Northern Guam Lens Aquifer

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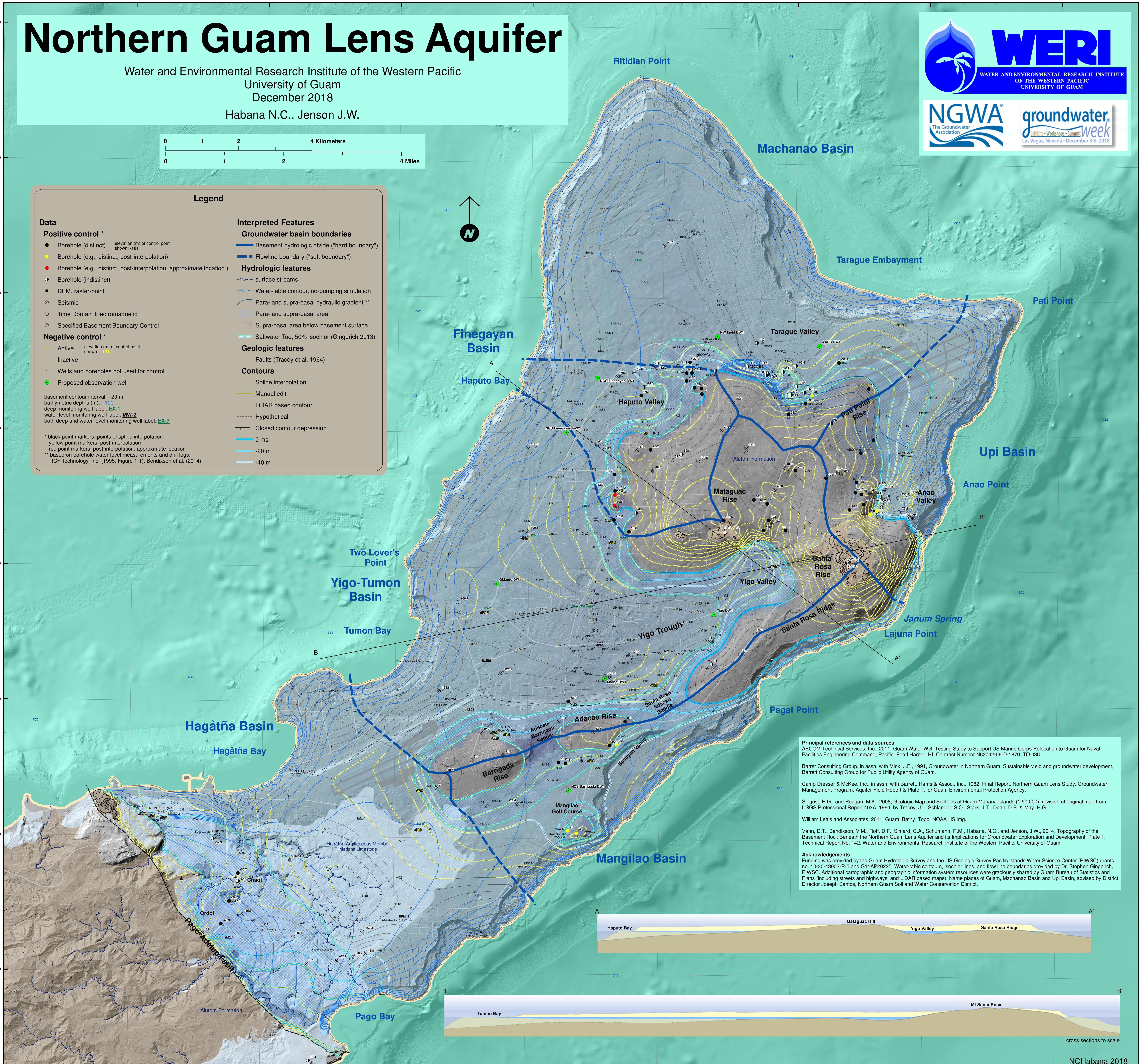

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THE NORTHERN GUAM LENS AQUIFER

The Northern Guam Lens Aquifer (Figure 1) is composed of very permeable limestone bedrock (Figure 2) that lies atop low-permeability volcanic basement rock (Figure 3). Rises and ridges in the basement rock that stand above sea level partition the aquifer into six semi-contiguous subterranean groundwater *basins*. Within each basin, freshwater is found in three distinct *zones* (Figure 4). Each of the three groundwater zones affords certain advantages while also presenting different challenges for groundwater exploration, development, and management.

Figure 1. Northern Guam Plateau. The Northern Guam Plateau, in an aerial photo, looking southeast from Two Lover's Point. Standing at some 200 to 600 ft (60 to 180 m) elevation, with 102 mi^2 (264 km^2) area, the plateau surface is the uplifted, eroded remnant of an ancient atoll-like reef-lagoon complex. It is now the catchment for the aquifer composed of the Miocene-Pleistocene limestone bedrock sequence beneath it.

In the *basal zone*, which comprises about 75% of the aquifer by area, freshwater flows through the porous limestone in a lens-shaped layer floating atop the saltwater that permeates the pore spaces in the limestone below the lens. As basal freshwater flows to the coast from the interior of the aquifer, it mixes at its base with the underlying saltwater, becoming progressively thinner until it discharges in brackish springs and seeps along the shoreline. Although basal water is easy to find, water quality is variable. The basal zone presents the greatest challenges for minimizing and managing salt-water contamination.

Figure 2. The Barrigada Limestone. A fresh exposure of the Miocene-Pliocene Barrigada Limestone, the core and dominant unit of the aquifer, at the Department of Public Works Quarry, Dededo.

The *para-basal zone* is a ribbon-shaped region adjoining the head of the basal zone, where freshwater that accumulates along the flanks of the rises and ridges in the basement rock displaces the adjacent saltwater. The para-basal zone forms the thickest part of the freshwater lens. Extending down to elevations a few tens of meters below sea level, freshwater in the para-basal zone is underlain by low-permeability volcanic basement rock rather than porous limestone filled with saltwater, as in the basal zone. These attributes make para-basal water much less vulnerable to saltwater contamination than basal water. The para-basal zone has thus historically been the zone of choice for development. Since it occupies less than 5% of the aquifer by area, however, exploration targeting para-basal water carries some attendant risks. Wells targeted for the para-basal zone but which are erroneously placed in the adjacent basal water may produce higher salinity water than could be obtained from nearby sites within the para-basal zone producing at the same, or even higher, rates. On the other hand, boreholes that miss the para-basal zone on the opposite side, intercepting basement rock above sea level, most often produce "dry holes." In addition to these risks, the much smaller size of the para-basal zone compared to the basal zone makes it proportionately more difficult to select productive sites that also have economical access to land, roads, and utilities.

Figure 3. The Alutom Formation. Outcrop of layered tuffaceous volcanic rock near the summit of Mount Alutom, the type locale of the Oligocene Alutom Formation, which on the northern plateau comprises the basement under the limestone bedrock aquifer.

In the *supra-basal zone*, freshwater percolating down from the ground surface reaches basement rises that stand above sea level, and then flows down-slope to the para-basal zone. The supra-basal zone comprises about 20% of the aquifer by area, but freshwater within this zone is mostly confined to a network of fractures, conduits, and discontinuous patches that occupies an even smaller total area than para-basal water. Supra-basal water is distinct from perched or "high" water because of its direct hydraulic connections to the downstream para-basal water. Its outstanding attributes are that it has minimum salinity and is invulnerable to contamination from saltwater within the aquifer. Wells in this zone can be very productive, but finding productive and accessible sites is even more risky and difficult than in the para-basal zone. Although water quality in the para-basal and supra-basal zones is normally higher than in the basal zone, the much smaller storage in these two zones makes water supply from them more vulnerable to drought or over-pumping.

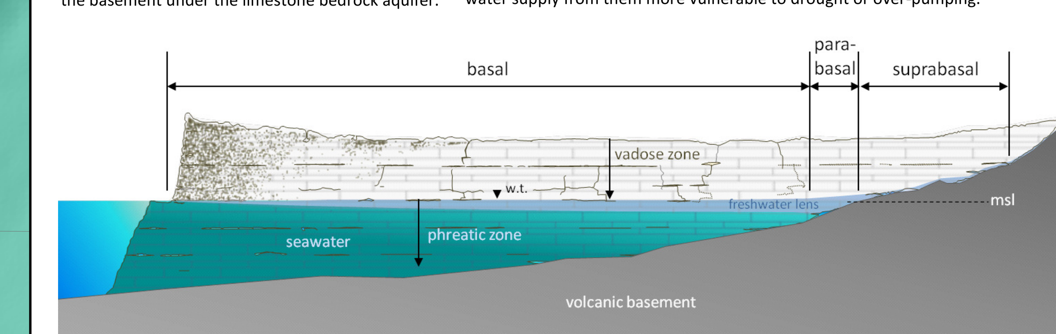

Figure 4. The three groundwater zones of the Northern Guam Lens Aquifer. The topography of the volcanic basement beneath carbonate island karst aquifers defines three groundwater zones (not to scale): 1) the *basal zone*, in which the freshwater lens is underlain by seawater, 2) the *para-basal* zone, 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.

Given the complexity of these considerations, the most fundamental tool for groundwater developers, modelers, managers, and regulators seeking to optimize production from the aquifer is an accurate and detailed map of basement topography and its consequent groundwater basins and zones. The first such map was produced from geophysical and borehole data obtained during the pivotal 1982 *Northern Guam Lens Study*[1]. The map shown on this poster is the first published revision in the subsequent three decades[2]. Prepared in support of the 2010-2013 *Guam Groundwater Availability Study* led by the USGS[3,4], the new basement map builds on the original 1982 data set, with revisions based on new, unpublished data accumulated since 1982 and consolidated by WERI. It also incorporates new insights gained from the broad-ranging 2010 *Exploratory Drilling Program* funded by *Naval Facilities Engineering Command Pacific*[5].
The new map updates and more precisely defines the boundaries of the aquifer's six groundwater basins. It also provides more accurate and detailed demarcation of the three groundwater zones within each basin. Names from the 1982 map are retained, but formal names are also assigned to previously unnamed but significant features. The new revision applied state-of-the-art screening and spatial analysis techniques to evaluate 697 records, from which 148 internal control points (80 from borehole data and 68 from geophysical surveys) were selected and applied along with 24 boundary conditions (2 LiDAR raster-points, 17 bathymetric points, and 5 specified points) to constrain basement topography. For each control point, the new map indicates the source or *type of data* (boundary condition, borehole, seismic, or time domain electromagnetic), *type of control* (positive or negative), and *precision of control* (distinct or indistinct). Elevations across the basement surface were thus interpolated from 173 control points, including the 24 along the boundary. Of the 148 internal control points, 132 positive control points provide absolute control for basement elevation, and 16 negative control points provide minimum measured depths of the limestone bedrock where the depth to the basement is otherwise unknown. Data used to build the map are summarized in Tables 1 and 2, below.

Data Type	Data Source	Disposition of screened data: Positive control: Applied Active	*Set aside	Total screened	Negative control: Applied: Active	Applied: Passive	*Set aside	Total screened	Total screened each source
Borehole	PUAG, EarthTech, GWA	32	2	35	9	96	36	140	175
Borehole	Navy (inc. AECOM)	2	0	2	3	7	24	34	36
Borehole	AF (inc. IRP)	16	0	16	0	10	191	201	217
Borehole	WERI / USGS	2	0	2	4	6	12	23	25
Borehole	Private	3	0	3	0	0	32	32	35
Borehole	Unknown	9	1	10	0	0	31	31	41
Total boreholes		65	3	68	15	120	326	461	529
Seismic	1982 Map	45	36	81					81
TDEM	1992 Map	23	64	87					87
TOTAL all sources		132	103	236	16 (136)	120 (136)	326	461	697

*Reasons for setting aside data include missing attributes, missing drill logs, lithology not discernible, data-rich area in which additional data are redundant or unnecessary, or data disagrees with borehole data (the last reason is applicable to seismic and TDEM only).

Table 1. Summary of internal control data: sources and disposition of all data screened. See Table 3, WERI Technical Report No. 142.

Type / Control	Boundary Conditions	Internal Control: Borehole	Internal Control: Borehole	Internal Control: Seismic	Internal Control: TDEM	Total
Precision	Distinct	Distinct	Indistinct	Indistinct	Indistinct	
Positive control	24	46	19	45	23	157
Negative control		15				15
Total	24	61	19	45	23	172

Table 2. Summary of active applied control points. See Table 4, WERI Technical Report No. 142.

[1] 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.
[2] Vann, D.T., Bendixson, V.M., Roff, D.F., Simard, C.A., Schumann, R.M., Habana, N.C., and Jenson, J.W. (2014). Topography of the Basment Rock beneath the Northern Guam Lens Aquifer and Its Implications for Groundwater Exploration and Development. *WERI Technical Report No. 142*. Mangilao, Water & Environmental Research Institute of the Western Pacific, University of Guam: 71 p.
[3] Gingerich, S.B. and Jenson, J.W. (2010). Groundwater availability study for Guam; goals, approach, products, and schedule of activities. USGS Fact Sheet 2010–3084.
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