Guam Groundwater-Availability Study: Preliminary Results Presented at Technical Working Group Meeting on May 16, 2013

Outline of Meeting

- **Project goals, products, timeline**
- Review of project products
- Numerical modeling – final scenarios
  - Calibration to baseline condition
  - Coastal discharge
  - Drought condition (driest 5-year period)
  - Future pumping scenarios

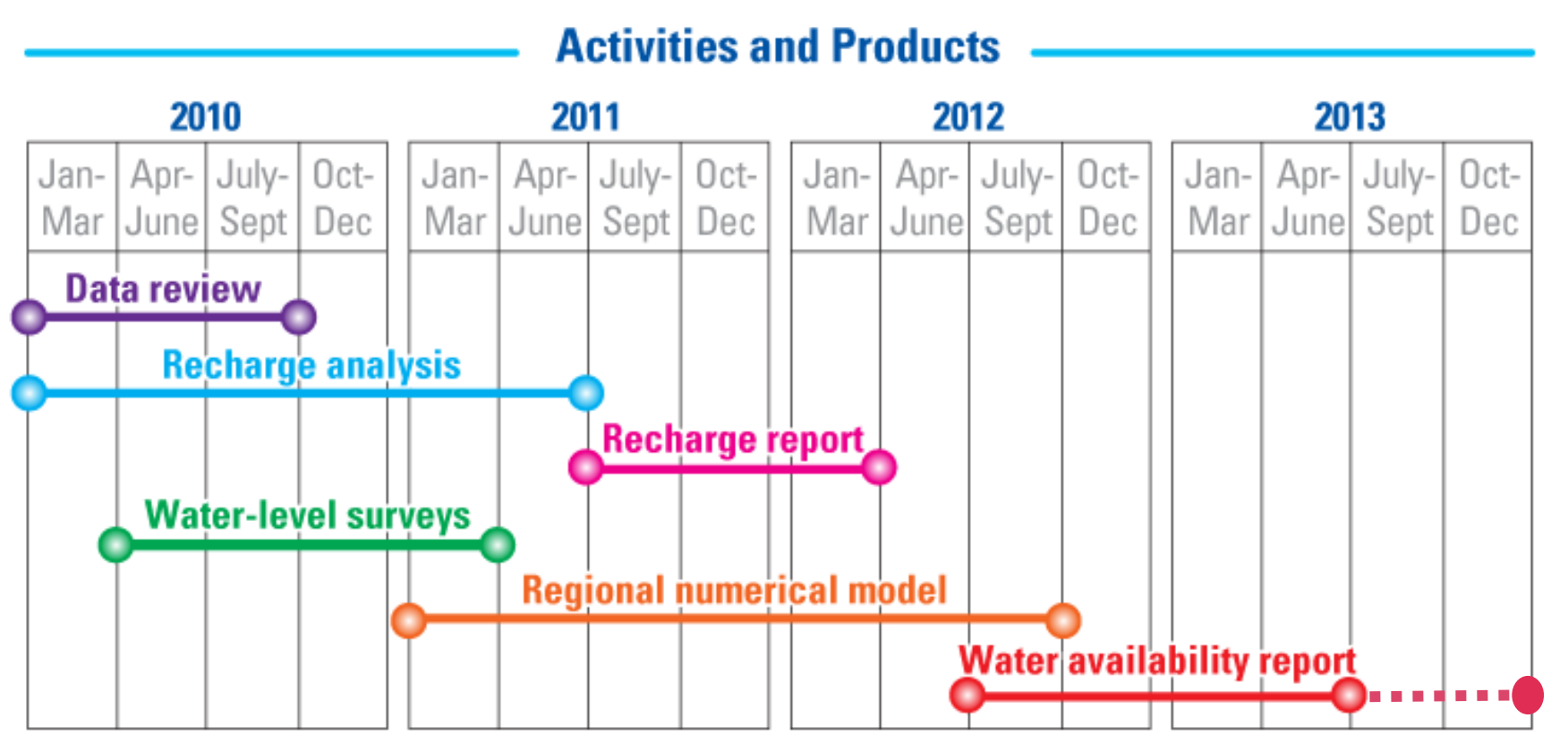
Study Objectives

- 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

Timelines



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

Outline of Meeting

- Project goals, products, timeline
- **Review of products from study**
- Numerical modeling – final scenarios
  - Calibration to baseline condition
  - Coastal discharge
  - Drought condition (driest 5-year period)
  - Future pumping scenarios

Project Products

- Study overview – USGS Fact Sheet
- Water budget – USGS SIR
- Hydraulic characteristics – Hydrogeology Journal
- Well database – WERI Tech Report (in prep)
- Volcanic basement map – WERI Tech Report (in prep)
- Groundwater Availability/Model – USGS SIR (in prep)

Published Reports

Study overview
USGS Fact Sheet

USGS science for a changing world

WERI

Groundwater Availability Study for Guam—Goals, Approach, Products, and Schedule of Activities

An expected significant population increase on Guam has raised concern about the sustainability of groundwater resources. In response, the U.S. Geological Survey (USGS), in collaboration with the University of Guam's Water and Environmental Research Institute of the Western Pacific (WERI) and with funding from the U.S. Marine Corps (USMC), is conducting a 2.5-year study to advance understanding of regional groundwater dynamics in the Northern Guam Lens Aquifer, provide a new estimate of groundwater recharge, and develop a numerical groundwater flow and transport model for northern Guam. Results of the study, including two USGS reports and a well database, will provide more reliable evaluations of the potential effects of groundwater production and help guide sustainable management of this critical resource.

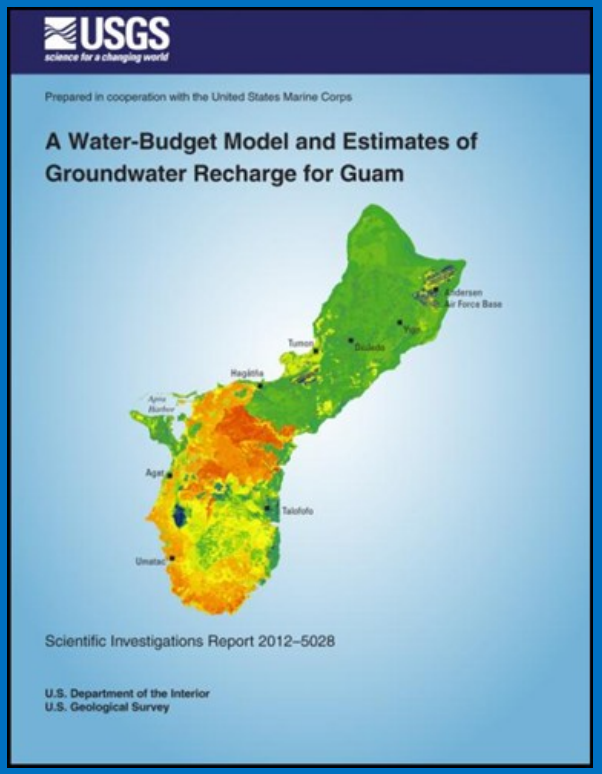
Introduction

The population of Guam is expected to increase substantially over the next decade during a proposed military forces relocation, which includes a major realignment of U.S. Marine Corps (USMC) personnel and their families to northern Guam. Groundwater production from the Northern Guam Lens Aquifer, currently about 40 million gallons per day, could significantly increase as a result. This prospective increase has prompted concerns over the sustainability of additional groundwater development on the island. Recognizing these concerns, Headquarters, USMC, has provided $1.2 million for the U.S. Geological Survey (USGS) to conduct a 3.5-year groundwater availability study that will provide information and tools to more effectively manage Guam's groundwater resources. The USGS has in turn engaged the University of Guam's Water and Environmental Research Institute of the Western Pacific (WERI), with whom it has had a long-standing collaborative relationship, to provide local scientific expertise and coordinate with local cooperating agencies in developing a well database.

The island of Guam, in the western Pacific Ocean, has a freshwater-lens system in the productive limestone aquifer (Northern Guam Lens Aquifer) underlying the island's northern half, where most of the population resides and where population is expected to increase substantially as a result of military expansion. A groundwater-availability study will help guide sustainable management of this critical and increasingly used resource. The darker "window" in the middle of the aquifer is the extent of the volcanic basement rock above sea level, where groundwater pumping is precluded by the very low permeability of the rock. (Image from U.S. Department of Agriculture, Natural Resources Conservation Service, 20060714, Orthophoto Mosaic for Guam).

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

Fact Sheet 2010–3084
2010



USGS science for a changing world

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

Water budget
USGS SIR

Aquifer characteristics
Hydrogeology Journal

Springer Link

Hydrogeology Journal
Official Journal of the International Association of Hydrogeologists
© Springer-Verlag Berlin Heidelberg 2013
10.1007/s10040-012-0949-9

Report

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

Kolja Rotzoll [1], Stephen B. Gingerich [2], John W. Jenson [3] and Aly I. El-Kadi [1]

(1) Water Resources Research Center, University of Hawaii, 2540 Dole Street, Honolulu, HI 96822, USA
(2) US Geological Survey, Pacific Islands Water Science Center, 677 Ala Moana Blvd, No. 415, Honolulu, HI 96813, USA
(3) Water and Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, GU 96923, USA

Kolja Rotzoll
Email: kolja@hawaii.edu

Received: 29 May 2012
Accepted: 18 December 2012
Published online: 15 January 2013

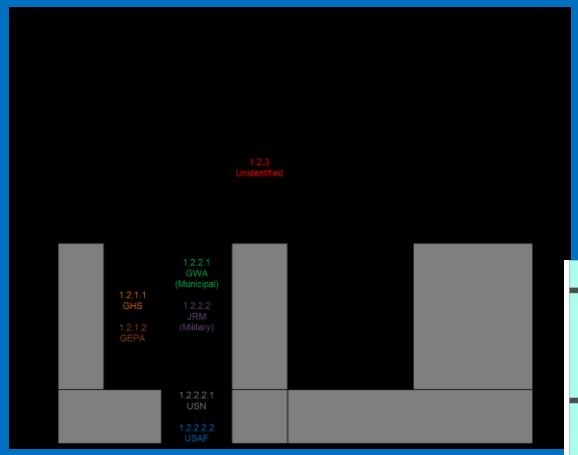
Abstract

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

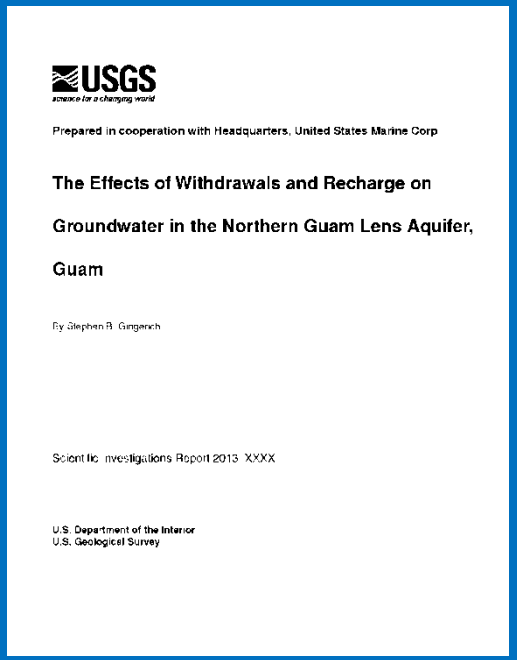
USGS science for a changing world

Reports in preparation

Well database
WERI Tech Report



Groundwater availability
USGS SIR


USGS
science for a changing world

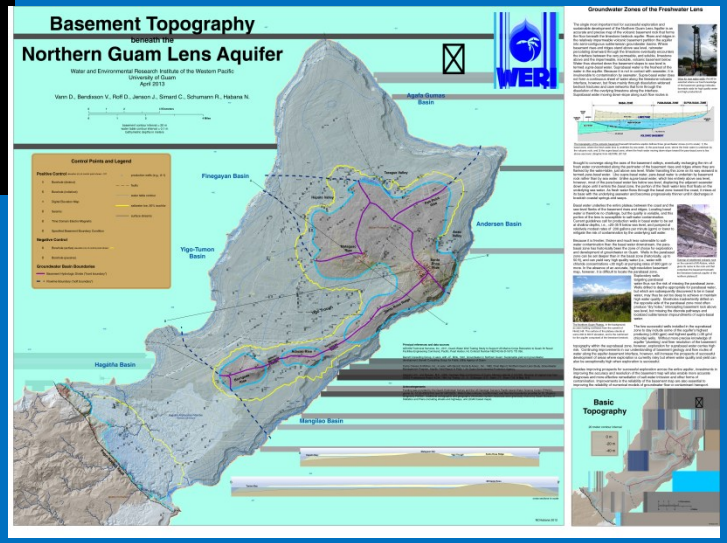
Prepared in cooperation with Headquarters, United States Marine Corp

The Effects of Withdrawals and Recharge on Groundwater in the Northern Guam Lens Aquifer, Guam

By Stephen B. Gingerich

Scientific Investigations Report 2013–XXXX

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



Volcanic basement
WERI Tech Report

Outline of Meeting

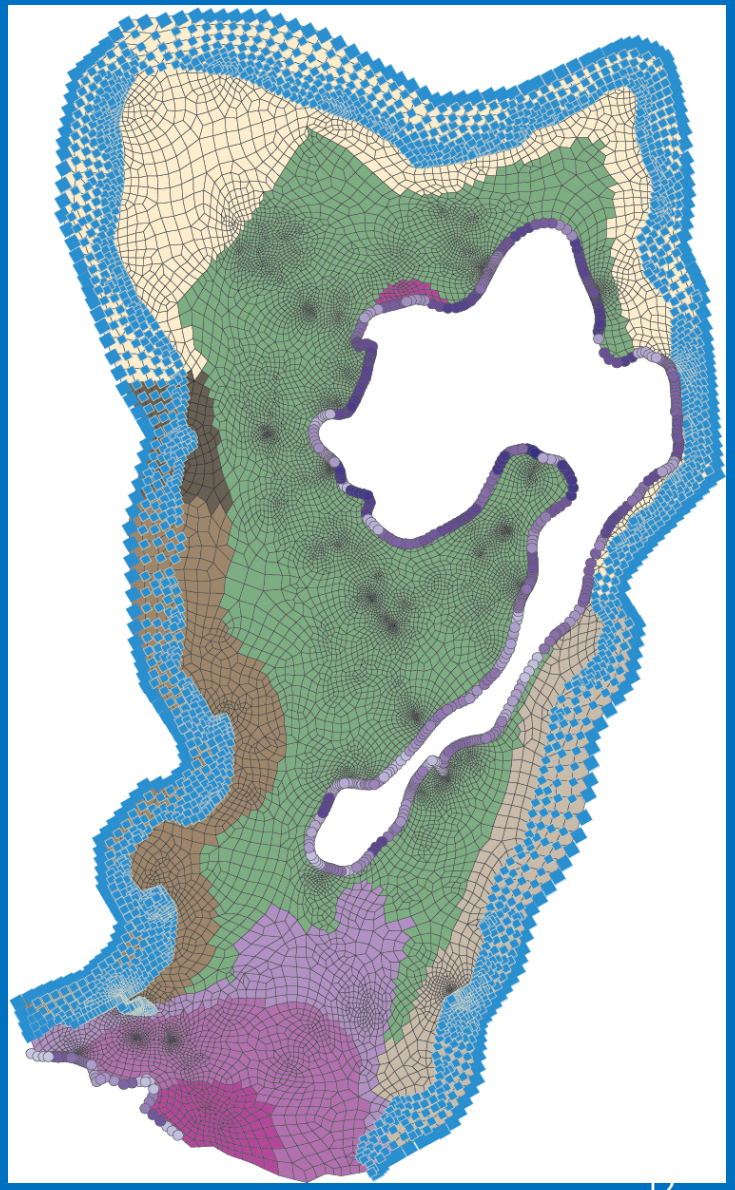
- Project goals, products, timeline
- Review of project products
- **Numerical modeling – final scenarios**
  - Calibration to baseline condition
  - Coastal discharge
  - Drought condition (driest 5-year period)
  - Future pumping scenarios

Model Calibration-Baseline Condition

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

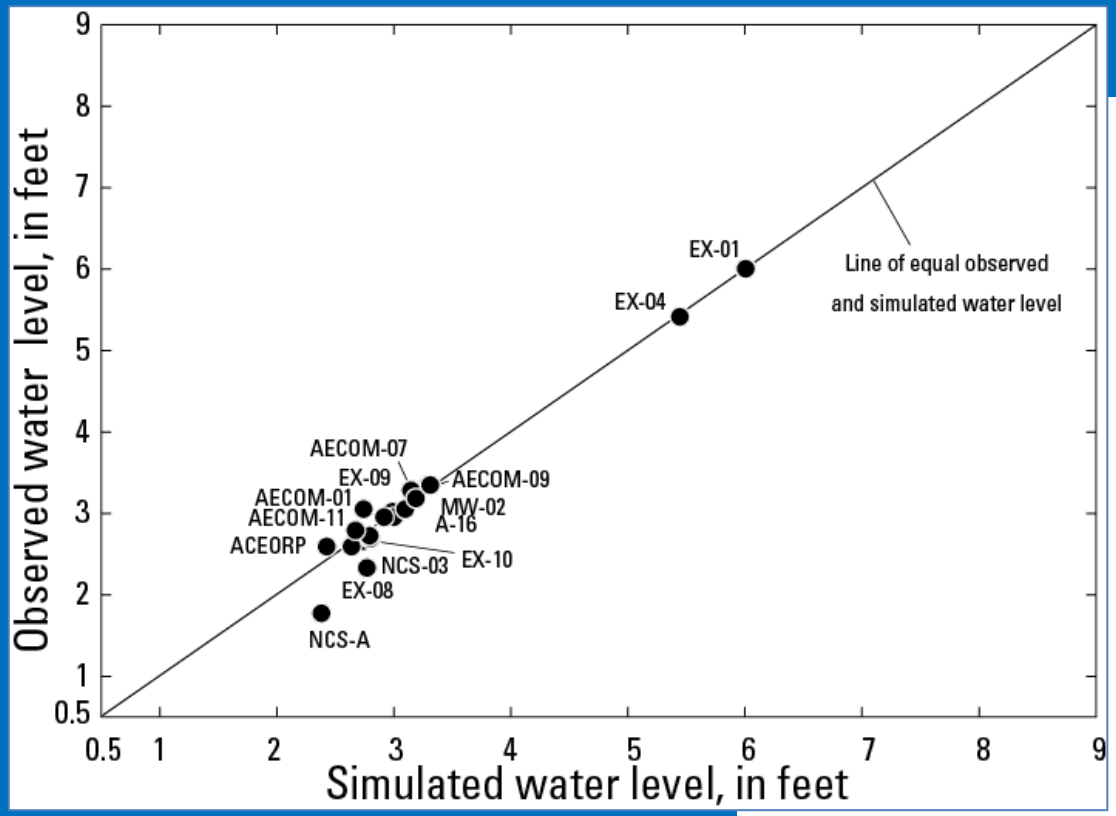
- Calibration targets
  - Average 2010 water levels and tidal fluctuations
  - December 2009 salinity profiles

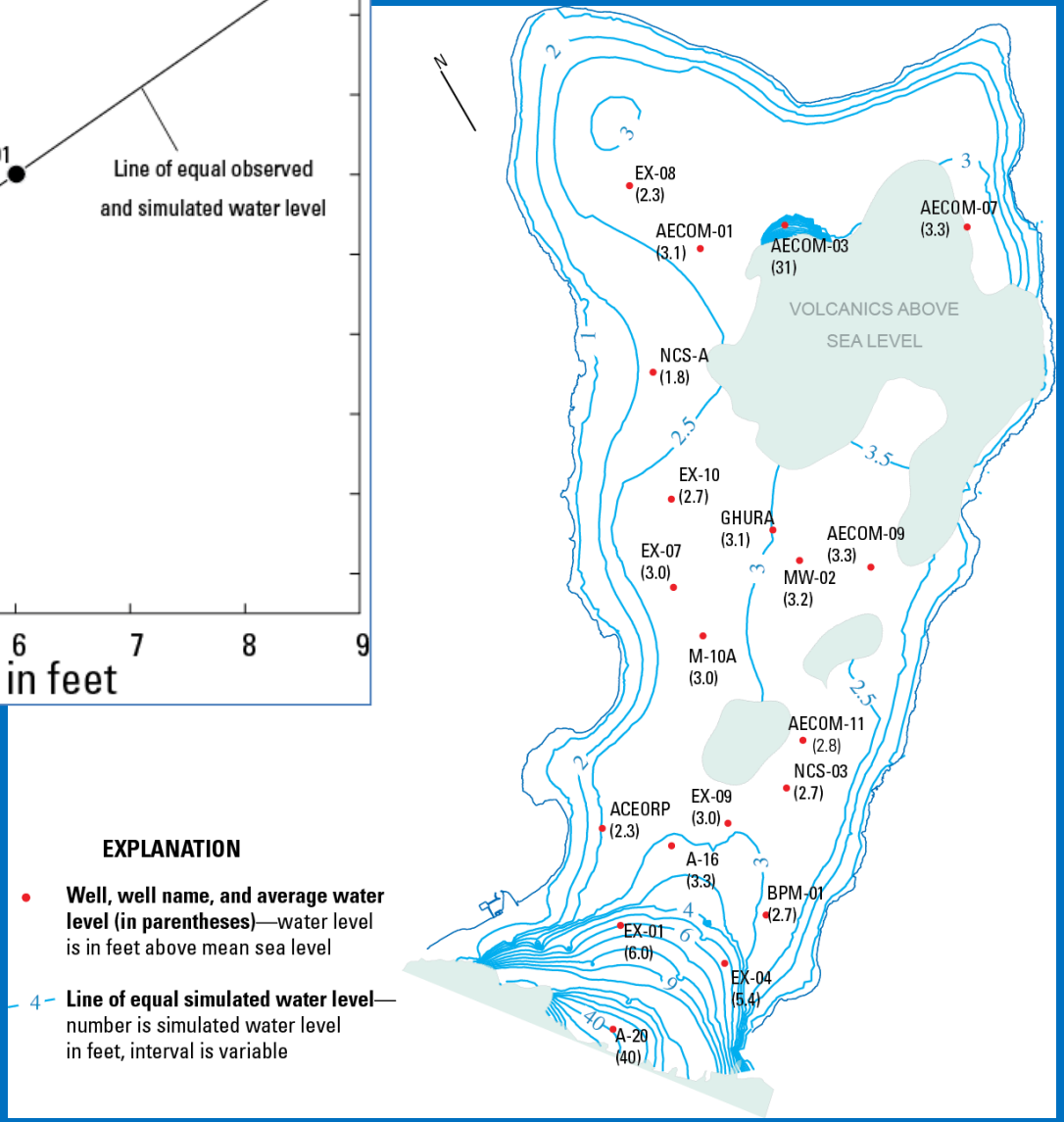
Observed and Simulated Water Levels



USGS
science for a changing world

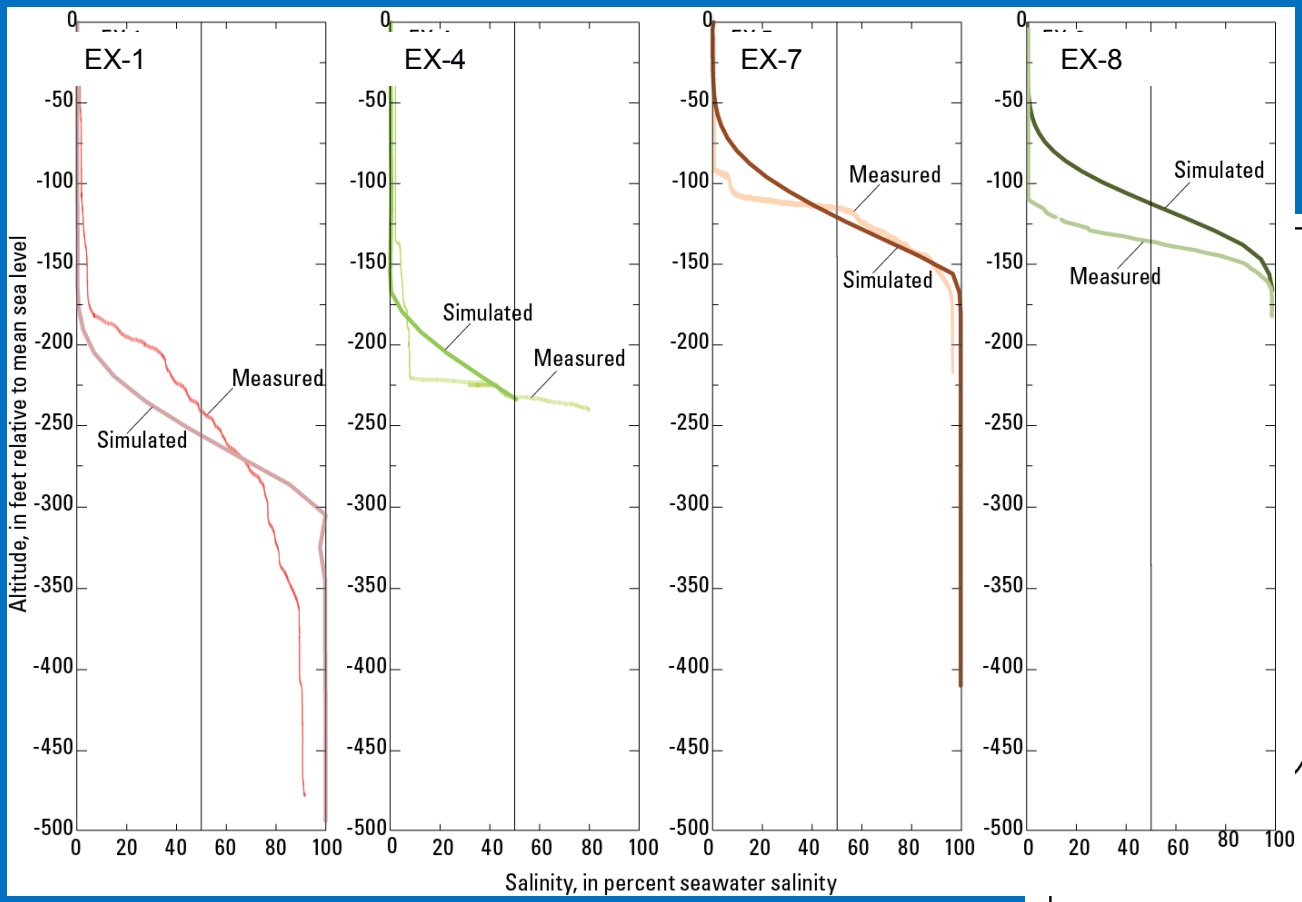
Observed and Simulated Water Levels

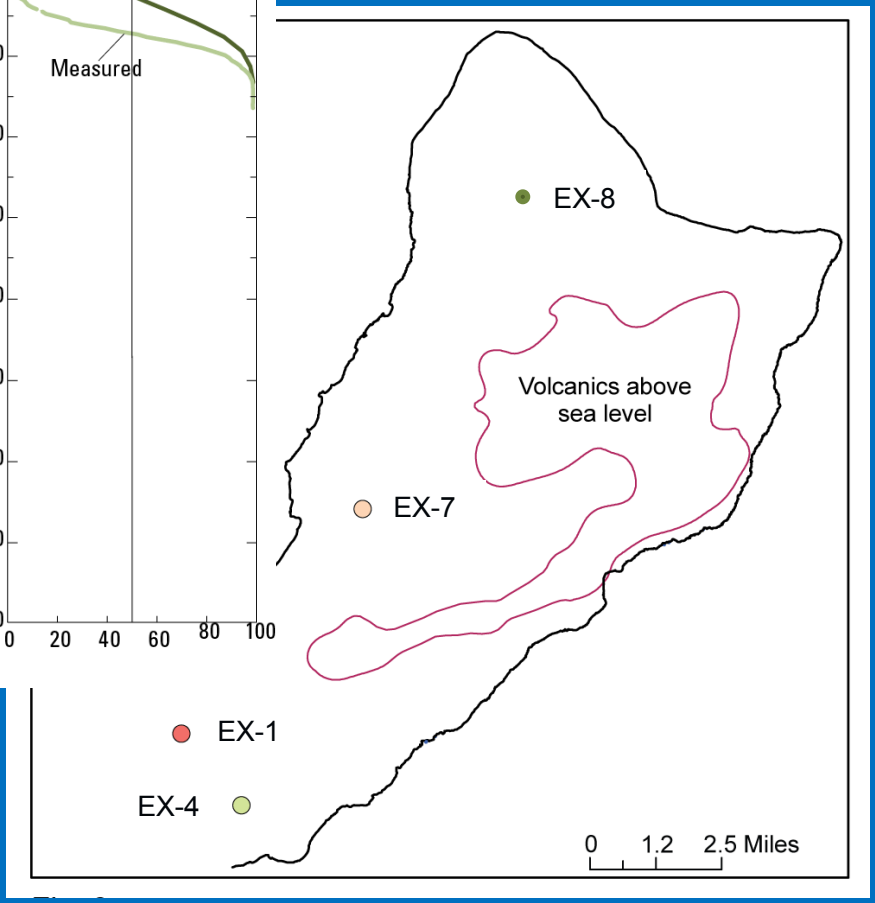




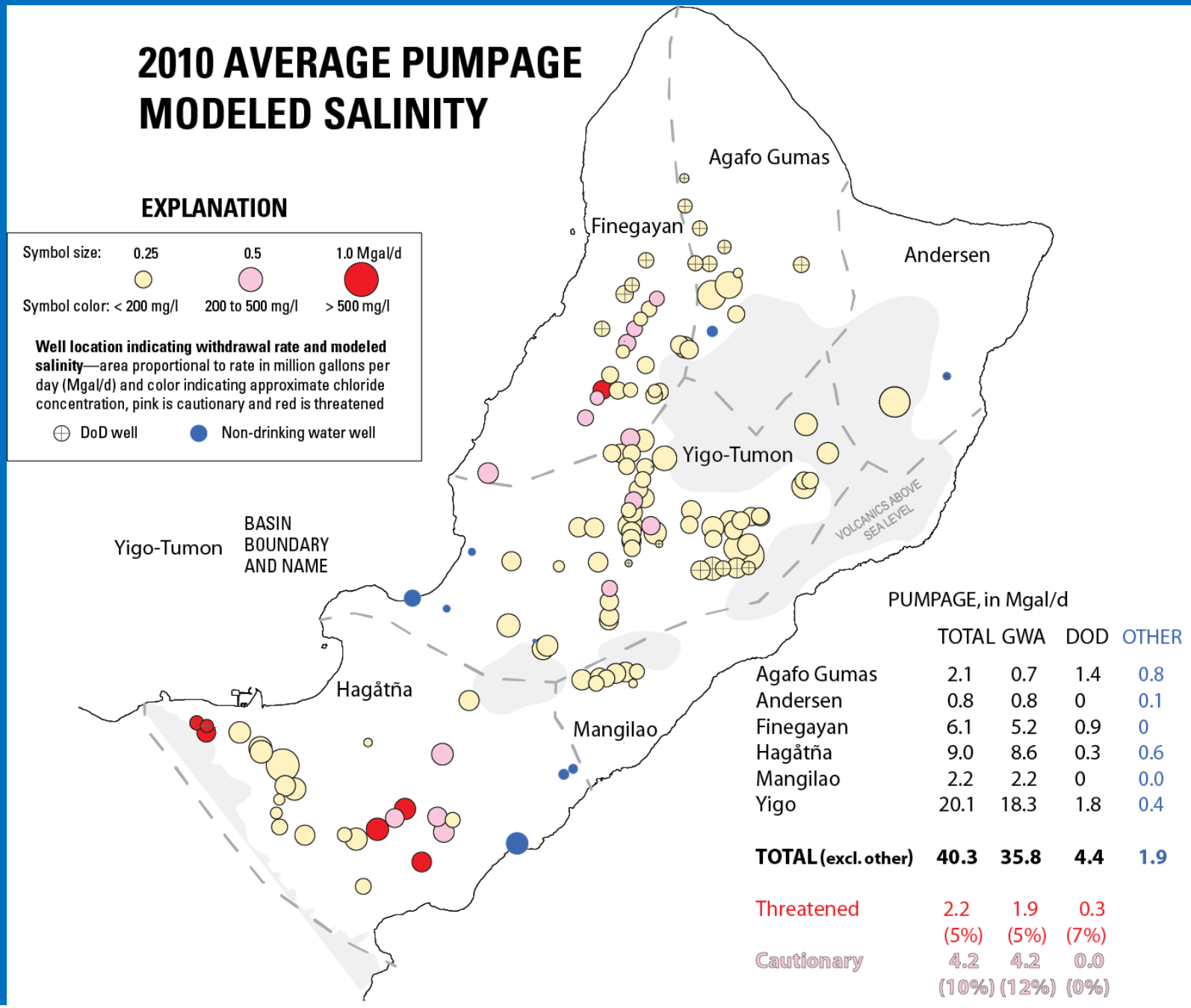
USGS science for a changing world

Observed and Modeled Salinity Profiles





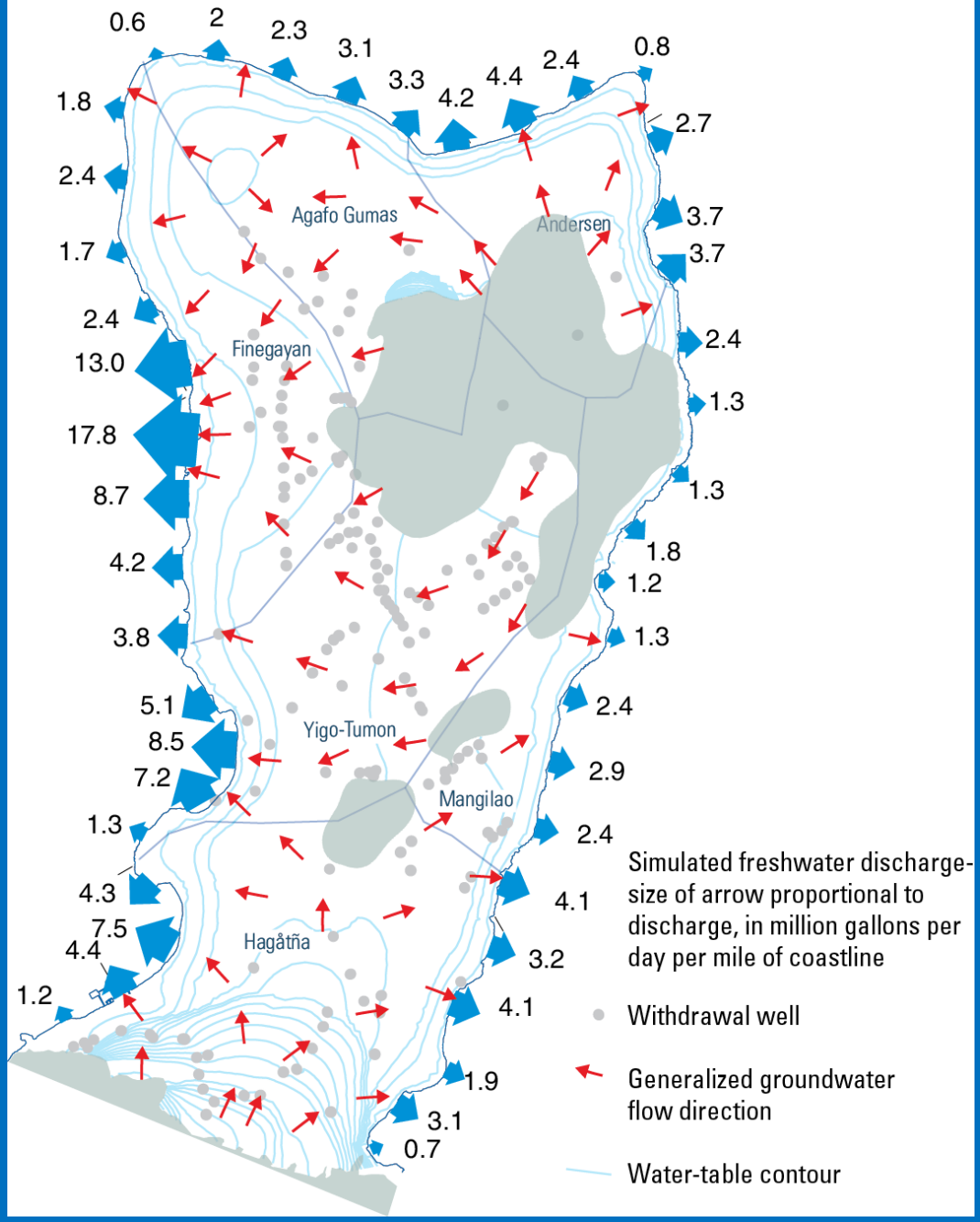
2010 AVERAGE PUMPAGE MODELED SALINITY



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	9.0	8.6	0.3	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	20.1	18.3	1.8	0.4
TOTAL (excl. other)	**40.3**	**35.8**	**4.4**	**1.9**
Threatened	2.2 (5%)	1.9 (5%)	0.3 (7%)	
Cautionary	4.2 (10%)	4.2 (12%)	0.0 (0%)	

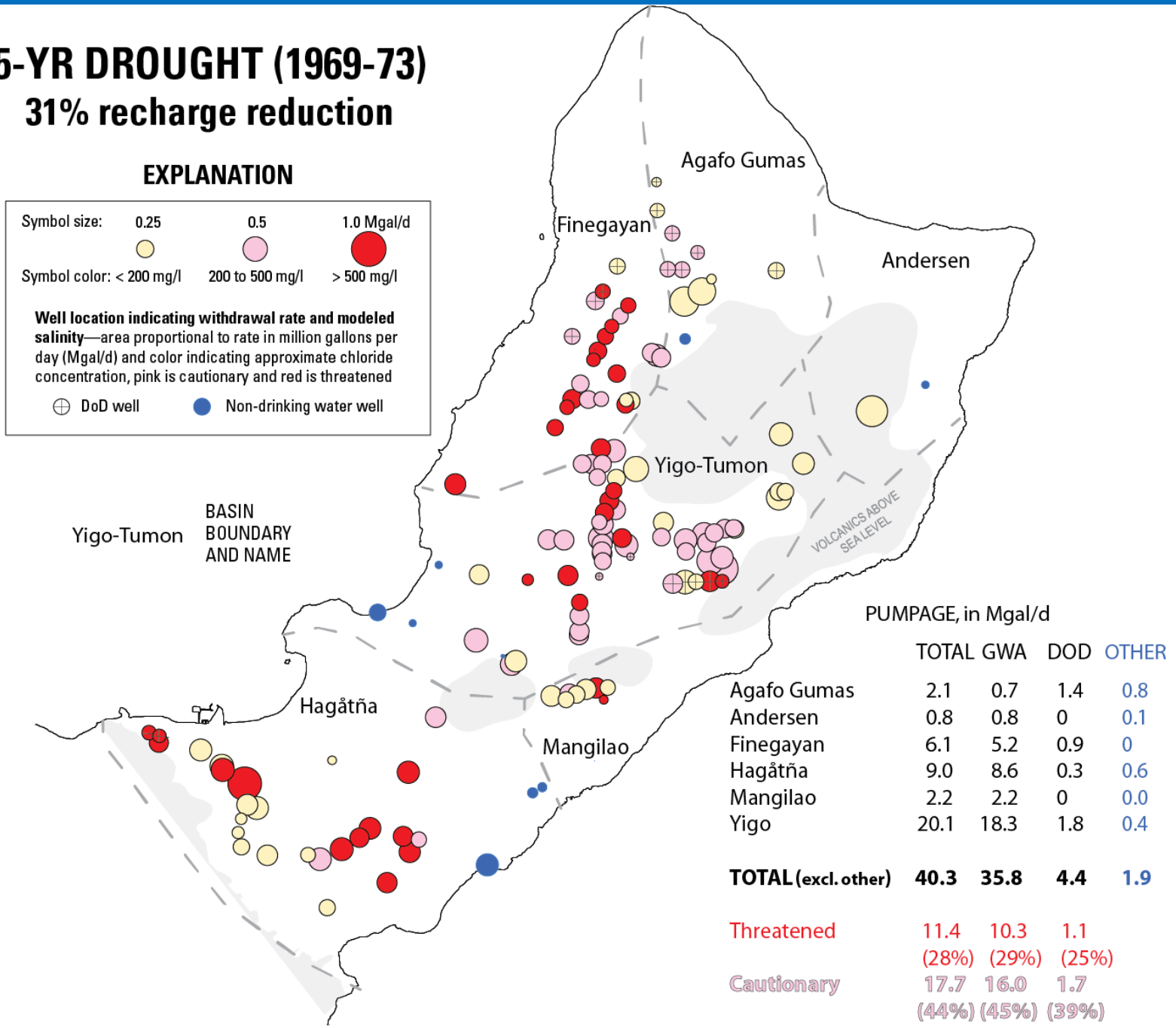
Simulated coastal freshwater discharge



Drought Condition

- Hydrologic conditions
  - Driest 5-yr period (31% reduction in recharge)
    - 1969-73 rainfall
    - 2004 land cover
  - 2010 pumping rates
- Results after 5 years of pumping at steady rates

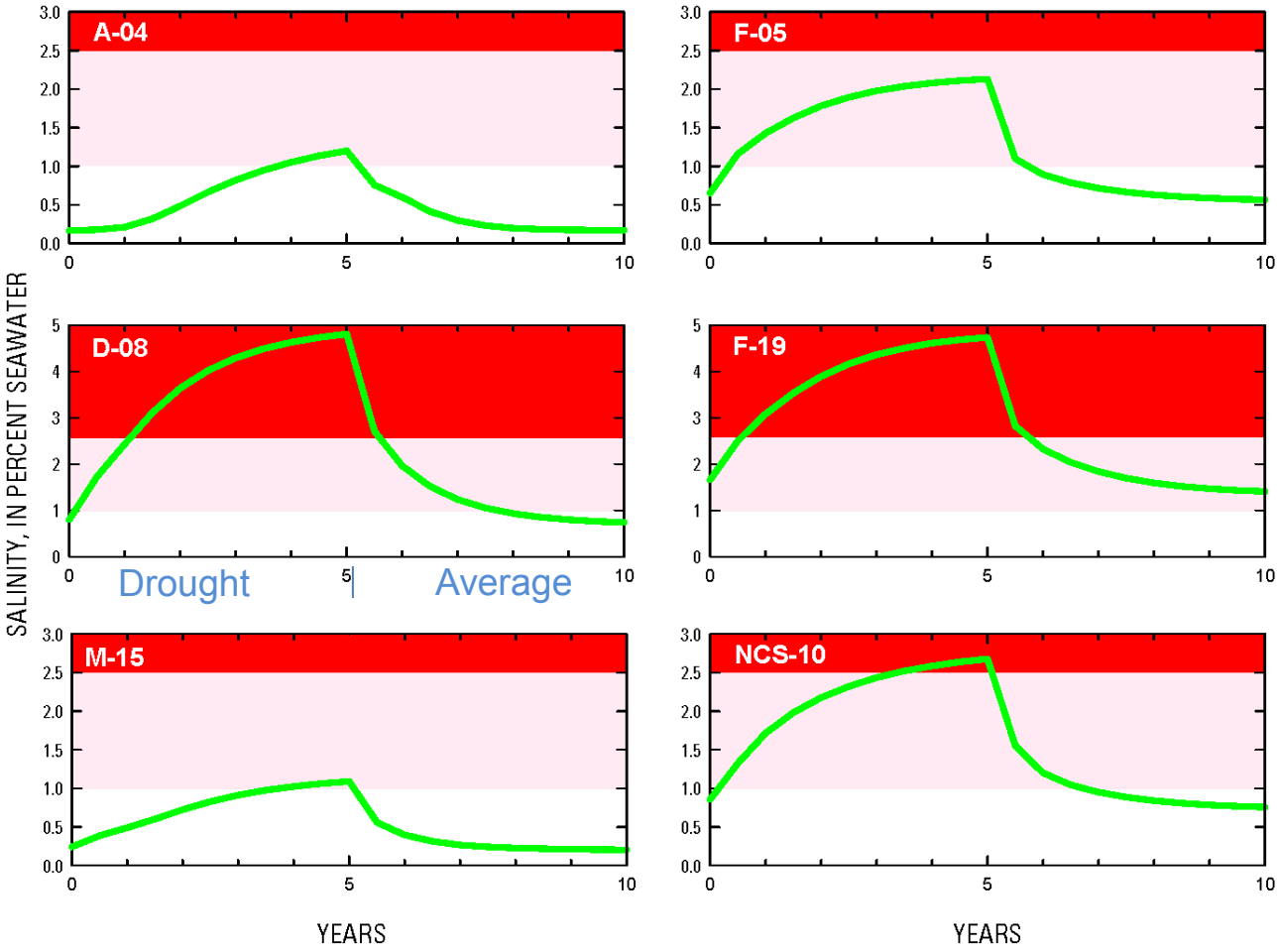
5-YR DROUGHT (1969-73)
31% recharge reduction



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	9.0	8.6	0.3	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	20.1	18.3	1.8	0.4
TOTAL (excl. other)	**40.3**	**35.8**	**4.4**	**1.9**
Threatened	11.4 (28%)	10.3 (29%)	1.1 (25%)	
Cautionary	17.7 (44%)	16.0 (45%)	1.7 (39%)	

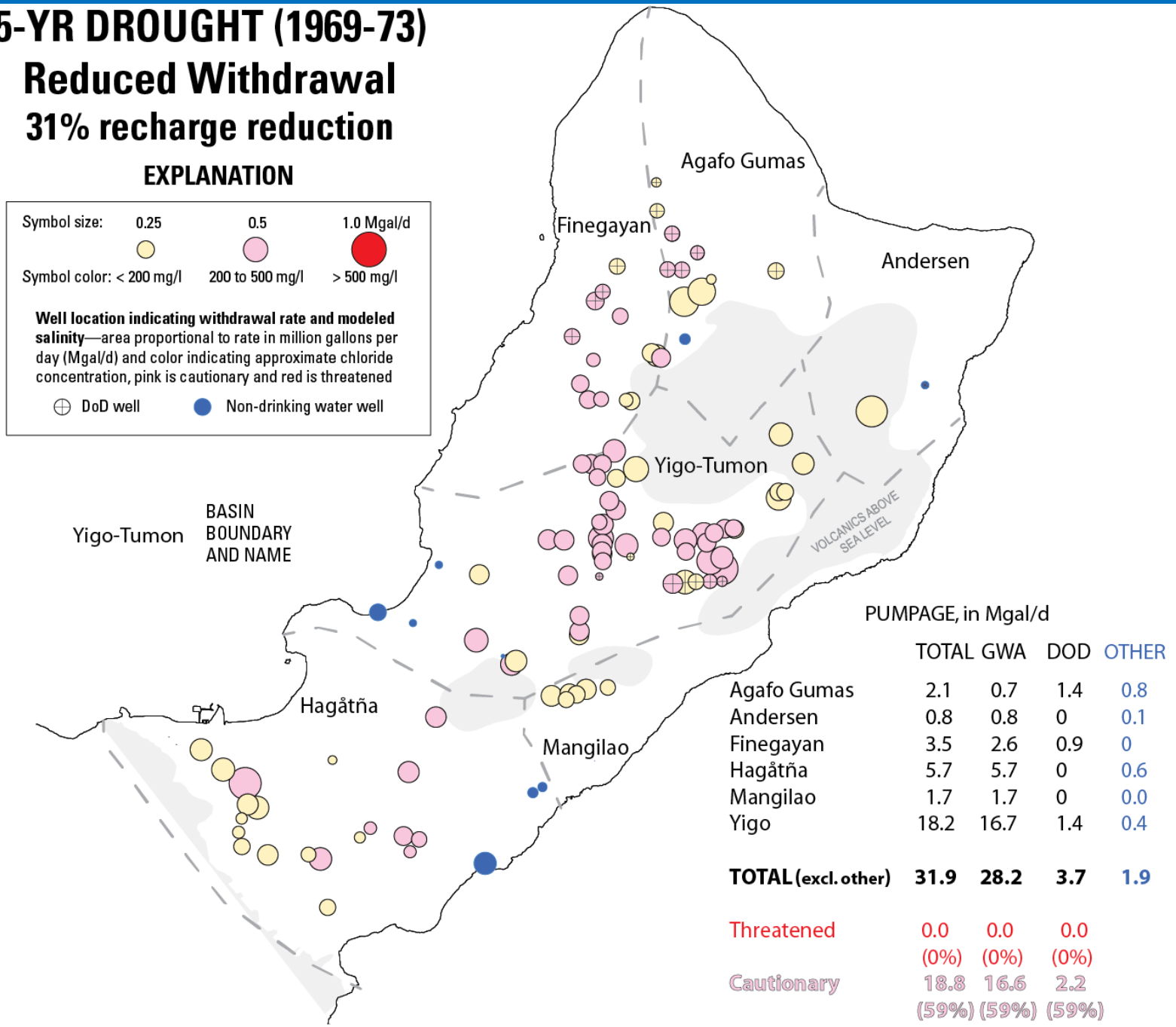
Drought Condition



Drought Condition-Reduced Withdrawal

- Hydrologic conditions
  - Driest 5-yr period (31% reduction in recharge)
    - 1969-73 rainfall
    - 2004 land cover
  - Reduced pumping rates to eliminate threatened wells
- Results after 5 years of pumping at steady rates

5-YR DROUGHT (1969-73)
Reduced Withdrawal
31% 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	3.5	2.6	0.9	0
Hagåtña	5.7	5.7	0	0.6
Mangilao	1.7	1.7	0	0.0
Yigo	18.2	16.7	1.4	0.4
TOTAL (excl. other)	**31.9**	**28.2**	**3.7**	**1.9**
Threatened	0.0 (0%)	0.0 (0%)	0.0 (0%)	
Cautionary	18.8 (59%)	16.6 (59%)	2.2 (59%)	

Outline of Meeting

- Project goals, products, timeline
- Review of project products
- Numerical modeling – final scenarios
  - Calibration to baseline condition
  - Coastal discharge
  - Drought condition (driest 5-year period)
  - **Future pumping scenarios**

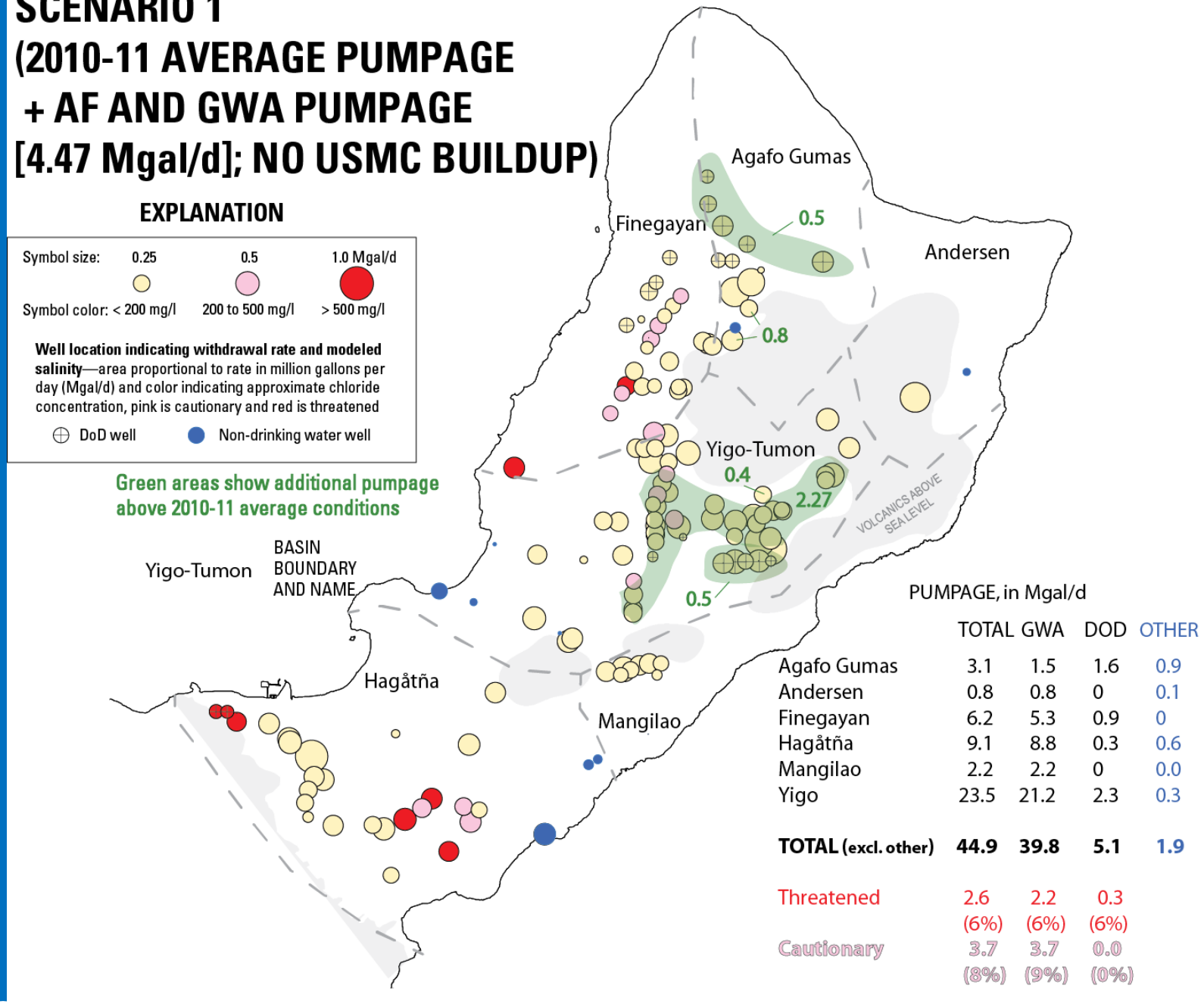
Future Scenarios

1. Expected growth with no USMC buildup
2. Expected growth plus USMC buildup
3. Expected growth plus redistributed USMC buildup
4. Redistributed USMC buildup w/drought
5. Scenario 3 with redistributed GWA

Scenario 1
Expected Growth with No USMC buildup

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1.2 Mgal/d
  - GWA Yigo-Tumon wells
    - Additional 2.27 Mgal/d
  - Air Force 10 existing wells (AF01–05, MW05–09)
    - Additional 0.97 Mgal/d

SCENARIO 1
(2010-11 AVERAGE PUMPAGE + AF AND GWA PUMPAGE [4.47 Mgal/d]; NO USMC BUILDUP)



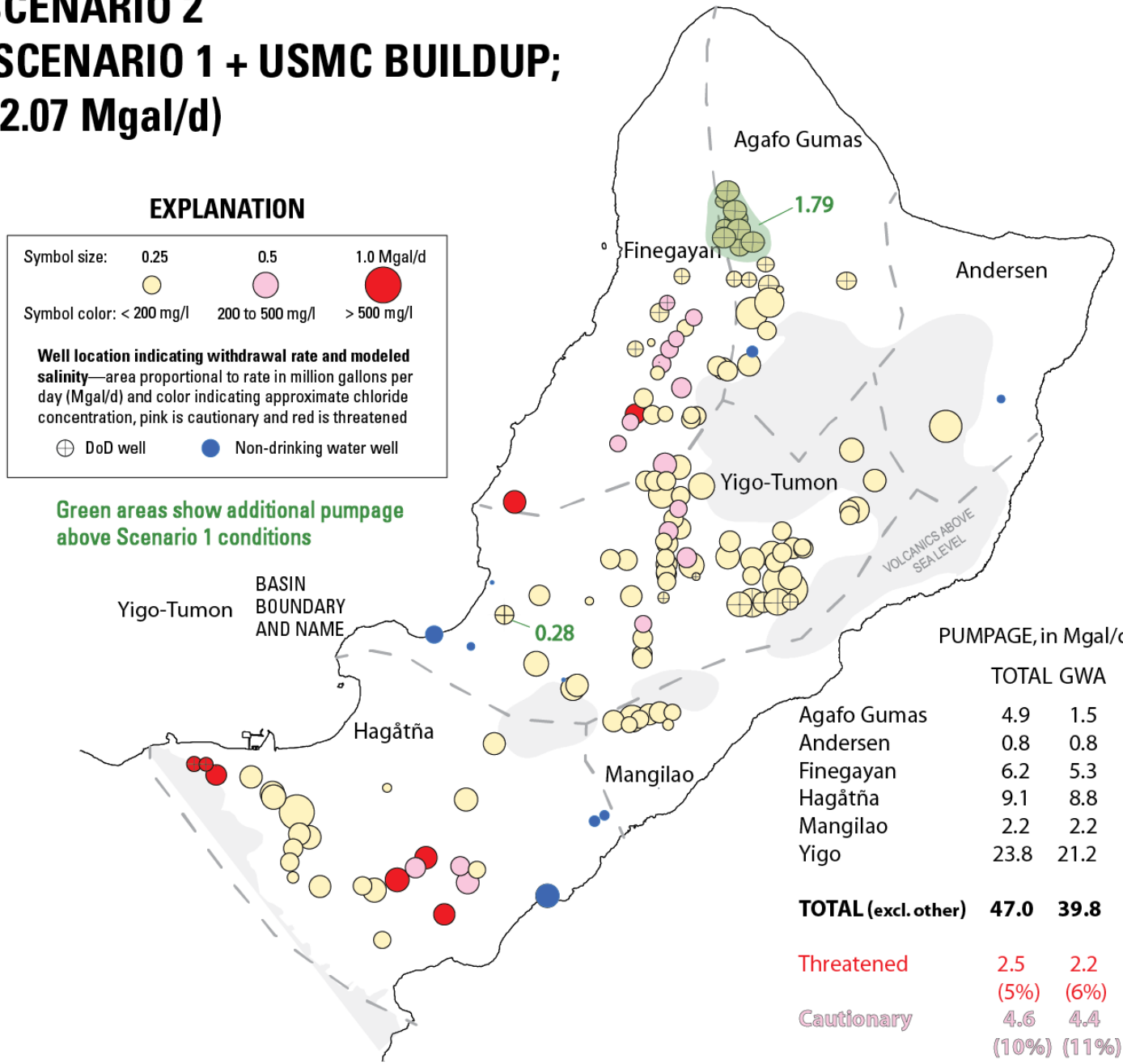
PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	3.1	1.5	1.6	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	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	23.5	21.2	2.3	0.3
TOTAL (excl. other)	**44.9**	**39.8**	**5.1**	**1.9**
Threatened	2.6 (6%)	2.2 (6%)	0.3 (6%)	
Cautionary	3.7 (8%)	3.7 (9%)	0.0 (0%)	

Scenario 2
Scenario 1 plus USMC buildup

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1.2 Mgal/d
  - GWA Yigo-Tumon wells
    - Additional 2.27 Mgal/d
  - Air Force 10 existing wells (AF01–05, MW05–09)
    - Additional 0.97 Mgal/d
  - USMC Tumon well - 0.28 Mgal/d
  - USMC new wells - 1.79 Mgal/d in Agafo Gumas

SCENARIO 2 (SCENARIO 1 + USMC BUILDUP; +2.07 Mgal/d)



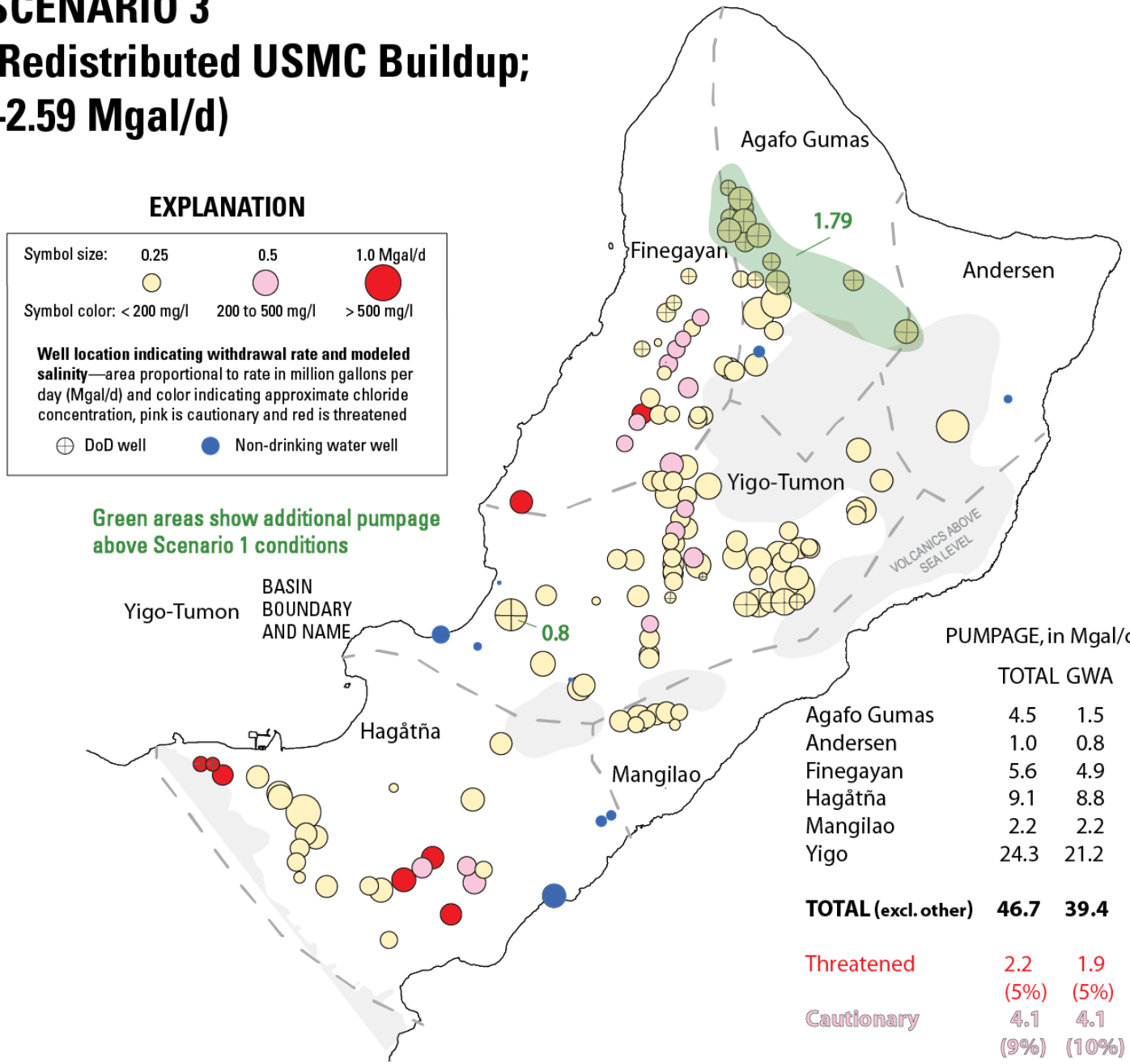
PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	4.9	1.5	3.4	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	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	23.8	21.2	2.6	0.3
TOTAL (excl. other)	**47.0**	**39.8**	**7.2**	**1.9**
Threatened	2.5 (5%)	2.2 (6%)	0.3 (4%)	
Cautionary	4.6 (10%)	4.4 (11%)	0.2 (3%)	

Scenario 3
USMC buildup (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 1.2 Mgal/d
  - GWA Yigo-Tumon wells
    - Additional 2.27 Mgal/d
  - Air Force 10 existing wells (AF01–05, MW05–09)
    - Additional 0.97 Mgal/d
  - USMC Tumon well - 0.8 Mgal/d (DoD:GWA; 50:50 split)
  - USMC new wells - 1.79 Mgal/d in Agafo Gumas and Andersen

SCENARIO 3 (Redistributed USMC Buildup; +2.59 Mgal/d)



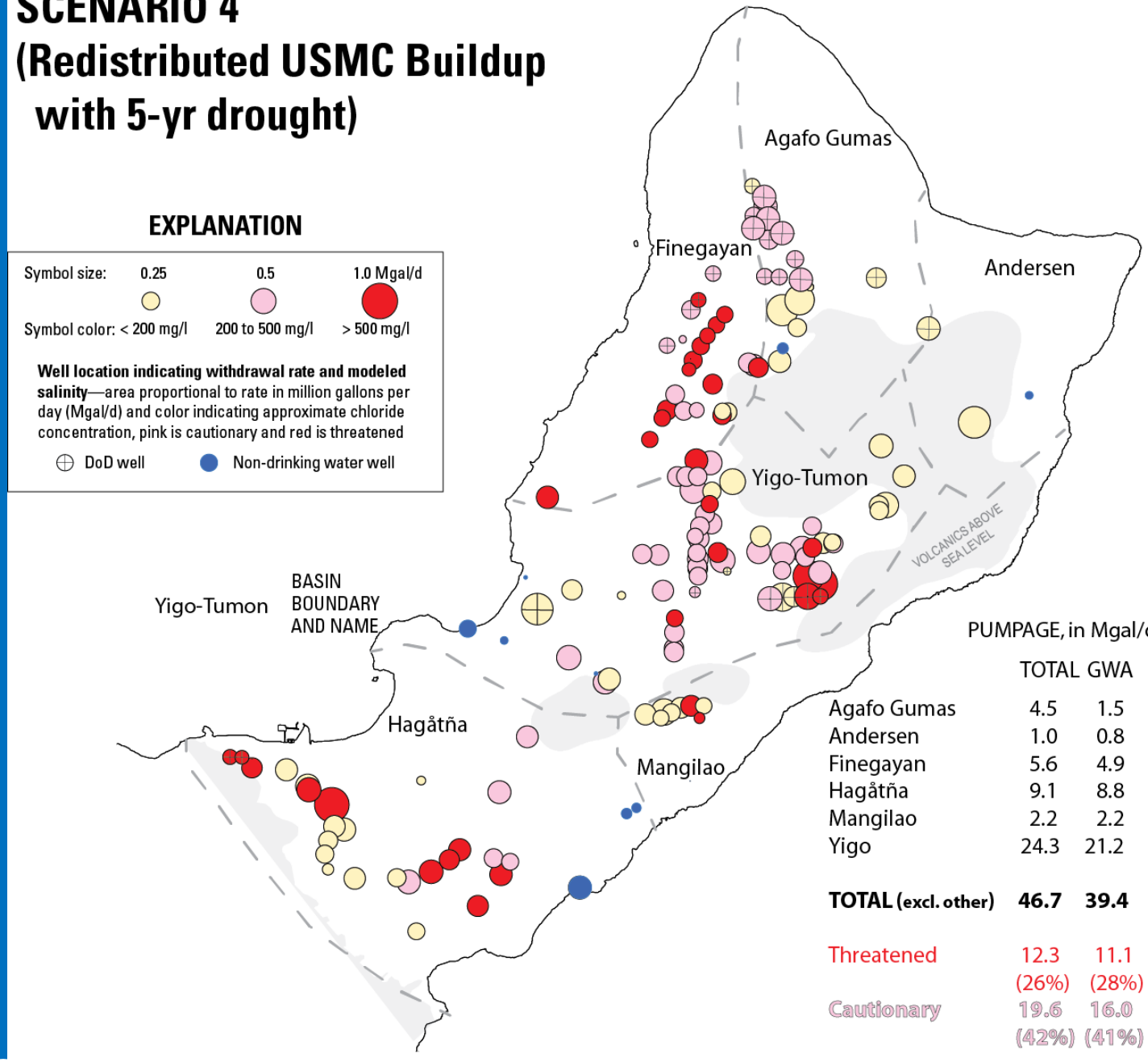
PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	4.5	1.5	3.0	0.9
Andersen	1.0	0.8	0.3	0.1
Finegayan	5.6	4.9	0.7	0
Hagåtña	9.1	8.8	0.3	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	24.3	21.2	3.1	0.3
TOTAL (excl. other)	**46.7**	**39.4**	**7.4**	**1.9**
Threatened	2.2 (5%)	1.9 (5%)	0.3 (4%)	
Cautionary	4.1 (9%)	4.1 (10%)	0.0 (0%)	

Scenario 4
Redistributed USMC buildup w/Drought

- Hydrologic conditions
  - 1969-73 drought recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1.2 Mgal/d
  - GWA Yigo-Tumon wells
    - Additional 2.27 Mgal/d
  - Air Force 10 existing wells (AF01–05, MW05–09)
    - Additional 0.97 Mgal/d
  - USMC Tumon well - 0.8 Mgal/d (DoD:GWA; 50:50 split)
  - USMC new wells - 1.79 Mgal/d in Agafo Gumas and Andersen

SCENARIO 4
(Redistributed USMC Buildup with 5-yr drought)



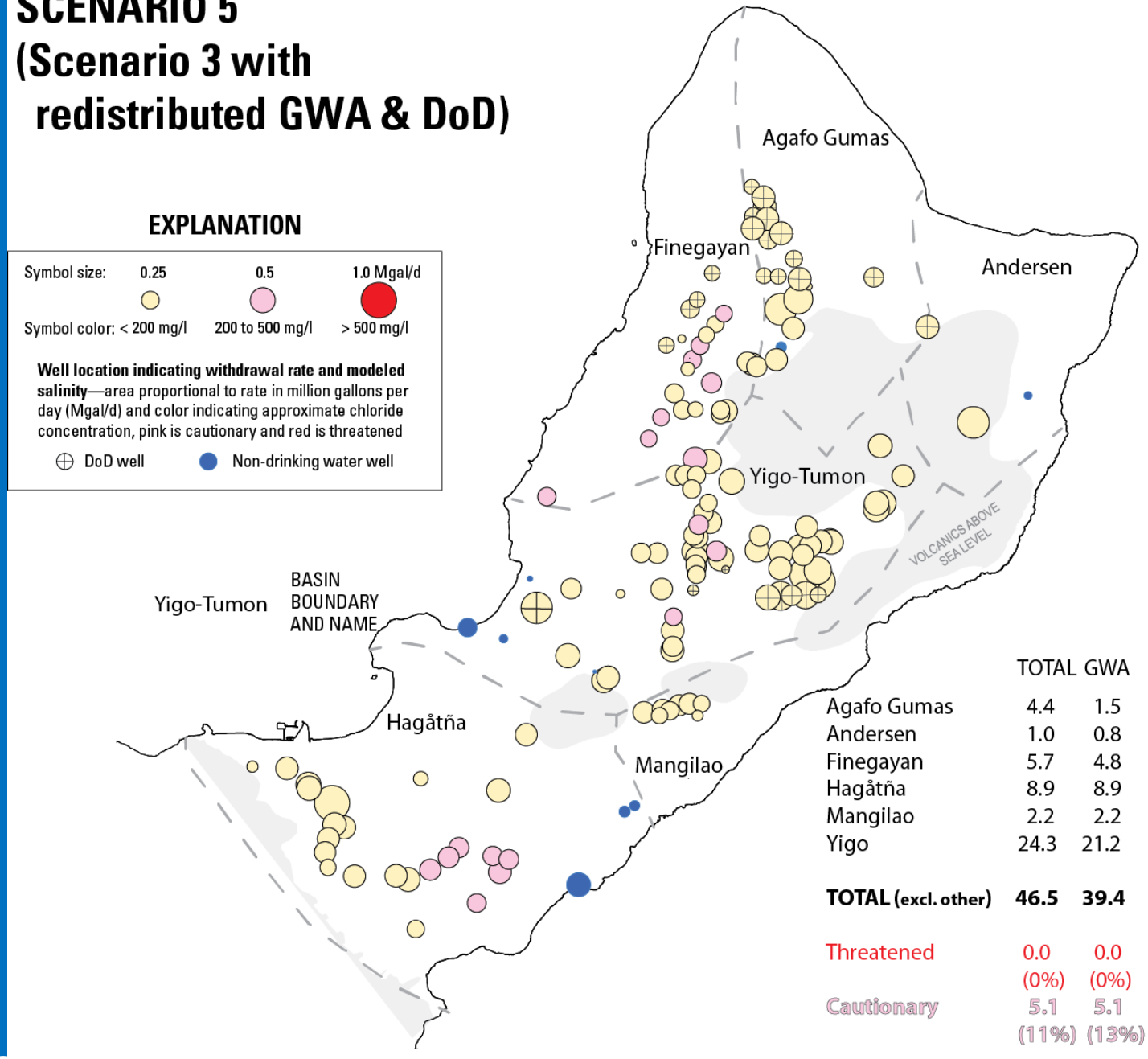
PUMPAGE, in Mgal/d

	TOTAL	GWA	DOD	OTHER
Agafo Gumas	4.5	1.5	3.0	0.9
Andersen	1.0	0.8	0.3	0.1
Finegayan	5.6	4.9	0.7	0
Hagåtña	9.1	8.8	0.3	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	24.3	21.2	3.1	0.3
TOTAL (excl. other)	**46.7**	**39.4**	**7.4**	**1.9**
Threatened	12.3 (26%)	11.1 (28%)	1.2 (16%)	
Cautionary	19.6 (42%)	16.0 (41%)	3.6 (49%)	

Scenario 5
Scenario 3 with Redistributed DoD and GWA

- Hydrologic conditions
  - Average long-term recharge
  - 2010-11 pumping rates (GWA, DoD, private wells)
  - GWA 3 new wells (AG10, Site 08, Site 12)
    - Additional 1.2 Mgal/d
  - GWA Yigo-Tumon wells
    - Additional 2.27 Mgal/d
  - Air Force 10 existing wells (AF01–05, MW05–09)
    - Additional 0.97 Mgal/d
  - USMC Tumon well - 0.8 Mgal/d (DoD:GWA; 50:50 split)
  - USMC new wells - 1.79 Mgal/d in Agafo Gumas and Andersen

SCENARIO 5
(Scenario 3 with redistributed GWA & DoD)



	TOTAL	GWA	DOD	OTHER
Agafo Gumas	4.4	1.5	2.9	0.9
Andersen	1.0	0.8	0.3	0.1
Finegayan	5.7	4.8	0.9	0
Hagåtña	8.9	8.9	0	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	24.3	21.2	3.1	0.3
TOTAL (excl. other)	**46.5**	**39.4**	**7.2**	**1.9**
Threatened	0.0 (0%)	0.0 (0%)	0.0 (0%)	
Cautionary	5.1 (11%)	5.1 (13%)	0.0 (0%)	

Modeling Implications

- Basins cannot be managed independently; for example, withdrawal from Agafo Gumas causes salinity increase in Finegayan
- Impact to GWA and DoD groundwater sources, in Mgal/d:

Condition	Total	Threatened	Cautionary
Baseline	40.3	2.2	4.2
Drought	40.3	11.4	17.8
Drought-minimized	31.9	0.0	18.8
Scenario 1	44.9	2.6	3.7
Scenario 2	47.0	2.5	4.6
Scenario 3	46.7	2.2	4.1
Scenario 4	46.7	12.3	19.6
Scenario 5	46.5	0.0	5.1

Next Steps

- Groundwater-Availability Study
  - Technical stakeholder meeting on Guam – September 2013
  - Publish final report – December 31, 2013
- Topics for consideration by DoD and GovGuam
  - New deep monitor wells and expanded monitoring
  - Groundwater modeling training
- Plans for DoD Strategic Environmental Research Development Program (SERDP) study of climate-change impacts on water resources in Guam