# Guam Groundwater-Availability Study

Technical Working Group Meeting

August 26, 2010

# Outline of Meeting

- Project goals, products, timeline – *Steve Gingerich*
- Informational fact sheet, chloride and pumpage history – *Steve Gingerich*
- Groundwater recharge study – *Adam Johnson*
- Water-level monitoring – *Steve Gingerich*
- Well database – *Vivianna Bendixson*
- Hydrology/Modeling workshops – *John Jenson*
- Requests for stakeholder input and wrap-up – *Steve Gingerich*

# Guam Groundwater-Availability Study

- $1.2M from the USMC over 3.5 years (collaborative effort with WERI)
- Stakeholder involvement critical to long-term success of numerical modeling effort for aquifer management

# Guam Groundwater-Availability 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

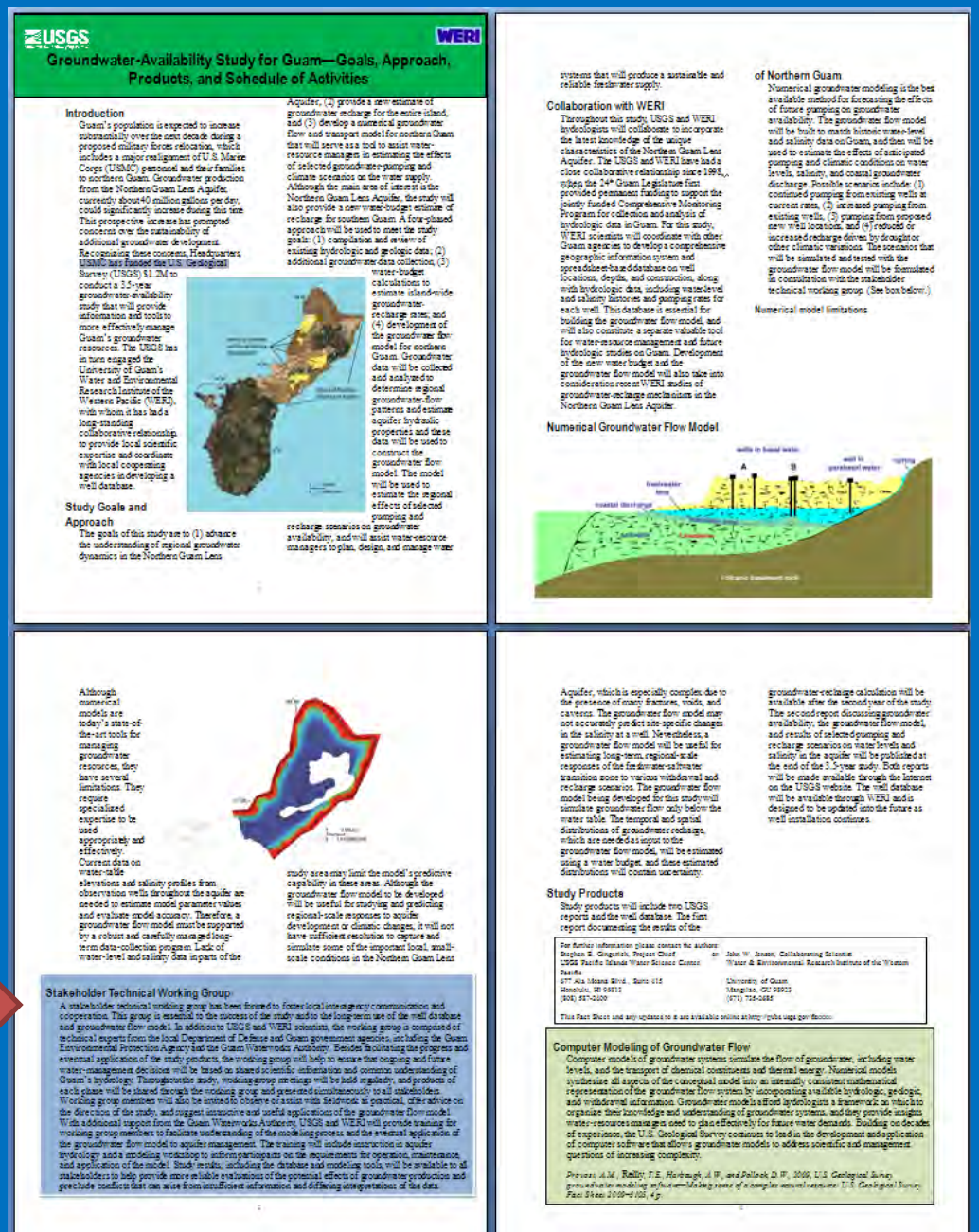
# Guam Groundwater-Availability Study Approach

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 transport model for northern Guam

# Timelines

| Activity | 2010 | | | | 2011 | | | | 2012 | | | | 2013 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Apr | Jul | Oct | Jan | Apr | Jul | Oct | Jan | Apr | Jul | Oct | Jan | Apr | Jul |
| Data Review | | | | | | | | | | | | | | | |
| Recharge Analysis | | | | | | | | | | | | | | | |
| Water Budget Report | | | | | | | | | | | | | | | |
| Water-Level Surveys | | | | | | | | | | | | | | | |
| Regional Numerical Model | | | | | | | | | | | | | | | |
| Groundwater Availability Report | | | | | | | | | | | | | | | |

# Informational Fact Sheet



USGS WERI

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

### Introduction

Guam's population 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 during this time. This prospective increase has prompted concerns over the sustainability of additional groundwater development. Recognizing these concerns, Headquarters, USMC has funded the U.S. Geological Survey (USGS) $1.2M 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.

### Study Goals and Approach

The goals of this study are to (1) advance the understanding of regional groundwater dynamics in the Northern Guam Lens Aquifer, (2) provide a new estimate of groundwater recharge for the entire island, and (3) develop a numerical groundwater flow and transport model for northern Guam that will serve as a tool to assist water-resource managers in estimating the effects of selected groundwater-pumping and climate scenarios on the water supply. Although the main area of interest is the Northern Guam Lens Aquifer, the study will also provide a new water-budget estimate of recharge for southern Guam. A four-phased approach will be used to meet the study goals: (1) compilation and review of existing hydrologic and geologic data; (2) additional groundwater data collection; (3) water-budget calculations to estimate island-wide groundwater-recharge rates; and (4) development of the groundwater flow model for northern Guam. Groundwater data will be collected and analyzed to determine regional groundwater-flow patterns and estimate aquifer hydraulic properties and these data will be used to construct the groundwater flow model. The model will be used to estimate the regional effects of selected pumping and recharge scenarios on groundwater availability, and will assist water-resource managers to plan, design, and manage water systems that will produce a sustainable and reliable freshwater supply.

### Collaboration with WERI

Throughout this study, USGS and WERI hydrologists will collaborate to incorporate the latest knowledge of the unique characteristics of the Northern Guam Lens Aquifer. The USGS and WERI have had a close collaborative relationship since 1995, when the 24th Guam Legislature first provided permanent funding to support the jointly funded Comprehensive Monitoring Program for collection and analysis of hydrologic data in Guam. For this study, WERI scientists will coordinate with other Guam agencies to develop a comprehensive geographic information system and spreadsheet-based database on well locations, depths, and construction, along with hydrologic data, including water-level and salinity histories and pumping rates for each well. This database is essential for building the groundwater flow model, and will also constitute a separate valuable tool for water-resource management and future hydrologic studies on Guam. Development of the new water budget and the groundwater flow model will also take into consideration recent WERI studies of groundwater-recharge mechanisms in the Northern Guam Lens Aquifer.

### Numerical Groundwater Flow Model

Although numerical models are today's state-of-the-art tools for managing groundwater resources, they have several limitations. They require specialized expertise to be used appropriately and effectively. Current data on water-table elevations and salinity profiles from observation wells throughout the aquifer are needed to estimate model parameter values and evaluate model accuracy. Therefore, a groundwater flow model must be supported by a robust and carefully managed long-term data-collection program. Lack of water-level and salinity data in parts of the study area may limit the model's predictive capability in these areas. Although the groundwater flow model to be developed will be useful for studying and predicting regional-scale responses to aquifer development or climate changes, it will not have sufficient resolution to capture and simulate some of the important local, small-scale conditions in the Northern Guam Lens Aquifer, which is especially complex due to the presence of many fractures, voids, and caverns. The groundwater flow model may not accurately predict site-specific changes in the salinity at a well. Nevertheless, a groundwater flow model will be useful for estimating long-term, regional-scale responses of the freshwater-saltwater transition zone to various withdrawal and recharge scenarios. The groundwater flow model being developed for this study will simulate groundwater flow only below the water table. The temporal and spatial distributions of groundwater recharge, which are needed as input to the groundwater flow model, will be estimated using a water budget, and these estimated distributions will contain uncertainty.

### Study Products

Study products will include two USGS reports and the well database. The first report documenting the results of the groundwater-recharge calculation will be available after the second year of the study. The second report discussing groundwater availability, the groundwater flow model, and results of selected pumping and recharge scenarios on water levels and salinity in the aquifer will be published at the end of the 3.5-year study. Both reports will be made available through the Internet on the USGS website. The well database will be available through WERI and is designed to be updated into the future as well installation continues.

### Stakeholder Technical Working Group

A stakeholder technical working group has been formed to foster local interagency communication and cooperation. This group is essential to the success of the study and to the long-term use of the well database and groundwater flow model. In addition to USGS and WERI scientists, the working group is composed of technical experts from the local Department of Defense and Guam government agencies, including the Guam Environmental Protection Agency and the Guam Waterworks Authority. Besides facilitating the progress and eventual application of the study products, the working group will help to ensure that ongoing and future water-management decisions will be based on shared scientific information and common understanding of Guam's hydrology. Throughout the study, working group meetings will be held regularly, and products of each phase will be shared through the working group and presented simultaneously to all stakeholders. Working group members will also be invited to observe or assist with fieldwork as practical, offer advice on the direction of the study, and suggest innovative and useful applications of the groundwater flow model. With additional support from the Guam Waterworks Authority, USGS and WERI will provide training for working group members to facilitate understanding of the modeling process and the eventual application of the groundwater flow model to aquifer management. The training will include instruction in aquifer hydrology and a modeling workshop to inform participants on the requirements for operation, maintenance, and application of the model. Study results, including the database and modeling tools, will be available to all stakeholders to help provide more reliable evaluations of the potential effects of groundwater production and preclude conflicts that can arise from insufficient information and differing interpretations of the data.

### Computer Modeling of Groundwater Flow

Computer models of groundwater systems simulate the flow of groundwater, including water levels, and the transport of chemical constituents and thermal energy. Numerical models synthesize all aspects of the conceptual model into an internally consistent mathematical representation of the groundwater flow system by incorporating available hydrologic, geologic, and withdrawal information. Groundwater models afford hydrologists a framework on which to organize their knowledge and understanding of groundwater systems, and they provide insights water-resources managers need to plan effectively for future water demands. Building on decades of experience, the U.S. Geological Survey continues to lead in the development and application of computer software that allows groundwater models to address scientific and management questions of increasing complexity.

*Provost, A.M., Reilly, T.E., Harbaugh, A.W., and Pollock, D.W., 2000, U.S. Geological Survey groundwater modeling software—Making sense of a complex natural resource: U.S. Geological Survey Fact Sheet 2000–0118, 4 p.*

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Need agency logos in vector format:
WERI
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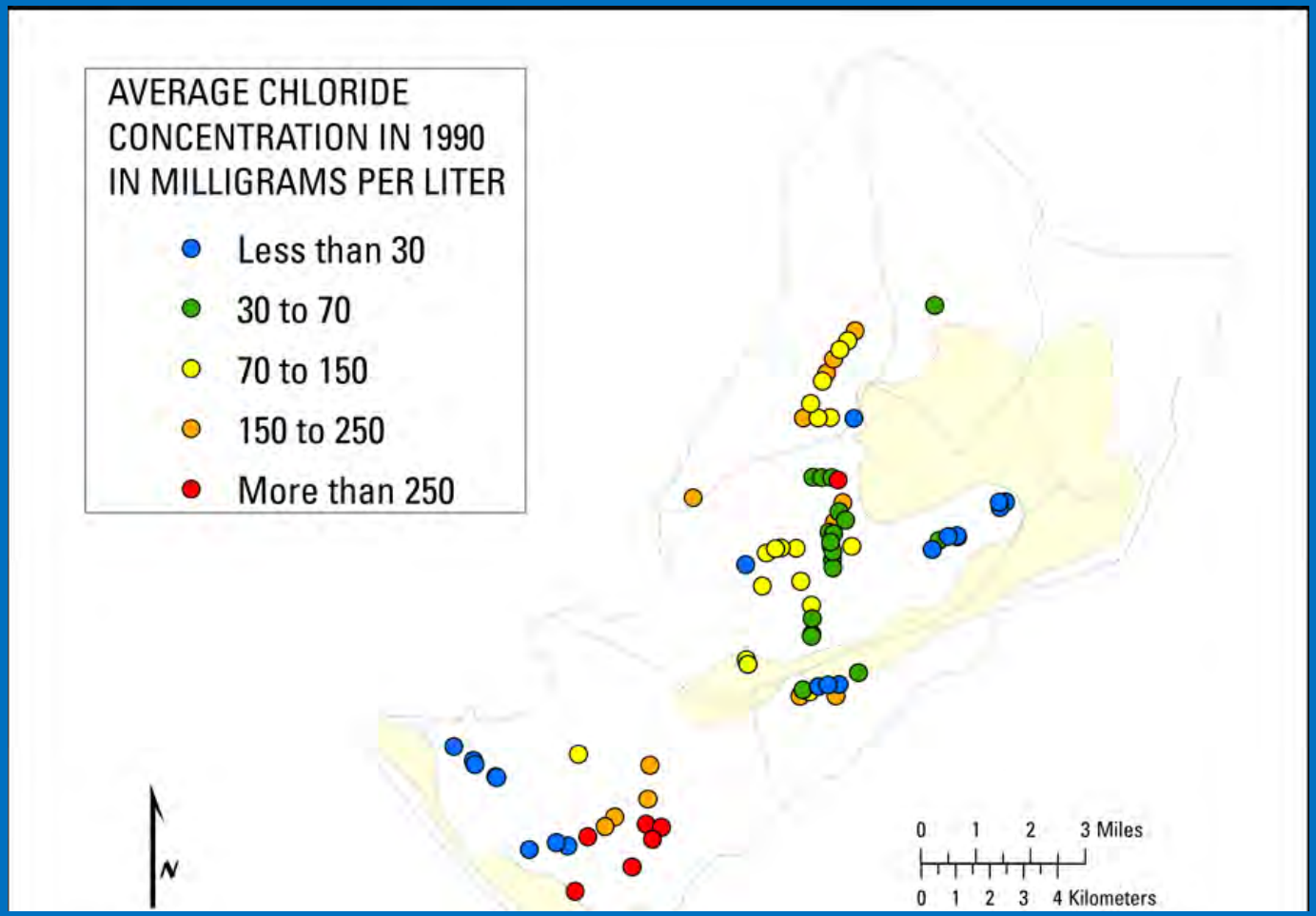
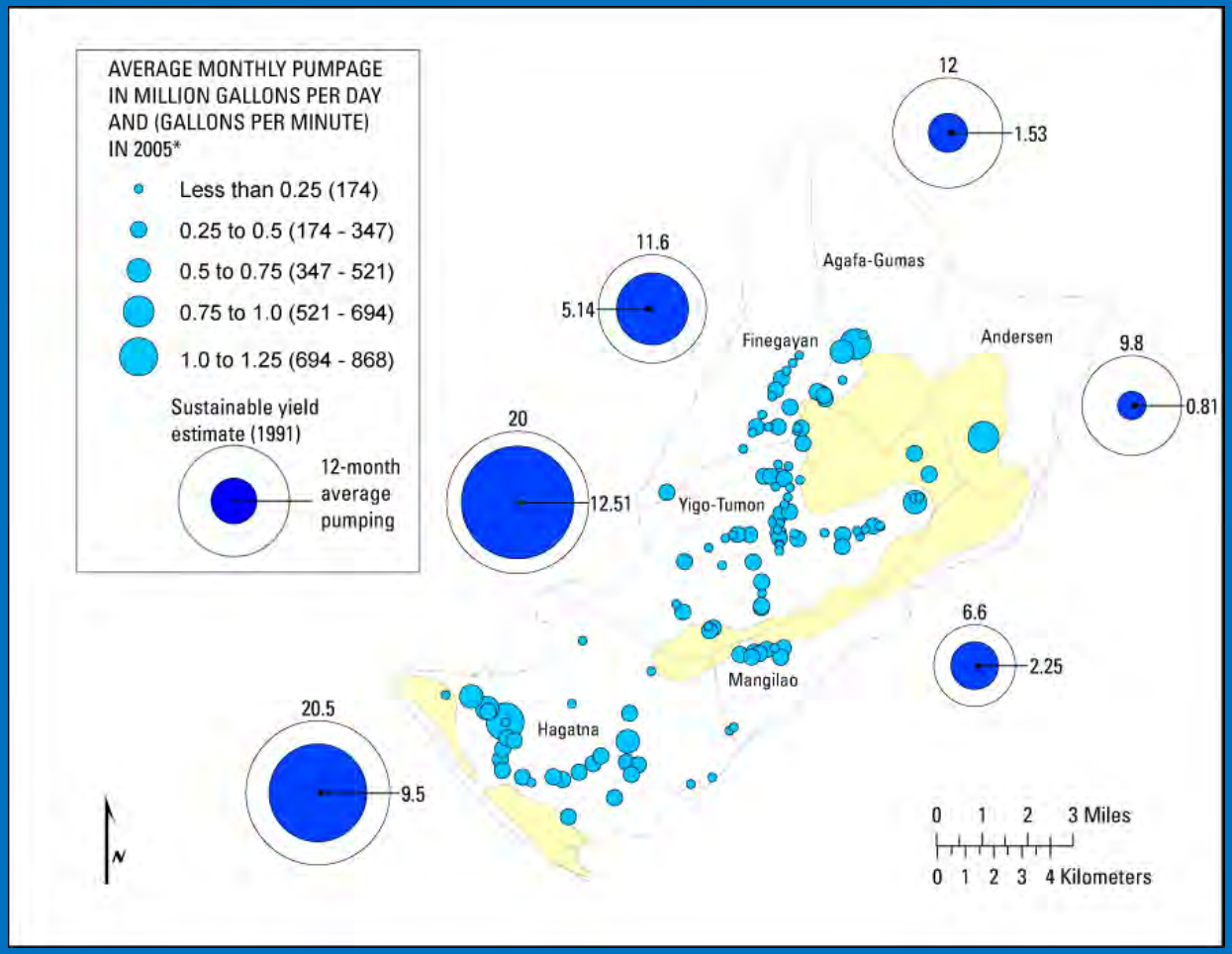
GEPA

# GWA and Navy production wells chloride history 1990-2009



# GWA and Navy production wells pumpage history 2005-09



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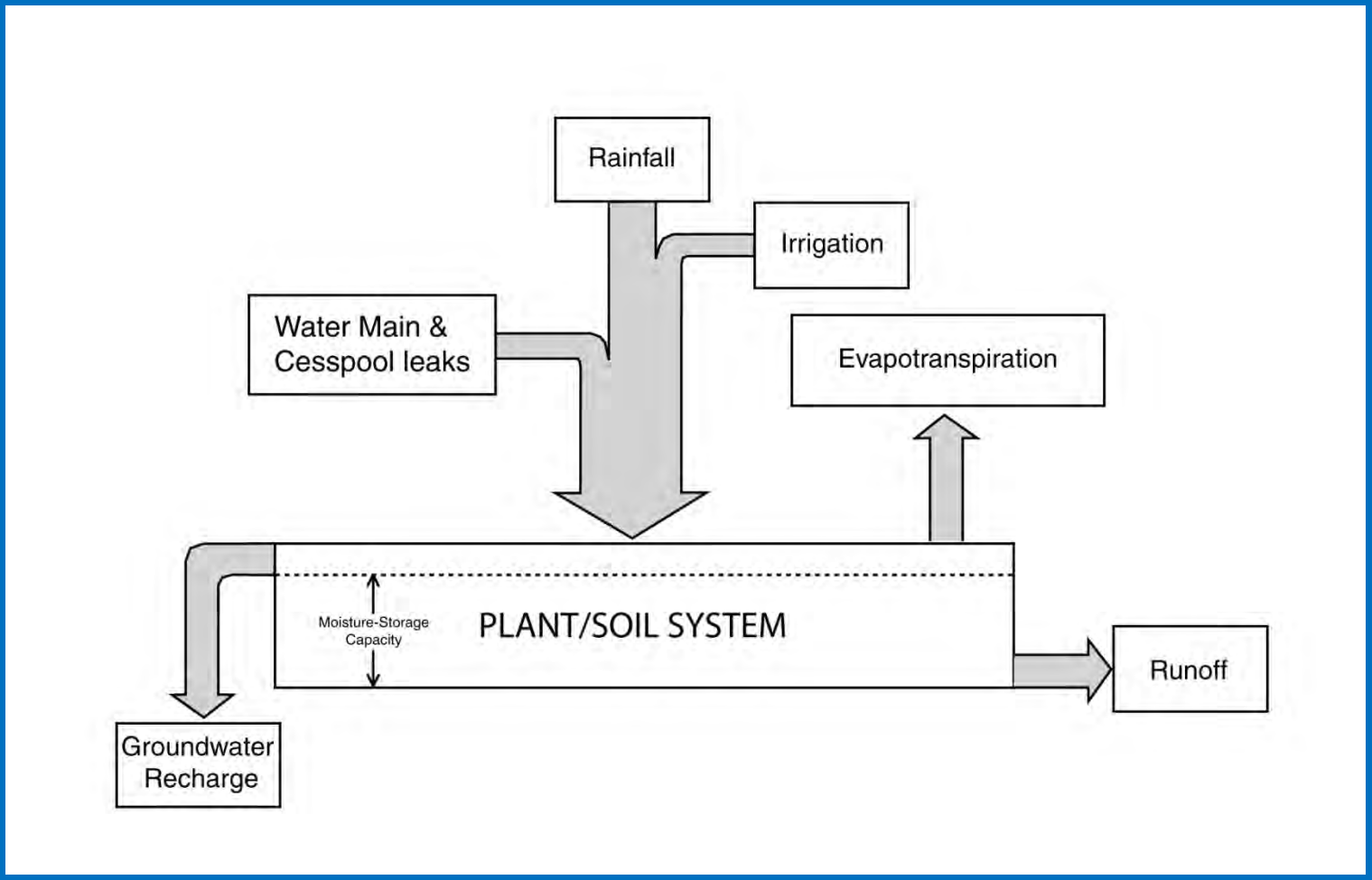
# Groundwater Recharge

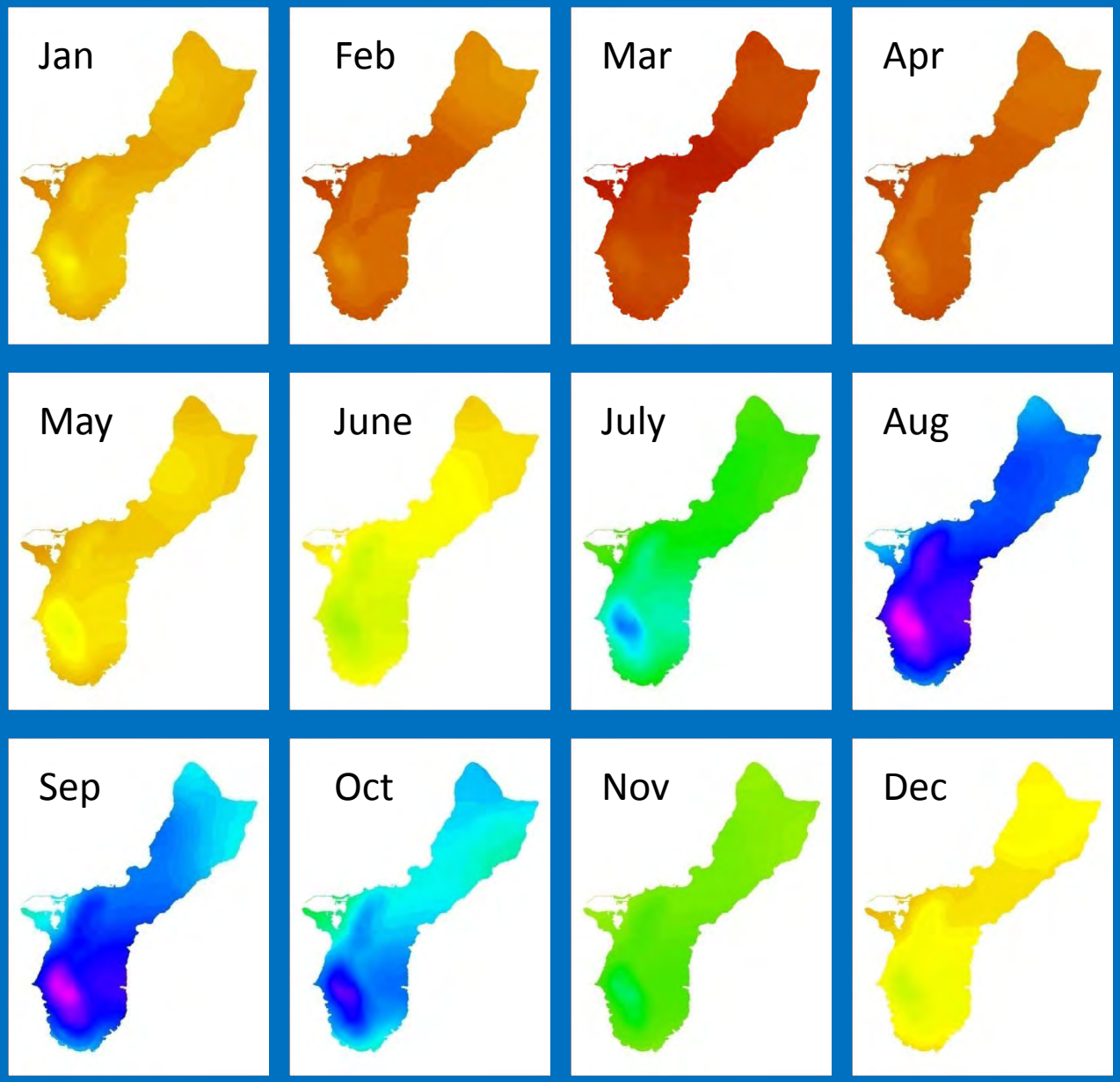
Objective: Estimate the spatial distribution of long-term average groundwater recharge for the entire island

Methods:

1. Water-budget model
2. Chloride mass balance

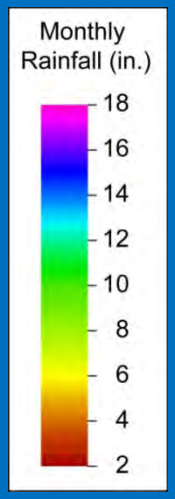
# Water-Budget Method






# RAINFALL

- 1971 – 2000 average monthly rainfall distribution
- Island-wide rainfall rate: 390 – 1,750 mgd




Derived from PRISM (2006) http://www.prism.oregonstate.edu/products/pacisl.phtml

# RAIN GAGES

- 21 gages with daily rainfall records
- Used to generate daily rainfall patterns for the model
- Data Sources:
  - USGS
  - National Climatic Data Center
  - WERI (Lander 2003)

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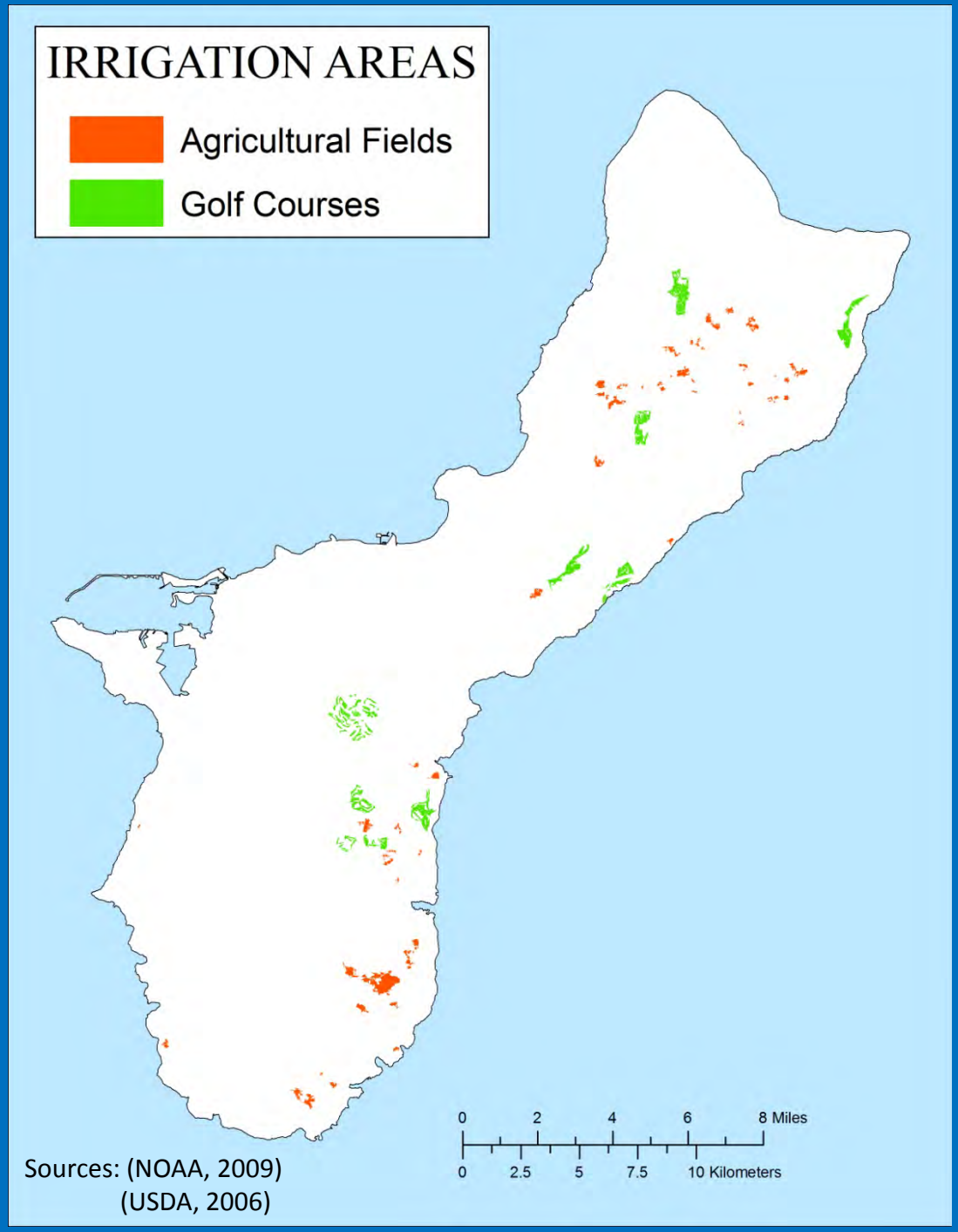


Sources: (NOAA, 2009)
(USDA, 2006)

# IRRIGATION

- Applied to:
  - Agriculture Fields
  - Golf Courses
- Irrigation rates:
  - Agriculture: 1.2 mgd
  - Golf Courses: 0.05 mgd
  - Irrigation (unknown sites): 0.13 mgd
  - Based on GWA Annual Reports
  - Varied monthly according to season

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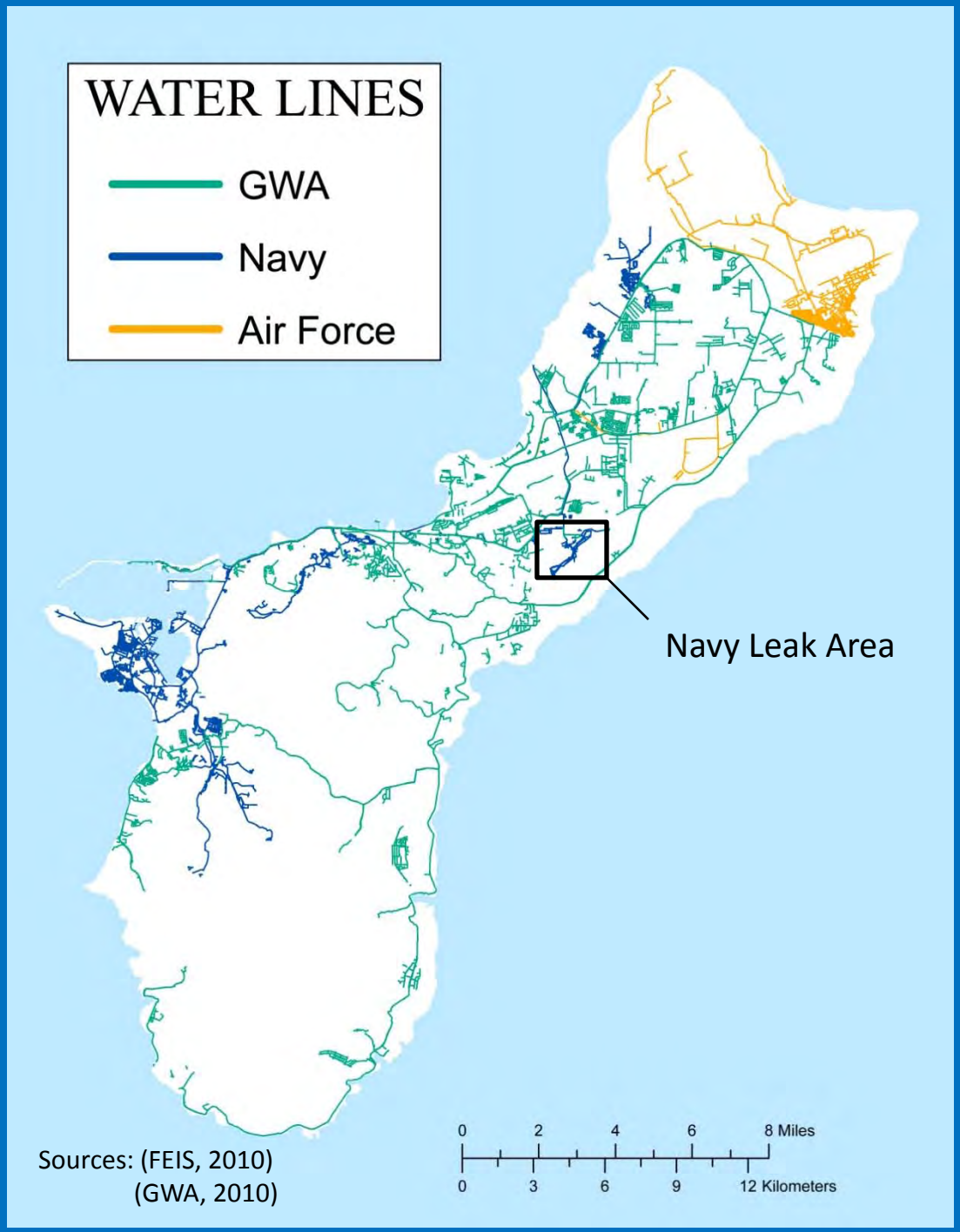


Sources: (FEIS, 2010)
(GWA, 2010)

# WATER MAIN LEAKS

- GWA:
  - 4 mgd
  - Distributed evenly across its system
  - 1.7 gal/d per foot of pipe
- Navy:
  - Barrigada: 0.36 mgd
  - NCS Barrigada: 0.07 mgd
  - Others?
- Air Force: ?

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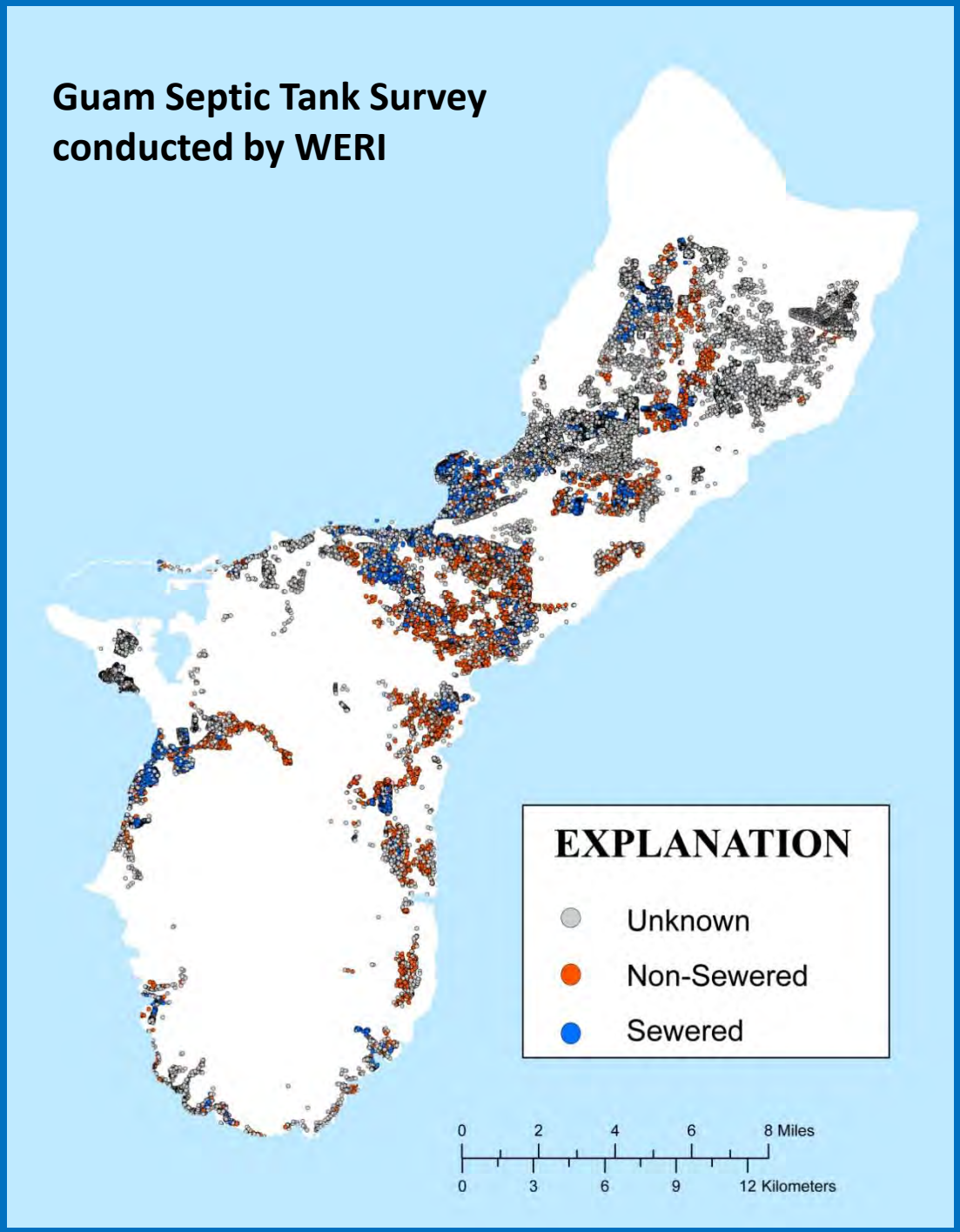


# CESSPOOLS & SEPTIC TANK LEAKS

Houses on septic tank or cesspool: 10,848

Average Household water use: 339 gal/day (GWA 2007)

Maximum water input from cesspools & septic tanks: 3.7 mgd

Status of "unknown" buildings to be determined based on proximity to sewer lines.

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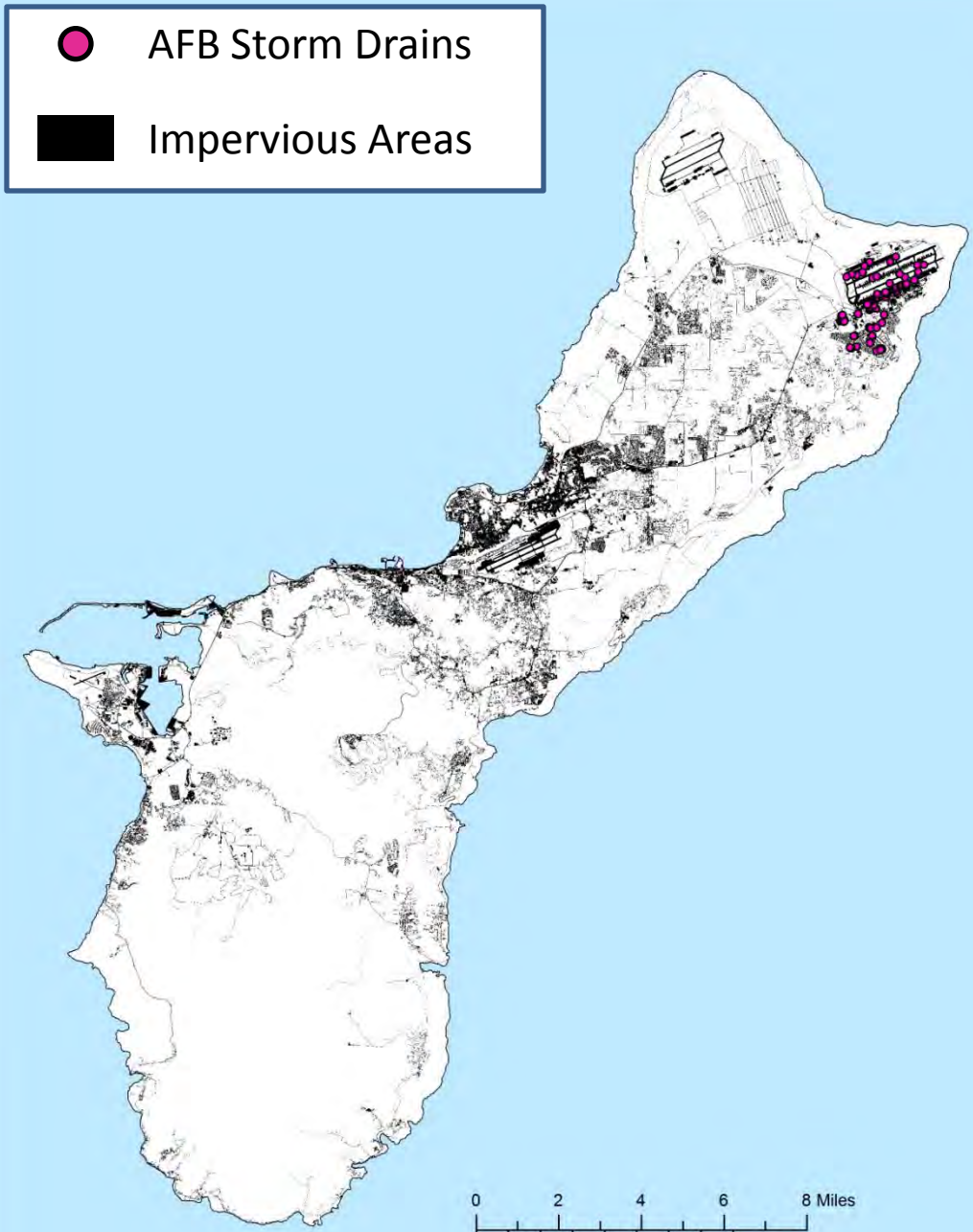


Sources: (NOAA, 2009)
(Earth Tech 1999)

# IMPERVIOUS SURFACES

- Roads, buildings, parking lots
- 9% of total land surface (2006)
- Incident rainwater will either:
  - Evaporate
  - Runoff to adjacent pervious areas and sinkholes
  - Flow into storm drains
    - Locations unknown

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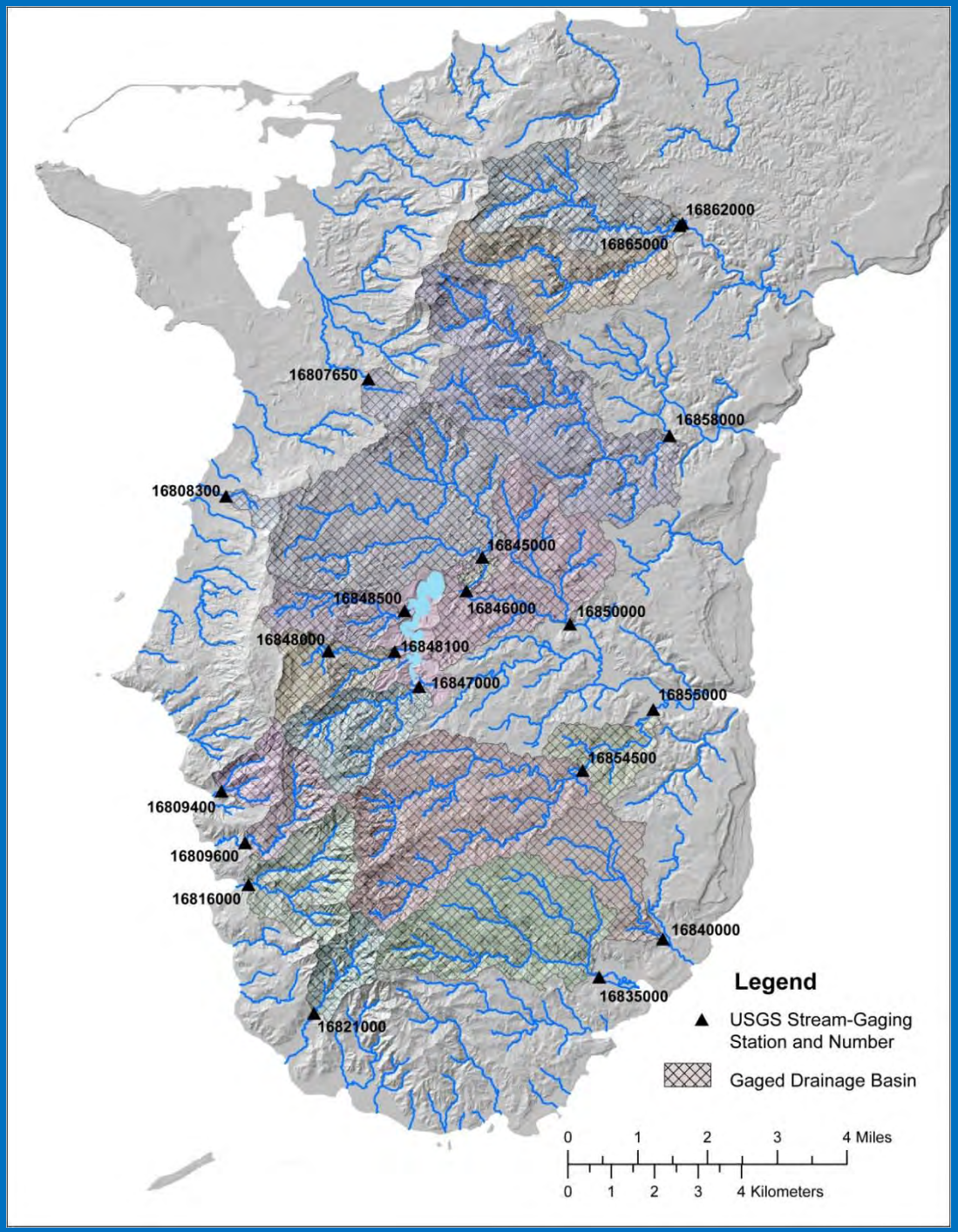


# RUNOFF

- 20 historic USGS Stream gages
  - 8 currently active
- Runoff estimates will be adjusted to 1971 – 2000
- Monthly runoff-to-rainfall ratios will be computed for each gage's drainage basin
- Estimate runoff from ungaged areas using records from nearby gages with similar geologic conditions

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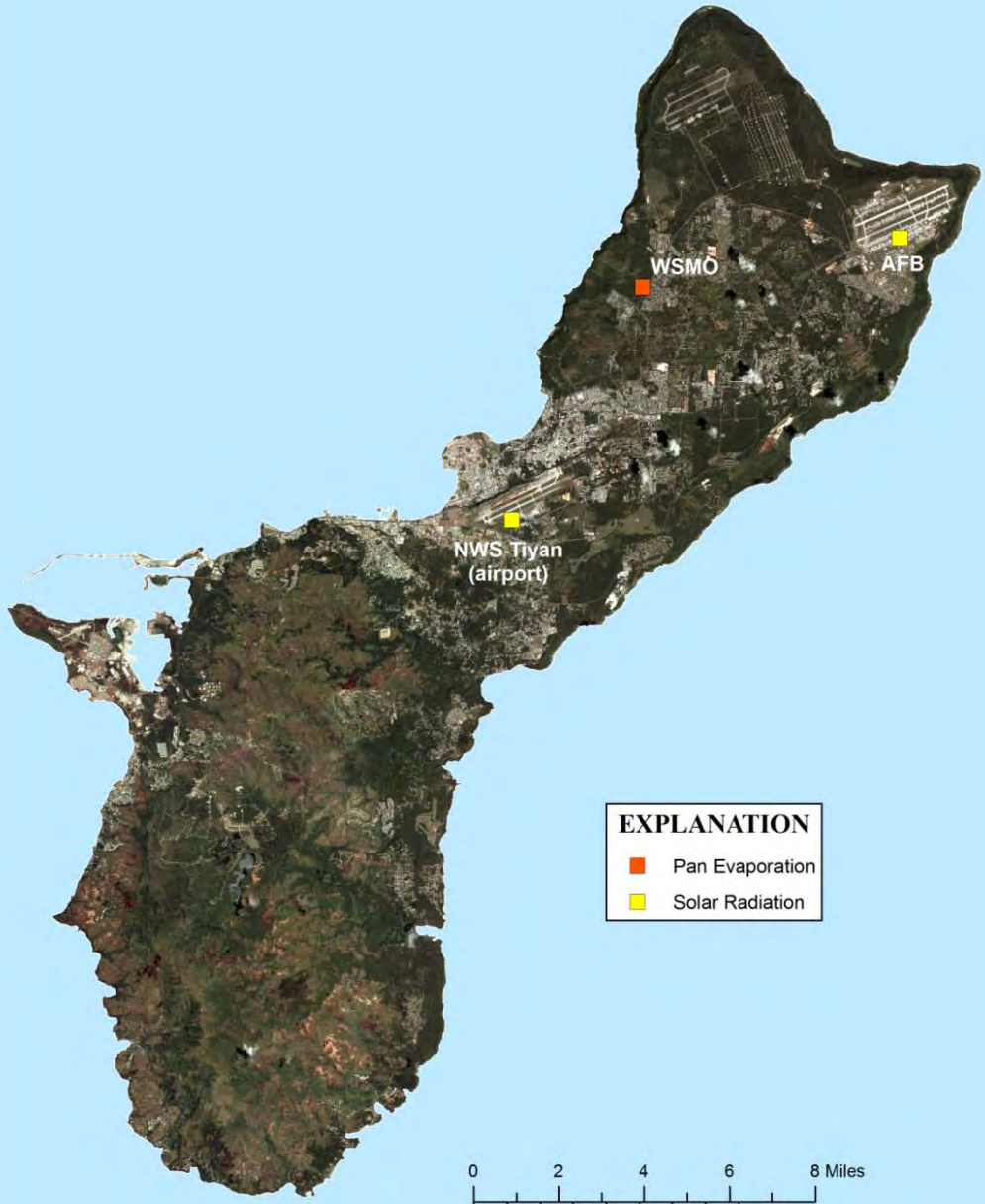
# EVAPOTRANSPIRATION




Sources: (NCDC, 2010)
(NSRDB, 2006)

- Pan Evaporation: WSMO (1958 – 1998)
- Estimate Pan Evaporation at the airport and AFB using solar-radiation data

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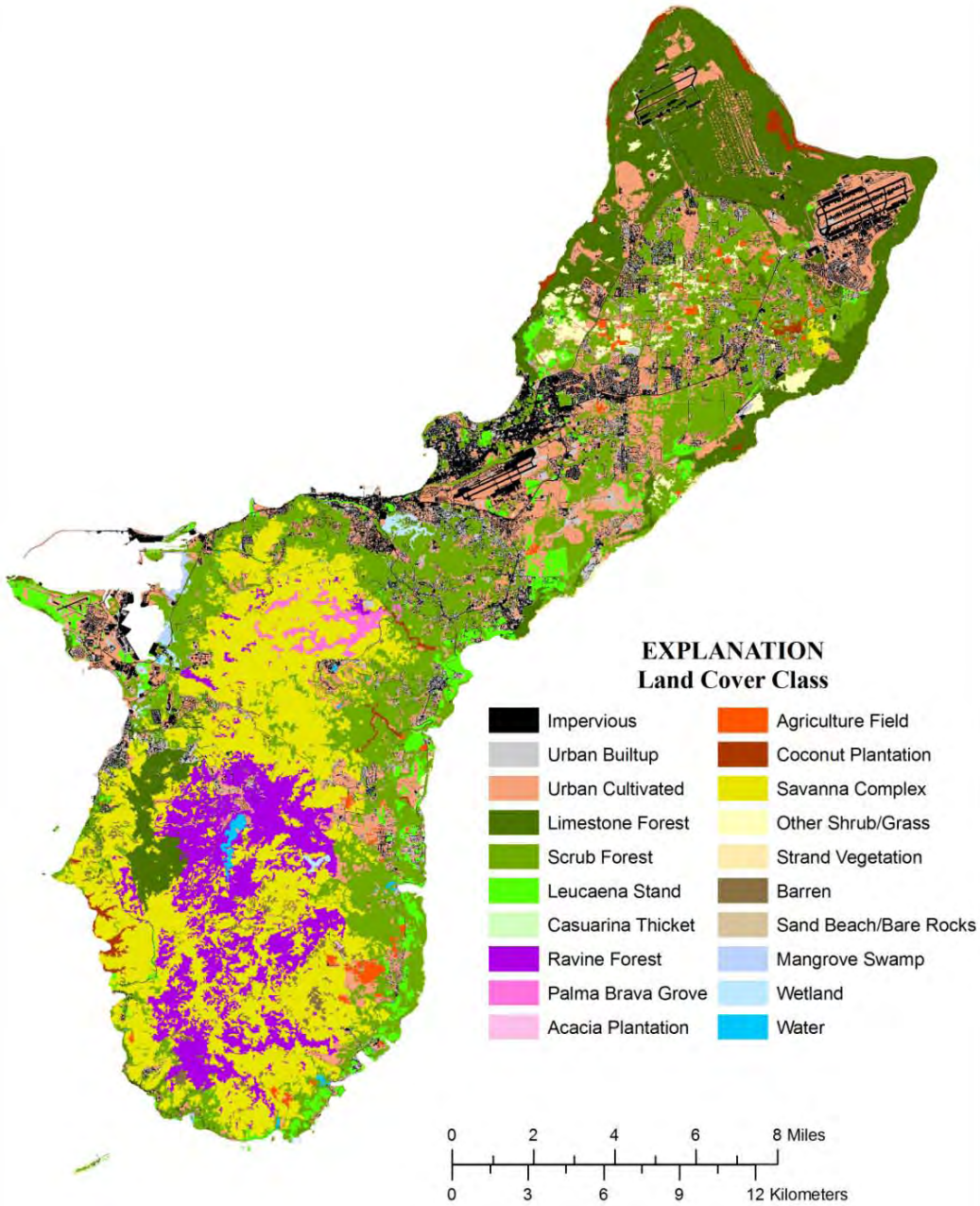


# LAND COVER

- Source: USDA 2006
- Details vegetation type
- Pan Coefficient
  - relates Pan Evaporation to Potential Evapotranspiration
- Forested Areas:
  - Canopy interception of rainfall
- Root Depths

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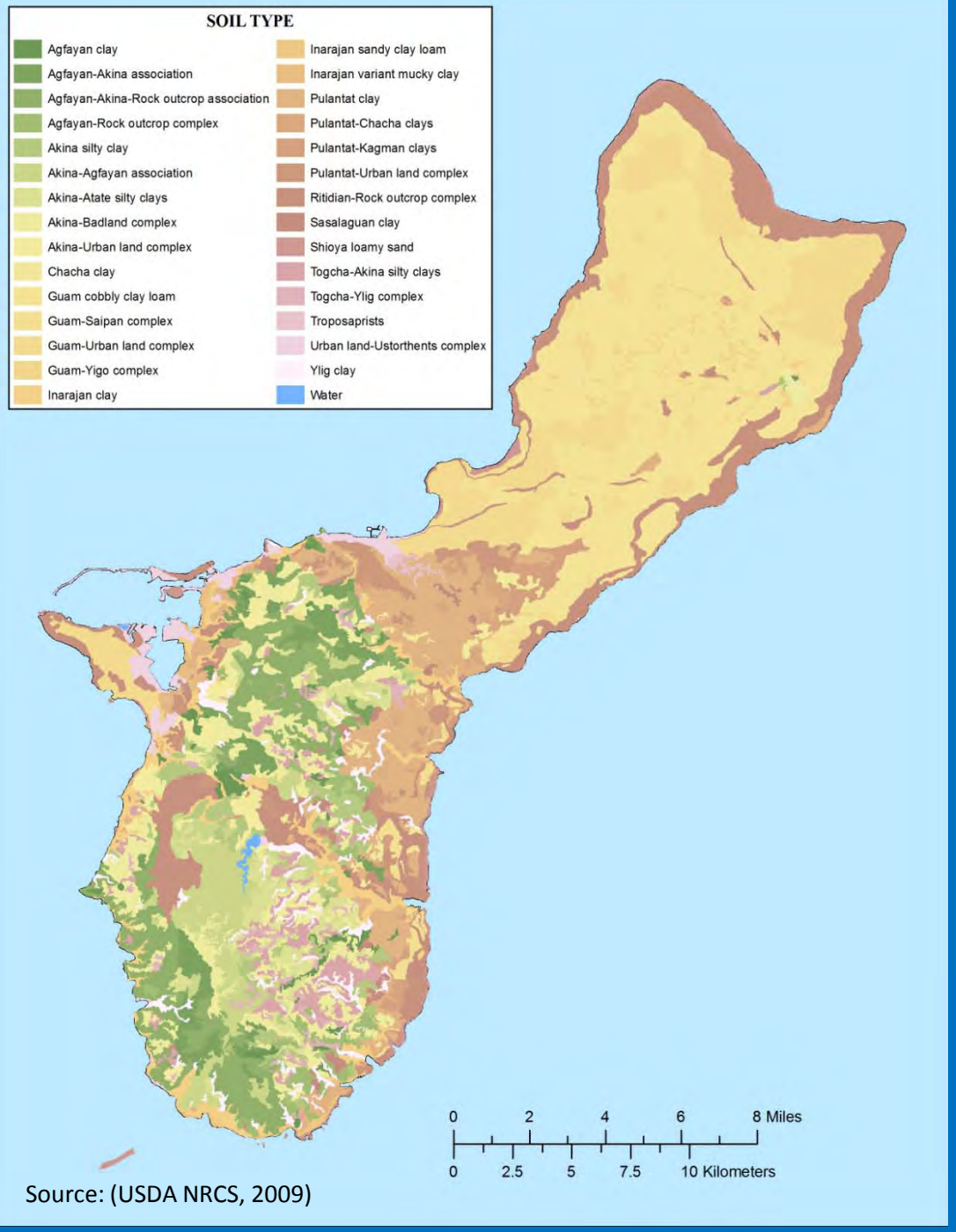


Source: (USDA NRCS, 2009)

# SOILS

Available Water Capacity

- varies by soil type

Moisture-Storage Capacity = Available Water Capacity * Root Depth

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# LAND-COVER CHANGES

- Proposed impervious surfaces (FEIS 2010)
- New road surfaces outlined in the Guam Road Network; coverage needed
- Land-Cover Changes not documented in FEIS?

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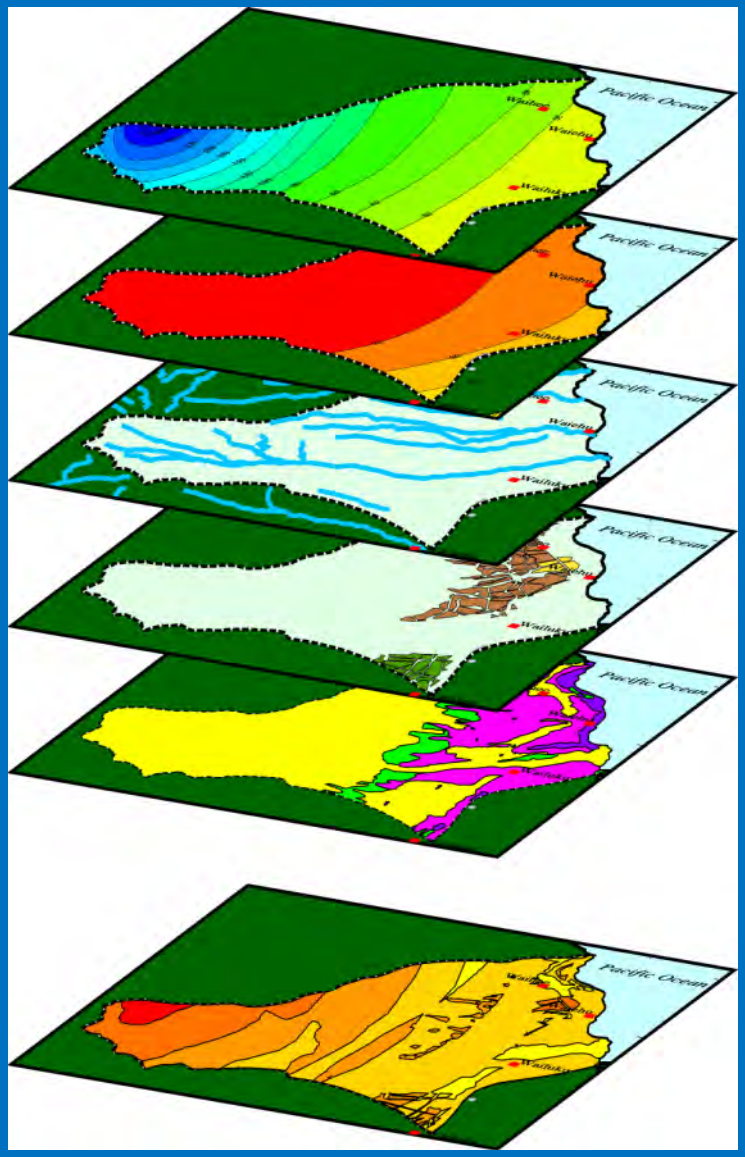
# Compute Recharge




Rainfall + Irrigation + Leakage

Evapotranspiration

Runoff

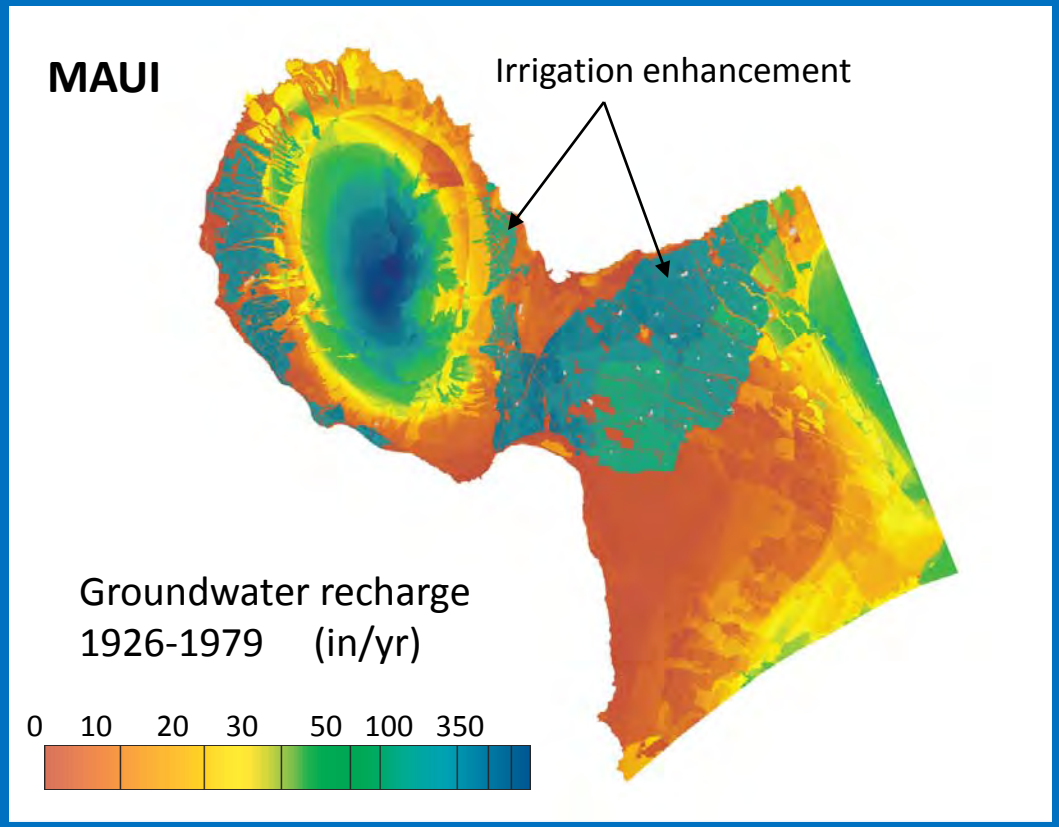
Land Cover

Soils

↓

Units of Common Hydrologic Properties

# Example

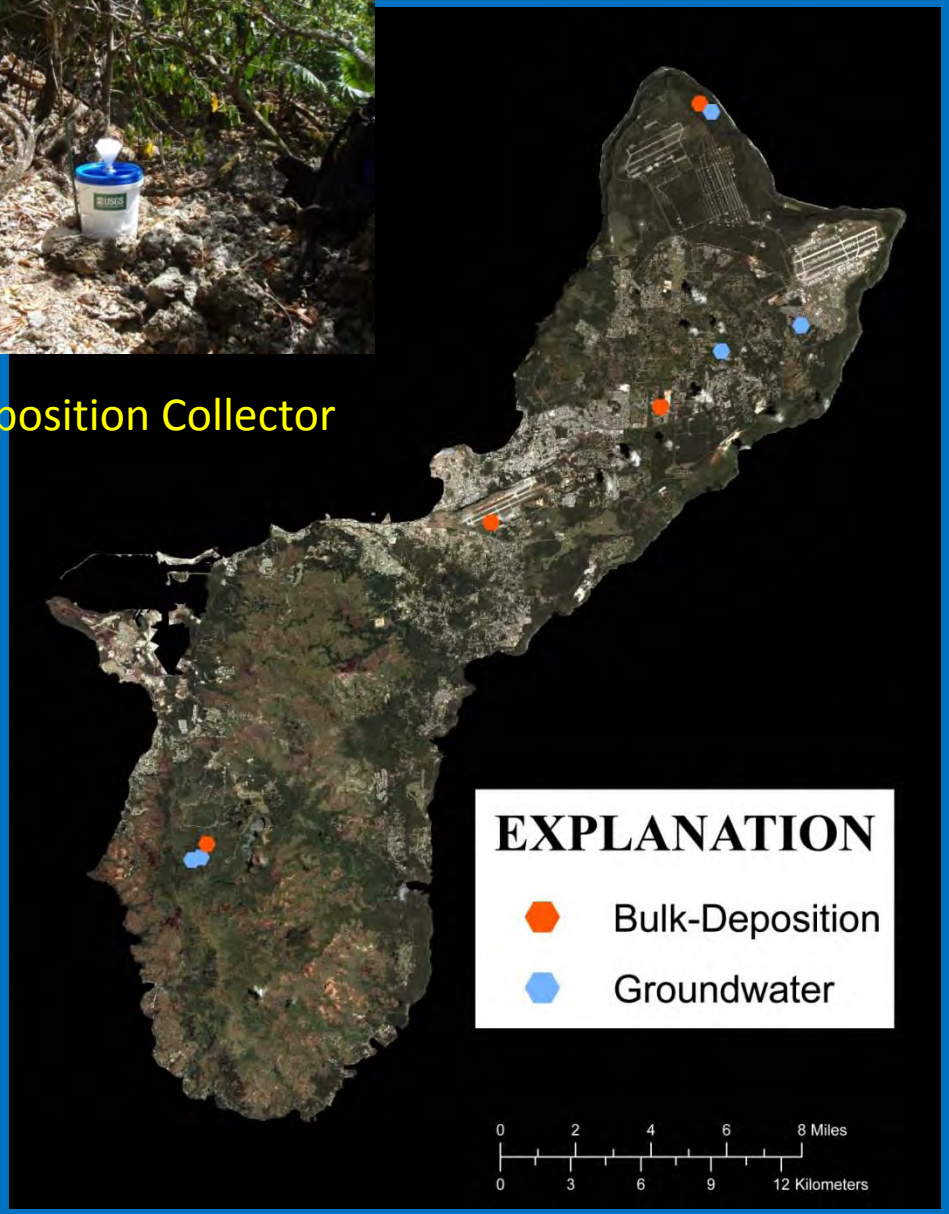



(Engott and Vana, 2007)

- Run the model using daily time step for 1971 – 2000
- Average daily recharge will be computed and mapped for the entire island
- Scenarios:
  - New impervious surfaces (FEIS)
  - Drought conditions
  - Climate change predictions if available

# Chloride Mass Balance (CMB)

Bulk-Deposition Collector




- Four bulk-deposition sites
- Five groundwater sites
- Sampled in June, August
- Sample in October, December

Groundwater site

Cave drippings

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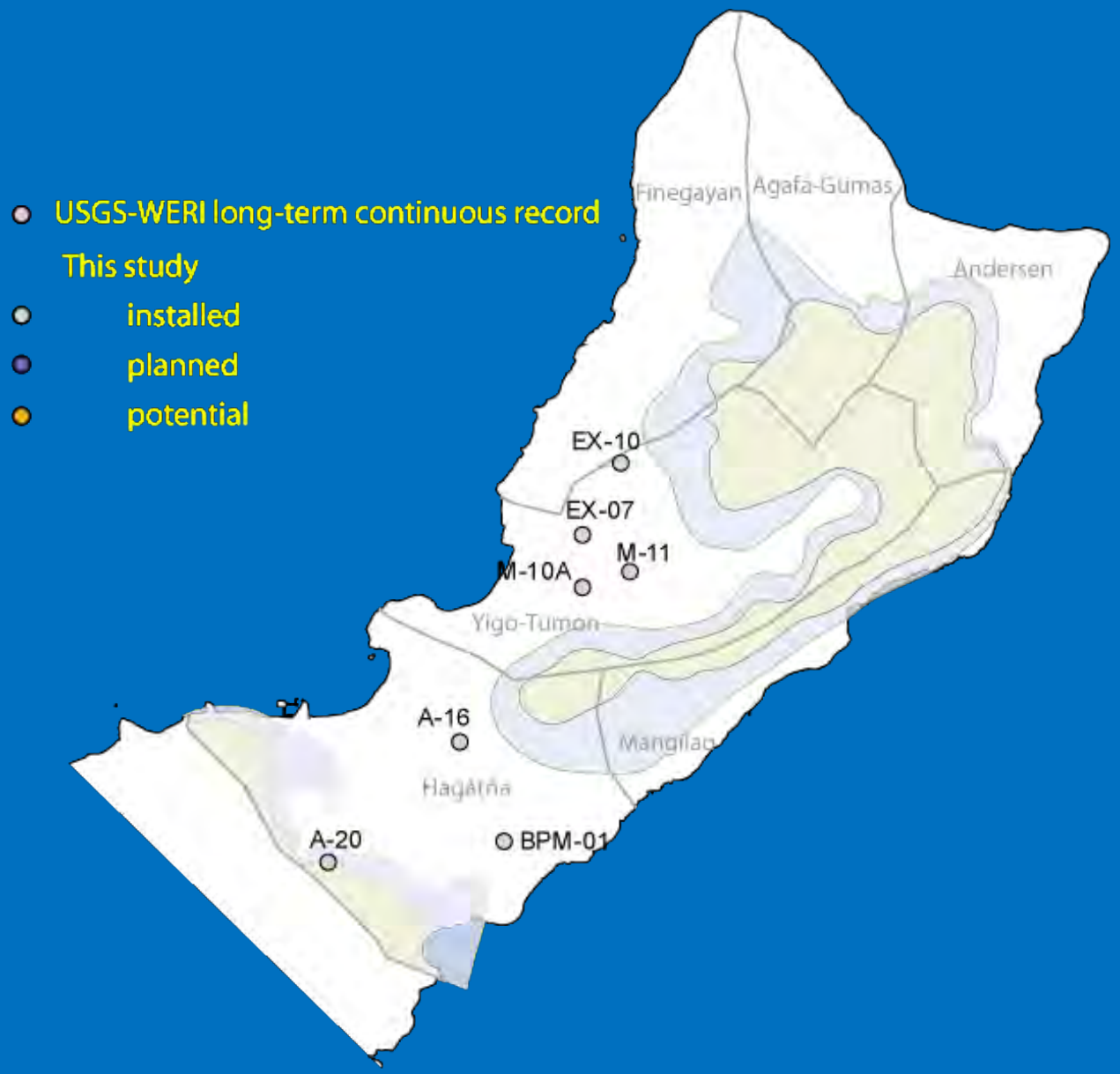
# Water-Level Monitoring

- Measure water levels in selected areas for several months
- Characterize distribution of aquifer properties (tidal analysis)
- Define spatial distribution of water levels (calibration target)
- Estimate recharge from storms/typhoons
- Identify long-term monitoring needs

# Distribution of wells monitored by USGS



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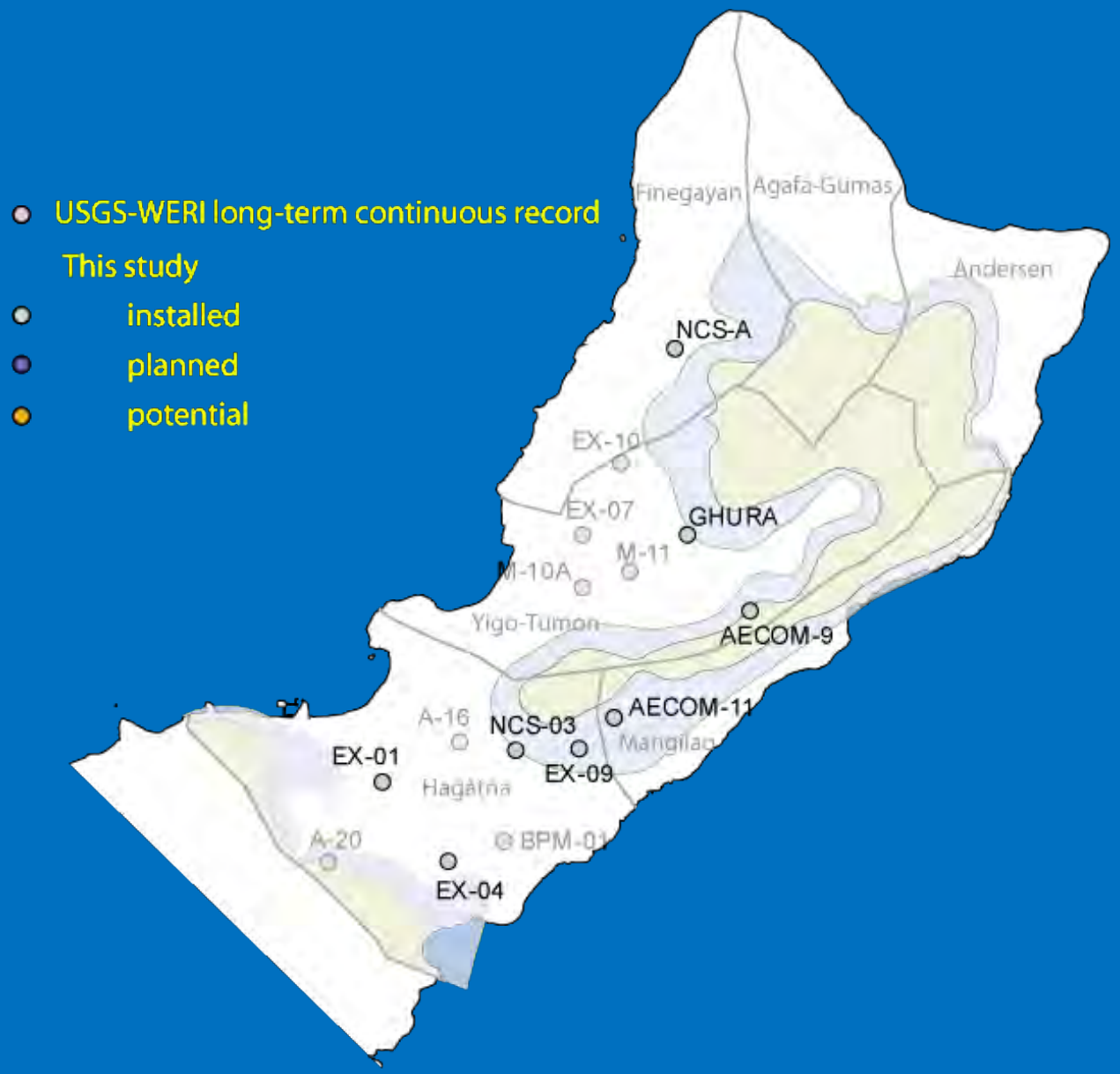


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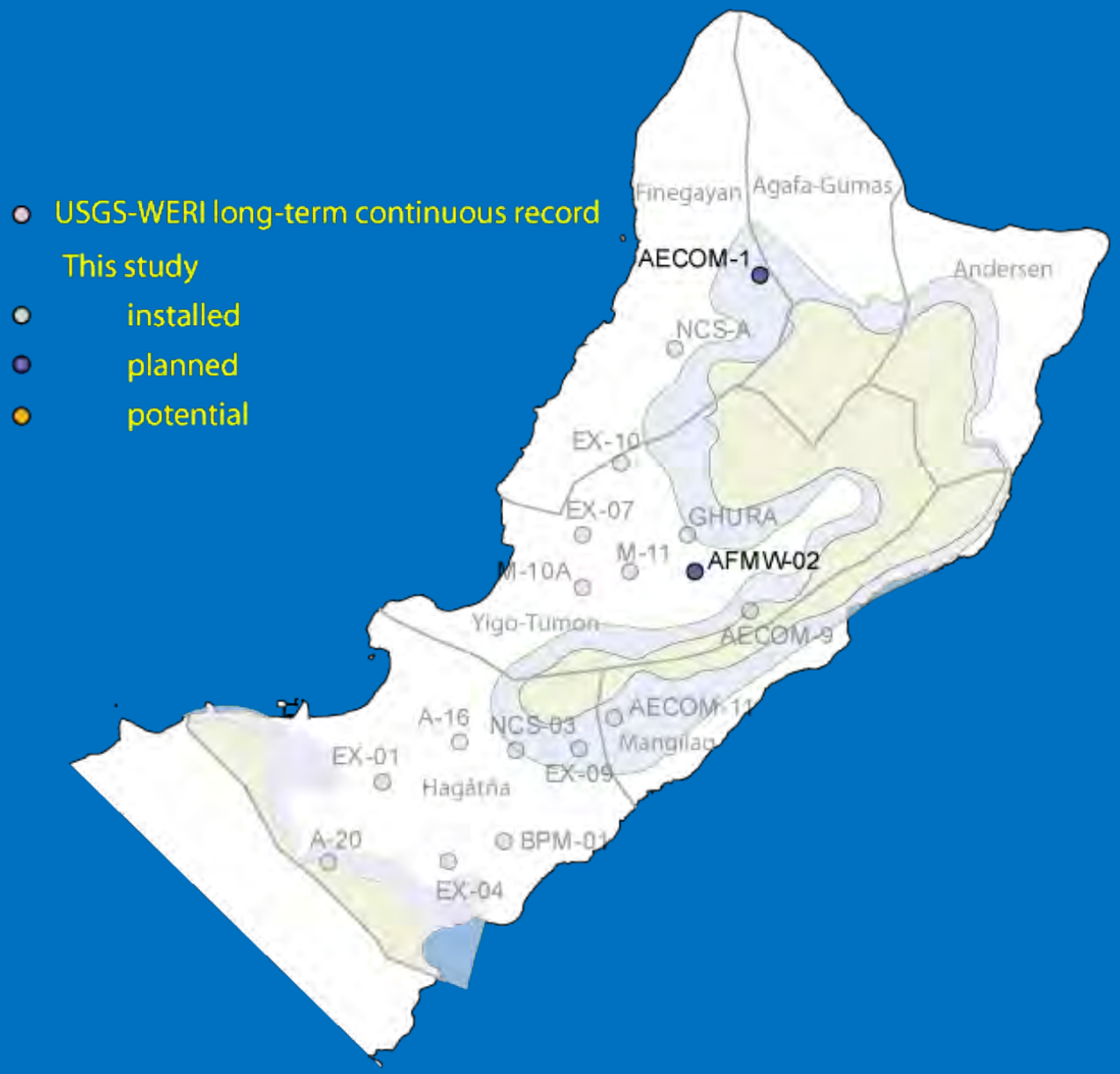


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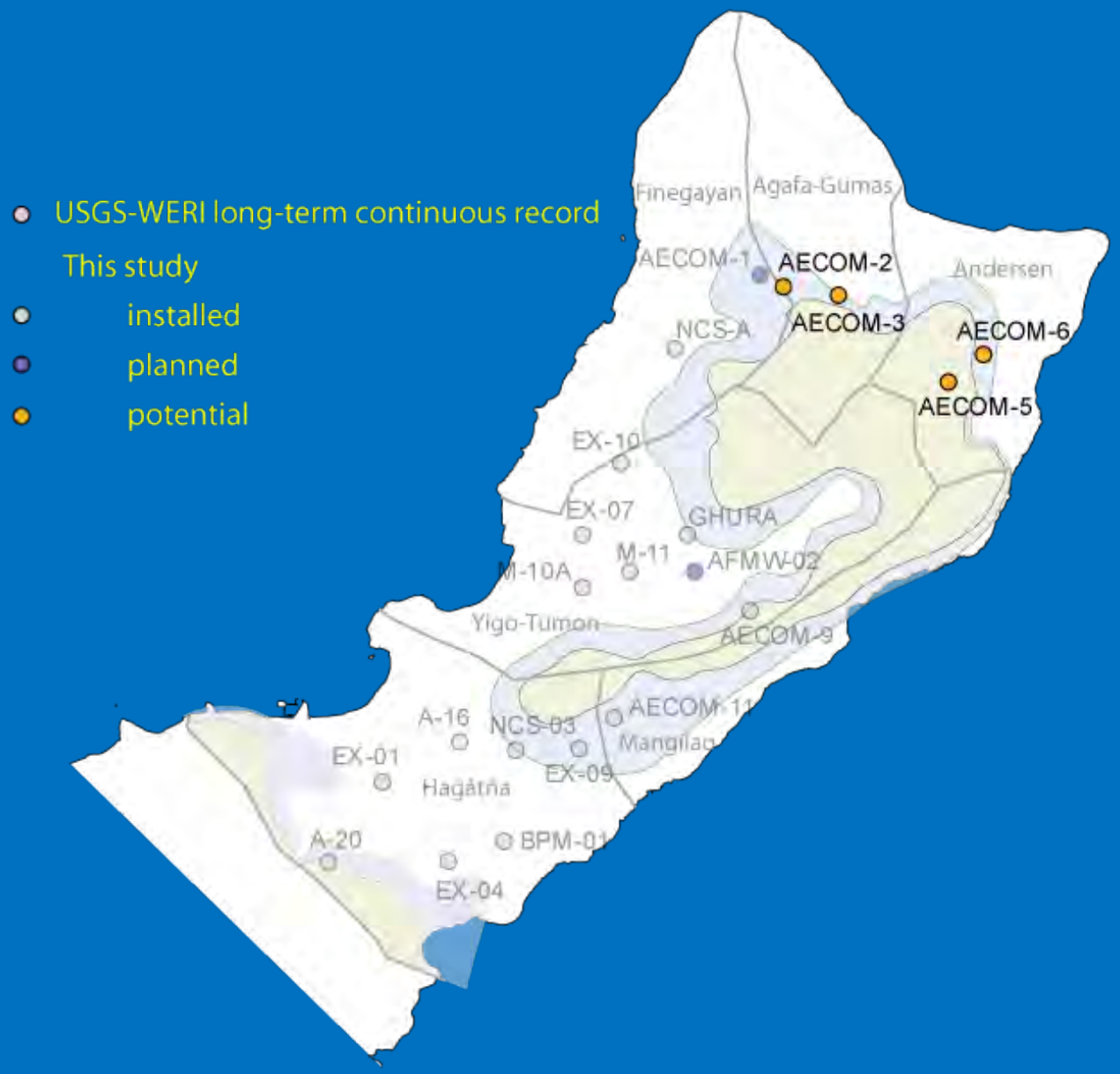


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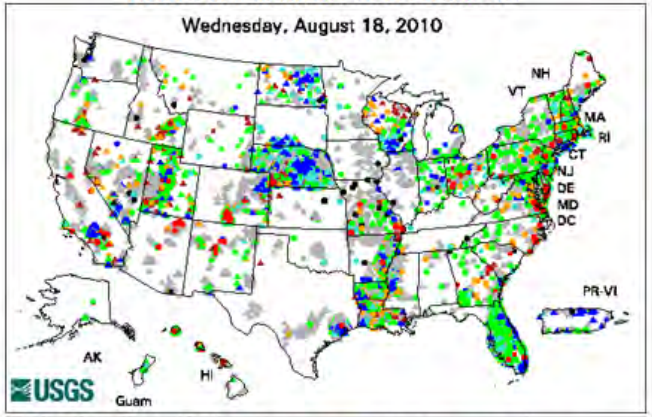
## Groundwater Watch

### Active Groundwater Level Network

Wednesday, August 18, 2010




Explanation - Percentile classes (symbol color based on most recent measurement)

| Low | <10 Much Below Normal | 10-24 Below Normal | 25-75 Normal | 76-90 Above Normal | >90 Much Above Normal | High | Not Ranked |
|---|---|---|---|---|---|---|---|

Real Time
Continuous
Periodic Measurements

Active Well Count

Real-Time: 1,238 Daily: 1,233 Periodic: 17,608

Map generated 8/18/2010 7:31:16 AM

Groundwater Watch Help Page | Download Google Earth Version NEW | National Map Animation

For a list of network wells, click on a State above or select from the box: Alabama

The Active Groundwater Level Network contains water levels and well information from more than 20,000 wells that have been measured by the USGS or USGS cooperators at least once within the past 13 months. This network includes all of these wells, regardless of measurement frequency, aquifer monitored, or the monitoring objective.

The U.S. Geological Survey has a database/archive of about 850,000 wells across the Nation. Information about these wells is available to the world via NWISWeb (http://waterdata.usgs.gov/nwis/gw). Through various groundwater programs, the USGS actively measures water levels in, or collects data from more than 20,000 of these wells each year. These wells are measured for a variety of disparate purposes, such as statewide monitoring programs, or more local effects like monitoring well drawdown, hydrologic research, aquifer tests, or even earthquake effects on water levels.

There also are a variety of networks among these actively measured wells; a National Climate Response Network for wells, Regional Networks like the High Plains Aquifer Monitoring Program that is designed to monitor storage changes in the High Plains Aquifer, state-based networks that are designed to monitor statewide groundwater conditions, and local networks designed to monitor pumping effects.

**http://groundwaterwatch.usgs.gov/**

*References to non-Department of the Interior (DOI) products do
By viewing the Google Maps API on this web site

Accessibility FOIA Privacy Policies and Notices

U.S. Department of the Interior | U.S. Geological Survey
URL: http://groundwaterwatch.usgs.gov/default.asp
Page Contact Information: OGW Webmaster
Last update: Sunday, July 11, 2010 at 13:51

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# Water-Level Data Consistency

- Accurate water-level data is needed to determine spatial changes
- Errors can be large fraction of water-level difference between wells in Guam's freshwater lens
- Water-level tape accuracy
- Water-level measuring point with updated elevation surveyed to a common datum
- Important for data sharing among all agencies

# Water-Level Tape Calibration

- Use master calibration tape
- Calibrate new tapes to establish baseline
- Re-calibrate on a regular schedule
- Calibrate over a range of depths
- Account for environmental factors
- Retire tapes out of calibration (> 0.05% error usually due to kinking)
- Involve all agencies collecting water-level data

| Calibration Table effective beginning July 2008 for tape PIWSC-05 | | |
|---|---|---|
| From (ft) | To (ft) | Subtract from tape (ft) |
| 44.70 | 123.21 | 0.01 |
| 123.22 | 191.80 | 0.02 |
| 191.81 | 253.47 | 0.03 |
| 253.48 | 309.97 | 0.04 |
| 309.98 | 362.42 | 0.05 |
| 362.43 | 411.58 | 0.06 |
| 411.59 | 458.00 | 0.07 |
| 458.01 | 500.00 | 0.08 |

* Values in red are extrapolations beyond deepest test measurement

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# Well Database

Wells commented_july 7 2010_0938 - Microsoft Excel

D6 | A-2

| | 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 | Mang | Agafa Guma | Andersen | | | INACTIVE WELLS | | | | | | | |
| 2 | | | | GWA | | | EARTH TECH | NAVY | AIR FORCE | USGS | | | | | | | | | Avg last 3 yrs - GWA | |
| 3 | | Sub-Basin www database | | WERI Tech Report | Latitude | Longitude | Land surface elevation | Well Dept h | 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 | Chlorid e 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 ? | | | 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 | 33 | | | 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 | | | 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 | | 18-13 | 52.33' |

UOG:
A-6 Well Info Layne Internattional

Sheet1 Sheet2

Cell O10 commented by UOG

80%

USGS
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# Outline of Meeting

- Project goals, products, timeline – *Steve Gingerich*
- Informational fact sheet, chloride and pumpage history – *Steve Gingerich*
- Groundwater recharge study – *Adam Johnson*
- Water-level monitoring – *Steve Gingerich*
- Well database – *Vivianna Bendixson*
- Hydrology/Modeling workshops – *John Jenson*
- Requests for stakeholder input and wrap-up – *Steve Gingerich*

# Workshops/field trips

Separate presentation by Dr. John Jenson, WERI

# Stakeholder input

- Logos for fact sheet – vector format
- Data needs
  - Status of Air Force pumpage
  - Storm drain distribution system
  - New road locations
  - Non-DOD developments
  - Updated non-sewered house distribution
  - Contact person at NavFacMar and access to historic documents and well information
- Interest in workshops/field trips
- Interest in water-level tape calibration
  - What agencies? What equipment?