THE NORTHERN GUAM LENS AQUIFER DATABASE

by

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OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

Technical Report No. 141

May 2013

AN ABSTRACT OF THE PROFESSIONAL PROJECT REPORT OF Vivianna M. Bendixson for the Master of Science in Environmental Science presented April 16, 2013.

Title: The Northern Guam Lens Aquifer Database

Approved: ____
John W. Jenson, Chairman, Professional Project Committee

The Northern Guam Lens Aquifer supplies 80% of the island's drinking water. Anticipated growth in demand, including a possible surge to support expansion of military activities during the coming decade has elicited interest and support from both the federal and local governments for acquiring tools to support timely development and sustainable management of the aquifer. This report describes the content and organization of the *Northern Guam Lens Aquifer Database*, a comprehensive centralized database containing information on custodianship, function, operational status, and the geographical, hydrological, engineering, and geological attributes of each well installed in northern Guam for which records could be found. The database is integrated with current ArcGIS® geospatial information visualization tools. Developed in support of the 2010-2013 *Guam Groundwater Availability Study* led by the USGS's Pacific Islands Water Science Center, with funding by the US Marine Corps, and in conjunction with the 2010 NAVFACPAC Exploratory Drilling Program on northern Guam, its integration into WERI's Guam Hydrologic Survey Program will keep it up to date and make it permanently and readily accessible to professional and scientific users. The database is also the foundational component for WERI's topographic map of the basement rock beneath the aquifer. In preparing the database, over 4,000 pages of documents were digitally saved and organized into 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 stormwater management wells. Each well folder is electronically linked to its corresponding record in a Microsoft Excel® spreadsheet, which contains key engineering and hydrogeological data. To organize, classify, and relate the enormous amount of disparate data required development of a specialized taxonomic system for the database. This 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, and limitations; and assumptions and choices made in interpreting and classifying data. Finally, recommendations are offered on database maintenance and updating; improvements, refinements, and expansion; supporting operational and administrative procedures; and desirable future studies.

TO THE OFFICE OF GRADUATE STUDIES

The members of the committee approve the professional project report of Vivianna M. Bendixson presented April 16, 2013.

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THE NORTHERN GUAM LENS AQUIFER DATABASE

BY

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A professional project report submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

IN

ENVIRONMENTAL SCIENCE

UNIVERSITY OF GUAM

TECHNICAL REPORT NO. 141

MAY 2013

This work was funded by the Pacific Islands Water Science Center, U.S. Geological Survey, department of the Interior: "Hydrogeological Database of Northern Guam," grants number G11AP20225, and administered through the Water and Environmental Research Institute of the Western Pacific (WERI). The content of this report does not necessarily reflect the views and policies of the Department of the Interior, nor does the mention of trade names or commercial products constitute their endorsement by the United States Government.

ACKNOWLEDGEMENTS

Professional acknowledgements

Interagency cooperation was required to make this database complete. USGS provided much historical data and the funding for this project. WERI and GHS provided the starting point for document searches. Joint Region Marianas provided support through their respective USN and USAF offices, NAVFACMAR and the 36th Civil Engineering Environmental Flight. Guam Waterworks Authority, having the bulk of utility wells, provided the most data. GEPA was highly involved in the process and provided listings and coordinates of well locations. Finally, a few private well owners provided additional drill logs and pump tests.

Specifically thanks to Steve Anthony, Steve Gingerich, Todd Presley, Benny Cruz, Francis Mendiola, Martin Roush, Brett Railey, Delfyn Quitlong, Raymond Camacho, Paul Owen, Bob Clark, Greg Ikehara, and Gary Denton, and Dr. K. Without your support and cooperation this project would not be a possible.

Personal acknowledgements

I thank God for placing this opportunity before me. To my advisor Dr. John Jenson, I appreciate all your encouragement, assistance, and continuous feedback. I couldn’t ask for a better advisor and friend. I continually learn from you, professionally, academically and personally. Thanks for being you. To my committee, Dr. Roseann Jones and Dr. Dan Lindstrom, my sincerest thanks for not giving up and sticking with me.

To the staff at WERI, Norma, Gwen, Jen, Chris, Nate and Leena, thanks for always having my back. Thanks to the Research Assistants that helped with countless hours of scanning, Lauren, Jacob, and Walter. Thank you to my dear friends that have suffered through many moments of self-doubt, Miranda Minshew, Maria Kottemair, Rosanna Barcinas, Leanne Obra, without you ladies I wouldn’t have the courage to get out of and stay out of my comfort zone. To my cuata, Christine Simard, the many hours we spent together in the field, behind the computer, and at a special sandwich shop mean more to me than you’ll know. I’ll cherish our friendship always.

Thanks to my family, biological and military, for encouraging and cheering me on. And last but certainly not least, to my husband Shawn, you believe in me when I don’t believe in myself without you this would still be a dream. There are no words to express my gratitude for what you have endured and sacrificed for me to get here, so I’ll just say thank you and I love you very much.

“Whether you think you can, or you think you can’t—you’re right.”
-Henry Ford

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ACRONYMS AND ABBREVIATIONS

AAFB	Andersen Air Force Base
CIKM	Carbonate Island Karst Model
CMP	Comprehensive Monitoring Program
DOD	Department of Defense
DVD	digital video disc
ET	evapotranspiration
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency
GEPA	Guam Environmental Protection Agency
GHS	Guam Hydrologic Survey
GIS	Geographic Information System
gpm	gallons per minute
GWA	Guam Waterworks Authority
IRP	Installation Restoration Program
mgd	million gallons per day
MLLW	mean low low water level
MSL	mean sea level
NAS	Naval Air Station
NGLA	Northern Guam Lens Aquifer
NGLS	Northern Guam Lens Study
NAVFAC	Naval Facilities Engineering Command
NAVFACPAC	Naval Facilities Engineering Command Pacific
NAVFACMAR	Naval Facilities Engineering Command Marianas
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PIWSC	Pacific Islands Water Science Center
UOG	University of Guam
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USMC	United States Marine Corps
USN	United States Navy
UTM	Universal Transverse Mercator
VHS	video home system
WERI	Water and Environmental Research Institute of the Western Pacific
WGS	World Geodetic System
WSMO	Weather Service Meteorological Observatory

Executive summary

NORTHERN GUAM LENS AQUIFER DATABASE

I. Background and geographic setting

Guam is a US territory and located in the western Pacific Ocean. The 212-square mile island is divided in half by a fault with the northern half comprised of limestone bedrock underlain by volcanic basement rock. The limestone bedrock contains the Northern Guam Lens Aquifer, a sole-source aquifer supplying 80% of Guam's drinking water.

Aquifer drilling began on Guam since 1937 and consistently after the Japanese occupation 1941-1944 ended. Since the time after the first drilling there has been no systematic effort to consolidate and compile drilling information. Many efforts have been made for specific research and projects but prior to this database a complete record across all interested agencies had never been compiled.

II. Northern Guam Lens Aquifer (NGLA)

NGLA is a carbonate island karst aquifer the bedrock of which is primarily comprised of two major limestone units: the Miocene-Pliocene Barrigada Limestone and the Pliocene-Pleistocene Mariana Limestone. The body of fresh water within the limestone forms an elongate "lens" floating atop the underlying sea water permeating down to the basement rock. This older relatively impermeable volcanclastic rock partitions the aquifer into six groundwater basins.

III. Purpose of report

This report describes the methods used for compilation, interpretation, organization, and utilization of the Northern Guam Lens Aquifer Database, created in conjunction with the United States Geological Survey 3.5 year groundwater availability study funded by the Department of the Navy for a military relocation to Guam. Per the Final Environmental Impact Statement 2010, plans include providing an additional 11.3 million gallons per day (42.8 million liters per day) of potable water. As of publishing the number of proposed military could decrease the amount of construction and therefore amount of potable water needed might also decrease.

IV. Project Objectives

The objectives for this professional project were to

1. *Locate, consolidate, organize, and store* well, borehole, and other data relevant to
2. *Exploration, development, and management* of the NGLA, into a

3. *Centralized database*, in formats that readily support
4. *Descriptive and quantitative analyses of the aquifer and its infrastructure*, including spatial and statistical analyses and numerical modeling.

Additional supporting attributes are as follows:

1. *Completeness and accessibility*: An extensive search was made to collect and compile current and historical information from federal, local and private agencies.
2. *Ease of use*: Maximum use was made of commonly used software applications (specifically, Microsoft Excel 2010®) and familiar methods.
3. *Organization*: Data are organized in a deliberate and logical framework reflecting conventional groundwater industry terminology and standards.
4. *Digital storage media*: All “hard copy” historical records were scanned, stored, and catalogued in a computer-based directory.
5. *Documentation*: Metadata were appended so that users can evaluate the reliability and suitability of the data for their desired application.
6. *Indexing*: All entities of interest are indexed to relevant textual (historical document) data, alpha-numerical (spreadsheet-based) data, and graphical data.
7. *Integration with other Internet sources*: The historical database described above is integrated with current on-line databases.

V. Components of the database

The individual components of the NGLA Database are organized as follows:

<u>Incorporated components</u>

1. Quantitative data in Excel 2010 spreadsheets.
2. A concealed comprehensive spreadsheet catalogue of well site locations.
3. Digital folders containing .pdf files of source documents.
4. An interactive Geographic Information System (GIS)-interface.
5. Links to other web-based data.

<u>Unincorporated components</u>

6. Shelved binders containing paper copies of the original records.
7. Drawers containing maps, photographs, video-cassettes, and other media.

VI. Data Organization

A distinct taxonomic system was developed to organize, classify, and relate the enormous amount of disparate data from which the database is derived. The NGLA well data were first broken into two broad categories called *sections*: (1)

operations data, and (2) *field data*. The second division down from *section* is *attribute* for operations data (Figure 3-1a), and *mode* for field data (Figure 3-1b). Attribute and mode are further divided into a third level, *division*, which is divided into the fourth, *type*, which in turn is divided into the fifth level of *sub-type*. Where a sixth level is necessary, *sub-type* is divided into *sub-sub-type*.

VII. Database content and indexing

This part of the report briefly describes, in descending order of the indexing system, each of the indexed taxa of the database, along with pertinent considerations such as agency histories and mandates; definitions and conventions adopted or devised; data complexities, nuances, and limitations; and assumptions and choices made in interpreting and classifying data.

Over 4,000 pages of documents were saved digitally into 525 corresponding well folders (see Table 3-2) divided by owner/operator, well functions, well types and current status.

Well function			1 – Data Collection				2 – Utility				3 – Stormwater Management		Unidentified	TOTAL
Well type			1 – Exploratory (one time)		2 – Observation/ Monitoring (on-going)		1 – Drinking Water		2 – Agriculture/ Industrial					
Researcher		1 – GHS			11	0								26
					2	13								
					0									
Regulator		2 – GEPA	0	0	0	0								0
			0	0	0	0								
					0									
Producers	Municipal	3 – GWA	0	2			103	11						171
			0	4			1	36						
							14							
	Military Joint Region Marianas (JRM)	4 – USN	0	0			12	0			0	0		36
			9	0			0	13				2		
							0				0			
		5 – USAF	0	0	65	0	13	1	1		102	0		211
			0	5	0	17	0	1				0		
					0		6				0			
	Commercial	6 – Private			1	0			17	0				40
					0	4			4	11				
					0				3					
		7 – Unidentified	0	0	0	0	0	0	0	0			35	41
			0	0	0	2	0	1	0	3				
			0		0		0		0					
TOTAL			20		115		212		39		104		35	525

Status		
	1 – Active	4 – Abandoned
	2 – Inactive	5 – Unknown
	3 – Offline	

Table 3-2. Summary table of well functions, well types, well status and owner/operators. The five status divisions are laid out within each bold-outline cell as shown at left.

VIII. Recommendations

A. Database maintenance and updates

Established Arrangements. The NGLA Database has been prepared in conformance with mandates and agreements for database development, maintenance, and data-sharing that are already in place:

1. Guam Hydrologic Survey Program. Maintenance of the NGLA database is consistent with the mission of the Guam Hydrologic Survey established by Public Law 24-247.
2. 16 July 2010 Memorandum of Understanding between Joint Region Marianas, Guam Consolidated Commission on Utilities, Naval Facilities Engineering Command Marianas, and Guam Waterworks Authority. This formal agreement established a Technical Experts group on Guam to share water resources data in real time.

Periodic Updates. T*he NGLA Database needs to be maintained continually* to keep up with the continual streams of monthly and quarterly data.

- *Annual review by the Technical Experts group* and recommended refinements and modifications be made during the subsequent year. With each year's update incorporating the latest technologies and techniques to keep abreast of the rapid ongoing improvements in database and GIS technologies.
- *Annual review of the NGLA Database to coincide with the Water & Environmental Research Institute of the Western Pacific's (WERI) Advisory Council meeting*.

B. Database Improvement, Refinement, and Expansion

The following steps can be taken to improve the quality, refine the structure, and expand the coverage of the database:

1. Field-checking of data. Geographic data were entered "as is". Reliability would be enhanced by conducting a systematic and exhaustive field.
2. Refinement of lower-priority data. Priority for verification was given to active production wells and boreholes utilized for WERI's development of the basement map. Records for many other wells now need to be examined, verified and mapped.
3. Inclusion of other well data. Lower priority well information was not as actively sought out and should now be made a priority.
4. Inclusion of new data. "Placeholder" elements have been incorporated for parameters beyond the scope of this project. Inclusion of this information can be done as priorities dictate and resources permit.
5. storage of samples, video, photos, maps, and other reports. Proper storage, archiving, and maintenance of unique single-opportunity assets, most especially drill cuttings, core samples, videos, photos, maps, and reports pertinent to aquifer management.

C. Operational and administrative recommendations

The following are recommendations for changes in operational and administrative procedures that follow from insights and experience in building the database. These will require inter-agency collaboration and agreement, as in some cases modest commitments of additional resources by the agencies involved. In all cases, however, the returns will improve not only the content and utility of the database, but will also enhance the management of the aquifer.

1. Groundwater basin boundary usage review. With the recent update of the groundwater basin boundaries, agencies that utilize this information are advised to update, review, and consider their usage of previous groundwater basin boundaries.
2. Establishment of well naming conventions. Currently, wells are named according to which groundwater basin they draw from, followed by a number. Since groundwater basin delineations have and will change, the Technical Experts should take up this discussion for resolution and agreement, and make a recommendation to the permitting authority for establishment of a permanent, systematic convention for naming of boreholes and wells.
3. Video logging at all uncased and newly drilled wells. Although drill cutting collection and, in some cases, geophysical logging are being conducted some features can be difficult to interpret or are indistinguishable with these tools. The technology is already available on island and its usefulness has been proven.
4. Establishment of NGLA Database User's Group. Creation of a formal user's group would facilitate access to the NGLA Database, including its source documents, spreadsheets, and shapefiles, particularly when uncertain whether information is proprietary.

6. Future studies

Maintenance and expansion of the database as described above will support future improvements in basement mapping, such as 3-D modeling of basement, bedrock and water-flow pathways in the aquifer.

THE NORTHERN GUAM LENS AQUIFER DATABASE

Vivianna Martinez Bendixson

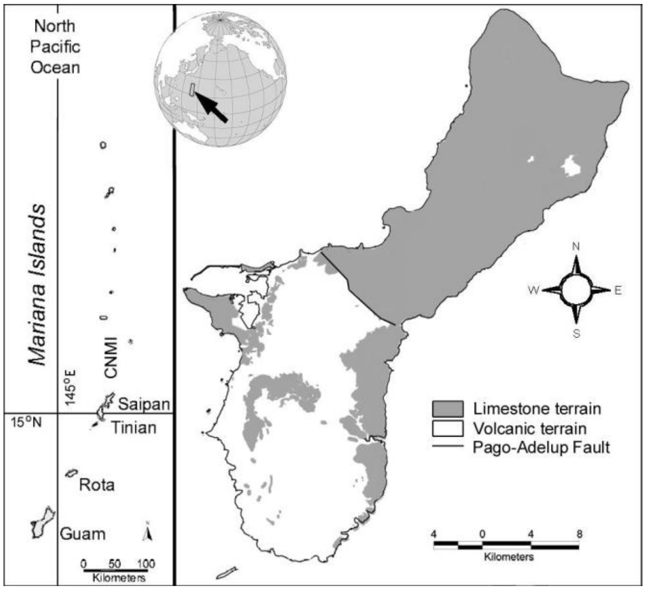

Figure 1-1 Guam location map (from Taboroši, 2005).

1. Background

A. Groundwater demand on Guam

The US Territory of Guam, in the western Pacific Ocean, latitude 13°28′N and longitude 144°45′E, is the largest and southernmost of the Mariana Islands (Fig. 1-1). The 212-square mile island is divided in half by a major fault, which separates it into two physiographic provinces: the southern volcanic upland and the northern limestone plateau. The limestone bedrock beneath the northern plateau comprises the Northern Guam Lens Aquifer (NGLA), a United States Environmental Protection Agency (USEPA)-designated sole-source aquifer[1], which supplies Guam with 80% of its drinking water, and which still has considerable potential for development.

Guam currently has a resident population of about 160,000 (CIA, 2013) and hosts over a million visitors a year (GVB, 2011). Guam's decadal population growth is expected to be around 5.6% by the end of the current decade (BSP, 2011). However, the Department of Defense has initiated a military build-up, in which United States Marine Corps (USMC) personnel and families are to be relocated from Okinawa. The buildup was originally anticipated to begin in 2010 and peak in 2014 and called for accommodating a maximum peak influx of some 79,000 active-duty personnel and families, civilian military workers and families, and off-island workers and families for indirect and induced jobs (Figure 1-2) (JGPO, 2010). The 2010 Final Environmental Impact Statement (FEIS) accordingly called for an increase of drinking water production of 11.3 million gallons per day (mgd), which, if composed entirely of groundwater from the aquifer as it is proposed, would have constituted a 25% increase over the current 45 million mgd (Figure 1-3). The start of the build-up has been delayed, however, and the ultimate magnitude and implementation schedule are still under discussion. Nevertheless, local military and civilian water resource managers must prepare not only for the increased demand for groundwater production that will follow from ongoing domestic population growth and economic expansion, but also from any new military build-up and the associated local economic growth that it will create. Even if the build-

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[1] NGLA Sole Source Aquifer was designated under the authority of Section 1424(e) of the Safe Drinking Water Act, Federal Register Citiation-43 FR 17888, Publication Date – 04/26/1978.

up is only a third of the original projection, the associated demand for additional drinking water will be substantial.

As part of the initial preparation for the anticipated build-up, US Naval Facilities Engineering Command Pacific (NAVFACPAC) conducted an exploratory drilling program on Guam, in which 11 test wells were installed in areas where development was deemed most feasible (AECOM Technical Services Inc., 2011). In addition, Headquarters USMC contracted in 2010 with the United States Geological Survey (USGS) to conduct the soon-to-be completed 3.5-year *Groundwater Availability Study for Guam* (Gingerich and Jenson, 2010) to provide up-to-date information and additional new tools to help manage Guam's groundwater resources through the buildup and beyond. As part of the study, USGS engaged the University of Guam's Water and Environmental Research Institute of the Western Pacific (WERI) to provide local scientific expertise, coordinate collaboration between local cooperating agencies, and develop a comprehensive database of the aquifer to support the development of a new numerical model of the NGLA. The *NGLA Database*, as described in this report, provides essential information on well placement, design, and operation with which to configure the numerical model. In addition, it is also the primary source of information for a detailed map of the aquifer basement rock (Vann et al., 2013, in prep.), which is an essential tool for successful groundwater exploration, as well as for construction of future numerical models of the aquifer.

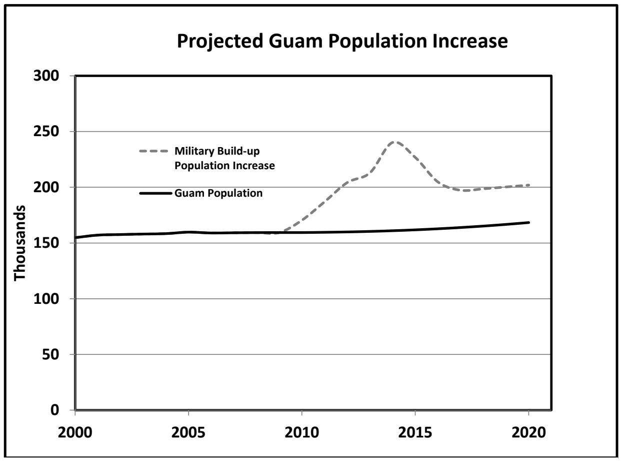

Figure 1-2. Projected Guam population increase. Guam population extracted from Guam Statistical Yearbook 2011 (Bureau, 2012). The build-up was originally planned to begin in 2010, peak in mid-decade during construction, and stabilize with the withdrawal of the construction labor force by late in the decade (JGPO, 2010).

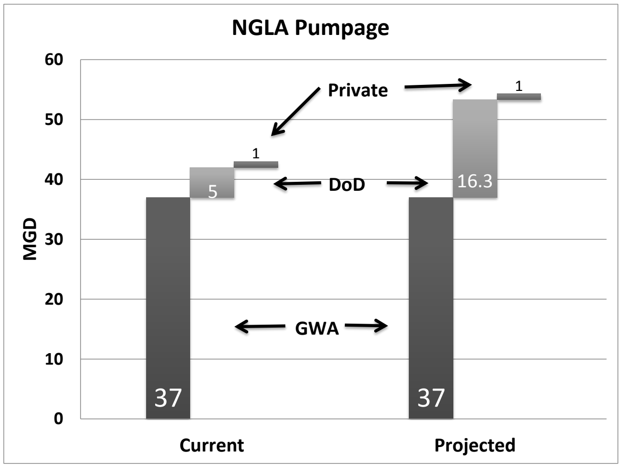

Figure 1-3. Original potable water production based on the following data: DOD from FEIS (JGPO, 2010); GWA from internal 2012 Water Production Report (Railey, 2013); Private from GEPA 2011 Annual Private Well Production Report (GEPA, 2012). Note that projections include only DOD expansion plans–other water expansion projections for GWA or Private wells are not included.

B. The Northern Guam Lens Aquifer

This component of the report provides a brief description of the aquifer to define and place in context the concepts and terminology used in building and applying the database. References cited are the fundamental and most useful sources for obtaining historical as well as current information on the aquifer, and include some of the sources for the *Database*.

The NGLA is primarily comprised of two limestone units: the Miocene-Pliocene Barrigada Limestone and the Pliocene-Pleistocene Mariana Limestone (Tracey et al., 1964) (Appx A-1). The Barrigada Limestone forms the core of the aquifer and is overlain and surrounded by Mariana Limestone. The Barrigada Limestone is a grey to white, indurate to friable, dense to porous fine-grain detrital limestone deposited in deep water. The Mariana Limestone is a complex of reef and lagoonal limestone that surrounds and overlies most of northern Guam. The peripheral reef facies form the steep cliffs of northern Guam, which display some large openings and solution channels (Taboroši et al., 2013, in press).

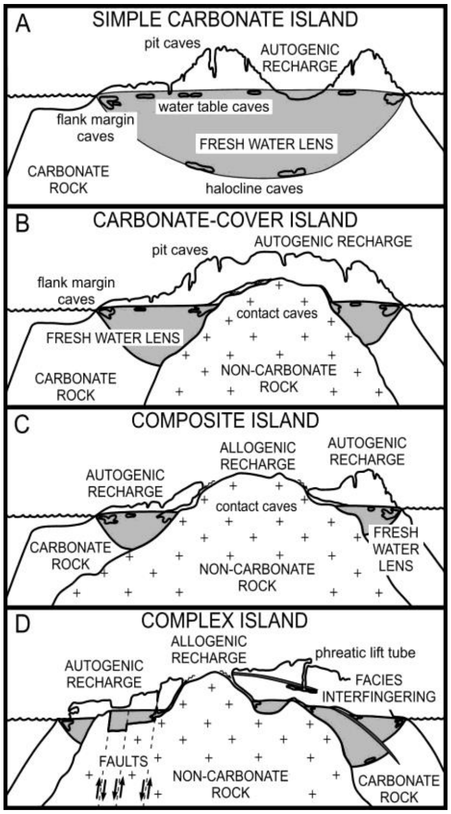

Figure 1-4. Carbonate Island Karst Model A) *Simple carbonate islands* contain a classic freshwater lens; B) The lens in *carbonate-cover islands* is partitioned where the basement aquiclude stands above sea level; C) On *composite islands* the basement core breaches the surface and weathers to form surface-water catchments that shunt allogenic waters to insurgents formed at the contact with the surrounding limestone terrain; D) Aquifers of *complex islands* reflect complex structural and stratigraphic histories (after Stafford et al., 2004). (Vertical dimension exaggerated)

Mylroie and Jenson (2000) developed the Carbonate Island Karst Model (CIKM) (Figure 1-4) to describe the unique karst that forms on small uplifted limestone islands such as Guam, where geologically young and porous limestone bedrock lies atop a relatively impermeable basement of older volcaniclastic rock (CDM, 1982). The ridges and rises in the volcanic basement partition the NGLA into six groundwater basins (Mylroie and Jenson, 2000; Mylroie et al., 2001; Vann et al., 2013, in prep.) (Figure 1-4 & Appx A-2) Taboroši et al. (2005) noted that the groundwater basins of northern Guam occupy simple, carbonate-cover, and composite environments (Figures 1-4A-C). Recent results of exploratory drilling (AECOM Technical Services Inc., 2011), however, suggest the head of the Yigo-Tumon Basin, (Appx A-2) may have attributes of the complex model (Figure 1-4D).

The body of fresh water within the NGLA forms an elongate “lens” floating atop the underlying sea water (Figure 1-5) that permeates the bedrock aquifer down to the underlying basement aquiclude. The thickness of the freshwater lens in theory extends about 40 feet (12 m) below sea level for every 1 foot (0.3 m) above sea level (Fetter, 2001). For the NGLA the actual ratio of freshwater lens thickness to freshwater head has been noted to range from 29:1 to 46:1, with a mean of 37:1 (Simard et al., 2013, in review). The portion of the freshwater lens that is underlain by seawater is termed the “basal zone” (CDM, 1982). The portion underlain by the volcanic basement rock is termed the “para-basal zone.” The area where freshwater traveling down the flank of the volcanic basement rock stands above mean sea level is now called the “supra-basal zone” (AECOM Technical Services Inc., 2011) (Figure 1-5).

Karst aquifers typically contain triple-porosity networks, in which matrix, fracture, and conduit porosity make varying contributions to storage and transport (Worthington, 1999). While matrix porosity is virtually absent in continental karst aquifers formed in Paleozoic limestones, all three porosities play important roles in carbonate island karst aquifers. Vacher and Mylroie (2002) have proposed that in the latter, horizontal hydraulic conductivity is enhanced along the water table as primary vugs become increasingly hydraulically connected. Vertical conductivity is generally much lower, except where ponding of surface water in dolines promotes development of high-conductivity shafts that provide vadose fast-flow routes (Jocson et al., 2002). Hydraulic characteristics of the NGLA thus exhibit high variability in both magnitude and direction, with horizontal hydraulic conductivities ranging from 500 ft/day (150 m/day) in the argillaceous limestone (Appx A-1) of the Hagåtña Basin (Appx A-2) to 90,000 ft/day (27,400 m/day) (Rotzoll et al., 2013) along the axis of the Yigo-Tumon Trough (Appx A-2). The recent field study by Rotzoll et al. confirms the hypothesis first suggested by Ayers and Clayshulte (1984) that the hydraulic conductivity of the peripheral rock is much lower than that of the interior rock. Although the contrast is roughly contiguous with the distribution of the two major limestone units, Taboroši et al. (2013, in press) propose that the distribution of hydraulic conductivity reflects regional-scale diagenetic and speleogenetic redistribution of porosity rather than primary characteristics of the respective limestone units, and thus is not necessarily coincident with the lithologic boundaries between the two rock units.

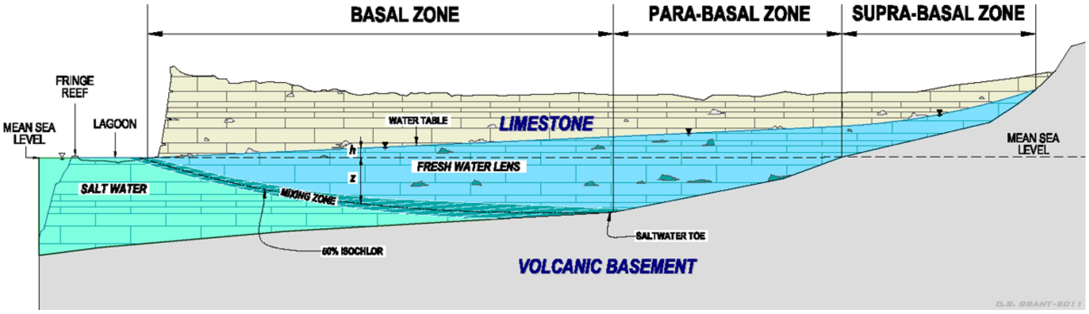

Figure 1-5. The topography of the volcanic basement beneath carbonate island karst aquifers defines three groundwater zones (not to scale): 1) the basal zone, in which the freshwater lens is underlain by sea water, 2) the para-basal zone, where the freshwater is underlain by basement rock below sea level, and 3) the supra-basal zone, in which freshwater lies above sea level, on the flanks of the basement rises and ridges. Graphic from AECOM Technical Services, Inc., 2011.

Given the general stratigraphic relation between the Barrigada and Mariana Limestones, as described above, it is generally assumed that most wells—especially in the interior, where most wells are, in fact, located—penetrate and terminate in the Barrigada Limestone. Drillers preparing the drill logs are seldom trained to distinguish between the different limestone units, nor is the distinction of immediate or direct importance in predicting or assessing the hydraulic properties of the rock at the drill site. The crucial hydrogeological distinction between rock units is rather between the water-bearing limestone bedrock and the non-productive volcanic basement. As explained by Vann et al. (2013, in prep.) determining the depth of the bedrock-basement contact even from borehole data is not always straightforward. Information from drilling logs, especially historical logs, can be difficult to interpret. Nevertheless, historical data, especially from previous systematic studies of the aquifer, are of considerable value.

C. Past aquifer research and data collection programs

The first systematic hydrologic study on Guam was done in 1937 by H.T. Stearns of the USGS (Stearns, 1937). Drilling for potable water on Guam began in May 1937, a month after the United States Navy (USN) brought a drill rig to the island (Mink, 1976). During the early years of groundwater development, most wells eventually failed due to poor placement, excessive withdrawal, or inadequate maintenance. No exploration or development of groundwater was undertaken by the occupying forces of Japan during World War II. Following the war, the US Army retained the USGS to map and document the geology of Guam (Tracey et al., 1964), which included a field study of the hydrology (Ward et al., 1965). The next general study of Guam's groundwater resources was J.F. Mink's 1976 report, commissioned by the Guam Environmental Protection Agency (GEPA) and subsequently published as WERI Technical Report #1.

Soon afterward, GEPA, with $1.2M in federal funding from the US Environmental Protection Agency, commissioned Camp, Dresser & McKee to undertake a comprehensive three-year study (CDM, 1982), which was also led by Mink. Referred to as the Northern Guam Lens Study (NGLS), this effort included the construction of several permanent observation wells, rain gages, and evaporation stations; the extraction of continuous core samples from one of the wells (EX-5A); a comprehensive seismic refraction survey to produce the first reliable map of the volcanic basement topography; evaluations of aquifer recharge; and the first numerical modeling study of the aquifer. As part of the study, Ayers and Clayshulte (1984) conducted a study of regional hydraulic conductivity based on tidal signals in five wells of varying distance from the coast, and a petrographic evaluation of the core sample from the aforementioned continuous core taken from the drilling of EX-5A (Appx A-2). The NGLS comprises several volumes, covering the hydrogeology (*Aquifer Yield Report*), along with manuals for well design and maintenance, and an *Executive Summary* of the entire report. The 1982 NGLS remains the most comprehensive study to date and thus the point of departure for subsequent studies, including the study reported herein.

A decade later, Mink (BCG, 1992) was again commissioned by GEPA to prepare an update to the 1982 study. Although of much smaller scope than the original study, the 1992 update took advantage of data collected during the intervening decade from the several hydrologic stations installed during the original study, along with the next decades' advances in computing and modeling technology. Also during the 1990s, the Department of Defense sponsored several Installation Restoration Program (IRP) projects on the military installations, which produced some significant studies relevant to the aquifer, including dye traces (Barner, 1997). Aquifer modeling studies conducted by WERI in the 1990s and early 2000s include projects by Contractor and Srivastva (1990), Contractor and Jenson (2000) and Jocson et al. (2002).

Most recently, the USMC, as noted above, retained the USGS to conduct the new $1.2M *Groundwater Availability Study for Guam* (Gingerich and Jenson, 2010). Five component projects were undertaken in collaboration with WERI:

1. The comprehensive *NGLA Database* described in this report
2. The most detailed and comprehensive study of aquifer recharge since the 1982 NGLS (Johnson, 2012)

3. A comprehensive field study of regional hydraulic conductivity (Rotzoll et al., 2013, in press) utilizing tidal-signal data from some 34 sites, including historical data as well as new data from wells drilled for the 2010 Navy Exploratory Drilling Program (AECOM, 2011)
4. An update of the aquifer basement map (Vann et al., 2013, in prep)
5. A three-dimensional numerical model of the aquifer to help predict the response of the lens to anticipated development and natural changes in recharge (see Gingerich and Jenson, 2010)

2. Purpose, Objectives, Scope, and Methods

There were two fundamental purposes behind the development of the *Database*:

1. For the near term, provide a comprehensive database of well and borehole data to support the three concurrent projects cited above, in section 1.A:
    - USGS-led construction of the numerical model for the *Groundwater Availability Study for Guam* (Gingerich and Jenson, 2010)
    - WERI's update of the basement map of Guam (Vann et al., 2013, in prep.)
    - NAVFACPAC's groundwater exploration program (AECOM Technical Services Inc., 2011)
2. For the long term, incorporate these and other relevant hydrologic data related to aquifer management (Table 2-1) into a state-of-the-art centralized database, to be permanently maintained at WERI, to support the long-term development, management, and protection of Guam's groundwater resources. This second objective follows from WERI's ongoing mission of administering the *Guam Hydrologic Survey* program.[2]

Geographical	Hydrological	Engineering	Geological
• Watershed • Coordinates • Elevation	• Rainfall • Evapotranspiration • Tidal influence	• Construction • Well design • Well hydraulics • Water quality • Maintenance	• Drill logs • Depth to basement • Deepest known depth of limestone • Sample collection • Borehole video

Table 2-1. Categories of data relevant to the NGLA Database.

This report explains the content of the *NGLA Database* and the principles, structure, and methods applied for compiling, interpreting, screening, and organizing the data. It also explains how to maintain and use the *Database*, and thus constitutes a "database user's manual."

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[2] Under *Guam Public Law 24-247, 14 Aug 1998*, WERI administers the *Guam Hydrologic Survey (GHS) Program*, which is tasked with "…collecting,…consolidating and storing all of the water resource data on Guam, and for making all of it readily retrievable for use by the people of Guam." Section 3, *Exchange of Data*, specifically provides that "WERI shall coordinate with the USGS and other Federal agencies to ensure that data collected by Federal agencies are immediately accessible to the Guam Hydrologic Survey," and that "All government of Guam agencies, including but not limited to the Guam Environmental Protection Agency (GEPA) and the Guam Waterworks Authority (GWA), shall transmit a copy of all nonproprietary data to WERI for consolidation in the GHS."

The specific tasks and objectives in assembling the *NGLA Database* were to

8. *Locate, consolidate, organize, and store* well, borehole, and other data relevant to
9. *Exploration, development, and management* of the NGLA, into a
10. *Centralized database*, in formats that readily support
11. *Descriptive and quantitative analyses of the aquife and its infrastructure,* including spatial and statistical analyses and numerical modeling.

Desired attributes of the *Database*, to facilitate its long-term application and maintenance include the following:

1. *Completeness and accessibility*: A extensive search was made to collect and compile current and historical geographical, hydrological, engineering and geological information on the NGLA from federal, local and private agencies.
2. *Ease of use*: Maximum use was made of commonly used software applications (specifically, Microsoft Excel 2010®) and familiar methods.
3. *Organization*: Data are organized in a deliberate and logical framework reflecting conventional groundwater industry terminology and standards to allow users to easily navigate through the systematic design.
4. *Digital storage media*: All "hard copy" historical records were scanned, stored, and catalogued in a computer-based directory.
5. *Documentation*: Metadata (i.e., data about the data) were meticulously appended throughout the data records so that users can know the available history and evaluate the reliability and suitability of the data for their desired application.
6. *Indexing*: All entities of interest are indexed to relevant textual (historical document) data, alpha-numerical (spreadsheet-based) data, and graphical data.
7. *Integration with other Internet sources*: The historical database described above is integrated with current on-line databases (such as currently reside on USGS website) by an index of internet links placed in a column titled *Outside Links*.

Scope and Methods. The development of the *NGLA Database* spanned three years, from March 2010 to March 2013, of continuous work by WERI faculty and staff, and by full-time and part-time graduate and undergraduate research assistants.

The scope of tasks ranged from attendance at training workshops and meetings on technologies and concepts for information management and database design, to hundreds of hours spent sifting through, gathering, and scanning paper documents; extracting, importing, and consolidating digital data from various media; and manually entering data into spreadsheets. As noted earlier, a concentrated effort was made to collect all historic and current well data, but emphasis was necessarily placed on active production wells and on wells/boreholes encountering volcanic basement rock during drilling. Although attempts to collect all available data were made within the time available, there are admittedly more data that remain to be (and should be) sought out.

On Guam, as in most other municipalities, groundwater production, management, research, development, and regulation are undertaken by separate agencies that collect information for different purposes, by different methods, with different standards, in different formats, and at different intervals. Historical records of variable quality and completeness reside in disparate locations, and are not systematically maintained or curated. In the absence of a formal inter-agency structure to promote collaboration and standardization, such compartmentalization precludes routine centralized collection and consolidation of data.

Acquisition, compilation, and consolidation of data sources for the *NGLA Database* therefore required a great deal of "detective work." Challenges included the necessity of extracting historical data residing on media ranging from barely legible yellowed paper file copies in dusty cabinets to the hard drives on people's personal computers, sometimes no longer maintained by the person who originally entered or kept the data, and sometimes no longer in use by anyone. Long-term data management does not always have high priority, especially when personnel and other agency resources are limited. Turnover of agency personnel often precludes adequate overlap and training in data management, resulting in breaks in file maintenance. Some paper files have been lost, misplaced, or damaged by storms.

For the *NGLA Database*, the term *original documents* refers to the "hard copy" historical records, and *source documents* refers to the corresponding scanned digital records (i.e., .pdf versions) made from them. "Source" is applied to the derivative digital documents because within the *Database* it is the digital versions of the original documents to which the numerical and other digital data are electronically traced. The content of each source document was compared with similar source documents to resolve discrepancies and ensure source documents were not duplicated. This was very time consuming, especially given irregularities and inconsistencies in naming conventions and coordinate systems, and given that source documents came from several different agencies. In addition, there could be multiple source documents for a given well, sometimes different documents with different data, but with the same date or same well name; sometimes the same or similar documents with different dates or well names. Some historical documents for a given well appear to describe an entirely different well than previous documents. Great care was taken to resolve such inconsistencies, and to document the resolutions in the *Database*.[3] Some errors, however, are bound to remain.

Because the immediate objectives of assembling the *NGLA Database* were to support the development of the basement map (Vann et al., 2013, in prep.) and numerical model (Gingerich and Jenson, 2010) by WERI and USGS respectively, the focus of this project and technical report is (1) the set of all boreholes and wells known to have encountered basement rock at the bottom of the aquifer and (2) all of the active production wells that currently extract water from the aquifer.

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[3] An example is provided in Appendix B, where two different wells were apparently named D-17. In this case, the current operating well was assigned the name D-17 and the other well is now named D-17X. The record in the database is annotated accordingly.

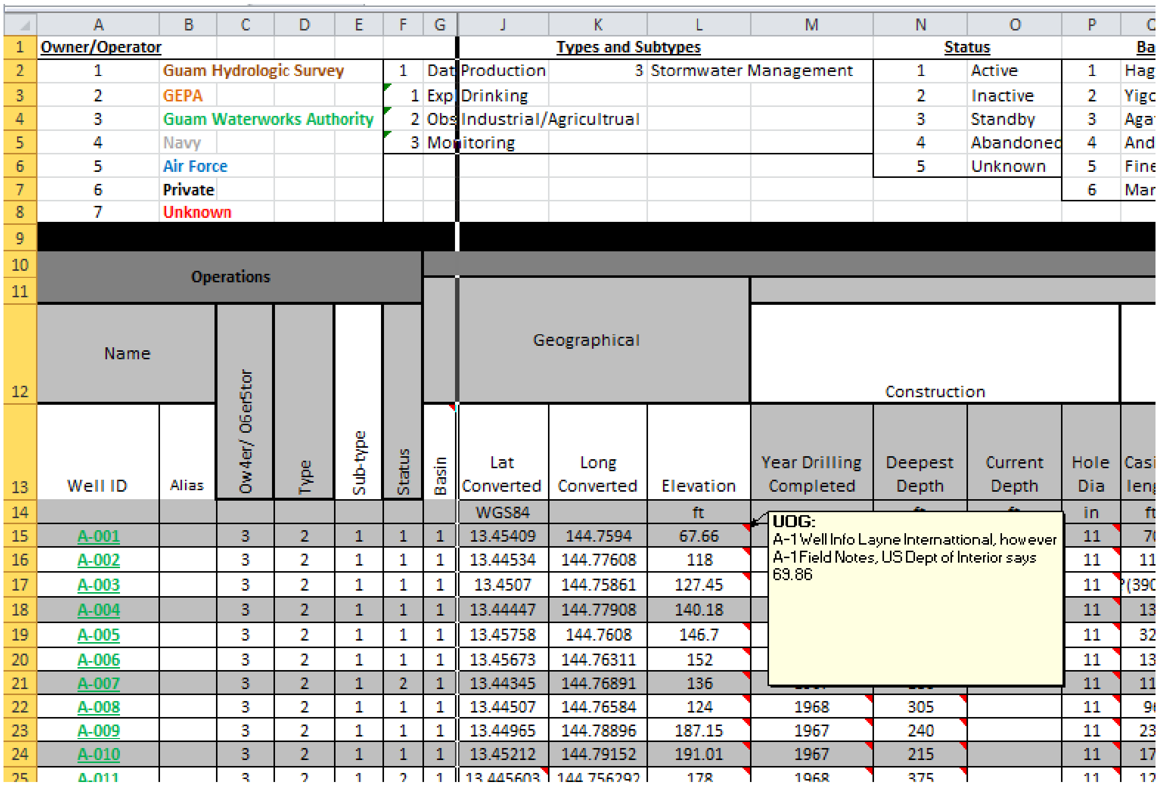
3. Components and organization of the *Database*

Components

As noted above, this report constitutes a user's manual for navigating through and extracting data from the *NGLA Database*. As also noted, the *Database* consists not only of digital data—which reside on the WERI server and are available through the WERI website—but also physical collections of written data on paper and graphic data on other media, which include copies of logs and other records; maps and photographs on paper and compact discs (CD) or digital video discs (DVD); and old video cassettes.   The individual components of the *NGLA Database* are thus organized as follows:

Incorporated components

1. *Quantitative data in Excel 2010 spreadsheets* (Appx C). The master copy resides on the WERI server in a folder named *NGLA Database*. Each entry in a spreadsheet cell is referred to as a *data record*. Each data record contains a "pop-up" comment note, activated when the computer mouse is held over the cell (Figure 3-1). The comments contain pertinent metadata, such as where to find the source data or information regarding conflicting data.



	A	B	C	D	E	F	G	J	K	L	M	N	O	P	C
1	Owner/Operator								Types and Subtypes				Status		Ba
2	1	Guam Hydrologic Survey				1	Dat	Production	3	Stormwater Management		1	Active	1	Hag
3	2	GEPA				1	Exp	Drinking				2	Inactive	2	Yig
4	3	Guam Waterworks Authority				2	Obs	Industrial/Agricultrual				3	Standby	3	Aga
5	4	Navy				3	Monitoring					4	Abandone	4	And
6	5	Air Force										5	Unknown	5	Fine
7	6	Private												6	Mar
8	7	Unknown													
9															

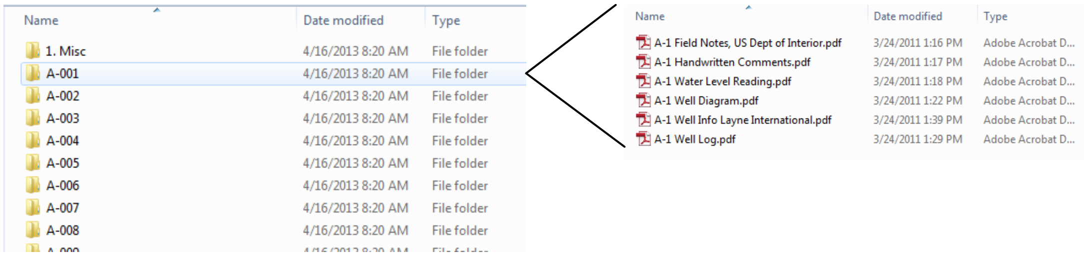
10	Operations														
11															
12	Name							Geographical			Construction				
13	Well ID	Alias	Ow4er/ O6erStor	Type	Sub-type	Status	Basin	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Deepest Depth	Current Depth	Hole Dia	Casi leng
14								WGS84		ft		ft	ft	in	ft
15	A-001		3	2	1	1	1	13.45409	144.7594	67.66				11	7
16	A-002		3	2	1	1	1	13.44534	144.77608	118				11	11
17	A-003		3	2	1	1	1	13.4507	144.75861	127.45				11	?(39
18	A-004		3	2	1	1	1	13.44447	144.77908	140.18				11	13
19	A-005		3	2	1	1	1	13.45758	144.7608	146.7				11	32
20	A-006		3	2	1	1	1	13.45673	144.76311	152				11	13
21	A-007		3	2	1	2	1	13.44345	144.76891	136				11	11
22	A-008		3	2	1	1	1	13.44507	144.76584	124	1968	305		11	9
23	A-009		3	2	1	1	1	13.44965	144.78896	187.15	1967	240		11	23
24	A-010		3	2	1	1	1	13.45212	144.79152	191.01	1967	215		11	17
25	A-011		3	2	1	2	1	13.445603	144.756292	178	1968	375		11	12

UOG:
A-1 Well Info Layne Internattional, however A-1 Field Notes, US Dept of Interior says 69.86

Figure 3-1. Screen shot of NGLA Database spreadsheet with "pop-up" comment box activated by holding mouse over the cell. This comment contains information regarding the data source and conflicting information in another source.

2. A *concealed comprehensive spreadsheet catalogue of well site locations* (access is restricted to users with explicit permission from the agency that owns or manages the well).[4]

3. *Digital folders containing .pdf files of source documents*. Original documents were collected and scanned, as noted in the previous section. In the spreadsheet the name of each well is electronically linked to a digital folder (named for the well) containing all source documents for the well. Although most easily accessed by way of this link, each folder can also be accessed separately within the master *NGLA Database* digital folder.



Name	Date modified	Type
1. Misc	4/16/2013 8:20 AM	File folder
A-001	4/16/2013 8:20 AM	File folder
A-002	4/16/2013 8:20 AM	File folder
A-003	4/16/2013 8:20 AM	File folder
A-004	4/16/2013 8:20 AM	File folder
A-005	4/16/2013 8:20 AM	File folder
A-006	4/16/2013 8:20 AM	File folder
A-007	4/16/2013 8:20 AM	File folder
A-008	4/16/2013 8:20 AM	File folder

Name	Date modified	Type
A-1 Field Notes, US Dept of Interior.pdf	3/24/2011 1:16 PM	Adobe Acrobat D...
A-1 Handwritten Comments.pdf	3/24/2011 1:17 PM	Adobe Acrobat D...
A-1 Water Level Reading.pdf	3/24/2011 1:18 PM	Adobe Acrobat D...
A-1 Well Diagram.pdf	3/24/2011 1:22 PM	Adobe Acrobat D...
A-1 Well Info Layne International.pdf	3/24/2011 1:39 PM	Adobe Acrobat D...
A-1 Well Log.pdf	3/24/2011 1:29 PM	Adobe Acrobat D...

Figure 3-2. Screen shot of the NGLA Database digital folders with the contents of A-001, including .pdf files of source documents.

4. *An interactive Geographic Information System (GIS)-interface*. This includes geographical and engineering data, and the updated volcanic basement topography map (Vann et al., 2013, in prep.). Using *ArcGIS Online*®, members of the NGLA Database User's Group (see Recommendations Section 5.C.4) can instantly upload and utilize shapefiles[5] and other relevant layers.[6]

5. *Links to other web-based data sources*. These include the websites of other agencies, such as the USGS website, which, for example, contains water levels and salinity profiles from Guam Hydrologic Survey (GHS) wells.

<u>Unincorporated components</u>

6. *Shelved binders containing paper copies of the original records*. These are primarily the *original documents*, from which digital *source documents* were scanned, and from which spreadsheet data were compiled.

7. *Drawers containing maps, photographs, video-cassettes, and other media*.

Organization

The focus of the *NGLA Database* was well and borehole data needed to support concurrent exploration, mapping, and modeling work as well as future work on aquifer hydrology and management. The organization of the entire *Database* thus reflects the relationship of the data to the source wells and boreholes. To organize the well data, it

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[4] Various agency security restrictions that followed the September 11, 2001 attack mandate that location information will not be made publicly available and can only be obtained with permission from the owner/operator.

[5] Shapefiles are an Environmental Systems Research Institute, Inc. (ESRI) format for geospatial vector data for its GIS software (ArcGIS). The files store nontopological geometry and attribute information for spatial features in a data set. For more information see ESRI Shapefile Technical Desription, An ESRI White Paper-July 1998.

[6] ArcGIS Online is a medium by which remote users can access the most current data without the expense of traveling to retrieve files from different agencies. It also protects against loss of data by ensuring only authorized users are able to access and save relevant files.

was necessary to develop a distinctive taxonomic system (Figure 3-1) to classify and relate the enormous amount of disparate data (Table 1-1) from which the *Database* is derived. The indexing conventions are shown in Figure 3-3 while Table 3-1 shows an example of how records for Borehole Depth are indexed.

The kinds of data outlined in Table 1-1 were first divided into two broad categories, called *sections*: (1) *operations data* (Figure 3-3a), and (2) *field data* (Figure 3-3b):

- Operations data provide administration information: well name/ID number, owner/operator, function or use of the well and the operational status of the well (e.g., whether is active or inactive).
- Field data describe the mechanical, hydrologic, or geologic characteristics or conditions of the well. Such information include the geographic coordinates and surface elevation; hydrologic conditions and variables that may affect the well; engineering data on well design, construction, maintenance, performance, and water quality; and geologic data, especially for boreholes and wells providing control for the basement map.

The second division down from *section* is *attribute* for operations data (Figure 3-1a), and *mode* for field data (Figure 3-1b). Attribute and mode are further divided into a third level, *division*, which divided into the fourth, *type*, which in turn is divided into the fifth level of *sub-type* and where a sixth level is necessary, *sub-type* is divided into *sub-sub-type*. Each taxa is accordingly assigned an index number of up to 6 digits, separated by periods (Table 3-1 and Figure 3-3). Figure 3-3 shows the entire conceptual framework of the *Database*. Note that the layout of the *NGLA Database* Excel spreadsheet (Appx C) reflects the organization displayed in Figure 3-3.

Example: 2.1.3.1.2.1 Borehole depth		
Taxon	Index fields	NGLA WELL DATA
Section	X	2. Field
Attribute or Mode	X.X	2.1 Incorporated
Division	X.X.X	2.1.3 Engineering
Type	X.X.X.X	2.1.3.1 Construction
Sub-type	X.X.X.X.X	2.1.3.1.2Depth
Sub-sub-type	X.X.X.X.X.X	2.1.3.1.2.1 Borehole depth

Table 3-1. Indexing of Borehole Depth, where digits 2.1.3.1.2.1, reflect Field, Incorporated, Engineering, Construction, Depth, Borehole Depth, respectively. See text and Fig. 3.3 for explanation.

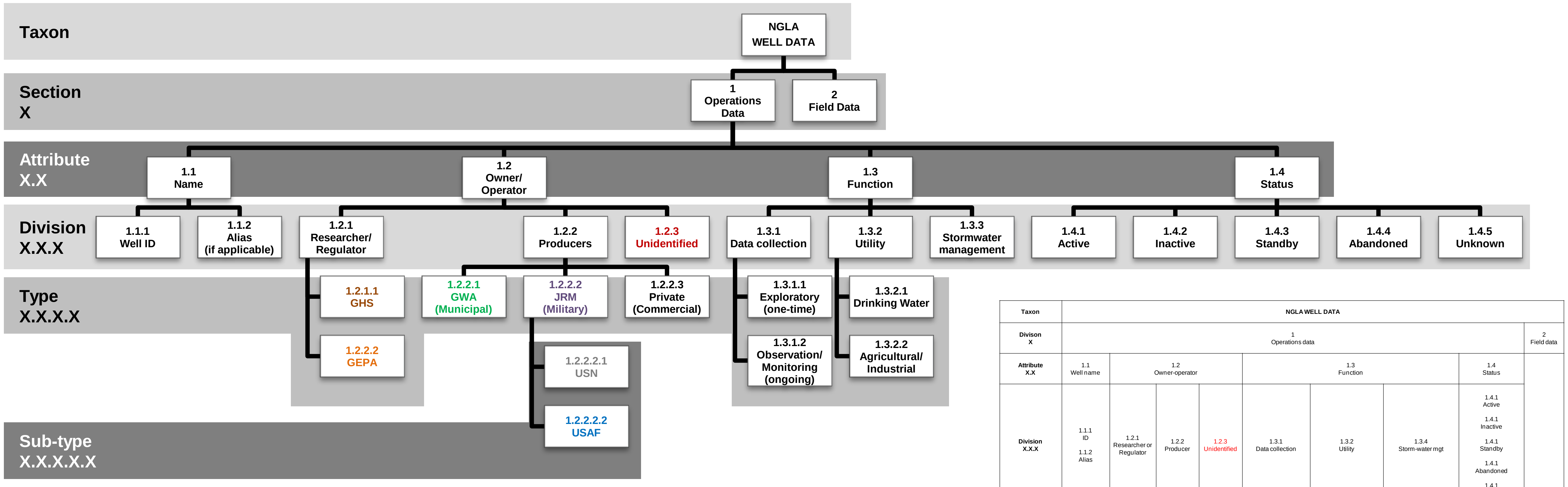
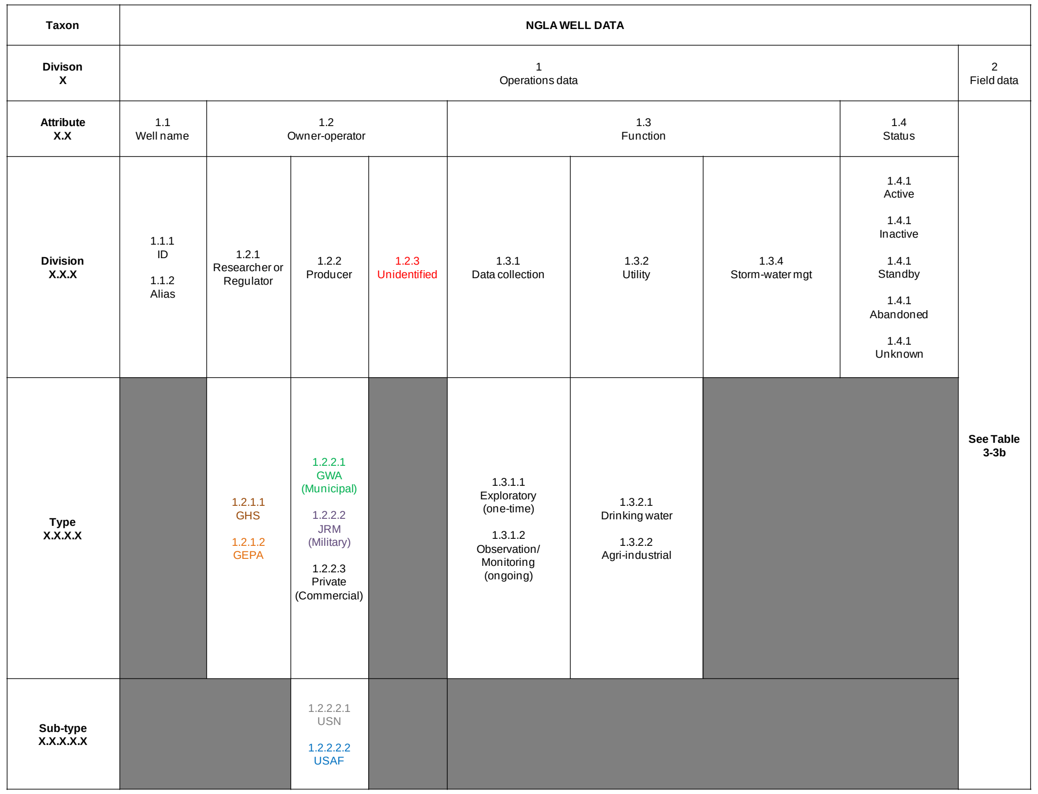
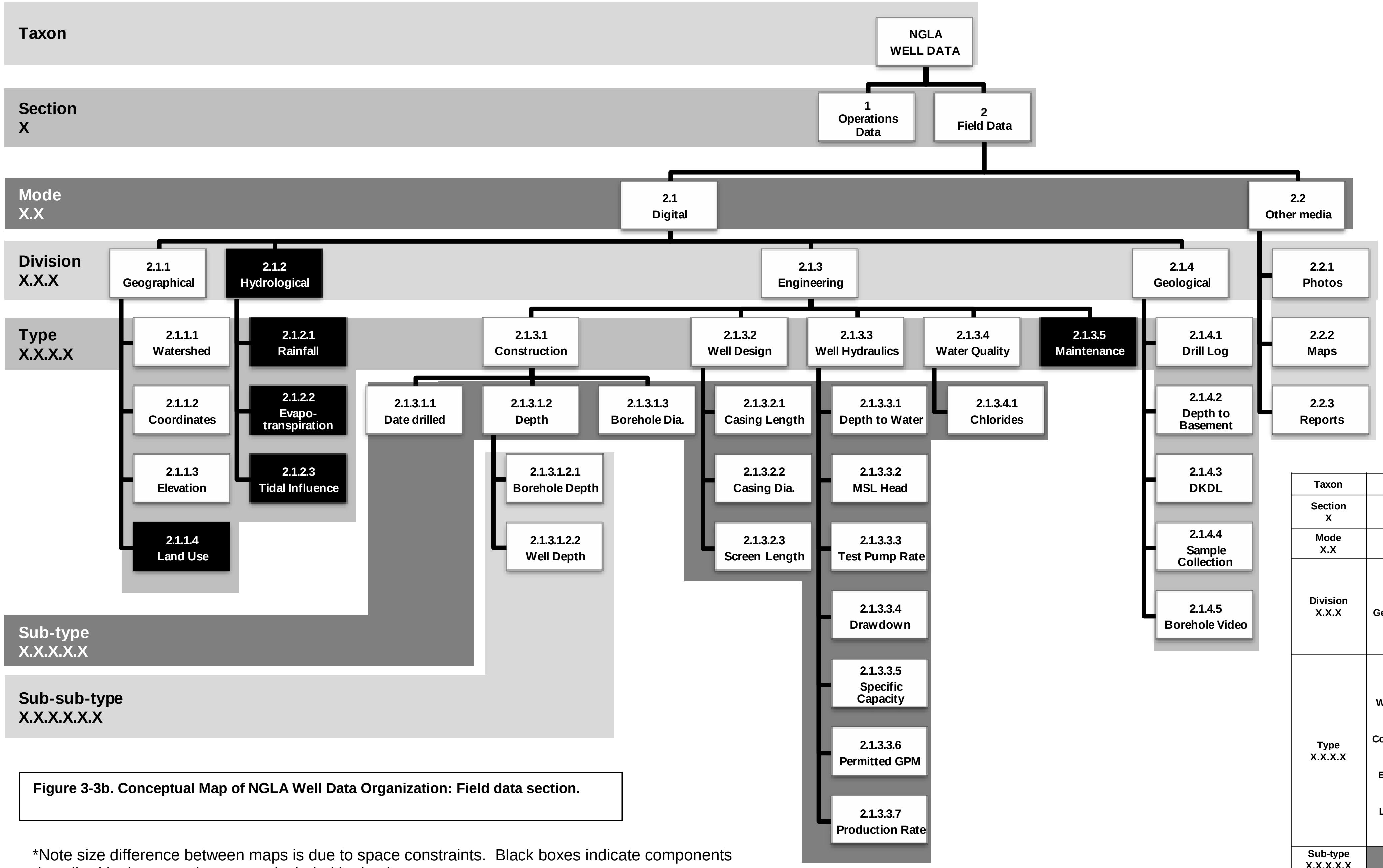


Figure 3-3a. Conceptual Map of NGLA Well Data Organization: Operations data section.



Taxon	NGLA WELL DATA								
Divison X	1 Operations data								2 Field data
Attribute X.X	1.1 Well name	1.2 Owner-operator			1.3 Function			1.4 Status	**See Table 3-3b**
Division X.X.X	1.1.1 ID 1.1.2 Alias	1.2.1 Researcher or Regulator	1.2.2 Producer	1.2.3 Unidentified	1.3.1 Data collection	1.3.2 Utility	1.3.4 Storm-water mgt	1.4.1 Active 1.4.1 Inactive 1.4.1 Standby 1.4.1 Abandoned 1.4.1 Unknown	
Type X.X.X.X		1.2.1.1 GHS 1.2.1.2 GEPA	1.2.2.1 GWA (Municipal) 1.2.2.2 JRM (Military) 1.2.2.3 Private (Commercial)		1.3.1.1 Exploratory (one-time) 1.3.1.2 Observation/ Monitoring (ongoing)	1.3.2.1 Drinking water 1.3.2.2 Agri-industrial			
Sub-type X.X.X.X.X			1.2.2.2.1 USN 1.2.2.2.2 USAF						



Taxon	Data				
Section X	2 Field data				
Mode X.X	2.1 Incorporated				2.2 Unincorporated
Division X.X.X	2.1.1 Geographic	2.1.2 Hydrologic	2.1.3 Engineering	2.1.4 Geologic	2.2.1 Photos 2.2.2 Maps 2.2.3 Reports
Type X.X.X.X	2.1.1.1 Watershed 2.1.1.2 Coordinates 2.1.1.3 Elevation 2.1.1.4 Land Use	2.1.2.1 Rainfall 2.1.1.2 Evapo-transpiration 2.1.1.3 Tidal effects	2.1.3.1 Construction 2.1.3.2 Well design 2.1.3.3 Well hydraulics 2.1.3.4 Water quality 2.1.3.5 Maintenance	2.1.4.1 Drill logs 2.1.4.2 Depth to basement 2.1.4.3 Deepest known depth of limestone (DKDL) 2.1.4.4 Sample collections 2.1.4.5 Borehole video	
Sub-type X.X.X.X.X			*See Diagram		
Sub-sub-type X.X.X.X.X.X			*See Diagram		

Figure 3-3b. Conceptual Map of NGLA Well Data Organization: Field data section.

*Note size difference between maps is due to space constraints. Black boxes indicate components described in the report but not yet included in database.

4. Database content and indexing

This part of the report briefly describes, in descending order of the indexing system, each of the indexed taxa of the *Database*, along with pertinent considerations such as agency histories and mandates; definitions and conventions adopted or devised; data complexities, nuances, and limitations; and assumptions and choices made in interpreting and classifying data. It should be noted here that while each of the various *taxa* by which a characteristic of given well is classified is an *element* of the *Database*, each of the cells in the spreadsheet (Appx C) contains a *data record* (i.e., the actual data entry). In the description below, headings are colored according to the corresponding color code used in the spreadsheet (AppxC).

SECTION 1 OPERATIONS DATA

Operations information for each well or borehole is divided into four attributes: *name*, *owner/operator*, *function*, and *status*. See Table 4-2 for a summary of well classification in the *Database*, including well function, well type, well status, and owner/operators, as defined above.

Attribute 1.1 Name

Identifying each well in the original documents sometimes required resolving apparent or suspected changes in well names, or deviations from naming conventions. As noted earlier, careful judgment was required to resolve records of different wells having the same or similar names, and records apparently for the same well but with different names—and in either case, sometimes over the same span of time and sometimes over different spans of time. Source documents for unresolvable cases are set aside in the M*iscellaneous* folder.

Division 1.1.1 Well ID

Where there were multiple names, the *Database* attempts to utilize the most commonly referred-to Well ID.   In the spreadsheet, well IDs are numbered out to three digits to facilitate record sorting within the spreadsheet. For example, A-2 becomes A-002. To save space on maps, however, the place-holding zeros are dropped from map labels; A-002 in the spreadsheet is A-2 on the map. The shapefile for well locations generated from the *Database* thus contains two fields: one, “Well ID,” from the spreadsheet, and a second, “Name,” that contains the “short version” for display on a map.

Division 1.1.2 Alias (as applicable)

When additional names were discovered that were apparently in use during all or part of the lifetime of a well/borehole, they are recorded in a separate column of the spreadsheet, adjacent to the Well ID column.

Attribute 1.2 Owner/Operator

The owner/operator is the last known agency responsible for well maintenance, operations, or data collection at the wellhead or from instruments installed in the well. The owner/operator of a given well can and has changed over time, especially in association with changes in well functions.

Division 1.2.1 Researchers and Regulators

Researchers and regulators are agencies tasked with collecting information at the wellhead (in the field) to study components of the aquifer.

Type 1.2.1.1 Guam Hydrologic Survey (GHS) – 1

During a severe El Niño drought in 1997-1998, the 24th Guam Legislature mandated and permanently established the Guam Hydrologic Survey with Public Law 24-247. WERI was charged with administering the program. Among its responsibilities are consolidating and analyzing hydrologic data on Guam, conducting research into selected water problems, and producing scientific reports and educational materials on water use, trends, and key concerns regarding Guam's water resources.

That same year, Public Law 24-161, *Drought Management and Comprehensive Water Conservation Plan*[7], was enacted which mandated WERI "administer a Comprehensive Monitoring Program regarding data collection on saltwater intrusion, water lens thickness in the northern part of Guam…and related matters." Beginning in 1998, WERI and USGS's Pacific Islands Water Science Center (PIWSC), Honolulu, restored most of a data-collection program that had been originally put in place during the 1982 NGLS, and have since collaborated on a cost-share agreement to collect data on water levels and salinity profiles at selected observation wells, along with other hydrologic data.

Type 1.2.1.2 Guam Environmental Protection Agency (GEPA) – 2

GEPA is the territorial environmental protection agency that enforces local and federal aquifer protection and water quality standards and regulations. It currently do not administer or maintain any observations wells or boreholes, but prior to 1998 was the custodial and collaborating agency with USGS for the wells that are now administered under the WERI-USGS Comprehensive Monitoring Program agreement. Given its previous custodianship for data-collection wells, GEPA could feasibly acquire new observation or monitoring wells for which it might have custodianship and therefore is reserved a space as a potential owner/operator.

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[7] Under *Guam Public Law 24-161, 14 Aug 1998*, *Guam Drought Management and Comprehensive Water Conservation Plan*. The Comprehensive Monitoring Program was established. More information can be found at: http://www.guamlegislature.com/Public_Laws_24th/P.L.%2024-247.pdf.

Attribute 1.2 Owner/Operator

Division 1.2.2 Producers

Producers are agencies operating wells that produce drinking water.

Type 1.2.2.1 Guam Waterworks Authority (GWA) (Municipal) – 3

Public Law 23-119[8] established the Guam Waterworks Authority in 1996; previously Public Utility Agency of Guam (PUAG), from 1950 to 1996. GWA is the sole civilian public water purveyor on Guam.

Type 1.2.2.2 Joint Region Marianas (JRM) (Military)

JRM, created in 2009 by the Department of Defense, consolidated the utilities of Naval Base Guam and Andersen Air Force Base (AAFB) and formally places them under Navy custodianship, however, separate utilities continue to administer the wells on their respective installations.

Sub-Type 1.2.2.2.1 United States Navy (USN) – 4

Naval Facilities Engineering Command Marianas (NAVFACMAR) maintains the wells on the naval facilities; only northern Guam sites are considered for the *Database*.

Sub-Type 1.2.2.2.2 United States Air Force (USAF) – 5

The 36th Civil Engineering Squadron Environmental Flight maintains the AAFB water system.

Type 1.2.2.3 Private Agencies (PVT) (Commercial) – 6

These include all private businesses that operate wells, e.g., rock quarries, golf courses, beverage plants, agricultural, and aquaculture facilities, etc.

Division 1.2.3 Unidentified (UNID) – 7

These include wells and boreholes whose owners or operators could not be determined or verified. These are temporarily set aside for later investigation; the majority appears to be historical exploratory wells that have most likely undergone name changes.

Attribute 1.3 Function

The wells and boreholes belonging to the various owner/operators are further divided according to function:

Division 1.3.1 Data Collection – Type 1

Data collection wells provide information on lithology, groundwater zones, and groundwater hydrology. Some were installed by design as data-collection wells; others were originally intended as utility wells, but because they proved ill-suited for their original purpose, or for other operational considerations, were converted to data-collection wells.

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[8] *Guam Public Law 23-119, 31 Jul 1996, An Act to Add a New Chapter 14 to Title 12 of the Guam Code Annotated Relative to Creating the Guam Waterworks Authority…* More information can be found at: http://www.guamlegislature.com/Public_Laws_23rd/P.L.%2023-119%20(SB%20511(LS).pdf

Division 1.3.1 Data Collection (cont'd.)

Type 1.3.1.1 Exploratory (One-time) – Sub-type 1

These can be boreholes drilled initially primarily for water exploration with no plan to bring them on line for data-collection or production, or boreholes drilled with the hope of making them into production wells, but which proved ill-suited for production.

Type 1.3.1.2 Observation/Monitoring (Ongoing) – Sub-type 2

These include non-pumping wells and boreholes where continuous data are collected for scientific observation or environmental monitoring.

Division 1.3.2 Utility – Type 2

Commonly known as "production wells," these wells produce water, either fresh, brackish, or saline for public, private, or commercial purposes.

Type 1.3.2.1 Drinking Water – Sub-type 1

Drinking water wells are specifically designed to supply potable water through municipal and military utilities. Water collected at these wells is tested and treated to levels safe for human consumption.

Type 1.3.2.2 Agricultural/Industrial – Sub-type 2

Agricultural and industrial wells supply water for irrigation, livestock, and private industry. A few of these wells purposely produce brackish or saltwater, e.g., the Fadian Fish Hatchery wells, the University of Guam (UOG) Marine Laboratory well, and the Underwater World Aquarium well.

Division 1.3.3 Stormwater Management – Type 3

Locally referred to as *Underground Injection Wells* (UIC) or "dry wells", these wells contribute to stormwater management by enhancing natural infiltration capacity. The *Database*, however, reserves the term "injection well" for wells that inject fluids under pressure into the aquifer (of which there are none on Guam). "Dry wells" on northern Guam do not inject water under pressure but collect and enhance the infiltration of storm water runoff. In the *Database* they are therefore placed under a *stormwater management* division. However, to avoid confusion when referring to the wells, in the *Database* they have retained their UIC names as assigned by the owner/operator.

Attribute 1.4 Status

Status is the best known current operational state of a well or borehole.

Division 1.4.1 Active – Status 1

The well is currently in service—pumping or collecting data. In other words, the well is functional and performing its intended function.

Division 1.4.2 Inactive – Status 2

The well is functional, but not currently performing its intended function. AECOM-3 and AECOM-9 wells are current examples; they were built as observation wells and are functional, but since funding has not been secured to bring them into the monitoring program they are not currently in service.

Division 1.4.3 Offline – Status 3

The well requires significant rehabilitation before normal operations may continue. The well is not functional and thus not performing its intended function.

Division 1.4.4 Abandoned – Status 4

Abandoned wells are those that are taken out of service and for which no future use is anticipated. Abandoned wells are required by GEPA regulations to be formally reported, closed, and permanently sealed according to specifications in the regulations.[9] The well is not functional, it is not performing its intended function and no rehabilitation is anticipated.

Division 1.4.5 Unknown – Status 5

No information on the current state of the well has yet been located. It is not known whether the well is functional, if it is performing its intended function, if any rehabilitation is needed or planned, or if it has been properly abandoned.

SECTION 2 FIELD DATA

Field data are defined as physical information about the borehole or well site and are classified into two *modes*: *incorporated* and *unincorporated data*.

Mode 2.1 Incorporated data

Incorporated data are recorded electronically in the *Database*, as numbers, characters, or images taken from source documents.

Division 2.1.1 Geographical

Geographical data are the physical characteristics that pertain to a well's location and include watershed, coordinates, elevation, and land use.

Type 2.1.1.1 Watershed

Each well and borehole in the *Database* occupies one of six subterranean watersheds, called *groundwater basins* (Appx A-2; Vann et al., 2013, in prep). The basin in which each well/borehole is located is shown in the spreadsheet by a single-digit code in the "watershed" column, as follows: Hagåtña Basin (previously Agana Sub-basin): 1; Yigo-Tumon Basin (previously Yigo Sub-basin): 2; Agafa Gumas Basin: 3; Andersen Basin: 4; Finegayan Basin: 5; Mangilao Basin: 6.

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[9] 22 GAR 2-§7103, Guam Administrative Rules and Regulations, Title 22 Guam Environmental Protection Agency, Division 2 Water Control, Chapter 7 Water Resources Development and Operating Regulations, Definitions. http://www.guamcourts.org/compileroflaws/GAR/22GAR/22GAR002-7a.pdf

Well function			1 – Data Collection				2 – Utility				3 – Stormwater Management		Unidentified	TOTAL
Well type			1 – Exploratory (one time)		2 – Observation/ Monitoring (on-going)		1 – Drinking Water		2 – Agriculture/ Industrial					
Researcher		1 – GHS			11	0								26
					2	13								
					0									
Regulator		2 – GEPA	0	0	0	0								0
			0	0	0	0								
					0									
Producers	Municipal	3 – GWA	0	2			103	11						171
			0	4			1	36						
							14							
	Military Joint Region Marianas (JRM)	4 – USN	0	0			12	0			0	0		36
			9	0			0	13				2		
							0				0			
		5 – USAF	0	0	65	0	13	1	1		102	0		211
			0	5	0	17	0	1				0		
					0		6				0			
	Commercial	6 – Private			1	0			17	0				40
					0	4			4	11				
					0				3					
		7 – Unidentified	0	0	0	0	0	0	0	0			35	41
			0	0	0	2	0	1	0	3				
			0		0		0		0					
TOTAL			20		115		212		39		104		35	525

Status	1 – Active	4 – Abandoned
	2 – Inactive	5 – Unknown
	3 – Offline	☒

Table 3-2. Summary table of database wells including well functions, well types, well status and owner/operators. The five status divisions are laid out within each bold-outline cell as shown at left.

Division 2.1.1 Geographical (cont'd.)

Type 2.1.1.1 Watershed

Up until the current revision of the basement map (Vann et al., 2013, in prep.) groundwater basins were called "aquifer sub-basins" in the professional and regulatory literature. The customary naming convention used by PUAG/GWA for municipal wells has been to apply a basin identifier followed by a serial number, based on the sub-basin names and locations from the 1982 basement map (CDM, 1982). Sub-basin identifiers used in well IDs were thus "AG" for Agafa Gumas, "F" for Finegayan, "A" for Agana (now Hagåtña), "M" for Mangilao, and "Y" for Yigo. (There are no commercial or municipal wells in the Andersen Basin.) In following this naming convention, a recent new well in the Agafa Gumas Basin, for example, is "AG-10."

It should be noted that basin boundaries (Appx A-2) are based on basement topography and simulated groundwater flow-lines from numerical models, and therefore are subject to change with each revision of the basement map and numerical models[10] (See Vann et al., 2013, in prep.). Some wells named on the basis of the 1982 boundaries now lie on the other side of the boundary of an adjacent basin, but the original well IDs are retained. F-7, for example, originally in the Finegayan Sub-basin, is now in the Yigo-Tumon Basin (Appx A-2). It should also be noted that although the *NGLA Database* uses the new basin boundaries delineated by Vann et al. (2013, in prep.), local agencies (other than WERI and USGS) as of this publication still utilize the sub-basin boundaries designated by the 1982 NGLS as the recognized watershed boundaries for management and regulatory purposes. (See Section 5. Recommendations)

Type 2.1.1.2 Coordinates

General background. Coordinates describe an exact location based on a reference system called a coordinate system. Because of the substantial challenges met in determining and resolving questions concerning positional data and the importance of verified locations to the interpolated basement topography and the USGS numerical model, some background is provided here before describing the particular characteristics and conventions used in the *Database*.

The *two common types of coordinate systems* used in GIS are *geographic* and *projected* coordinate systems:

- *Geographic coordinate systems* are based on spherical measures of latitude and longitude, with units in degrees and degree fractions.

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[10] Moreover, simulated numerical flow lines only theoretical approximations to the likely actual flow paths in karst aquifers, which are very difficult to determine, even with expensive field studies.

Type 2.1.1.2 Coordinates

- *Projected coordinate systems* are based on a selected geographic coordinate system, which is then projected onto a flat surface, and are usually expressed in distance units (Bolstad, 2008).

Important *parameters for defining a coordinate system* include:

- the geographic coordinate system (also called the datum)
- the unit of measurement (feet or meters)
- the zone (for Universal Transverse Mercator, UTM)
- and the projected coordinate system (also called the projection).

Guam coordinate systems. The first and most critical question in dealing with spatial data is identifying the referenced coordinate system. Unfortunately this is not always included in the dataset or metadata, especially in historical data. Reasonable assumptions were made when transforming spatial data for the *NGLA Database* and corresponding map (Appx A-2). Although there are several choices of geographic and projected coordinate systems, the most widely used on Guam are shown in Table 4-1. *Well locations in the NGLA Database are given in the UTM Zone 55N World Geodetic System (WGS)84 coordinate system* (UTM/Z55N-WGS84).

Quality and treatment of original data. Although coordinates from the original documents have been converted as necessary to UTM/Z55N-WGS84 for the GIS shapefile, they were extracted "as is" and referenced with a "pop-up" note from available sources in the spreadsheet. The identity or positions of some wells may be uncertain to various degrees. There may be other wells for which positional data are incorrect or inexact, but the uncertainty remains undiscovered because there was no apparent reason to question it. *The current positional data for every well should therefore be regarded as preliminary or unverified, especially for historical wells, until they can be verified by field survey*.

The transformation of data prior to importing into the shapefile required unit conversions (e.g., feet to meter, degree-min-sec to decimal degrees), datum conversions (Guam 1963NAD83 to WGS84), and conversion from geographic to projected coordinate systems (e.g., WGS84 to UTM Zone 55N WGS84). When cross-checking ArcGIS transformed coordinates, inaccuracies were sometimes found due to the aforementioned uncertainties. In these instances, each pair of coordinates was instead transformed using the GuamPRJ Version 2.01 Beta tool created by Brian P. Farm of USGS. This Guam-specific coordinate system conversion tool proved to be extremely helpful and more accurate in transforming coordinates for Guam when the original coordinate system was unknown.

Type 2.1.1.2 Coordinates

It should be noted, however, that the tool does not transform to or from the Guam Geodetic Network of 1993 coordinate system, and hence may introduce some error when transforming such data.

Verification. Although verification by field-checking was beyond the scope of this project (see section 5, "Recommendations"), attempts were made as time permitted to improve confidence by cross-checking positional data against previous layers and imagery. The greatest confidence in well positions lies with active production wells, as they have the most documentation for comparison and have been the subjects of the most accurate and current surveys.

Application of data. Appx A-2 is a map showing the general locations of approximately 64% of the 525 wells from the *NGLA Database*. Of the remaining 189 unmapped wells, 103 are stormwater management wells that have yet to be incorporated into GIS shapefiles since they were set aside as lower priority. Seventeen wells have coordinates that have yet to be identified or transformed. Five wells are identified as in same land parcel as the well they were drilled to replace so the coordinates could be interchangeable. Five wells are identified as a secondary name to a well already mapped. Some 50 wells, less than 10% of the 525 in the *NGLA Database*, are left with no coordinates available. For this project these wells were set aside and will possibly never be reconciled as the coordinate information is unreadable, too sparse, or obviously incorrect to be useful.

Locations for wells plotted on the map at Appx A-2 were taken from the following four sources:

1. Shapefiles obtained from GWA including work by Federal Emergency Management System (FEMA) in 2002 through the US Army Corps of Engineers under the Project *FEMA-1426-DR-GU, Typhoon Chata'an, Deep-wells*.
2. Previous WERI studies including, "*Spatio-temporal analysis of groundwater quality from 1996-2009*," which included a cross-reference for GWA wells and provided some JRM and private production well locations.
3. USGS website provided locations for observation wells in the WERI-USGS Comprehensive Monitoring Program.
4. Other sources as collected, such as well logs for exploratory drillings and other data-collection wells (besides the WERI-USGS Comprehensive Monitoring Program (CMP) wells), and records of abandoned wells. Each source is documented in the spreadsheet.

Geographic Coordinate Systems	Projected Coordinate Systems
GCS_Guam_1963 Angular Unit: Degree (0.017453292519943295) Prime Meridian: Greenwich (0.000000000000000000) Datum: D_Guam_1963 Spheroid: Clarke_1866 Semimajor Axis: 6378206.400000000400000000 Semiminor Axis: 6356583.799998980900000000 Inverse Flattening: 294.978698200000000000	Guam_Geodetic_Triangulation_Network_1963 Projection: Azimuthal_Equidistant False_Easting: 50000.000000 False_Northing: 50000.000000 Central_Meridian: 144.748751 Latitude_Of_Origin: 13.472466 Linear Unit: Meter (1.000000) Geographic Coordinate System: GCS_Guam_1963
GCS_North_American_1983_HARN Angular Unit: Degree (0.017453292519943299) Prime Meridian: Greenwich (0.000000000000000000) Datum: D_North_American_1983_HARN Spheroid: GRS_1980 Semimajor Axis: 6378137.000000000000000000 Semiminor Axis: 6356752.314140356100000000 Inverse Flattening: 298.257222101000020000	NAD_1983_HARN_UTM_Zone_55N Projection: Transverse_Mercator False_Easting: 500000.000000 False_Northing: 0.000000 Central_Meridian: 147.000000 Scale_Factor: 0.999600 Latitude_Of_Origin: 0.000000 Linear Unit: Meter (1.000000) Geographic Coordinate System: GCS_North_American_1983_HARN
GCS_WGS_1984 Angular Unit: Degree (0.017453292519943299) Prime Meridian: Greenwich (0.000000000000000000) Datum: D_WGS_1984 Spheroid: WGS_1984 Semimajor Axis: 6378137.000000000000000000 Semiminor Axis: 6356752.314245179300000000 Inverse Flattening: 298.257223563000030000	WGS_1984_UTM_Zone_55N Projection: Transverse_Mercator False_Easting: 500000.000000 False_Northing: 0.000000 Central_Meridian: 147.000000 Scale_Factor: 0.999600 Latitude_Of_Origin: 0.000000 Linear Unit: Meter (1.000000) Geographic Coordinate System: GCS_WGS_1984
	Guam_Geodetic_Network_1993 Projection: Transverse_Mercator False_Easting: 100000.000000 False_Northing: 200000.000000 Central_Meridian: 144.750000 Scale_Factor: 1.000000 Latitude_Of_Origin: 13.500000 Linear Unit: Meter (1.000000) Geographic Coordinate System: GCS_North_American_1983_HARN

Table 4-2. Geographic and Projected coordinate systems identified in use on Guam and listed in chronological order. Information on systems extracted from ESRI © ArcMap XY Coordinate System, located in shapefile properties.

Type 2.1.1.3 Elevation

Background. *Elevation* in the *Database* refers to ground surface elevation (called altitude in some documents). In the database, elevation is computed as the distance in feet measured vertically from Mean Sea Level (MSL) to a given point[11] which in most cases is ground surface. *MSL is the arithmetic mean of hourly heights observed over the National Tidal Epoch.*[12] The National Tidal Epoch is a specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datums. The present NTDE is 1983-2001. See Figure 4-1 for Guam MSL trends.

Data quality and verification. Ground surface elevations in the *Database* are in some cases taken directly from the source documents and in other cases calculated from information in the source documents. In a few cases, elevation was extracted from a digital elevation model from the WERI GHS Files. As with the coordinate data, elevation data should be regarded as unverified in absence of conducting a field check, however, efforts were made to ensure consistency with all available data sources.

The reference against which elevation was measured is not certain in every case, as some agencies use MSL while others use *mean lower low water*[13] (MLLW) levels or other references. While efforts were made to identify datums and measuring points, the MSL and MLLW vary over time and contain a certain amount of inherent error. The error inherent data in conversion is about the same as the general difference between MSL and MLLW ± 0.3 meters (or about one foot). (See Figure 4.-1.) The *NGLA Database* therefore reports elevations as assumed to have been measured against MSL, with an error of up to ± 0.3 meters, without attempting to discriminate between measurements taken in terms on MLLW. If more precise values are needed, a careful, systematic, and laborious study would have to be made of the elevation data alone to identify the various datums used and make accurate systematic conversions—which simply won't be possible in many cases as many documents do not report which reference was used. Therefore, where more accurate and precise data are needed, the only certain, but obviously laborious and expensive approach would be simply to resurvey the site in the field.

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[11] 22 GAR 2-§7103, Guam Administrative Rules and Regulations, Title 22 Guam Environmental Protection Agency, Division 2 Water Control, Chapter 7 Water Resources Development and Operating Regulations, Definitions. http://www.guamcourts.org/compileroflaws/GAR/22GAR/22GAR002-7a.pdf

[12] Mean Sea Level as defined by National Oceanic and Atmospheric Administration, http://tidesandcurrents.noaa.gov/datum_options.html

[13] The USGS topographic maps of Guam use MLLW.

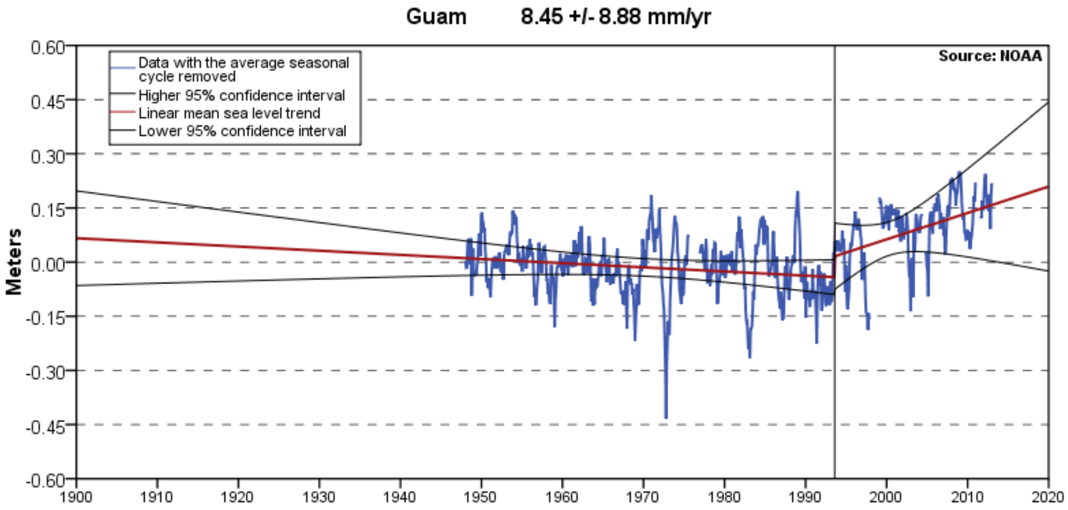

Figure 4-1. Guam mean sea level trend is 8.45 mm/yr with a 95% confidence interval of +/-8.88 mm/yr based on monthly mean sea level data from 1993 to 2006, equivalent to a change of 2.77 feet in 100 years. National Oceanic and Atmospheric Administration (NOAA) website http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1630000, accessed April 3, 2013. Note vertical black line in 1993 indicates a major shift caused by an earthquake.

Division 2.1.1 Geographical (cont'd.)

Type 2.1.1.4 Land Use

To accommodate future expansion of the *Database*, a *type* for land use data was reserved, but populating this element was beyond the scope of this project. Land use parameters relevant to groundwater management would be a valuable addition to the *Database* and much information on pertinent data and GIS files already exists, but comprehensive and detailed evaluation and documentation of land use will require a separate major research effort.

Division 2.1.2 Hydrologic

Hydrologic data relevant to management of the NGLA include rainfall, evapotranspiration, and tidal effects on water wells. These data have been, and continue to be, collected by various civil and military agencies, most of which now provide access to on-line databases containing current data, with historical data steadily being added. Since each end user must decide how reliable the data must be for their specific purposes, the *NGLA Database* does not extract, replicate, or attempt to consolidate hydrologic data for Guam that are accessible in such on-line databases. Rather, it provides information and references to the primary or most reliable sources for hydrologic data elements. Because these links require continual update and refinements no attempt is made to list them in this report; rather most can be found on the WERI website, under “Northern Guam Lens Aquifer Database: Links to Guam Hydrologic Data Sources,” where they are maintained by the Guam Hydrologic Survey.

Mode 2.1 Incorporated data

Division 2.1.2 Hydrologic (cont'd.)

Hydrologic data collection on Guam through 1998—which coincides with the rehabilitation of the Guam CMP and the establishment of the Guam Hydrologic Survey—is documented in WERI Technical Report #83, *Hydrologic Data Collection on Guam: FY1998 Report*[14] (Jenson and Jocson, 1998). Locations of the current CMP data-collection stations and the data obtained from them can now be accessed on the *Data Collection Sites*[15] page of the PIWSC website.

Information for these database elements is provided below:

Type 2.1.2.1 Rainfall

<u>Data-collection activities</u>. The primary meteorological collection agencies include USGS, National Weather Service (NWS), USAF, and USN. The longest and most reliable rainfall records are from AAFB, Naval Air Station (NAS) Agana, and Weather Service Meteorological Observatory (WSMO) Finegayan.

<u>Current best reference</u>. Although there are many datasets available, the only legally recognized data are collected and verified by the National Climatic Data Center (NCDC). It should be noted there are data gaps in the NCDC data set that were addressed and reasonably estimated in WERI Technical Report #102, *Creation of a 50-Year Rainfall Database, Annual Rainfall Climatology, and Annual Rainfall Distribution Map for Guam,* Lander and Guard, 2003.

Type 2.1.2.2 Evapotranspiration (ET)

<u>Data-collection activities</u>. The only known and documented pan-evaporation measurements were taken at USGS weather station 914229 from 1957 until discontinuation in 1996 (see Jenson and Jocson, 1998). For links to current data sources, see the WERI website: "Northern Guam Lens Aquifer Database: Links to Guam Hydrologic Data Sources."

<u>Current best reference</u>. The most recent study of evapotranspiration on Guam is documented in the 2012 USGS report, *A Water-Budget Model and Estimates of Groundwater Recharge for Guam* Johnson (2012), conducted in support of the Groundwater Availability Study for Guam (Gingerich and Jenson, 2010). Johnson noted that no studies on precipitation reaching the ground beneath forest canopy have been made on Guam, no pan evaporation measurements have been taken since 1996, and there are no known studies of potential-ET rates for Guam's vegetation. He therefore utilized studies conducted in similar regions to estimate ET on Guam.

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[14] Available as of 30 Oct 2012 on-line at: http://www.weriguam.org/locally-sponsored-research/guam-hydrologic-survey/page/data-availability-reports

[15] Available as of 30 Oct 2012 at: http://hi.water.usgs.gov/infodata/index.html

Division 2.1.2 Hydrologic (cont'd.)

Type 2.1.2.3Tidal and water-level data

Data-collection activities. Tidal data are collected on Guam by the USGS at the Hagåtña Boat Basin, by the National Oceanic and Atmospheric Administration (NOAA) at Sumay Cove in Apra Harbor, and on the east coast at Pago Bay over various intervals (Jenson and Jocson, 1998). Well water-level data collected by the USGS from GHS and other wells on Guam can be found on the PIWSC page of the USGS website.

Current best reference. As part of the *Groundwater Availability Study for Guam* (Gingerich and Jenson, 2010), Rotzoll et al. (2013) conducted a comprehensive study of tidal signals in some 34 wells on Guam, including historical data from wells long out of service, data from the ongoing CMP, and new data from the 2010 Exploratory Drilling Program. The locations of these wells are published in their report.

Division 2.1.3 Engineering Data

Engineering data pertain to well characteristics and performance and were taken "as is" from the original documents but were checked against other source documents as necessary to resolve obvious errors or address uncertainties. For multiple records, inconsistencies, or other noteworthy considerations regarding the data sources or interpretations, "pop-up" annotations in the spreadsheet exist for the respective record. Field-checking of engineering data was beyond the scope of this project, and can be done only case-by-case when the need justifies the high cost of opening and inspecting a given well.

Type 2.1.3.1 Construction

Sub-type *2.1.3.1.1 Year completed drilling*

The *Database* identifies the year the original drilling was completed as could best be determined from the documents. Source documents are referenced by "pop-up" comments. Users should keep in mind that any given drilling might start and end in different years and that some wells have undergone more than one drilling. Where there was more than one drilling, the end year of the first drilling, considered to be the original drilling, was recorded in the *Database* record.

Sub-type *2.1.3.1.2 Borehole diameter*

Borehole diameters are recorded in inches and are usually as set at time of first drilling. Users should note that some well diameters have been enlarged particularly when small-diameter exploratory wells have been developed into production wells.

Type 2.1.3.1 Construction

Sub-type ***2.1.3.1.3 Depth***

Depth is measured in feet as the distance from the ground surface at the well head.

Sub-sub-type *2.1.3.1.3.1 Borehole depth*

Borehole depth is defined as the deepest depth recorded for the borehole.

Sub-sub-type *2.1.3.1.3.2 Well depth*

Entries in the *Database* spreadsheet reflect the current serviceable depth of the well, which may or may not be different than the borehole depth. Serviceable depths may be reduced inadvertently by sidewall or well collapse or sidewall squeezing. In some cases original borehole depths have been reduced deliberately by back-filling with concrete.

Type 2.1.3.2 Well Design

Well design information is taken "as is" from the original documents, usually the well log or as-built plans when available. Changes are rarely made since well modification and rehabilitation are expensive and results are unpredictable.

Sub-type ***2.1.3.2.1 Casing length***

Casing length recorded in the spreadsheet is the length in feet of the solid casing pipe, typically steel in older wells or PVC (polyvinyl chloride) in newer wells, down to the affixed screen or the perforated/slotted portion of the casing that otherwise constitutes the screen. The casing typically starts above or at ground surface elevation.

Sub-type ***2.1.3.2.2 Casing diameter***

Casing diameter recorded in the spreadsheet is the diameter in inches (assumed to be inside diameter unless otherwise noted) of the steel or PVC casing.

Sub-type ***2.1.3.2.3 Screen length***

Screen length recorded in the spreadsheet is the length in feet of the installed well screen or the portion of the end of the casing containing slots or holes that allow inflow of water. The screen/slotting typically starts a few feet below static water level and extends downward most of the way to the bottom of the borehole.

Division 2.1.3 Engineering Data

Type 2.1.3.3 Well Hydraulics

Well hydraulics records are extracted from historical records of pump tests, which describe the depth to the water table and the performance of the pumped well or borehole. Where more than one record was available, i.e., from multiple pump tests, multiple water level readings, etc., the most common record, the most relevant record, or the record closest to operating conditions was selected for placement in the *NGLA Database*, and the “pop-up” note was annotated accordingly. Information from available records can be found in the corresponding well folder.

Sub-type *2.1.3.3.1 Depth to water*

Depth to water is the distance in feet from ground surface at the well head to the non-pumping water level, usually referred to as *static water level* in drilling records.

Depth measurements can vary from one source record to another for several reasons: use of different measuring equipment; stretching in a given instrument; changes in methods or measuring points; and in all cases, the natural fluctuations of water levels in

Sub-type 2.1.3.3.1 Depth to water

response to tidal signals (see Figure 4-1). Data in the spreadsheet records are taken “as is” from the pump test record, with any concerns about the data noted in the “pop-up” note for the spreadsheet record.

It is noted here that the *depth to water* data in the *NGLA Database* refers only to the “snapshot” depth to water for the particular source document. Where rigorous measurements or time-series of water levels in the aquifer are needed, the most accurate are the continual readings obtained from the GHS observation wells, which are available on the USGS website.

Sub-type *2.1.3.3.2 MSL head*

MSL head is a derivative quantity, calculated in the *Database* from the surface elevation and depth to water values reported in the applicable pump test record, or where necessary, information from separate reports. It thus utilizes the previously mentioned *elevation*, subtracting the above mentioned *depth to water*:

$$MSL\ head = Elevation\ (ground\ surface) - Depth\ to\ water$$

Error may be introduced by each term in the expression. The *NGLA Database* spreadsheet therefore notes that this is a calculated quantity derived from extracted data in the separate source columns.

Type 2.1.3.3 Well Hydraulics

Sub-type *2.1.3.3.3 Pump test rate*[16]

The pump test is a type of aquifer test used to determine well performance. Pump tests on Guam usually consist of two phases. The first is a “stepped-drawdown” phase, in which the pumping rate is increased, usually in 50-to100-gpm (gallons per minute) increments an hour or two apart, over the span of a few hours starting from the minimum pump capacity, up to or somewhat above the permitted rate. The second is a 24-hour constant-rate test, usually at the permitted capacity. The pump test rate recorded in the *NGLA Database* spreadsheet is the one deemed most relevant to operational plans for the well, which is the 24-hour constant rate, unless otherwise noted on the spreadsheet record “pop-up” note.

Sub-type *2.1.3.3.4 Drawdown*

Drawdown is the difference in feet between the initial depth to water or static water level and final depth to water or pumping water level, as recorded by the driller who conducted the pump test:

Drawdown = Initial depth to water – Final depth to water

Sub-type *2.1.3.3.5 Specific Capacity*

Specific capacity is a measure of the productivity of a well in terms of production rate per unit of drawdown and is listed in gpm/ft:

Specific capacity = Pump test rate/Drawdown

The value recorded in the *NGLA Database* is the value reported by driller who prepared the pump test report.

Sub-type *2.1.3.3.6 Permitted GPM*

The entry in the *Database* is the GEPA-assigned and approved pumpage rate, taken from the operating permit.

Sub-type *2.1.3.3.7 Production rate*

Each producer maintains its own records on production rates, and at a minimum must report submit to GEPA, by the 15th of January each year, a report of the amount of monthly extractions.[17] Production rates for each well may fluctuate over time based on

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[16] Pump test is a type of aquifer test in which a well is pumped at a constant rate and measurements of water levels are made in the pumping well and/or observation wells, usually for the purpose of determining aquifer hydraulic properties and the capacity of the well. (From the American Geological Institute, Glossary of Hydrology)

[17] 10GCA §46105(d) The holder of every well operating permit shall file on of before January 15, annual reports on forms to be provided by, and containing such information as, the Administrator may require including, but not limited to, the amount of water extracted each month of the preceding twelve (12) month period.

different factors, including well status or well function, and the rates may be different than permitted pumping rate. A yearly

Type 2.1.3.3 Well Hydraulics

Sub-type 2.1.3.3.7 Production rate

average of the most current available actual withdrawal rate (gpm) as reported by the producer typically over the last calendar year was entered in the *NGLA Database*.

It is noted here that Simard (2012) has compiled tables and graphs of historical monthly production rates against reported chloride concentrations. Incorporation of these data into the *NGLA Database* is anticipated. (See “Water Quality,” below, and section 5, *Database* Expansion).

Type 2.1.3.1 Water Quality

As with other hydrologic parameters, the *Database* has been constructed to accommodate expansion to include water quality data. There is an enormous variety of water quality parameters and data. Data on salinity, however, which are obtained from the USGS-WERI Comprehensive monitoring program as well as regulatory testing of water from current productions wells, provide especially important insights into the natural conditions of the aquifer and its responses to pumping. The *NGLA Database* will therefore soon be incorporating the spreadsheet data from the recent work by Simard et al. (2013, in review).

Sub-type *2.1.3.1.1 Chlorides*

Chloride concentration is the main parameter for determining salt water contamination, a major concern for any coastal or island aquifer. The most recent comprehensive study of chloride (or salinity) in the NGLA was conducted by Simard et al. (2013, in review). Their report provides a summary of the previous studies and will be available on-line on WERI’s website.

Type 2.1.3.5 Maintenance data

This data is not included at this time but could accommodate such information as pump size and types.

Division 2.1.4 Geologic Data

This segment of the *Database* includes information on subsurface geology. The *NGLA Database* contains geologic parameters and is the central database for the current update of the basement map by Vann et al. (2013, in prep.). Other elements of the geologic division of the *Database* connect the exploratory drilling and groundwater development programs that it also supports.

Division 2.1.4 Geologic Data

Type 2.1.4.1 Drill log

Drill logs are the single most important clue to subsurface geology. This column in the spreadsheet shows which wells have a log on file:

> "Y" (i.e., "yes") = wells with a drill log, for which the scanned source document can be found in the corresponding well database folder.
>
> "N" (i.e., "no") = wells for which not drill log has yet been found

Type 2.1.4.2 Depth to basement

The measured depth in feet from the surface to the first non-carbonate material (presumably the beginning of the contact with the basement rock formation); positively identifies the basement rock.

In the spreadsheet, **bold** numbers indicate distinct points where the source documents indicate a sharp and unequivocal boundary, while **gray** numbers indicate indistinct points where the source documents could define only an imprecise range of possible values. Values in green-bordered cells were used in the 2013 Volcanic Basement Map (Vann et al., 2013, in prep.). For details on the definition and application of this parameter, see Vann et al.

Type 2.1.4.3 Deepest known depth of limestone

The *deepest known depth of limestone (DKDL)* is a parameter used in the construction of maps of the basement topography. It is the measured depth in feet from the surface to the bottom of wells terminating in limestone (but not necessarily reaching the bottom of the limestone formation, i.e., the contact with the basement rock). Although such wells do not provide information on where the basement contact is, they do provide limited information on where it is not—hence at least a minimum depth of the limestone.

In the spreadsheet, **bold** numbers indicate *active* negative control, where the interpolated basement topography in the Volcanic Basement Map (Vann et al., 2013, in prep) was adjusted to eliminate inconsistencies, i.e. the interpolated surface intercepted the DKDL and was adjusted accordingly. Gray numbers, on the other hand, indicate *passive* negative control, where the interpolated surface is at least lower than the DKDL, providing limited confidence in the interpolated surface. For details on the definition and application of this parameter see Vann et al. (2013, in prep.)

Division 2.1.4 Geologic Data

Type 2.1.4.4 Sample Collection

The main resource for geologic study of borehole lithology is drill cuttings from the tri-cone rotary bits that are generally used to cut through the limestone bedrock on Guam. These are lifted to the surface in the drilling foam. Drillers are required to keep a log in which the characteristics of the cuttings are described sequentially as the drill bit descends through the limestone bedrock. GEPA requires samples be collected each time the drill bit reaches another five feet during drilling operations[18].

Although there are no facilities for properly archiving rock samples, WERI is currently storing the collection of drilling cuttings from the 2010 NAVFACPAC exploratory drilling program (AECOM Technical Services Inc., 2011), and the collection of cuttings from AAFB's re-drilling of the MW-series (MW5-MW-9) wells in the MARBO Well area (also known as Andersen South).

Unfortunately, there are not yet any dedicated facilities on Guam to preserve and curate rock samples or other physical samples of geologic materials, and no plans exist to create such a facility. Nevertheless, the *Database* includes a column to document the availability of physical samples located at WERI.

Type 2.1.4.5 Borehole Video

The *Database* also contains an element for cataloging borehole video, even though there is at this time no requirement for routine video documentation of new boreholes, and no provisions for systematic cataloging and archiving of borehole video. Increasing use is being made of video as the instrumentation becomes cheaper and easier to use and maintain. Such videos are providing important new insights into aquifer hydrology. The most recent examples are the videos from the AECOM 2010 exploratory drilling program. These video clips are catalogued and archived as mp4 files in the corresponding well folders.

Other video exists, including recordings stored at WERI on video home system (VHS) tapes from drilling done in the 1990s for the Andersen AFB Installation Restoration Programs, but these have not been formally archived and curated. During the research for this project, some 35 VHS tapes were found, 30 of which exhibited a mold or fungus known to grow on this type of media in humid environments. It is not yet known if these can be salvaged.

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[18] 10GCA §46106(a) The drillers shall at the request of the Administrator also furnish samples of the materials encountered in the drilling of the well which shall be taken at intervals of five (5) feet, or at every change of formation.

SECTION 2 FIELD DATA

Mode 2.2 Unincorporated media

This section of the report describes the other types of data, in addition to the source documents, that are available in either the corresponding well folders or, in the case of the Reports, in a separate folder.

Division 2.2.1 Photos

These include various photographs of interest but not necessarily pertinent to the *Database*, saved for historical interest. Where available, the user is directed to the individual well folder.

Division 2.2.2 Reports

This division includes reports relevant to the aquifer. These were utilized in the creation of the *Database*, either as informational references or as tools in locating wells and boreholes on Guam. This list is not exhaustive but contains the most current or comprehensive reports and has digital copy links listed on the *NGLA Database* page on the WERI website:

1. AECOM Technical Services Inc., 2011. Guam Water Well Testing Study to Support US Marine Corps Relocation to Guam, Naval Facilities Engineering Command, Pacific, Pearl Harbor, HI.
2. Earth Tech, Inc., 2010, The United States Navy Installation Restoration Program, Final, Spring 2010, Groundwater Monitoring Report for Andersen Air Force Base, Guam, prepared for CAPE Inc and sponsored by The Air Force Center for Engineering and the Environment.
3. Earth Tech, Inc., 1999, Stormwater management/underground injection well closure plan, Andersen AFB – Territory of Guam, prepared for Institute for Environment, Safety, and Occupational Health Risk Analysis Environmental Analysis Division.
4. Hild, J., Blohm, R., Lahti, R., and Blohm, M., 1996, Geophysical Surveys for Ground Water Exploration in Northern Guam, 25th Symposium on the Application of Geophysics to Engineering and Environmental Problems: Keystone, Colorado, p. 331-341.
5. BCG, 1992. Groundwater in Northern Guam: Sustainable Yield and Groundwater Development Final Engineering Report, Barrett Consulting Group [now AECOM Technical Services, Inc.] in association with John F. Mink for Public Utility Agency of Guam.
6. CDM, 1982. Final Report, Northern Guam Lens Study, Groundwater Management Program, Aquifer Yield Report, Camp, Dresser and McKee, Inc. in assoc. with Barrett, Harris & Associates for Guam Environmental Protection Agency.
7. Tracey, J.I., Jr., Schlanger, S.O., Stark, J.T., Doan, D.B., May, H.G., 1964. General Geology of Guam. 403-A, U.S. Geological Survey Professional Paper, US Government Printing Office, Washington, D.C.

5. Recommendations

A. Database maintenance and updates

Established Arrangements. The *NGLA Database* has been prepared in conformance with mandates and agreements for database development, maintenance, and data-sharing that are already in place. These need only be continued in order to provide sufficient inter-agency support to maintain the *NGLA Database*:

1. Guam Hydrologic Survey Program. Maintenance of the *NGLA Database* is consistent with the mission of the Guam Hydrologic Survey established by Public Law 24-247 (Appx D-1) to "locate, inventory and evaluate all hydrologic data pertaining to Guam and consolidate the data into a single computer-based data library from which information can easily be accessed and retrieved." Public Law 24-247 also specifically requires:
    - Drilling permit applicants coordinate with WERI and provide a copy of any down-hole or geophysical data collected
    - All government of Guam agencies…transmit a copy of all nonproprietary data to WERI for consolidation by the GHS.
    - Each agency collecting water-related data shall maintain an active point of contact with the GHS regarding the collection, transmission and archiving of data.
2. 16 July 2010 Memorandum of Understanding (Appx D-2) between Joint Region Marianas, Guam Consolidated Commission on Utilities, Naval Facilities Engineering Command Marianas, and Guam Waterworks Authority.
    - This formal agreement established a *Technical Experts Group* on Guam "to maintain regular communication as needed to share water resource data real time and raise concerns and issues to the working group."
    - It further specified that "The Technical Experts [group] will maintain all databases and technical tools in cooperation with WERI and USGS needed to monitor and assess the health of the NGLA. The TE [group] will consist, at a minimum, of [members from] GWA engineering staff, NAVFAC MARIANAS UEM, GEPA, WERI, and USGS."

Periodic Updates. It should be noted that since most water-resource data collection, whether by government of Guam agencies, military activities, or federal agencies is done on a monthly-to-quarterly basis, *the NGLA Database needs to be maintained continually* to keep up with the steady streams of monthly and quarterly data.

- It is further recommended that the *Database be given an annual review by the Technical Experts group,* and that recommended refinements and modifications be made during the subsequent year.
- WERI also holds an annual meeting in the fall with its *Guam Advisory Council*, composed of representative from various government departments that deal with water and water related issues, public and private sector professionals, other scientific

colleagues, and interested members of the community. *It is recommended the annual review of the NGLA Database coincide with this Advisory Council meeting* as some of the members of the Advisory Council also compose the Technical Experts group. With each year's update, the latest technologies and techniques should be incorporated to keep abreast of the rapid ongoing improvements in database and GIS technologies.

B. Database Improvement, Refinement, and Expansion

The following steps can be taken to improve the quality, refine the structure, and expand the coverage of the *Database*:

1. Field-checking of data. As noted in Section 4, location, elevation, and other geographic data in the *Database* were entered "as is" from the original sources after resolving any inconsistencies with other records. Reliability of such data would be enhanced by conducting a systematic and exhaustive field survey to visit each well site and check its coordinates and elevation against the currently recorded data. Priorities could be assigned on the basis of the uncertainties uncovered during the development of the *Database* and areas of importance for new well development or rehabilitation.
2. Refinement of lower-priority boreholes and wells. For the reasons previously stated, priority for verification in the current *Database* was given to active production wells included in the USGS groundwater model and boreholes utilized for WERI's development of the basement map. Records for many other wells now need to be examined, verified and mapped, including stormwater wells, exploratory wells, etc.
3. Inclusion of other well data. As mentioned above and in Section 2, the lower priority well information was not as actively sought out and should now be made a priority to uncover any additional source documents and fill in data gaps for these wells.
4. Inclusion of new data. As mentioned in Section 4, "placeholder" elements have been incorporated in the *Database* for parameters beyond the initial scope of this project. These include land use, additional water quality markers, and maintenance data. Incorporation of this information can be done as priorities dictate and resources permit.
5. Storage of samples, video, photos, maps, and other reports. It is also recommended that proper storage and personnel be acquired to archive and maintain the unique single-opportunity assets that are acquired, most especially drill cuttings, core samples, and videos. In addition, photos, maps, and reports pertinent to aquifer management should be acquired and archived.

C. Operational and administrative recommendations

The following are recommendations for changes in operational and administrative procedures that follow from insights and experience in building the *Database*. These will require inter-agency collaboration and agreement, as in some cases modest commitments of additional resources by the agencies involved. In all cases, however, the returns will improve not only the content and utility of the *Database*, but will also enhance the management of the aquifer.

1. Groundwater basin boundary usage review. With the recent update of the groundwater basin boundaries (Vann et al, 2013), agencies that utilize this information are advised to update, review, and consider their usage of previous groundwater basin boundaries.
2. Establishment of well naming conventions. The most confusing, frustrating, and yet easily-resolvable issue encountered was the non-standard naming conventions used throughout the years. Currently, wells are named according to which groundwater basin they draw from, followed by a sequential number, presumably the next in the series of wells installed, but this is not always the case. (See *Attribute 1.1 Name* for a discussion on the issues encountered during the creation of the *NGLA Database*.) In addition to this issue, *Type 2.1.1.1 Watershed* also notes that groundwater basins can, and most likely will, change in the future. It is recommended the Technical Experts group take up this discussion for resolution and agreement, and make some recommendation to the permitting authority (GEPA) for establishment of a permanent, systematic convention for naming of boreholes and wells.
3. Video logging at all uncased and newly drilled wells. The technology exists and is accessible on island to video log uncased and newly drilled wells. The importance of video logging was recently documented when a well in the Agafa Gumas groundwater basin revealed the existence of a previously unknown feature, cascading water in the well some 80 feet above the water table. Although drill cutting collection, and in some cases geophysical logging, is being conducted there are features that can be difficult to interpret or indistinguishable with these tools. But working in conjunction with these tools, video logging would be a useful in studying not only the lithology of wells but also hydrologic conditions and behaviors, as demonstrated with the Agafa Gumas well.
4. Establishment of *NGLA Database* User's Group. Since some of the information presented here can be considered proprietary, the creation of a *NGLA Database* User's Group would alleviate some of the uncertainty when presenting, communicating, and sharing this information. Creation of a formal user's group would facilitate access to the *NGLA Database*, including its source documents, spreadsheets, and shapefiles, and access to shapefiles utilizing an ArcGIS Online® account with files managed by WERI. Each agency will be responsible for maintaining pass codes and access of their ArcGIS Online account.

6. Future studies

Maintenance and expansion of the *Database* as described above will support future improvements in basement mapping, such as 3-D modeling of basement, bedrock and water-flow pathways in the aquifer.

REFERENCES

AECOM Technical Services Inc., 2011. Guam Water Well Testing Study to Support US Marine Corps Relocation to Guam, Naval Facilities Engineering Command, Pacific, Pearl Harbor, HI.

Ayers, J.F., Clayshulte, R.N., 1984. A preliminary study of the hydrogeology of northern Guam, Water & Energy Research Institute, University of Guam, Mangilao.

Barner, W. L., 1997. Time of travel in the fresh water lens of northern Guam. Proceedings of the Eigth Symposium on the Geology of the Bahamas and Other Carbonate Regions, pp 1-12.

BCG, 1992. Groundwater in Northern Guam: Sustainable Yield and Groundwater Development Final Engineering Report, Barrett Consulting Group [now AECOM Technical Services, Inc.] in association with John F. Mink for Public Utility Agency of Guam.

Bolstad, P., 2008. GIS Fundamentals: A First Text on Geographic Information Systems. 3rd Edition. Elder Press,White Bear Lake, MN, Ch 3.

Bureau of Statistics and Plans, Office of the Governor, 2012. Guam Statistical Yearbook 2011 http://www.bsp.guam.gov/Gu%20Stat%20Yrbk_2011_Fnl_v3.pdf

CDM, 1982. Final Report, Northern Guam Lens Study, Groundwater Management Program, Aquifer Yield Report, Camp, Dresser and McKee, Inc. in assoc. with Barrett, Harris & Associates *for* Guam Environmental Protection Agency.

CIA, 2013. Central Intelligence Agency, CIA world factbook Guam, https://www.cia.gov/library/publications/the-world-factbook/geos/gq.html, accessed 24 March 2013.

Contractor, D.N., Jenson, J.W., 2000. Simulated Effect of Vadose Infiltration on Water Levels in the Northern Guam Lens Aquifer. Journal of Hydrology, 229: 232-254.

Contractor, D.N., Srivastava, R., 1990. Simulation of saltwater intrusion in the Northern Guam Lens using a microcomputer. Journal of Hydrology, 118: 87-106.

Fetter, C.W., 2001. Applied Hydrogeology. Prentice Hall, Upper Saddle River, NJ, 598 pp.

Gingerich, S.B., Jenson, J.W., 2010. Groundwater availability study for Guam; goals, approach, products, and schedule of activities. In: 2010–3084, U.S.G.S.F.S. (Ed.).

GEPA, 2012. 2011 Annual Private Well Production Report. Unpublished document, Guam Environmental Protection Agency.

GVB, 2011. Guam Visitors Bureau, Annual Report July 24, 2012, http://www.visitguam.org/docs/research-and-reports/reports/annual-reports/guam-visitors-beaureau-july-24-2012.pdf, accessed 14 March 2013.

Jenson, J.W., Jocson, J.M.U., 1998. Hydrologic data collection on Guam: FY 1998 Report. WERI Technical Report No. 83, Water & Environmental Research Institute of the Western Pacific, University of Guam, Mangilao.

JGPO, 2010. Joint Guam Program Office, Relocating marines from Okinawa; visiting aircraft carrier Berthing, and Army Air and Missile Defense Task Force. .

Jocson, J.M.U., Jenson, J.W., Contractor, D.N., 2002. Recharge and Aquifer Response: Northern Guam Lens Aquifer, Guam, Mariana Islands. Journal of Hydrology, 260: 231-254.

Johnson, A.G., 2012. A water-budget model and estimates of groundwater recharge for Guam, .

Lander, M.A., Guard, C.P., 2003. Creation of a 50-Year Rainfall Database, Annual Rainfall Climatology, and Annual Rainfall Distribution Map for Guam, WERI Technical Report No. 102.

Mink, J.F., 1976. Groundwater resources on Guam: Occurrence and Development, Water & Environmental Research Institute of the Western Pacific, University of Guam, Mangilao.

Mylroie, J.E., Jenson, J.W., 2000. The Carbonate Island Karst Model applied to Guam. Theoretical and Applied Karstology, 13-14: 51-56.

Mylroie, J.E. et al., 2001. Karst features on Guam in terms of a general model of carbonate island karst. Journal of Cave and Karst Studies, 63(1): 9-22.

Railey, B., 2013. 2012WtrProdRpt.xlsx (Jan-Jun). Unpublished internal document, Guam Waterworks Authority.

Rotzoll, K., Gingerich, S.B., Jenson, J.W., El-Kadi, A.I., 2013. Estimating hydraulic properties from tidal attenuation in the Northern Guam Lens Aquifer, Territory of Guam, USA. Hydrogeology Journal.

Simard, C.A., Jenson, J.W., Lander, M.A., 2013, in review. Analysis of Salinity in the Northern Guam Lens Aquifer. In: Savarese, M., Glumac, B. (Eds.), 16th Symposium on the Geology of the Bahamas and Similar Regions, Gerace Research Center, San Salvador Island, Bahamas.

Stafford, K.W., Mylroie, J.E., Jenson, J.W., 2004. Karst geology of Aguijan and Tinian, CNMI cave inventory and structural analysis of development, Water & Environmental Research Institute of the Western Pacific, University of Guam, Mangilao.

Stearns, H.T., 1937. Geology and Water Resources of the Island of Guam, Mariana Islands. US Navy Manuscript.

Taboroši, D., Jenson, J.W., Mylroie, J.E., 2005. Karst features of Guam, Mariana Islands. Micronesica, 38(1): 17-46.

Taboroši, D., Jenson, J.W., Mylroie, J.E., 2013, in press. Field observations of coastal discharge from an uplifted carbonate island aquifer, northern Guam, Mariana Islands: a descriptive geomorphic and hydrogeologic perspective. Journal of Coastal Research, JCOASTRES-D-12-00054.1.

Tracey, J.I., Jr., Schlanger, S.O., Stark, J.T., Doan, D.B., May, H.G., 1964. General Geology of Guam. 403-A, U.S. Geological Survey Professional Paper, US Government Printing Office, Washington, D.C.

Vacher, H.L., Mylroie, J.E., 2002. Eogenetic karst from the perspective of an equivalent karst medium. Carbonates and Evaporites, 17: 182-196.

Vann, D.T. et al., 2013, in prep. Topography of the basement rock beneath the northern Guam lens aquifer and its implications for groundwater exploration & development, Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao.

Ward, P.E., Hoffard, S.H., Davis, D.A., 1965. Hydrology of Guam, U.S. Geological Survey Professional Paper 403-H, US Government Printing Office, Washington, D.C.

Worthington, S.R.H., 1999. A comprehensive strategy for understanding flow in carbonate aquifers. In: Palmer, A.N., Palmer, M.V., Sasowsky, I.D. (Eds.), Karst Modeling Symposium. Karst Waters Institute, Charlottesville, VA, pp. 17-29.

GLOSSARY

Aquifer: A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water. (AGI p9)

Drainage well: (1) A well installed to drain surface water, storm water, or treated waste water into underground strata (after ASCE, 1985). (2) A water well constructed to remove subsurface water or to reduce a hydrogeologic unit's potentiometric surface (after ASCE, 1985).

Evapotranspiration: The combined loss of water from a given area by evaporation form the land and transpiration from plants (after SSSA, 1975).

Fresh water: Water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids; generally more than 500 mg/L is undesirable for drinking and many industrial uses (USGS, 1984).

Inactive well: A well whose use has been temporarily suspended and may be reactivated at a future date. (22 GAR 2-§7103)

Injection well: A well constructed for the purpose of introducing water or substances into the ground as a means of replenishing groundwater basins or repelling intrusion of sea water. 22 GAR 2-§7103

Exploratory drilling: A hole drilled for geologic or hydrologic exploration. 22 GAR 2-§7103 shortened

Observation well: A well used for the purpose of observing subsurface hydrologic conditions and collecting hydrologic or water quality data and not for use in extracting water from an aquifer for beneficial use. 22 GAR 2-§7103 monitoring

Production well: A well used to supply potable water. 22 GAR 2-§7103

Well: Any hole that is driven, drilled, dug, or bored at any angle, either cased or uncased, by any method into the ground, for the purpose of obtaining water or knowledge of water bearing or soil formations, or for the disposal of surface water drainage.

Well cuttings: Rock chips cut by a bit in the process of well drilling, and removed from the hole in the drilling mud in rotary drilling or by the bailer in cable-tool drilling. Well cuttings collected at closely space d intervals provide a record of the strata penetrated (Jackson, 1997).

APPENDIX A

Maps

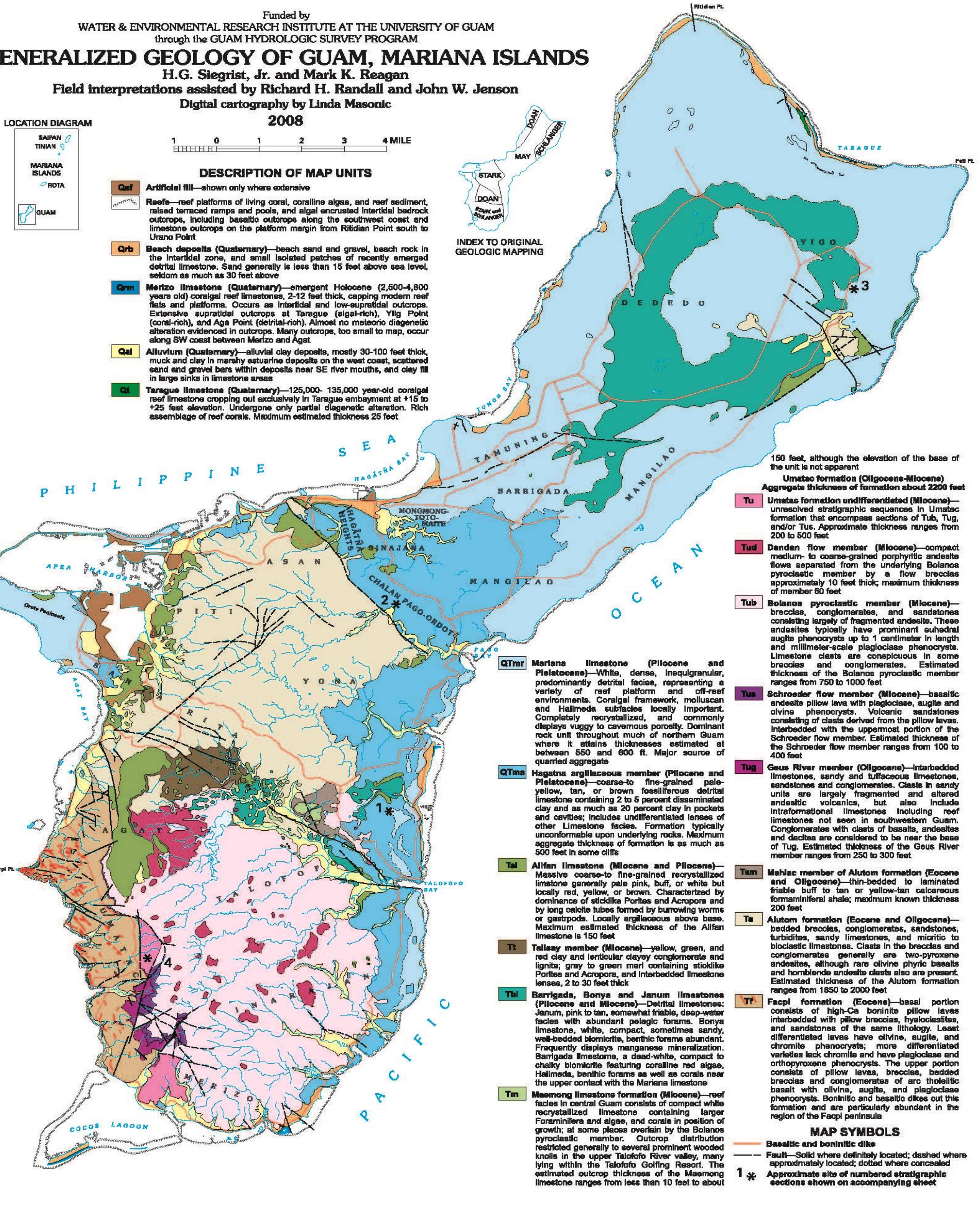
A-1 Generalized Geology, 2008…pg 46

A-2 NGLA Database Wells, 2013…pg 47

Funded by
WATER & ENVIRONMENTAL RESEARCH INSTITUTE AT THE UNIVERSITY OF GUAM
through the GUAM HYDROLOGIC SURVEY PROGRAM

GENERALIZED GEOLOGY OF GUAM, MARIANA ISLANDS

H.G. Siegrist, Jr. and Mark K. Reagan
Field interpretations assisted by Richard H. Randall and John W. Jenson
Digital cartography by Linda Masonic
2008



DESCRIPTION OF MAP UNITS

Qaf **Artificial fill**—shown only where extensive

Reefs—reef platforms of living coral, coralline algae, and reef sediment, raised terraced ramps and pools, and algal encrusted intertidal bedrock outcrops, including basaltic outcrops along the southwest coast and limestone outcrops on the platform margin from Ritidian Point south to Urano Point

Qrb **Beach deposits (Quaternary)**—beach sand and gravel, beach rock in the intertidal zone, and small isolated patches of recently emerged detrital limestone. Sand generally is less than 15 feet above sea level, seldom as much as 30 feet above

Qrm **Merizo limestone (Quaternary)**—emergent Holocene (2,500-4,800 years old) coralgal reef limestones, 2-12 feet thick, capping modern reef flats and platforms. Occurs as intertidal and low-supratidal outcrops. Extensive supratidal outcrops at Tarague (algal-rich), Yilg Point (coral-rich), and Aga Point (detrital-rich). Almost no meteoric diagenetic alteration evidenced in outcrops. Many outcrops, too small to map, occur along SW coast between Merizo and Agat

Qal **Alluvium (Quaternary)**—alluvial clay deposits, mostly 30-100 feet thick, muck and clay in marshy estuarine deposits on the west coast, scattered sand and gravel bars within deposits near SE river mouths, and clay fill in large sinks in limestone areas

Qt **Tarague limestone (Quaternary)**—125,000- 135,000 year-old coralgal reef limestone cropping out exclusively in Tarague embayment at +15 to +25 feet elevation. Undergone only partial diagenetic alteration. Rich assemblage of reef corals. Maximum estimated thickness 25 feet

QTmr **Mariana limestone (Pliocene and Pleistocene)**—White, dense, inequigranular, predominantly detrital facies, representing a variety of reef platform and off-reef environments. Coralgal framework, molluscan and Halimeda subfacies locally important. Completely recrystallized, and commonly displays vuggy to cavernous porosity. Dominant rock unit throughout much of northern Guam where it attains thicknesses estimated at between 550 and 600 ft. Major source of quarried aggregate

QTma **Hagatna argillaceous member (Pliocene and Pleistocene)**—coarse-to fine-grained pale-yellow, tan, or brown fossiliferous detrital limestone containing 2 to 5 percent disseminated clay and as much as 20 percent clay in pockets and cavities; includes undifferentiated lenses of other Limestone facies. Formation typically unconformable upon underlying rocks. Maximum aggregate thickness of formation is as much as 500 feet in some cliffs

Tal **Alifan limestone (Miocene and Pliocene)**—Massive coarse-to fine-grained recrystallized limstone generally pale pink, buff, or white but locally red, yellow, or brown. Characterized by dominance of stickdike Porites and Acropora and by long calcite tubes formed by burrowing worms or gastropods. Locally argillaceous above base. Maximum estimated thickness of the Alifan limestone is 150 feet

Tt **Tallsay member (Miocene)**—yellow, green, and red clay and lenticular clayey conglomerate and lignite; gray to green marl containing stickdike Porites and Acropora, and interbedded limestone lenses, 2 to 30 feet thick

Tbl **Barrigada, Bonya and Janum limestones (Pliocene and Miocene)**—Detrital limestones: Janum, pink to tan, somewhat friable, deep-water facies with abundant pelagic forams. Bonya limestone, white, compact, sometimes sandy, well-bedded biomicrite, benthic forams abundant. Frequently displays manganese mineralization. Barrigada limestome, a dead-white, compact to chalky biomicrite featuring coralline red algae, Halimeda, benthic forams as well as corals near the upper contact with the Mariana limestone

Tm **Maemong limestone formation (Miocene)**—reef facies in central Guam consists of compact white recrystallized limestone containing larger Foraminifera and algae, and corals in position of growth; at some places overlain by the Bolanos pyroclastic member. Outcrop distribution restricted generally to several prominent wooded knolls in the upper Talofofo River valley, many lying within the Talofofo Golfing Resort. The estimated outcrop thickness of the Maemong limestone ranges from less than 10 feet to about 150 feet, although the elevation of the base of the unit is not apparent

Umatac formation (Oligocene-Miocene)
Aggregate thickness of formation about 2200 feet

Tu **Umatac formation undifferentiated (Miocene)**—unresolved stratigraphic sequences in Umatac formation that encompass sections of Tub, Tug, and/or Tus. Approximate thickness ranges from 200 to 500 feet

Tud **Danden flow member (Miocene)**—compact medium- to coarse-grained porphyritic andesite flows separated from the underlying Bolanos pyroclastic member by a flow breccias approximately 10 feet thick; maximum thickness of member 50 feet

Tub **Bolanos pyroclastic member (Miocene)**—breccias, conglomerates, and sandstones consisting largely of fragmented andesite. These andesites typically have prominent euhedral augite phenocrysts up to 1 centimeter in length and millimeter-scale plagioclase phenocrysts. Limestone clasts are conspicuous in some breccias and conglomerates. Estimated thickness of the Bolanos pyroclastic member ranges from 750 to 1000 feet

Tus **Schroeder flow member (Miocene)**—basaltic andesite pillow lava with plagioclase, augite and olvine phenocrysts. Volcanic sandstones consisting of clasts derived from the pillow lavas. Interbedded with the uppermost portion of the Schroeder flow member. Estimated thickness of the Schroeder flow member ranges from 100 to 400 feet

Tug **Geus River member (Oligocene)**—interbedded limestones, sandy and tuffaceous limestones, sandstones and conglomerates. Clasts in sandy units are largely fragmented and altered andesitic volcanics, but also include intraformational limestones including reef limestones not seen in southwestern Guam. Conglomerates with clasts of basalts, andesites and dacites are considered to be near the base of Tug. Estimated thickness of the Geus River member ranges from 250 to 300 feet

Tam **Mahlac member of Alutom formation (Eocene and Oligocene)**—thin-bedded to laminated friable buff to tan or yellow-tan calcareous formaminiferal shale; maximum known thickness 200 feet

Ta **Alutom formation (Eocene and Oligocene)**—bedded breccias, conglomerates, sandstones, turbidites, sandy limestones, and micritic to bioclastic limestones. Clasts in the breccias and conglomerates generally are two-pyroxene andesites, although rare olivine phyric basalts and hornblende andesite clasts also are present. Estimated thickness of the Alutom formation ranges from 1650 to 2000 feet

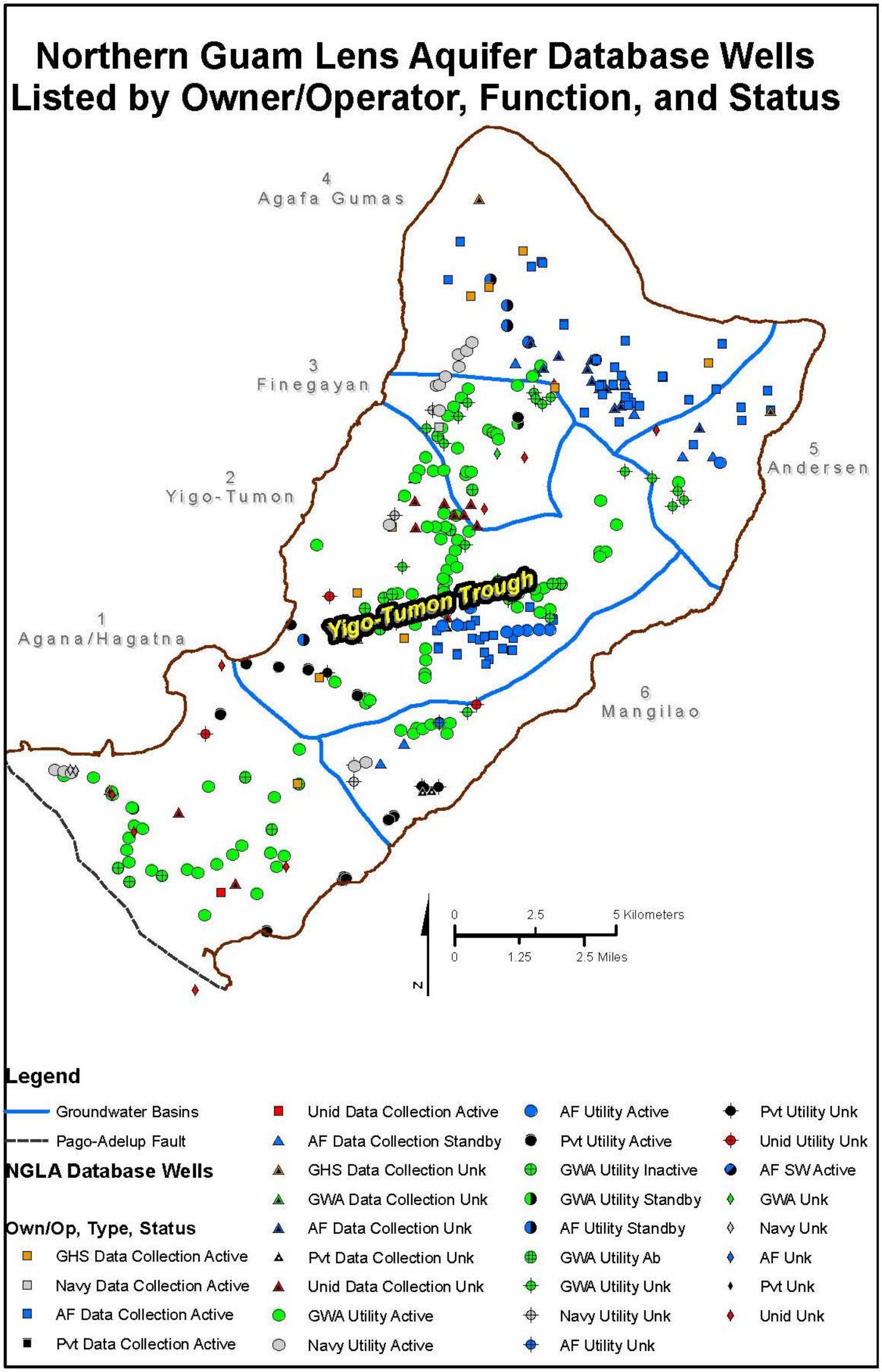
Tf **Facpi formation (Eocene)**—basal portion consists of high-Ca boninite pillow lavas interbedded with pillow breccias, hyaloclastites, and sandstones of the same lithology. Least differentiated lavas have olivine, augite, and chromite phenocrysts; more differentiated varieties lack chromite and have plagioclase and orthopyroxene phenocrysts. The upper portion consists of pillow lavas, breccias, bedded breccias and conglomerates of arc tholeiitic basalt with olivine, augite, and plagioclase phenocrysts. Boninitic and basaltic dikes cut this formation and are particularly abundant in the region of the Facpi peninsula

MAP SYMBOLS

Basaltic and boninitic dike

Fault—Solid where definitely located; dashed where approximately located; dotted where concealed

1 * **Approximate site of numbered stratigraphic sections shown on accompanying sheet**



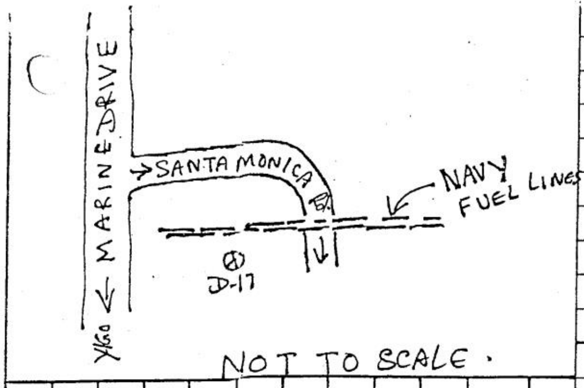
Northern Guam Lens Aquifer Database Wells Listed by Owner/Operator, Function, and Status

APPENDIX B

Drill Log for D-17…pg 50
Drill Log for D-17X…pg 53

~~3252500~~

PROJECT | WELL



D-17X | TOTAL D 350'

JOB NO: 07-11-01855 | LOGGED BY: M.K.R.

PROJ. Six Deep Wells | EDITED BY: M.K.R.

DRILLING CONTRACTOR: Pacific Drilling, Inc.

DRILL RIG TYPE: Failing 1500 Rotory

DRILLERS NAME: Tony Isimang

SAMPLING METHODS: Bag

HAMMER WT | DROP:

STARTED, TIME: 8:00 A.M. | DATE: 6/4/79

COMPLETED, TIME: 5:00 P.M. | DATE: 6/8/79

BORING DEPTH (ft.)	350'		
CASING DEPTH (ft.)	350'		
WATER DEPTH (ft.)	297'-5"		
TIME:	9:00A.M.		
DATE:	6/10/79		

BACKFILLED, TIME: | DATE: | BY:

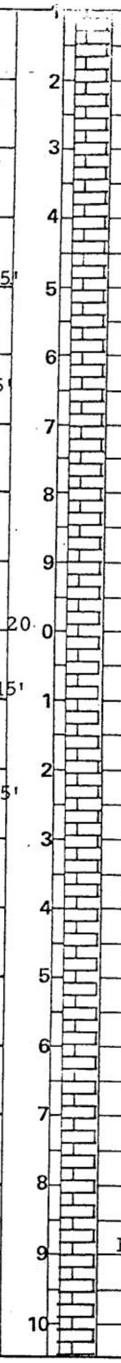
SURFACE ELEV: 302± | DATUM: MLLW.

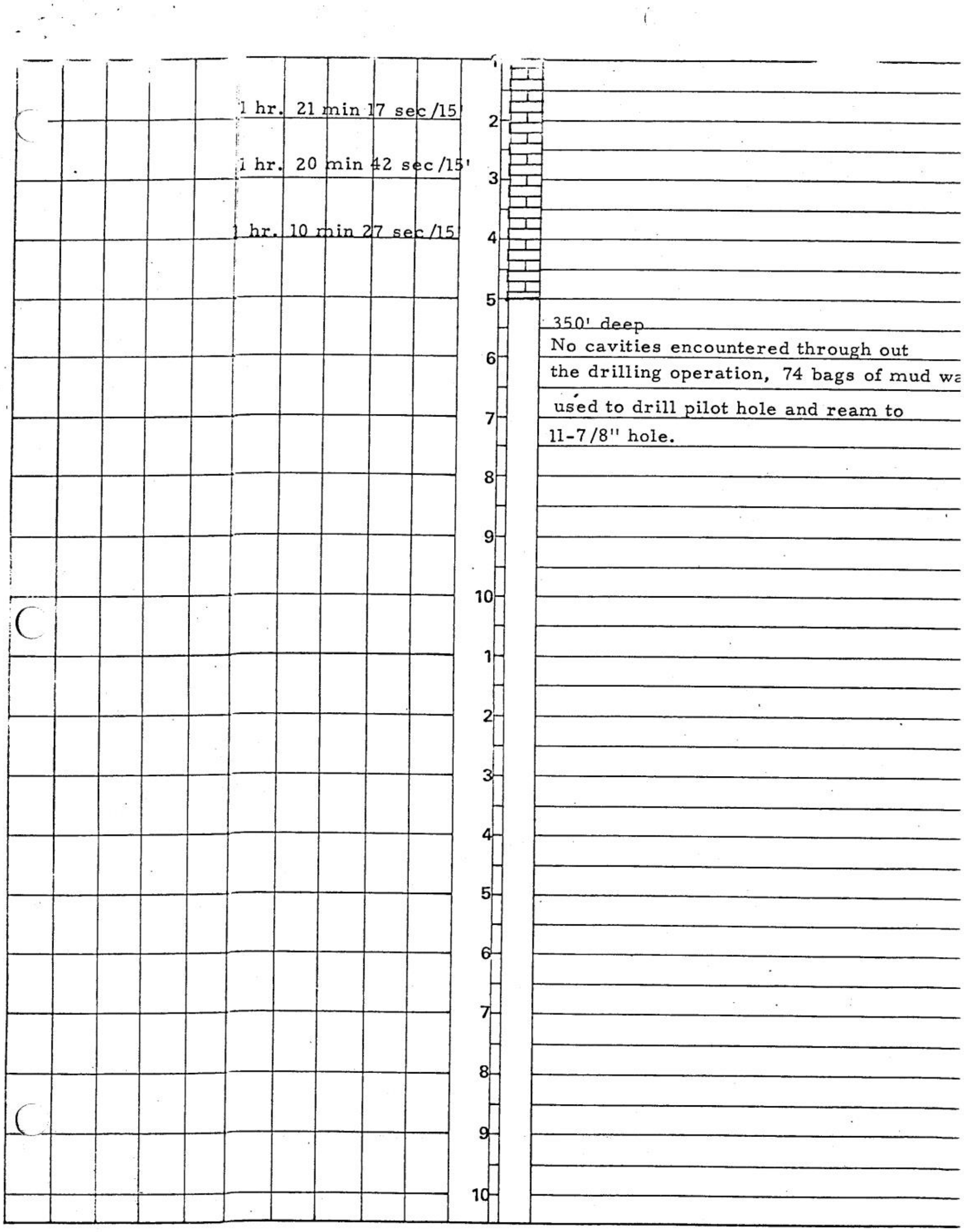
CONDITIONS: Surface was covered with trees.

SAMPLE DEPTH	SAMPLER TYPE	BLOWS/6-IN	INCHES DRIVEN	INCHES RECOVERED	SAMPLE CONDITION	DRILLING RATE (min/ft)				DEPTH IN FEET	GRAPHIC LOG	
												Surface covered with trees & brushes
1-10'	bag				1	hr.	5 min.	11 sec/	15'	1		R. brown silt, soft, moist with occasional
												gravels.
10-20'	bag									2		1st drill collar added at 20'
30-40'	bag				35	min	42	sec	/15'	3		2nd drill collar~~s~~ was added at 40'
50-60'	bag				32	min	8 s	ec/	15'	4		Color change to more white
										50		V. hard
					52	min	21	sec/	15'			
										6		Fine grained with abundant recrystallization.
70-80'	bag				25	min	18	sec/	15'	7		
										8		
80 '	bag				30	min	10	sec/	15'	9		
90-100'	bag				26	min	44	sec/	15'	100		

PACIFIC DRILLING INC.

110-120'	bag	40 min 13 sec/15'	
120-130'	bag		
		49 min 35 sec/15'	
			Becoming v. hard below 140'
140-150'	bag	1 hr. 10 min 12 sec/15'	
			W/ occasional thin hard ledges at 160'
		1 hr. 6 min 19 sec/15'	
160-170'	bag		
		55 min 31 sec/15'	
180-190'	bag		
		1 hr 8 min 38 sec/15'	
			Lost circulation at 199'
		1 hr. 29 min 53 sec/15'	
		1 hr. 36 min 42 sec/15'	
		1 hr 39 min 8 sec/15'	From 245' to 260' soft zone.
		25 min 22 sec/15'	
		34 min 46 sec/15'	
		53 min 7 sec/15'	
			Becoming hard below 299'
		1 hr 5 min 33 sec/15'	





1 hr. 21 min 17 sec/15'

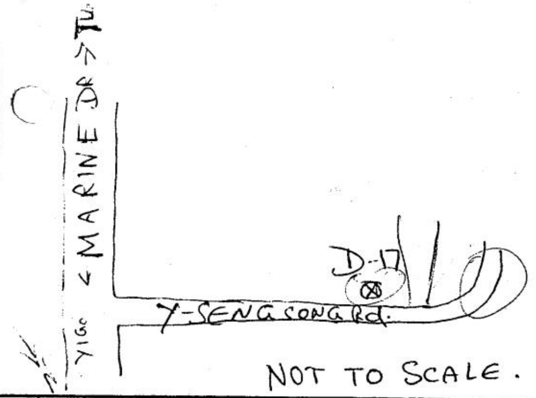
1 hr. 20 min 42 sec/15'

1 hr. 10 min 27 sec/15'

350' deep

No cavities encountered through out the drilling operation, 74 bags of mud wa used to drill pilot hole and ream to 11-7/8" hole.

325 2000



NOT TO SCALE.

PROJECT: Six Deep Wells
SHEET NO. 1/3
TOTAL DEPTH: 433'
JOB NO: 07-11-01855
LOGGED BY: M.K. Ra
PROJ. D-17X
EDITED BY: M.K. Ra
DRILLING CONTRACTOR: Pacific Drilling, Inc.
DRILL RIG TYPE: Rotary 7⅞" Bit
DRILLERS NAME: Antonio Isimang
SAMPLING METHODS: Bag
HAMMER WT —
DROP: —
STARTED, TIME: 8:00 A.M.
DATE: 1/26/79
COMPLETED, TIME: 5:00 P.M.
DATE: 2/8/79

BORING DEPTH (ft.)	433'		
CASING DEPTH (ft.)	-		
WATER DEPTH (ft.)	-		
TIME:	-		
DATE:			

BACKFILLED, TIME: - DATE: - BY -
SURFACE ELEV: 440.3'
DATUM: MLLW
CONDITIONS: Surface covered w/ trees, brushes

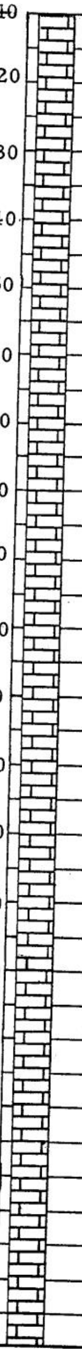
SAMPLE DEPTH	SAMPLER TYPE	BLOWS/6-IN	INCHES DRIVEN	INCHES RECOVERED	SAMPLE CONDITION	DRILLING RATE (min/ft)				DEPTH IN FEET	GRAPHIC LOG
				15	2 hrs	16min 12 sec/15'				10	
10-20	bag									20	
			30		2 hrs	41min19sec /15'-					
										30	
30-40	bag			45	1 hr	9min 42sec /15'				40	
										50	
				60	45 min	13 sec. /15'					
50-60	bag									60	
				75	1 hr	55 min 6sec /15'				70	
70-80	bag									80	
				90	1 hr	45 min 21 sec /15'				90	
90-100	bag			105	20 min	29 sec /15'				100	

8" R. brown silt, wet, soft w/ occasional boulders.

Lt. gray-white limestone, M. Hard, M. st
medium grained w/ abundant rex'llization,
moderate-deeply weathered.
1st Drill colar 20' was added at 30'
2nd Drill colar 15' was added at 45'

Boulders up to 20'
60'-80' drill head ratteling
68'-78' soft

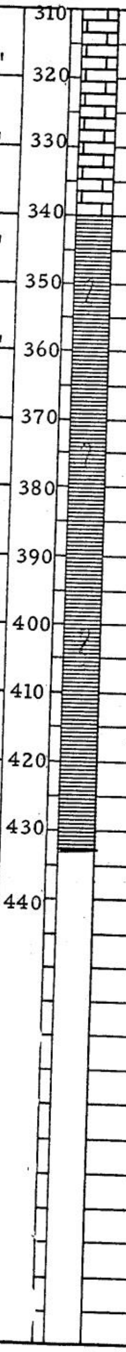
PACIFIC DRILLING INC.



110-120	bag	120 1 hr 15 min 14 sec/15'	110	Becoming v. hard, v. strong below 100'
			120	Lost circulation at 125'
		135 1 hr 4 min 11 sec/15'	130	W/ occasional thin hard ledges and sma cavities below 135'
			140	
		150 1 hr 20 min 32 sec/15'	150	
		165 1 hr 10 min 17 sec/15'	160	
		180 1 hr 16 min 2 sec/15'	170	
			180	
		195 1 hr 35 min 13 sec/15'	190	
		210 1 hr 6 min 35 sec/15'	200	
			210	
		225 1 hr 11 min 41 sec/15'	220	
		240 1 hr 19 min 21 sec/15'	230	
			240	
		255 1 hr 25 min 4 sec/15'	250	
			260	Drill head ratteling too much at 260'
		270 2 hrs 45 min 7 sec/15'	270	
		285 1 hr 45 min 18 sec/15'	280	
			290	
		300 1 hr 44 min 13 sec/15'	300	

3/3

315	1 hr 20 min 51 sec/15'
330	1 hr 55 min 14 sec/15'
345	2 hr 20 min 13 sec/15'
360	2 hr 35 min 29 sec/15'
375	2 hr 40 min 31 sec/15'
390	2 hr 45 min 49 sec/15'
405	3 hr 45 min 56 sec/15'
420	4 hrs 15 min 33 sec/15'



Below 340' might be in Volcanics ? from drilling, it appears to be the rock should be fine grained and masssive wit out any fractures zones.

APPENDIX C

NGLA Database Spreadsheet

WERI/UOG

	Owner/Operator		Type	Sub-type		Status		Basin	Geological
1	Guam Hydrologic Survey	1	DataCollection	1 Exploratory	1	Active	1	Hagatna/Agana	Used in 2013 Basement Map
2	GEPA			2 Observation/Monitoring	2	Inactive	2	Yigo-Tumon	Distinct/Active
3	Guam Waterworks Authority	2	Utility	1 Drinking	3	Offline	3	Finegayan	Indistinct/Passive
4	Navy			2 Industrial/Agricultrual	4	Abandoned	4	Agafa Gumas	Elevation
5	Air Force	3	Stormwater Management		5	Unknown	5	Andersen	
6	Private						6	Mangilao	
7	Unknown								

NGLA WELL DATA

Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
A-001	A-1		3	2	1	3						67.66	1965	221	221.31	11	70	8	150	9	58.66	210	103.49	2.03	216	275							USGS data
A-002	A-2		3	2	1	3						118	1965	172	171.41	11	110	8	60	106.3	11.70	210	23.23	9.04	241	201							USGS data
A-003	A-3		3	2	1	1						127.45	1967	410	366.4	11	390	8		105.8	21.65	273	98.00	2.79	180	262			383				USGS data
A-004	A-4		3	2	1	1						140.18	1967	300	301	11	130	8	170	134	6.18	300	19.00	15.79	244	301							USGS data
A-005	A-5		3	2	1	1						146.7	1969	332	323.14	11	323	8		137.45	9.25	100	1.25	80.00	269	234			332				USGS data
A-006	A-6		3	2	1	1						152	1967	306	307.33	11	136	8	170	142	10.00	325		0.00	241	281							USGS data
A-007	A-7		3	2	1	3						136	1967	186	186.86	11	116	8	70	126	10.00	210	35.00	6.00	113	0							
A-008	A-8		3	2	1	1						124	1968	305	305.17	11	96	8	205	109	15.00	270		0.00	206	264							
A-009	A-9		3	2	1	1						187.15	1967	240	235.78	11	237	8	70	180.5	6.65	83	1.20	69.17	230	244							USGS data
A-010	A-10		3	2	1	1						191.01	1967	215	215.25	11	171	8	45	184.5	6.51			0.00	233	171							USGS data
A-011	A-11		3	2	1	4						178	1968	375		11	125	8	205	131	47.00	150	201.00	0.75		160			320				USGS data
A-012	A-12		3	2	1	3						138	1968	390	338.45	11	103	8	225	108	30.00	330		0.00	176	176							USGS data
A-013	A-13		3	2	1	1						130.8	1968	418	324.38	11	205	8	120	123	7.80	250	28.25	8.85	237	301							USGS data
A-014	A-14		3	2	1	1						208	1973	260	270.06		220	8	40	206	2.00	160		0.00	147	172							
A-015	A-15		3	2	1	1						197.74	1973		251.03		210	8	50	194.5	3.24	235	13.67	17.19	231	300							USGS data
A-016	A-16	/Barrigac	1	1	2	1						207									207.00			0.00									USGS data
A-017	A-17		3	2	1	1						196	1973	235	232.77		195	8	40	192.75	3.25	180		0.00	180	180							
A-018	A-18		3	2	1	1						194.97	1973		239.97		227	8	40	193.5	1.47	135		0.00	229	229							
A-019	A-19		3	2	1	1						144	1973	165	160		135	8	20	133.3	10.70			0.00	138	138							USGS data
A-020	A-20		1	1	2	1						137		120				6		95	42.00			0.00									USGS data
A-021	A-21		3	2	1	1						194	1974		244		255			182.2	11.80			0.00	213	213							
A-022	A-22	ada Well	3	2	1	4															0.00			0.00									
A-023	A-23		3	2	1	1						34.5	1983	85	81.5					29	5.50	330		0.00	317	317							
A-025	A-25		3	2	1	4						59.96	1994	70.56	70.56		68	8	40	50.11	9.85	270	11.29	23.91	245	245							
A-026	A-26		3	2	1	1						156.5	1983	203.5	183.5					148.5	8.00	50	11.9	4.20	50								
A-027	A-27		3	2	1	4						150.5		197.5							150.50			0.00									
A-028	A-28		3	2	1	3						199	1983	246						195.1	3.90			0.00	223	223							
A-029	A-29		3	2	1	3						58.93	1988	105	95.03	15	60	10	40	52.33	6.60	275	8.59	32.01	403	403							
A-030	A-30		3	2	1	1						46.4	1988	100	73.91	18	40	12	40	40.5	5.90	275	1.17	235.04	755	755							
A-031	A-31		3	2	1	1						194.7		250	245	10				186.92	7.78	254	5.83	43.57	293	293							
A-032	A-32		3	2	1	1						147.65	1989	200	195	15	160	10	40	142.67	4.98	330	16.33	20.21	173	173							
A-33	A-33		3	2	1	4						105	1998	155		12				70	35.00			0.00									
ACEORP Tunnel	ACEORP Tunnel	uning (A	7	2	1	5						180									180.00			0.00									USGS data
AECOM-001	AECOM-1		4	1	1	2						475.82	2010	513						471.44	4.38	410	0.2400	1708.33									USGS data
AECOM-002	AECOM-2		4	1	1	2						485.42	2010	523		12				483	2.42	80	3.5400	22.60									
AECOM-003	AECOM-3		1	1	2	3						567.08	2010	583						537.6	29.48	250	12.8700	19.43					742				USGS data
AECOM-004	AECOM-4		4	1	1	2						532.09	2010	466		12				410	122.09			0.00									
AECOM-005	AECOM-5		4	1	1	2						555.15	2010	450						347.33	207.82			0.00					380				
AECOM-006	AECOM-6		4	1	1	2						531.52	2010	570						529.11	2.41	430	0.3100	1387.10									
AECOM-007	AECOM-7		4	1	1	2						523.84	2010	555		12				514	9.84	68	1.4000	48.57									USGS data
AECOM-008	AECOM-8		4	1	1	2						474.99	2010	360		12				316.66	158.33			0.00					333				
AECOM-009	AECOM-9		1	1	2	3						361.66	2010	430		12				358	3.66			0.00						610			USGS data
AECOM-010	AECOM-10		4	1	1	2						382.18	2010	422		12				379.44	2.74	500	0.3200	1562.50									
AECOM-011	AECOM-11		4	1	1	2						352.65	2010	390		12				350.85	1.80	500	0.3100	1612.90									USGS data
AF-001	AF-1	#3A	5	2	1	1						447.74	2005	498		20	496.2	12	36	445.69	2.05	300	14.6300	20.51		250							
AF-002	AF-2	#5	5	2	1	1						466.82	2005	515.5		20	470.74	12	38.96	461.77	5.05	200	16.0000	12.50		200							
AF-003	AF-3	#6	5	2	1	1						494.58	2005	539.7		20	494.48	12	45.22	492.3	2.28	200	0.5000	400.00		200							
AF-004	AF-4	#7	5	2	1	1						504.36	2002	553		20	504.36	12	45.24	502.72	1.64	250	1.1000	227.27		200							
AF-005	AF-5	#8	5	2	1	1						468.76	2005	514.5		20	470.74	12	38.96	466.53	2.23	200	16.7500	11.94		200							
AG-001	AG-1		3	2	1	3						470	1967	496.98	496	10				467	3.00	120		0.00	250	175							
AG-002	AG-2		3	2	1	4						503	1968	630	582.97	11	590	7.875	40	498	5.00			0.00		500			576				
AG-002A	AG-2A		3	2	1	1															0.00			0.00	500								USGS data
AG-003	AG-3		3	2	1	5						495.75	1994	720						495.2	0.55	30	35	0.86					545				
AG-004	AG-4		3	2	1	5						500.18	1994	700						484.94	15.24	60	40	1.50					560				
AG-005	AG-5		3	2	1	5						504.6	1994	700			10			485.1	19.50			Dry					580				
AG-006	AG-6		3	2	1	5						513.37		550		12				483.3	30.07	145	21.35	6.79									
AG-007	AG-7		3	2	1	5						512.82	1994	545		12				472.4	40.42	75	14.00	5.36					500				
AG-008	AG-8		3	2	1	5						516.33	1994	550		12					516.33			Dry					523				
AG-009	AG-9		3	2	1	5						525.49	1994	520		12				459.35	66.14			Test Failed					500				
AG-010	AG-10	CT-1	3	2	1	2						486.3	1994	520		12				482.6	3.70	225	0.5	450.00									

V. Bendixson
5/14/2013

WERI/UOG

Owner/Operator	
1	Guam Hydrologic Survey
2	GEPA
3	Guam Waterworks Authority
4	Navy
5	Air Force
6	Private
7	Unknown

Type	Sub-type
1 DataCollection	1 Exploratory 2 Observation/Monitoring
2 Utility	1 Drinking 2 Industrial/Agricultrual
3 Stormwater Management	

Status	
1	Active
2	Inactive
3	Offline
4	Abandoned
5	Unknown

Basin	
1	Hagatna/Agana
2	Yigo-Tumon
3	Finegayan
4	Agafa Gumas
5	Andersen
6	Mangilao

Geological
Used in 2013 Basement Map
Distinct/Active
Indistinct/Passive
Elevation

NGLA WELL DATA

Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
B-001	B-1		5	1	2	5															0.00			0.00								Y	
B-002	B-2		5	1	2	5															0.00			0.00					-151			Y	
B-003	B-3		5	1	2	5															0.00			0.00					-120			Y	
B-004	B-4		5	1	2	5															0.00			0.00					-126			Y	
B-005	B-5		5	1	2	5															0.00			0.00					-273			Y	
B-006	B-6		5	1	2	5						479.16									479.16			0.00					-89			Y	
B-007	B-7		5	1	2	5															0.00			0.00					-270			Y	
B-008	B-8		5	1	2	5															0.00			0.00					-243			Y	
B-009	B-9		5	1	2	5															0.00			0.00					-149			Y	
B-010	B-10		5	1	2	5															0.00			0.00					-266			Y	
B-011	B-11		5	1	2	5															0.00			0.00					-398			Y	
BCC Well	BCC Well		6	2	2	5						204		216							204.00			0.00									USGS data
BPM Well	BPM Well		5	2	2	1						495.97	1969	540			540	12			495.97	200	26	7.69		150							USGS data
BPM-001	BPM -1		7	0	0	5						209.9		235							209.90			0.00									USGS data
CPE-002	CPE-2		6	2	2	3															0.00			0.00		25							
CPE-006	CPE-6		6	2	2	1															0.00			0.00		25							
CPE-007	CPE-7		6	2	2	1															0.00			0.00		25							
CPE-009	CPE-9		6	2	2	1															0.00			0.00		6							
CT-001	CT-1	AG-10	7	0	0	5															0.00			0.00									
CT-003	CT-3		7	0	0	5						471.29		520						469.1	2.19	205	4.62	44.37									
CT-004	CT-4	F-17	7	0	0	5															0.00			0.00									
CT-005	CT-5	F-18	7	0	0	5						478.88	1994	540		12				474.75	4.13			0.00									
CTR-001	CTR-1		7	0	0	5															0.00			0.00									
D-001	D-1		3	2	1	1						384.25	1965	420	417	11	385	8	35	380.95	3.30	200	1.00	200.00	257	257							USGS data
D-002	D-2	3150-04	3	2	1	1						381	1965	417	417		382	8	35	379	2.00	230	5.95	38.66	187	187							
D-003	D-3	3150-24	3	2	1	3						384.45	1965	406	384.45		372	8	35	383	1.45			0.00	189								
D-004	D-4	3150-14	3	2	1	1						384	1965	408	409		375	8	35	378	6.00	260	12.00	21.67	172	172							USGS data
D-005	D-5		3	2	1	1						381	1965	412	410		372	8	40	376.43	4.57	165		0.00	166	166							
D-006	D-6	3150-34	3	2	1	1						387	1967	423	422	11	387	8	40	381	6.00			0.00	189	189							USGS data
D-007	D-7	3150-55	3	2	1	1						387	1966	437	437	11	377	8	60	382	5.00	210	6.00	35.00	198	198							USGS data
D-008	D-8		3	2	1	1						415		450	450		410		35	410.5	4.50	160	13.5	11.85	185	185							USGS data
D-009	D-9		3	2	1	1						388	1968	417	417	11	380.5	8	35	383	5.00	225	4	56.25	196	196							USGS data
D-010	D-10	3151-40	3	2	1	1						389.4	1968	414.6	414.6	11	381.6	8	35	384.7	4.70			0.00	351	351							USGS data
D-011	D-11	3150-34	3	2	1	1						393	1969	430	430	11	380	8	50	389	4.00	250		0.00	226	226							USGS data
D-012	D-12		3	2	1	1						422.21		470	465	11	415	8	50	417.5	4.71			0.00	188	188							USGS data
D-013	D-13		3	2	1	3						395	1971	455	455		412	8	40	399	-4.00	180	7	25.71	172	172							
D-014	D-14	41/Dede	3	2	1	1						312	1973	372	372	11	330	8	40	315.25	-3.25	200	9.75	20.51	200	200							USGS data
D-015	D-15	ededo 1	3	2	1	1						403	1974	452	452		412	8	40	363	40.00	198		0.00	202	202							USGS data
D-016	D-16	15/Dede	3	2	1	1						342		387	387					320.1	21.90			0.00	161								
D-017	D-17	14/Dede	3	2	1	3						440.3	1979	433	305						440.30			0.00	199				340				USGS data
D-017X	D-17X		3	1	1	4						302	1979	350			315		35	297.8	4.20	235	16.8	13.99									
D-018	D-18		3	2	1	3						314.54	1980	360	360		359.5			308.8	5.74			0.00	180								
D-019	D-19		3	2	1	1						389.7		438	438						389.70			0.00	227	227							
D-020	D-20		3	2	1	1						372		420.5	420.5						372.00			0.00	207	207							
D-021	D-21		3	2	1	1						371.3	1983	427	420	7.875					371.30			0.00	157	157							USGS data
D-022	D-22		3	2	1	4						449.71		600						398.1	51.61			0.00					440				
D-022A	D-22A		3	2	1	3						449.71	1995	445	435	12				408.06	41.65	125	1.02	122.55	200	200			440				
D-023	D-23		3	2	1	4						448.5		600		12				388	60.50	105		0.00		150			419				
D-024	D-24		3	2	1	1						437.11		600	498					433.62	3.49	215		0.00	180				540				
D-025	D-25		3	2	1	1						443.69	1994	490	445	12				378.8	64.89	35		0.00	400	400							
D-026	D-26		3	2	1	1									411						0.00			0.00	250	250							
D-027	D-27		3	2	1	1						413.46		478	478						413.46			0.00	400	400				478			
D-028	D-28		3	2	1	1									442						0.00			0.00	200	200							
D-030	D-30		3	2	1	4															0.00			0.00									
D-031	D-31		3	2	1	4															0.00			0.00									
DW-025	DW-25		7	0	0	5															0.00			0.00									
DW-026	DW-26		7	0	0	5															0.00			0.00									
ETD-001	ETD-1		7	0	0	5						450.3	1998	505		12				415	35.30			0.00									
ETD-001A	ETD-1A		7	0	0	5						421.86	1999	472		12				417.6	4.26			0.00									
ETD-002	ETD-2		7	0	0	5						440.3	1998	495		12				385	55.30			0.00					492				

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WERI/UOG

Owner/Operator	
1	Guam Hydrologic Survey
2	GEPA
3	Guam Waterworks Authority
4	Navy
5	Air Force
6	Private
7	Unknown

Type	Sub-type
1 DataCollection	1 Exploratory 2 Observation/Monitoring
2 Utility	1 Drinking 2 Industrial/Agricultrual
3 Stormwater Management	

Status	
1	Active
2	Inactive
3	Offline
4	Abandoned
5	Unknown

Basin		Geological
1	Hagatna/Agana	Used in 2013 Basement Map
2	Yigo-Tumon	Distinct/Active
3	Finegayan	Indistinct/Passive
4	Agafa Gumas	Elevation
5	Andersen	
6	Mangilao	

NGLA WELL DATA

Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
ETD-003	ETD-3		7	0	0	5						437.3	1998	390		12				310	127.30			0.00					380				
ETD-004	ETD-4		7	0	0	5						413	1999	465		12				420	-7.00			0.00									
ETD-005	ETD-5		7	0	0	5						436		490		12				432	4.00			0.00									
ETD-006	ETD-6		7	0	0	5						380.3	1998	445		12				380	0.30			0.00									
ETD-006A	ETD-6A		7	0	0	5						391.86	1999	442		12				388.8	3.06			0.00									
ETD-007	ETD-7		7	0	0	5						405.3	1998	470		12				420	-14.70			0.00									
ETD-008	ETD-8		7	0	0	5						408.3	1998	450		12					408.30			0.00									
ETD-009	ETD-9		7	0	0	5															0.00			0.00									
ETF-001	ETF-1		7	0	0	5						367.29	1998	440		12				364.45	2.84			0.00									
ETF-002	ETF-2	F-20	7	0	0	5						379.73	1998	445		12				376.5	3.23			0.00									
ETF-003	ETF-3		7	0	0	5						390.3	1998	465		12					390.30			0.00									
ETY-001	ETY-1	Y-18	7	0	0	5						396	1998	445		12	401	10	40	391	5.00			36									
ETY-002	ETY-2	Y-19	7	0	0	5						373	1998	426		12	378	12	40	369.76	3.24	500	0.25	2000									
ETY-003	ETY-3	Y-20	7	0	0	5						396.25	1998	446		12	401	12	40	392	4.25	500	0.25	2000									
EX-001	EX-1		1	1	1	1						94	1981	597	572	8		5			94.00			0.00									USGS data
EX-002	EX-2		1	1	1	5						564	1981								564.00			0.00									
EX-003	EX-3		1	1	1	5						447	1981								447.00			0.00					420				
EX-004	EX-4		1	1	1	1						152	1981	400							152.00			0.00									USGS data
EX-005	EX-5		1	1	1	5							1982								0.00			0.00									USGS data
EX-005A	EX-5A		3	2	1	1						386.33	1982	424.96	424.96						386.33			0.00	254	254							
EX-006	EX-6		1	1	1	5						309	1982	462							309.00			0.00									USGS data
EX-007	EX-7		1	1	1	1						283.31	1982	698							283.31			0.00						698			USGS data
EX-008	EX-8		1	1	1	1							1981								0.00			0.00									USGS data
EX-009	EX-9		1	1	1	1						238	1982	513			498				238.00			0.00						513			USGS data
EX-010	EX-10		1	1	1	1						348.54	1981	704							348.54			0.00						704			USGS data
EX-011	EX-11		3	2	1	1						389.96		463.22	460						389.96			0.00	210	210			440				USGS data
F-001	F-1		3	2	1	1						423	1969	460	460	11	415	8	45	420	3.00	130	14.00	9.29	140	140							USGS data
F-002	F-2		3	2	1	1						446.7	1971	490	490	11		8		446.7	0.00	130	3.89	33.42	121	121							USGS data
F-003	F-3		3	2	1	1						457.76		491.76	491.76	11	452	8	40	450.375	7.38	200		200gpm/1' 4"=150.00gpm/ft (16	142	142							USGS data
F-004	F-4		3	2	1	1						460	1975	495	495	11	460	8	35	460	0.00	140	4.90	28.57	137	137							USGS data
F-005	F-5		3	2	1	1						389.49	1975	425	424	11	385	8	40	386.4	3.09	165		0.00	145	145							
F-006	F-6		3	2	1	1						343.83	1975	370	370	11	340	8	30	346.11	-2.28	230	8.00	28.75	151	151							USGS data
F-007	F-7		3	2	1	1						369		385	388						369.00			0.00	170	170							
F-008	F-8		3	2	1	1						425		450	450					428	-3.00			0.00	149	149							
F-009	F-9		3	2	1	1						398		446	445		445	8	40	397.2	0.80	160		13.8 GPM/ft (160 GPM/15.	140	140							
F-010	F-10		3	2	1	1						433		483	483			8		434.5	-1.50	130	9.10	14.29	142	142							
F-011	F-11		3	2	1	1						437		487	487			8	40	436.8	0.20	130	5.60	23.21	148	113							
F-012	F-12		3	2	1	1						443	1989	496	495.63	10		10	40	441.2	1.80	250		250gpm/7.2'=34.72 (170 GPM	148	148							
F-013	F-13	F-15	3	2	1	1						433.83	1992	485	515					430.86	2.97	350		0.00	380	380							
F-014	F-14		3	2	1	4						453.43		503						448.94	4.49	275	3.00	91.67									
F-015	F-15		3	2	1	1						465.38	1994	515	485					460.8	4.58	215	5.90	gpm/5.9'=36.44gp	440	440							
F-016	F-16		3	2	1	1						471.29	1994	520	520					470.92	0.37			0.00	230	230							
F-017	F-17	CT-4	3	2	1	1						478.3	1994	540	525	12				474.85	3.45	235	0.05	4700	240	240				540			
F-018	F-18	CT-5	3	2	1	1						478.88	1994	540	523	12				474.75	4.13	240	5.15	46.60	240	200							
F-019	F-19		3	2	1	1									415						0.00			0.00	200	200							
F-020	F-20		3	2	1	1						511	1996	445	422	12					511.00			0.00	200	500			425				
F-020X	F-20X		3	1	1	4															0.00			0.00									
F-021	F-21		3	2	1	5						422.6	2000	480		12					422.60			0.00									
F-022	F-22		3	2	1	5															0.00			0.00									
F-023	F-23		3	2	1	5						445.14	2000	500		12				442.76	2.38			0.00									
F-024	F-24		3	2	1	5															0.00			0.00									
F-025	F-25		3	2	1	5						460.8	2000	520		12				458	2.80			0.00									
FatherDuenasWell	Father Duenas Well		1	1	2	1						179									179.00			0.00									USGS data
FFH-001	FFH-1		6	2	2	5															0.00			0.00									
FFH-002	FFH-2		6	2	2	5															0.00			0.00									
FFH-003	FFH-3		6	2	2	1						35.8		65.7							35.80			0.00		200							
FFH-004	FFH-4		6	2	2	2						34.12		35.98							34.12			0.00		200							
FFH-005A	FFH-5A		6	2	2	5															0.00			0.00									
FFH-006	FFH-6		6	2	2	5															0.00			0.00									
FFH-007	FFH-7		6	2	2	1						24.02									24.02			0.00		200							

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WERI/UOG

Owner/Operator	
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6	Private
7	Unknown

Type		Sub-type
1	DataCollection	1 Exploratory
		2 Observation/Monitoring
2	Utility	1 Drinking
		2 Industrial/Agricultrual
3	Stormwater Management	

Status	
1	Active
2	Inactive
3	Offline
4	Abandoned
5	Unknown

Basin	
1	Hagatna/Agana
2	Yigo-Tumon
3	Finegayan
4	Agafa Gumas
5	Andersen
6	Mangilao

Geological
Used in 2013 Basement Map
Distinct/Active
Indistinct/Passive
Elevation

NGLA WELL DATA

Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
FFH-008	FFH-8		6	2	2	1						42.22		150.22							42.22			0.00		300							
FM-001	FM-1	GS 3047	6	2	2	1						140.56		182							140.56			0.00		125							USGS data
GH-501	GH-501	GHURA	3	2	1	1						415	1979	460	460					410.75	4.25	230	9.42	24.42	183	183							
GhuraDededo	Ghura Dededo		1	1	2	1															0.00			0.00									USGS data
GIAA-001	GIAA-1		6	2	2	2						255.79									255.79			0.00		180							
GIAA-002	GIAA-2		6	2	2	2						233.93									233.93			0.00									
GIAA-003	GIAA-3		6	2	2	2						255.79									255.79			0.00		100							
GPA-001	GPA-1		7	1	2	5						359.26									359.26			0.00									
GPA-002	GPA-2		7	1	2	5						361.55									361.55			0.00									
GPH-001	GPH-1		6	2	2	1						136.91	1997	175		10	140	10	20	133.55	3.36			0.00		100							Guam Plaza H
GPH-002	GPH-2		6	2	2	1						156.98	1997	195		10	164	10	20	153.8	3.18			0.00		100							Guam Plaza H
H-001	H-1		3	2	1	1						391.95		441.95	441						391.95			0.00	288	288							
Hagatna-147	Hagatna-147		1	1	2	5						40		186						10.41	29.59			0.00									USGS data
Harmon-001	Harmon-1		7	0	0	5						267.96		292							267.96			0.00									USGS data
Harmon-003	Harmon-3	G-113/U	7	0	0	5															0.00			0.00									
HGC-002	HGC-2		3	2	1	1						495.82		575	552.82	12					495.82	410		0.00	444	444							
HGC-003	HGC-3		6	2	2	1						470.9		574.9							470.90			0.00		600							
HRP-001	HRP-1	ian Rock	6	2	2	1						327	1959	352		14	332	10	20		327.00			0.00		300							
HRP-002	HRP-2	n Rock	6	2	2	1						338		400							338.00			0.00		300							
IE-001	IE-1	and Equi	6	2	2	5															0.00			0.00									USGS data
IRP-001	IRP-1		5	1	2	1						284.46	1987	535		10	275.3	5	40.3	285.12	-0.66			0.00								Y	
IRP-002	IRP-2		5	1	2	1						370.92	1987	400		10	360.45	5	39.55	370.7	0.22			0.00								Y	
IRP-003	IRP-3		5	1	2	1						555.75	1987	600		10	543.26	5	40.6	552.7	3.05			0.00								Y	
IRP-004	IRP-4		5	1	2	1						533.34	1987	571		10.75	521.25	5	39.75		533.34			0.00								Y	
IRP-005	IRP-5		5	1	2	1						529.3	1987	580		10	504.2	5	40	509.2	20.10			0.00					511			Y	
IRP-006	IRP-6		5	1	2	1						538.48	1987	575		10.75	3.4?			514.6	23.88			0.00					456			Y	
IRP-007	IRP-7		5	1	2	1						492.08	1987	530		10	477.8	5	40.6	488.7	3.38			0.00								Y	
IRP-008	IRP-8		5	1	2	1						363.86	1987	390		10	350.27	5	39.73	361.95	1.91			0.00								Y	
IRP-009	IRP-9		5	1	2	1						456.78	1987	497		10	445.41	5	34.59	452.2	4.58			0.00								Y	
IRP-010	IRP-10		5	1	2	1						303.65	1987	330.5		10	291.15	5	39.35	342.21	-38.56			0.00								Y	
IRP-011	IRP-11		5	1	2	1						500.91	1987	573		9.5	446.5	5	40.7	455.8	45.11			0.00					524			Y	
IRP-012	IRP-12		5	1	2	1						341.83	1987	376.4		10	329.09	5	39.01	342.21	-0.38			0.00								Y	
IRP-013	IRP-13		5	1	2	1						528.81	1987	572		10.75	517.5	5	39.1		528.81			0.00								Y	
IRP-014	IRP-14		5	1	2	1						376.86	1989	412		10	362.07	5	40.73	372.74	4.12			0.00								Y	
IRP-015	IRP-15		5	1	2	1						309.61	1989	340		10	294.5	5	40.2	304.7	4.91			0.00								Y	
IRP-016	IRP-16		5	1	2	1						296.45	1989	326		10	281.5	5	40	295.09	1.36			0.00								Y	
IRP-017	IRP-17		5	1	2	1						534.8	1989	52		9.5	390.8		40.67	400.8	134.00			0.00					510			Y	
IRP-018	IRP-18		5	1	2	5						483.85									483.85			0.00								Y	
IRP-019	IRP-19		5	1	2	5						505.2									505.20			0.00								Y	
IRP-020	IRP-20		5	1	2	1						487.59	1989	543		9.5	474.5	5	40	484.5	3.09			0.00								Y	
IRP-021	IRP-21		5	1	2	1						458.2	1989	491.9		9.5	441.45	5	40	453.95	4.25			0.00								Y	
IRP-022	IRP-22		5	1	2	1						455.94	1989	480.94		9.5	440.88		40.86		455.94			0.00								Y	
IRP-023	IRP-23		5	1	2	1						318.365	1995	460		10		5.5	20	312	6.37			0.00									
IRP-024	IRP-24		5	1	2	1						314.175	1995	445		10	410	5	20	309	5.18			0.00									
IRP-025	IRP-25		5	1	2	1						363.295	1995	480		10		4.75	20	358	5.30			0.00									
IRP-026	IRP-26		5	1	2	1						321.171	1995	460		10		4.75	20	322	-0.83			0.00									
IRP-027	IRP-27		5	1	2	1						335.376	1995	480		10		4.75	20	326	9.38			0.00									
IRP-028	IRP-28		5	1	2	1						352.537	1995	480		10		4.75	20		352.54			0.00									
IRP-029	IRP-29		5	1	2	1						380.684	1995	520		10		4.75	20	374	6.68			0.00									
IRP-030	IRP-30		5	1	2	1						359.986	1995	480		10		4.75	20	354.4	5.59			0.00									
IRP-031	IRP-31		5	1	2	1						361.535	1995	480		10		4.75	20	357	4.54			0.00									
IRP-032	IRP-32		5	1	2	1								463							0.00			0.00									
IRP-032A	IRP-32A		5	1	2	1								410							0.00			0.00									
IRP-032B	IRP-32B		5	1	2	1						379.3		420							379.30			0.00									
IRP-033	IRP-33		5	1	2	1						402.352	1995	520		10		4.75	20	396	6.35			0.00									
IRP-034	IRP-34		5	1	2	1						403.747	1995	520		10		4.75	20	396	7.75			0.00									
IRP-035	IRP-35		5	1	2	1						284.765	1995	412		10		4.75	20	298	-13.24			0.00									
IRP-036	IRP-36		5	1	2	1								280							0.00			0.00									
IRP-037	IRP-37		5	1	2	1								340							0.00			0.00									
IRP-038	IRP-38		5	1	2	1								340							0.00			0.00									

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3	Guam Waterworks Authority	2	Utility	1 Drinking	3	Offline	3	Finegayan	Indistinct/Passive
4	Navy			2 Industrial/Agricultrual	4	Abandoned	4	Agafa Gumas	Elevation
5	Air Force	3	Stormwater Management		5	Unknown	5	Andersen	
6	Private						6	Mangilao	
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NGLA WELL DATA

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Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
IRP-039	IRP-39		5	1	2	1						553.31		660							553.31			0.00									
IRP-040	IRP-40		5	1	2	1						514.24		553							514.24			0.00									
IRP-041	IRP-41		5	1	2	1						535.89									535.89			0.00					660				
IRP-042	IRP-42		5	1	2	1						613.05									613.05			0.00									
IRP-043	IRP-43		5	1	2	1						491.35									491.35			0.00									
IRP-044	IRP-44		5	1	2	1						499.14									499.14			0.00									
IRP-045	IRP-45		5	1	2	1						464.83									464.83			0.00									
IRP-046	IRP-46		5	1	2	1						439.57									439.57			0.00									
IRP-047	IRP-47		5	1	2	1						436.51									436.51			0.00									
IRP-048	IRP-48		5	1	2	1						479.81									479.81			0.00									
IRP-049	IRP-49		5	1	2	1						514.44									514.44			0.00									
IRP-050	IRP-50		5	1	2	1						536.77		580							536.77			0.00									
IRP-051	IRP-51		5	1	2	1						457.69		540							457.69			0.00									
IRP-052	IRP-52		5	1	2	1						539.27									539.27			0.00									
IRP-053	IRP-53		5	1	2	1						492.02		530							492.02			0.00									
IRP-054	IRP-54		5	1	2	1						484.1		605							484.10			0.00									
IRP-055	IRP-55		5	1	2	1						447.49									447.49			0.00									
IRP-056	IRP-56		5	1	2	1						502.15									502.15			0.00									
IRP-057	IRP-57		5	1	2	1						495.4									495.40			0.00									
IRP-058	IRP-58		5	1	2	1						506.88		530							506.88			0.00									
IRP-059	IRP-59		5	1	2	1						561.3		436							561.30			0.00					392				
IRP-060	IRP-60		5	1	2	1						458.49									458.49			0.00									
IRP-061	IRP-61		5	1	2	1						336.82									336.82			0.00									
IRP-062B	IRP-62		5	1	2	1						347.54									347.54			0.00									
IRP-063	IRP-63		5	1	2	1						523.16									523.16			0.00									
IRP-064	IRP-64		5	1	2	1						556.94									556.94			0.00									
IRP-065	IRP-65		5	1	2	1						573.53									573.53			0.00									
KGC-001	KGC-1		7	2	2	5						500	1986	570		8				496.1	3.90			0.00					500				
KGC-002	KGC-2		7	2	2	5							1987	575		8					0.00			0.00									
KGC-003	KGC-3		7	2	2	5							1987	575		8				489.7	-489.70			0.00									
LF1-001			5	1	2	5						489.08	1985	535		7.875					489.08			0.00									
LF1-002	LF1-2		5	1	2	5						482.96	1978	507	503	11.5				480.7	2.26			0.00									
LF1-003			5	1	2	5							1985	521		7.785					0.00			0.00									
LF1-004	LF1-4		5	1	2	5						491.07	1986	530		12.5					491.07			0.00									
M-001	M-1		3	2	1	1						396	1965	450	450					391.8	4.20			0.00	109	109							USGS data
M-002	M-2		3	2	1	1						401	1968	460	451					396	5.00			0.00	184	184			410				
M-003	M-3	2950-04	3	2	1	1						423	1967	473	473		413.5	8	60	418.3	4.70			?/4.7'	177	177							USGS data
M-004	M-4		3	2	1	1						421	1967	472	472	11	412	8	60	418.2	2.80	150	4.80	31.25	138	138				420			USGS data
M-005	M-5		3	2	1	1						273	1969	405	405	11	280 (335)	8	70	267.3	5.70	200		200GPM/26'=7.69 (150 GPM/	176	176			490				
M-006	M-6	3050-22	3	2	1	1						325.97	1969	406	406	11	320	8	85 (80)	320.55	5.42			??/40.45'=	168								USGS data
M-007	M-7	3050-02	3	2	1	1						289	1969	340	340	11	290	8	50	284.2	4.80	180	5.10	35.29	175	175							
M-008	M-8	2950-05	3	2	1	1						443	1970	495	495	11	455	8	40		443.00	150	5.10	29.41	158	158				475			USGS data
M-009	M-9	2850-55	3	2	1	1						409.59	1970	500	480	11	460	8	40	392	17.59			0.00	162	162							USGS data
M-010	M-10		3	2	1	5															0.00			0.00									
M-010A	M-10A	mon Loo	1	1	2	1															0.00			0.00									USGS data
M-011	M-11	-40/Mar	3	2	1	5						295.82									295.82			0.00									USGS data
M-012	M-12	44A/Ma	3	2	1	3						271	1973	380	380		320	8	60	269.6	1.40	105	11.40	9.21	104	104							
M-013	M-13		3	2	1	5															0.00			0.00									
M-014	M-14	3149-02	3	2	1	3						294	1974	315	314		275	8	40	269.6	24.40	248	11.40	21.75	239	239							USGS data
M-015	M-15	3E+06	3	2	1	1						295.13	1982	347.38	347.38		320	8	40	292.09	3.04	194	1.49	130.20	172	172							USGS data
M-016	M-16		3	2	1	5						452.7	1985	500		8.5					452.70	150		0.00					402				
M-016B	M-16B		3	2	1	5						448.23	1985	495		8.5				445	3.23	180	9.92	18.15					495				
M-017A	M-17A		3	2	1	1						430.51	1989	485	475.51					427.12	3.39	415	3.05	136.07	202					485			
M-017B	M-17B		3	2	1	1						478.72	1989	520	520	10	480		40	475.25	3.47	280	0.67	417.91	354	354				520			
M-017X	M-17X		3	1	1	5						447		500		8				443.2	3.80			0.00									
M-018	M-18		3	2	1	1						207.87	1994	245	245	12				205.2	2.67	315	6.25	50.40	325	325							
M-019	M-19	M-20A	3	2	1	5															0.00			0.00									
M-019A	M-19A	M-20	3	2	1	5						460.93	1994	450		12					460.93			Dry									
M-020	M-20	M-19A	3	2	1	5						486.6									486.60			0.00									
M-020A	M-20A	M-19	3	2	1	1						486.6	1994	520	528	12				484.94	1.66	203	10.36	19.59	400	400				520			

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Owner/Operator		Type		Sub-type	Status		Basin		Geological
1	Guam Hydrologic Survey	1	**DataCollection**	1 Exploratory	1	Active	1	Hagatna/Agana	Used in 2013 Basement Map
2	GEPA			2 Observation/Monitoring	2	Inactive	2	Yigo-Tumon	**Distinct/Active**
3	Guam Waterworks Authority	2	**Utility**	1 Drinking	3	Offline	3	Finegayan	Indistinct/Passive
4	Navy			2 Industrial/Agricultrual	4	Abandoned	4	Agafa Gumas	Elevation
5	Air Force	3	**Stormwater Management**		5	Unknown	5	Andersen	
6	**Private**						6	Mangilao	
7	Unknown								

NGLA WELL DATA

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Name							Geographical						Engineering															Geological					
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Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
M-021	M-21		3	2	1	1						355		395	395					349.75	5.25			0.00	200	250							
M-023	M-23		3	2	1	1						401	1998	475	451	12				394.6	6.40			0.00	225	225							
MCR-001	MCR-1		6	2	2	5															0.00			0.00									
MGC-001	MGC-1		6	2	2	3						386.8		320.8		10					386.80			0.00		100							
MGC-002	MGC-2		6	2	2	3						203	1991								203.00			0.00		200			410				
MGC-004A	MGC-4A		6	2	2	1						393.7		436.4							393.70			0.00		180							
MGC-005	MGC-5		6	2	2	5															0.00			0.00									
MGC-006A	MGC-6A		6	2	2	5															0.00			0.00									
MGG-021	MGG-21		7	0	0	5															0.00			0.00					47				
MGG-034	MGG_34		7	0	0	5															0.00			0.00					246				
MGG-055	MGG-55		7	0	0	5															0.00			0.00					0				
MGG-120	MGG-120		7	0	0	5															0.00			0.00					-252				
MGG-129	MGG-129		7	0	0	5															0.00			0.00					20				
MGG-130	MGG-130		7	0	0	5															0.00			0.00					206				
MGG-147	MGG-147		7	0	0	5															0.00			0.00					-106				
MHR-001	MHR-1		6	2	2	5															0.00			0.00									
MW-001	MW-1		5	2	1	1						346.85	1944	389		12					346.85	320		0.00		320							USGS data
MW-002	MW-2		5	2	1	1						350.89	1945	379		10	386.5				350.89	225		0.00		225							USGS data
MW-003	MW-3		5	2	1	1						408.3	1944	422		10	428				408.30	235		0.00		225							USGS data
MW-004	MW-4		5	2	1	5															0.00			0.00									
MW-005	MW-5		5	2	1	1						417.38	1972	495		12	440				417.38			0.00		190							USGS data
MW-005A	MW-5A		5	2	1	3							2010	454		12				415.4	-415.40	200	0.90	222.22									
MW-006	MW-6		5	2	1	1						394	1965	495		12	495	10			394.00	300	13.58	22.09		500							USGS data
MW-006A	MW-6A		5	2	1	3							2010	430		12				392.43	-392.43	500	0.39	1282.05									
MW-007	MW-7		5	2	1	1						367.84	1965	410		12	410	10			367.84	300		0.00		280							USGS data
MW-007A	MW-7A		5	2	1	3						367.7	2010	411.2		12				366.52	1.18	280	8.75	32									
MW-008	MW-8		5	2	1	1						356	1965	384		12		10			356.00	300		0.00		410							USGS data
MW-008A	MW-8A		5	2	1	3						356	2010	397		12				354.04	1.96	410	0.18	2277.78									
MW-009	MW-9		5	2	1	1						355.79	1965	387		12					355.79	300		0.00		450							USGS data
MW-009A	MW-9A		5	2	1	3						356	2010	395		12				351.44	4.56	450	0.03	15,000									
NAS-001	NAS-1		3	2	1	1						282.33	1989	350	372					276.67	5.66	200	16.91	11.83	200	200				350			
NCS-001	NCS-1	90, 118	4	2	1	5						335.95	1993	380		12					335.95			0.00									
NCS-001A		91, 119, 667	4	2	1	5						429	1954	463		10	433		30	425.3	3.70			0.00		200	269						
NCS-001B			4	2	1	5															0.00			0.00									
NCS-002	NCS-2		4	2	1	5						364	1989	410		15		10			364.00	250	29.75	8.40									
NCS-002A	NCS-2A		4	2	1	5						456.805	1995	515						453.6	3.20			0.00		225							
NCS-003	NCS-3		4	2	1	5						472.9	1993	515		10					472.90			0.00									USGS data
NCS-003A	NCS-3A		4	2	1	5							2009	331		12				291.3	-291.30			0.00		125							
NCS-004	NCS-4		4	2	1	1						490	1994	530		12				488.3	1.70			0.00									
NCS-005	NCS-5		4	2	1	5															0.00			0.00		150							
NCS-006	NCS-6		4	2	1	1															0.00			0.00		200							
NCS-007	NCS-7		4	2	1	1															0.00			0.00		250							
NCS-008	NCS-8		4	2	1	5															0.00			0.00		200							
NCS-009	NCS-9		4	2	1	5															0.00			0.00									
NCS-009A	NCS-9A		4	2	1	1															0.00			0.00		250							
NCS-010	NCS-10		4	2	1	1						454.7	2003	490		12				451	3.70			0.00		200							
NCS-011	NCS-11		4	2	1	1						491.25	2006	527		12				484.84	6.41			0.00		200							
NCS-012	NCS-12		4	2	1	1						488.5	2006	525		12				484.4	4.10			0.00		200							
NCS-1X			4	2	1	5															0.00			0.00									
NCS-A	NCS-A		4	2	1	1						429	1967	463		16		10			429.00	200	25.00	8		180							USGS data
NCS-B	NCS-B		4	2	1	5															0.00			0.00									
NCS-B1	NCS-B1		4	2	1	1															0.00			0.00		175							
NRMC-001	NRMC-1	NH-001	4	2	1	1							1988								0.00			0.00		200				200			
NRMC-002	NRMC-2	NH-002	4	2	1	1							1988								0.00			0.00		200				196			
NRMC-003	NRMC-3	NH-003	4	2	1	1							1988								0.00			0.00		250				200			

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6 Private				6 Mangilao	
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Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
NRMC-03A			4	2	1	5															0.00			0.00									
NVY-001	NVY-1		4	3	0	5															0.00			0.00									
NVY-002	NVY-2		4	3	0	5															0.00			0.00									
PBI-001	PBI-1		6	2	2	1						325	1988	365	376					320	5.00			0.00		200							
PIC-001	PIC-1		6	2	2	1						18.74		230.04							18.74			0.00		200							
TaragueWell-004	Tarague Well 4		5	2	1	4															0.00			0.00									USGS data
TGGR-003	TGGR-3		6	2	2	5						340	2000	400		12				337	3.00			0.00									
Tumon Maui Well	Tumon Maui Well	2/Tumor	5	2	1	3							1947	654							0.00	1000		0.00		900							USGS data
UIC-001	UIC-1		5	3	0	1								427				18			0.00			0.00									
UIC-002	UIC-2		5	3	0	1								374				18	364		0.00			0.00									
UIC-003	UIC-3		5	3	0	1								33				18	23		0.00			0.00									
UIC-004	UIC-4		5	3	0	1								36				18			0.00			0.00									
UIC-005	UIC-5		5	3	0	1								173				18	164		0.00			0.00									
UIC-006	UIC-6		5	3	0	1								536				18		518	-518.00			0.00									
UIC-007	UIC-7		5	3	0	1								107				18			0.00			0.00									
UIC-008	UIC-8		5	3	0	1								76				26.5			0.00			0.00									
UIC-009	UIC-9		5	3	0	1								52				16	42		0.00			0.00									
UIC-010	UIC-10		5	3	0	1								85				18			0.00			0.00									
UIC-011	UIC-11		5	3	0	1								33				16.25	23		0.00			0.00									
UIC-012	UIC-12		5	3	0	1								241				18			0.00			0.00									
UIC-013	UIC-13		5	3	0	1								250				20			0.00			0.00									
UIC-014	UIC-14		5	3	0	1								316				20	306		0.00			0.00									
UIC-015	UIC-15		5	3	0	1								365				18	355		0.00			0.00									
UIC-016	UIC-16		5	3	0	1								394				18	384		0.00			0.00									
UIC-017	UIC-17		5	3	0	1								320				20			0.00			0.00									
UIC-018	UIC-18		5	3	0	1								346				19.5			0.00			0.00									
UIC-019	UIC-19		5	3	0	1								197				19.5			0.00			0.00									
UIC-020	UIC-20		5	3	0	1								271				19			0.00			0.00									
UIC-021	UIC-21		5	3	0	1								363				19.5	353		0.00			0.00									
UIC-022	UIC-22		5	3	0	1								302				24			0.00			0.00									
UIC-023	UIC-23		5	3	0	1								154				22			0.00			0.00									
UIC-024	UIC-24		5	3	0	1								152				20		130	-130.00			0.00									
UIC-025	UIC-25		5	3	0	1								222				19			0.00			0.00									
UIC-026	UIC-26		5	3	0	1								154				21			0.00			0.00									
UIC-028	UIC-28		5	3	0	1								168				17	158		0.00			0.00									
UIC-029	UIC-29		5	3	0	1								190				20	180		0.00			0.00									
UIC-030	UIC-30		5	3	0	1								133				20			0.00			0.00									
UIC-031	UIC-31		5	3	0	1								162				20	152		0.00			0.00									
UIC-032	UIC-32		5	3	0	1								168				20			0.00			0.00									
UIC-033	UIC-33		5	3	0	1								266				20			0.00			0.00									
UIC-034	UIC-34		5	3	0	1								107				15			0.00			0.00									
UIC-035	UIC-35		5	3	0	1								189				18			0.00			0.00									
UIC-036	UIC-36		5	3	0	1								125				18			0.00			0.00									
UIC-037	UIC-37		5	3	0	1								120				18			0.00			0.00									
UIC-038	UIC-38		5	3	0	1															0.00			0.00									
UIC-040	UIC-40		5	3	0	1												15			0.00			0.00									
UIC-041	UIC-41		5	3	0	1								253				18			0.00			0.00									
UIC-042	UIC-42		5	3	0	1								95				12			0.00			0.00									
UIC-043	UIC-43		5	3	0	1								14				8			0.00			0.00									
UIC-044	UIC-44		5	3	0	1								346				8			0.00			0.00									
UIC-045	UIC-45		5	3	0	1								27				12			0.00			0.00									
UIC-046	UIC-46		5	3	0	1								46				12			0.00			0.00									
UIC-047	UIC-47		5	3	0	1												6			0.00			0.00									
UIC-048	UIC-48		5	3	0	1								520				24			0.00			0.00									
UIC-049	UIC-49		5	3	0	1								488				17			0.00			0.00									
UIC-050	UIC-50		5	3	0	1								28				17.25			0.00			0.00									
UIC-051	UIC-51		5	3	0	1								495				17.25			0.00			0.00									
UIC-052	UIC-52		5	3	0	1								460				18			0.00			0.00									
UIC-053	UIC-53		5	3	0	1								182				18			0.00			0.00									
UIC-054	UIC-54		5	3	0	1								125				24			0.00			0.00									

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WERI/UOG

Owner/Operator	Type	Sub-type	Status	Basin	Geological
1 Guam Hydrologic Survey	1 DataCollection	1 Exploratory	1 Active	1 Hagatna/Agana	Used in 2013 Basement Map
2 GEPA		2 Observation/Monitoring	2 Inactive	2 Yigo-Tumon	Distinct/Active
3 Guam Waterworks Authority	2 Utility	1 Drinking	3 Offline	3 Finegayan	Indistinct/Passive
4 Navy		2 Industrial/Agricultrual	4 Abandoned	4 Agafa Gumas	Elevation
5 Air Force	3 Stormwater Management		5 Unknown	5 Andersen	
6 Private				6 Mangilao	
7 Unknown					

NGLA WELL DATA

Operations							Field																										
													Engineering																				
Name							Geographical						Construction				Well Design			Well Hydraulics							Water Quality	Geological					
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
UIC-055	UIC-55		5	3	0	1								156				18			0.00			0.00									
UIC-056	UIC-56		5	3	0	1								125				24			0.00			0.00									
UIC-056A	UIC-56A		5	3	0	1								149				17.25			0.00			0.00									
UIC-057	UIC-57		5	3	0	1								229				18			0.00			0.00									
UIC-058	UIC-58		5	3	0	1								151				18			0.00			0.00									
UIC-059	UIC-59		5	3	0	1								89				18			0.00			0.00									
UIC-060	UIC-60		5	3	0	1								136				18			0.00			0.00									
UIC-061	UIC-61		5	3	0	1								146				18			0.00			0.00									
UIC-062	UIC-62		5	3	0	1								32				18			0.00			0.00									
UIC-063	UIC-63		5	3	0	1								107				20			0.00			0.00									
UIC-064	UIC-64		5	3	0	1								164				20			0.00			0.00									
UIC-065	UIC-65		5	3	0	1								165				20			0.00			0.00									
UIC-066	UIC-66		5	3	0	1								54				17.25			0.00			0.00									
UIC-067	UIC-67		5	3	0	1								51				17.25			0.00			0.00									
UIC-068	UIC-68		5	3	0	1								516				18			0.00			0.00									
UIC-069	UIC-69		5	3	0	1								346				18			0.00			0.00									
UIC-070	UIC-70		5	3	0	1								26				18		6	-6.00			0.00									
UIC-071	UIC-71		5	3	0	1								154				24			0.00			0.00									
UIC-072	UIC-72		5	3	0	1								50				17.5			0.00			0.00									
UIC-073	UIC-73		5	3	0	1								100				17			0.00			0.00									
UIC-074	UIC-74		5	3	0	1								107				24			0.00			0.00									
UIC-074A	UIC-74A		5	3	0	1								25				13			0.00			0.00									
UIC-075	UIC-75		5	3	0	1								34				13			0.00			0.00									
UIC-076	UIC-76		5	3	0	1								76				14			0.00			0.00									
UIC-077	UIC-77		5	3	0	1								54				18			0.00			0.00									
UIC-078	UIC-78		5	3	0	1								63				18			0.00			0.00									
UIC-079	UIC-79		5	3	0	1								24				10			0.00			0.00									
UIC-080	UIC-80		5	3	0	1								77				18			0.00			0.00									
UIC-080A	UIC-80A		5	3	0	1								42				18			0.00			0.00									
UIC-081	UIC-81		5	3	0	1								66				20			0.00			0.00									
UIC-082	UIC-82		5	3	0	1								66				20			0.00			0.00									
UIC-083	UIC-83		5	3	0	1								287				18			0.00			0.00									
UIC-084	UIC-84		5	3	0	1								236				18			0.00			0.00									
UIC-085	UIC-85		5	3	0	1								276				18			0.00			0.00									
UIC-086	UIC-86		5	3	0	1								404				18			0.00			0.00									
UIC-087	UIC-87		5	3	0	1								168				20			0.00			0.00									
UIC-088	UIC-88		5	3	0	1								187				20			0.00			0.00									
UIC-089	UIC-89		5	3	0	1								392				17			0.00			0.00									
UIC-090	UIC-90		5	3	0	1								238				18		133	-133.00			0.00									
UIC-091	UIC-91		5	3	0	1								268				18			0.00			0.00									
UIC-092	UIC-92		5	3	0	1								96				16.25	86		0.00			0.00									
UIC-093	UIC-93		5	3	0	1								90				16.25	90		0.00			0.00									
UIC-094	UIC-94		5	3	0	1								285				20.75	275		0.00			0.00									
UIC-095	UIC-95		5	3	0	1								45				26.5			0.00			0.00									
UIC-096	UIC-96		5	3	0	1								76				20			0.00			0.00									
UIC-097	UIC-97		5	3	0	1								95				20			0.00			0.00									
UIC-098	UIC-98		5	3	0	1												18			0.00			0.00									
UIC-099	UIC-99		5	3	0	1								29				15			0.00			0.00									
UIC-100	UIC-100		5	3	0	1								293				24			0.00			0.00									
UIC-101	UIC-101		5	3	0	1								35				15			0.00			0.00									
UIC-102	UIC-102		5	3	0	1								54				15			0.00			0.00									
UOG-001	UOG-1		6	2	2	1						38	2000	345						245	-207.00			0.00		280							
USGS-033	USGS-33	WAAB v	1	1	2	5						486	1945	520		12					486.00	150	14.50	10.34									
USGS-055	USGS-55		1	1	2	5						545	1945	575		10					545.00			0.00									
USGS-056	USGS-56	rthwest	1	1	2	5						490.22	1945	515		12	486.4	10	30	487.16	3.06			0.00								Y	

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WERI/UOG

Owner/Operator		Type		Sub-type	Status		Basin		Geological
1	Guam Hydrologic Survey	1	DataCollection	1 Exploratory	1	Active	1	Hagatna/Agana	Used in 2013 Basement Map
2	GEPA			2 Observation/Monitoring	2	Inactive	2	Yigo-Tumon	**Distinct/Active**
3	Guam Waterworks Authority	2	Utility	1 Drinking	3	Offline	3	Finegayan	Indistinct/Passive
4	Navy			2 Industrial/Agricultrual	4	Abandoned	4	Agafa Gumas	Elevation
5	Air Force	3	Stormwater Management		5	Unknown	5	Andersen	
6	Private						6	Mangilao	
7	Unknown								

NGLA WELL DATA

Operations							Field																										
Name							Geographical						Engineering															Geological					
													Construction				Well Design			Well Hydraulics							Water Quality						
Well ID	Name	Alias	Owner/ Operator	Type	Sub-type	Status	Basin	Latitude	Longitude	Lat Converted	Long Converted	Elevation	Year Drilling Completed	Borehole Depth	Well Depth	Hole Dia	Casing length	Casing Dia	Screen length	Depth to water	MSL_Head	Pump Test Rate	Drawdown	Specific capacity	Permitted Production Rate	Production Rate	Chlorides	Drill Log	Positive Control	Negative Control	Sample collection	Video	Outside Links
										WGS84		ft		ft	ft	in	ft	in	ft	ft	ft	GPM	ft	GPM/ft	GPM	GPM	Avg 3 yrs		ft	ft			
USGS-059	USGS-59	1-866/2	1	1	2	5						121	1945	132				8		117	4.00			0.00									
USGS-075	USGS-75		1	1	2	5						527.82	1945	563		11.5	261.54	10	40		527.82			0.00								Y	
USGS-099	USGS-99		1	1	2	5						559.23									559.23			0.00								Y	
USGS-112	USGS-112	ion Field	1	1	2	5						204	1945	216				10			204.00	140	0.10	1400									
USGS-150	USGS-150		1	1	2	5						459.21									459.21			0.00								Y	
UWA-001	UWA-1		6	2	2	1						10.57		152.57							10.57			0.00		350							
Y-001	Y-1		3	2	1	1						413.8	1967	450	450	11	410	8	40	408	5.80	170	19.00	8.95	141	141							USGS data
Y-002	Y-2	3152-34/	3	2	1	1						417	1967	467	467	11	397	8	70	412.5	4.50	140		140 GPM/	161	161							USGS data
Y-003	Y-3		3	2	1	1						417		470	470					412	5.00			0.00	138	138							USGS data
Y-004	Y-4	2-12/Yig	3	2	1	1						398.5	1974	445		11	405	8	40	394.5	4.00	200		200/55 (states no drawdown)									USGS data
Y-004A	Y-4A		3	2	1	5						400	1994	450	450	10				395.91	4.09			0.00	180	220							
Y-005	Y-5	2-33/Yig	3	2	1	1						434	1974	480	480		445		35	429.55	4.45	220	6.00	36.67	148	148							USGS data
Y-005A	Y-5A		3	2	1	5						420.1	1999	470		12				419.1	1.00			0.00									
Y-005X	Y-5X		3	1	1	5						420.1	1999	470		12				416	4.10	275	14.50	18.97									
Y-006	Y-6		3	2	1	1						430		480	480						430.00			0.00	136	136							
Y-007	Y-7		3	2	1	1						411.75	1982	475	475.27	8			30	408.88	2.87	610		610GPM/5.5"(0.458')=1	514								USGS data
Y-008	Y-8		3	2	1	5						502	1985	552		8.5				498.2	3.80			0.00									
Y-009	Y-9		3	2	1	1						402	1986	454	454	8				399.75	2.25			0.00	472	472							
Y-010	Y-10		3	2	1	1						390.01	1994	445	447	12				388.8	1.21	237	9.98	23.75	250	250							
Y-011	Y-11		3	2	1	5						401.85	1994	445		12				399.44	2.41	90	29.96	3.00									
Y-012	Y-12	Y-14	3	2	1	1						404.72	1994	445	430	12				397.3	7.42	237	0.10	2370.00	235	235							
Y-013	Y-13		3	2	1	5						587		345							587.00			Dry					290				
Y-014	Y-14	-12, Y-1	3	2	1	1						408.4	1994	445	447	12				404.44	3.96	250	0.76	328.95	400	400							
Y-015	Y-15	-23, Y-1	3	2	1	1						523.68	1994	445	445					327.4	196.28	280	0.80	350.00	600	600			390				USGS data
Y-016	Y-16	Y-11	3	2	1	1						404	1998	445	445					402.23	1.77	195	0.02	9750.00	200	200							
Y-017	Y-17	Y-14	3	2	1	1						521	1998	325	335	12				337.4	183.60			0.00	300	300			312				
Y-018	Y-18	A-33	3	2	1	1						396	1998	433	446	20	401	10.5	40	397	-1.00	250		0.00	250	250			133				
Y-019	Y-19		3	2	1	1						513.13	1994	560	429	12				497.8	15.33			Test Failed	500	500			**530**				
Y-019X	Y-19X		3	1	1	5															0.00			0.00									
Y-020	Y-20		3	2	1	1						560.23	1994	520	448	12					560.23			0	500	500			**463**				
Y-020A	Y-20A		3	2	1	5						543	1995	370		12					543.00			Dry					323				
Y-020X	Y-20X		3	1	1	5															0.00			0.00									
Y-021	Y-21		3	2	1	5							1998	420							0.00			0.00									
Y-021A	Y-21A		3	2	1	1						381	1999	422	425	12				378.7	2.30			0.00	350	350							
Y-022	Y-22		3	2	1	1						518	1998	260	475	12					518.00			0.00	300	300			180				
Y-023	Y-23	Y-15	3	2	1	1						514	1998	415	416	12				343.43	170.57			0.00	300	300			340				
Y-024	Y-24		3	2	1	5						543	1998	445		12					543.00			0.00					380				
Y-025	Y-25		3	2	1	5						554	1998	320		12					554.00			0.00					307				
Y-025A	Y-25A		3	2	1	5															0.00			0.00									
Y-026	Y-26		3	2	1	5															0.00			0.00									
Y-027	Y-27		3	2	1	5						429	1998	480						415	14.00			0.00									
Y-028	Y-28		3	2	1	5						589.3	1998	360		12				233	356.30			0.00					350				
Y-029	Y-29		3	2	1	5															0.00			0.00									
Y-030	Y-30		3	2	1	5						587	1998	200							587.00			0.00					**181**				
Y-032	Y-32		3	2	1	5						521	1998	265		12				200	321.00			0.00					245				
Ypao Natural Well	Ypao Natural Well		7	0	0	5															0.00			0.00									USGS data

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APPENDIX D

D-1 Public Law 24-247…pg 78

D-2 16 July 2010 Memorandum of Understanding…pg 87

Refer to
Legislative Secretary

CARL T.C. GUTIERREZ
GOVERNOR OF GUAM

Office of the Speaker
ANTONIO R. UNPINGCO
Date: 8/17/98
Time: 11:15am
Rec'd by:
Print Name: ANNDee FRANCISCO

AUG 14 1998

OFFICE OF THE LEGISLATIVE SECRETARY
ACKNOWLEDGMENT RECEIPT
Received By Rosario
Time 8:45am
Date 8/18/98

The Honorable Antonio R. Unpingco
Speaker
Mina'Bente Kuåttro na Liheslaturan Guåhan
Twenty-Fourth Guam Legislature
Guam Legislature Temporary Building
155 Hesler Street
Hagåtña, Guam 96910

Dear Speaker Unpingco:

Enclosed please find Substitute Bill No. 652 (LS), "AN ACT TO ESTABLISH THE GUAM HYDROLOGIC SURVEY AS A PERMANENT PROGRAM TO BE ADMINISTERED BY THE WATER AND ENERGY RESEARCH INSTITUTE OF THE WESTERN PACIFIC, UNIVERSITY OF GUAM", which I have **signed** into law today as **Public Law No. 24-247.**

The General Appropriation Act for Fiscal Years 1998-99 directed the Water and Energy Research Institute of the Western Pacific (WERI), located at the University of Guam, to establish the Guam Hydrologic Survey, and appropriated $200,000 for 1998 only.

The duties of WERI under this legislation are essentially the same, which is to conduct the Guam Hydrologic Survey, however, this legislation is more specific by including the respective roles of WERI, Guam Environmental Protection Agency, and the Guam Waterworks Authority.

The legislation directs WERI to create and administer the Guam Hydrologic Survey, and appropriates $265,000 for Fiscal Year 1999. The intent section states that the legislation is to establish a permanent program for collecting, consolidating and storing all of the water resource data on Guam, and making all of this information readily retrievable for use by the people of Guam. The "permanency" established is the provision that WERI

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prepare and submit an annual budget request for the Guam Hydrologic Survey to the Legislature by August 1st of each year.

Very truly yours,

Carl T. C. Gutierrez
I Maga'lahen Guåhan
Governor of Guam

00363

Attachment: copy attached for signed bill
original attached for vetoed bill

cc: The Honorable Joanne M. S. Brown
Legislative Secretary

MINA'BENTE KUATTRO NA LIHESLATURAN GUAHAN
1998 (SECOND) Regular Session

CERTIFICATION OF PASSAGE OF AN ACT TO *I MAGA'LAHEN GUAHAN*

This is to certify that Substitute Bill No. 652 (LS), "AN ACT TO ESTABLISH THE GUAM HYDROLOGIC SURVEY AS A PERMANENT PROGRAM TO BE ADMINISTERED BY THE WATER AND ENERGY RESEARCH INSTITUTE OF THE WESTERN PACIFIC, UNIVERSITY OF GUAM," was on the 29th day of July, 1998, duly and regularly passed.

ANTONIO R. UNPINGCO
Speaker

Attested:

Joanne M.S. Brown
JOANNE M.S. BROWN
Senator and Legislative Secretary

This Act was received by *I Maga'lahen Guahan* this 3rd day of August, 1998, at 9:05 o'clock a.M.

Assistant Staff Officer
Maga'lahi's Office

APPROVED:

CARL T. C. GUTIERREZ
I Maga'lahen Guahan

Date: 8-14-98

Public Law No. 24-247

MINA'BENTE KUATTRO NA LIHESLATURAN GUAHAN
1998 (SECOND) Regular Session

Bill No. 652 (LS)
As substituted by the Committee
on Natural Resources and amended
on the Floor.

Introduced by:

J. M.S. Brown
T. C. Ada
A. C. Blaz
F. B. Aguon, Jr.
Francisco P. Camacho
Felix P. Camacho
M. C. Charfauros
E. J. Cruz
W. B.S.M. Flores
Mark Forbes
L. F. Kasperbauer
A. C. Lamorena, V
C. A. Leon Guerrero
L. A. Leon Guerrero
V. C. Pangelinan
J. C. Salas
A. L.G. Santos
F. E. Santos
A. R. Unpingco
J. Won Pat-Borja

AN ACT TO ESTABLISH THE GUAM HYDROLOGIC SURVEY AS A PERMANENT PROGRAM TO BE ADMINISTERED BY THE WATER AND ENERGY RESEARCH INSTITUTE OF THE WESTERN PACIFIC, UNIVERSITY OF GUAM.

BE IT ENACTED BY THE PEOPLE OF GUAM:

Section 1. Legislative Intent. *I Liheslaturan Guahan* recognizes the need for accurate baseline data and up-to-date analyses of Guam's water resources. As Guam's population and economy continue to grow, the Island must develop new sources and improve existing sources of drinking water. There is currently no permanent and comprehensive program in place to ensure information on Guam's water resources is systematically collected, stored, analyzed and reported so that the people of Guam can be supplied with up-to-date and accurate information and scientific advice.

Public Law Number 24-161, which instituted the Guam Drought Management and Comprehensive Water Conservation Plan, took an important first step toward alleviating some crucial shortfalls in basic data collection by establishing the Comprehensive Monitoring Program, which rehabilitates and re-activates the joint, fifty percent (50%) matching Federal funds, program under which the U.S. Geological Survey ("USGS") will collect key data on rainfall across the Island, ground water levels, salt water intrusion and water lens thickness in northern Guam, and stream flow in southern Guam. Important deficiencies remain, however. In particular, there is no standard for collecting and interpreting geologic data on new wells drilled on Guam. Such data are crucial for locating new sources of fresh water and for determining where the fresh-water lens is vulnerable to contamination by salt water or surface contaminants.

The most important deficiency, however, is that Guam has no permanent program in place to consolidate and preserve the data that are being collected so that they can be readily retrieved to support local scientific and engineering analyses, or other needs of local decision-makers and citizens for timely information on Guam's water resources. Data collected by the USGS are currently archived in Hawaii or on the Mainland. Data collected by local agencies currently accumulate in various repositories without being systematically cataloged or archived so that potential users can find it when they need it, or even determine what data are available. There is thus no means for rapidly and economically locating and retrieving hydrologic data for use by scientists, engineers, public agencies, private businesses, educators, or the general public to support scientific analyses, public or private projects, or educational programs on Guam.

The intent of this legislation is to establish a permanent program for not only collecting, but also for consolidating and storing all of the water resource data on Guam, and for making all of it readily retrievable for use by the people of Guam. The program established under this legislation will also ensure that ongoing analyses of local water resource concerns are conducted by local scientists so that the Island's water resource policy-makers, managers, regulators, educators, businesses, and citizens have timely information and readily accessible advice for sound decisions regarding use, conservation and development of Guam's water resources.

Section 2. Establishment of a Permanent Guam Hydrologic Survey Program. The Water and Energy Research Institute of the Western Pacific ("WERI") shall create and administer the Guam Hydrologic Survey ("GHS"). The mission of the GHS shall be to:

a. locate, inventory and evaluate all hydrologic data pertaining to

Guam and consolidate the data into a single computer-based data library from which information can be easily accessed and retrieved;

b. 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;

c. conduct analyses to assess the status of Guam's water resources, and publish annual and other regular concise reports on water use, trends and key concerns for use by *I Maga'lahen Guahan*, *I Liheslaturan Guahan*, public agencies and private business, and citizens of Guam;

d. provide educational materials and regular forums for Island educators and the general public to raise the level of public understanding of Guam's water resources, problems and the issues that must be addressed to solve them; and

e. conduct research into selected water resource problems of current concern, and publish reports to provide scientific data on which to base sound corrective policy, regulations and management decisions.

Section 3. Exchange of Data. (a) Comprehensive Monitoring Program. WERI shall determine data collection requirements and administer the joint WERI-USGS Comprehensive Monitoring Program on Guam, as mandated by Public Law Number 24-161. WERI shall coordinate with the USGS and other Federal agencies to ensure that data collected by Federal agencies are immediately accessible to the Guam Hydrologic Survey. All government of Guam agencies shall provide WERI and USGS access to such public property and facilities as are required to implement the Comprehensive Monitoring Program.

(b) Guam Hydrologic Survey. All government of Guam agencies, including, but not limited to, the Guam Environmental Protection Agency ("GEPA") and the Guam Waterworks Authority ("GWA"), shall transmit a copy of all nonproprietary data to WERI for consolidation by GHS. Each agency collecting water-related data shall maintain an active point of contact with the GHS regarding the collection, transmission and archiving of data. Agencies may execute a Memorandum of Understanding ("MOU") with WERI to facilitate scientific hydrologic data collection.

(c) Drilling and Geophysical Data Collection. WERI shall assist GEPA in preparing and maintaining a standard for geologic data collection during drilling on Guam. Prior to the start of the drilling, the permit applicant shall coordinate with WERI so that on-site data collection can be supervised by a WERI geologist and recorded by the GHS. A copy of any down-hole or geophysical data collected on Guam shall be archived with the GHS.

Section 4. Appropriation for Guam Hydrologic Survey. Two Hundred Sixty-five Thousand Dollars ($265,000.00) is appropriated from the General Fund to WERI for the continued implementation of the Guam Hydrologic Survey, as created by §29 of Chapter III of Public Law Number 24-59 for Fiscal Year 1999. Henceforth, WERI shall prepare and submit the annual budget request for the Guam Hydrologic Survey to *I Liheslaturan Guahan* by August 1st of each year.

Section 5. Comprehensive Monitoring Program. In accordance with Public Law Number 24-161, WERI will work with the USGS to prepare the annual work plan on budget for the Comprehensive Monitoring Program. WERI will submit the annual budget request for Guam' fifty percent (50%) to the Comprehensive Monitoring Program to *I Liheslaturan Guahan* by August 1st of each year.

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 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 commitments.

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	
PAUL BUSHONG, RADM **Commander, Joint Region Marianas**	**SIMON A. SANCHEZ II** **Chairman, Consolidated Commission on Utilities**
Date: 16 JUL 10	Date: 16 /JUL/ 10
Peter S. Lynch	
PETER S. LYNCH, CAPT **Commanding Officer** **Naval Facilities Engineering Command Marianas**	**JOHN BENAVENTE** **General Manager** **Guam Waterworks Authority**
Date: 16 JULY 2010	Date: 16/JUL/10