Work Plan: Water Use Data and Research in Guam

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US Geological Survey Cooperative Agreement Award: G18AC00265

January 25, 2021

Introduction

The Water and Environmental Research Institute (WERI) of the Western Pacific is one of the 54 National Institutes for Water Resources Research (NIWRR) established under the Water Resources Research Act of 1975. WERI is charged to 1) arrange for competent research that addresses water problems or expands understanding of water and water-related phenomena, 2) help train future water scientists and engineers, 3) get results of sponsored research to water managers and the public, and 4) operate water and hydrogeology databases in Guam.

Water Use and Data Research (WUDR) in Guam has been collaboratively conducted with local and regional agencies. In 2010, a Memorandum of Understanding (MOU) between Guam Waterworks Authorities (GWA) and Department of Defense (DOD) was established for the *One-Guam Initiative*, in which the U.S. Navy assists in the improvement of Guam's power and water utilities. Additionally, in 2016, another MOU was developed between GWA and WERI, under which GWA provides data to WERI to maintain a reliable database for Guam water systems.

The Guam Hydrologic Survey (GHS) and the Comprehensive Water Monitoring Program (CWMP) were created in 1998 by the 24th Guam Legislature under Public Laws No. 24-247 and 24-161, respectively. WERI was charged with administering these two programs. Under the GHS mandate, WERI maintains a hydrologic database for Guam and provides regular reports to policy-makers and managers of Guam's water resources. WERI also leverages its expertise on local geology and hydrology with national resources through active partnership with the United States Geological Survey's (USGS) Pacific Islands Water Science Center (PIWSC) in Honolulu, Hawaii, with which it jointly administers the USGS Groundwater and Streamflow Information Program for Guam through the locally-funded Guam CWMP.

Background

Guam is the largest and southernmost of the Mariana Islands. Freshwater production in Guam is about 36 MGD. About 85% of Guam's freshwater comes from the Northern Guam Lens Aquifer (NGLA). Surface water resources are primarily confined to the Ugum River and Fena Lake in the southern part of the island. Currently, the Guam Waterworks Authority (GWA), manages about 120 production wells in the north and the Ugum plant in the south (Fig. 1).

GWA delivers to about 45,000 service connections (water meters). GWA produces about 85% of the total freshwater on Guam. Naval Facilities Engineering Command Marianas (NAFVACMAR) produces the other 15% through 14 production wells, as well as the Fena Lake reservoir. Most of the water produced through NAFVACMAR is consumed by the military, although a surplus of some 1.5 MGD is sold to GWA.

The population of Guam currently stands at around 165,000 (http://worldpopulationreview.com). In recent years, approximately 1.5 million tourists have visited Guam every year (Guam Visitors Bureau). The relocation of military personnel and their families from Okinawa, Japan to Guam is predicted to raise the population. This will place additional demands on Guam's water resources as well as the island's water production, distribution, and wastewater treatment infrastructure.

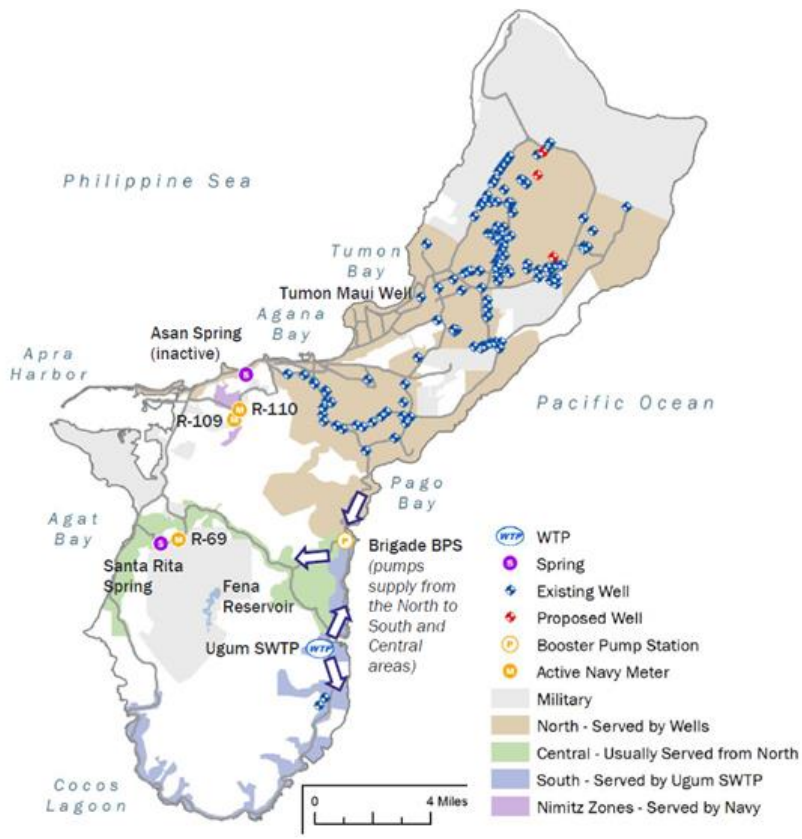

Figure 1. Water system boundaries and supply sources (Brown and Caldwell, 2018).

The production wells in Guam are spread out over six basins: Hagatna, Yigo-Tumon, Finegayan, Machanao, Upi, and Mangilao (Fig. 2). Each basin includes supra-basal, para-basal and basal groundwater zones[1]. About 53% of freshwater is produced from the Yigo-Tumon Basin (19.7 MGD) and about 21% of freshwater comes from Hagatna Basin. In 2019, GWA, the US Air Force and the US Navy produced 37.1, 2.0 and 1.9 MGD, respectively, from the NGLA. NGLA production from GWA production wells in 2019 is shown in Table 1.

Table 1. NGLA GWA freshwater production in 2019 (WERI, 2020).

Basins	Yigo-Tumon	Hagatna	Finegayan	Mangilao	Upi	Machanao
Production (MGD)	19.7	7.9	4.6	2.1	1.6	1.2

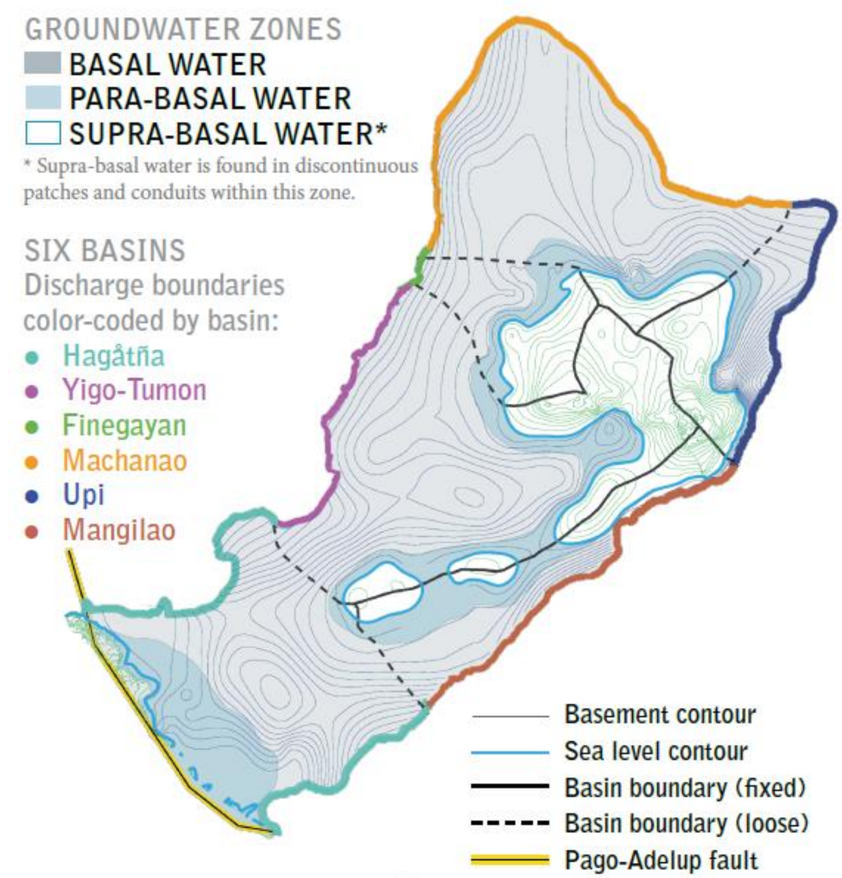

Figure 2. Groundwater basins and zones of the NGLA (WERI, 2019).

[1] The supra-basal zone freshwater travels down the flank of the volcanic basement rock that stands above sea level. The para-basal zone is underlain by volcanic basement rock. The basal zone is the portion of the freshwater lens that is underlain by seawater.

Problem Statement

The average annual rainfall on the island is about 100 inches. However, despite high average rainfall, there are large variations of rainfall at all time scales. There is typically a six-month dry season during which only 30 inches of the annual 100 inches accrues. It is thought that very little of the dry season rainfall recharges the aquifer (Jocson et al., 1999). The current estimate of average daily recharge for the NGLA is 238 MGD (Johnson, 2012). Groundwater daily production in the NGLA ranges from 35 to 40 MGD, or 15 to 17% of average recharge. An informal rule of thumb is that 30 to 40% water recharge is the maximum that can be economically extracted from an aquifer. However, given that the most accessible and productive locations are usually the first to be developed, the costs of new development begin to rise rapidly past this threshold as increasingly remote and less productive. Because of these limited geographical characteristics, while estimates of the aquifer's sustainable water resources remain adequate for the current population, there is concern that the projected population increase will also severely compromise the island's drinking water supply.

In addition to facing increasing demand for production as the population and economy expand, there are increasing risks to water quality in the NGLA. Increasing chloride concentration trends in production wells have been observed at over 70% of the wells for several decades (Simard et al., 2015). Some GWA production wells have been shut off due to chloride concentrations exceeding local regulatory standards (>250 mg/L, the USEPA secondary standard). Additionally, increasing nitrate-nitrogen concentration trends have observed at 30% of the production wells (McDonald, 2002). Furthermore, septic systems are currently in use throughout Guam for wastewater treatment. These systems are a potential source of nitrate- or ammonium-nitrogen. Four GWA production wells have been shut-off due to exceeding regulated/unregulated contaminant levels. Chlordane (in 1983) and perchloroethylene (PCE) (in 2006) were detected above maximum contaminant levels (MCLs) at some production wells. Recently (2017), perfluorooctanesulfonic acid (PFOS) has also been detected above health advisory levels at two production wells. In addition, unexpected leaking of both freshwater and wastewater have resulted in water loss as well as water contamination.

Guam has a unique environment of water production, supply, and data management. GWA distributes water to civilian customers, while water production and distribution to the military bases is handled by NAFVACMAR. As the island's national water research institute, WERI actively collaborates with both local and regional agencies, especially the USGS PIWSC in Honolulu, regarding water quantity, water quality and database management. One of WERI's main roles is to collect water quality and quantity data from local agencies and to maintain a hydrologic database. Although GWA and NAVFACMAR willingly share their water-use data, the management of the database has been mostly concentrated on water production with some interest in water quality data. Therefore, more sophisticated data management procedures should be re-established. While USGS guidelines outline national standard water use categories, GWA utilizes its own water use and distribution categories. Data collection and management mostly fit into Tier 1 of the USGS water use category, but some adjustments are required. For example, GWA includes hotel and government in this category due to the unique economic environment that relies on tourism and military bases.

Work Plan

Monitoring Well Rehabilitation

Accurate and detailed data on aquifer hydrology and geology are required to support sustainable management of all aquifers. In Guam, development of new production wells in undeveloped locations is expected over the coming decades. Monitoring freshwater lens thickness, salinity and regulated contaminants in the six basins is the most important task to ensure the protection of the groundwater.

Since 1998, WERI and USGS PIWSC have conducted the CWMP that includes monitoring of rainfall at three sites, groundwater levels in eight wells, and salinity profiles in seven deep monitor wells. All the deep monitor wells, however, are concentrated in the Hagatna Basin and in the central part of Yigo-Tumon Basin—with the single exception of the EX-8 deep monitor well in Machanao Basins (Fig. 3). Additional observation wells are required in the Finegayan Basin and the eastern part of the Yigo-Tumon Basin in which new groundwater development is anticipated to support the expansion of military activities in Guam.

In 2017, the One-Guam Aquifer Monitoring Program (OGAMP) has launched to provide critical infrastructure improvements needed to expand the CWMP. The Department of Defense Office of Economic Adjustment (OEA) has provided a grant to GWA to fund constructing and testing seven new deep-monitor wells, and rehabilitating 12 existing monitor wells in the NGLA (Fig. 3). In support of the OEA-funded OGAMP, WERI and USGS are expanding their collaborative work to analyze and interpret new data from the expanded monitoring system. Monitoring well rehabilitation and new well installations are anticipated to be complete by the end of 2021.

Steady monitoring of the water table and saltwater intrusion are of utmost importance in this program. These data will enable researchers to evaluate and consider seasonal and long-term changes in rainfall, groundwater levels, and salinity in relation to sustainable groundwater production from the NGLA. At present, the WERI and the USGS PIWSC are pursuing long-term funding for the continuation of monitoring at these wells. The expansion of the existing hydrologic data collection network will help ensure effective management of existing wellfields as well as soon-to-be-developed new wellfields.

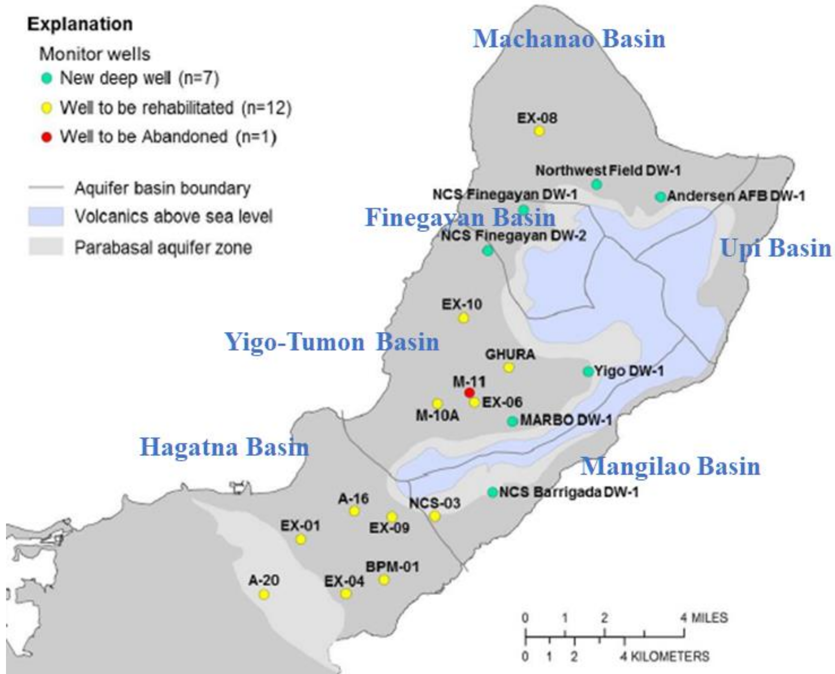

Figure 3. Location of proposed seven new deep monitoring well and twelve rehabilitation wells in Basins of the NGLA (USGS-WERI, 2017).

Production Well Rehabilitation

GWA operates about 120 production wells, of which about 100 are on-line at any given time. Over the past few years, GWA has undertaken a systematic rehabilitation program for its non-performing (closed) wells. Observations of those production wells showed that there are three main categories for why the closed wells originally failed: 1) deterioration due to age; 2) contamination of water at the site; and 3) historically poor performance. Aging problems include broken or corroded well casing, stuck pumps from previous maintenance failures, and screen deteriorations. Contamination problems include saltwater contamination and the occurrence of contaminants originating from surface activities. The latter includes contamination by chlordane, PCE and PFOS. Wells closed for chronic underperformance or mis-performance appear to have been installed in locations where geologic conditions produce large seasonal variations in local storage and water levels. Drilling of adjacent replacement wells performed by GWA showed that well performance can vary greatly between identical boreholes located only a few tens of feet from one another—reflecting the high heterogeneity in the hydraulic properties of the NGLA. The NGLA is a composite to complex island karst aquifer with a thick vadose zone, forming an uplifted plateau (> 60 m), and a highly anisotropic and permeable porous media (Jenson et al., 2006). This aquifer bears a meteorically-recharged freshwater lens atop saltwater, partitioned by the underlying volcanic basement rock into six aquifer basins containing basal and parabasal groundwater zones with varying lens thickness.

Well rehabilitation is one of GWA's long term water system improvement projects. Thus, a well rehabilitation procedure applicable to island karst aquifers is required to help local drillers better manage site selection, and well installation, preventive maintenance, and rehabilitation.

Water Quality Management

Saltwater contamination risks. As an index of saltwater in coastal and island aquifers, chloride concentration in production wells is of central importance to local groundwater managers and regulators. Spatial patterns provide clues to aquifer hydrogeological conditions, and temporal trends reflect changes in recharge or withdrawal. In 2003, WERI analyzed trends from 128 production well, and found that 64 wells showed increasing chloride (McDonald, et al., 2003). In 121 production wells for which trends were plotted form 2000 to 2010 (Simard et al., 2015), 12 exceeded 250 mg/L, which value is the USEPA secondary standard for drinking water (Fig. 4). Management of salinity remains a top priority for Guam's groundwater resource managers. Thus, continuous monitoring of chloride trends and the analysis of variables that affect them—such as changes in the number or pumping rates of production wells, and changes in rainfall or sea level—is an essential element of supporting water-resources research programs.

Sewage contamination risks. There are two general potential sources of sewage contamination in aquifers: sewer line leaks, and septic tanks. GWA operates seven wastewater treatment plants, but they do not treat all sewage on Guam. Forty-one percent of island households still use septic tanks (GWA, 2006). Septic tanks release treated wastewater containing nitrate-nitrogen and ammonium-nitrogen into individual drain-fields, and there is high potential that additional pollutants may be released into the aquifer, especially if the septic tanks are not properly managed. WERI has compiled historical measurements of nitrate concentrations form GWA records for 146 wells from across the aquifer beginning in the mid-1980s (McDonald, 2002). Spatial variations in nitrate concentrations are complex (Fig. 5). The general observation, however, that nitrate concentrations have risen over the past four decades in nearly 60% of the 146 wells for which historical records are available, and that they are continuing to rise in at least 44% of the wells, indicates that there are widely—if complexly—distributed sources of nitrate that have, and continue, to contribute steady-to-increasing amounts of nitrate to the aquifer. These patterns may be related to either leaking sewage lines or to septic tanks. Further investigation is required.

Surface-source contamination risks. Per- and poly-fluoroalkyl substances (PFAS) contamination has also recently become an issue. In 2015, six PFAS constituents, including PFOS, were monitored for all production wells. Three wells were found to be contaminated with PFOS, with concentrations above the EPA health advisory limit of 70 ng/L. Two wells, located in Hagatna, are the most contaminated with PFOS, and were shut down. Contamination sources remain unknown. WERI is conducting research in collaboration with GWA to assess potential PFAS contamination. NAVFAC Pacific is also monitoring for PFAS in the water supply to the military installations. Finding contamination sources will be continued to find solutions in protecting these freshwater resources.

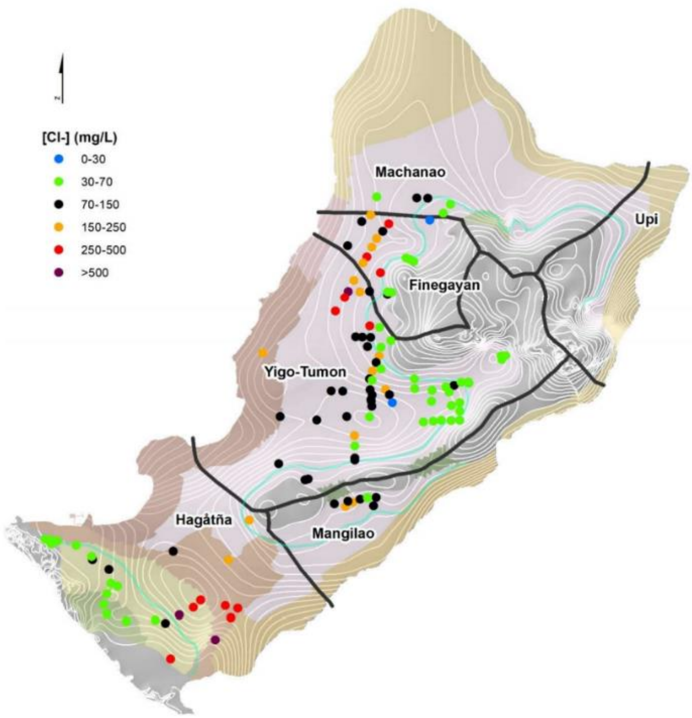

Figure 4. Salinity data in GWA production wells (Superales et al., 2019).

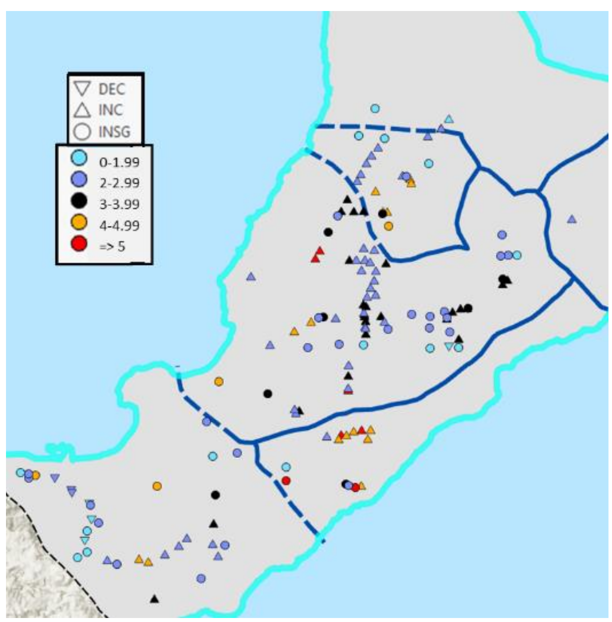

Figure 5. Map of wells, showing nitrate concentrations, by color, in mg/L (Bulaklak et al., 2020).

Management of Water Loss from Water Distribution Systems

GWA has conducted several water inventories in recent years. About 60% of water delivered into the system is unaccounted for (Office of Public Accountability, 2018). GWA engineers estimate that line leakage accounts for most of it. In 2006, GWA began mapping leaks, and in 2011, undertook a leak detection and control program to analyze leaks and compile statistics, including pipe pressure data (Fig. 6). GWA continues to monitor and repair these systems, however, more advanced techniques will be required to minimize water loss. Application of a real-time monitoring systems is one of many promising ways to detect water leaks and breaks. With existing pressure data, changes in pressure can provide clues to constrain leaking areas, but more sophisticated instrumentation is needed to develop a real-time monitoring system. If funding can be obtained, GWA hopes to begin with a pilot program on a selected part of the system, in which measured pressure will be compared with simulated pressures from a computer model of the system.

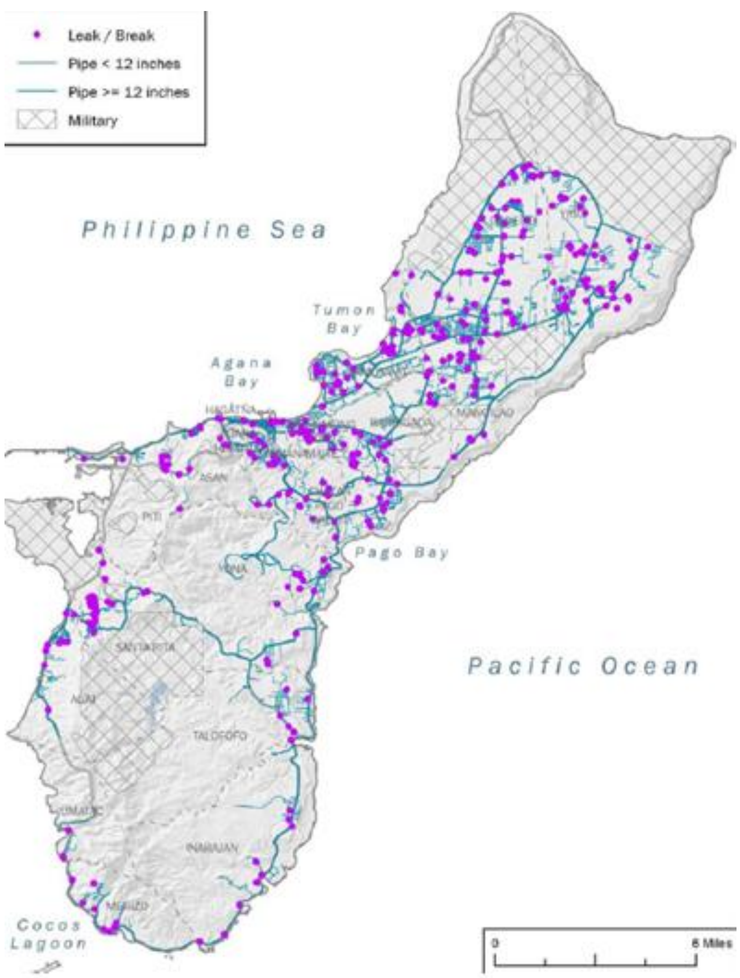

Figure 6. Location of pinpointed leaks measured in 2011-2013 (Brown and Caldwell, 2018).

Priorities for Water Use Data

The main industry in Guam is tourism. There is also a significant but secondary contribution by the US military installations. Consumption relies on imports; there is no domestic industrial manufacturing sector or significant commercial agriculture. Most water consumption is thus by residential and commercial customers. GWA produces 85% of the island's potable water, with remaining 15% produced by the military for its own use. GWA's standard for water use categories fit mostly in line with USGS WUDR categories (Tier 1), but GWA also designates certain customer categories of its own, such as hotel and government. Some effort will be required to align GWA and USGS water use categories. All the data will be compared according to the baseline standard of USGS WUDR (Tier 1). Major categories are (Table 2):

1) type of water: fresh vs saline,
2) withdrawals: surface water vs groundwater,
3) water distribution: public supply, self-supplied, irrigation, livestock, aquaculture, industrial, mining commercial, hydroelectric power and thermoelectric power, and
4) water delivery from wastewater treatment to other users.

Priorities for improving water use data is to enhance data collection of some categories that are not well developed in Guam. Industries of agriculture, livestock, aquaculture and mining exist, but their proportions are quite small. However, it is necessary to improve data collection to meet the requirement of the WUDR program. Private production wells can be installed by the permission of Guam EPA. Thus, the investigation of number of self-supplied production wells will be the first step of improving a self-supplied domestic category. Guam's main electricity source is power plants. Tier 1 in thermoelectric category is classified by cooling-system type, water source and water types, and the source of the plants and government agency. Thus, existing water supply data of the power plants will be re-categorized to meet the WUDR requirement. Guam does not have rivers that are enough to generate hydroelectric power. Thus, no data on hydroelectric power exists. Detailed summary of baseline standards for water use data by water-use category is shown in Table 2.

Based on these analyses, we will evaluate the status of the water use data management in Guam and develop a logical and accurate framework for comparing and realigning available water use data to the WUDR rubric.

Table 2. Baseline goal for WUDR (Bold – standard met, Regular-standard not met or further study required).

Category	Tier 1	Tier 2	Tier 3
Public Supply	**Monthly withdrawals reported by system, water source, and water type.** **Deliveries to domestic users from public-supply systems, and populations served.** Report system information relevant to HUC-8 and county, and groundwater withdrawals with aquifer designation.	**Site-specific annual and monthly withdrawals (by intake, well, or well field) reported by water source, and by water type.** **Quantity of water purchased between systems, and source(s) of purchased water.** **Quantity of water sold between systems.** Reporting and/or verification of water deliveries for domestic, commercial, industrial, thermoelectric and other use.	Interbasin transfers. System uses (internal and other non-revenue uses) and losses. Improve estimates of populations served by site (for example, by surface-water intake, well or well field). Use of reclaimed wastewater for public or landscape irrigation.
Industrial	**Annual withdrawals by facility, reported by water source, by water type, and industry classification.** **Groundwater withdrawals reported with reference to aquifer.**	**Site-specific (by intake and/or well) annual and monthly withdrawals reported by water source, by water type, and industry classification.** **Deliveries from public supply to industrial facility, and deliveries from other sources, such as treated wastewater.**	Site-specific consumptive use estimates. Site-specific discharges to surface water, or land application.
Irrigation-Crop	Aggregate annual withdrawals reported by water source, by water type, acres irrigated, and method of irrigation. Aggregate areas may be sub-county levels, but are feasible to summarize to county or HUC8.	**Site-specific monthly withdrawals by well and/or diversion from surface-water feature, or delivery from reclaimed wastewater.** Monthly withdrawals reported by water source, water type, with associated acres irrigated and crop type, and method of irrigation system.	Consumptive use and conveyance loss estimates by aggregate area (sub-county, county, HUC8, or up to HUC12. Site-specific return flows.
Thermoelectric	Site-specific, annual and monthly withdrawals, and net power generation reported by cooling-system type (once-through or recirculating), by water source and by water type, and the source of the information (plant, govt. agency, etc.). Site-specific return flows.	Site-specific annual and monthly consumptive use.	

Self-Supplied Domestic	Self-supplied domestic populations, by HUC8 and county, and by water source.	Studies of actual metered domestic withdrawals, monthly by source. Improve estimates of self-supplied populations by utilizing property data and/or public water supply service	
Irrigation – Golf Courses	**Site-specific annual and monthly withdrawals reported by water source, by water type, and** acres irrigated**. Groundwater withdrawals designated by aquifer.**	Consumptive use estimates, by course, reported by month or annual. Acres irrigated by system type, by course.	
Livestock	Annual withdrawals for major facilities, reported by water source and by water type.	Site-specific annual and monthly withdrawals for all facilities reported by source of water, and by water type. Site-specific animal counts and animal type.	Improved and verified coefficients for water use per head for animal type, confined or open-range, seasonal variability, and other variables. Water withdrawals from sources supported by USDA programs to protect streams.
Mining	Annual withdrawals reported by HUC-8 and county, by source of water, and by water type.	Site-specific annual and monthly withdrawals. Site-specific commodity identified.	Evaluation/reporting on water use by process (commodity processing, dewatering, dust suppression, etc.). Reporting on return flows/discharge of water from dewatering.
Aquaculture	Annual withdrawals reported by HUC-8 and county, by source of water, and by water type.	Site-specific annual and monthly withdrawals. Site-specific facility information (method, species cultured, etc.)	
Commercial	**Annual and monthly deliveries from public supply for commercial use.**	Site-specific annual and monthly withdrawals for self-	
Hydroelectric Power	Site-specific, annual and monthly water use (water use to spin turbines) by water source and water type, and the source of the information (plant, govt. agency, etc.).		

Wastewater Treatment	Annual and monthly deliveries from wastewater treatment plants to other users. Specify category delivered to (i.e. industrial, thermoelectric, irrigation, etc.)		
Water Use Data Storage and Availability			
Water use database	Monthly and annual withdrawal data are reported to the state agency and stored in an electronic format.	Withdrawal data are entered electronically into a database. Automatic QA/QC checks are integrated into the electronic database and/or data entry routines.	Withdrawal data include water source, water type and location (county and HUC-12). Data are made available for export by the state agency or for download.

Recommendation to Address Data Priorities

Under the GHS program mandated by Public Law 24-247 and the 2016 MOU between GWA and WERI (WERI, 2017), WERI collects, compiles, and manages all water-related data generated in Guam (Bendixson, 2013). The WERI database includes basic historical production-well information: location, well depth, pump tests, contaminants, and borehole videos. GWA provides monthly water production data. Some contaminant data, such as chloride and nitrate-nitrogen concentrations in drinking water are also being shared by GWA. WERI also works closely with the USGS PIWSC, with whom it jointly administers the USGS groundwater and streamflow information program for Guam, which is funded by the Guam Legislature as the Guam Comprehensive Water Monitoring Program under Public Law 24-161. All Guam water and hydrogeology related database can be assessed though hydroguam.net and guamhydrologicsurvey.uog.edu, which are administered by WERI. Some water data, such as water production, is shared with NAVFACMAR.

Although WERI, GWA, DOD, NAVFACMAR and other local agencies, such as Guam EPA, work closely through the One-Guam Initiative, comprehensive and systematic sharing of water use data has yet to be formally addressed. Thus, the first step to address data priorities is to set up a formal meeting to discuss existing water database (paper and digital files) and quality assurance/quality control (QA/QC). The second step is to standardize data acquisition, processing and management for the purpose of building up a water use inventory. We have not fully discovered the difference of water data management among agencies. Thus, development of Guam’s water use database should be discussed further while we conduct first two steps of data priorities.

Collaboration

WERI will closely collaborate with GWA, NAVFACMAR, and USGS PIWSC to develop the work plan.

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