the projected additional water and waste water requirements of the proposed military build up in Guam due to the planned relocation of Marines from Okinawa to Guam and other matters identified in the Draft EIS/OEIS Guam and CNMI Military Relocation. The Parties further recognize that this MOU, and the objectives, goals, and processes agreed upon are subject to applicable laws of the United States and the Government of Guam, and that such legal requirements applicable to either Party take precedence over any understanding reflected in this MOU.

III. REPRESENTATION

The Parties may appoint and designate representatives to meet, at such times and places as are mutually convenient. As necessary, the Parties may invite representatives from relevant Federal and Gov. Guam agencies that may have a

stake in these matters to participate in the discussions. The parties agree to work in good faith to accomplish the objectives set forth in this MOU.

IV. INFORMATION SHARING AND DECISION MAKING

The Parties agree to make every reasonable effort to share with one another existing information relevant to their water-related requirements and proposed solutions in a timely manner. Such information may consist of technical descriptions of each supplier's facilities, planning studies, estimates, requirements, designs, rates, schedules, and forecasts. Each Party will designate a representative to respond promptly to requests for information or explain why such information cannot be provided.

V. OBJECTIVES

The Parties recognize that all the water resources on Guam are critical assets essential to the future of Guam and must be protected for present and future uses. This fundamental principle will guide the objectives set forth below, the efforts to provide water for the people of Guam and cooperation between the Parties.

The Parties understand that the following general objectives are to be achieved:

1. Identify costs attributable to increased military requirements. Details concerning allocation of those costs will be incorporated into the agreements as appropriate.
2. Cooperate with federal and local agencies to resolve the challenges, including

funding, to provide potable water and waste water treatment services for DoD and civilian population growth associated with the military build-up.

3. Work to develop and utilize common standards related to security, reliability, interoperability, construction and performance.

4. Utilize available financing from the Government of Japan (GOJ) to the extent available.

DRINKING WATER OBJECTIVES:

1. Develop processes for sharing information and making resource and infrastructure decisions, with the ultimate goal of joint management of the Northern Guam Lens Aquifer (NGLA) and protection of water resources on Guam.

2. Develop permanent drinking water supplies sufficient to meet:

a. the requirements of the military buildup on Guam and associated requirements identified in the EIS, and

b. the requirements of Guam's projected civilian growth and development.

c. future requirements of the people of Guam extending beyond the military buildup and its related impacts.

3. Improve the overall quality, reliability and availability of the water supply for all of Guam.

4. Provide the framework for subsequent agreements for the transfer, exchange and cost recovery of water resources between the Parties.

5. Coordinate efforts to resolve the challenges of providing water treatment for DoD and civilian populations.

WASTE WATER OBJECTIVES

1. Cooperate with regulatory agencies to resolve the challenges of providing waste water treatment for Guam civilian and DoD population growth.

2. Improve waste water collection and treatment for all of Guam.

3. Cooperate in making facility and infrastructure planning decisions.

4. Support GWA efforts to improve capability of its existing waste water treatment plants to continue to support DoD needs.

5. Provide the framework for subsequent agreements for the treatment of DoD wastewater at GWA facilities.

FUTURE OBJECTIVES

1. The Parties agree to evaluate opportunities to integrate military and civilian water and wastewater systems on Guam. Such integration may involve the future transfer of production, distribution, collection, and treatment systems from Navy to GWA. The Parties understand that such transfer would require agreement on terms and conditions acceptable to both GWA and DoD, subject to GWA meeting reasonable minimum reliability and quality standards, and possible legislative authorization.

2. The Parties agree to establish an interagency agreement for laboratory services.

VI. PROPOSED SOLUTIONS

The following proposals represent the most promising solutions based upon current information, financial, technical, and legal constraints to the objectives identified above.

1. GWA will develop and/or upgrade water and waste water distribution, collection, and treatment systems not located on DoD property, but required to support the increased DoD loads.

2. The Parties will cooperate in determining the most cost effective and timely source(s) of funding to facilitate the proposed solutions.

3. The Parties will identify potential sources of funding for infrastructure impacts associated with the military buildup to include funding from GOJ.

4. Agreed upon costs associated with meeting DoD requirements will be allocated to and paid for by DoD through a utility agreement.

DRINKING WATER

1. The Parties will cooperate in completing studies related to meeting the water needs of Guam including NGLA sustainability studies. DoD studies related to water resources will seek prior coordination with GWA and, as needed, GEPA, United States Geological Survey (USGS) and University Of Guam Water & Environmental Research Institute (UOG/WERI). Future studies will be coordinated between GWA, DoD and other Federal and Gov. Guam agencies that may have a stake or required expertise in these matters. GWA will assist DoD in the development of the objectives and methodology to accomplish such studies.

2. The Parties will cooperate in the selection of future water well sites.

3. The Parties will cooperate in developing appropriate plans for the integration of new water production and distribution infrastructure with existing water systems.

4. The Parties will share water resources as needed to address urgent needs.

WASTEWATER

1. The preferred option for addressing all wastewater needs in northern Guam is to upgrade and/or expand Guam's Northern District Waste Water Treatment Plant (NDWWTP).

2. The Parties will develop a process that addresses the planning loads for the NDWWTP as a basis for calculating cost sharing and sources of funds to facilitate agreement on responsibility for each element.

3. The Parties agree to cooperate in efforts to increase the capacity of the NDWWTP to address applicable regulatory requirements and recognize that such projects must be planned and phased consistent with available funding and regulatory requirements.

4. The parties agree to cooperate to assess potential impacts to other wastewater infrastructure and identify options for mitigating the impacts.

LONG TERM AQUIFER MANAGEMENT

The Parties will cooperate in all aspects of water resource development on Guam to ensure the long term, sustainable management of the NGLA. In order to accomplish this objective, the Parties will designate representatives to convene a management advisory team to make recommendations on priorities and issues. The following provides an initial outline for this team:

1. Senior Advisory Group (SAG) – This group will meet to review recommendations of the Working Group (WG), technical experts and regulatory agencies. SAG will cooperate in developing a prioritization of major water

resource infrastructure projects and sharing of water resources based on current assessments of the NGLA. SAG will likely consist at a minimum of:

a. GWA General Manager or designated representative.

b. CO, NAVFAC MARIANAS or designated representative.

c. CCU, Chairman or designated representative

d. GEPA, Administrator or designated representative

e. UoG-WERI Director or designated representative

2. Working Group (WG) – This group will meet regularly but no less than quarterly to assess the health of the NGLA, make minor adjustments as needed to water resource sharing, and develop a prioritized list of recommendations for SAG on proposed, major water resource infrastructure projects. WG will consist at a minimum of:

a. GWA Chief Engineer

b. NAVFAC MARIANAS UEM Product Line Coordinator

c. GEPA Representative

3. Technical Experts (TE) – This group will maintain regular communication as needed to share water resource data real time and raise concerns and issues to the WG. TE will develop and maintain all databases and technical tools in cooperation with WERI and USGS needed to monitor and assess the health of the NGLA. TE will consist, at a minimum, of:

a. GWA Engineering Staff

b. NAVFAC MARIANAS UEM

c. GEPA

d. WERI

e. USGS

VII. NEXT STEPS

In order to facilitate the possible implementation of the foregoing solutions the parties agree to have further discussions to:

1. Evaluate appropriate rate structures that will provide reasonable security to any private entity and to GWA for the development of additional water and waste water infrastructure.

2. Evaluate applicable laws, service rules and contracts for DoD contributions to system development and determine if such provisions are adequate and fair to IO both parties.

3. Evaluate the feasibility of a private entity performing the upgrade and/or expansion of the NDWWTP and other infrastructure related to the operation and maintenance of the facility. Identify any legal or financial barriers and proposed solutions. Identify any required technical assistance from DoD.

4. Evaluate and monitor the timelines required to implement the proposed solutions relative to the timelines required to meet the demand increase resulting from military and civilian population growth.

5. Develop agreements to formalize the concepts provided herein.

VIII. OTHER PROVISIONS

1. This MOU may be amended subject to the mutual written agreement of the Parties.

2. This MOU does not obligate the funds of either Party and makes no financial commitmen

3. This MOU may be terminated by either Party upon providing 30 days written notice to the other.

4. This MOU is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity, by any party against the United States or GWA, or agencies, instrumentalities, officers, employees, or agents, of either.

PAUL BUSHONG, RADM
Commander, Joint Region Marianas

Date: 14 Jul 10

SIMON A. SANCHEZ II
Chairman, Consolidated Commission on Utilities

Date: 16 Jul 10

PETER S. LYNCH, CAPT
Commanding Officer
Naval Facilities Engineering Command Marianas

Date: 16 July 2010

JOHN BENAVENTE
General Manager
Guam Waterworks Authority

Date: 16 Jul 10

APPENDIX II

Recommended Sites for the
New Deep Observation Wells for the
Northern Guam Lens Aquifer

Background: At its meeting of 26 Aug 2016, the Guam Water Resources Technical Experts Group agreed to stand up a field team to visit the tentative sites (marked by open circles in the maps below) within the general locations (marked by orange polygons) proposed by WERI and USGS for each of the seven new deep observation wells to be installed in the aquifer, and designate at each location a suitable site at which to drill the well (green circles with black dots).

The team was to be led by WERI Senior Hydrogeologist, Dr. John Jenson, and to include technical staff and consultants from Guam Waterworks Authority (GWA), Naval Facilities Engineering Command Marianas (NAVFACMAR), and the 36th Civil Engineering Squadron (36 CEV) Environmental Flight. Team members received training on Munitions and Explosives of Concern (MEC) on 13 Oct and 16 Nov 2016, and deployed to the field on 28, 29, and 30 Nov, and 20 Dec 2016, as described below.

Purpose of this report: This report describes the activities, observations, and recommendations of the field team for each proposed well site. The report is organized chronologically, by the date and time each location was visited.

28 November 2016

1. <u>Northwest Field Deep Well 1 (NWF-DW1)</u>. Time of visit: 1050/28 Nov 16. Field team: John Jenson, WERI; Gregg Ikehara, 35 CES; Bob Shambach, EA Engineering; Brett Railey, GWA; Prudencio Aguon, GWA; Vince Laguana, GWA; Erin Miller, WERI.

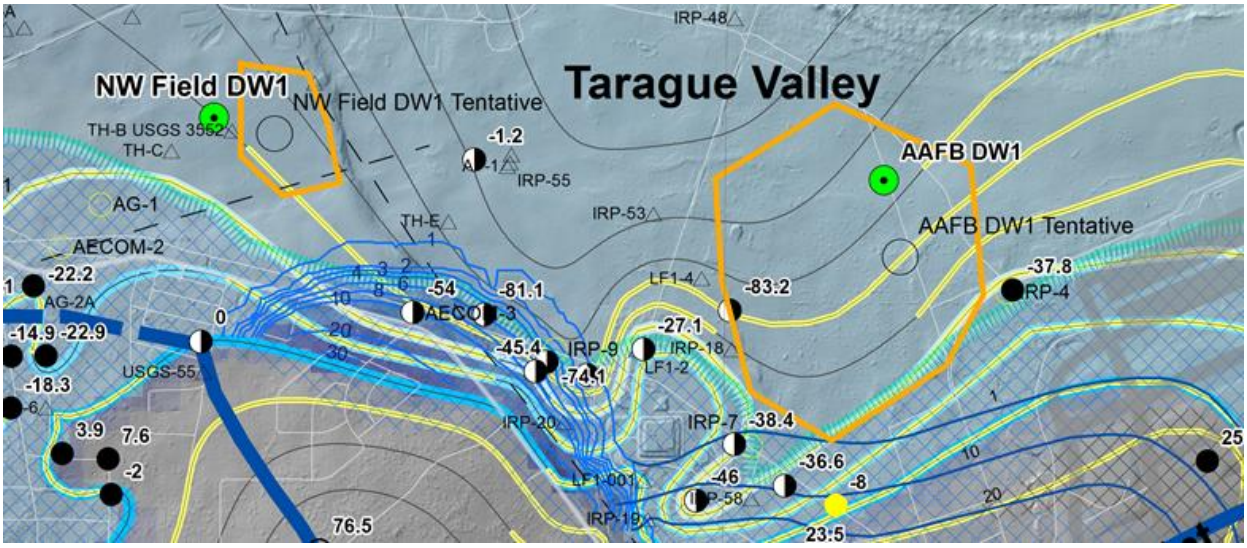


Figure 1a. NWF-DW1 Hydrogeological Considerations: This well is to be placed on the north flank of the Mataguac Rise, just east of the Andersen Air Force Base (AAFB) landfill, on the west (up-thrown) side of the normal fault that can be seen trending NW-SE to the middle of the map. Note that the geology is relatively complex here. Previous observations from nearby AECOM-3 may help in the interpretation of conditions found at the proposed new well.

Actions: The team drove first to well AG-1 (see Figure 1a) and then followed a slightly overgrown jeep trail (Figure 1b) that previously provided access to monitoring well TH-C (now abandoned). Except for knee-high growth of vegetation on the road surfaces, the roads are visible and open. We found a suitable site NW of the preliminary site and perhaps farther from the saltwater toe (see Figure 1a). GPS failed at the site, but we obtained a signal just a few meters away.

Figure 1b. Condition of the access road from TH-C site to designated site for NWF-DW1.

Observations and Engineering/ Construction Considerations: It appears that an extensive network of now slightly overgrown access roads, which apparently supported the previous monitoring wells, exists in this area. The designated site for NWF-DW1 (Figure 1c) is accessible via roads that once serviced monitoring wells TH-B and TH-C (now abandoned). Although the roads are now moderately overgrown (Figure 1b) they are still visible, can be easily cleared, and will support bringing in a drill rig and associated equipment. Due to the soft clayey soil on this terrain, it is advisable to place gravel on the roadway into the site to initially support drill rig access and ultimately support subsequent access of technical personnel to service and collect data from the well.

Recommendations: Install well at the designated site (Figure 1c). It appears that the selected site is outside of the Munitions Storage Area (MSA) arc; however, it would be prudent to confirm this. The site will also require Section 7, Section 106, and MEC surveys prior to bringing in and setting up the drill rig. An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 1c. Designated site for NWF-DW1 (arrow). GPS coordinates in Table 1.

2. <u>Anderson Air Force Base Deep Well 1 (AAFB DW-1).</u> Time of visit: 1300/28 Nov 16. Field team: John Jenson, WERI; Gregg Ikehara, 36 CEV; Bob Shambach, EA Engineering; Brett Railey, GWA; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI.

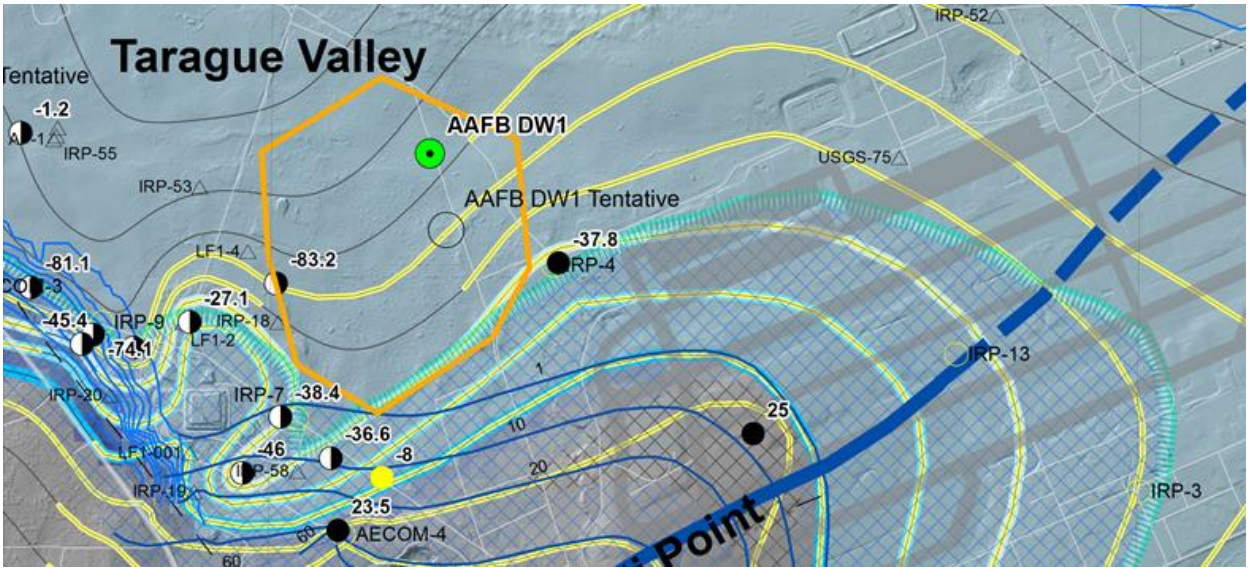


Figure 2a. AAFB-DW1 Hydrogeological Considerations: This well is placed to monitor the freshwater lens along the axis of the Tarague Valley, and it thus to be positioned seaward of the inferred saltwater toe (hachured blue line).

Actions: The team marked the original, preliminary site, then went farther down the utility access road and designated a site west of the access, also along the side of the road, but further seaward from the inferred salt-water toe (Fig. 2b).

Figure 2b. General location for AAFB DW1, looking SE.

Observations and Engineering/ Construction Considerations: The designated location lies on the utility corridor, and appears to be within the environmental monitoring corridor for project J-200. The modest setback requirement will minimize effort and expense for MEC clearance and natural resources compliance, however Section 7, Section 106, and Explosive Safety Submission (ESS) compliance will be necessary.

Recommendations: Install well at the designated site (Figure 2c). This well can be placed along the side of the road, with minimum setback. An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 2c. Designated site for AAFB-DW1 (arrow). GPS coordinates in Table 1.

29 November 2016

3. <u>Naval Communications Station-Finegayan Deep Well 2 (NCSF-DW2)</u>. Time of visit: 1340/29 Nov 16. Field team: John Jenson, WERI; Ramon Camacho, NAVFACMAR; Bob Shambach, EA Engineering; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI.

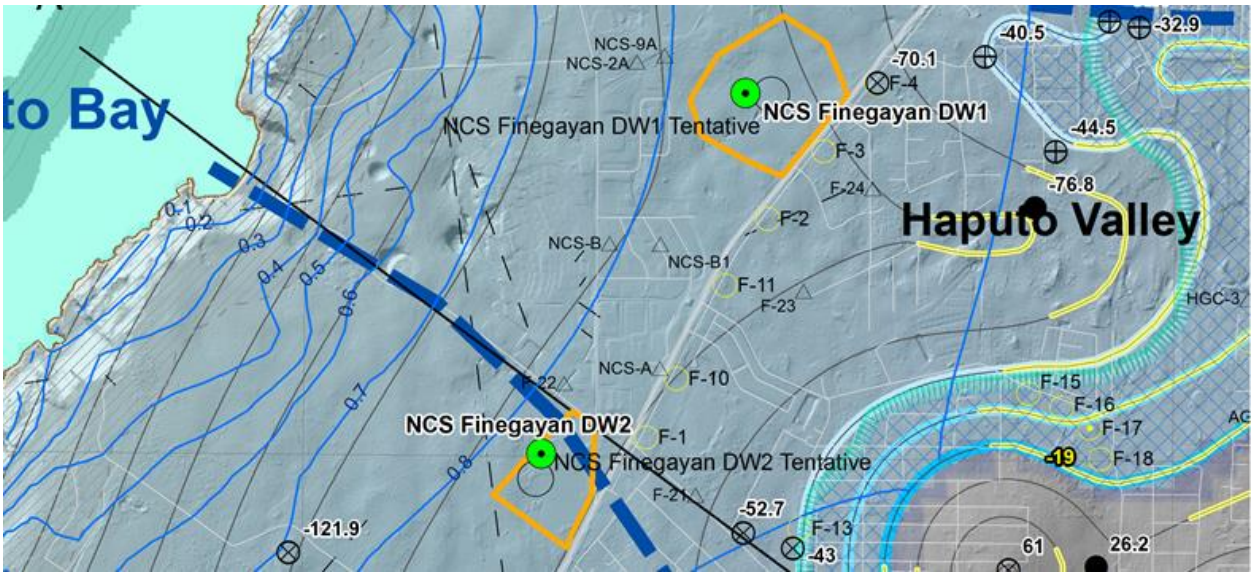


Figure 3. NCSF-DW2 Hydrogeological Considerations: This well is to be placed on the west flank of the Mataguac Rise, along the route of the converging flow inferred (Vann et al., 2014) to form the boundary (dashed blue line) between the Yigo-Tumon Basin (SW side) and Finegayan Basin (NE side). This well is also close to but down-gradient of the F-series wells along the opposite side of the road. This area is structurally and geomorphically complex, containing several mapped faults and sinkholes.

Actions: Field team marked the designated site near the old Officers Mess, north of the ballfield (Figures 3b and 3c).

Figure 3b. General location for NCSF-DW2, looking NNE.

Observations and Engineering/ Construction Considerations: This area is open, clear, and accessible. However, DoD land-use managers will need to confirm that this area is not otherwise already designated for conflicting future development. This site can readily accommodate a drill rig and construction equipment.

Recommendations: Install well at the designated site (Figure 3c). An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 3c. Designated site for NCSF-DW2 (arrow). GPS coordinates in Table 1.

4. <u>Naval Communications Station-Finegayan Deep Well 1 (NCSF-DW1)</u>. Time of visit: 1415/29 Nov 16. Field team: John Jenson, WERI; Ramon Camacho, NAVFACMAR; Bob Shambach, EA Engineering; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI.

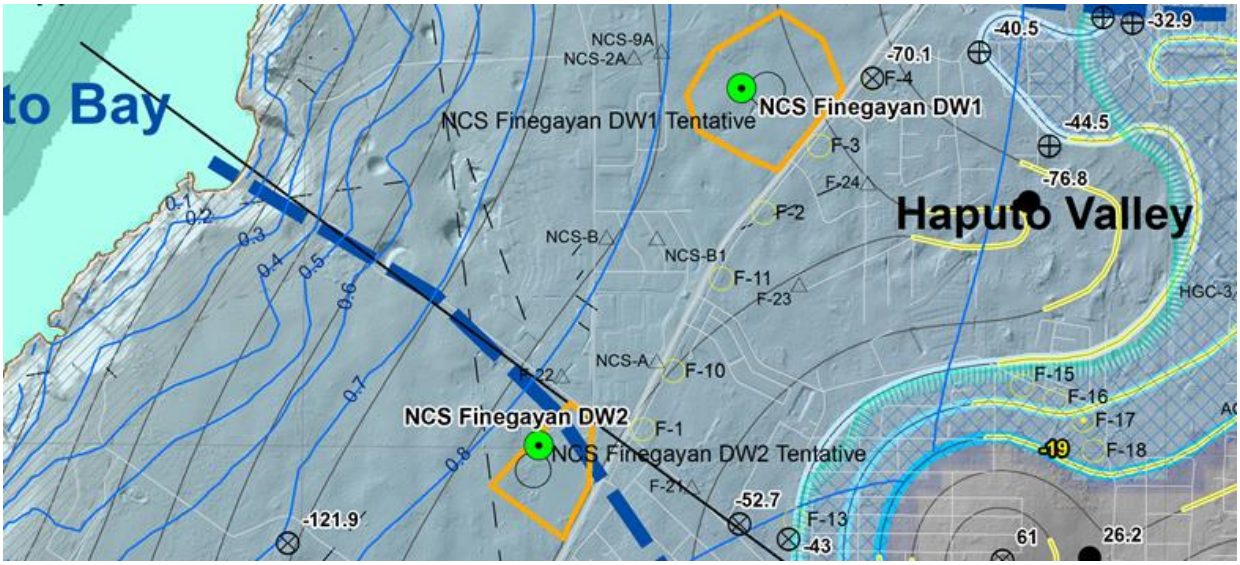


Figure 4a. NCSF-DW1 Hydrogeological Considerations: This well is to be placed near the axis of the Haputo Valley. Note that the proposed location is close by and down-gradient from the Guam Water Authority F-series wells on the opposite side of the road.

Actions: The team drove down the utility easement behind the radar, and found a suitable site close to the tentative location.

Observations and Engineering/ Construction Considerations: This site lies along an established and maintained utility corridor. With attention to the placement of the utilities lines (Figure 4b) the well should be set back from the easement (Figure 4c). The modest setback requirement will minimize effort and expense for MEC clearance and natural resources compliance, however Section 7, Section 106, and ESS compliance will be necessary.

Recommendations: Install well at the designated site (Figure 4c). An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

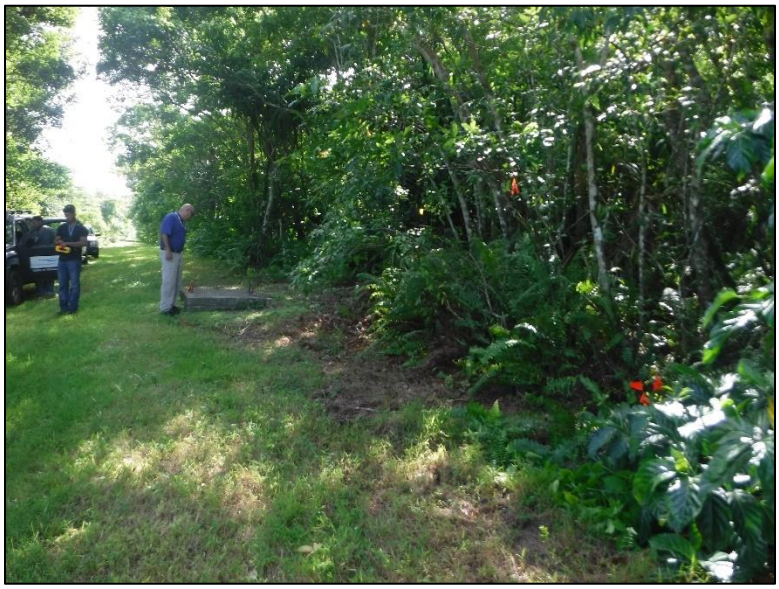


Figure 4b. General location for NCSF-DW1. Note utility manhole access on right-of-way.

Figure 4c. Designated site for NCSF-DW1 (arrow). GPS coordinates in Table 1.

30 November 2016

5. **<u>Naval Communications Station-Barrigada Deep Well 1 (NCSB-DW1)</u>.** Time of visit: 1430/30 Nov 16. Field team: John Jenson, WERI; Ramon Camacho, NAVFACMAR; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI; Matt Spharler, WERI; Bekah Dougher, WERI.

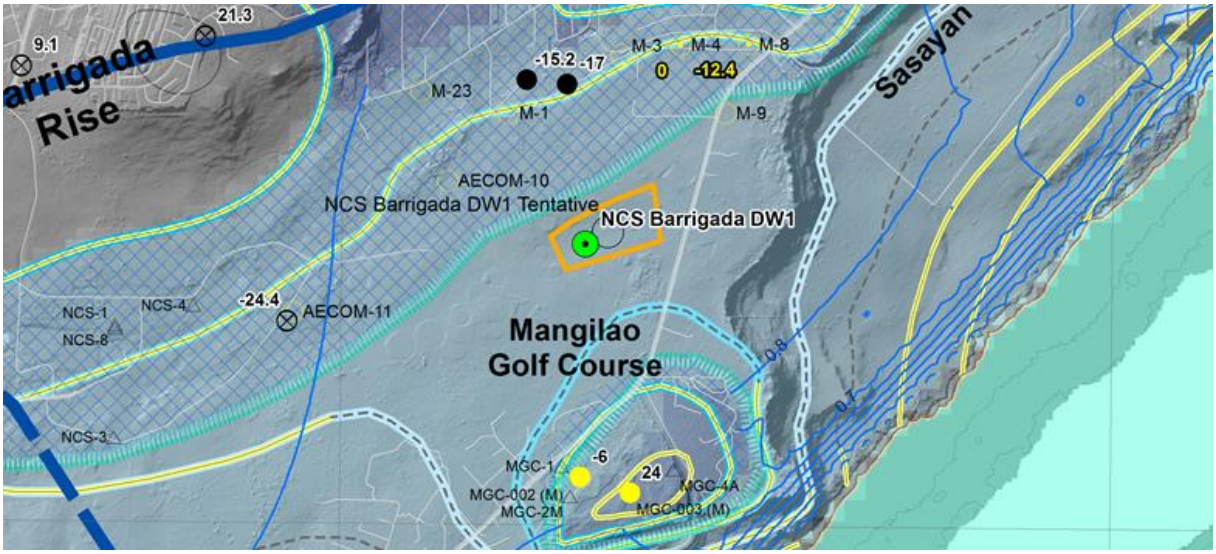


Figure 5a. NCSB-DW1 Hydrogeological Considerations: The hydrogeologic conditions (i.e., the extent and depth of the lens, basement topography, and flow paths) are very poorly known here, despite the intensive development along the Adacao Rise. The proposed well therefore has an exploratory objective to help fill some crucial gaps in baseline knowledge. The inferred depth to the bottom of the lens here, based on inferred (modeled) hydraulic head, suggests that the lens could be thicker than the depth to basement (which is also poorly known). In such a case, the water here could be para-basal. On the other hand, the proximity to the coast imposes the prospect that the lens could be discontinuous here, and that flow might converge on discrete pathways as the water nears the coast. Data from nearby (up-gradient) AECOM-10 and AECOM-11 exploratory wells could aid in the interpretation of observations from this site.

Figure 5b. General location for NCSF-DW1. Note utility

Actions: The team followed the utility corridor to the end of easement on the east end of the line, about 400 feet SW of the tentative site location.

Observations and Engineering/Construction Considerations: This site has open access. There are no obstacles to getting drill rig and construction equipment to the site. With attention to the placement of the utilities lines (Figure 5b) the well should be set back from the easement. The modest setback requirement will minimize effort and expense for MEC clearance and natural resources compliance, however, Section 7, Section 106, and ESS compliance will be necessary.

Recommendations: Install well at the designated site (Figure 5c). An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 5c. Designated site for NCSB-DW1 (arrow). GPS coordinates in Table 1.

6. <u>MARBO Deep Well 1 (MARBO-DW1)</u>. Time of visit: 1600/30 Nov 16. Field team: John Jenson, WERI; Ramon Camacho, NAVFACMAR; Bob Shambach, EA Engineering; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI; Matt Spharler, WERI; Bekah Dougher, WERI.

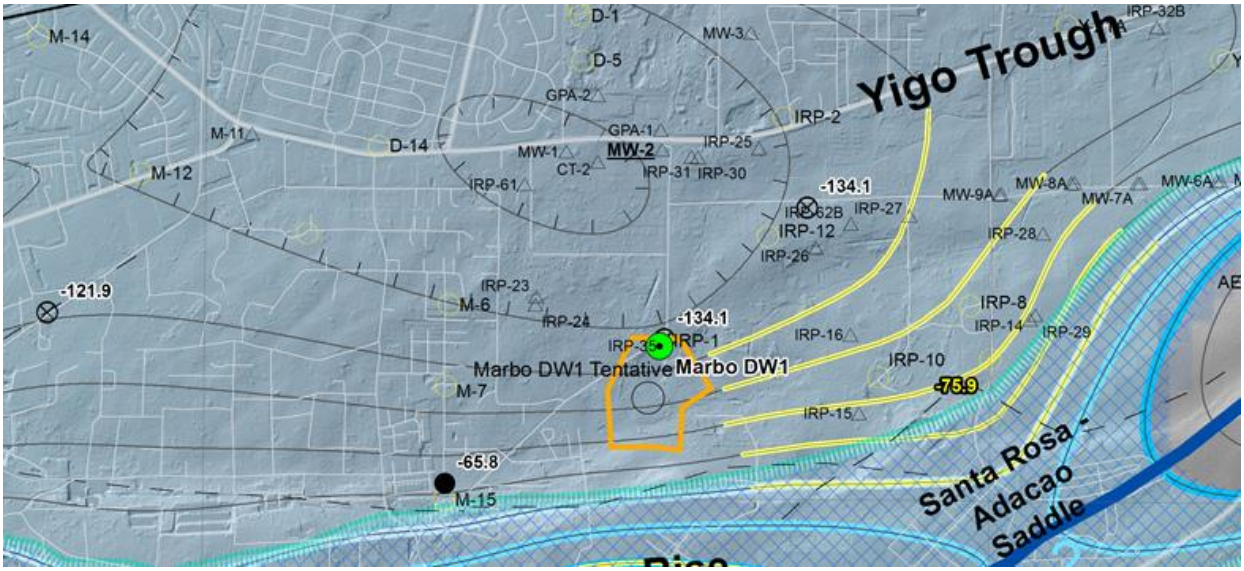


Figure 6a. MARBO-DW1 Hydrogeological Considerations: This well will monitor lens dynamics this highly developed part of the aquifer, along the south flank of the Yigo Trough. Note that the proposed location is close to but presumably seaward of the saltwater toe inferred along the north flank of the Adacao Rise. The DoD's MW-series wells can be seen in the NE corner of the map segment.

Actions: The team drove to the site on the road behind the Guam Home Center, along East Liguan Avenue to the power line easement.

Observations and Engineering/ Construction Considerations: This site is located on the fringe of a closed depression on the flank of the Adacao Rise, in and open area located on DOD property (Figure 6b). DOD should confirm if the location will be impacted by conflicting future development planned for the MARBO Annex. Section 7, Section 106, and ESS compliance will be necessary.

Recommendations: Install well at the designated site (Figure 6c). An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 6b. General location for MARBO-DW1.

Figure 6c. Designated site for MARBO-DW1 (arrow). GPS coordinates in Table 1.

7. <u>Yigo Deep Well 1 (Yigo-DW1)</u>. Time of visit: 1705/30 Nov 16. Field team: John Jenson, WERI; Bob Shambach, EA Engineering; Vince Laguana, GWA; Prudencio Aguon, GWA; Erin Miller, WERI; Matt Spharler, WERI; Bekah Dougher, WERI.

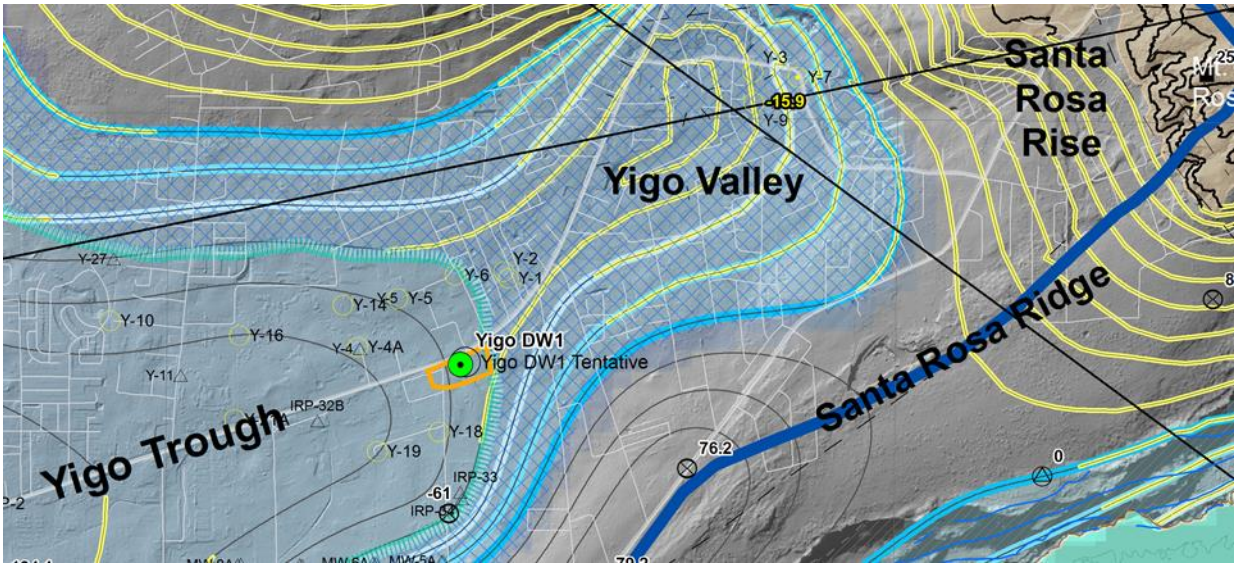


Figure 7a. Yigo-DW1 Hydrogeological Considerations: This well will be the first deep observation well in the head of the Yigo-Tumon Basin. Note that it is to be placed just seaward of the inferred saltwater toe. It should be kept in mind, however, that the mapped location of the saltwater toe is based on the 50% isochlor calculated by the recent modeling study (Guam Groundwater Availability Study, Gingerich, 2013) and the basement topography inferred from a limited number of control points (WERI TR 142, Vann et al., 2014). This well is thus exploratory; it could end up on either side of the saltwater toe. Because of the shallow depth and low topographic gradient of the basement, this important production area could experience profound migration of the saltwater tow. This well should thus be drilled to the bedrock-basement contact, to enhance the prospect of locating and definitively tracking migration of the saltwater toe in this highly developed and crucial part of the aquifer. Note the numerous Guam Water Authority Y-series and Department of Defense (DOD) MW-series wells.

Figure 7b. General location for Yigo-DW1, looking ENE. The designated site is in the jungle behind the fence (arrow). Route 1 is to the left of the photo.

Actions: The team reconnoitered the jungle area on the east side of the Yigo Fire Station fence to find a location close to the preliminary site location. To meet the exploratory criteria described above, it is important to place this well as close as practical to the originally proposed location.

Observations and Engineering/Construction Considerations: The site is located on DOD property with ease of access and minimum MEC requirements. Section 7, Section 106, and ESS compliance will be necessary.

Recommendations: Install well at the designated site (Figure 7c). An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 7c. Designated site for Yigo-DW1 (arrow). GPS coordinates in Table 1.

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8. <u>Okkodo Deep Well 1 (Okkodo-DW1)</u>. Time of visit: 0915/20 Dec 16. Field team: John Jenson, Erin Miller, Matt Spharler, WERI.

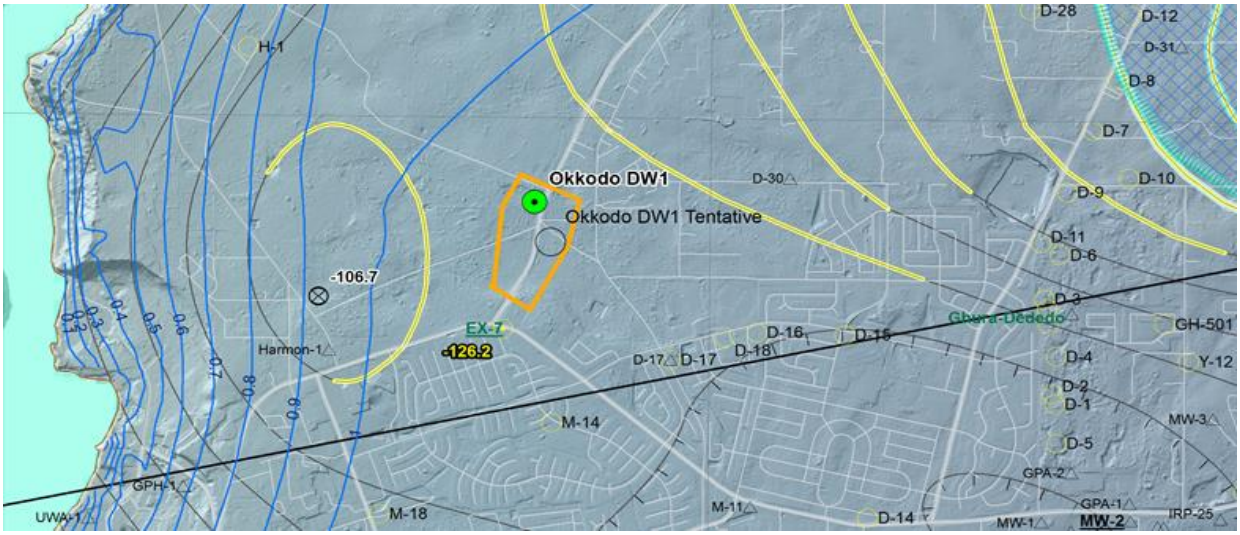

Figure 8a. Okkodo-DW1 Hydrogeological Considerations: Since it was installed in 1982, EX-7, at Wettengel Junction **(**south central part of map), has provided data on freshwater lens conditions along the axis of the Yigo Trough, which is the most intensively developed and highest producing portion of the entire aquifer. However, it is anticipated that EX-7 will be closed when Marine Corps Drive (Route 1) is widened to accommodate the military buildup. Okkodo DW1 is needed to replace the capability that will be lost with the closure of EX-7 in this important part of the aquifer.

Actions: The team reconnoitered the area inside the orange polygon shown in Figure 8a.

Observations and Engineering/ Construction Considerations: The field visit revealed several constraints to selecting sites across this area. The polygon straddles a moderately deep, elongate, ENE-trending sinkhole (Figure 8b). Route 3, running NNE, is built across the axis of the sinkhole (Figure 8c), and a culvert beneath the road has been installed to allow water flow from the east to the west end of the sinkhole.

Figure 8b. Sinkhole straddling Route 3 (left side of photo). Arrow pointing ENE shows axis of sinkhole. Perspective is looking east across sinkhole axis from top of soil mound on construction site on the east side of Route 3.

The recommended site (Figure 8d) is at the intersection of an ENE-trending power line utility easement that intersects Route 3 from the west (Figure 8e). The site stands above Route 3 and slopes SW, away from Route 3, which will accommodate dispersal of the drilling foam and cuttings during drilling. After carefully exploring other hydrogeologically suitable sites in the general area, the team deliberately selected this location on an existing easement for the purpose of minimizing ownership, land-use, and access issues.

Recommendations: It will be necessary to ascertain land ownership and resolve any land-use permission and access considerations before proceeding at this site. Development construction is underway on the east side of Route 3 (Figures 8b and 8f), and a portion of the land on the west side is marked with a “for sale” sign (Figure 8g). Otherwise the designated site (Figure 8d) is suitable in terms of geologic, engineering, and construction criteria. An area of approximately 50 feet by 50 feet will be needed for the drill rig and support equipment.

Figure 8c. Route 3 looking NNE from east side of road.

Figure 8d. Designated site for Okkodo-DW1 (arrow). GPS coordinates in Table 1. Note Guam Medical City Hospital in background.

Figure 8e. Power line easement, looking west from designated site. Note Guam Medical City Hospital in background at left.

Figure 8f. Public notice posted on construction site on east side of Route 3.

Figure 8g. For-sale sign on west side of Route 3, south of designated site for Okkodo-DW1.

Table 1. GPS coordinates for each of the designated well sites.

Name	Latitude	Longitude	Map
NW Field DW1	13.590759	144.880434	Figure 1a
AAFB DW1	13.588623	144.906147	Figure 2a
NCS Finegayan DW2	13.566813	144.842522	Figure 3a
NCS Finegayan DW1	13.580353	144.850237	Figure 4a
NCS Barrigada DW1	13.478581	144.843912	Figure 5a
Marbo DW1	13.506319	144.852678	Figure 6a
Yigo DW1	13.522250	144.880164	Figure 7a
Okkodo DW1	13.529377	144.825345	Figure 8a

This report was prepared by J. Jenson, N. Habana, and E. Miller, Water & Environmental Research Institute of the Western Pacific (WERI), with assistance from P. Aguon. V. Laguana, and J. Tadeo, Guam Waterworks Authority (GWA); and R. Shambach, EA Engineering. Final draft was checked by each of the above, and reviewed by B. Railey, GWA; G. Ikehara, 36 CEV; R. Camacho, NAVFACMAR; and S. Anthony, T. Hylton, and T. Presley, USGS. For follow-up questions or comments, contact J. Jenson, WERI, ph. 671 735-2685; email: jjenson@triton.uog.edu.

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