Guam Groundwater-Availability Study: Preliminary Results Presented at Technical Working Group Meeting on January 31, 2013

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Outline of Meeting

- **Project goals, products, timeline**
- Review of aquifer properties, database, volcanic-rock basement map, water-budget results
- Numerical modeling – preliminary findings
  - Calibration to baseline condition
  - Drought condition (driest 5-year period)
  - Future pumping scenarios
- Expanded monitoring needs
- Next steps

Study Objectives

- Obtain a better understanding of the regional groundwater flow system in northern Guam
- Update estimates of groundwater recharge for the entire island
- Estimate effects of selected withdrawal scenarios within northern Guam, using a numerical groundwater flow and transport model, on water levels and the transition zone between freshwater and saltwater

Study Approach

1. Compile, review, and analyze existing data
2. Collect additional groundwater data in northern Guam
3. Develop daily water budget to estimate groundwater recharge rates
4. Develop numerical groundwater flow and salinity model for northern Guam

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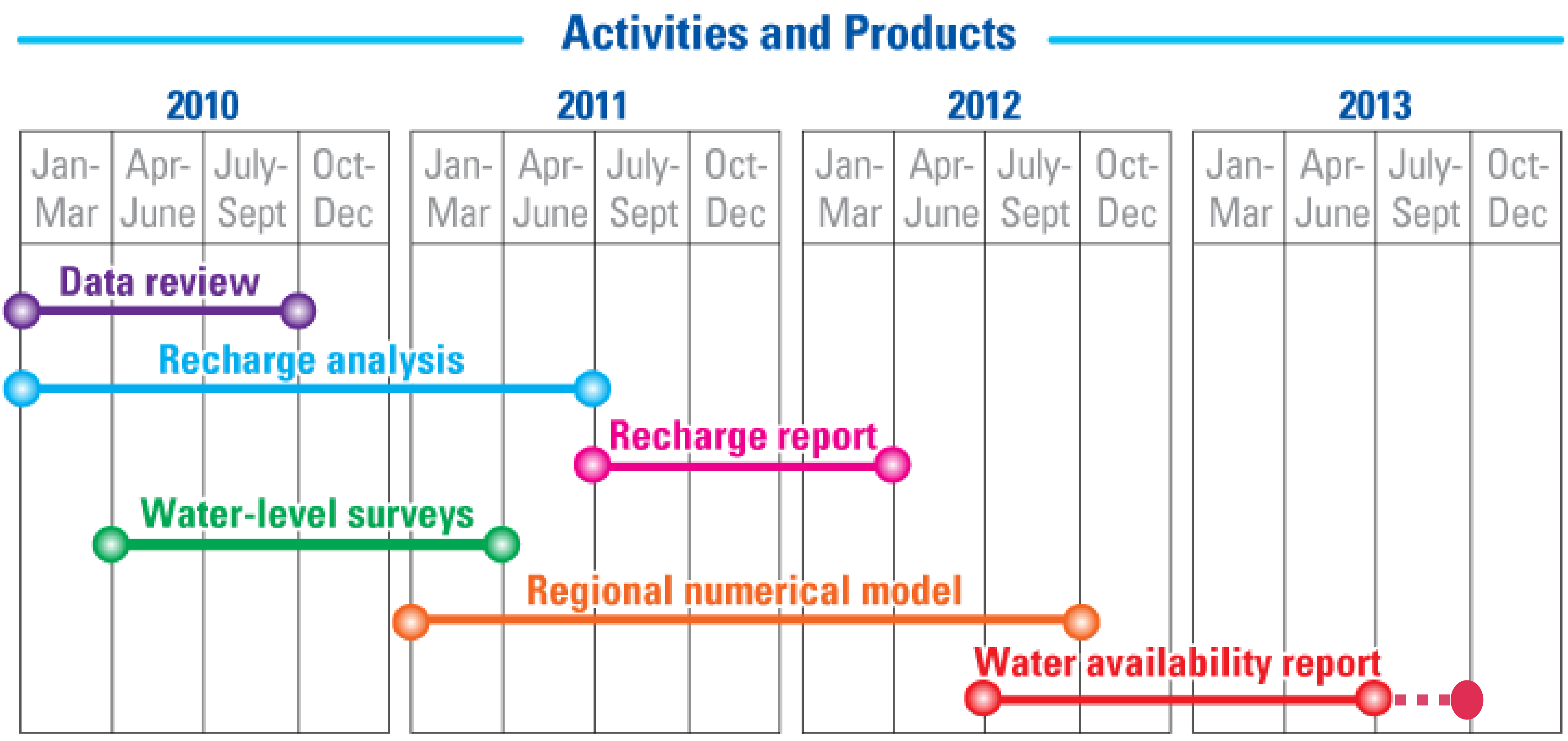
Timelines



Planned schedule for the various activities and products of the groundwater-availability study of northern Guam.

Outline of Meeting

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- **Review of aquifer properties, database, volcanic-rock basement map, water-budget results**
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Aquifer Properties of Northern Guam

- Use tidal fluctuations in monitoring wells to determine aquifer properties
- Compared results using numerical model
- Led to a refined conceptual model of the aquifer
- Published on-line in Hydrogeology Journal

Springer Link

Hydrogeology Journal
Official Journal of the International Association of Hydrogeologists

10.1007/s10040-012-0949-9

Report

Estimating hydraulic properties from tidal attenuation in the Northern Guam Lens Aquifer, territory of Guam, USA

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Abstract

Tidal-signal attenuations are analyzed to compute hydraulic diffusivities and estimate regional hydraulic conductivities of the Northern Guam Lens Aquifer, Territory of Guam (Pacific Ocean), USA. The results indicate a significant tidal-damping effect at the coastal boundary. Hydraulic diffusivities computed using a simple analytical solution for well responses to tidal forcings near the periphery of the island are two orders of magnitude lower than for wells in the island's interior. Based on assigned specific yields of ~0.01–0.4, estimated hydraulic conductivities are ~20–800 m/day for peripheral wells, and ~2,000–90,000 m/day for interior wells. The lower conductivity of the peripheral rocks relative to the interior rocks may best be explained by the effects of karst evolution: (1) dissolutional enhancement of horizontal hydraulic conductivity in the interior; (2) case-hardening and concurrent reduction of local hydraulic conductivity in the cliffs and steeply inclined rocks of the periphery; and (3) the stronger influence of higher-conductivity regional-scale

http://link.springer.com/article/10.1007/s10040-012-0949-9

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Well Database

Wells commented_july 7 2010_0938 - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		Agana (Hag		Yigo			Finegayan	Mangi	Agafa Guma	Andersen			INACTIVE WELLS							
2				GWA			EARTH TECH	NAVY	AIR FORCE	USGS									Avg last 3 yrs - GWA	
3		Sub-Basin	GWA databas	WERI Tech Report	Latitude	Longitude	Land surface elevation	Well Depth	Solid Casing Length	Screen Length	Hole Diameter (inches)	Casing Diameter (inches)	Date Started Drilling	Date Completed Drilling	Test Pumping Rate (GPM)	Drawdown (ft)	Specific capacity (gpm/ft) pumping rate/drawdown	Depth to volcanic baseme	Chloride data	Water Level data (relative to MSL)
4				Production																
5		Agana	A01	A-1			67.66'	221.0'	70'	150'	11	8	13-Feb-65	20-Nov-65	210	103.49'	210/103.49'		36	18.91'
6		Agana	A02	A-2			118'	172'	110'	60'	11	8	19-Aug-65	8-Oct-65	210	23.23'	210/23.23'		33	106.1' ?
7		Agana	A03	A-3			127.45'	410'	???(390' ho	???	11	8	11-Apr-66	7-Jun-67	273	98'	273/98'		29	105.8'
8		Agana	A04	A-4			140.18'	300'	130'	170'	11	8	28-Jun-66	21-Mar-67	300		300/???		96	134'
9		Agana	A05	A-5			146.7'	332'	323'		11	8	3-Aug-66	18-Feb-69	100 ?	[illegible]	[illegible]' ?	340'	33	322' (137.45'?)
10		Agana	A06	A-6			152'	306'	136'	170'/11	11	8	19-Jul-67	9-Sep-67	325				40	142'
11		Agana	A07	A-7			136'	186'	116'	70'	11	8	18-Apr-67	8-May-67	210	35[illegible]			102	126'
12		Agana	A08	A-8			124'	305'	96'	205'	11	8	26-May-67	20-Jul-68	270				34	109'
13		Agana	A09	A-9			187.15'	240'	237'	70'	11	8	24-Mar-67	23sep??	83	1.2	83/1.2		228	180.5'
14		Agana	A10	A-10			191.01'	215'	171'	45'	11	8	10-May-67	???			???		372	184.5'
15				A-11			178'	375'	125'	205'	11	8	7-Jun-68	23-Jul-68	150	201'	150/201'		3	131'
16		Agana	A12	A-12			138'	390'	103'	225'	11	8	24-Jul-68	29-Aug-68	330		330/		37	108'
17		Agana	A13	A-13			130.8'	418'	205'	120'	11	8	24-Oct-68	10-Dec-68	200		10.5 GPM/FT @ 200 GPM /250GPM/2		512	123'
18		Agana	A14	A-14			208'	260'	220'	40'		8		05/21/73 (date	160		160 GPM/??		341	206'
19		Agana	A15	A-15			197.74'		210'	50'		8		06/13/73 (date	235		235 GPM/13.67'=17.19		168	194.5'
20				A-16																
21		Agana	A17	A-17			196'	235'	195'	40'		8		08/17/73 (date	180		180 GPM/		441	192.75'
22		Agana	A18	A-18			265.5' (205')	250'	227' (210')	40'		8	19-Sep-73	22-Sep-73	135		135 GPM/		391	172' (204')
23		Agana	A19	A-19				165'	135'	20'		8		08/17/73 (date drilled)			120		400	133.3'
24				A-20																
25		Agana	A21	A-21					255'(260' 19feb98 GWA Maint Rec)										413	180.9'
26				A-22																
27		Agana	A23	A-23										5/10/1983 (date	330		330 GPM/?		70	
28		Agana	A25	A-25			59.96'	70.56'	68'	40'		8		4/10/1994 (date	270		270 GPM/11.29'=23.91		89	50.11'
29		Agana	A26	A-26			156.5'	203.5'						05/05/83 (date	50		50 GPM/11.9'=4.20		84	148.5'
30				A-27			150.5'	197.5'												
31		Agana	A28	A-28			246'	242'						05/05/83 (date drilled)						199.6'
32		Agana	A29	A-29			58.93' (54.4')	105'	60'	40'	15	10	18-May-88	19-May-88	275		275gpm/8.59'=32.01gpm/ft		16-18	52.33'

UOG:
A-6 Well Info Layne Internattional

Sheet1 Sheet2

Cell O10 commented by UOG

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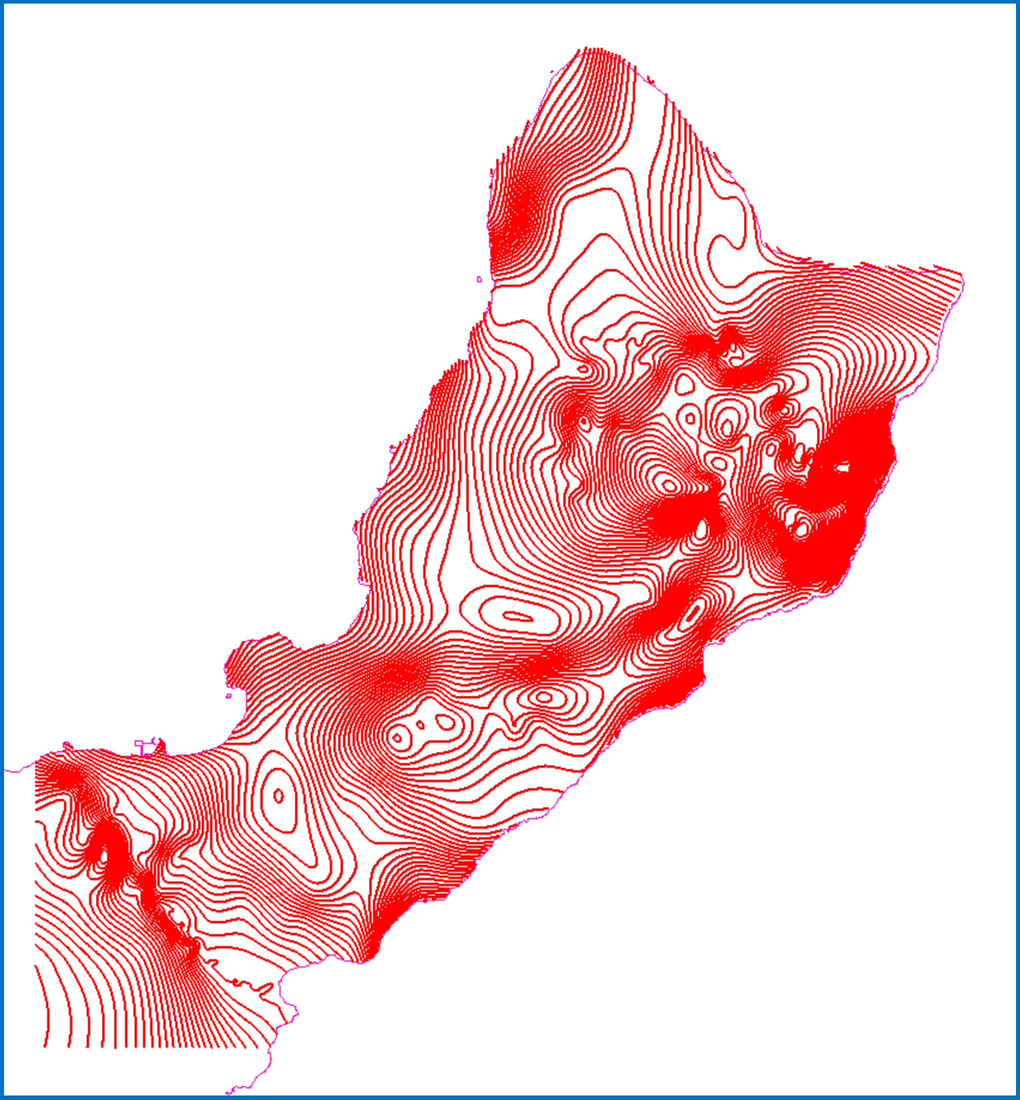
Updated Volcanic-Rock Basement Map



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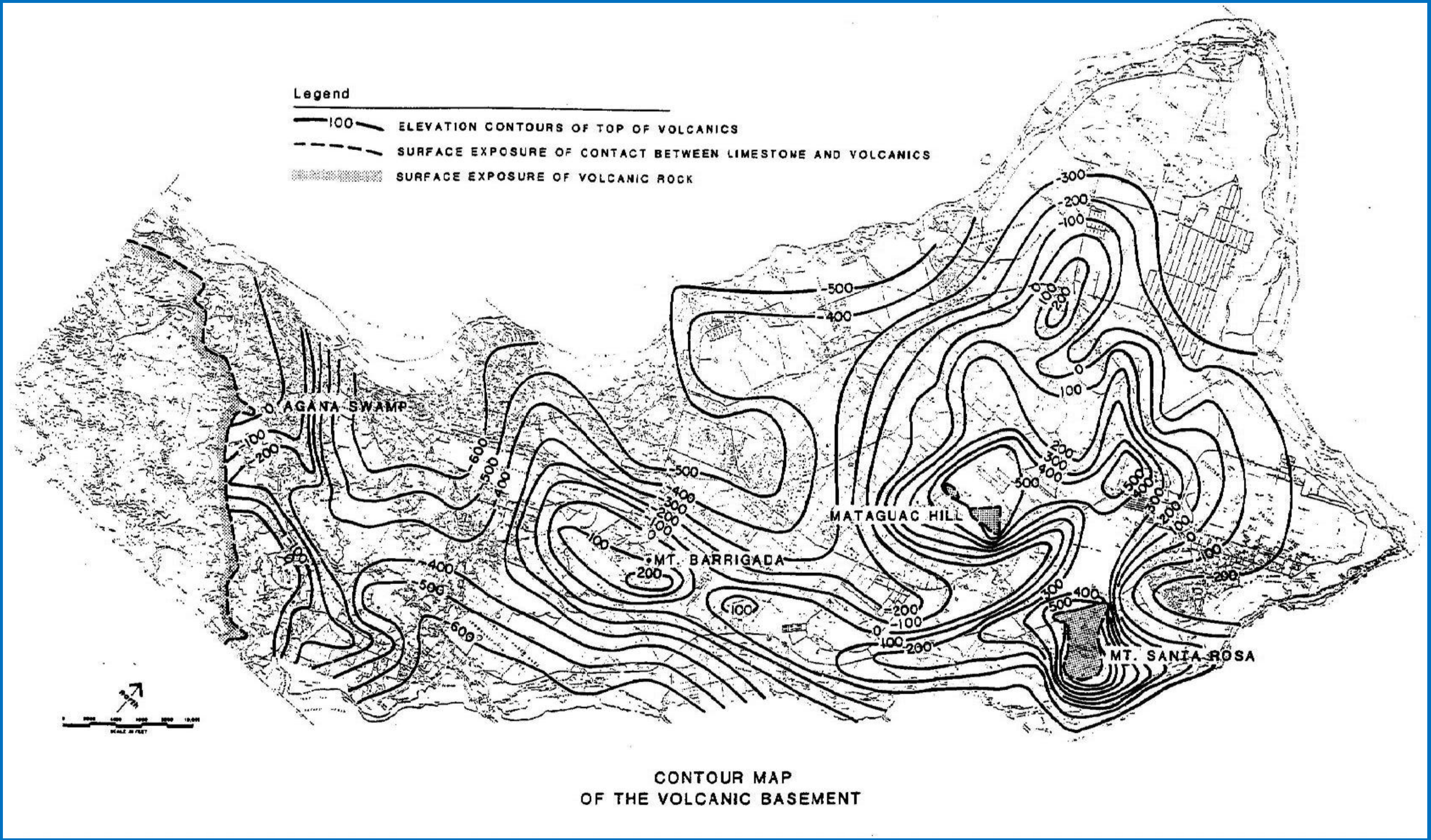
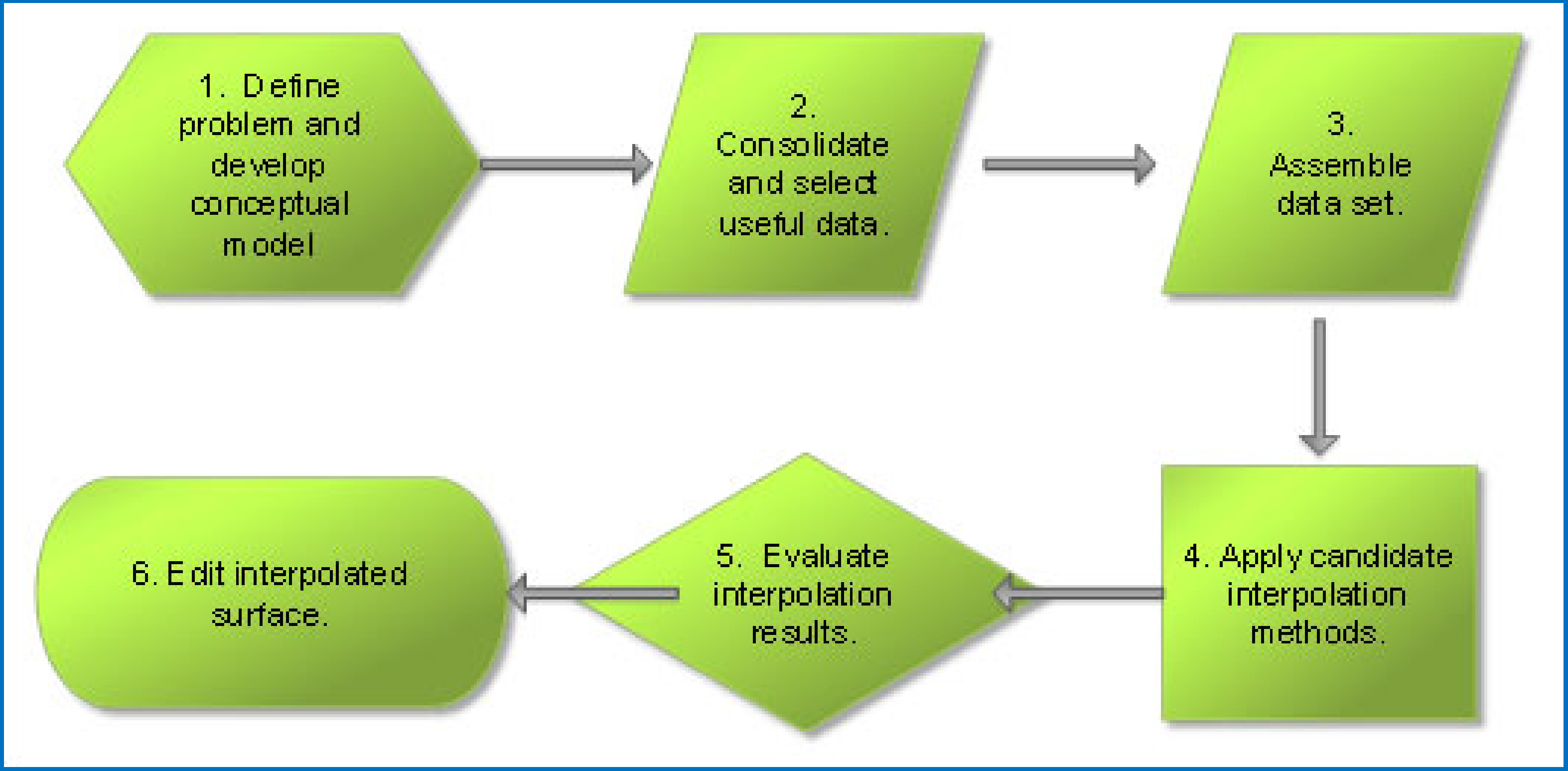
1982 Basement Contour Map



Six-step comparative analysis process

(building on Hunter, 1992)



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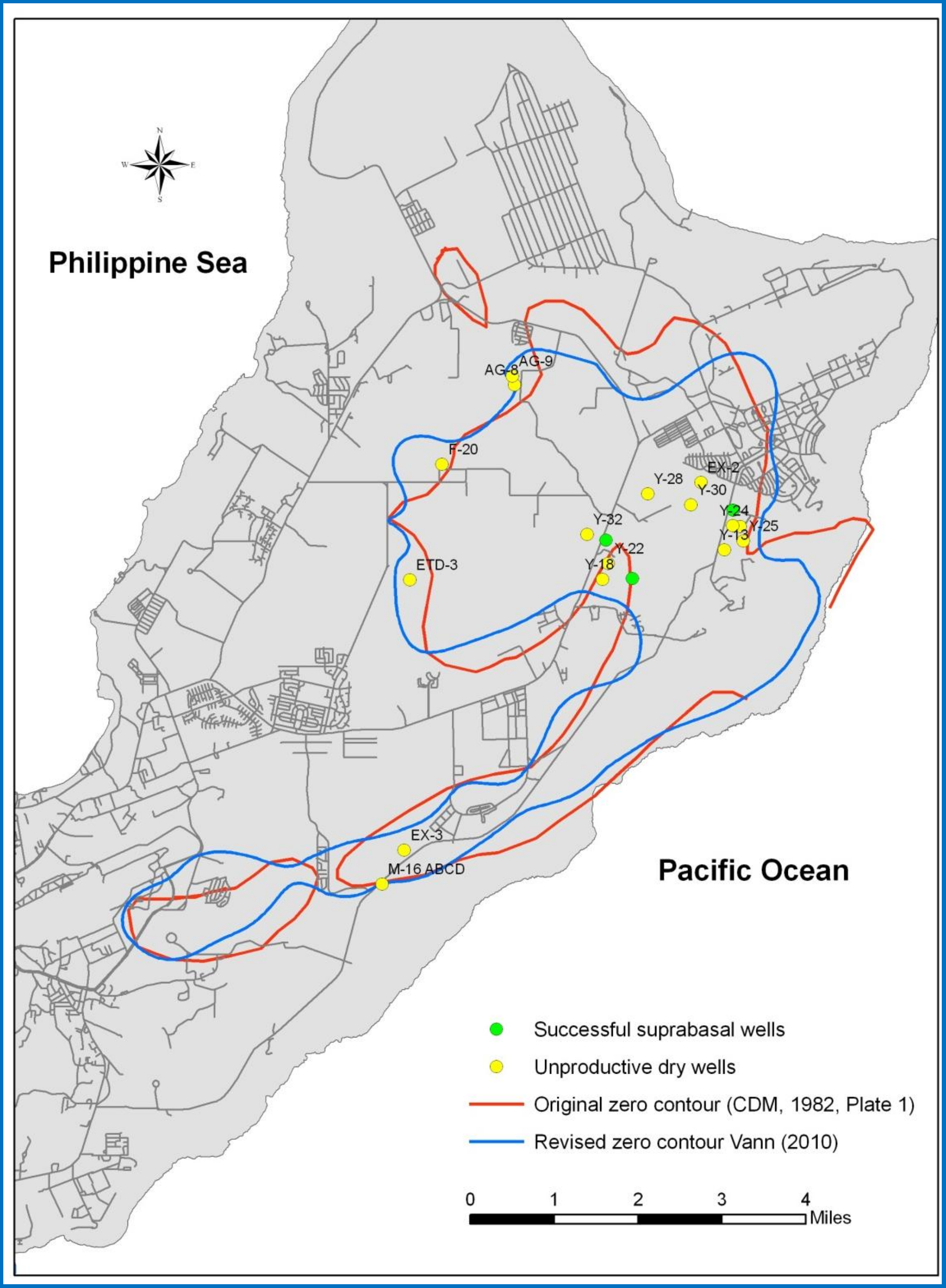
Sea level contours of basement

2010 (blue) update
1982 (red) original



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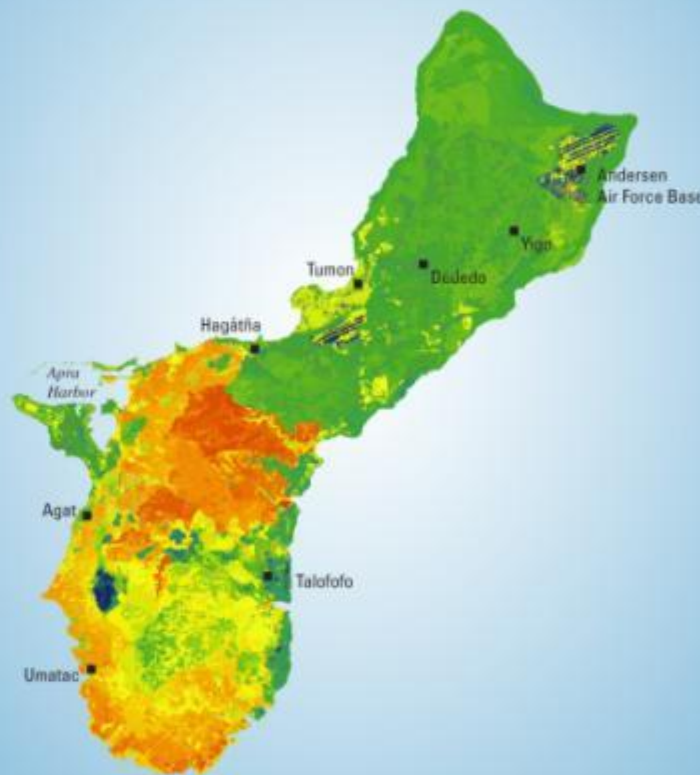
Prepared in cooperation with the United States Marine Corps

A Water-Budget Model and Estimates of Groundwater Recharge for Guam



Scientific Investigations Report 2012–5028

U.S. Department of the Interior
U.S. Geological Survey

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Water-Budget Summary

- Recharge estimated for the northern aquifer subbasins is 32% to 49% greater than recharge estimated by the Northern Guam Lens Study (1982)
- Recharge is about 40%-60% of water input in limestone areas and less than 30% in volcanic areas
- Potential land-cover changes incurred during the proposed military buildup likely will not reduce overall recharge to Guam
- Compared to long-term average, recharge is 34% lower during drought conditions

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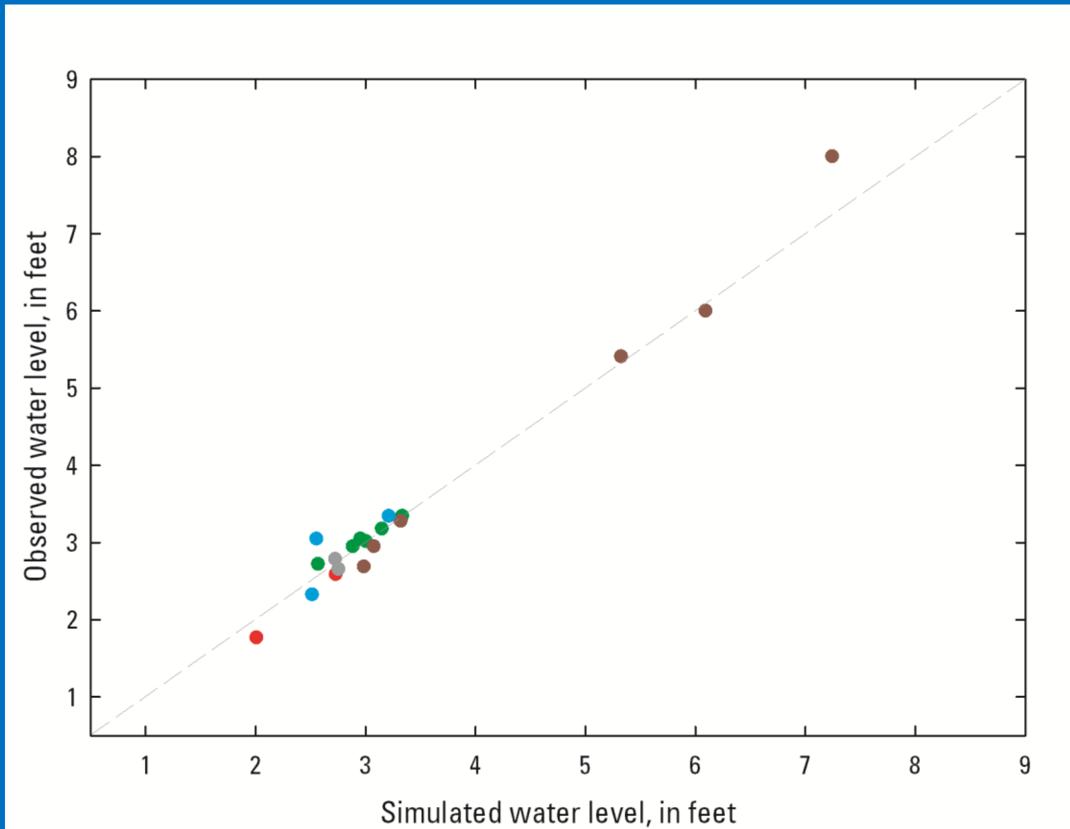
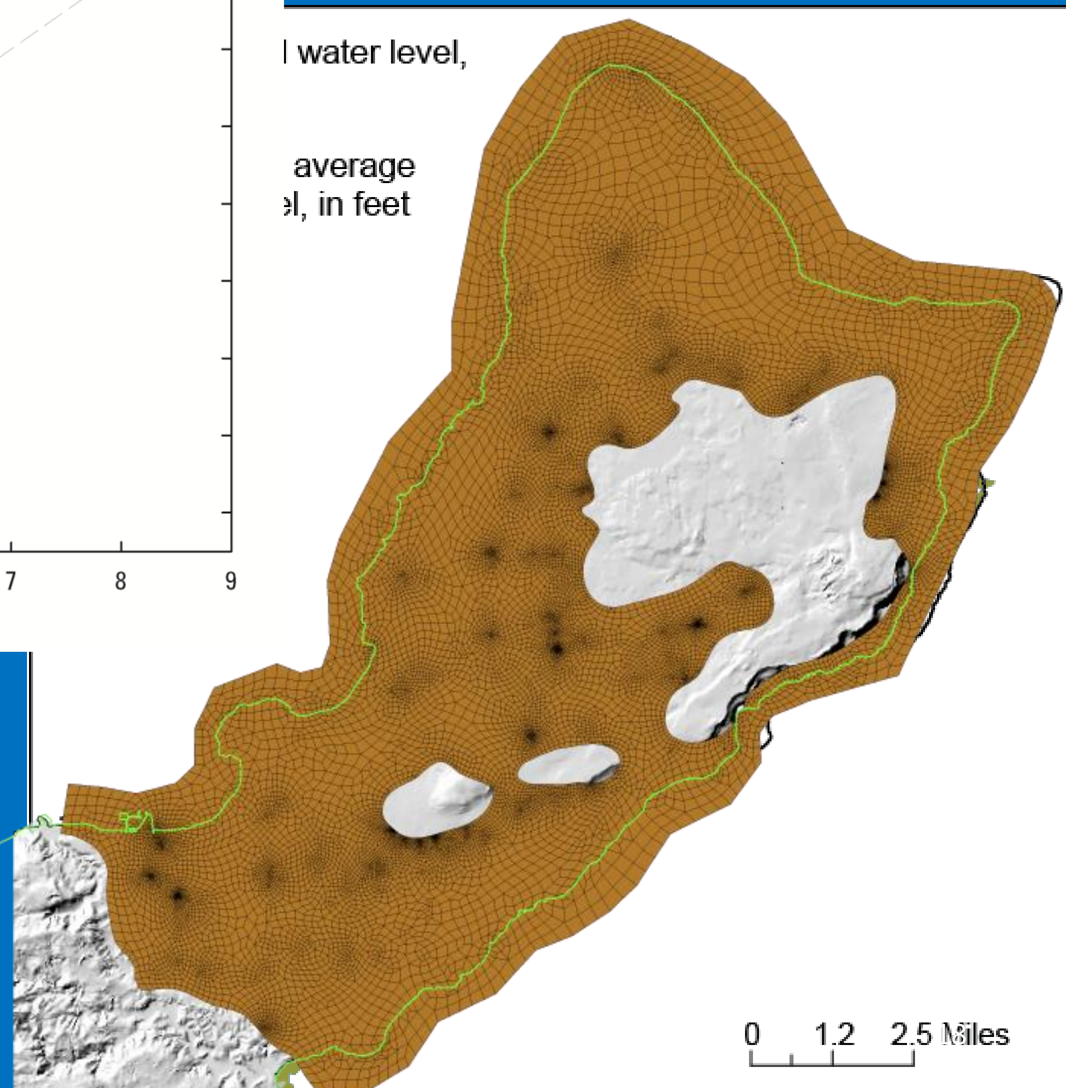
Model Calibration-Baseline Condition

- Hydrologic conditions
  - Long-term average recharge (1961-2005 rainfall; 2004 land cover)
  - 2010 pumping rates

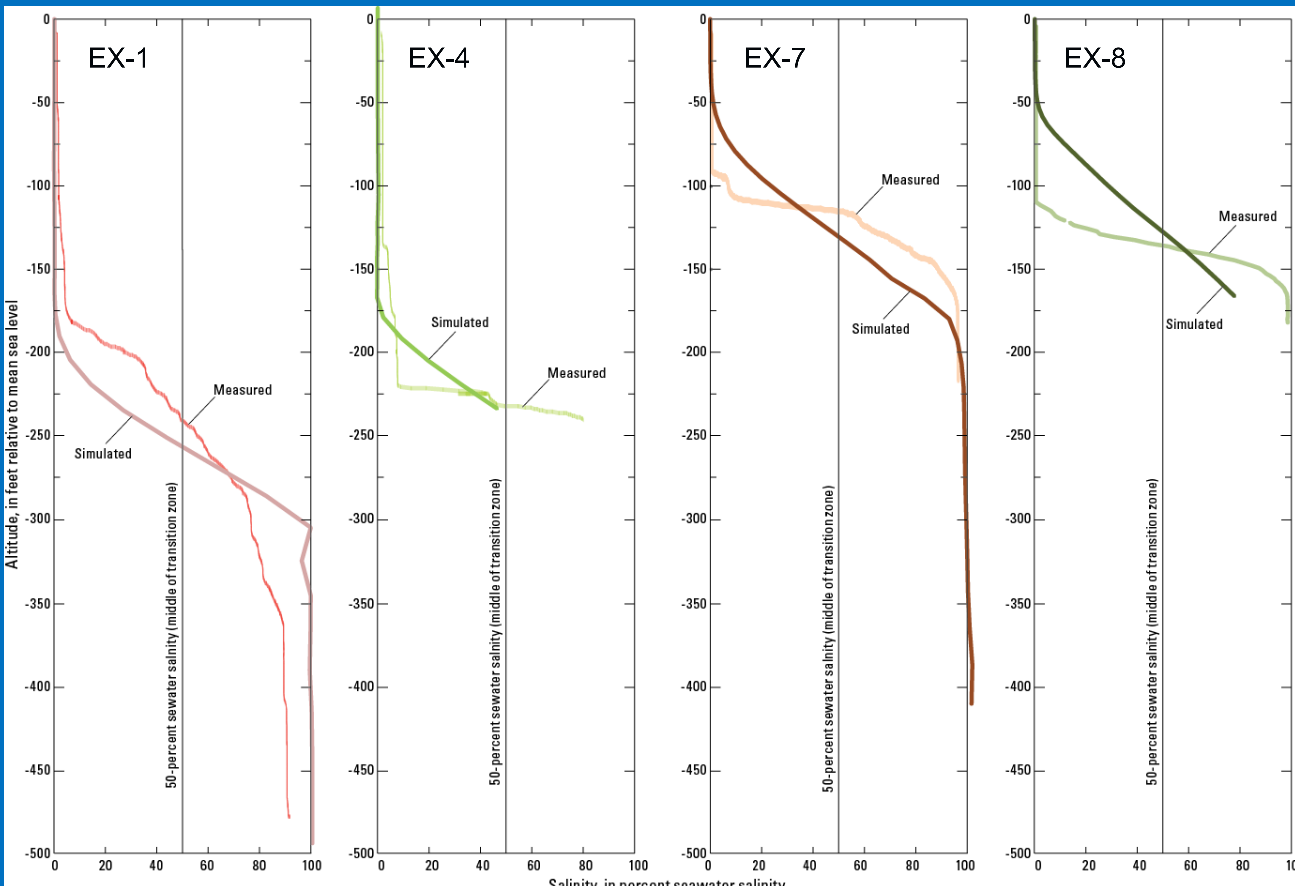
- Calibration targets
  - Average 2010 water levels and tidal fluctuations
  - December 2009 salinity profiles

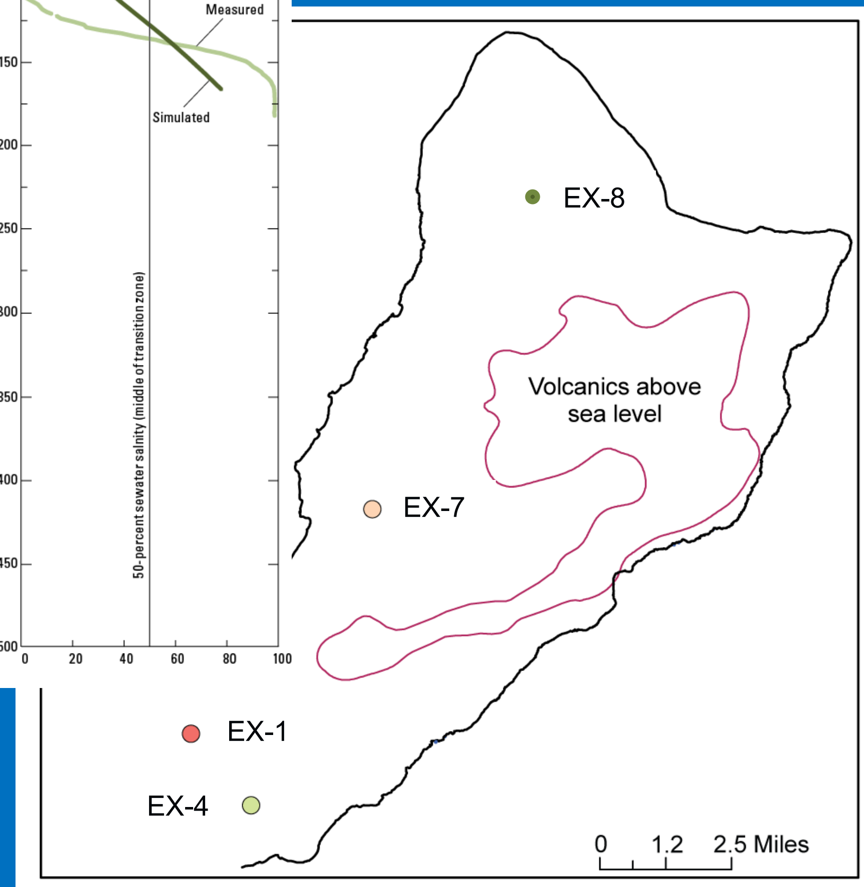
Observed and Modeled Water Levels



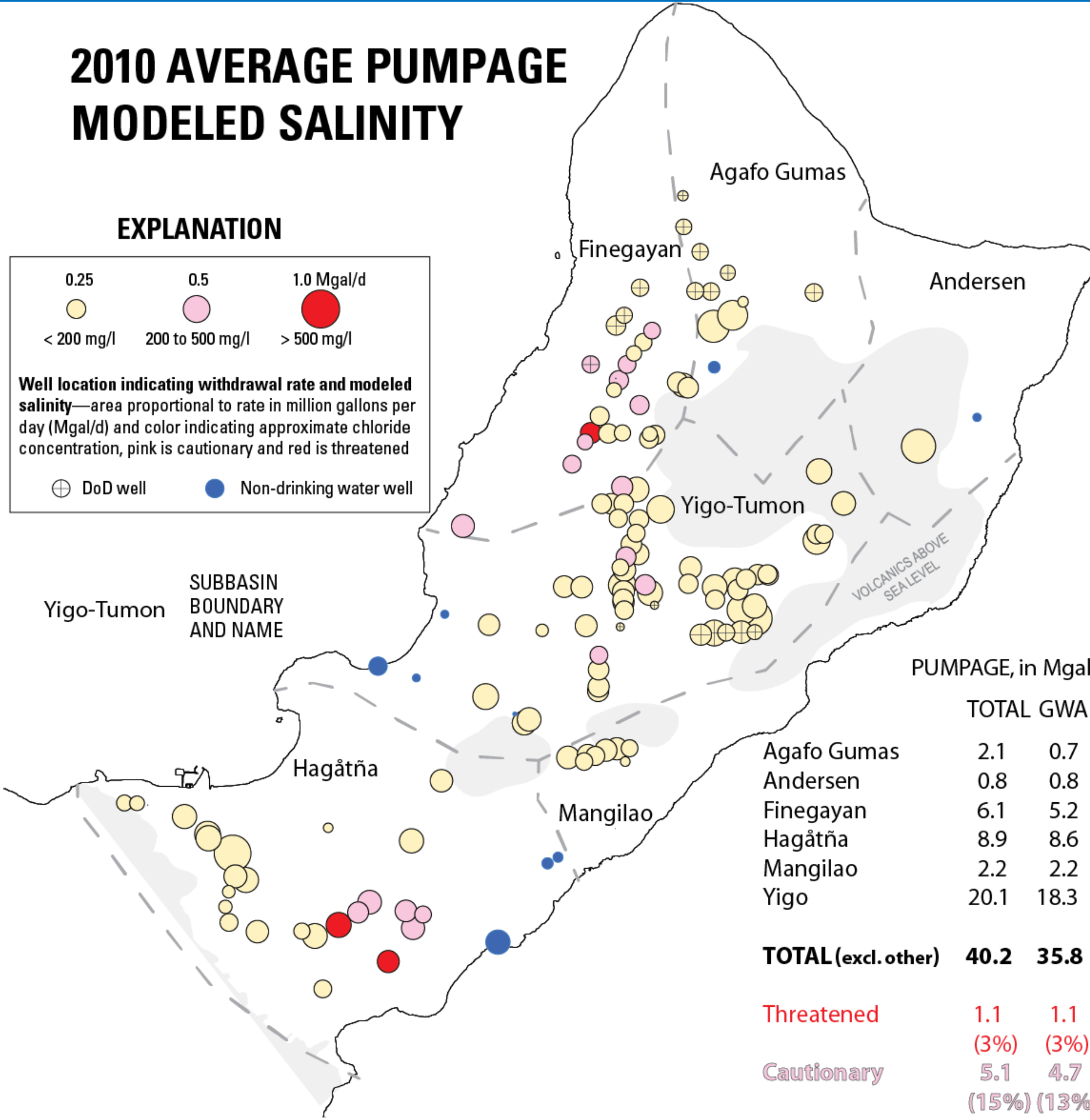


Observed and Modeled Salinity Profiles





2010 AVERAGE PUMPAGE MODELED SALINITY



PUMPAGE, in Mgal/d

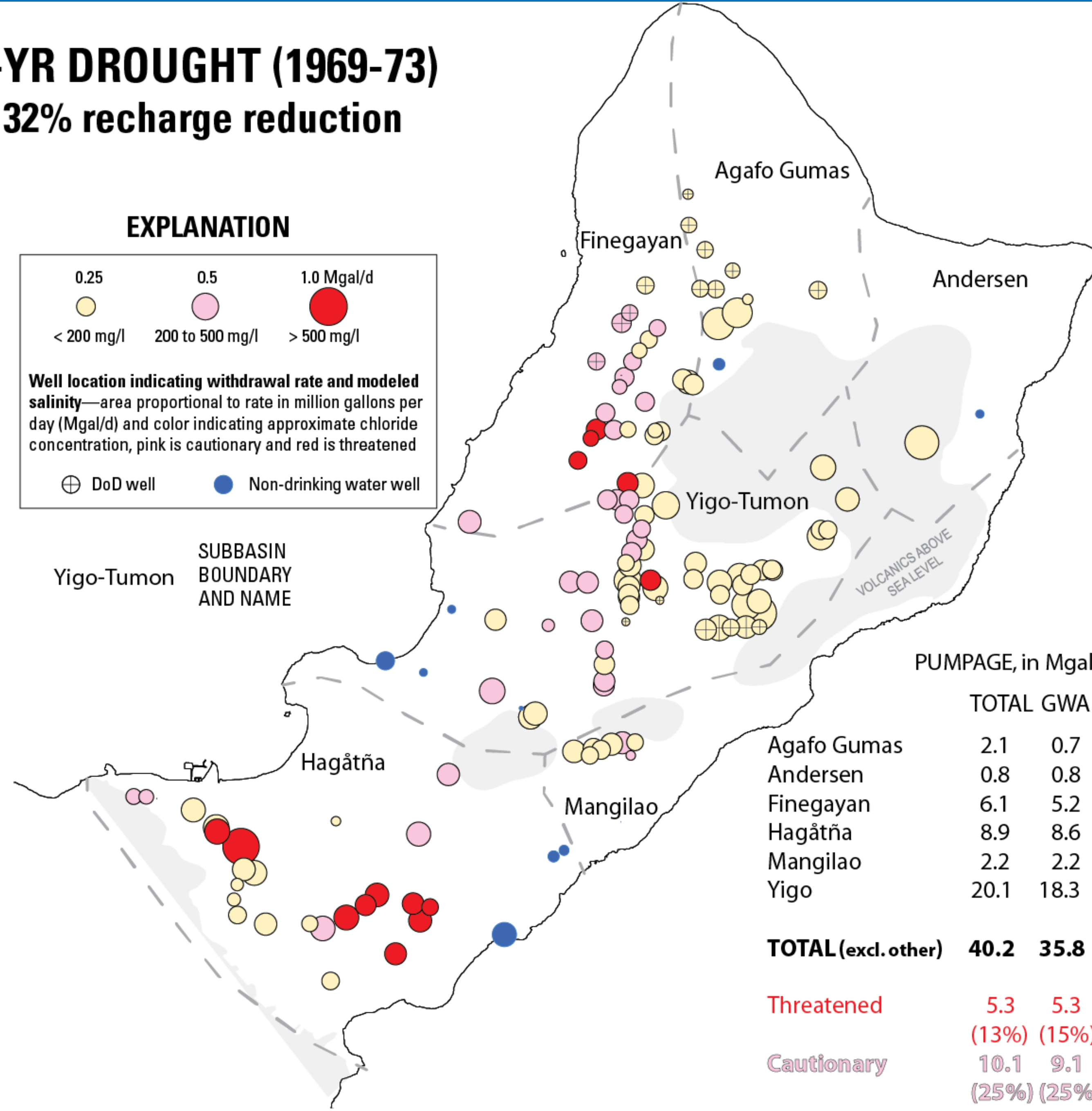
	TOTAL	GWA	DOD	OTHER
Agafo Gumas	2.1	0.7	1.4	0.8
Andersen	0.8	0.8	0	0.1
Finegayan	6.1	5.2	0.9	0
Hagåtña	8.9	8.6	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	20.1	18.3	1.8	0.4
TOTAL (excl. other)	**40.2**	**35.8**	**4.4**	**1.9**
Threatened	1.1 (3%)	1.1 (3%)	0 (0%)	
Cautionary	5.1 (15%)	4.7 (13%)	0.4 (9%)	

Drought Condition

- Hydrologic conditions
  - Driest 5-yr period (34% reduction in recharge)
    - 1969-73 rainfall
    - 2004 land cover
  - 2010 pumping rates
- Results after 5 years of pumping at steady rates

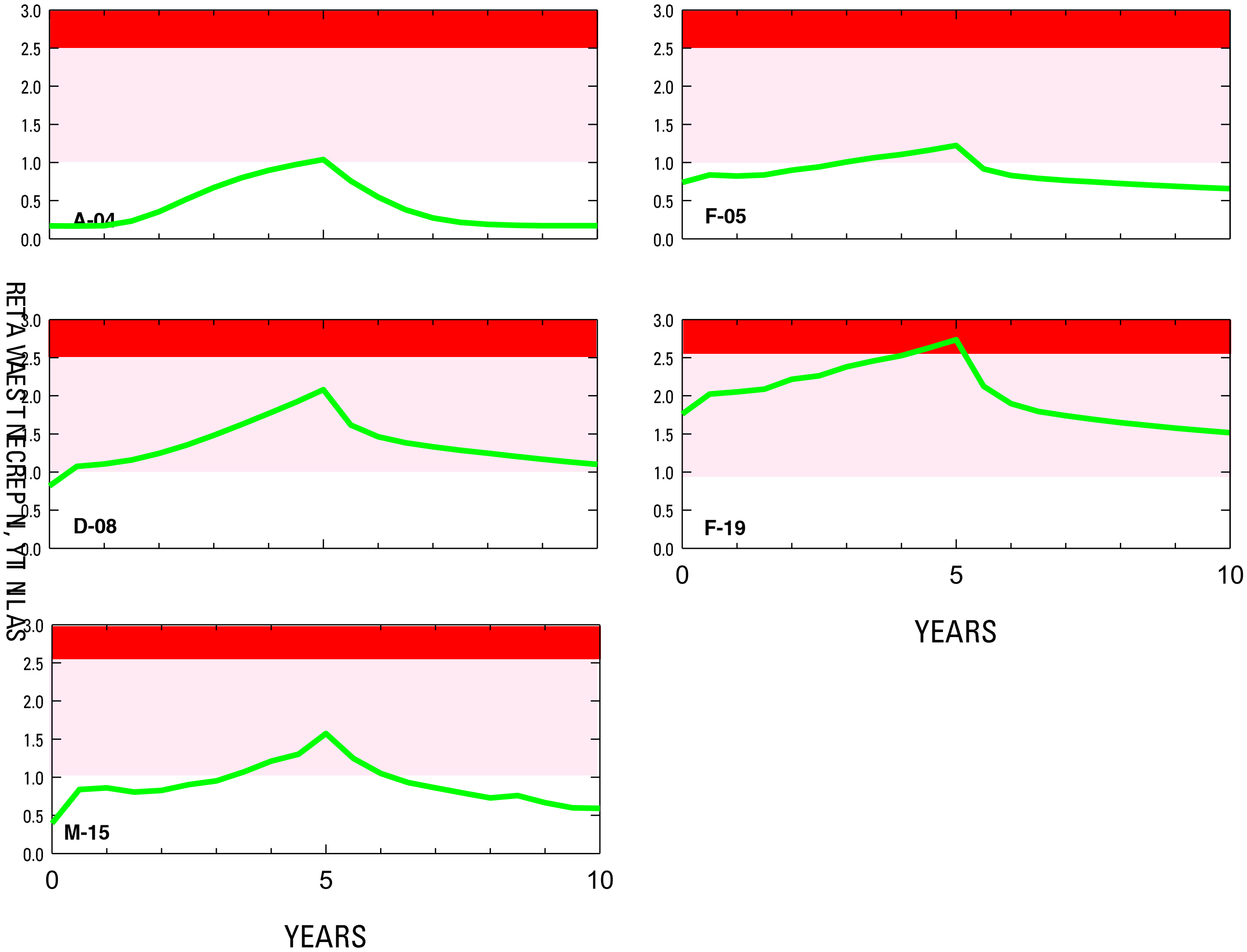
5-YR DROUGHT (1969-73)

32% recharge reduction



PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	2.1	0.7	1.4	0.8
Andersen	0.8	0.8	0	0.1
Finegayan	6.1	5.2	0.9	0
Hagåtña	8.9	8.6	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	20.1	18.3	1.8	0.4
TOTAL (excl. other)	**40.2**	**35.8**	**4.4**	**1.9**
Threatened	5.3 (13%)	5.3 (15%)	0.0 (0%)	
Cautionary	10.1 (25%)	9.1 (25%)	1.0 (23%)	


SALINITY, IN PERCENT SEAWATER
A-04
F-05
D-08
F-19
M-15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
YEARS

Final

Guam Water Well Testing Study to Support U.S. Marine Corps Relocation to Guam

April 2011

JOINT GUAM PROGRAM OFFICE

Department of the Navy
Naval Facilities Engineering Command, Pacific
258 Makalapa Drive, Suite 100
Pearl Harbor, HI 96860-3134

NAVFAC
Naval Facilities Engineering Command
NAVFAC PACIFIC

Contract Number N62742-06-D-1870, TO 0036

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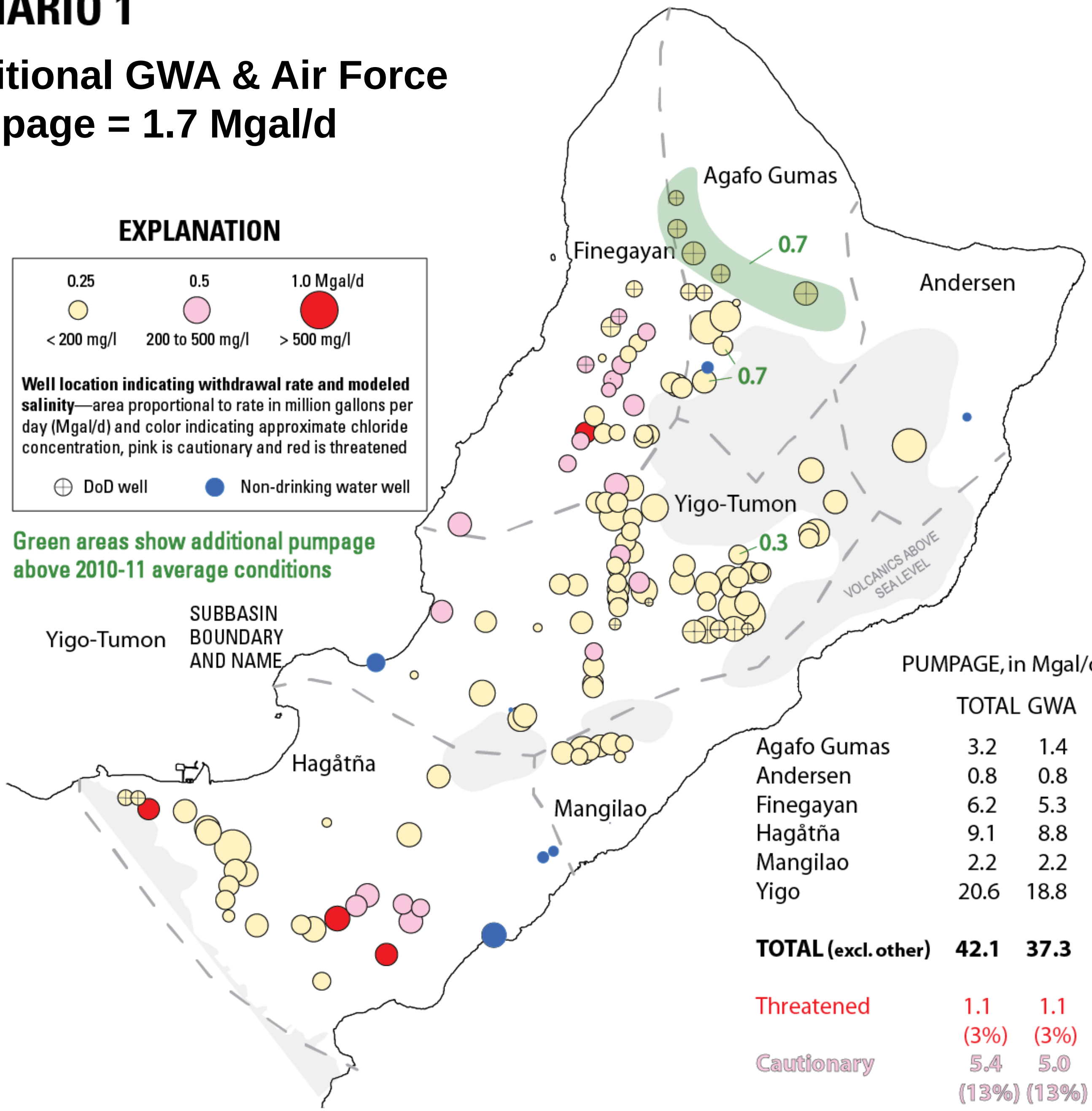
Scenario 1
Additional GWA and AF pumpage

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1 Mgal/d
  - Air Force 5 existing wells (AF01-AF05)
    - Additional 0.7 Mgal/d

SCENARIO 1

Additional GWA & Air Force pumpage = 1.7 Mgal/d



PUMPAGE, in Mgal/d

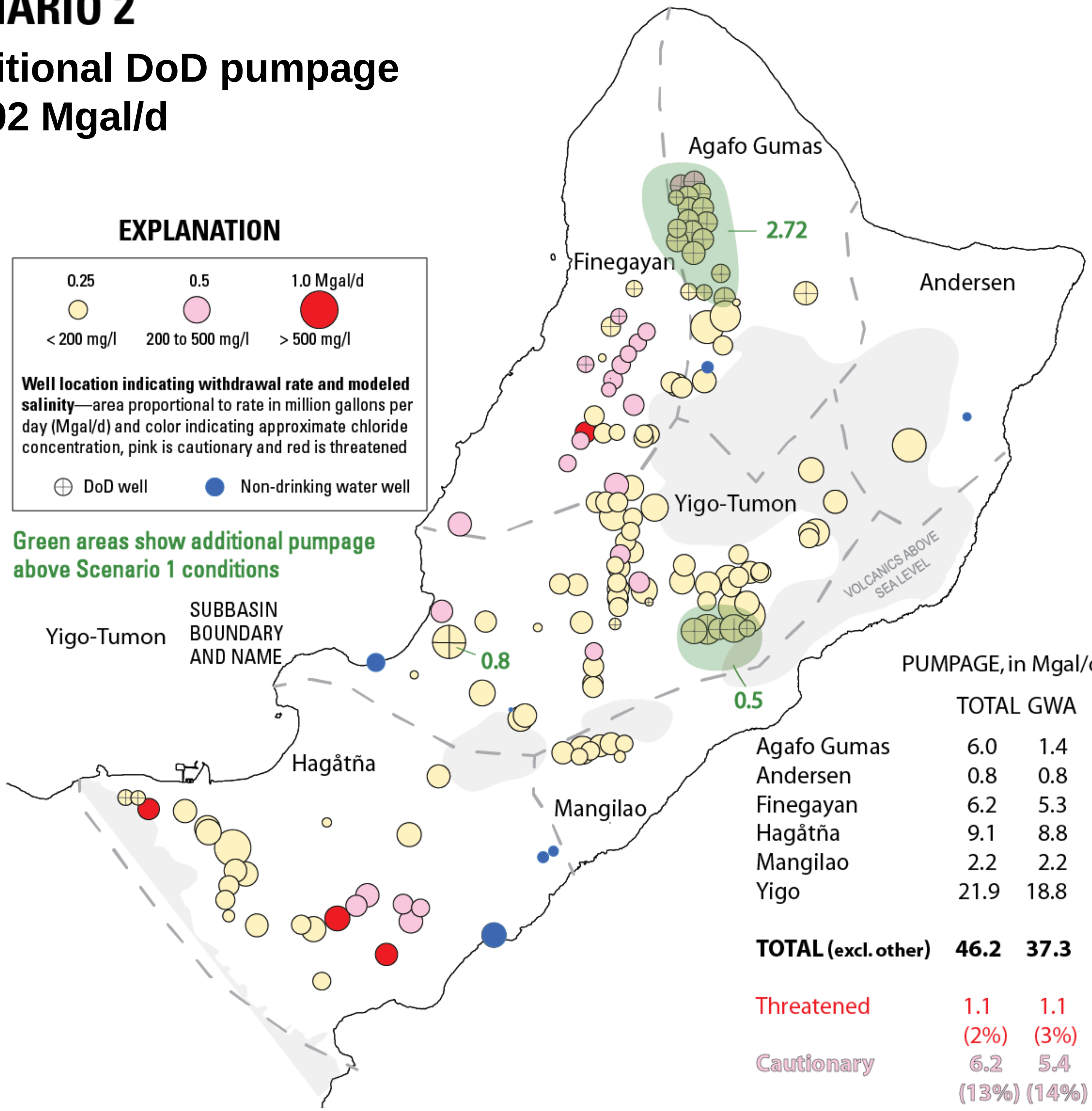
	TOTAL	GWA	DOD	OTHER
Agafo Gumas	3.2	1.4	1.8	0.9
Andersen	0.8	0.8	0	0.1
Finegayan	6.2	5.3	0.9	0
Hagåtña	9.1	8.8	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	20.6	18.8	1.8	0.7
TOTAL (excl. other)	**42.1**	**37.3**	**4.8**	**2.3**
Threatened	1.1 (3%)	1.1 (3%)	0 (0%)	
Cautionary	5.4 (13%)	5.0 (13%)	0.4 (8%)	

Scenario 2
Scenario 1 plus additional DoD pumpage

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1 Mgal/d
  - Air Force 5 existing wells (AF01-AF05)
    - Additional 0.7 Mgal/d
  - Tumon: Additional 0.8 Mgal/d
  - Marbo: Additional 0.5 Mgal/d
  - USMC: Additional 2.72 Mgal/d

SCENARIO 2

Additional DoD pumpage = 4.02 Mgal/d



PUMPAGE, in Mgal/d

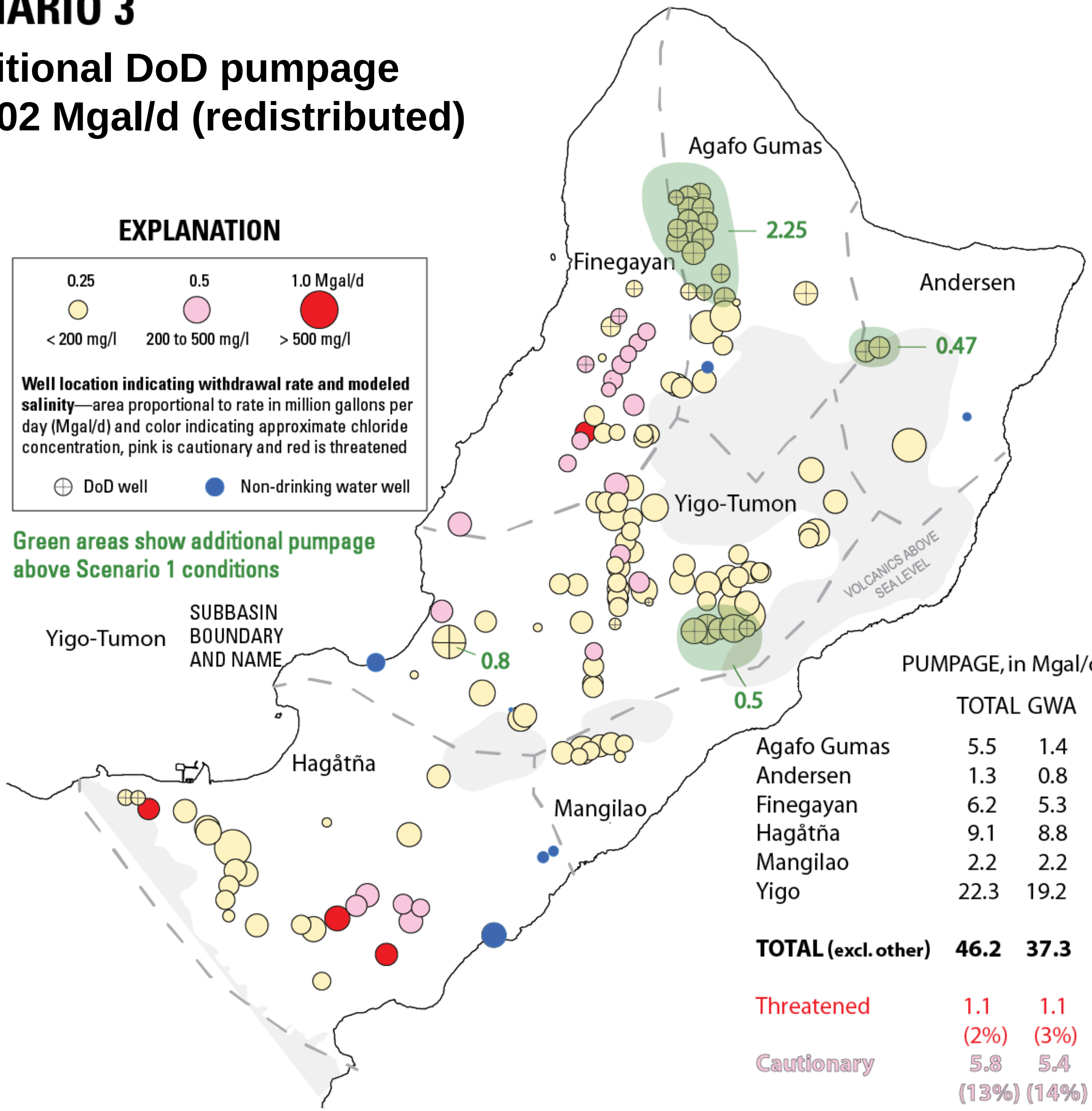
	TOTAL	GWA	DOD	OTHER
Agafo Gumas	6.0	1.4	4.6	0.9
Andersen	0.8	0.8	0	0.1
Finegayan	6.2	5.3	0.9	0
Hagåtña	9.1	8.8	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	21.9	18.8	3.1	0.7
TOTAL (excl. other)	**46.2**	**37.3**	**8.9**	**2.3**
Threatened	1.1 (2%)	1.1 (3%)	0 (0%)	
Cautionary	6.2 (13%)	5.4 (14%)	0.8 (9%)	

Scenario 3
Additional DoD pumpage (redistributed)

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1 Mgal/d
  - Air Force 5 existing wells (AF01-AF05)
    - Additional 0.7 Mgal/d
  - Tumon: Additional 0.8 Mgal/d
  - Marbo: Additional 0.5 Mgal/d
  - USMC: Additional 2.72 Mgal/d (redistributed)

SCENARIO 3

Additional DoD pumpage = 4.02 Mgal/d (redistributed)



PUMPAGE, in Mgal/d

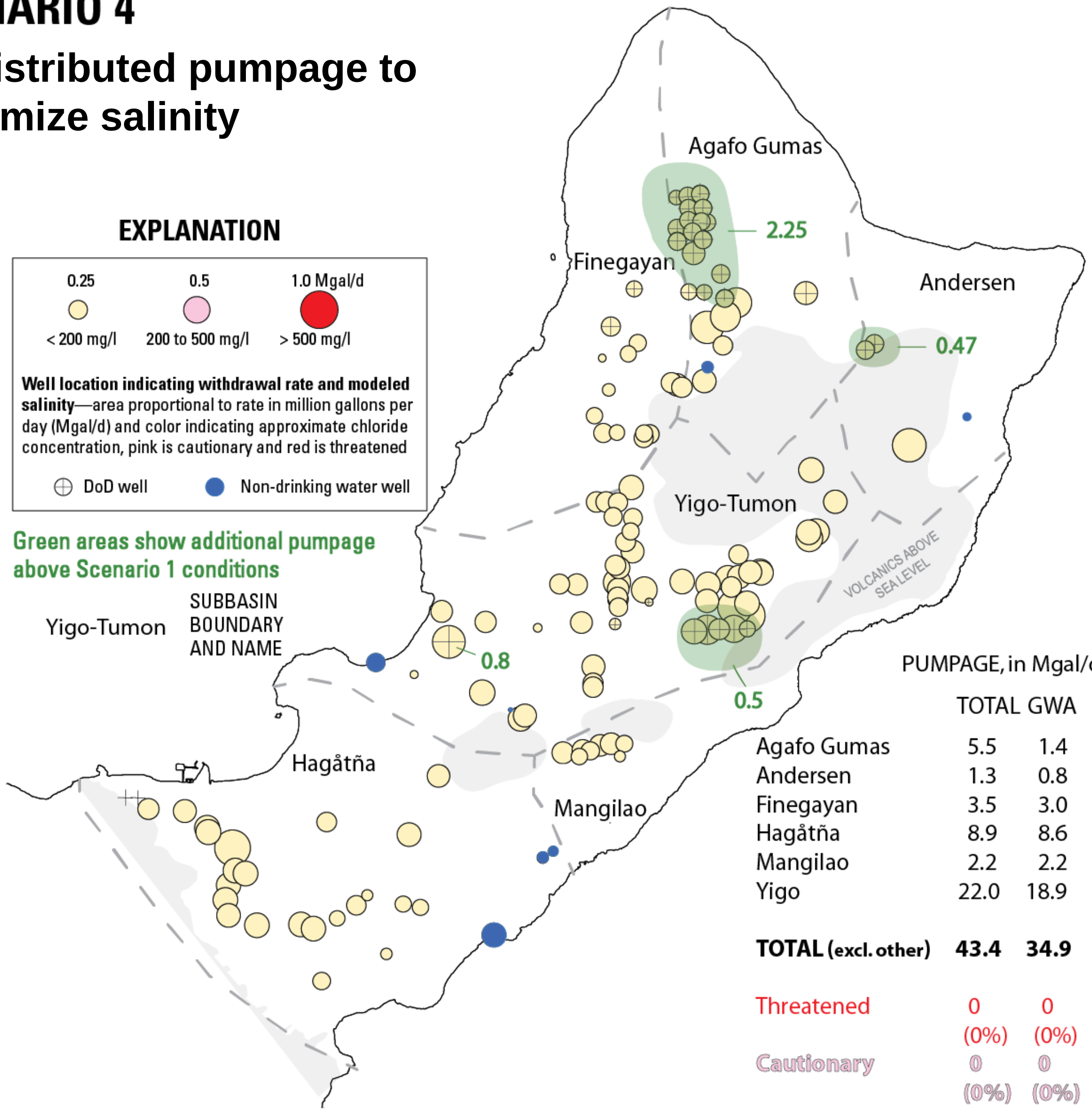
	TOTAL	GWA	DOD	OTHER
Agafo Gumas	5.5	1.4	4.1	0.9
Andersen	1.3	0.8	0.5	0.1
Finegayan	6.2	5.3	0.9	0
Hagåtña	9.1	8.8	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	22.3	19.2	3.1	0.7
TOTAL (excl. other)	**46.2**	**37.3**	**8.9**	**2.3**
Threatened	1.1 (2%)	1.1 (3%)	0 (0%)	
Cautionary	5.8 (13%)	5.4 (14%)	0.4 (5%)	

Scenario 4
Redistributed Pumpage to Minimize Salinity

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1 Mgal/d
  - Air Force 5 existing wells (AF01-AF05)
    - Additional 0.7 Mgal/d
  - Tumon: Additional 0.8 Mgal/d
  - Marbo: Additional 0.5 Mgal/d
  - USMC: Additional 2.72 Mgal/d

SCENARIO 4

Redistributed pumpage to minimize salinity



PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	5.5	1.4	4.1	0.9
Andersen	1.3	0.8	0.5	0.1
Finegayan	3.5	3.0	0.5	0
Hagåtña	8.9	8.6	0.3	0.2
Mangilao	2.2	2.2	0	0.4
Yigo	22.0	18.9	3.1	0.7
TOTAL (excl. other)	**43.4**	**34.9**	**8.5**	**2.3**
Threatened	0 (0%)	0 (0%)	0 (0%)	
Cautionary	0 (0%)	0 (0%)	0 (0%)	

Modeling Implications

- Sub-basins cannot be managed independently; for example, withdrawal from Agafa Gumas causes salinity increase in Finegayan
- Distribution and rates of proposed DoD wells need further refinement to minimize salinity increases in existing wells
- Impact to GWA and DoD groundwater sources, in Mgal/d:

Condition	Total	Threatened	Cautionary
Baseline	40.2	1.1	5.1
Drought	40.2	5.3	10.1
Scenario 1	42.1	1.1	5.4
Scenario 2	46.2	1.1	6.2
Scenario 3	46.2	1.1	5.8
Scenario 4	43.4	0	0

Remaining Tasks

- Finalize future pumping scenarios
  - NavFacPac
  - GWA
- Present updated findings – ?
- Publish final report – September 2013

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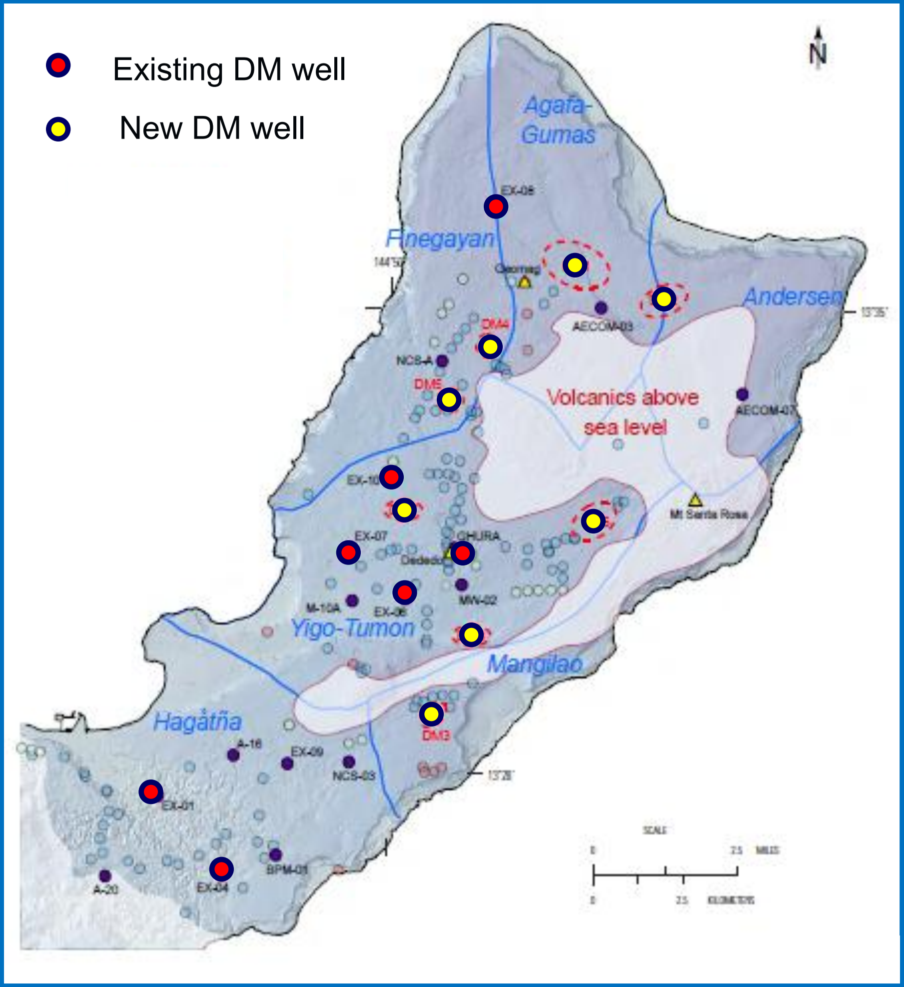
Outline of Meeting

- Project goals, products, timeline
- Review of aquifer properties, database, volcanic-rock basement map, water-budget results
- Numerical modeling – preliminary findings
  - Calibration to baseline condition
  - Drought condition (driest 5-year period)
  - Future pumping scenarios
- **Expanded monitoring needs**
- Next steps

Reasons for Expanded Monitoring

1. Sustainable groundwater development requires accurate and detailed data on aquifer hydrology and geology
   - Water levels, salinity
2. Existing network inadequate to support proposed groundwater development
   - Track responses to development & natural changes
3. Evaluate model predictions & improve future models
   - Models are only as good as the data that go into them

Expansion of Hydrologic Data Collection Network



Groundwater Monitoring Wells

- Existing network of 7 deep wells is limited to 2 of the 6 sub-basins
- 8 new deep wells are needed in areas with little/no coverage (4 of 6 sub-basins)
  - Agafa-Gumas/Andersen (DM1, DM2)
  - Finegayan (DM4, DM5)
  - Yigo-Tumon (DM6, DM7, DM8)
  - Mangilao (DM3)

Groundwater Monitoring Strategy

- Water levels, continuous
  - 15 long-term index sites
  - 8 additional sites (7 days every 5 years)
- Salinity
  - Continuous monitoring at 2 fixed depths
    - Above and below mid-point of transition zone
    - Long-term: 2 index sites
    - Short-term: 2 deep wells, rotated for 1-yr periods
  - Semi-annual monitoring of vertical profile of salinity in the water column (all deep wells)

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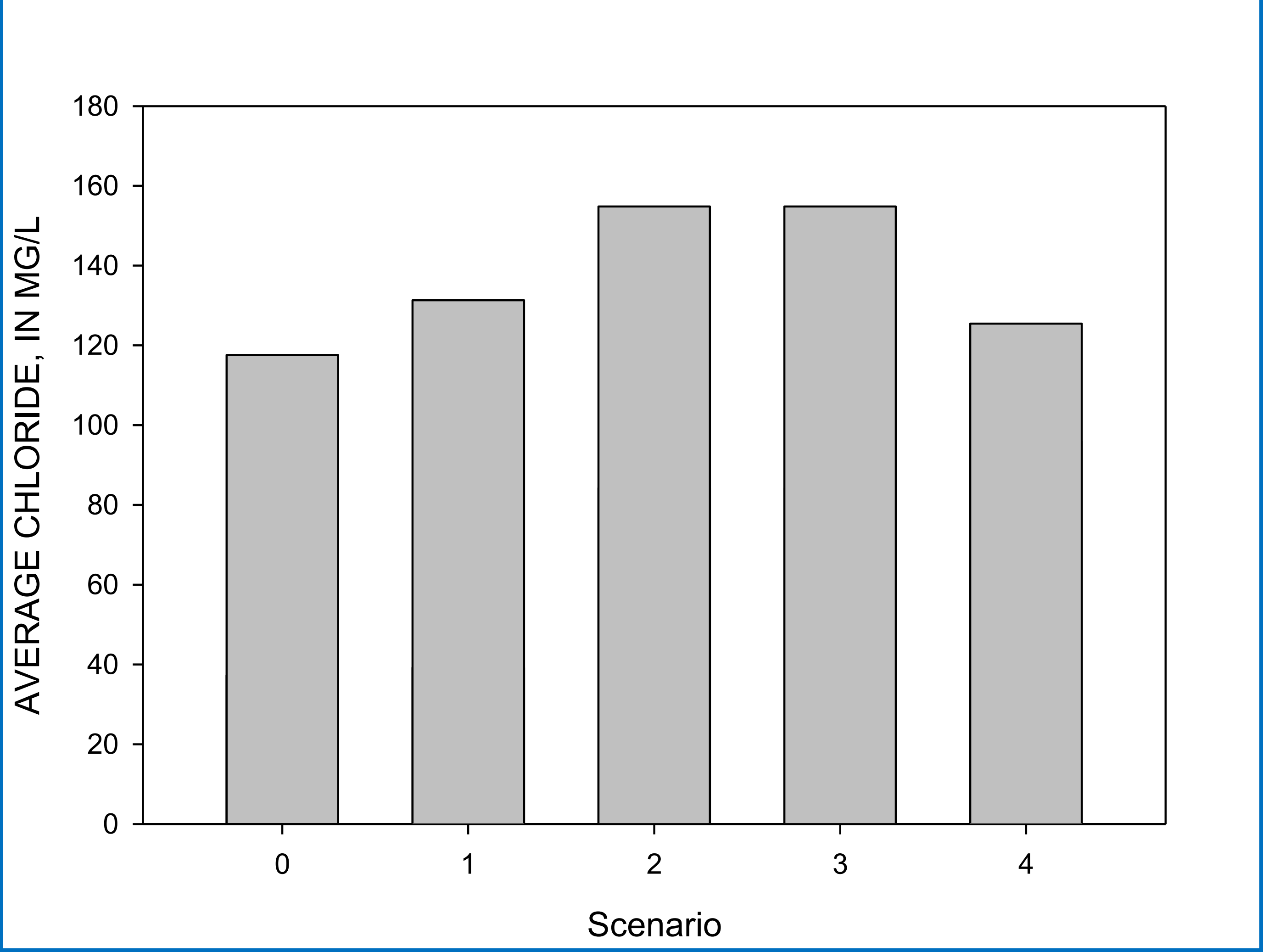
WERI
WATER AND ENVIRONMENTAL RESEARCH INSTITUTE OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

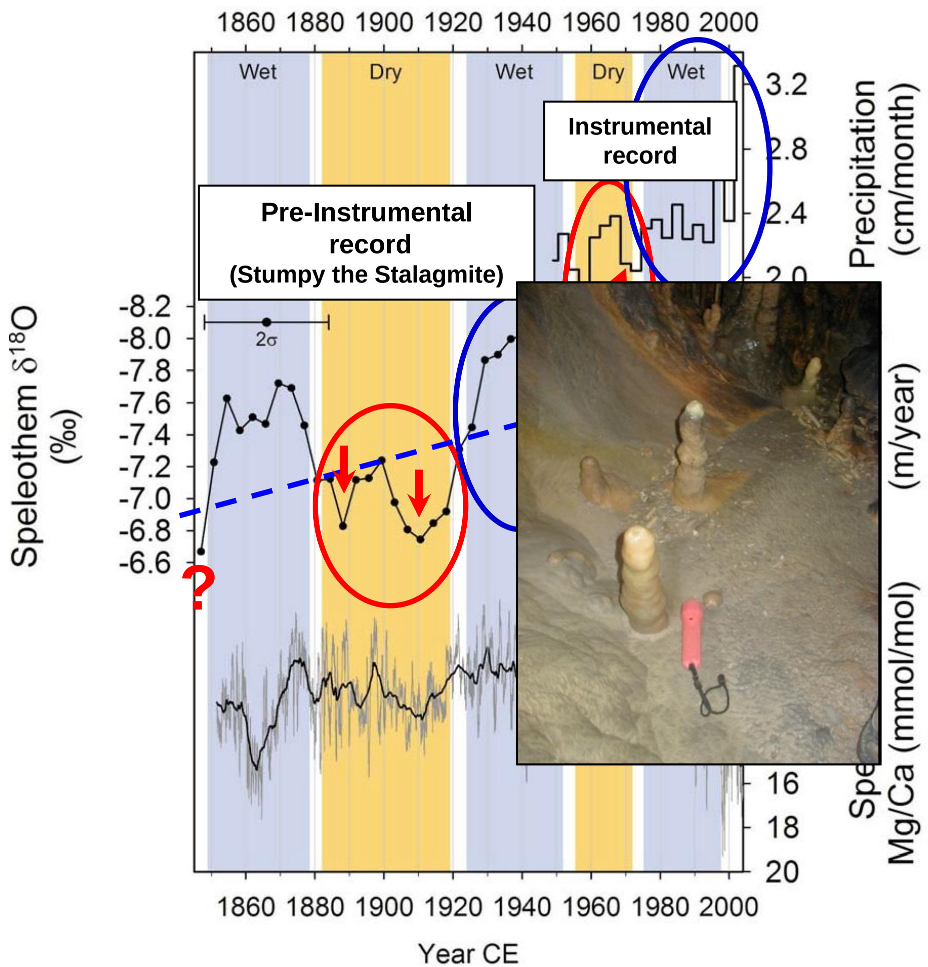
Average Chloride Concentration for Selected Wells in Finegayan Sub-Basin



USGS
science for a changing world

Record of Rainfall History

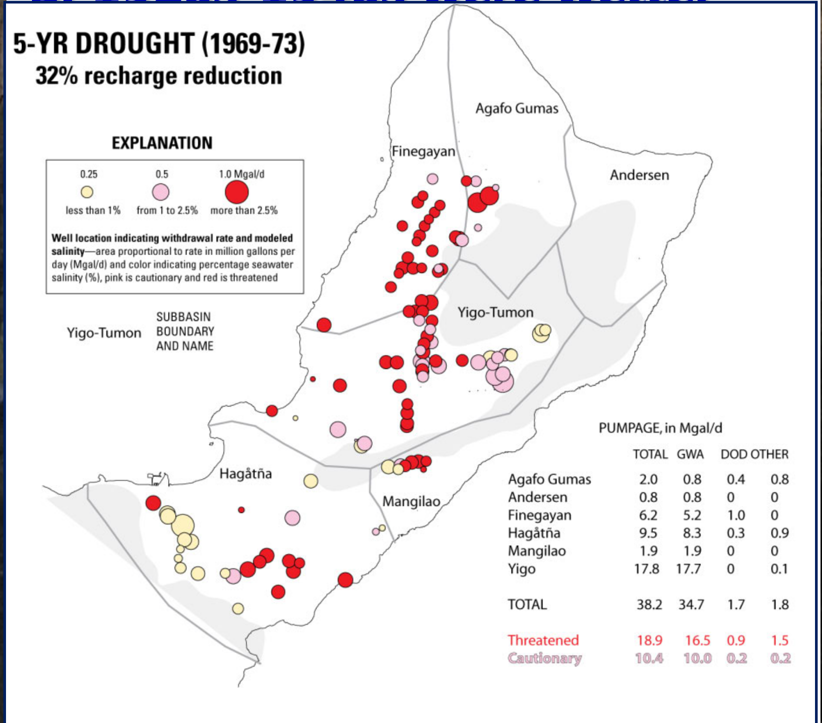
Jinapsan Cave Stalagmites: Past 160 years



Partin, Jenson & Banner et al., 2012

Decadal Oscillations

1. Wet since the 1970s
   – But current conditions are not the long-term norm—if there is one…
2. 1950s & 1960s much drier
   – 1969-1973 drought in the new USGS groundwater model
3. 1920s-1940s were wetter



Proposed Funding Breakdown

Agency	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
DoD	14,000	57,000	73,000	62,000	62,000
GovGuam	127,000	196,000	190,000	226,000	221,000
USGS	70,000	70,000	70,000	70,000	70,000
Total	**211,000**	**323,000**	**333,000**	**358,000**	**353,000**

Eight new deep monitor wells are needed for areas that lack a deep monitor well but are either already developed or planned for groundwater development.

Cost of design and construction for each new deep monitor well is estimated to be $100K.

Next Steps

- Groundwater-Availability Study
  - Finalize future pumping scenarios –
    - NavFacPac/NavFacMar
    - GWA
  - Present updated findings – ?
  - Publish final report – September 30, 2013
- Topics for consideration by DoD and GovGuam
  - Cost-share agreements for new deep monitor wells and expanded monitoring
  - Groundwater modeling training

Water Resources on Guam: Potential Impacts of Adaptive Response to Climate Change for DoD Installations

- Requested by the DoD Strategic Environmental Research and Development Program (SERDP)
- $2.3 M over 4 years beginning in fiscal year 2014
- 11 principal investigators: USGS, WERI, University of Hawaii, University of Texas, East-West Center

Study Objectives

- How will streamflow, sediment loads, and turbidity be modified and how will this affect surface-water availability?
- How will groundwater recharge and salinity be modified?
- What are climate-change impacts to DoD infrastructure supplying surface water and groundwater and what are the adaptive strategies to maximize the water resources?
- How will information about potential climate-change impacts be communicated to water managers evaluating and implementing adaptive strategies?

1. Projection of Future Climate

International Pacific Research Center, University of Hawaii at Manoa

- Evaluate accuracy of global climate models for application in Guam
- Generate downscaled climate projections
- Provide future estimates of rainfall, temperature, surface solar flux, surface wind, and evapotranspiration

2. Update and Expansion of Watershed Model for Southern Guam

USGS PIWSC

- Expand USGS watershed model for the Fena Valley watershed to all of southern Guam
- Calibrate using NEXRAD rainfall data aggregated to daily totals
- Provide streamflow estimates for a range of projected climate conditions

3. Impact of Modified Sediment Loads and Turbidity on Surface Water

USGS PIWSC

- Update bathymetric survey of Fena Valley Reservoir
- Update Fena Valley Reservoir water-balance model
- Estimate sedimentation rate from hand cores and bathymetric changes
- Provide sedimentation and high turbidity event estimates for a range of projected climate conditions

4. Computation and Geochemical Characterization of Past, Present, and Future Groundwater Recharge

USGS PIWSC, UoG WERI, University of Texas

- Update water budget with climate and land-cover projections
- Evaluate fast and slow recharge mechanisms using geochemical tracers
- Analyze groundwater, soil water, cave water, rain water, and limestone units for trace elements, Sr ratios, and $\delta 18O$
- Use geochemical models to understand water origins and flow paths

5. Application of Numerical Groundwater Flow and Salinity Model

USGS PIWSC

- Apply future climate and sea-level projections
- Evaluate a range of climate change and pumping scenarios to address future groundwater availability

Task 6. Evaluation of Climate-Change Induced Modifications and Adaptive Strategies for the DoD Water-Resource Infrastructure

USGS PIWSC

- Evaluate storage conditions in the Fena Valley Reservoir for a range of future climate conditions
- Evaluate adaptive strategies for the Fena Valley Reservoir
- Evaluate aquifer conditions for a range of future climate conditions
- Evaluate strategies for conjunctive use of surface-water and groundwater resources.

Task 7. Communicating information about climate change impacts to water-resource managers

East-West Center

- Establish rigorous stakeholder participation
- Interviews, workshops, and surveys of stakeholders
- Create decision support tools for stakeholders based on findings

Questions