USGS
science for a changing world

Groundwater

NASA / USAID / World Bank
MENA-WISP meeting – Morocco

Daniel J. Goode, Ph.D.
Research Hydrologist

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

NASA Goddard Space Flight Center
December 3, 2013

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

Mission:

The USGS provides reliable scientific information to:

- **Describe and understand the Earth**
- **Minimize loss of life and property from natural disasters**
- **Manage water, biological, energy, and mineral resources**
- **Enhance and protect our quality of life**

The USGS is the Nation's largest earth - and life - science agency and has the principal responsibility within the Federal government for providing hydrologic information and appraising the Nation's water resources.

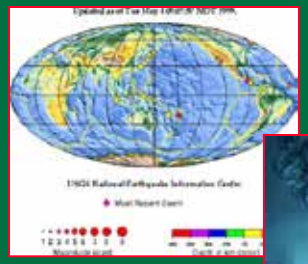
USGS
science for a changing world

USGS Science

Integrated Taxonomic Information System

Fish and Wildlife Disease Studies

Landslide Hazard Assessments

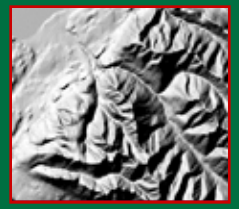


Real-time Earthquake Data

Volcanic Hazards

Biology Geology
Mapping Water

Maps



Elevation

Satellite Imagery

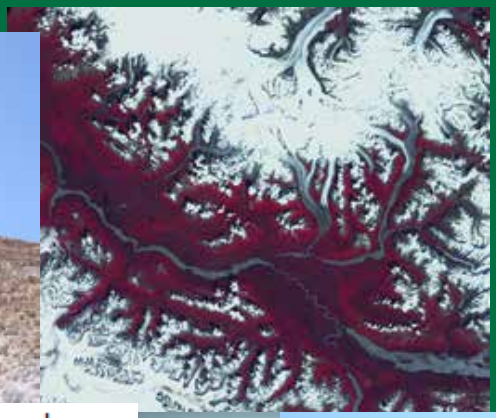
Water Quality Data

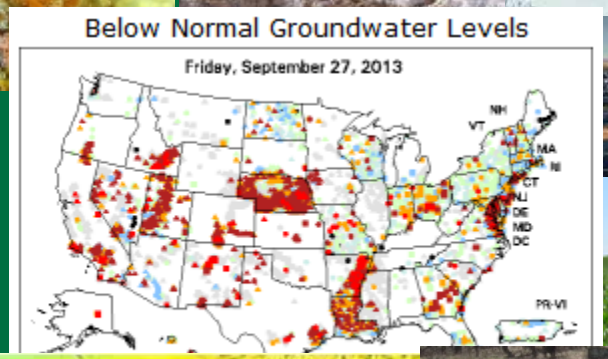
Real-time Water Data

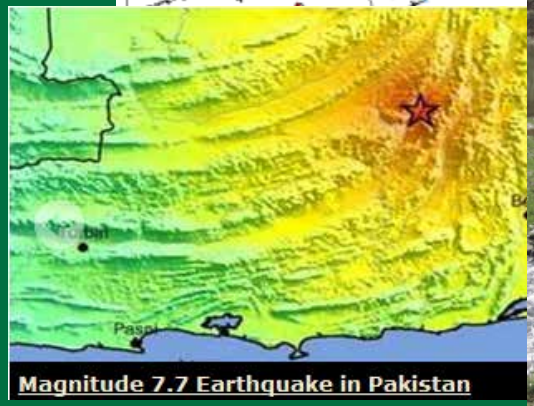
USGS
science for a changing world

Mission Areas

- Climate & Land Use Change
- Ecosystems
- Energy & Minerals
- Environmental Health
- Natural Hazards
- Water







Ecosystems: Turtles in Morocco

HERPETOLOGICAL JOURNAL 22: 43–49, 2012

Clutch and egg allometry of the turtle *Mauremys leprosa* (Chelonia: Geoemydidae) from a polluted peri-urban river in west-central Morocco

Mohamed Naimi[1], Mohammed Znari[1], Jeffrey E. Lovich[2], Youssef Feddadi[1] & Moulay Abdeljalil Ait Baamrane[1]

[1]*Laboratory "Biodiversity & Ecosystem Dynamics", Department of Biology, Faculty of Science - Semlalia, Cadi Ayyad University, Avenue Prince Moulay Abdellah, P.O. Box 2390, 40000, Marrakech, Morocco*

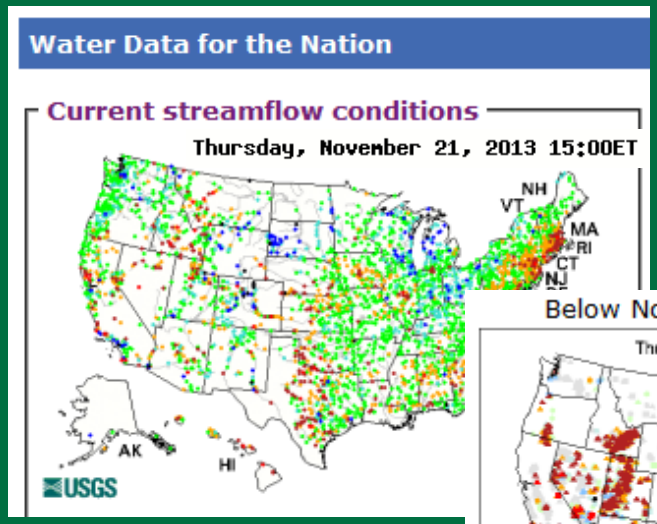
[2]*U.S. Geological Survey, Southwest Biological Science Center, 2255 North Gemini Drive, MS-9394, Flagstaff, Arizona 86001, USA*

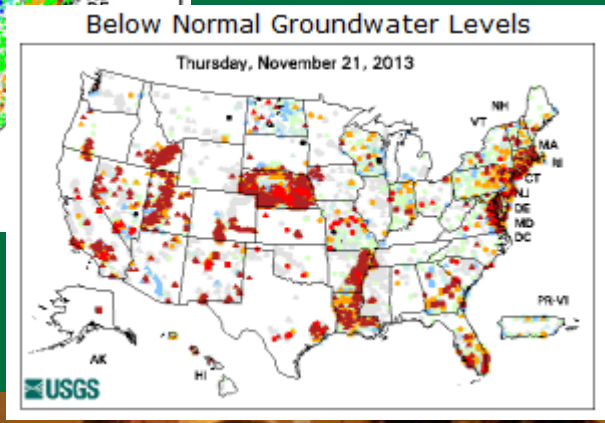
USGS

Cadi Ayyad University

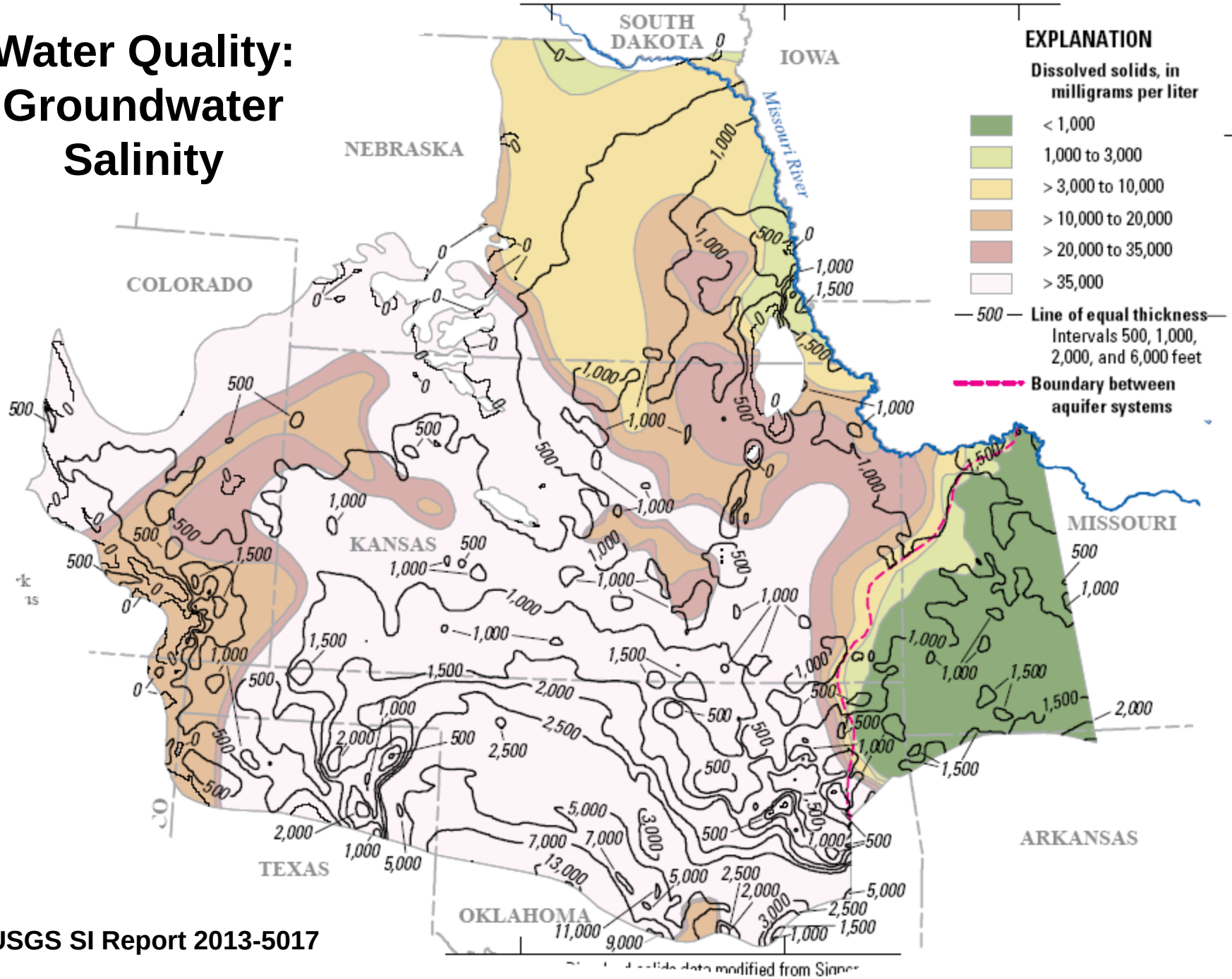
Water Programs ($)

- Cooperative Studies
- Streamflow
- Groundwater Resources
- Networks & Analysis
- National Water Quality Assessment
- Research & Development
- Toxic Substances (EH)
- National Water Census (Initiative)



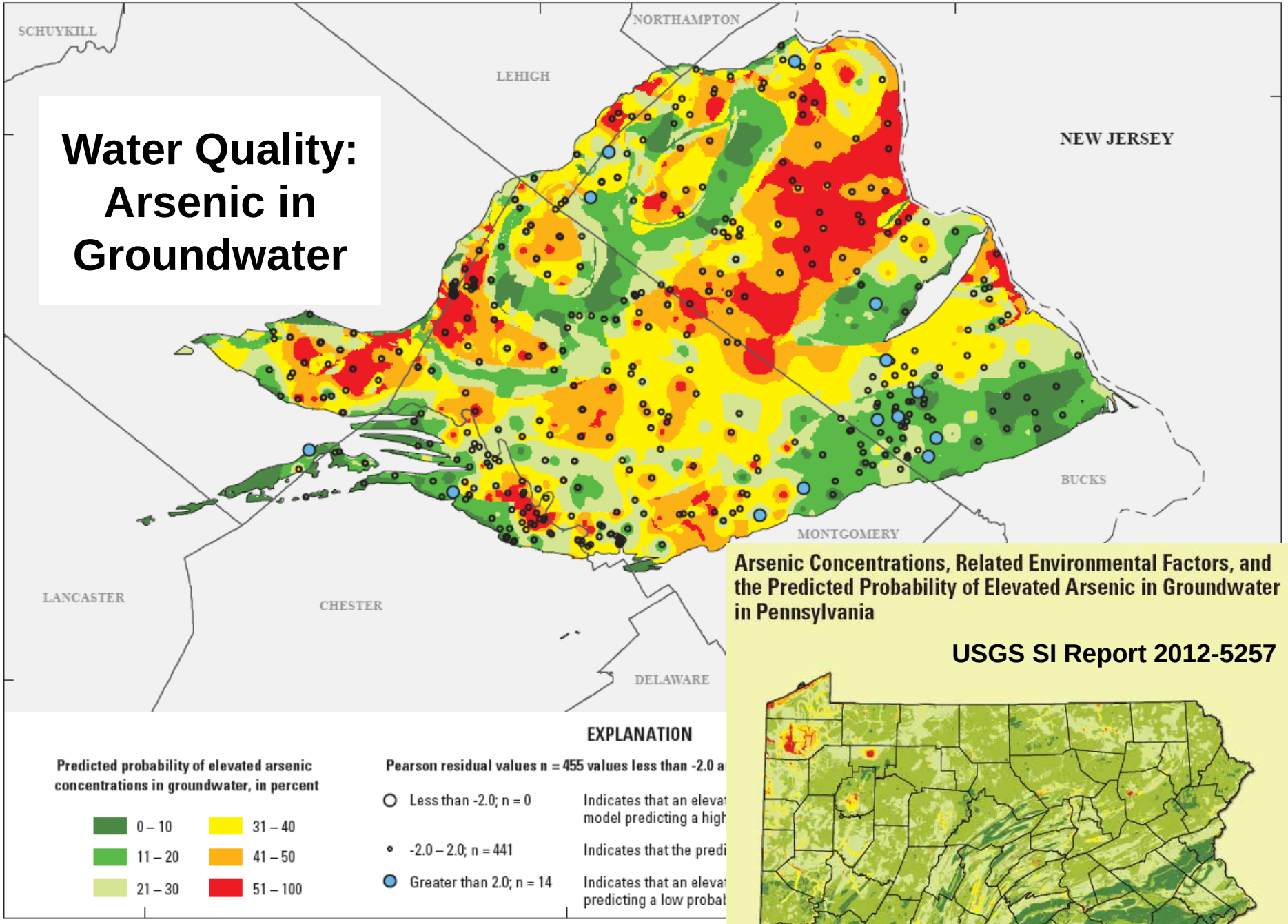


Water Quality: Groundwater Salinity



USGS SI Report 2013-5017

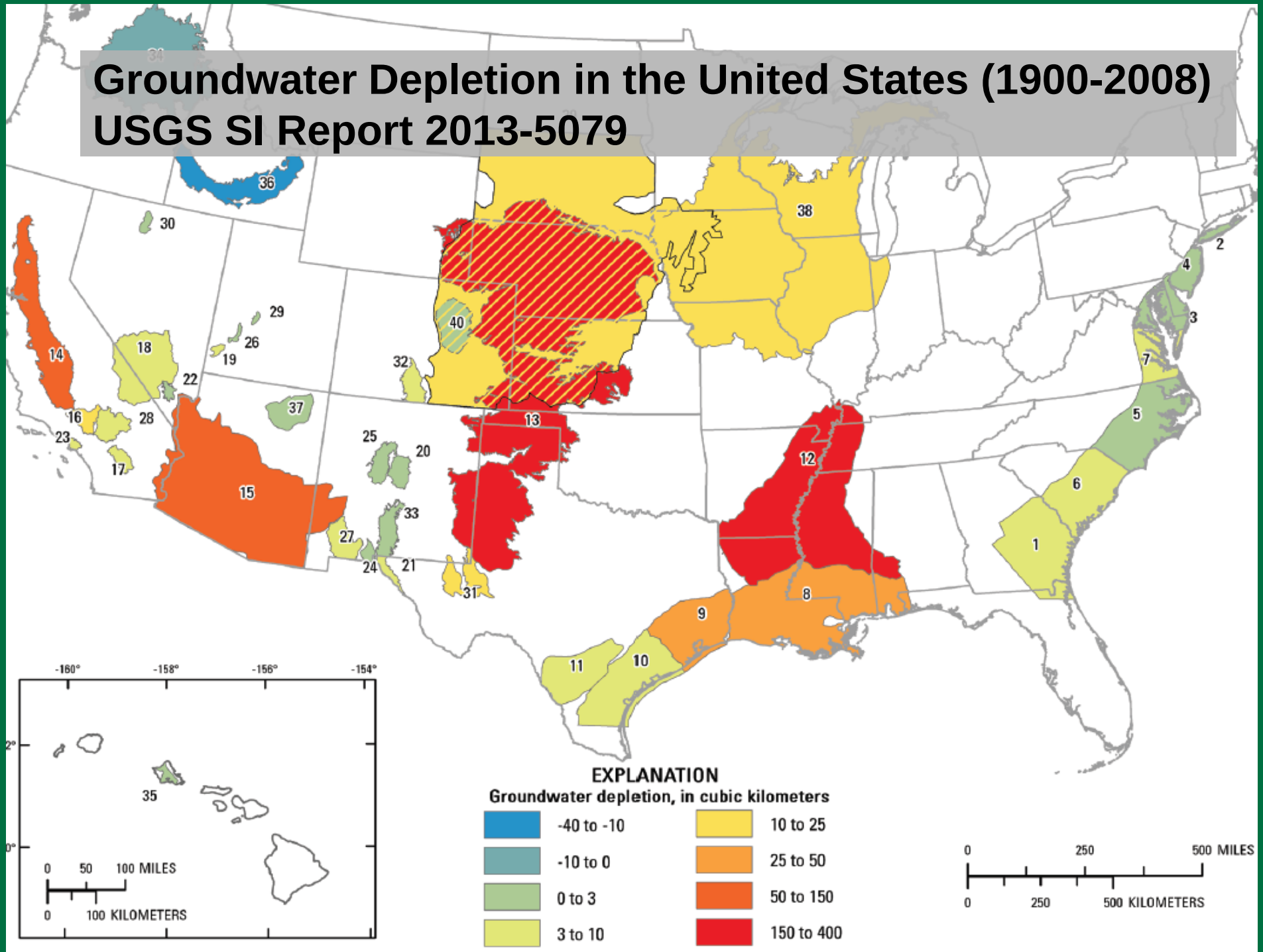
Water Quality: Arsenic in Groundwater



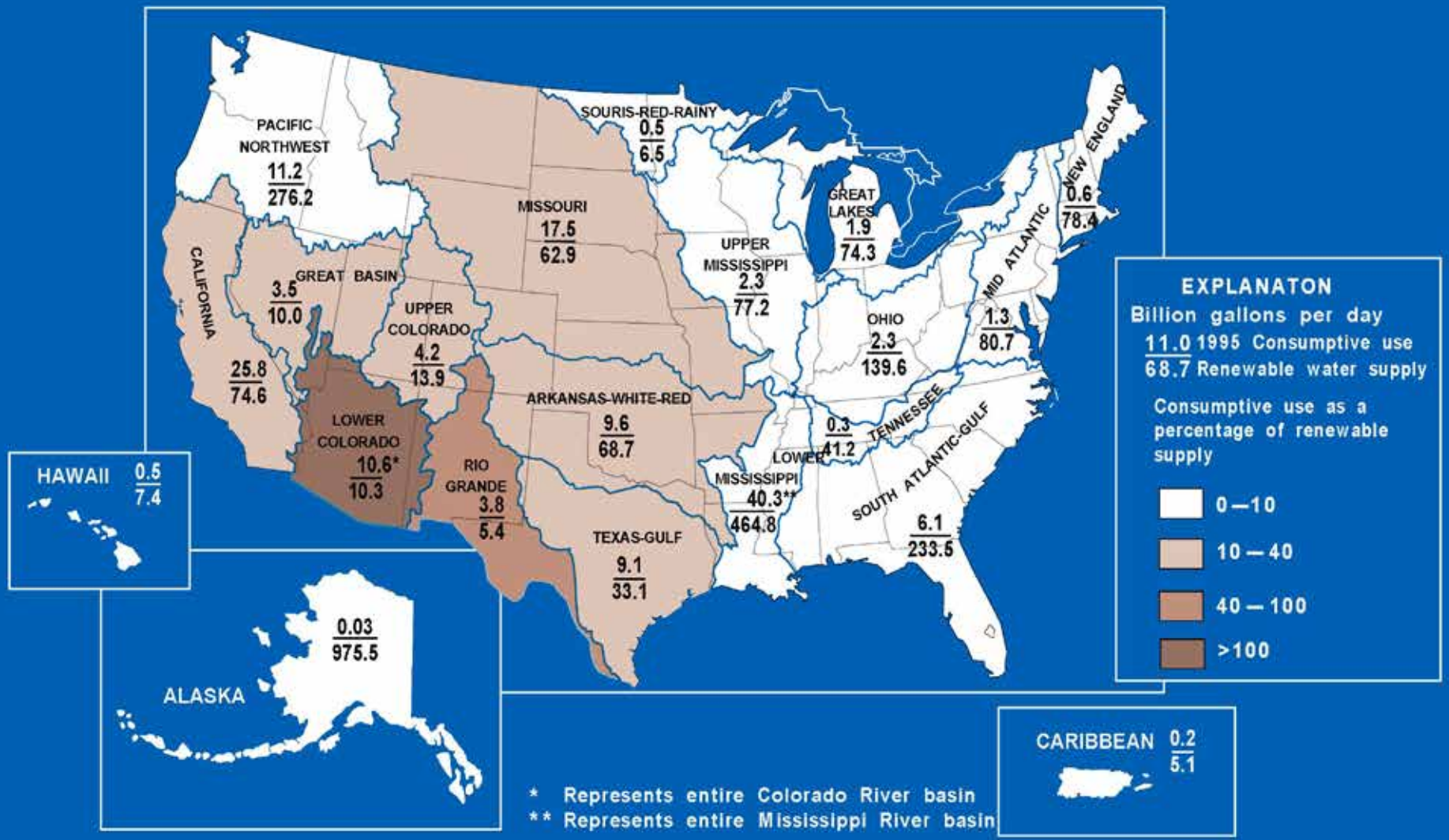
Arsenic Concentrations, Related Environmental Factors, and the Predicted Probability of Elevated Arsenic in Groundwater in Pennsylvania

USGS SI Report 2012-5257

Groundwater Depletion in the United States (1900-2008)
USGS SI Report 2013-5079



CONSUMPTIVE USE AND RENEWABLE WATER SUPPLY, BY WATER-RESOURCES REGION



USGS

Consumptive Use vs. Non-Consumptive Use

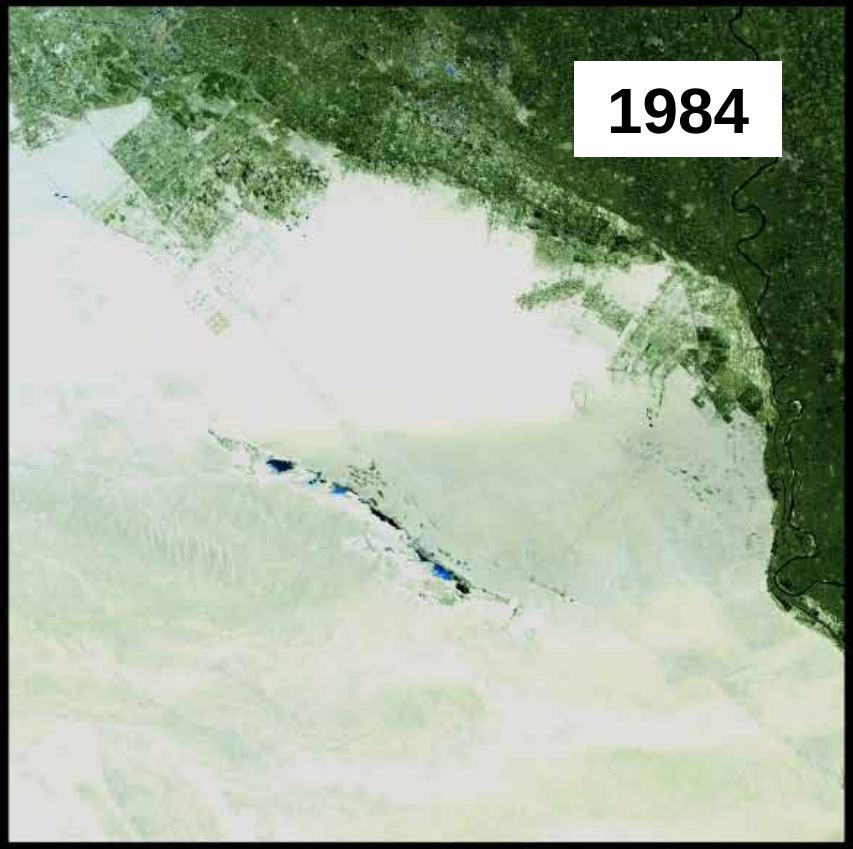
- Agriculture is 80-100% consumptive (lost to evaporation)
- Other uses 60-80% non-consumptive (stays in local water system, as liquid)
- Non-consumptive water can be reused
- In Jordan, municipal and industrial water is used, collected, treated, and re-used for agriculture.

California Dept. of Water Resources

USGS

USGS
science for a changing world

NASA



Agriculture transforms Egyptian Desert

USGS

Excess irrigation has created a shallow groundwater table, which is being pumped and used (recycled) for irrigation.

Agro-Hydrologic Monitoring of "Irrigated" Systems in Euphrates and Tigris Region

Gabriel Senay and Mike Budde

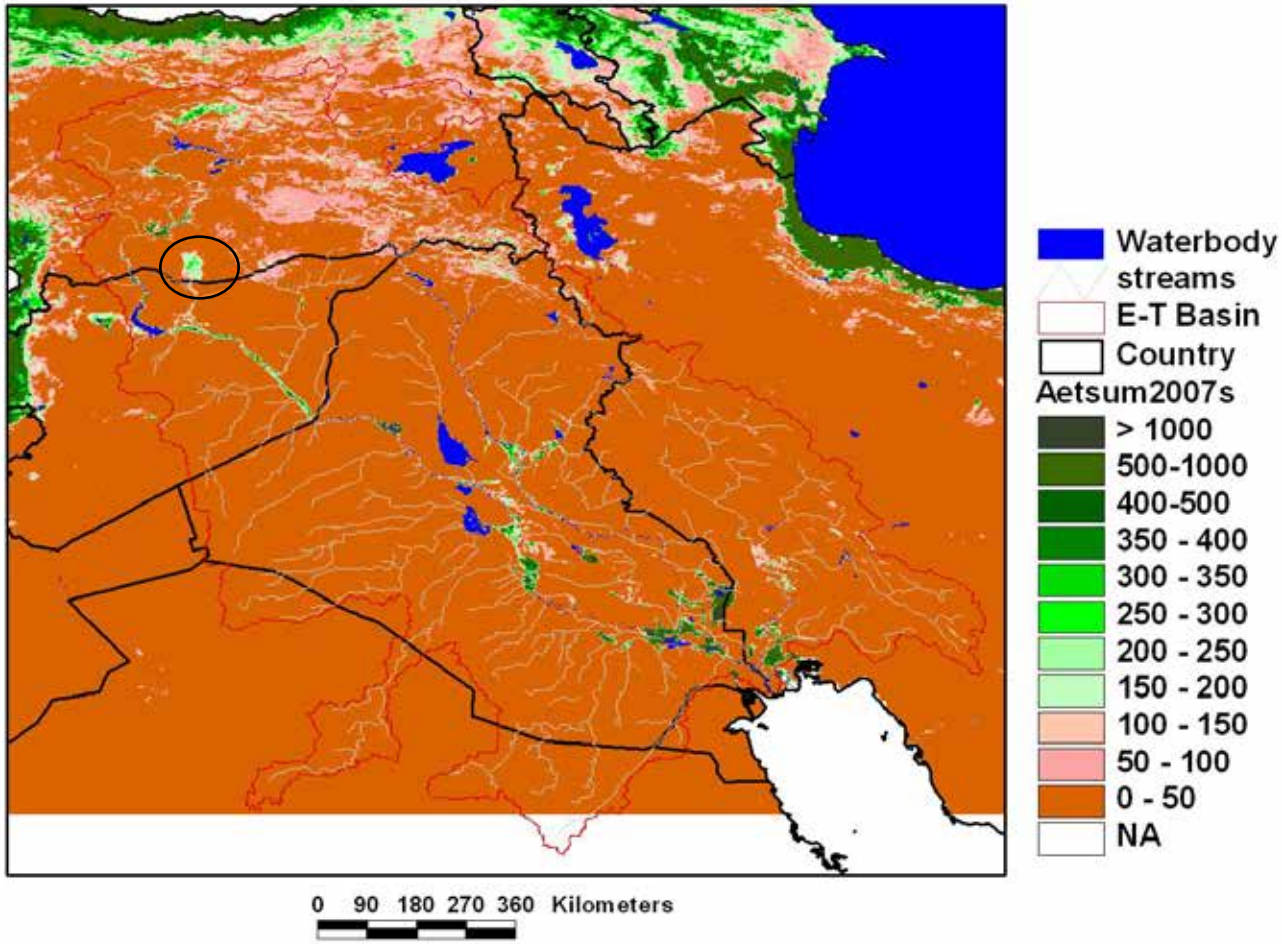
U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center

Iraq Water Resources Assessment Training

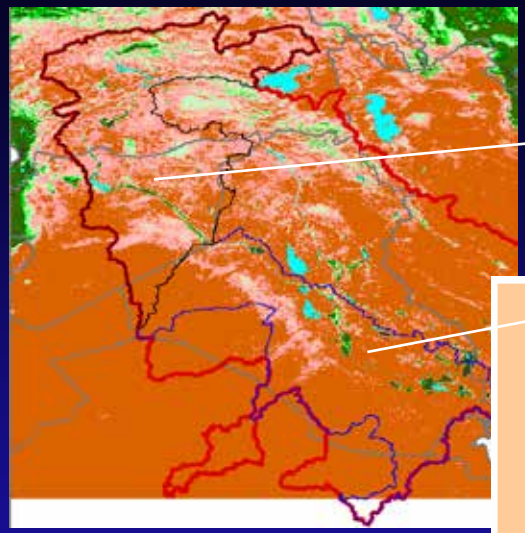
Amman, Jordan: Nov 9-20, 2008

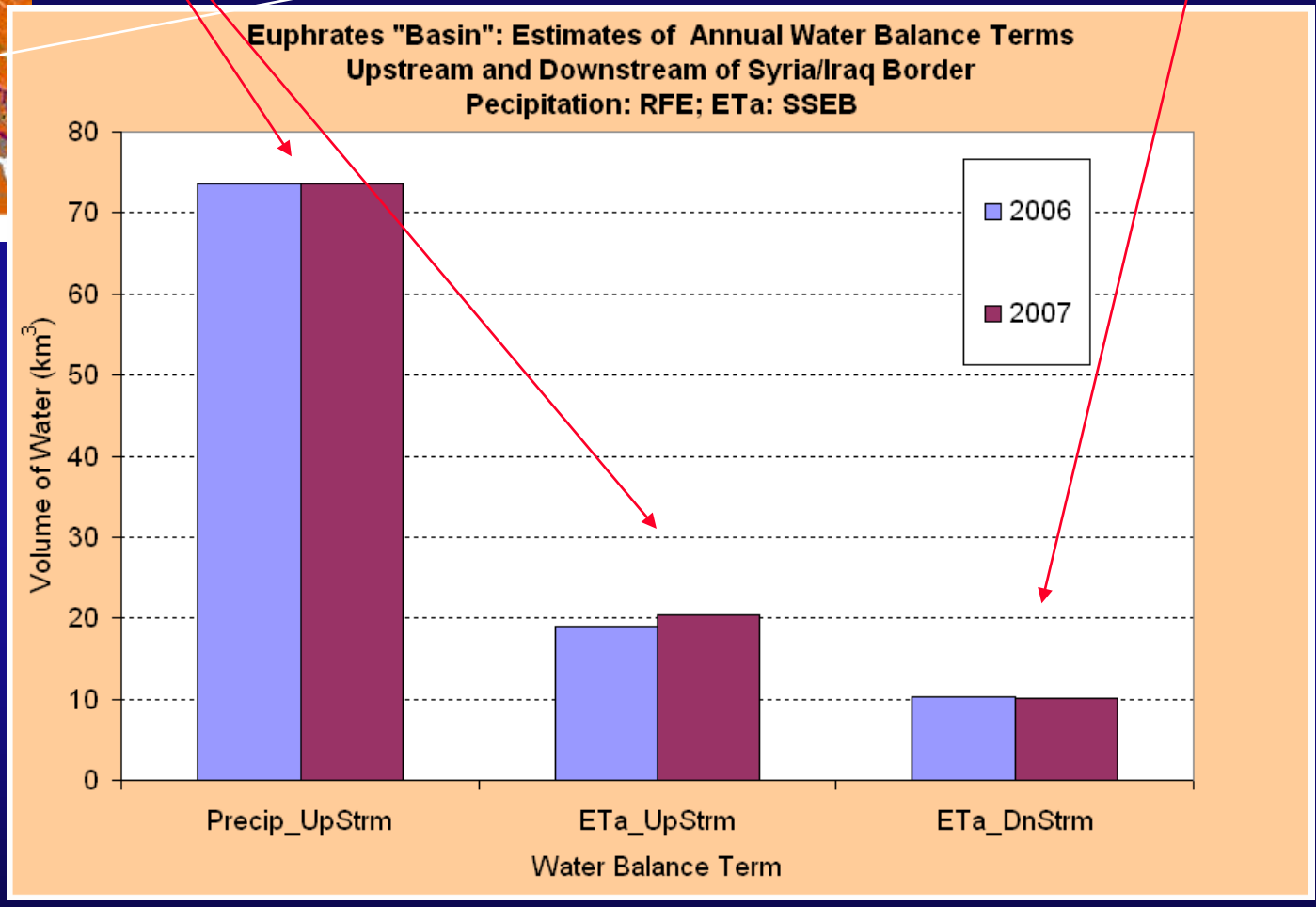
U.S. Department of the Interior
U.S. Geological Survey

2007 Seasonal ETa (mm)
(SSEB Model: May-Sep)



USGS

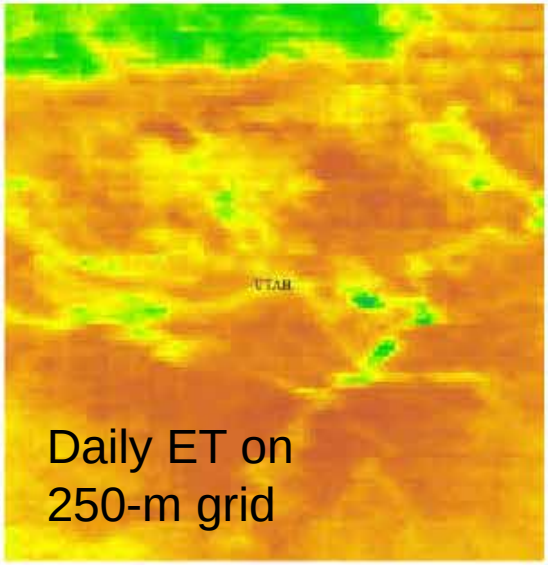


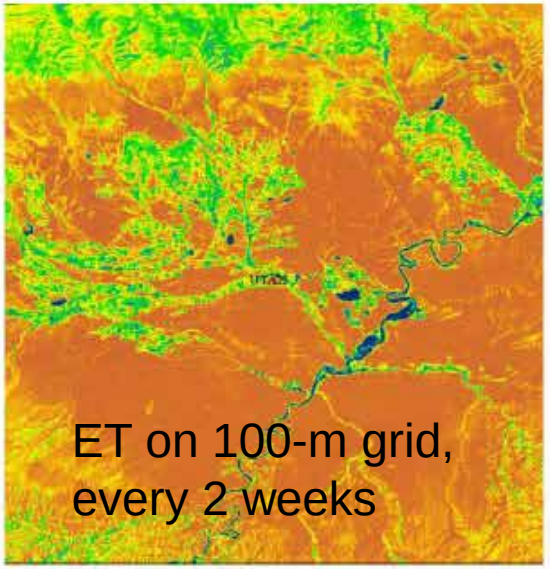

Euphrates "Basin": Estimates of Annual Water Balance Terms
Upstream and Downstream of Syria/Iraq Border
Pecipitation: RFE; ETa: SSEB
Volume of Water (km3)
80
70
60
50
40
30
20
10
0
2006
2007
Precip_UpStrm
ETa_UpStrm
ETa_DnStrm
Water Balance Term

USGS

The figure below show the spatial scale differences between Landsat and MODIS. Although MODIS cannot resolve ET use by individual irrigated fields, the basin-wide estimate is comparable to spatial aggregates derived from Landsat based ET.

ET = EvapoTranspiration
Sum of evaporation and transpiration by plants





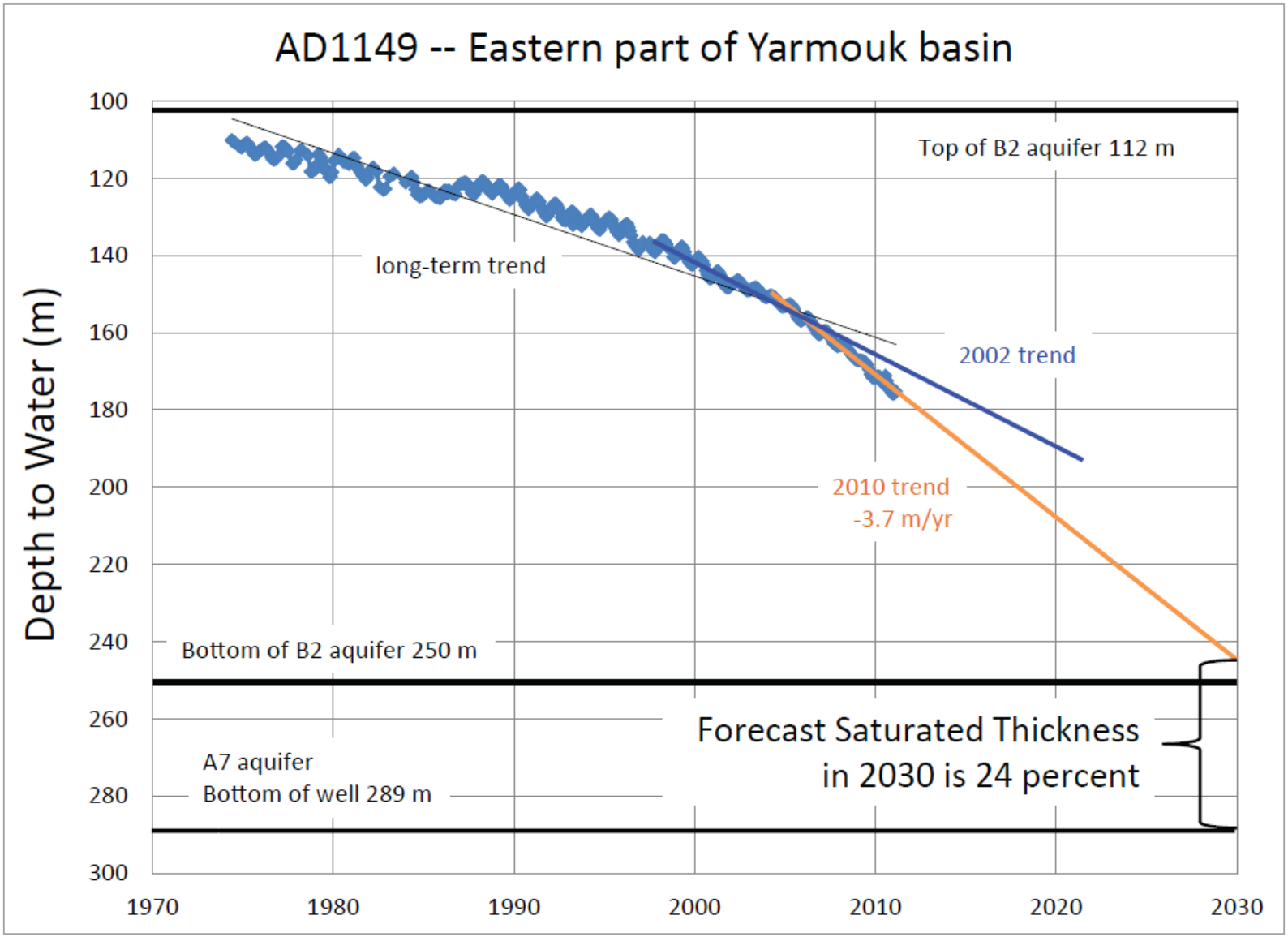
Base Map MODIS ET Landsat ET

0 1000 mm

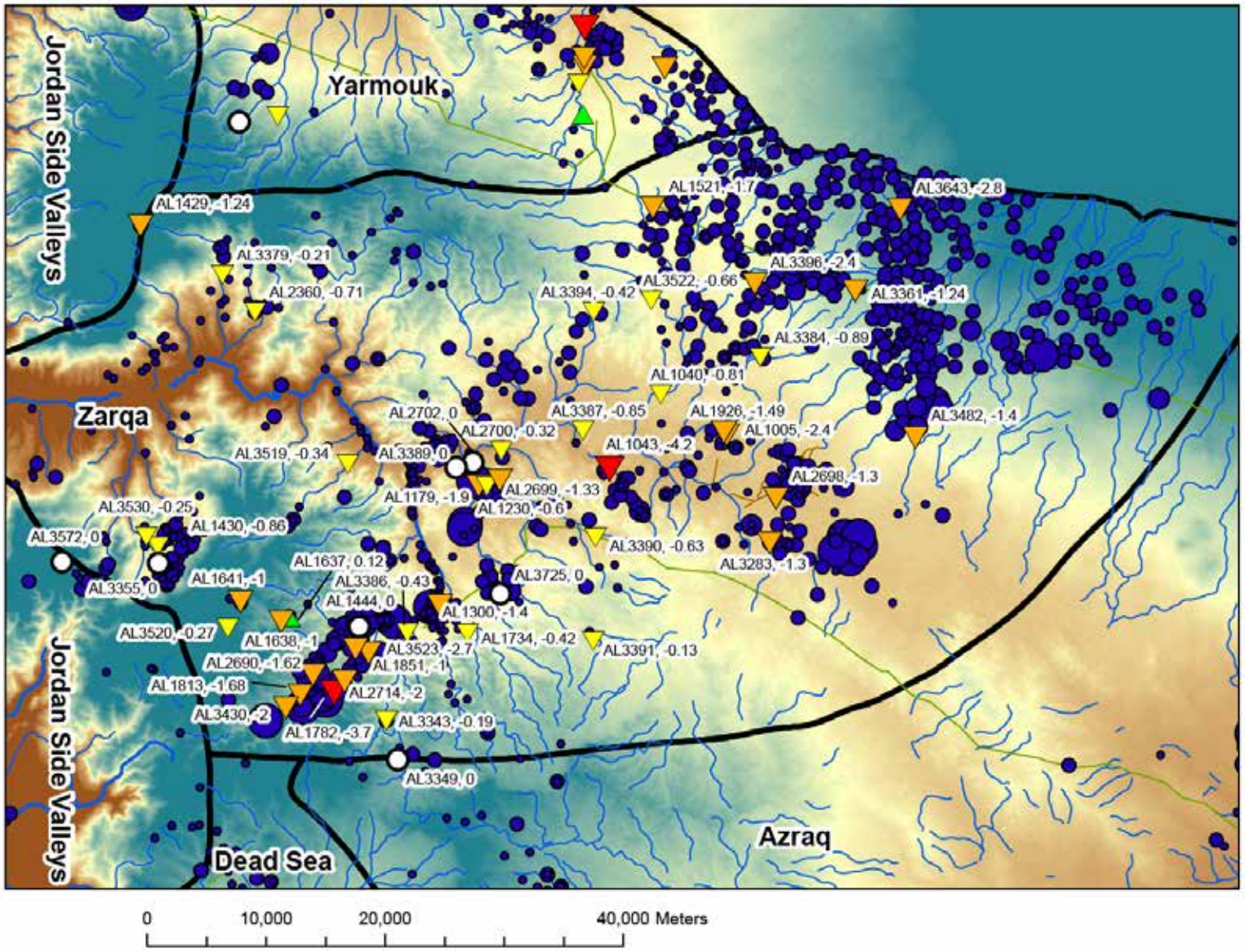
Comparison of 2010 Annual ET for Duchessne,

Gabriel Senay, USGS, South Dakota

Scarcity: Trends in Aquifers



Amman-Zarqa basin
Average trend= -1.1 meters per year

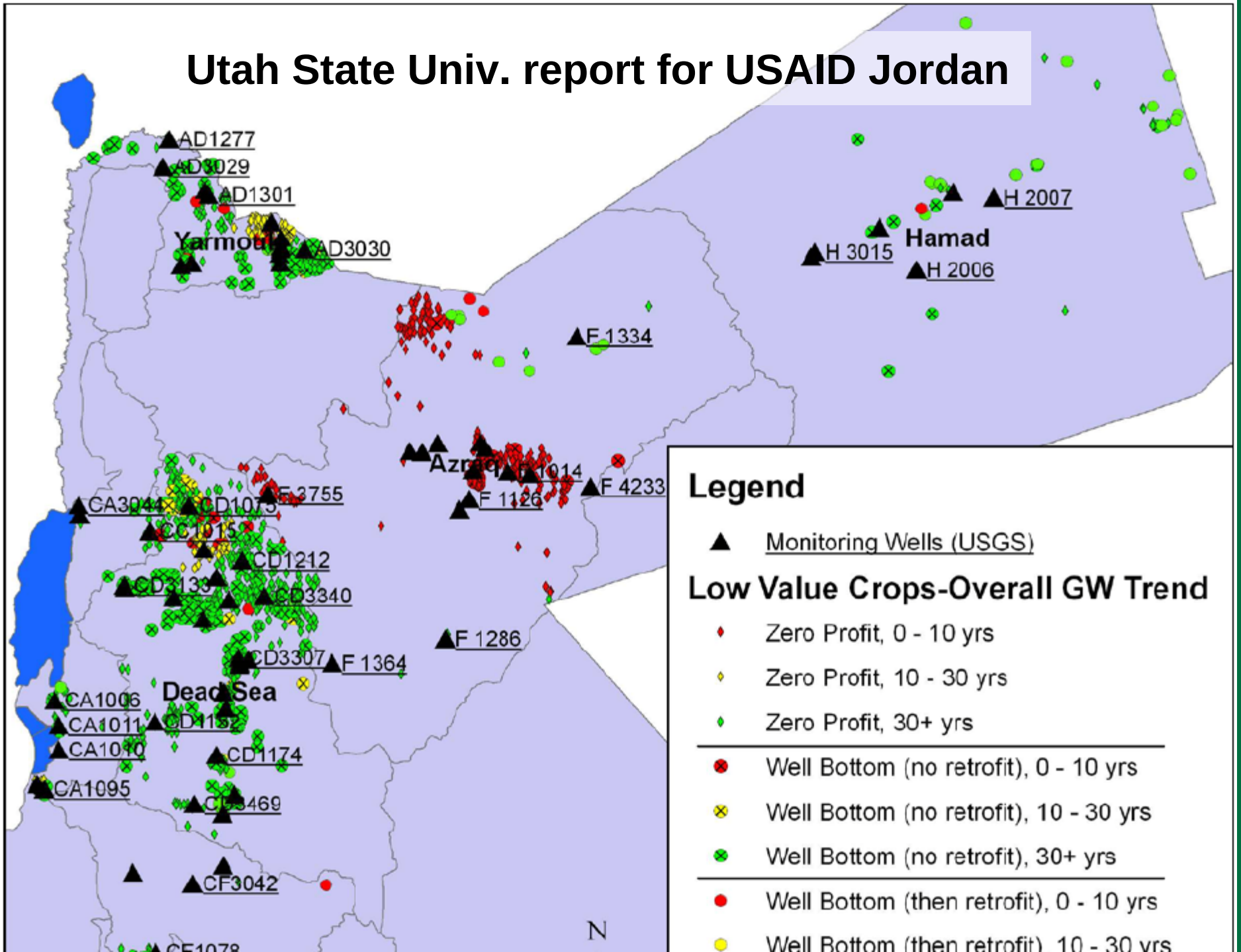


Groundwater Basin	# Wells	Groundwater Level Trend 2010 (m/yr)	
		Average	Maximum
Hammad	4	0	-0.2
Yarmouk	11	-1.1	-3.7
Jordan Side Valleys (Wadis)	9	-1.9	-9
Dead Sea	30	-0.8	-9
Amman-Zarqa	48	-1.1	-4.2
Azraq	15	-0.8	-2.3

USGS

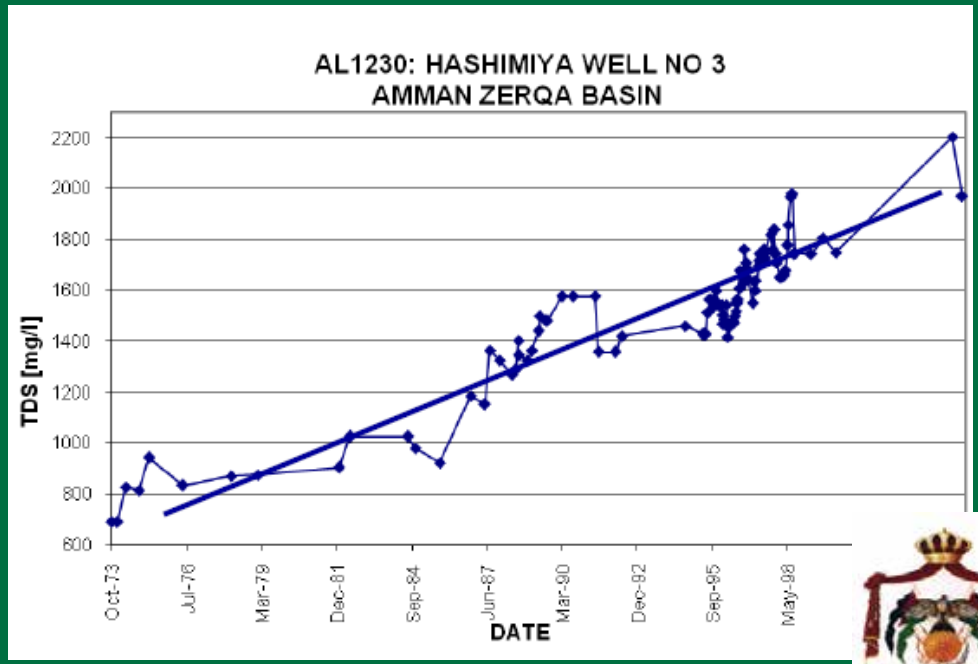
USAID | الأردن
من الشعب الأمريكي

Utah State Univ. report for USAID Jordan

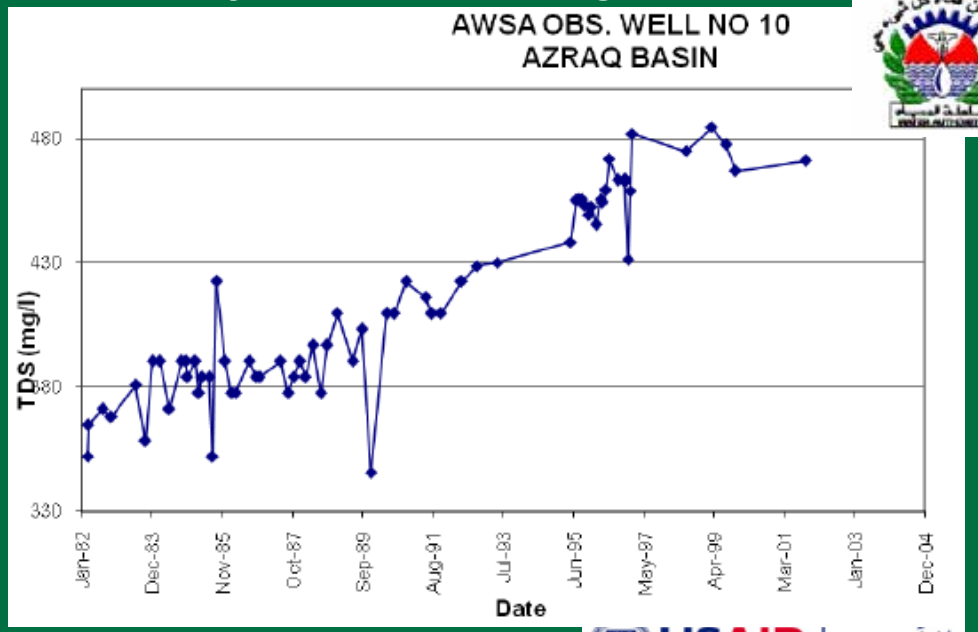


Context – Salinity

- Wells show increasing salinity (as Total Dissolved Solids, or Electrical Conductivity, TDS≈0.7*EC)
- Salinity may force blending or treatment before use, or crop changes
- Wells have been abandoned or ‘rested’ due to salinity



Ministry of Water and Irrigation, 2010

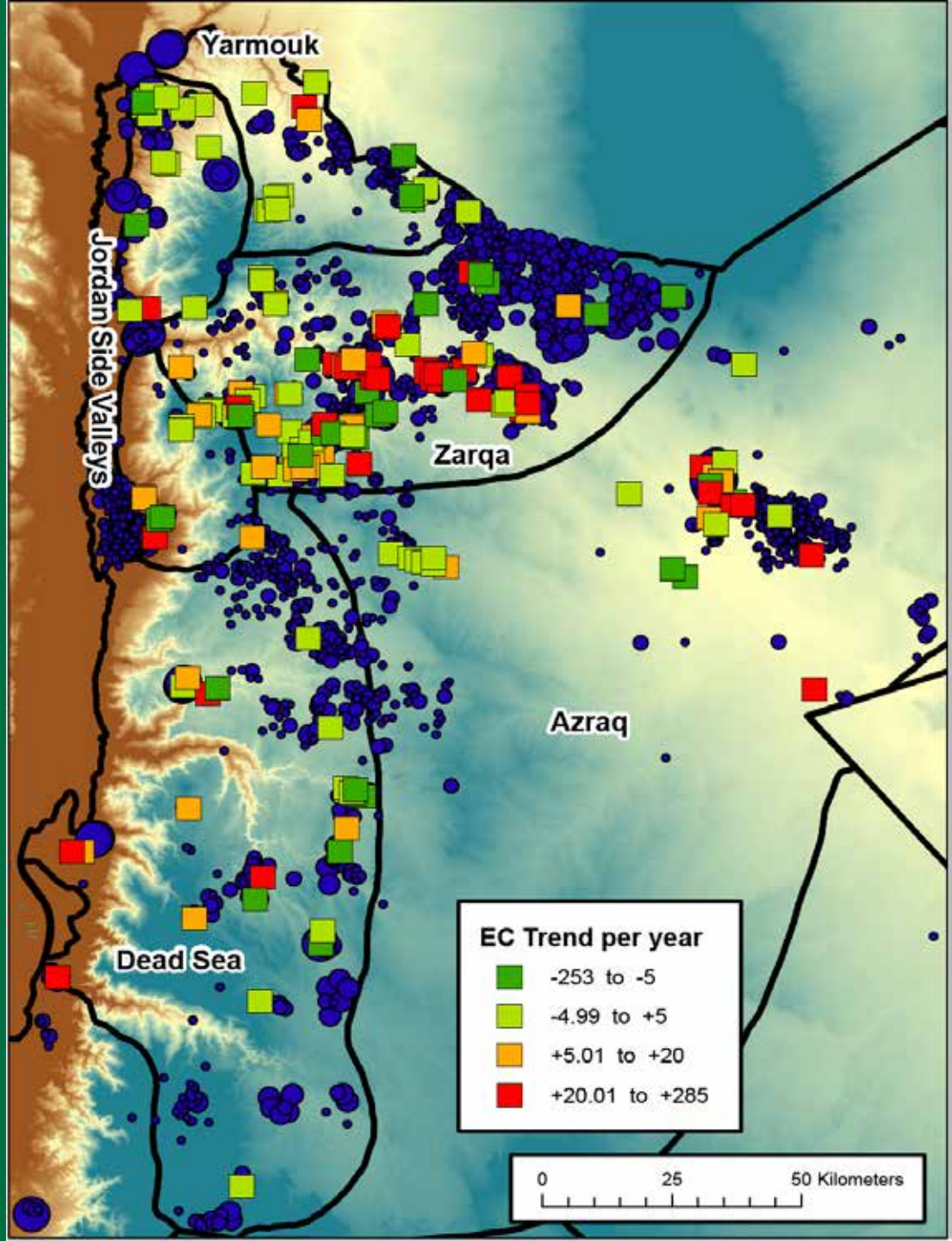


USGS

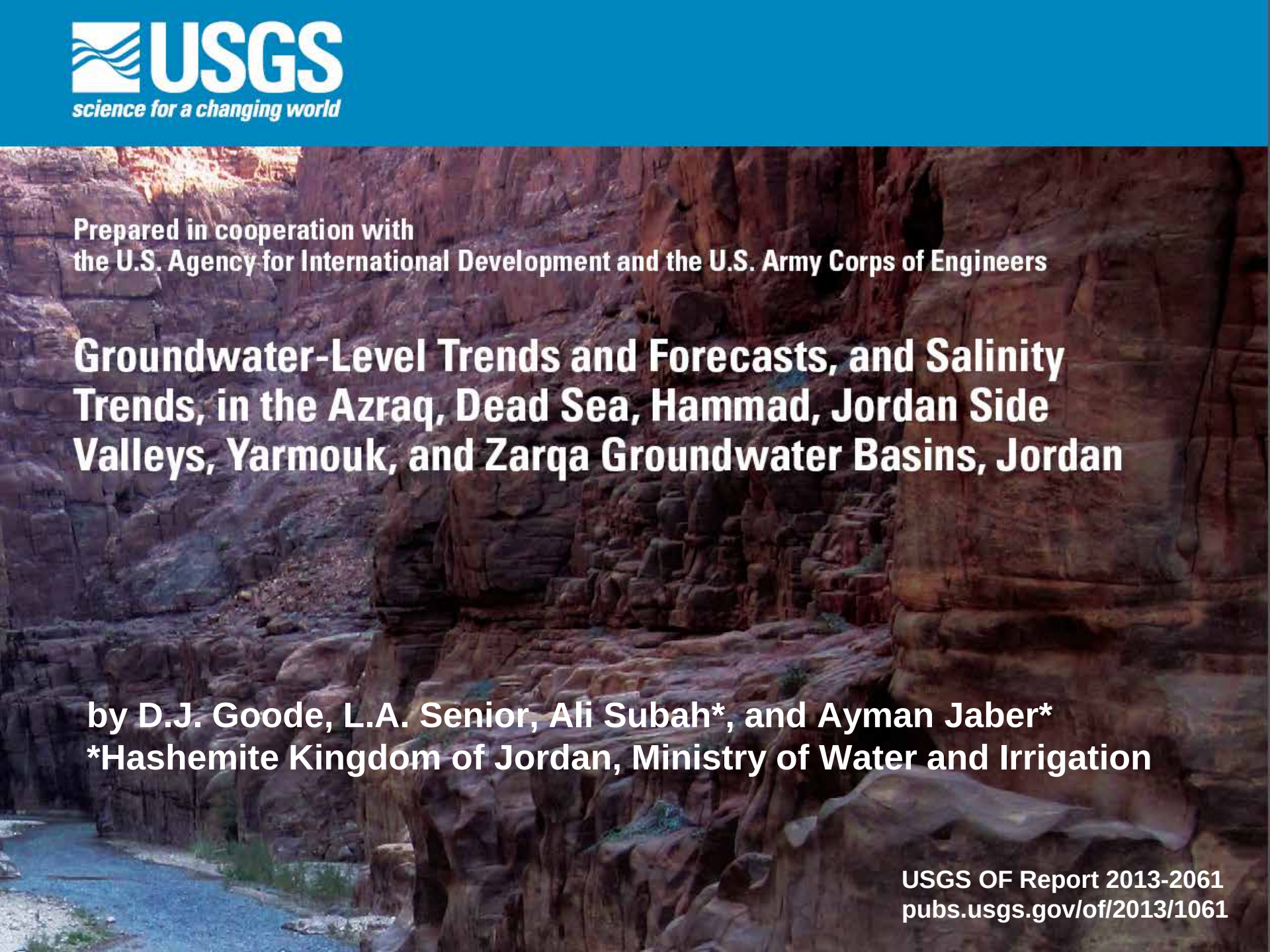
USAID | الأردن من الشعب الأمريكي

Salinity Trends – Not necessarily increasing when water level falls

- Salinity generally not increasing rapidly in recharge areas, despite level declines
- Salinity increasing rapidly in pumping centers in basin discharge areas
- Hammad basin highest salinity and upward trend (not shown), but no trend in water level



USGS



USGS
science for a changing world

Prepared in cooperation with
the U.S. Agency for International Development and the U.S. Army Corps of Engineers

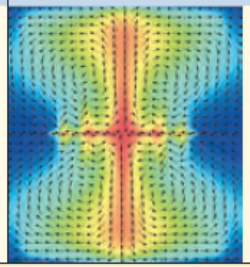
Groundwater-Level Trends and Forecasts, and Salinity Trends, in the Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa Groundwater Basins, Jordan

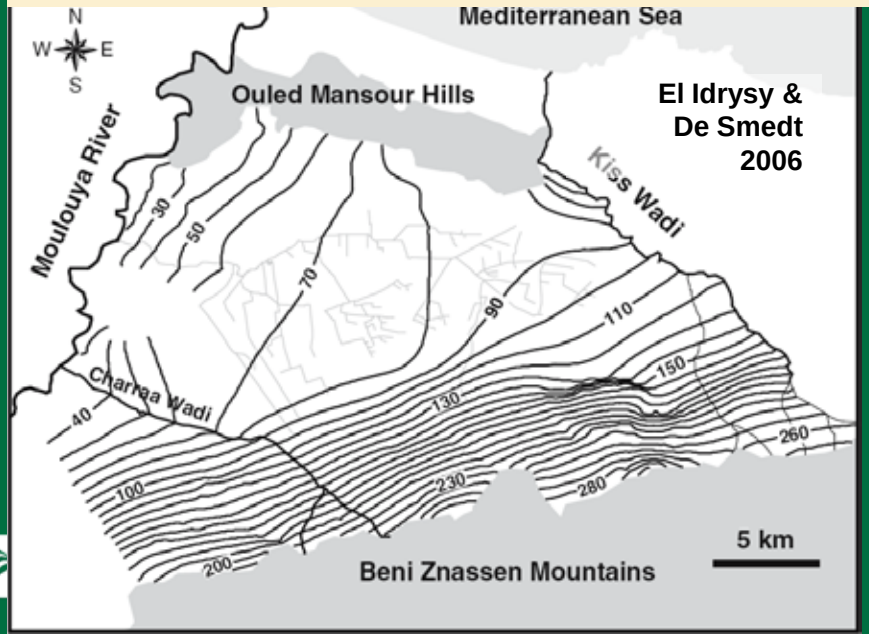
by D.J. Goode, L.A. Senior, Ali Subah*, and Ayman Jaber*
*Hashemite Kingdom of Jordan, Ministry of Water and Irrigation

USGS OF Report 2013-2061
pubs.usgs.gov/of/2013/1061

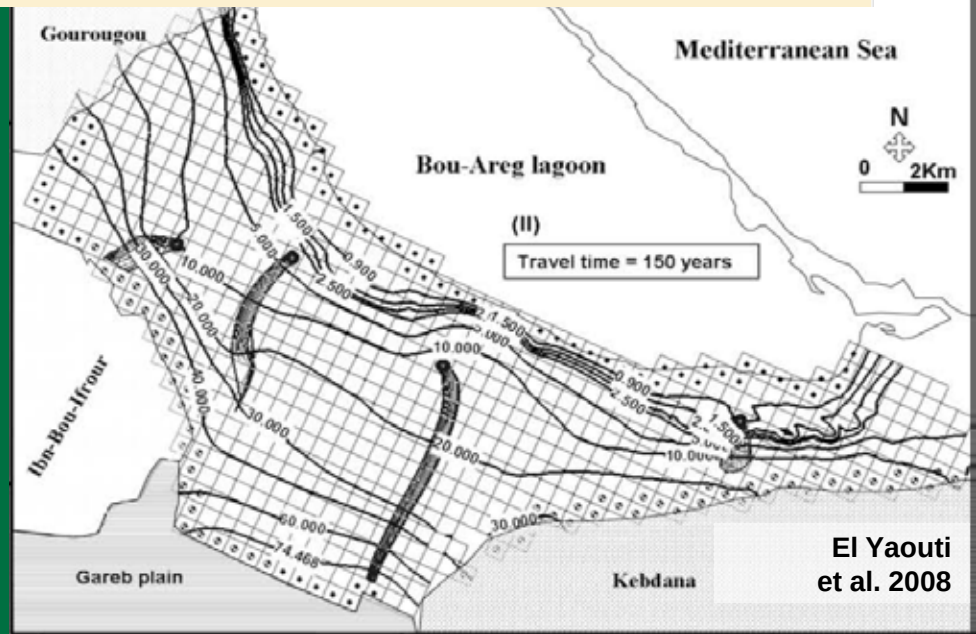
Models are multi-purpose tools for hydrologic analysis

Table 1. Applications of USGS groundwater modeling software range from support of management decisions to cutting-edge research.

Evaluation of water-management alternatives[1]	Demonstration of general hydrologic principles[3]
	
Effects of groundwater withdrawals on water levels and native vegetation Conjunctive management of groundwater and surface-water resources Management responses to saltwater intrusion	Effects of groundwater withdrawals on discharge to streams and springs Importance of transient groundwater response times in long-term planning Importance of post-auditing and updating groundwater models
Hydrogeologic and geochemical characterization[2]	**Basic research[4]**
	
Evaluation of changes to the water budget of an aquifer resulting from changes in land use, withdrawals, and climate Use of environmental tracers to estimate ground-water age and identify sources of recharge	Development and testing of new modeling techniques Study of the role of groundwater flow and chemistry in geologic processes



El Idrysy & De Smedt 2006



El Yaouti et al. 2008

USGS develops open-source groundwater modeling software [water.usgs.gov/software]

MODFLOW: 3D Finite-Difference Groundwater Flow Model

Status of MODFLOW Versions and MODFLOW-Related Programs Available on USGS Web Pages *(January, 2011)*
To view PDF documents, you may need the PDF reader or other compatible software.
MODFLOW-2005 Version: 1.11.00 *(Aug. 8, 2013)* new
MODFLOW-LGR Version: 2.0.0 *(Sept. 19, 2013)* new
MODFLOW-NWT Version: 1.0.8 *(Sept. 26, 2013)* new
MODFLOW-USG Version: 1.0 *(May 3, 2013)*
(**MODFLOW-2000** can be found under the banner "Legacy and Superseded Software")

Related Programs for Simulation of Hydrologic Processes, Model Calibration, and Groundwater Management

CFP Version 1.8 *Feb 23, 2011*
Conduit Flow Process for MODFLOW 2005

GEN_LHS and MCDRIVER_LHS Version 1.0,0 *Aug. 27, 2011*
Programs for calibration-based Monte Carlo simulation of recharge areas

GSFLOW Version: 1.1.6 *(Posted Mar. 28, 2012)*
Coupled Groundwater and Surface-water FLOW model based on the USGS Precipitation-Runoff Modeling System (PRMS) and Modular Groundwater

GWM-2000 Version 1.1.4 *[May 31, 2011]* and **GWM-2005** Version 1.5.0 *[Sept. 24, 2013]* new
Capability for groundwater management using optimization techniques with either MODFLOW-2000 or MODFLOW-2005

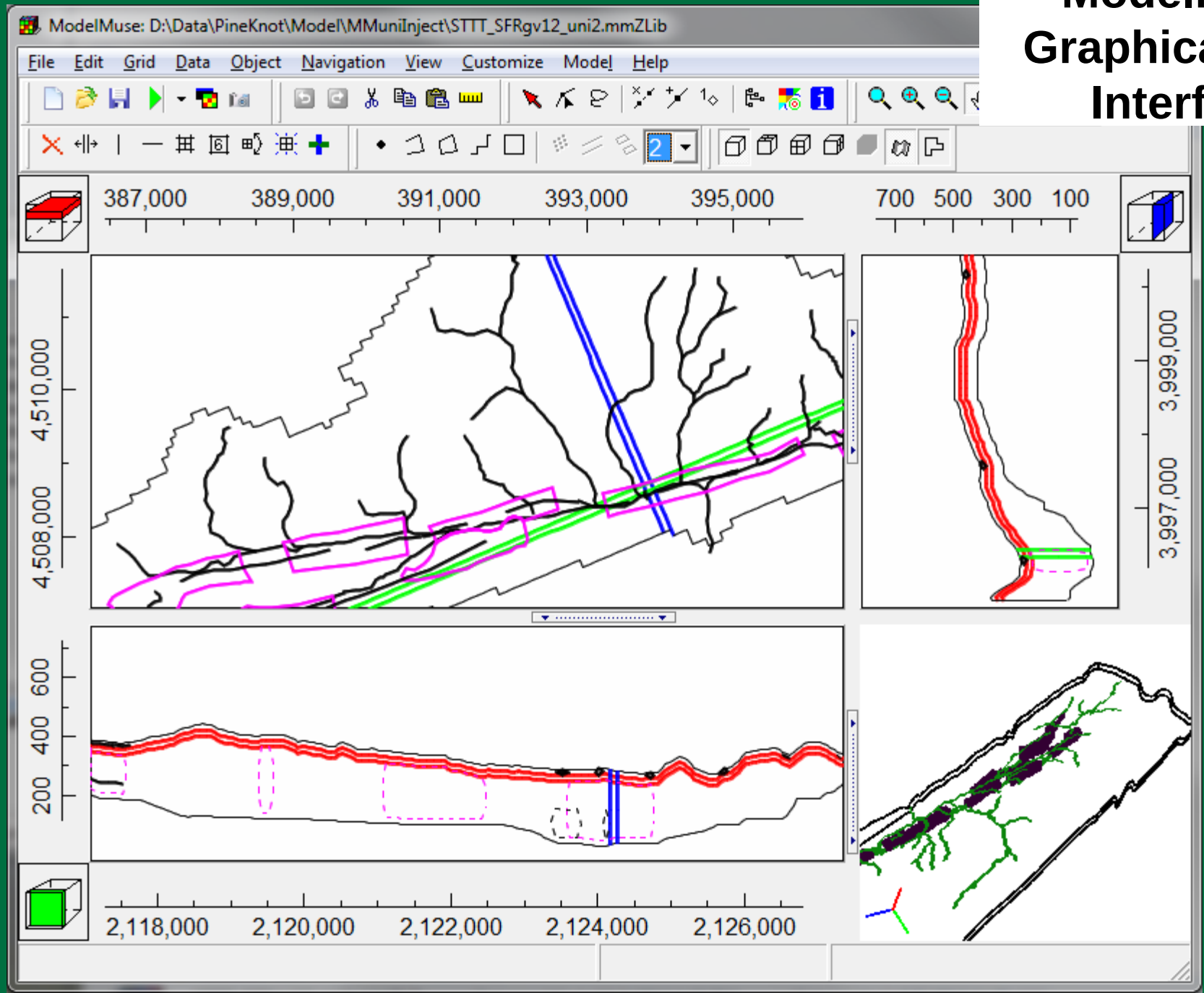
MF2K-FMP (Win) Version 1.00, *(May 19, 2006)* and **MF2005-FMP2** **(Win) Version 1.0.00,** *(Oct. 28. 2009)*
Estimate dynamically integrated supply-and-demand components of irrigated agriculture as part of the simulation of surface-water and groundwater flow.

MF2K-GWT Version 1.9.8 and **MOC3D** Version 3.52, *(Oct. 22, 2008)*
Version of MODFLOW-2000 with Groundwater Transport Process to simulate concentration changes

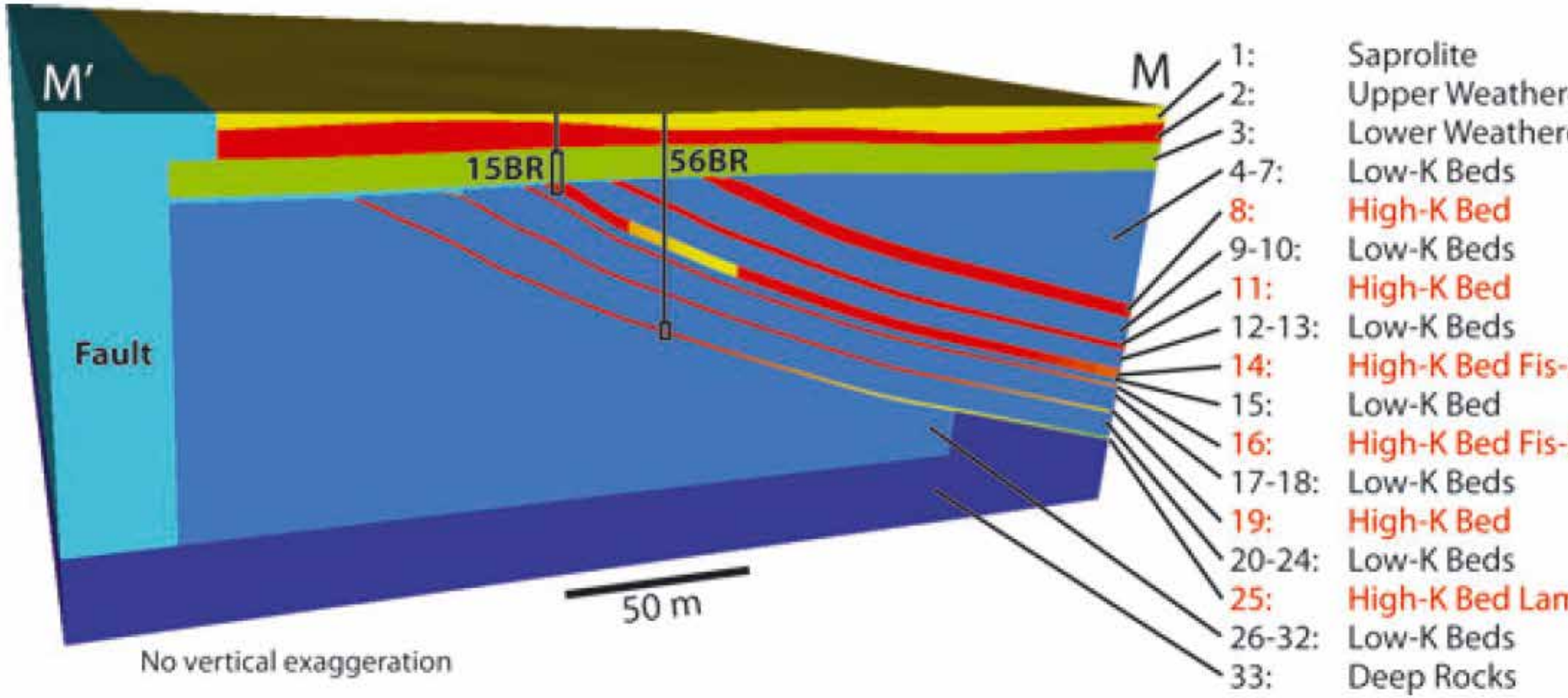
MODBRNCH Version: 3.7 *(Jun 5 1997)*
Groundwater/Surface-Water Coupled Flow Model using USGS MODFLOW and BRANCH Models

MODOPTIM Version 1.0 *(May 5, 2006)*
A general optimization program for aquifer-test analysis, groundwater flow model calibration, and groundwater management with MODFLOW.

ModelMuse Graphical User Interface

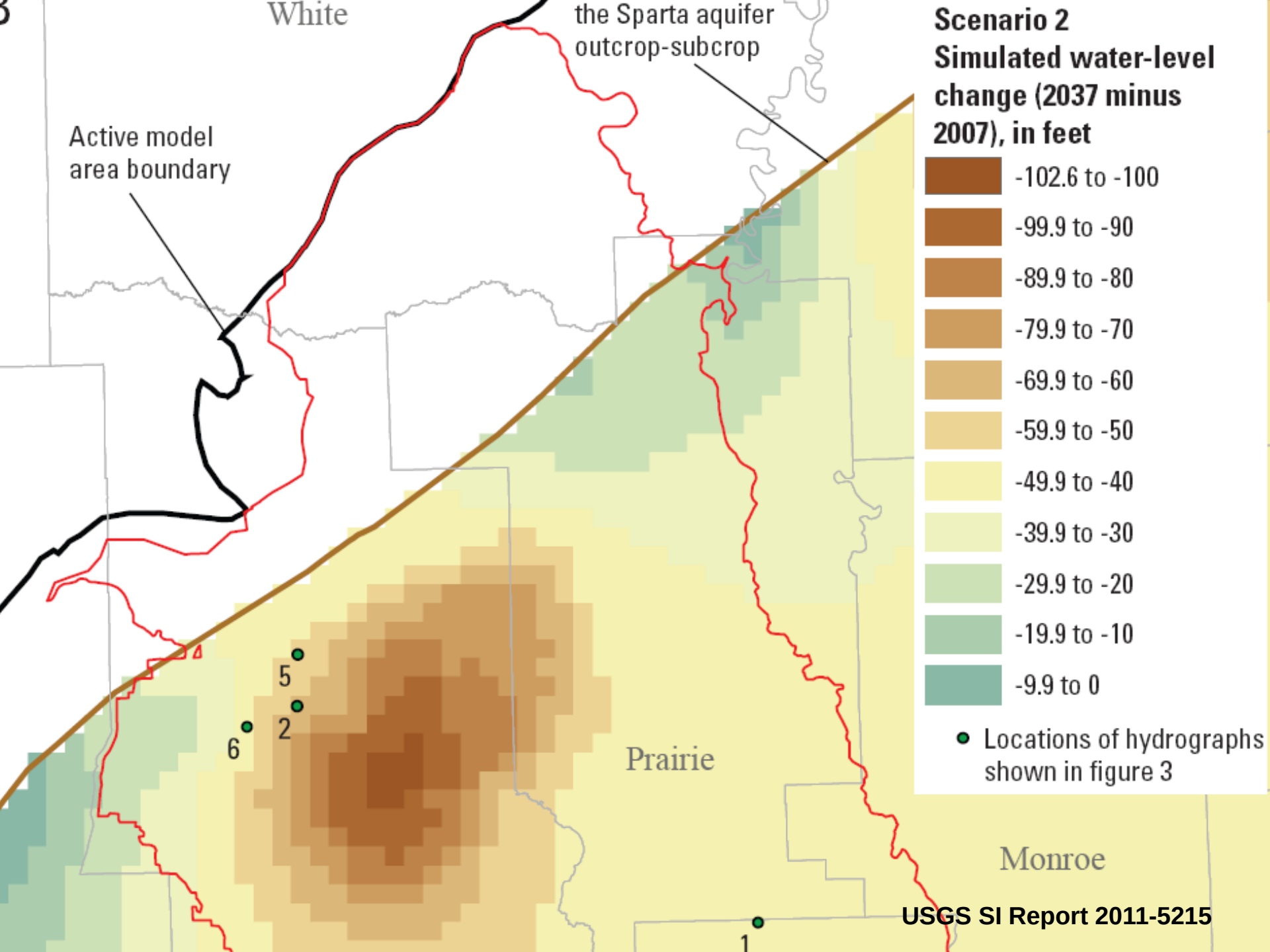


3D Geology controls Site-scale Flow



USGS

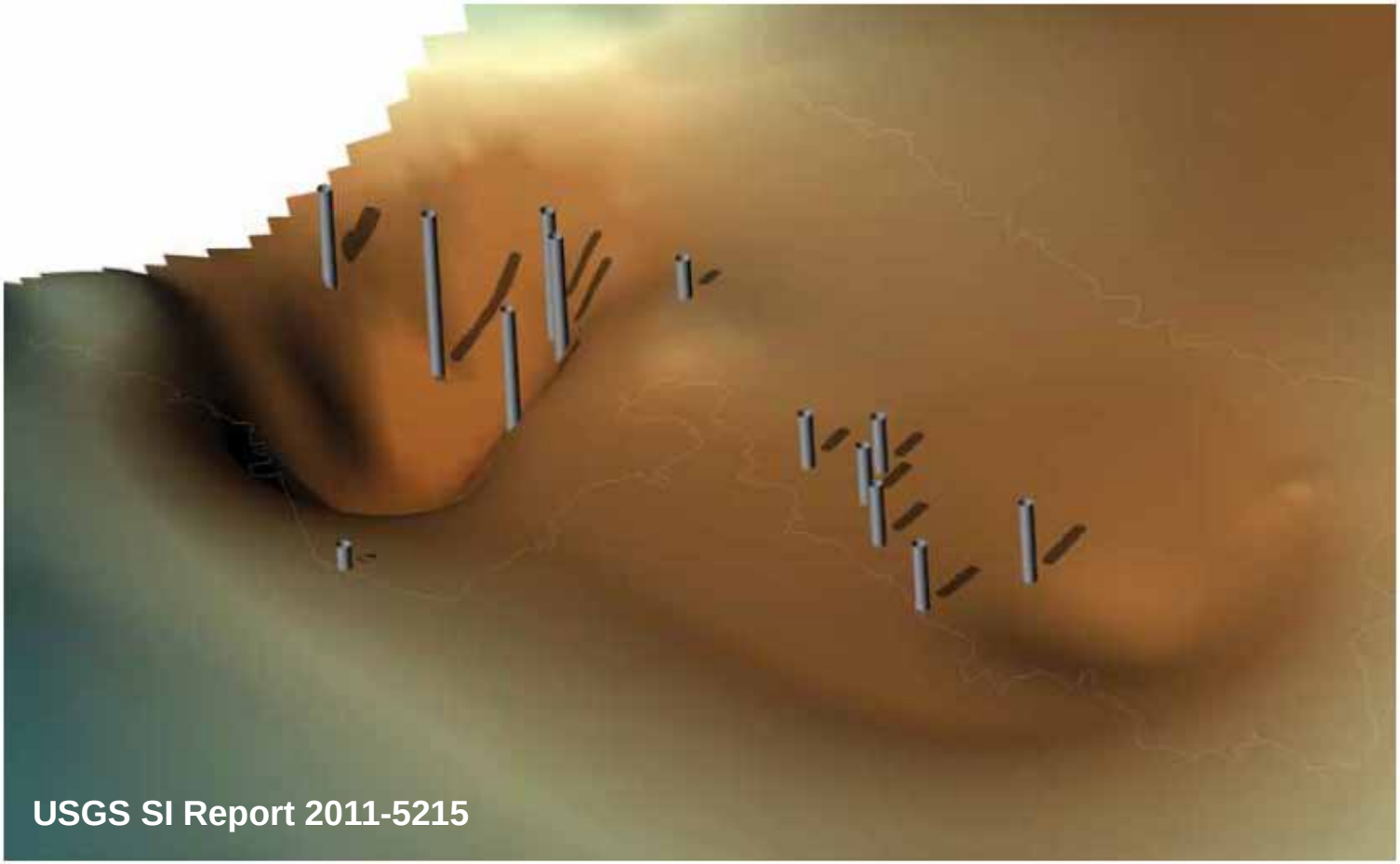
Tiedeman et al. *Ground Water* 2010



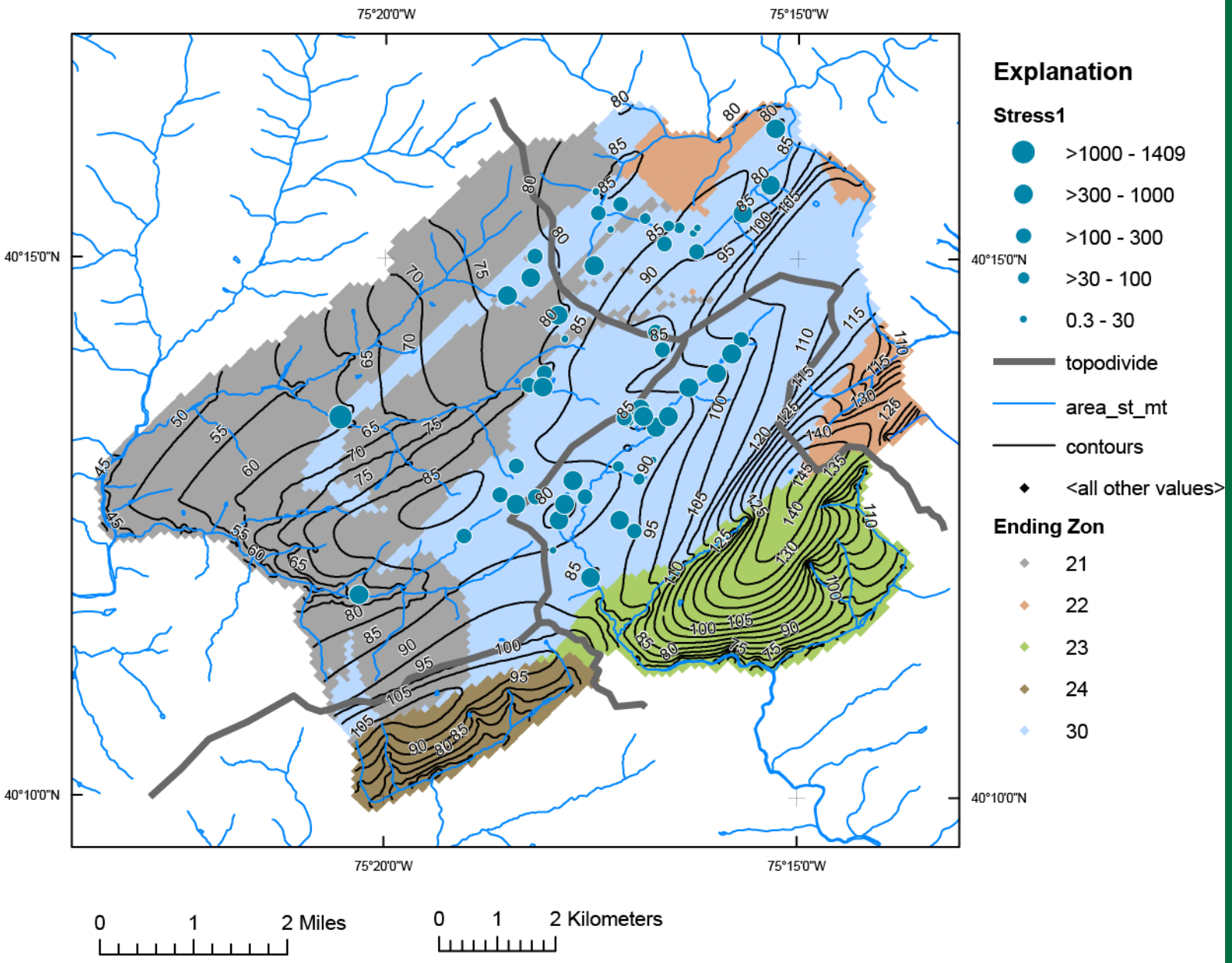
USGS SI Report 2011-5215

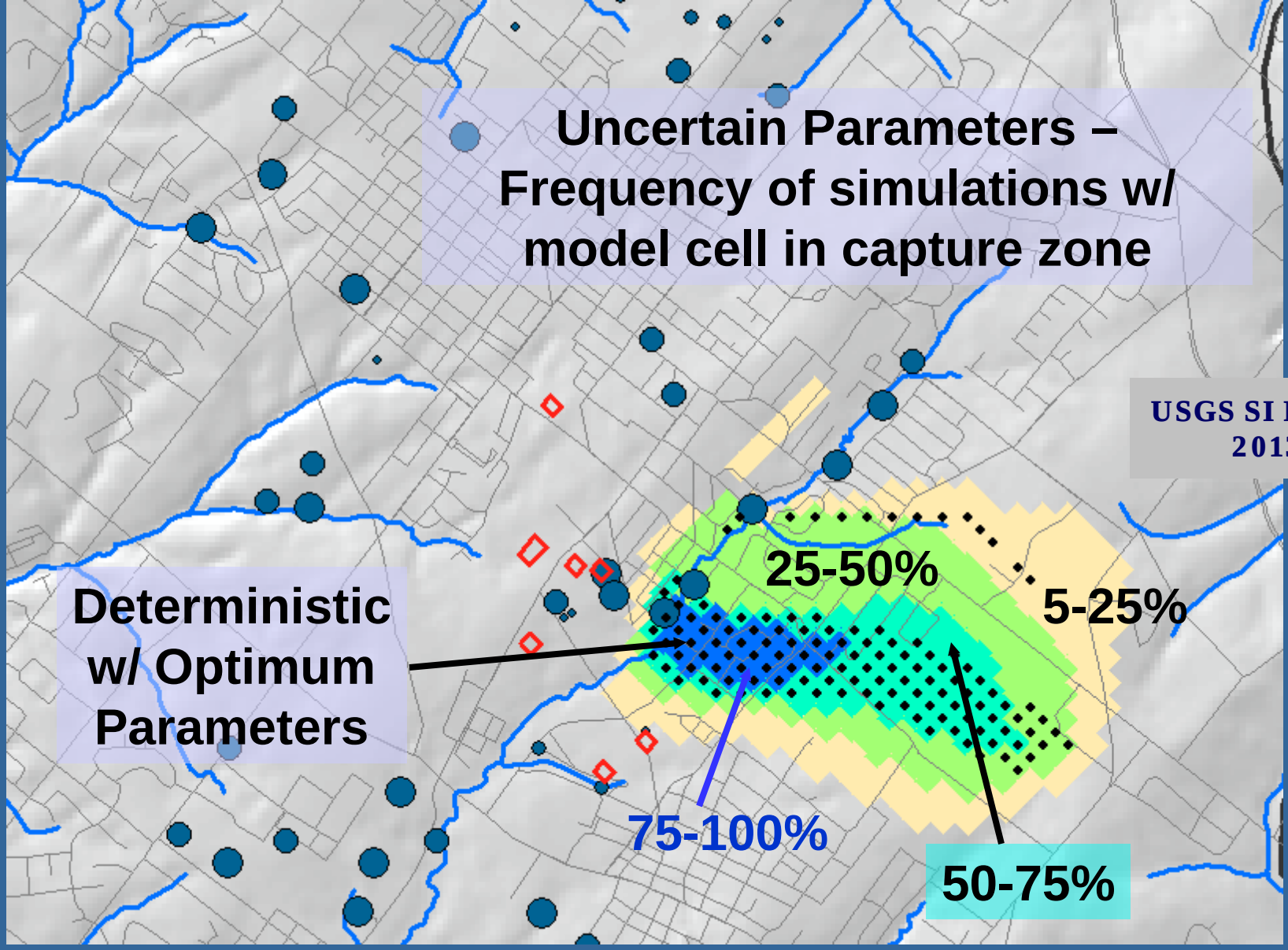
Prepared in cooperation with the Arkansas Natural Resources Commission

Simulation of the Effects of Groundwater Withdrawals on Water-Level Altitudes in the Sparta Aquifer in the Bayou Meto-Grand Prairie Area of Eastern Arkansas, 2007–37



USGS SI Report 2011-5215


75°20'0"W
75°15'0"W
40°15'0"N
40°10'0"N
Explanation
Stress1
>1000 - 1409
>300 - 1000
>100 - 300
>30 - 100
0.3 - 30
topodivide
area_st_mt
contours
<all other values>
Ending Zon
21
22
23
24
30
0 1 2 Miles
0 1 2 Kilometers



Area of Recharge that Discharges to Pumping Well, with Uncertainty (for EPA)

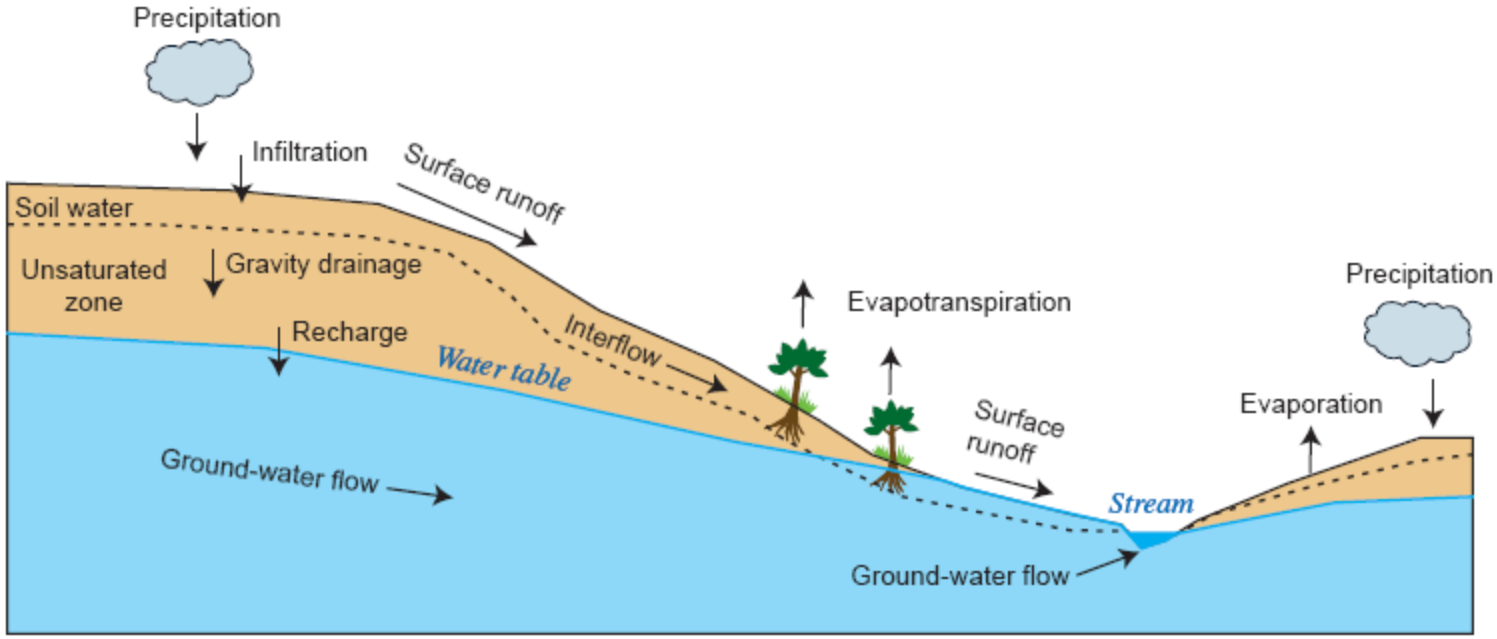
science

GSFLOW—Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)

Chapter 1 of

Section D, Ground-Water/Surface-Water

Book 6, Modeling Techniques



USGS MODLOW with the FARM PROCESS—Features and Capabilities

Farm Demand for Irrigation

Non-Routed Deliveries as Water Transfers

Routed Surface-Water Delivery to Farm

Groundwater Pumpage by Well

Streamflow Conveyance and Drain Network

Natural and Artificial Recharge

Water-Use Management

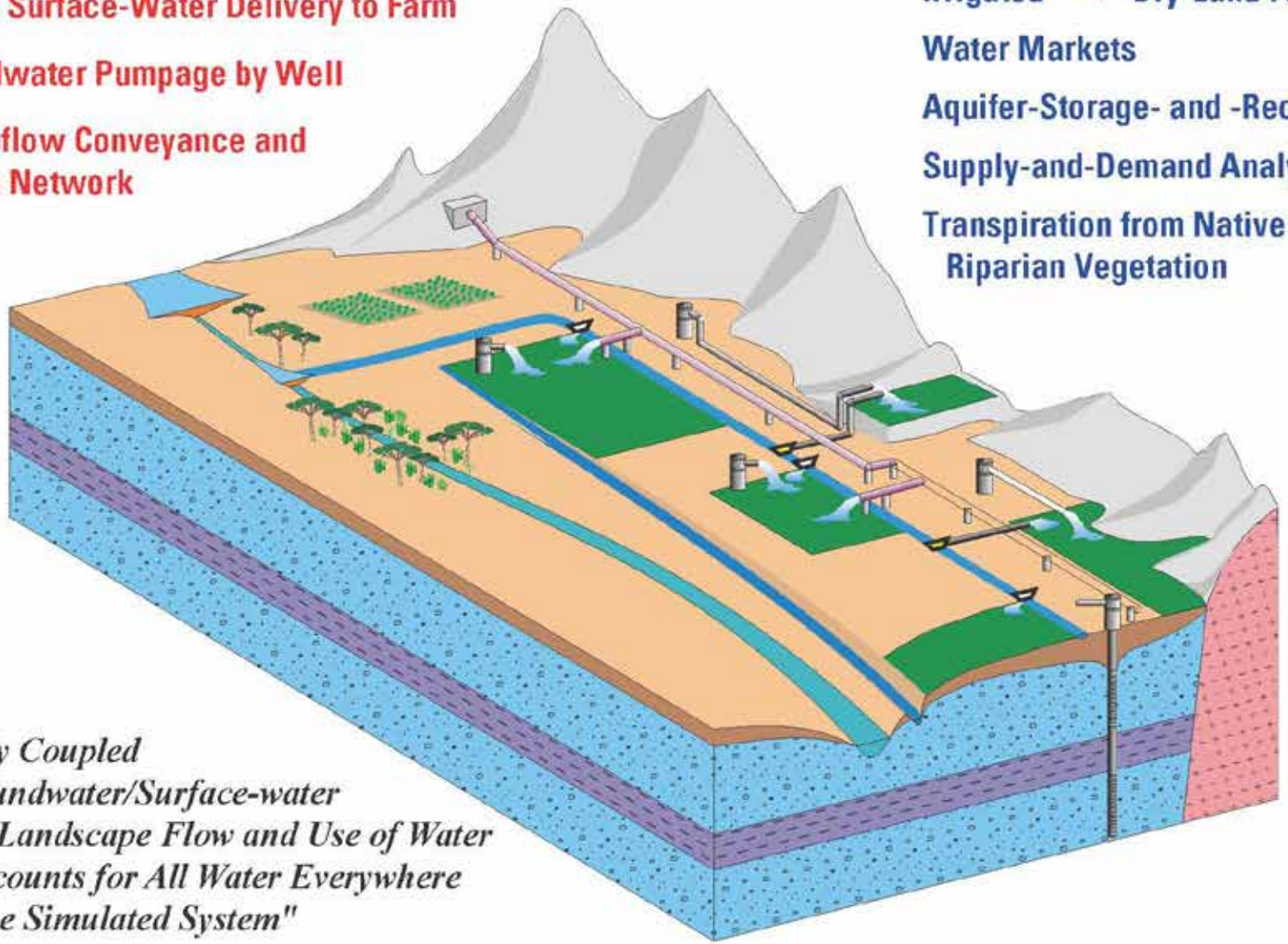
Irrigated ⟶ Dry-Land Farming

Water Markets

Aquifer-Storage- and -Recovery Systems

Supply-and-Demand Analysis

Transpiration from Native and Riparian Vegetation



Fully Coupled Groundwater/Surface-water and Landscape Flow and Use of Water "Accounts for All Water Everywhere in the Simulated System"

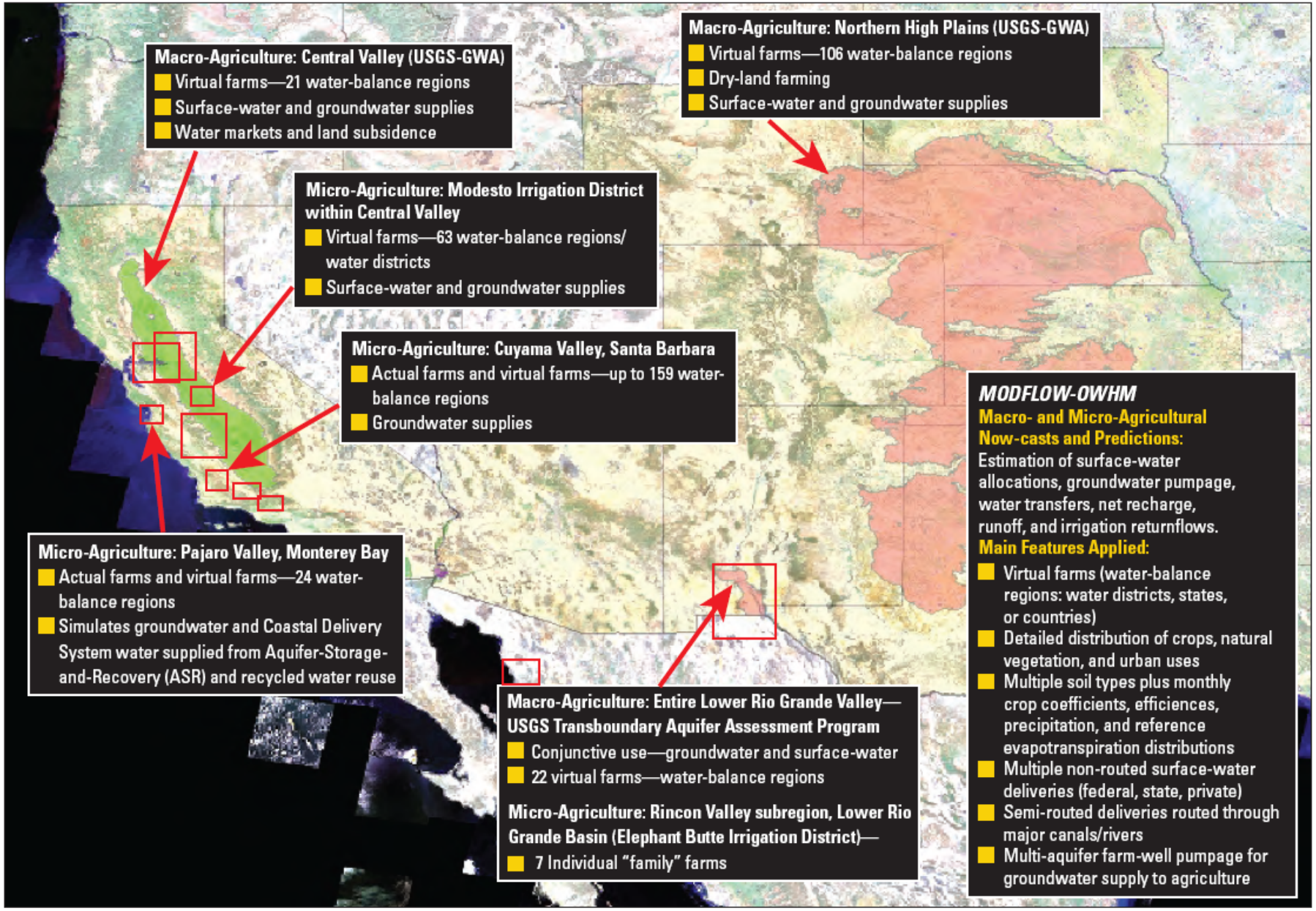


Figure 2. U.S. Geological Survey applications of MODFLOW One-Water Integrated Hydrologic Model in the United States.

Ideas for Groundwater Modeling with Morocco

- Improve Understanding of Aquifer Dynamics
- Identify Improvements needed in Monitoring Systems & Databases
- Water Budgets
- Forecast Groundwater-Level Declines (and Recovery) and Economic Impacts
- Simulation of GW Management Scenarios
- Link Land Surface with Groundwater (via recharge/discharge) – Climate Change

USGS

Ideas for Groundwater Modeling with Morocco

- Use of Aquifers as Storage Reservoirs
- Integrate MODFLOW with Water Allocation Models to Jointly Manage Groundwater and Surface Water (Dams)
- Identification of Source Areas for Protection of Water Supply Infrastructure
- Understand and Forecast Salinity Changes due to Groundwater-Level Declines, and Irrigation
- Capacity Building!

USGS

Thank You!

www.usgs.gov
djgoode@usgs.gov

USGS