Water Resources on Guam: Potential impacts and adaptive response to climate change for Department of Defense installations

Project "Kick-off" Meeting

February 24, 2014

Ricardo J. Bordallo Governor's Complex

Adelup, Guam

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SERDP DOD • EPA • DOE

Outline of Meeting

- **Overview of USGS water programs in Guam**
- Brief summary of recently completed USMC-funded groundwater-availability study
- Climate-change overview
- DoD-funded study on impacts of climate change on water resources in Guam
- Stakeholder participation

Mission of the USGS Pacific Islands Water Science Center

- Provide information to manage, protect, and enhance water resources
- Address water-related hazards
- Non-regulatory role
- Provide information that is reliable, impartial, and timely to all stakeholders

Most USGS Water Programs are conducted in cooperation with Federal, State, and local agencies. USGS can provide up to 50% of the funds for programs with State and local agencies (including territories and freely associated nations). Other Federal agencies provide 100% of the funds.

USGS Water-Resource Monitoring, FY2014

Funding

• USGS	$84K
• WERI	$145K
• U.S. Navy	$142K
Total	$371K

Monitoring stations

8 Rainfall

6 Streamflow

1 Reservoir water level

8 Groundwater levels

7 Groundwater-salinity profiles

U.S. Navy:

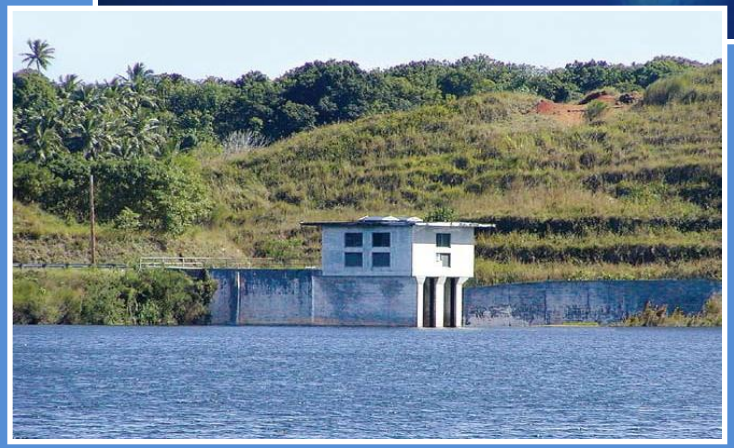
2 rainfall, 3 streamflow, and 1 reservoir water-level monitoring station

Semi-annual surveys of Fena Dam settlement markers

Quarterly updates on projected water storage in Fena Valley Reservoir

Surface-Water Availability and Flooding in Southern Guam

- High inter-annual and inter-decadal variability in climate
- Seasonal variability influenced by the El Nino Southern Oscillation (ENSO)
- Events occur every 3-7 years and last 6-18 months
- Quarterly projections of Fena reservoir storage are developed using 6-month ENSO rainfall forecast and USGS rainfall/runoff and water-balance models



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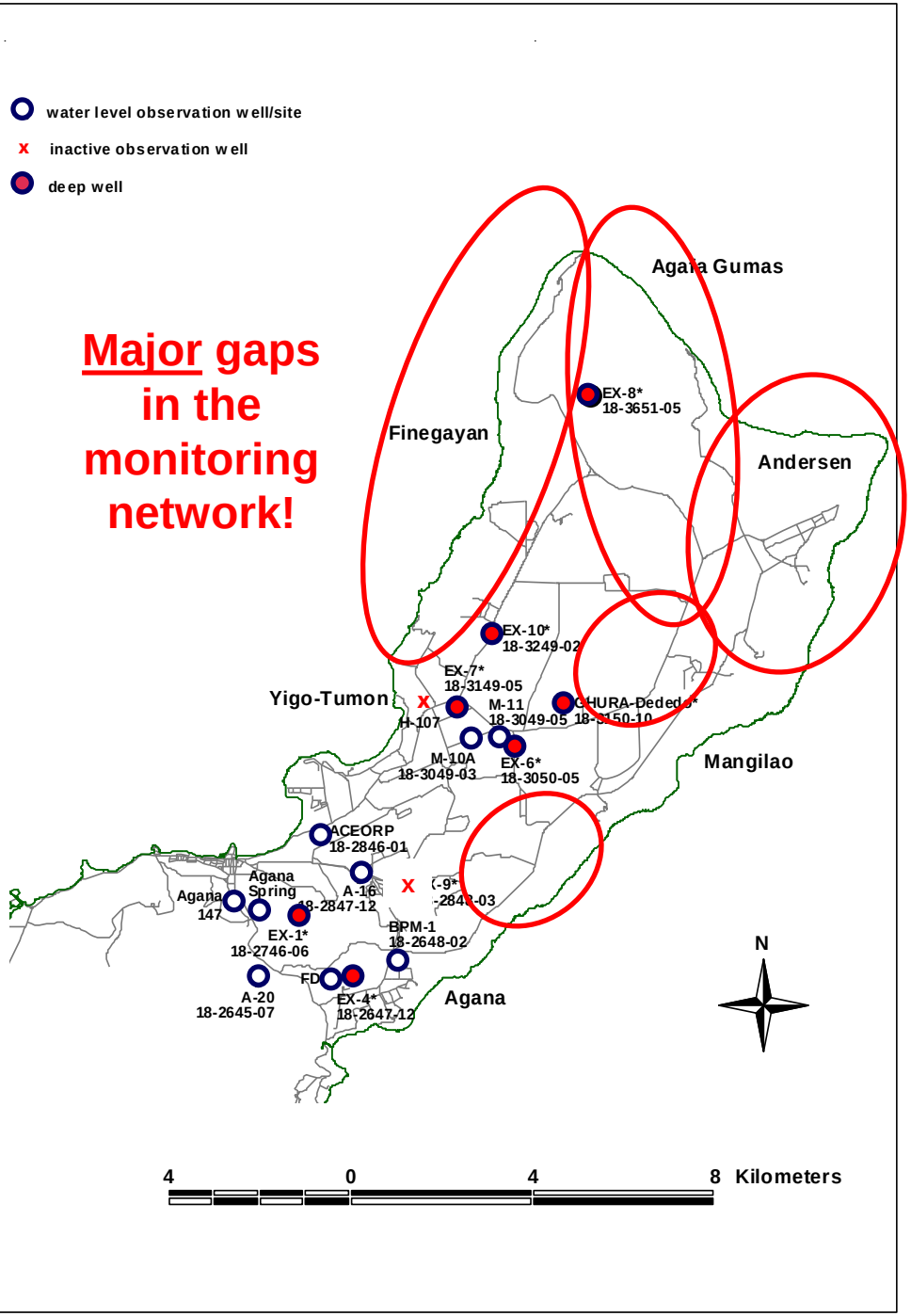
Well Monitoring in Northern Guam

- Water levels are measured continuously in 8 wells
- Salinity profiles are collected quarterly to measure the thickness of the freshwater lens in 7 wells
- Salinity was measured continuously at multiple depths in cooperation with GEPA, 2004
- Information needed to understand how current withdrawals are affecting the resource and how future changes in climate and withdrawals may affect long-term groundwater availability

Well monitoring is conducted in cooperation with WERI



Aquifer Monitoring

- Existing network
  - Major gaps in 4 of 6 basins
  - Mostly excludes DoD land
  - Installed in 1982
  - Last rehab in 1998
- WERI-USGS proposal
  1. Rehab existing wells
  2. Upgrade instruments
  3. Install additional wells
  4. Expanded long-term monitoring

Proposed Expansion of Long-Term Aquifer Monitoring in Northern Guam

- Capital improvement costs for rehabilitation of existing wells, and design, construction, and testing of new deep monitoring wells - $2-3M
  - 15 existing monitoring wells need to be rehabilitated
  - 8 new deep monitoring wells are needed for areas that lack a deep monitor well but are either already developed or planned for groundwater development
  - Office of Economic Adjustments is possible funding source
- Annual costs for expanded long-term aquifer monitoring

Agency	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
DoD	57,000	73,000	63,000	63,000	95,000
GovGuam	196,000	190,000	226,000	221,000	216,000
USGS	70,000	70,000	70,000	70,000	70,000
Total	**$323,000**	**$333,000**	**$359,000**	**$354,000**	**$381,000**

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Guam Groundwater-Availability Study

Funded by U.S. Marine Corps during 2010–13 to:

- 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

Published Reports

Study overview
USGS Fact Sheet

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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 3.5-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.

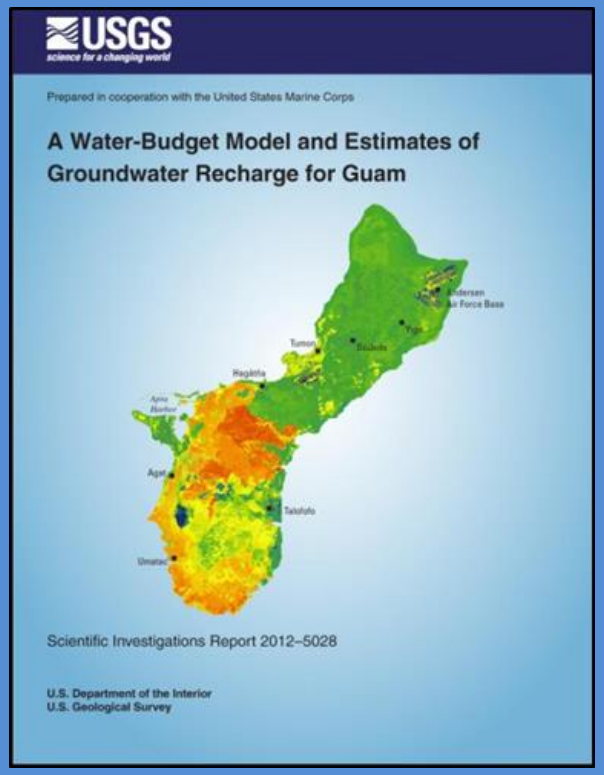
Introduction

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



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Prepared in cooperation with the United States Marine Corps

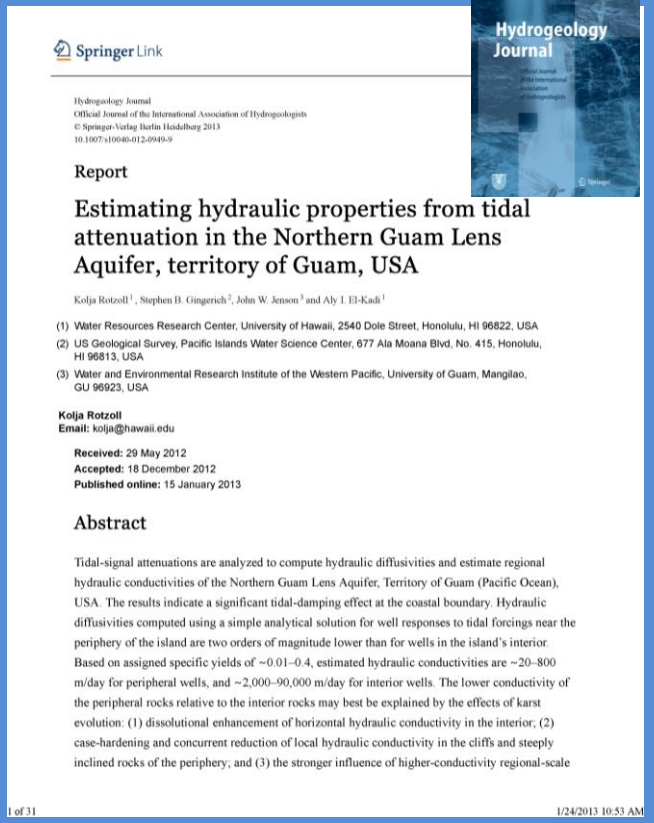
A Water-Budget Model and Estimates of Groundwater Recharge for Guam

Scientific Investigations Report 2012–5028

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

Recharge estimate
USGS Report

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

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(2) US Geological Survey, Pacific Islands Water Science Center, 677 Ala Moana Blvd, No. 415, Honolulu, HI 96813, 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

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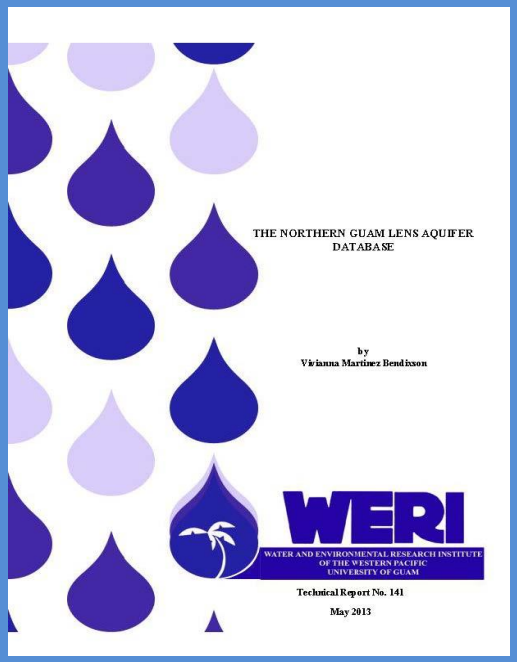
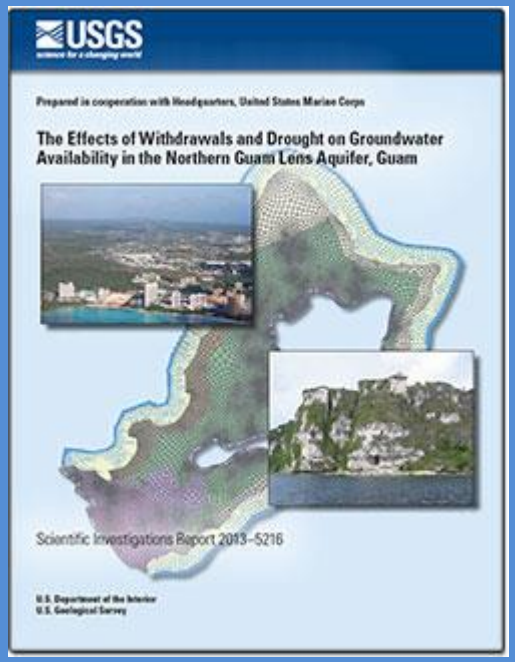
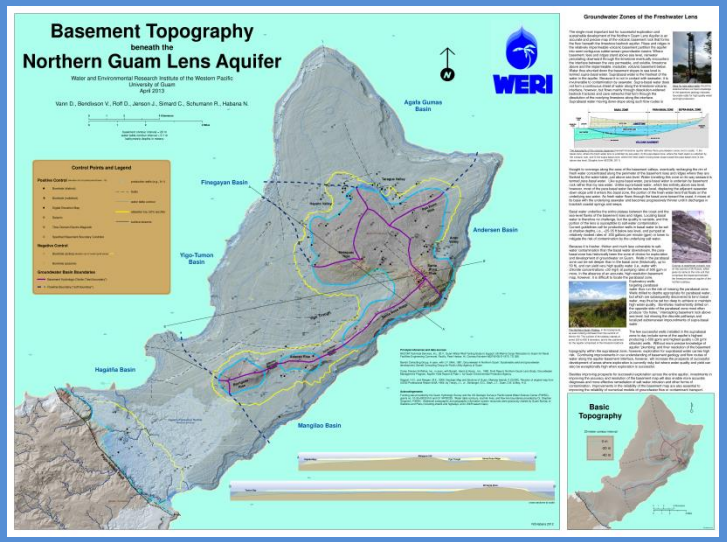
Published Reports

Well database
WERI Tech Report



Groundwater availability
USGS Report



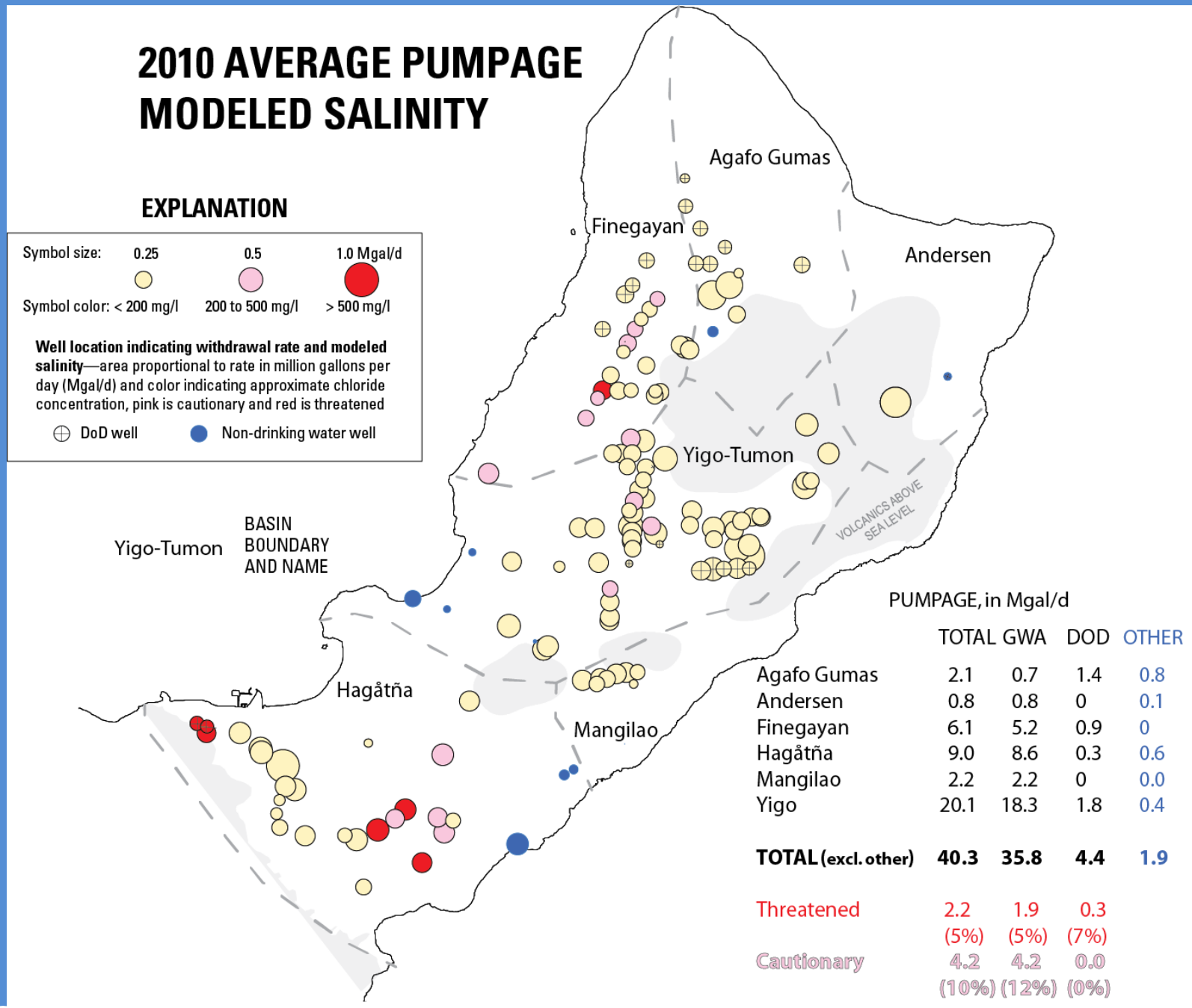


Volcanic basement
WERI Tech Report

Groundwater Model Calibration – Baseline Condition

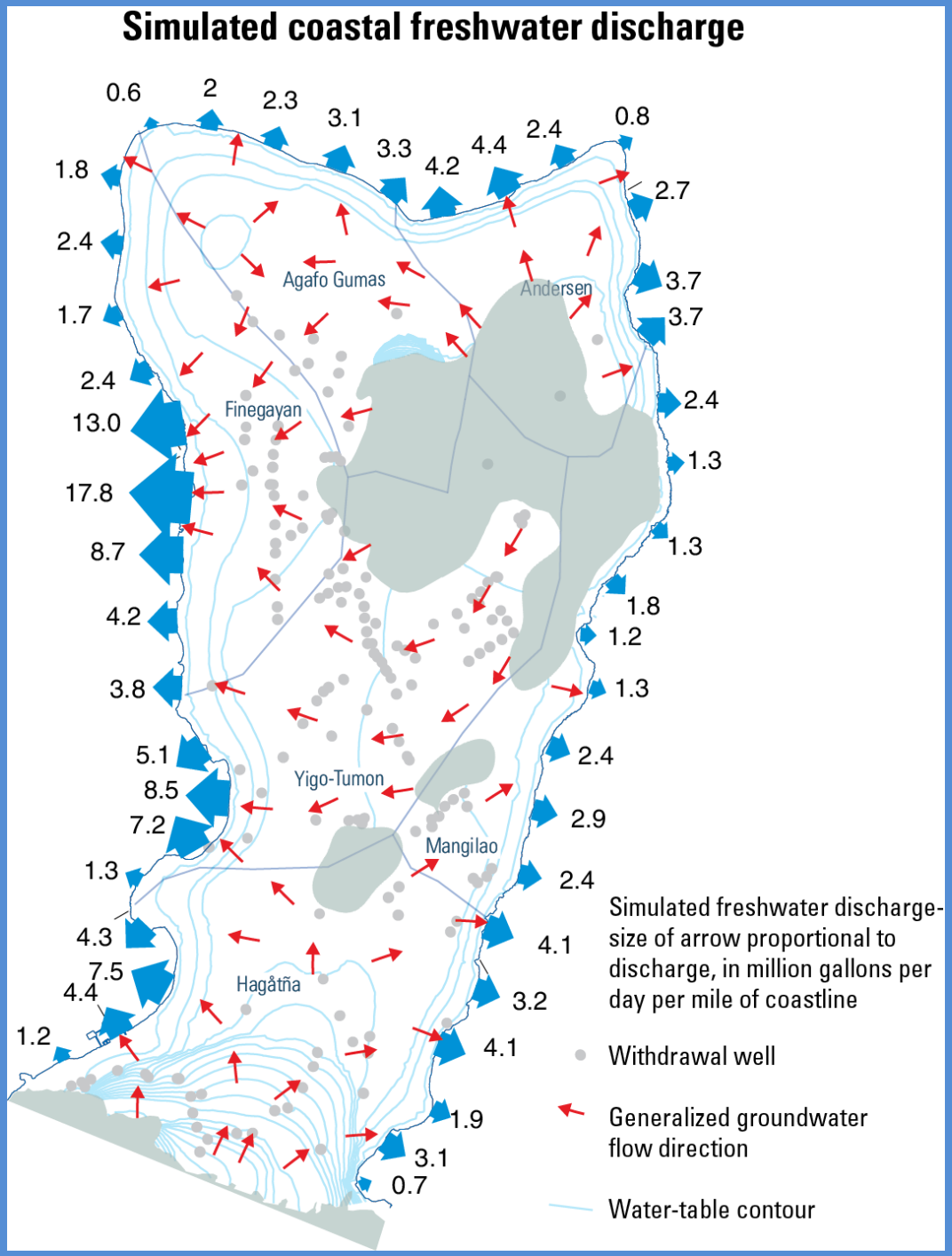
- Hydrologic conditions
  - Long-term average recharge
    - 1961-2005 rainfall
    - 2004 land cover
  - 2010 pumping rates
- Calibration targets
  - Average 2010 water levels and tidal fluctuations
  - December 2009 salinity profiles

2010 AVERAGE PUMPAGE MODELED SALINITY



PUMPAGE, in Mgal/d

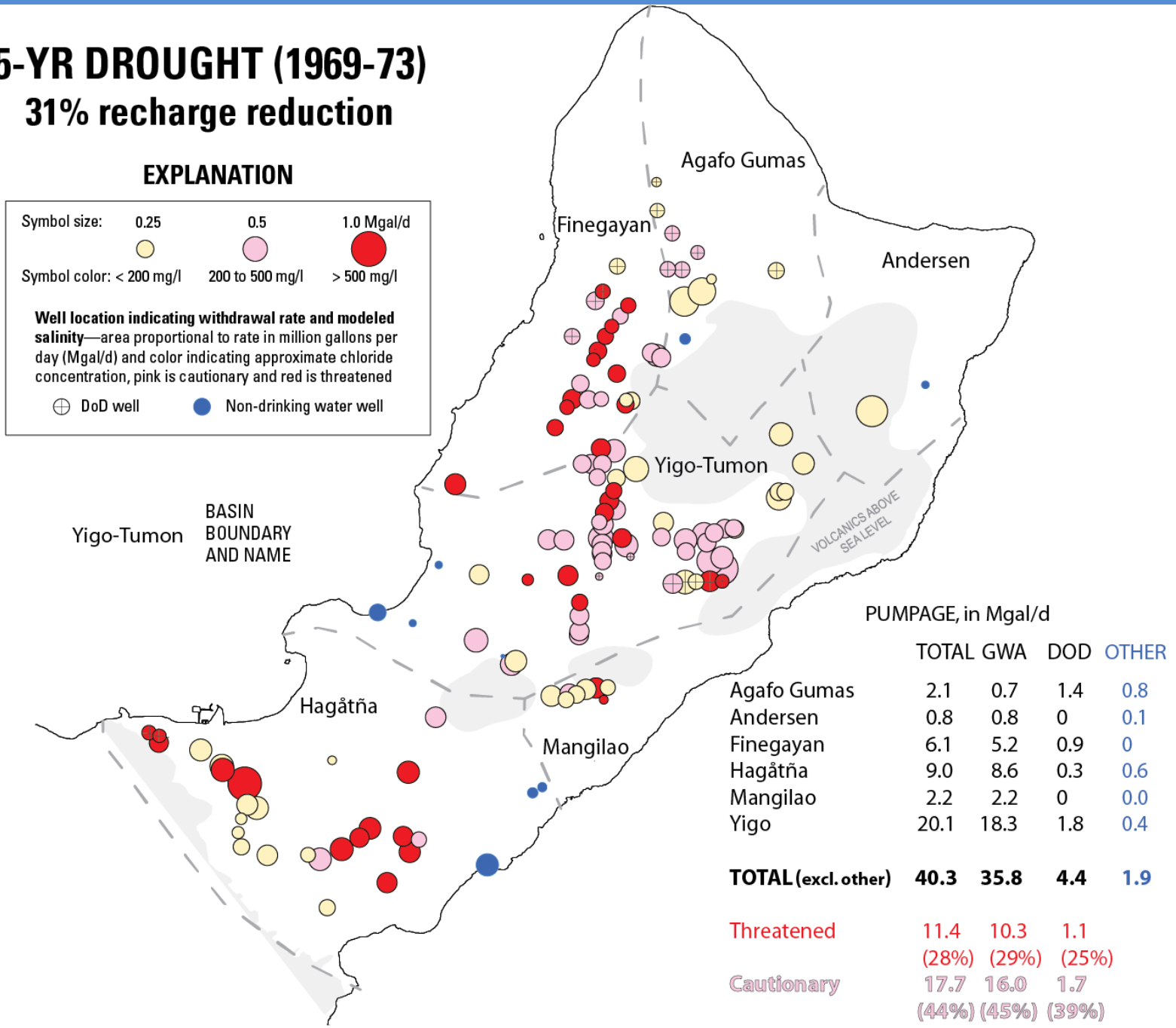
	TOTAL	GWA	DOD	OTHER
Agafo Gumas	2.1	0.7	1.4	0.8
Andersen	0.8	0.8	0	0.1
Finegayan	6.1	5.2	0.9	0
Hagåtña	9.0	8.6	0.3	0.6
Mangilao	2.2	2.2	0	0.0
Yigo	20.1	18.3	1.8	0.4
TOTAL (excl. other)	**40.3**	**35.8**	**4.4**	**1.9**
Threatened	2.2 (5%)	1.9 (5%)	0.3 (7%)	
Cautionary	4.2 (10%)	4.2 (12%)	0.0 (0%)	


Simulated coastal freshwater discharge
0.6
2
2.3
3.1
3.3
4.2
4.4
2.4
0.8
1.8
2.7
2.4
3.7
1.7
3.7
2.4
2.4
13.0
1.3
17.8
1.3
8.7
1.8
4.2
1.2
3.8
1.3
5.1
2.4
8.5
2.9
7.2
2.4
1.3
4.3
4.1
7.5
4.4
3.2
1.2
4.1
1.9
3.1
0.7
Agafo Gumas
Andersen
Finegayan
Yigo-Tumon
Mangilao
Hagåtña
Simulated freshwater discharge-size of arrow proportional to discharge, in million gallons per day per mile of coastline
Withdrawal well
Generalized groundwater flow direction
Water-table contour

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



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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%)	

Groundwater-Availability Study Findings

- Acceptable yield (total minus threatened and cautionary) reduced from 33.9 Mgal/d to 11.5 Mgal/d during 5-yr drought
- Future growth + buildup leads to increased salinity, mainly in Finegayan and Agafo Gumas basins
- Basins cannot be managed independently; for example, withdrawal from Agafo Gumas causes salinity increase in Finegayan
- Redistribution of withdrawal can improve overall pumped-water salinity and provide 46.5 Mgal/d
- Groundwater model and expanded monitoring needed for continuing sustainable management of Northern Guam Lens Aquifer

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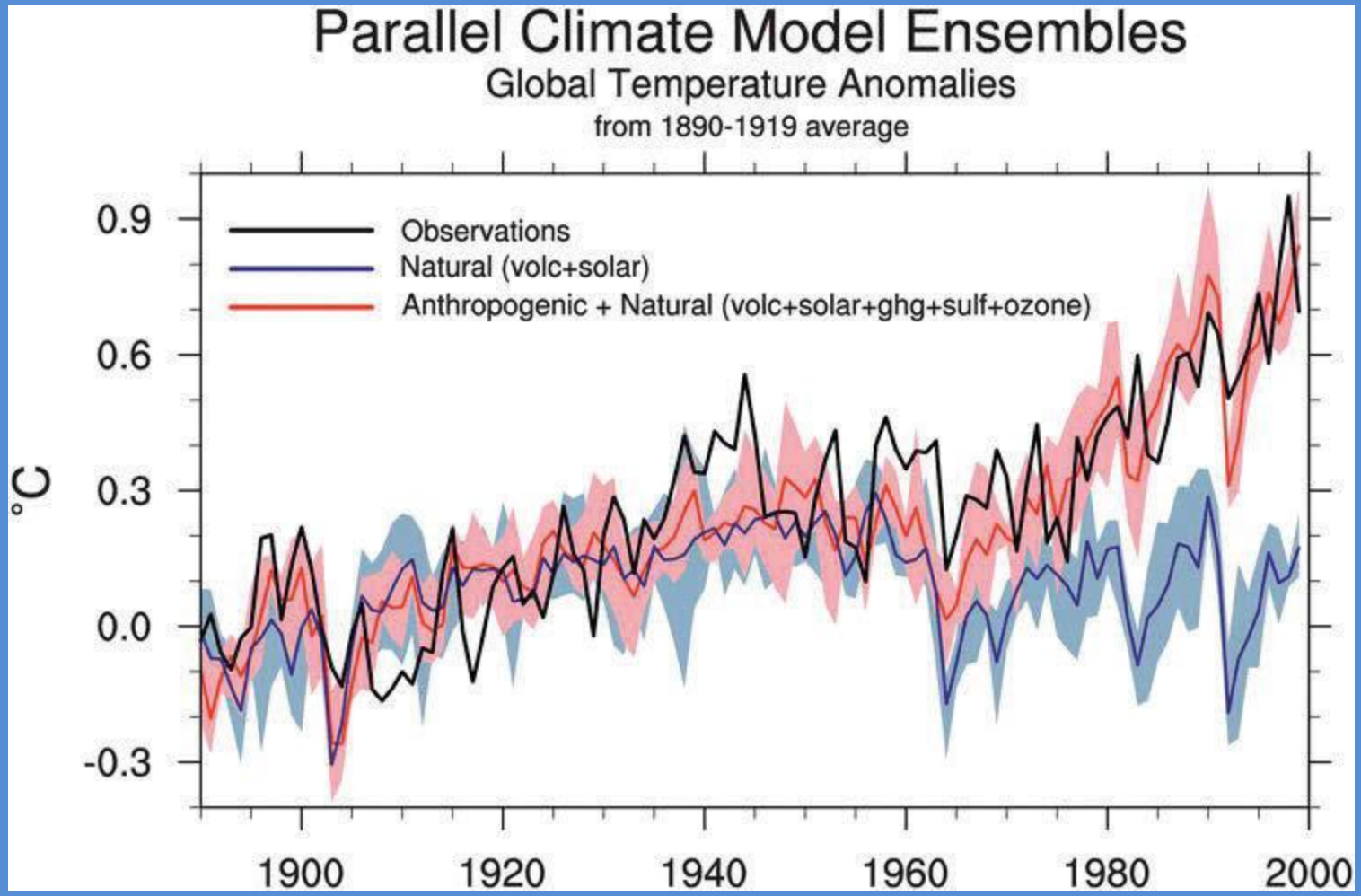
Simulated Natural vs. Human-Induced Global Temperature, 1890-2000



Meehl, G. A., Hu, A., & Santer, B. D. (2009). The mid-1970s climate shift in the Pacific and the relative roles of forced versus inherent decadal variability. Journal of Climate, 22(3), 780–792. doi:10.1175/2008JCLI2552.1

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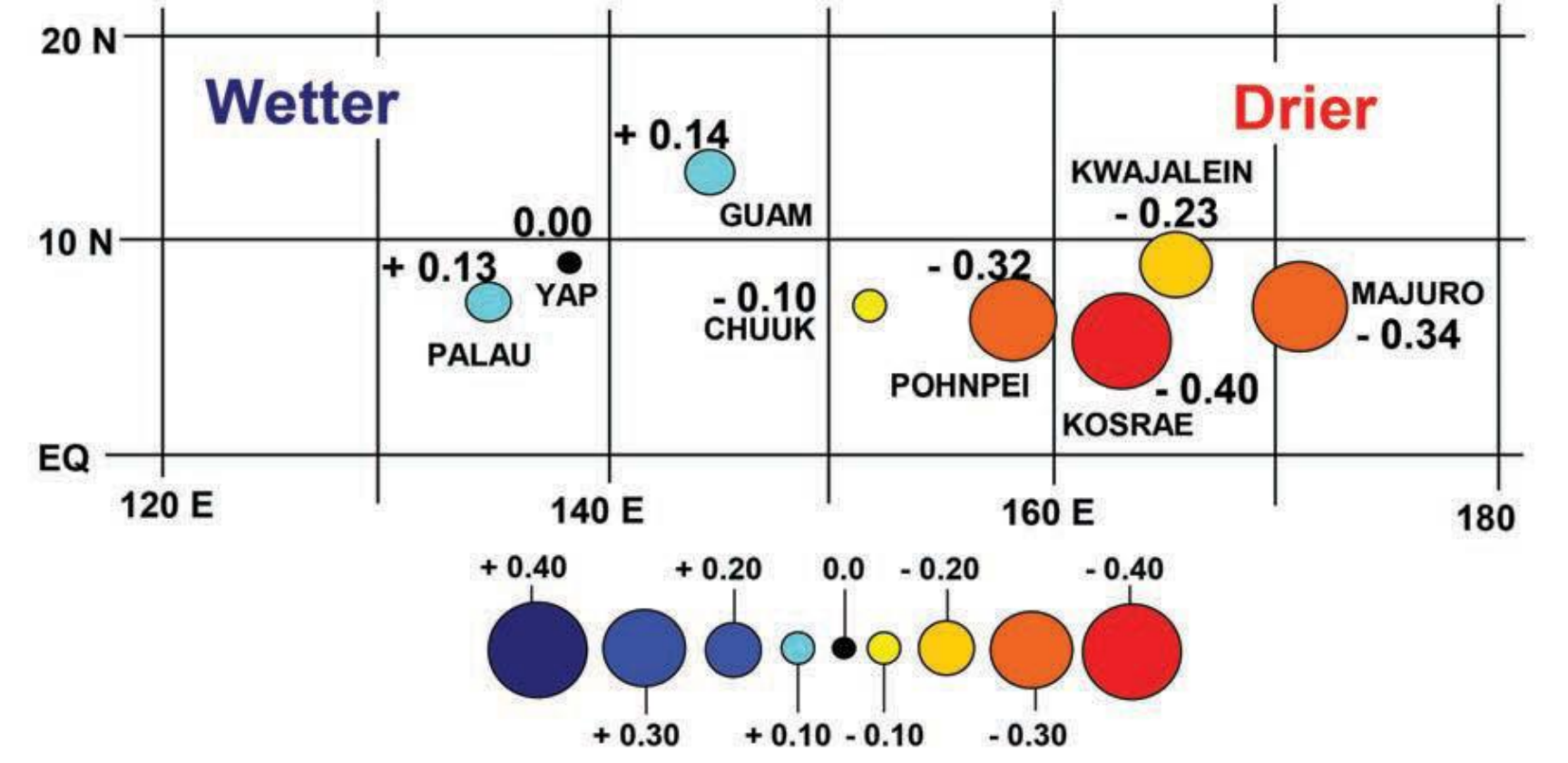
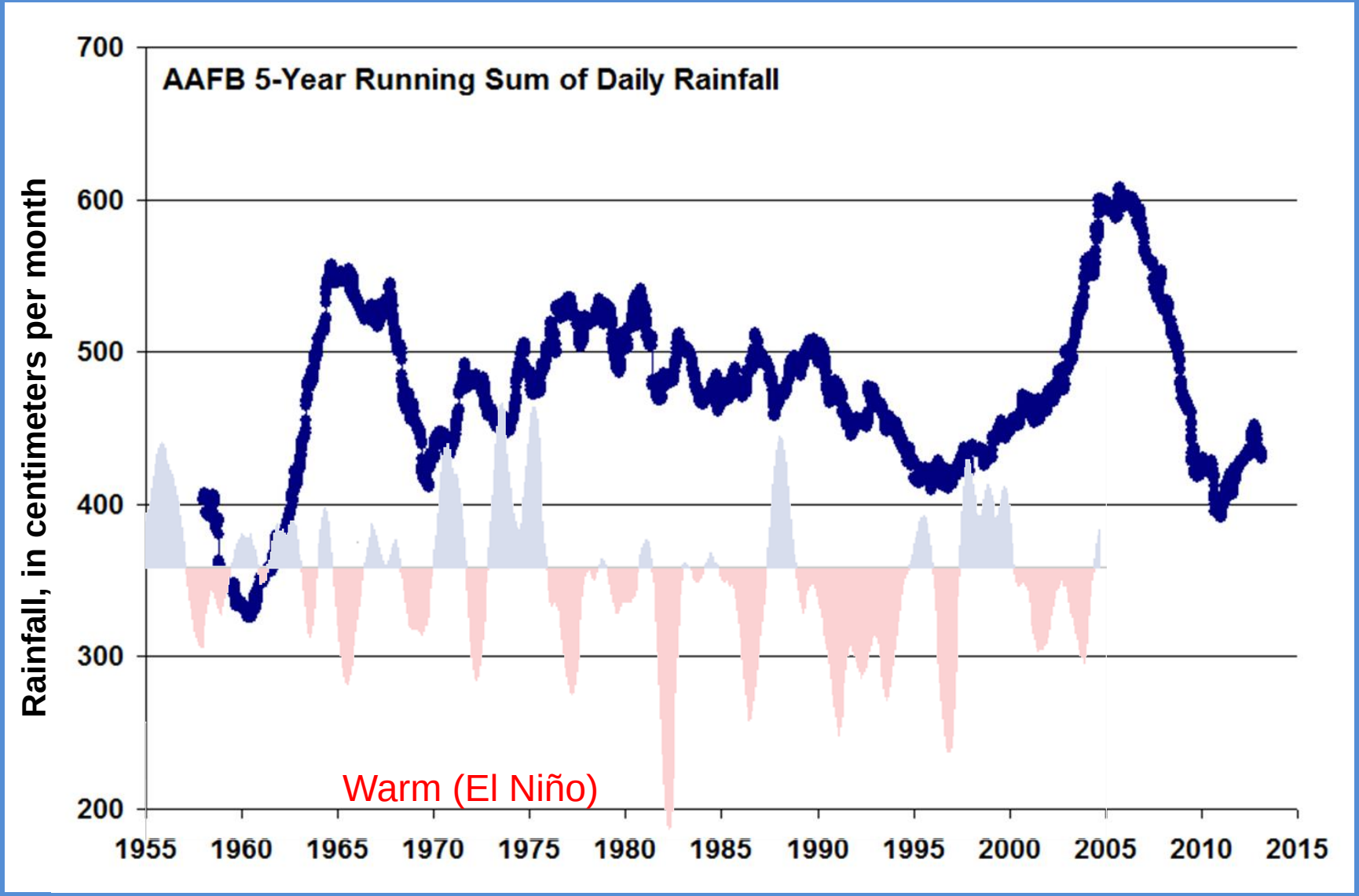
Annual Rainfall Anomaly, 1950-2010

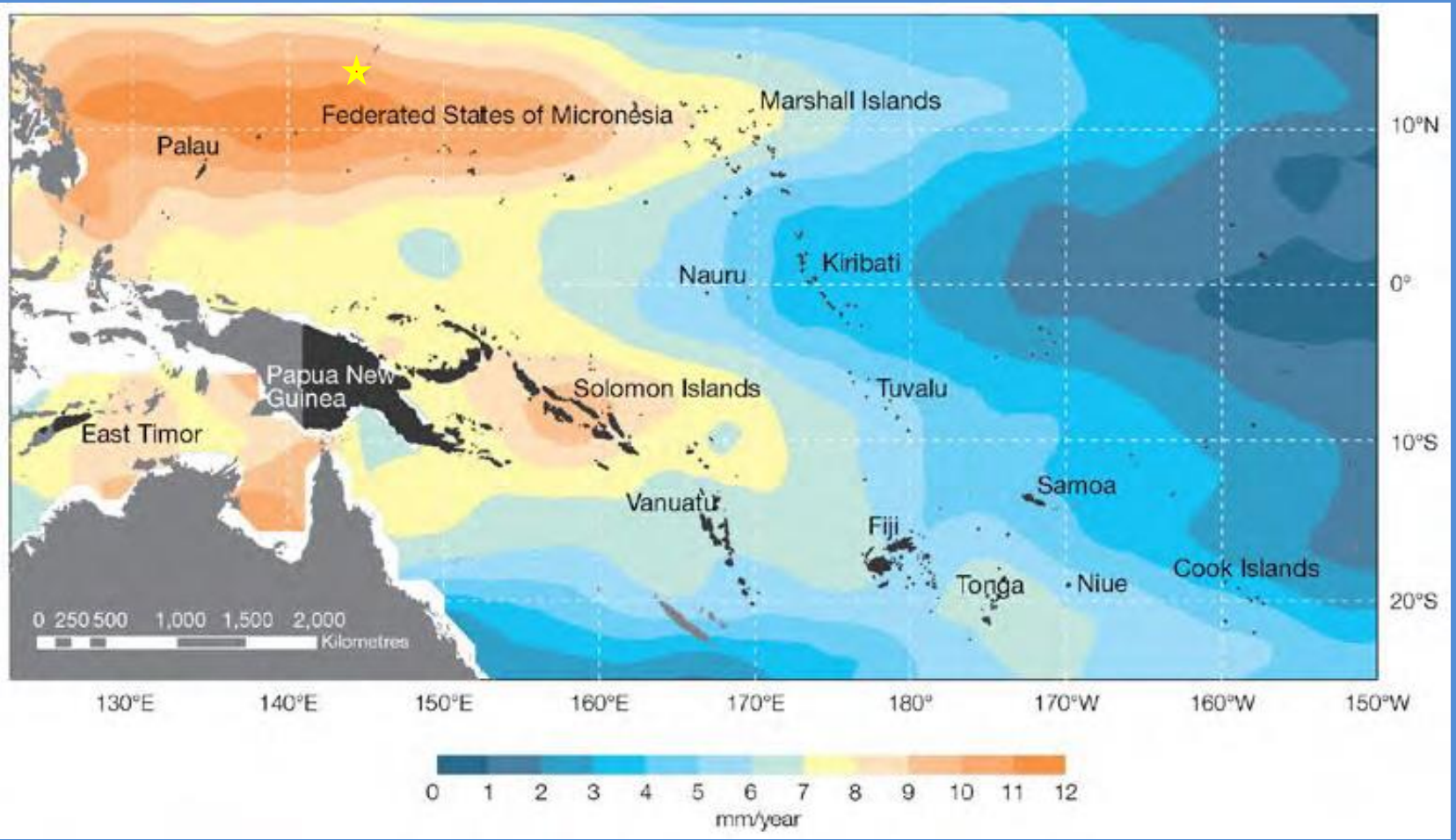


Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). (2012). Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment. Washington, DC: Island Press.

Annual Rainfall Variability, 1956–2013



Observed Sea-Level Rise, 1993–2009



Church, J. A. and N.J. White (2011), Sea-level rise from the late 19th to the early 21st Century. Surveys in Geophysics, doi:10.1007/s10712-011-9119-1.

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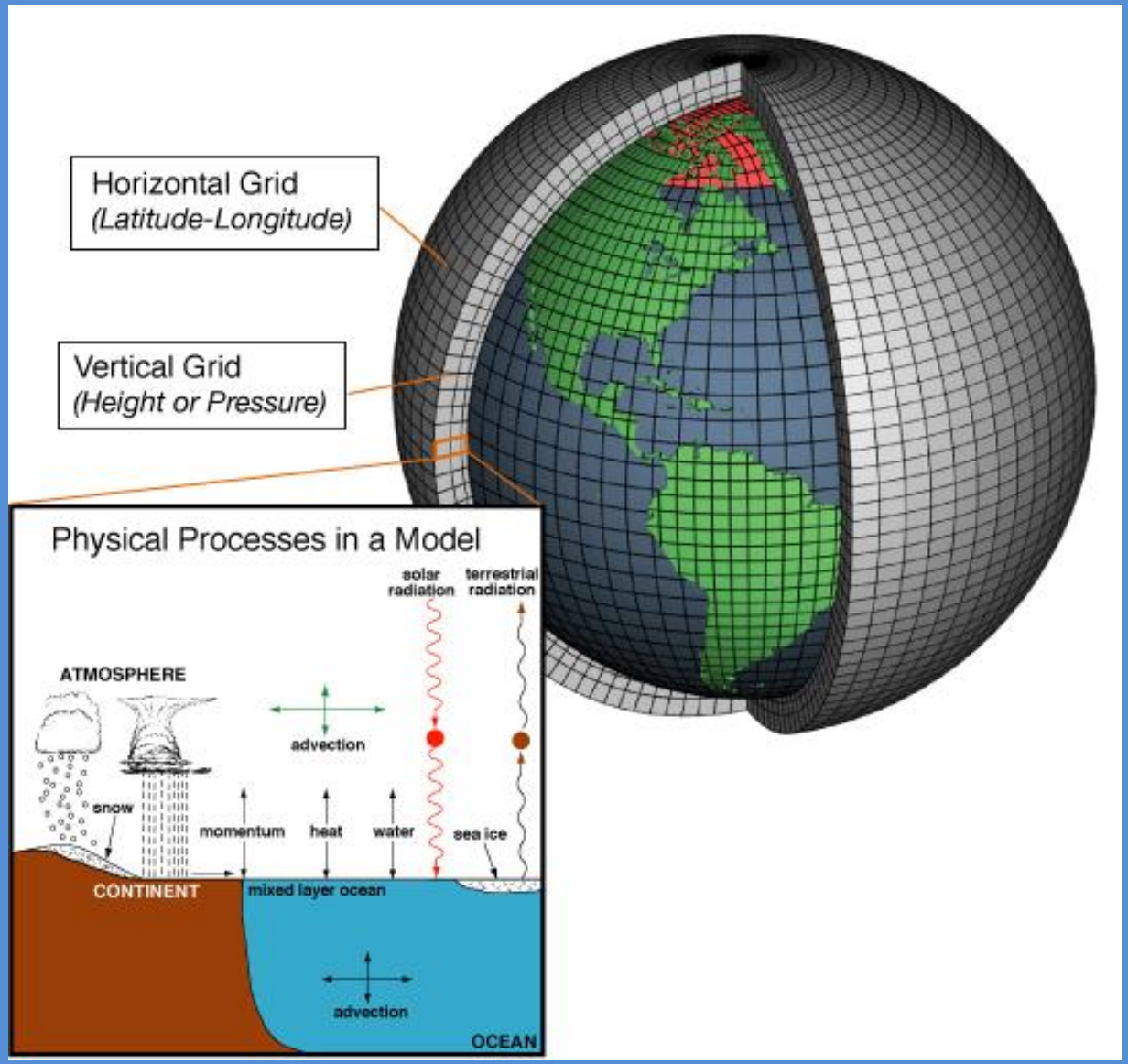
Future Climate Predicted from Global Models



NOAA, 2012

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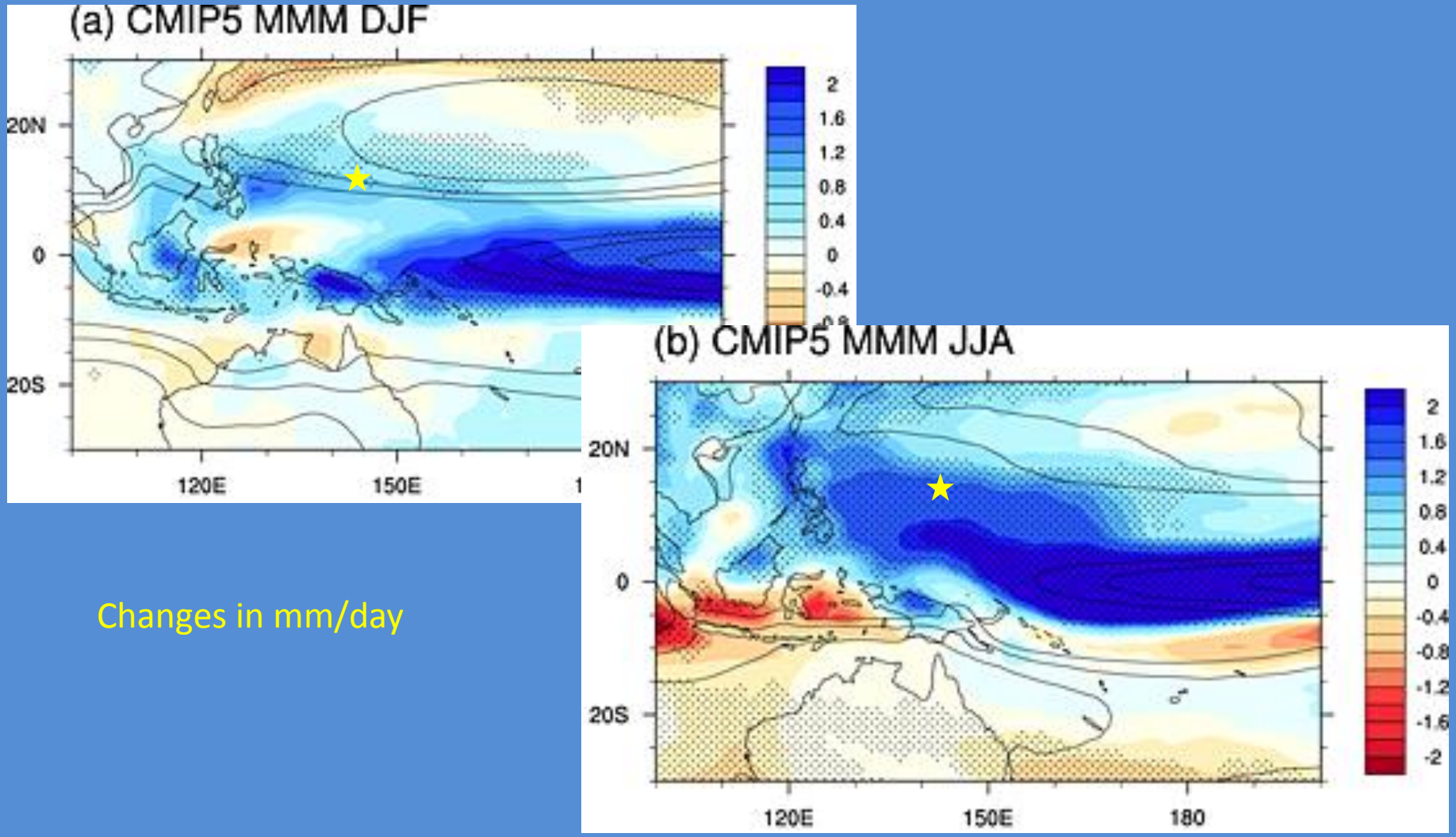
Projected Changes in Rainfall, 2090



Changes in mm/day

Journal of Geophysical Research: Atmospheres Volume 118, Issue 22, pages 12,458-12,475, 22 NOV 2013 DOI: 10.1002/2013JD020290

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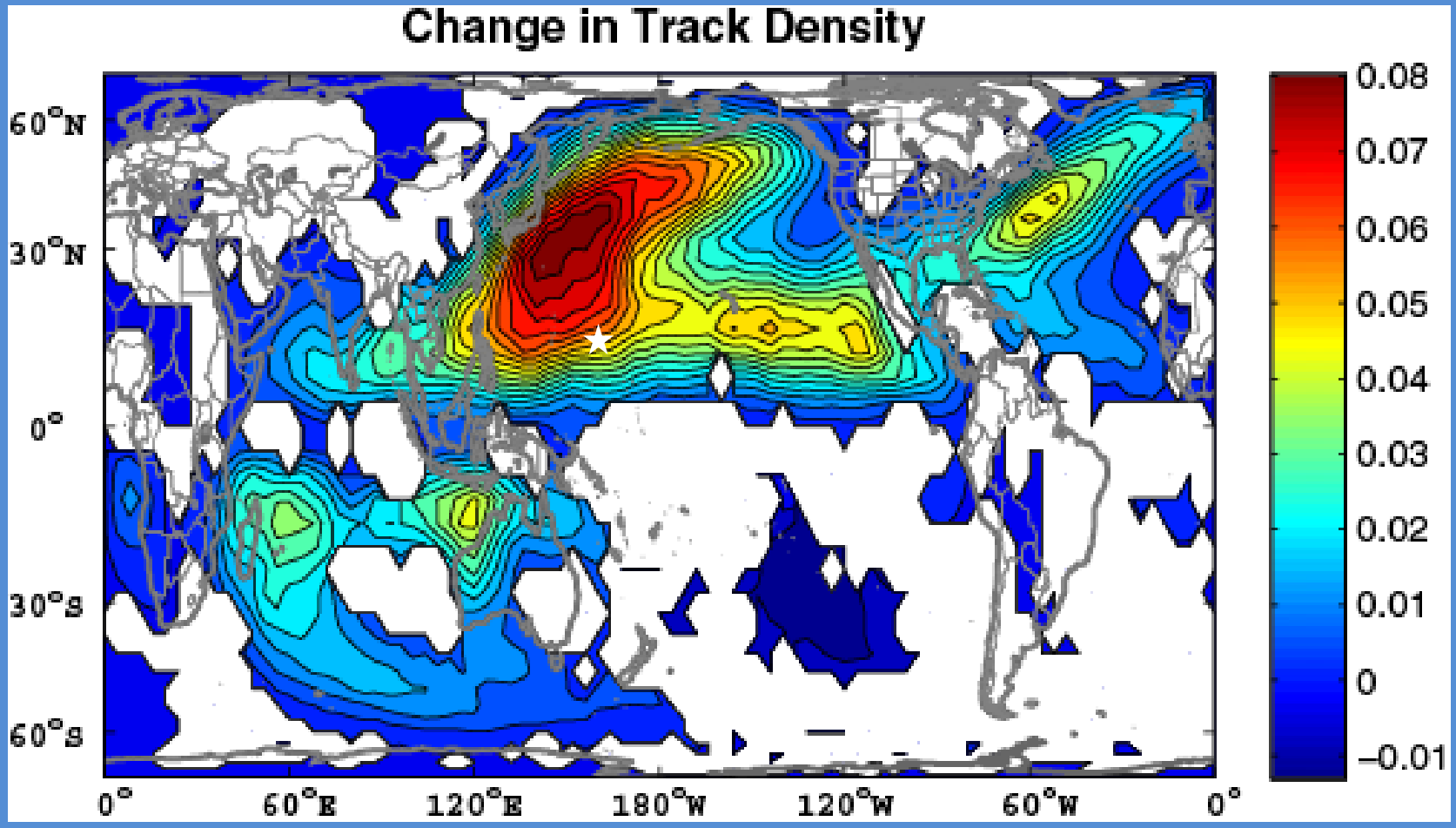
Projected Changes in Typhoons, 2006–2100



Emanuel, K.A., 2013, Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century: www.pnas.org/cgi/doi/10.1073/pnas.1301293110

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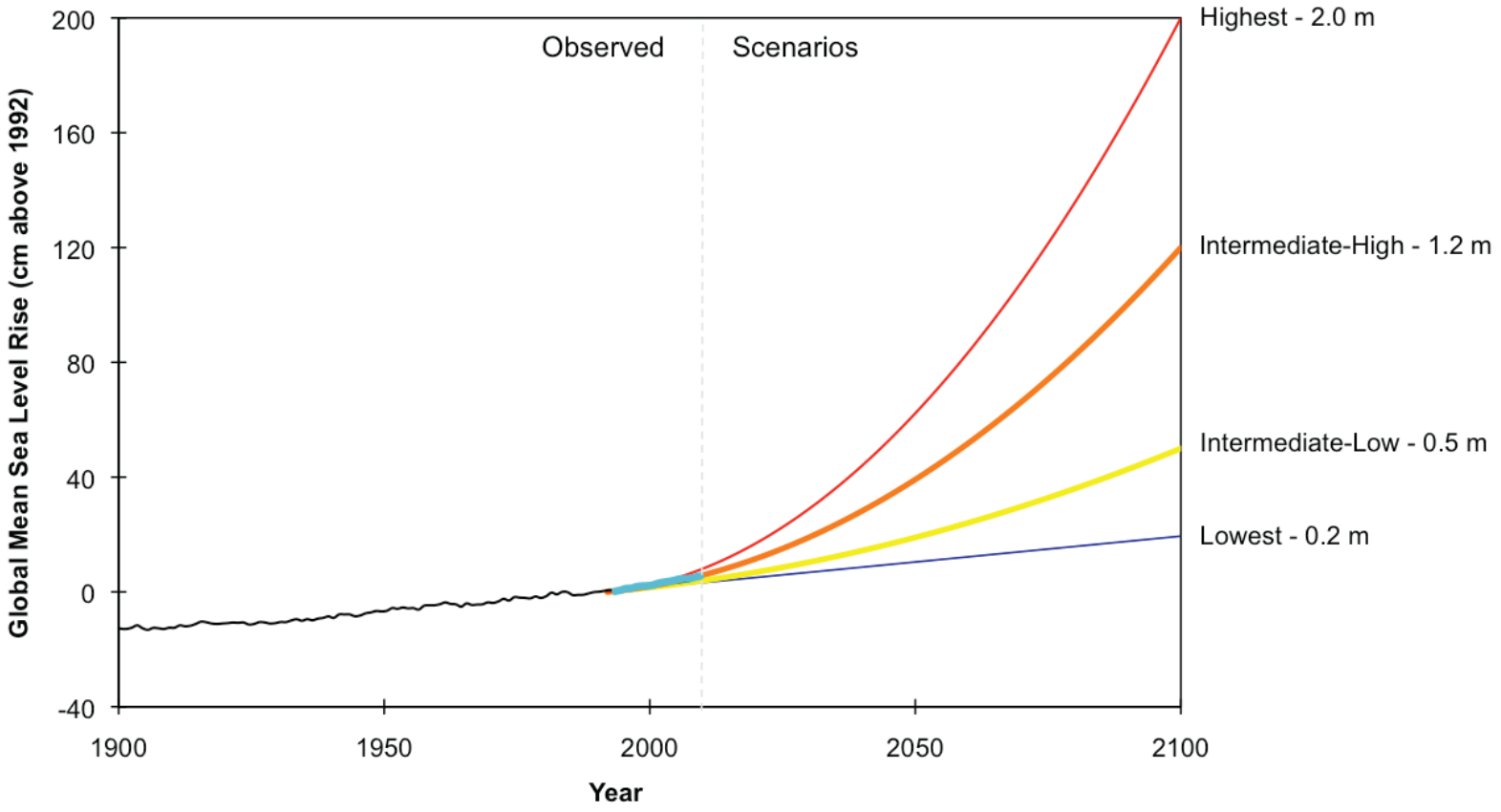
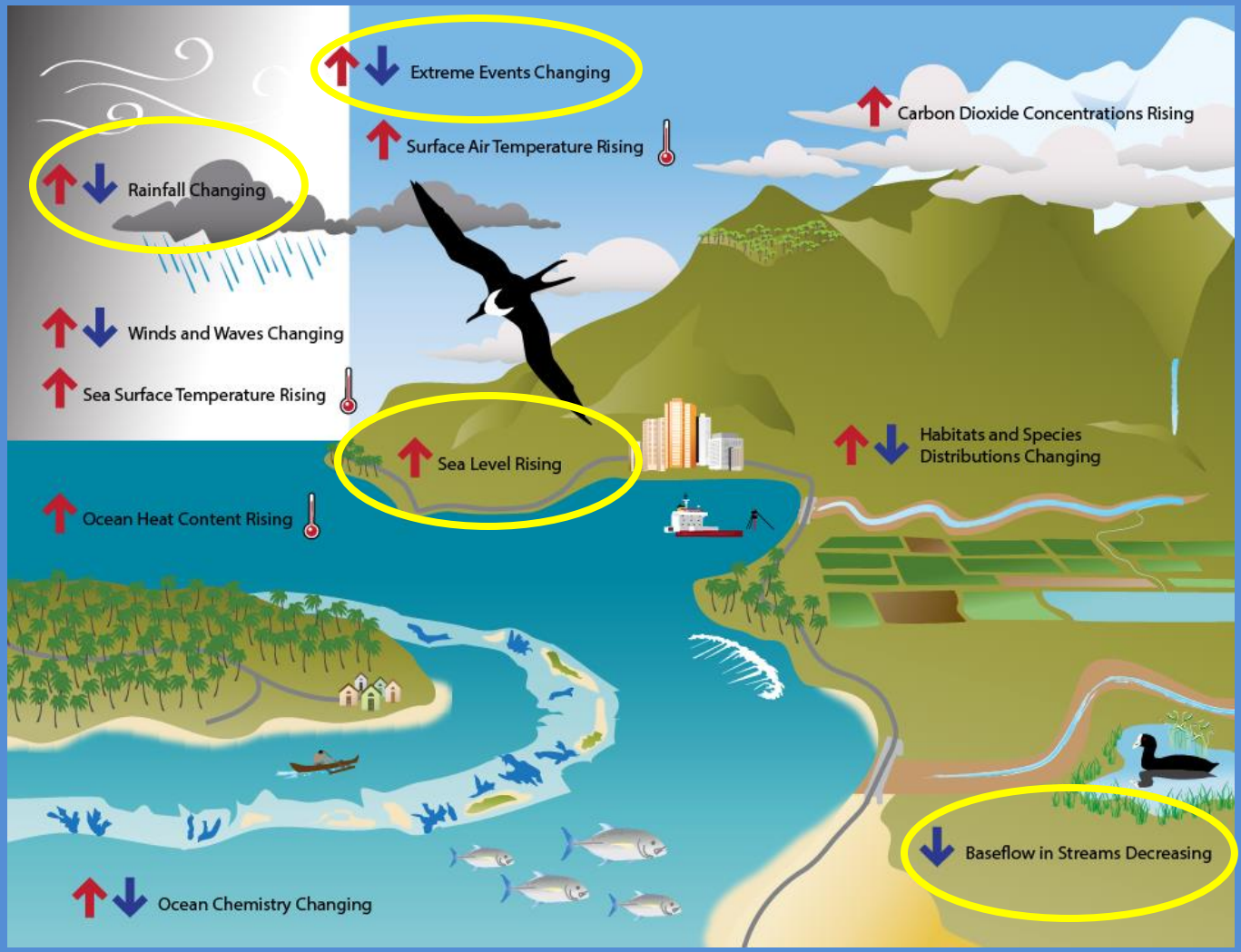
Global Mean Sea-Level Rise Scenarios



Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

Indicators of Climate Change



Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). (2012). Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment. Washington, DC: Island Press.

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SERDP
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Strategic Environmental Research and Development Program

Water Resources on Guam: Potential Impacts and Adaptive Response to Climate Change for Department of Defense Installations

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IPRC
INTERNATIONAL PACIFIC RESEARCH CENTER

THE UNIVERSITY OF TEXAS AT AUSTIN

WERI

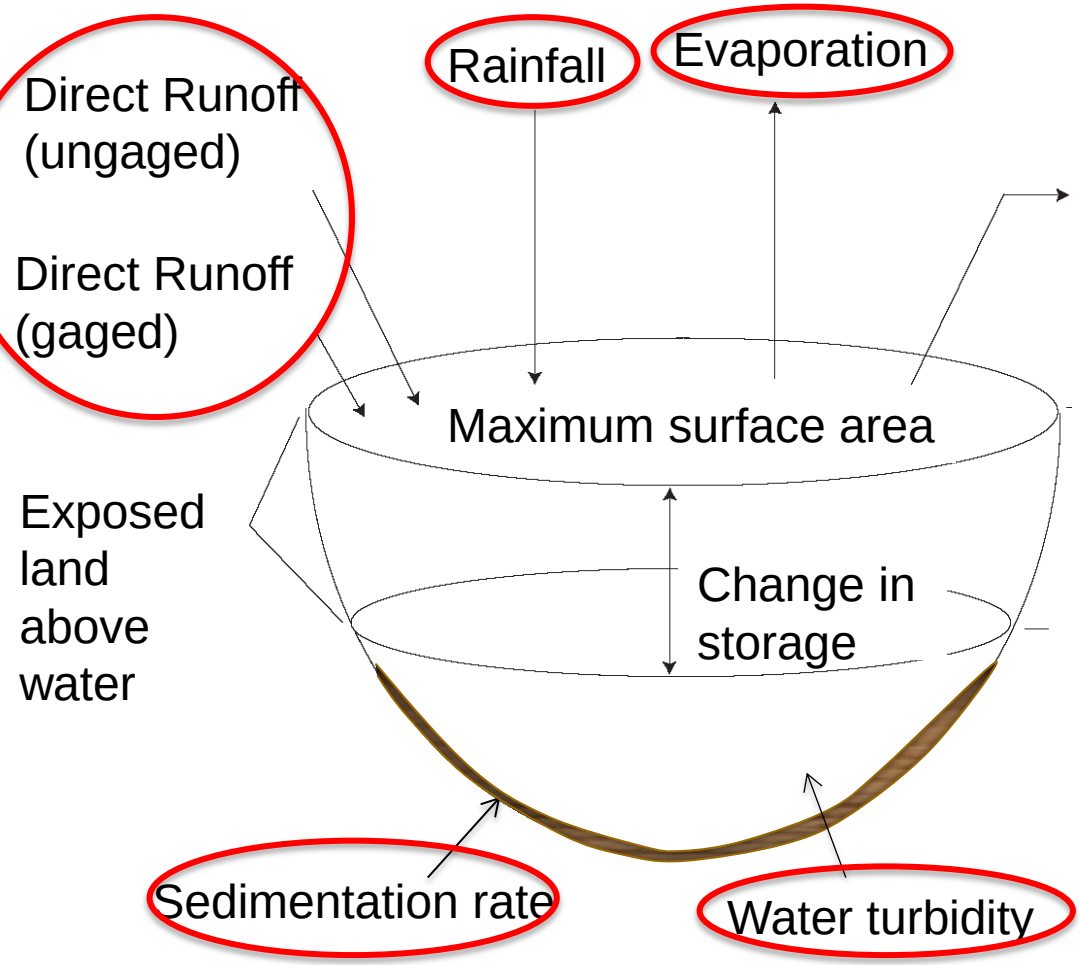
EAST-WEST CENTER

SERDP 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?

Fena Valley Reservoir

Affected by climate change



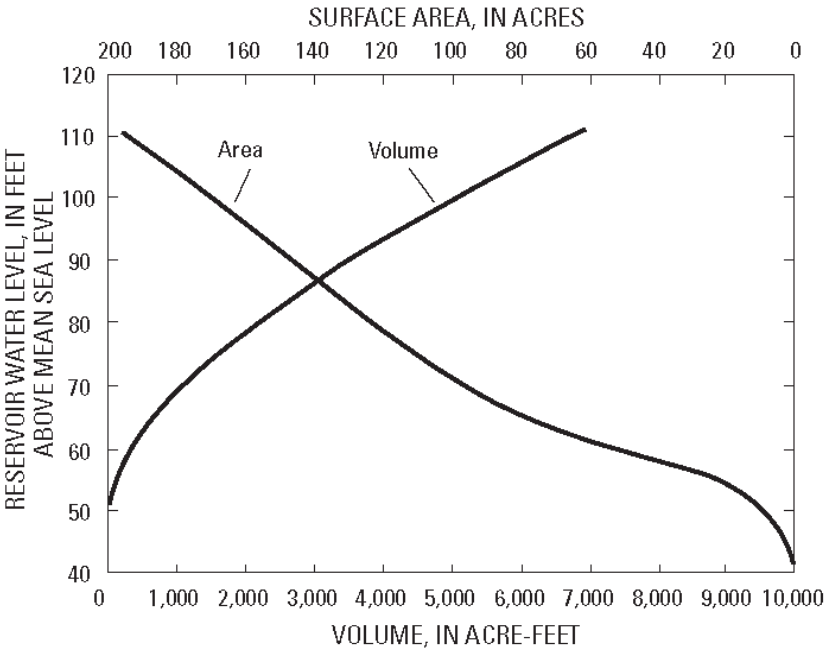
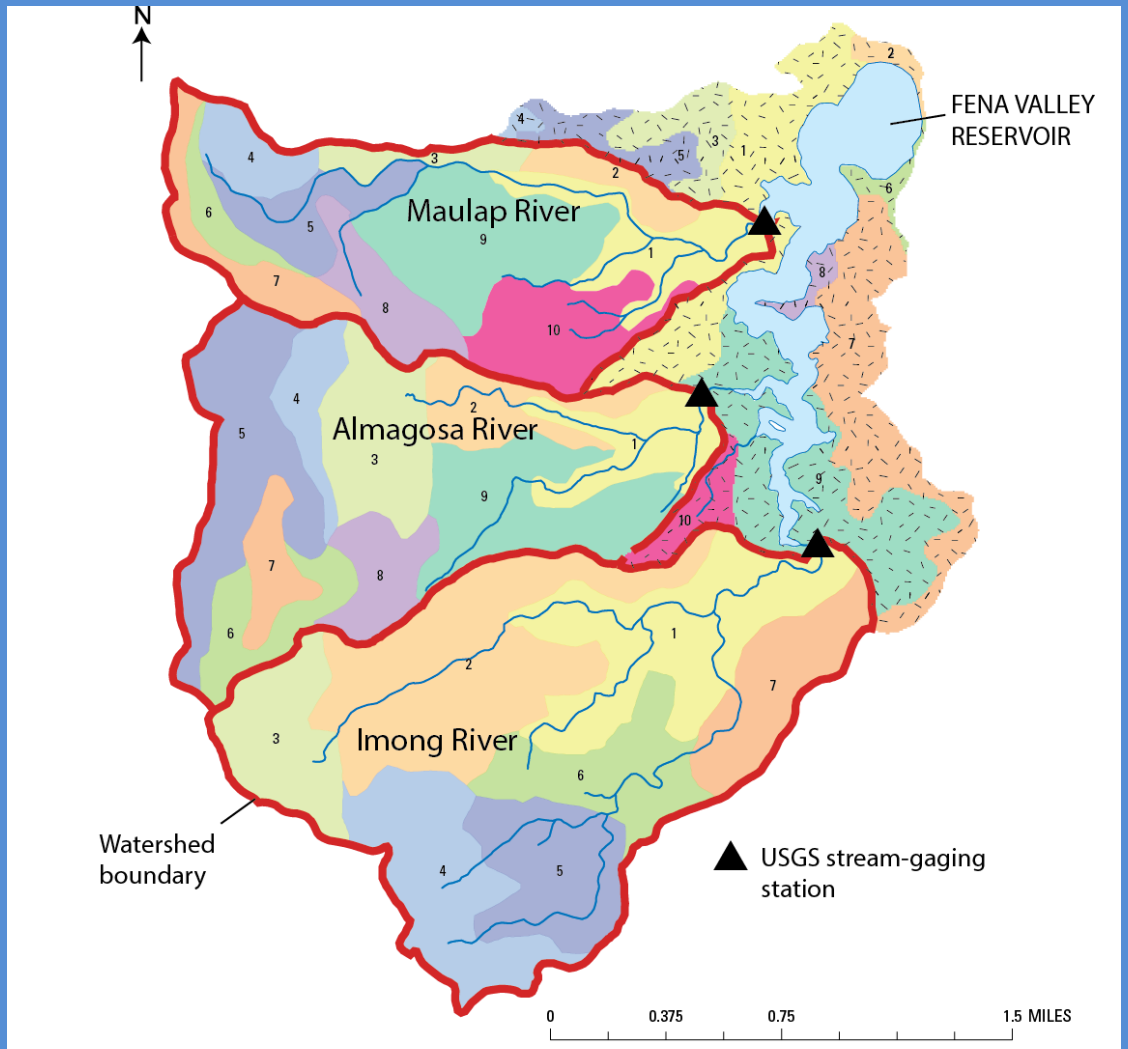


Figure 27. Water level-surface area and water level-capacity curves for the Fena Valley Reservoir, Guam, 1990 (Nakama, 1992).

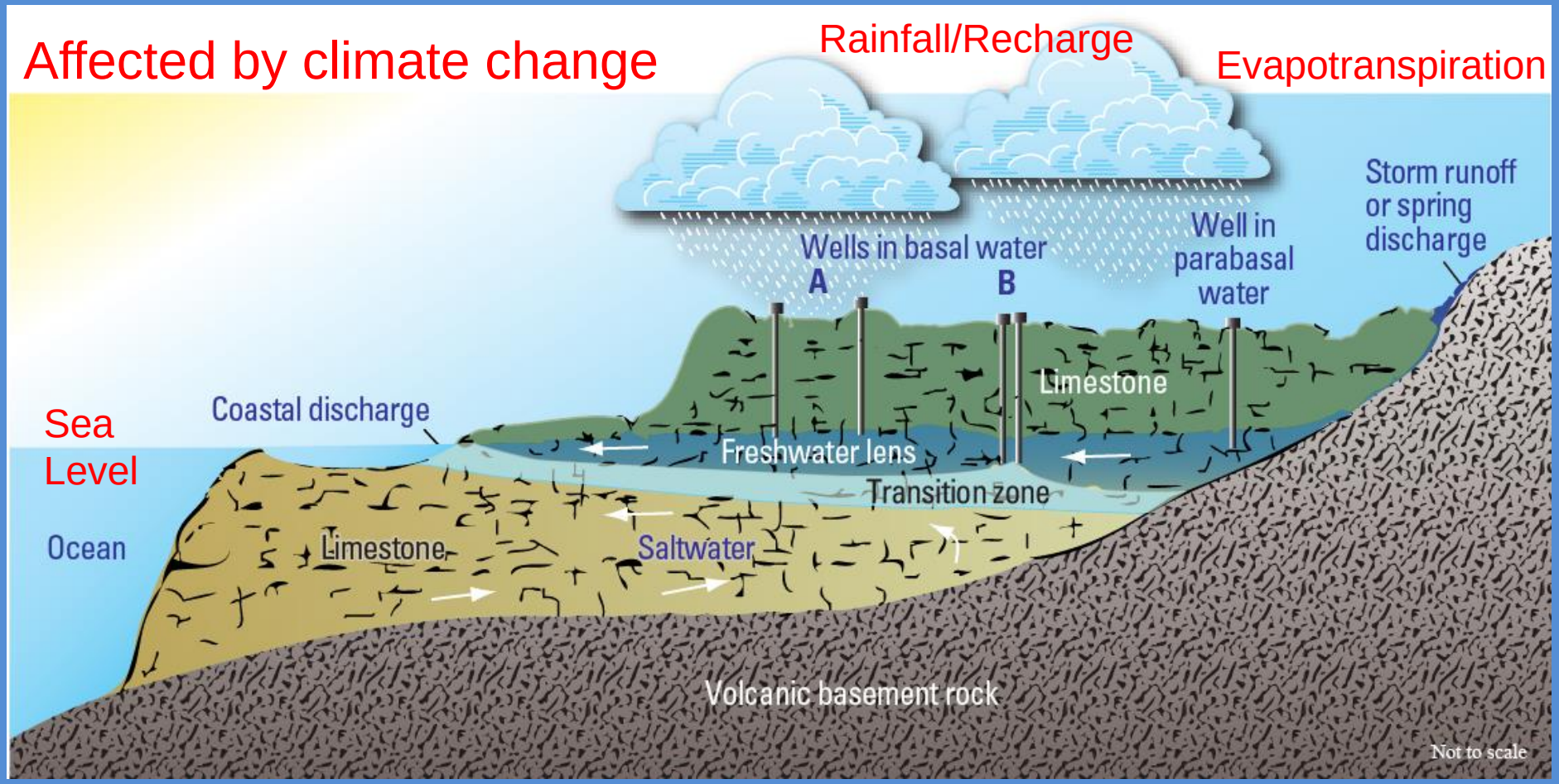
Fena Valley Watershed

- Existing USGS Precipitation-Runoff Modeling System (PRMS)
- Calibrated using USGS stream-gaging stations and rainfall stations
- Limited areal extent
- Factors vulnerable to climate change
  - Vegetation
  - Rainfall
  - Evapotranspiration
  - Runoff
  - Extreme event size and frequency

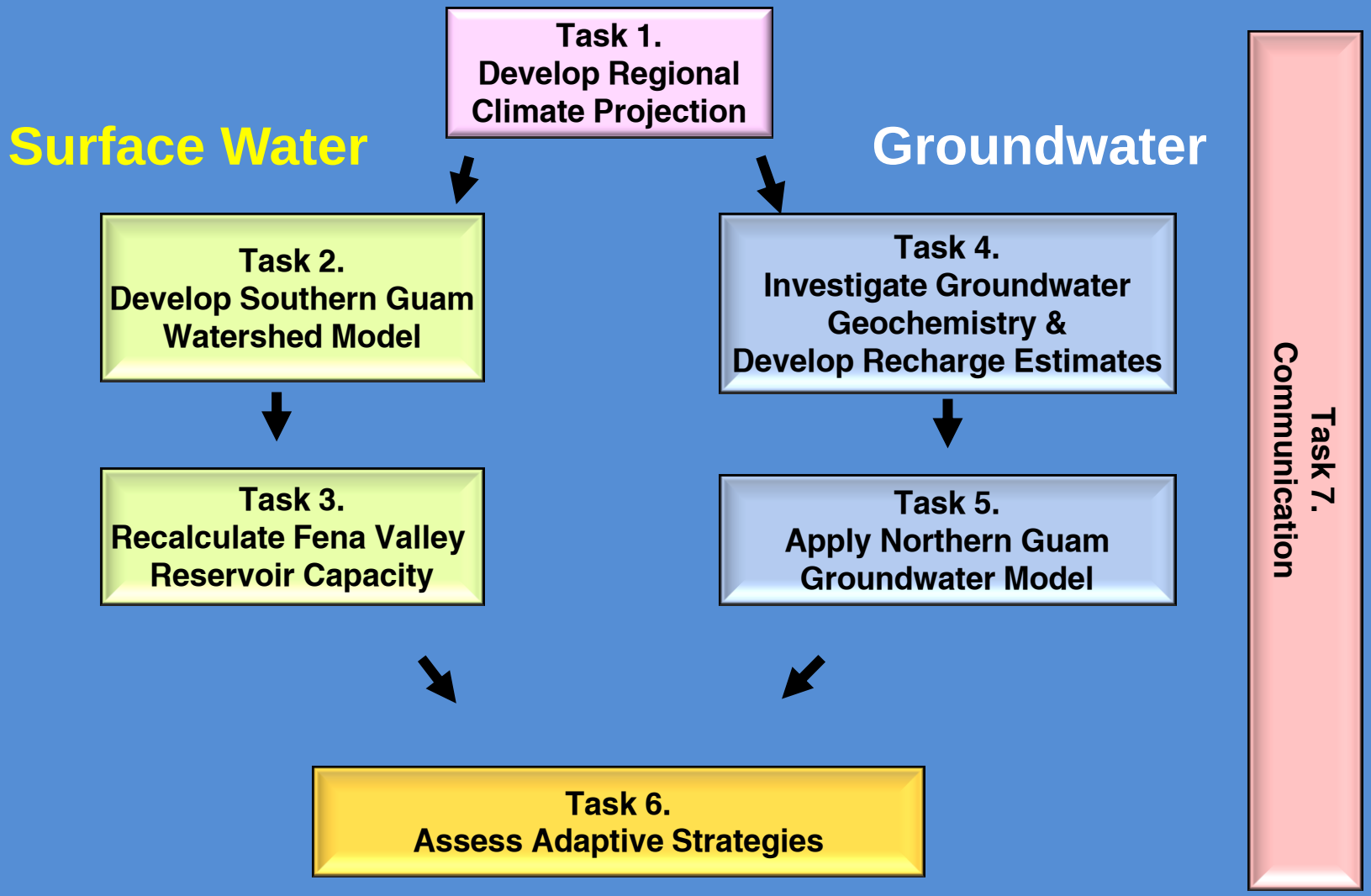


Three main watersheds supplying Fena Valley Reservoir in Southern Guam

Northern Guam Lens Aquifer

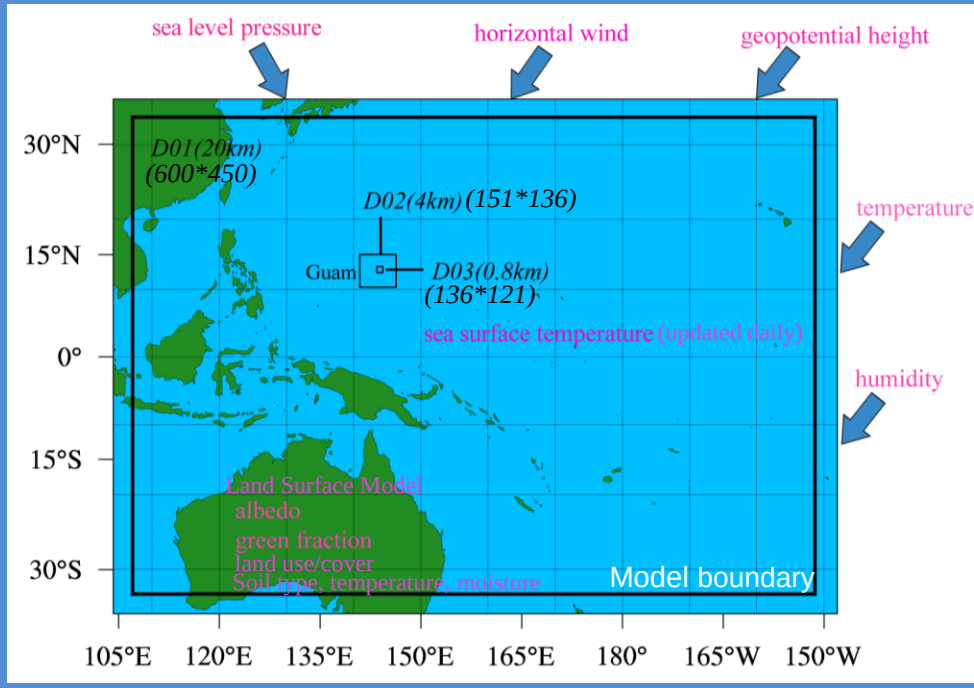


Technical Approach



Task 1: Climate Projection

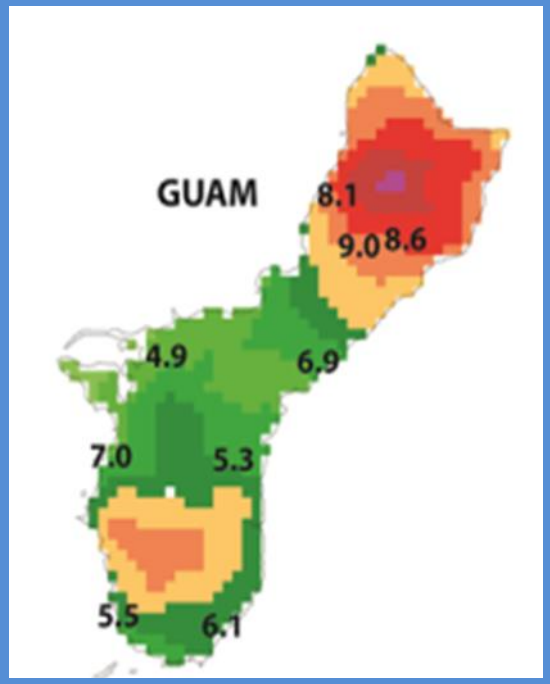
- Future climate may have different daily and drought conditions and typhoon frequency and intensity (typhoons produce about 12% of rainfall)
- Assess Coupled Model Intercomparison Project (CMIP5) simulations – choose "best models" matching rainfall and sea-surface temperature at coarse resolution
- Design experiments with fine-resolution (1-3 km) regional model
  - UH-IPRC regional atmospheric model (iRAM) to improve understanding of long-term changes in tropical cyclone behavior
- Examine changes in occurrence probability of storm characteristics
- TRACK program will objectively identify features that are tracked through the time sequence to produce feature trajectories

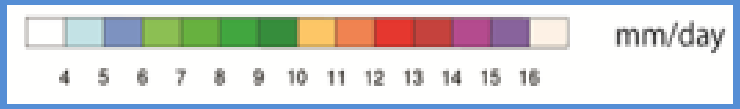


- Produce a range of estimates of rainfall, wind speed, evaporation, etc. to feed into surface-water and groundwater-recharge models

Task 1: Climate Projection

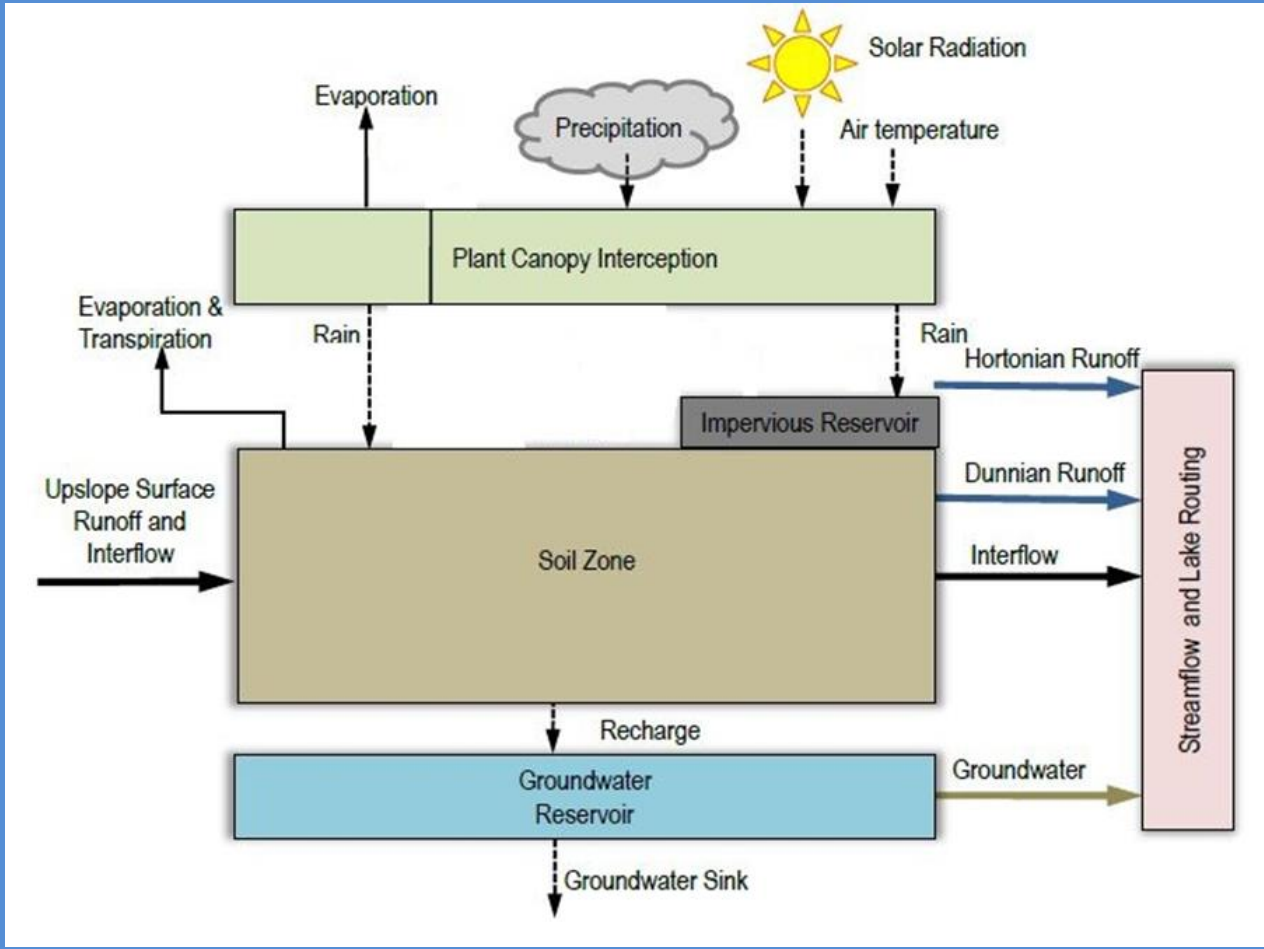
- Preliminary results for annual mean daily rainfall rate from a single year (1990) of integration with 800-m horizontal resolution in the innermost domains over Guam
- The numbers show the observed mean rainfall rate in 1990 from individual stations.
- These preliminary results suggest an overall wet bias in the model simulations and the model is now being modified to improve the rainfall simulations.





Task 2: Southern Guam Watershed Model

- Current USGS PRMS model can be improved and expanded to other watersheds providing surface water in southern Guam
- Calibrate model with USGS streamflow and rainfall data in gaged basins
- Supplement with Next-Generation Radar (NEXRAD) rainfall data for ungaged areas
- Evaluate streamflow response to climate change using calibrated model to provide estimates of a range of future streamflow conditions



Task 3: Fena Valley Reservoir Capacity

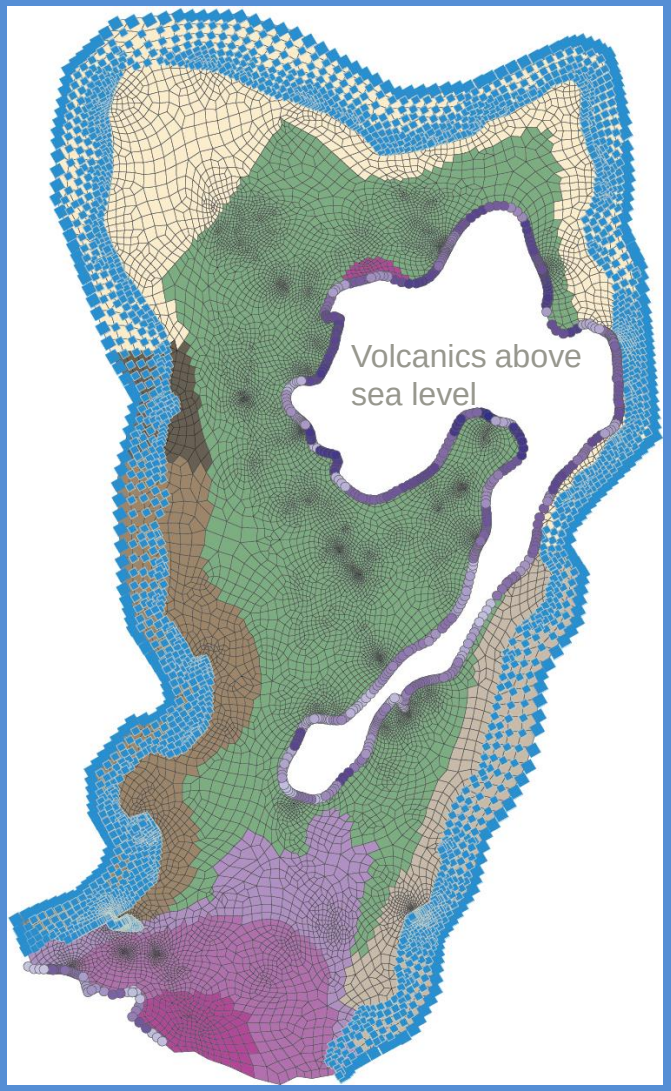
- Knowledge of reservoir capacity based on 23-yr old bathymetry data
- New data collection & analysis needed to update reservoir model
  - Perform bathymetric survey
  - Differential Global Positioning System (GPS)
  - Survey-grade echo sounder accurate to < 1 cm
  - Collect sediment cores at about 10 sites & analyze for bulk density & grain-size distribution
  - Compare new bathymetry to past bathymetry to get sedimentation rate
  - Compare sediment record with typhoon record to correlate events
  - Compare turbidity record with rainfall record to correlate events
- Update reservoir water-balance model
  - Incorporate new reservoir volume
  - Incorporate new streamflow estimates from watershed model
  - Apply a range of projected meteorological conditions to estimate future volumes
  - Evaluate reoccurrence interval for high-turbidity conditions

Task 4: Groundwater Geochemistry and Water Budget

- Determining 1) rate and timing of recharge and 2) groundwater flow paths are critical for understanding groundwater resources
- Use geochemical tracers to reveal groundwater flow paths & residence times (fast vs. slow pathways)
- Sample rain, cave drip water, wells, springs, and rocks across northern Guam for cations, anions, Sr and water isotopes; ~100 samples/year for 3 years
- Reevaluate and refine USGS water-budget model to account for fast and slow recharge out of soil reservoir
- Recompute current recharge using refined water-budget model
- Apply a range of projected meteorological conditions to determine a range of future recharge estimates
- New estimates of current and future recharge will be available for the existing groundwater model

Task 5: Northern Guam Groundwater Model

- Recently developed SUTRA groundwater model is the best tool to evaluate future pumping scenarios for DoD and public demand
- Evaluate model using updated current recharge and if needed, recalibrate by adjusting hydraulic properties
- Apply a range of future recharge and sea-level estimates to evaluate the impacts to the salinity of DoD and public-supply wells



Task 6: Adaptive Strategies

- ***What are the effects of applying different adaptive management strategies to water-resource management?***

Surface-water examples:

- Provide estimates of volume increase to Fena Valley Reservoir by:
  - Dredging
  - Raising spillway height
  - Modifying water intake height
- Provide estimates of expected increases in high-turbidity water episodes requiring treatment

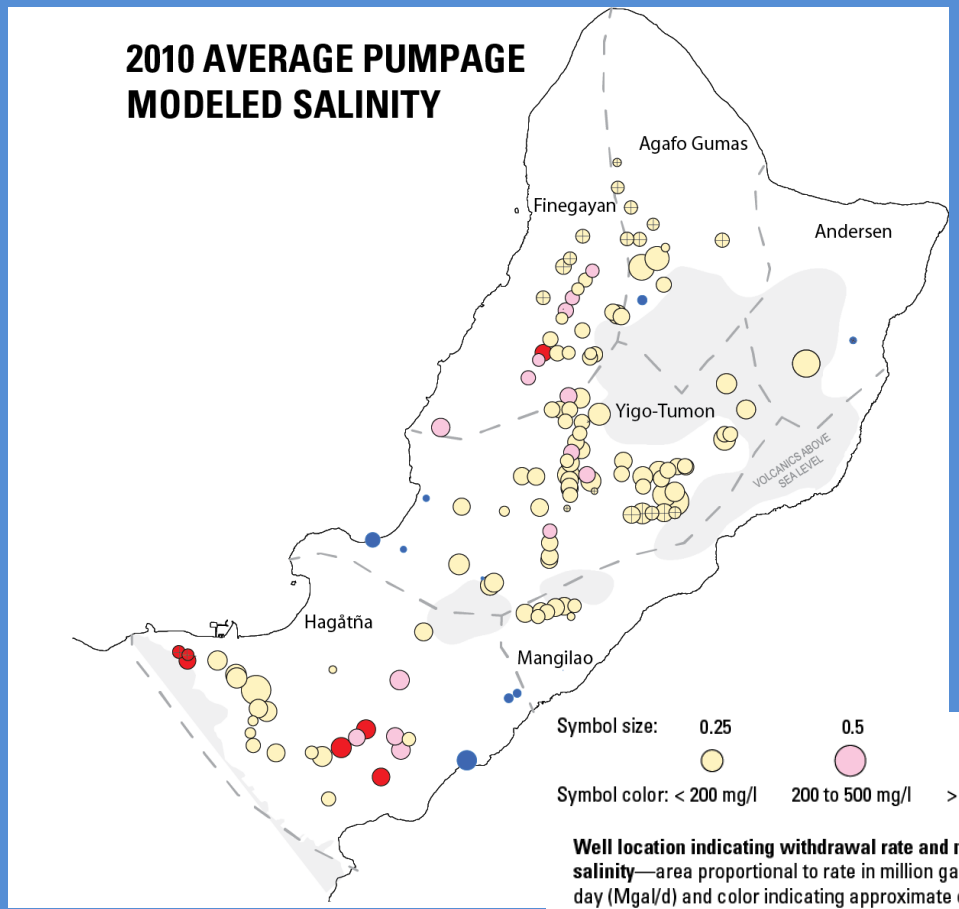
Groundwater examples:

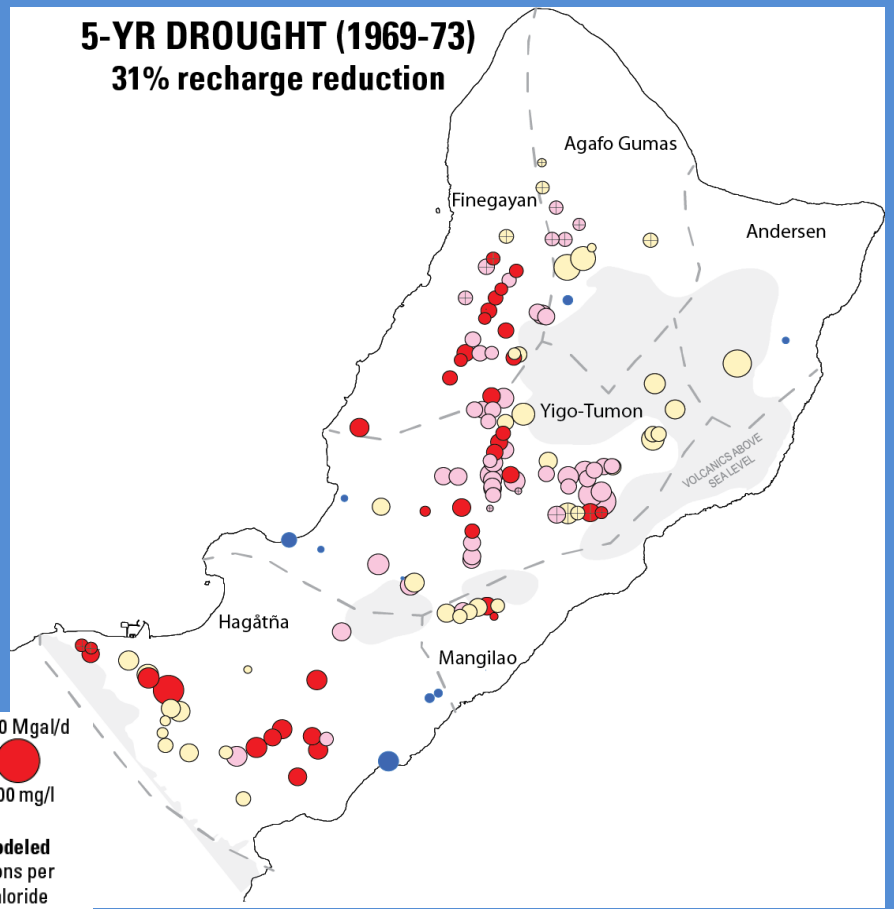
- Provide estimates of pumping rate & salinity distribution in wells for:
  - "Taking no action"
  - Modifying pumping rates at existing wells
  - Replacing wells that are too deep
  - Modifying pump intake depths to account for rising sea level
  - Shifting production to less-vulnerable locations

Evaluate salinity & volume with conjunctive use of surface water & groundwater

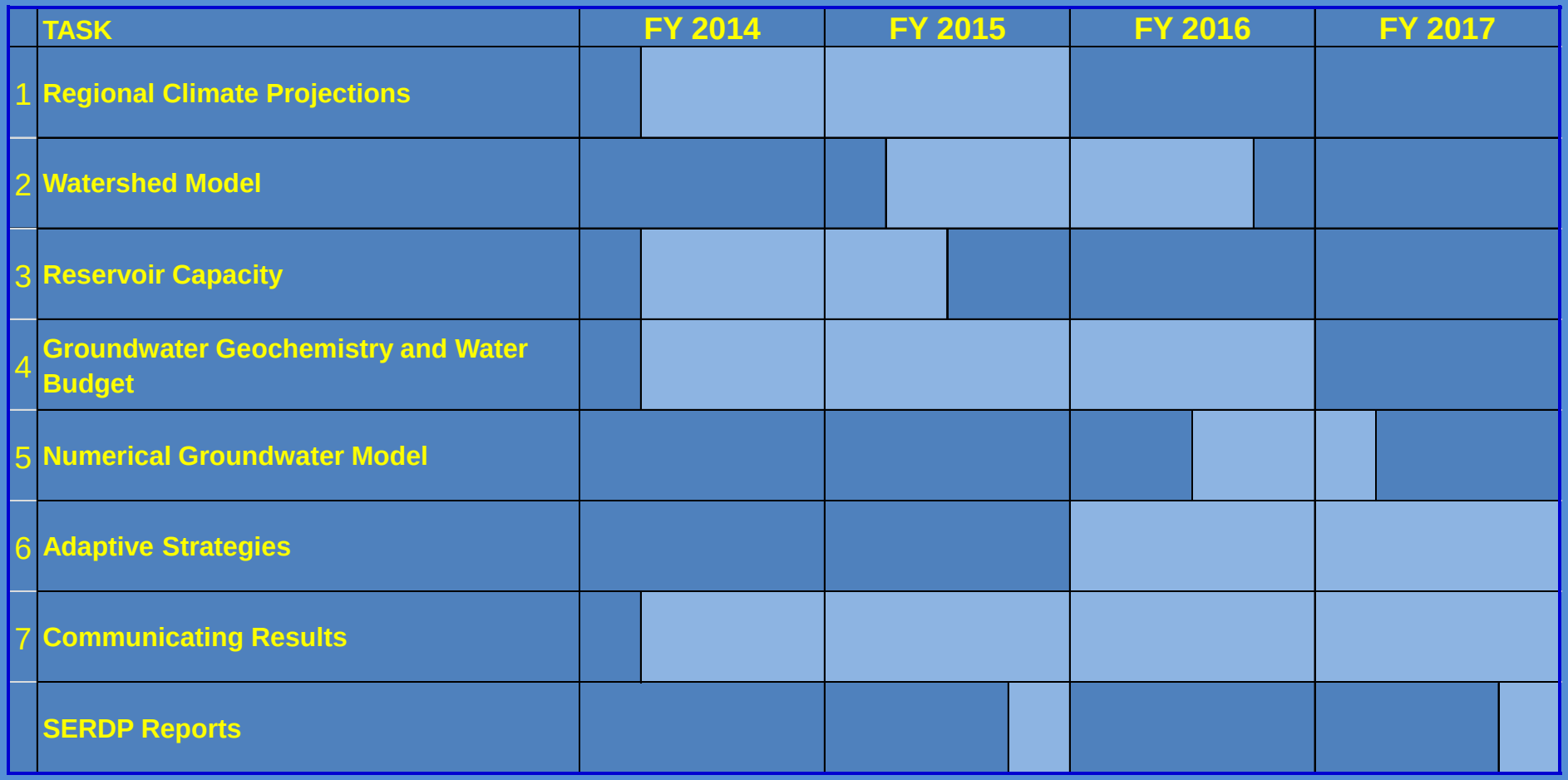
Task 7: Communicating Results

Examples of salinity distribution maps for average & historical drought conditions





SERDP Study Timeline



Outline of Meeting

- Overview of USGS water programs in Guam
- Brief summary of recently completed USMC-funded groundwater-availability study
- Climate-change overview
- DoD-funded study on impacts of climate change on water resources in Guam
- **Stakeholder participation**