Humboldt River Basin Modeling Workshop

STATE ENGINEER STATE OF NEVADA

DRI Desert Research Institute

USGS

**Lovelock
November 2, 2015**

**Elko & Winnemucca
November 3, 2015**

DEPARTMENT OF CONSERVATION & NATURAL RESOURCES

Humboldt River Basin Modeling Workshop - Outline

- Review of Actions Taken in 2015
  - Orders
  - PCWCD Legal
  - Glover analysis
- Hydrologic Conditions and Forecast
- Capture Modeling Overview
  - What is it
  - How might modeling and results be used
- Humboldt River Capture Models: USGS and DRI
- Q & A

Review of Previous Meetings and State Engineer Actions

November 2014: Grass Valley and Winnemucca Segment closed to new appropriations

January 2015: No curtailment of groundwater pumping in 2015. Analysis shows no significant additional flows would result from curtailment.

February 2015: Meter requirement for Humboldt River Basin groundwater wells (Order 1251)

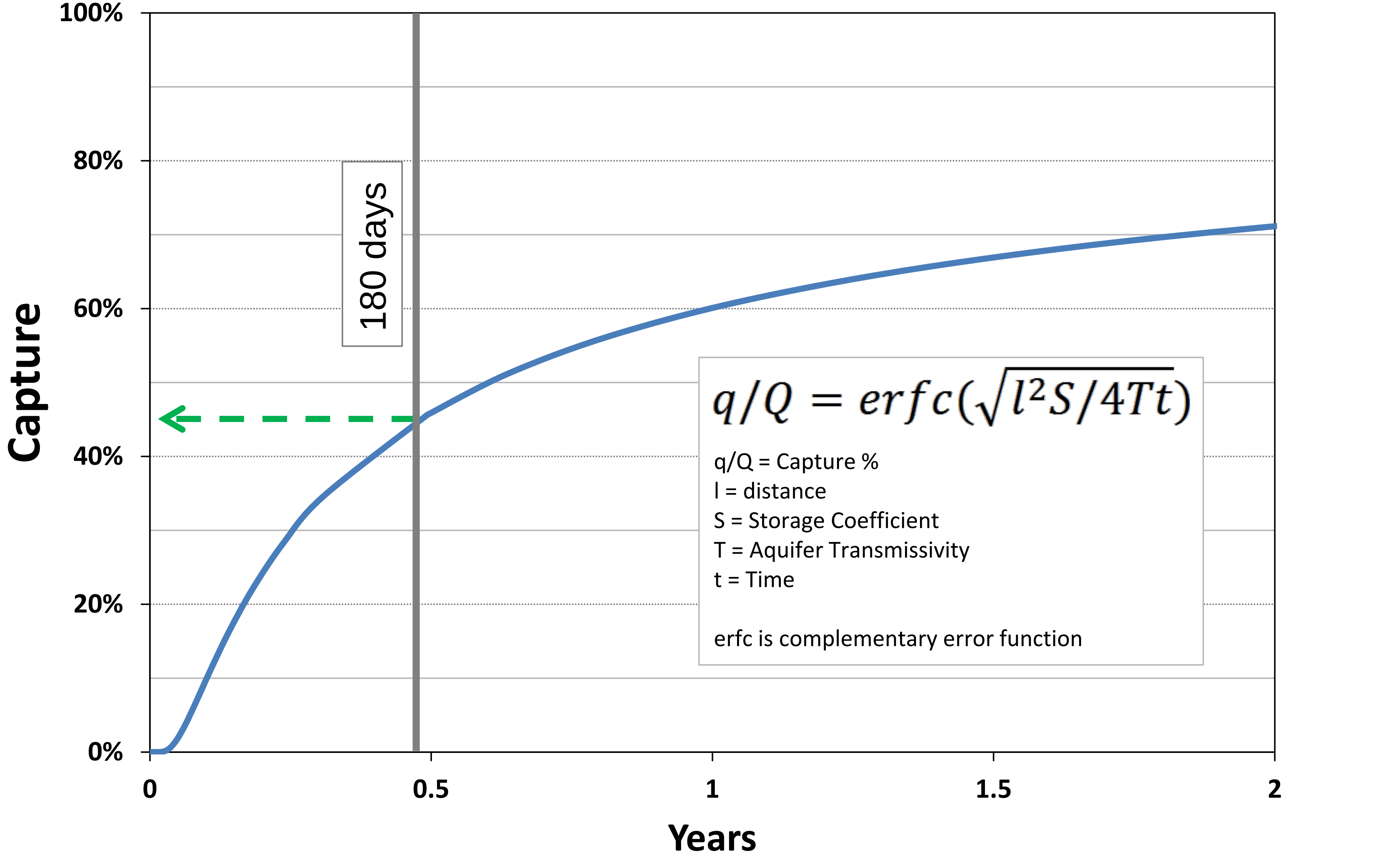
March-July 2015: Designation of all groundwater basins in the Humboldt Region

Entire 2015 Season: No deliveries to diversified pasture

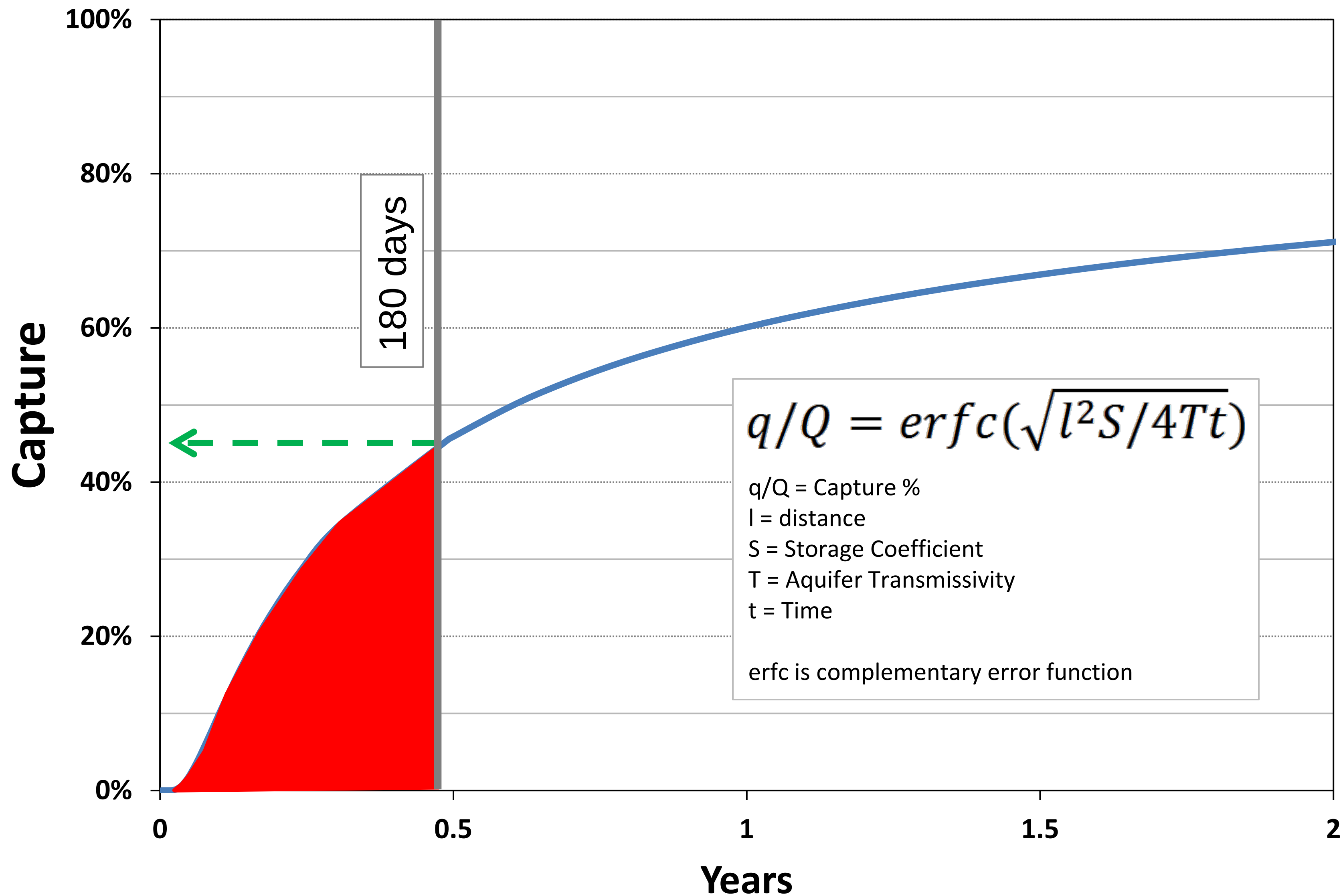
Review of Previous Meeting and State Engineer Actions

- PCWCD legal action
  - Seeks a Writ of Mandamus from the Pershing County District Court to require the State Engineer to:
    - Establish Critical Management Areas in over-appropriated groundwater basins to reduce appropriations to the Perennial Yield and eliminate interference with senior surface water rights, and
    - Regulate mining and milling as permanent appropriative rights
  - Current status
    - Motions to intervene by affected parties
    - Briefing to be heard by District Court on motion to dismiss

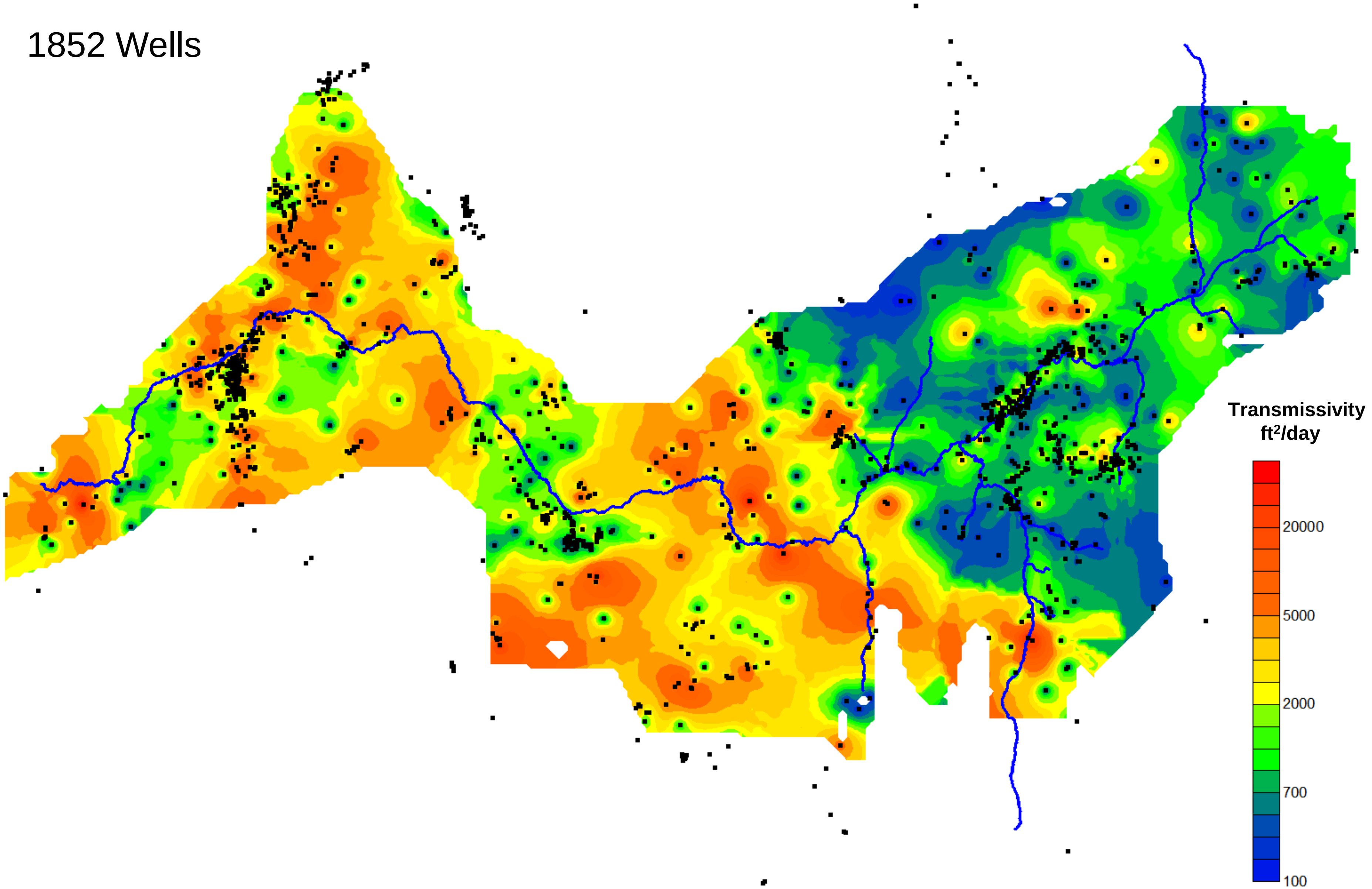
GLOVER'S SOLUTION

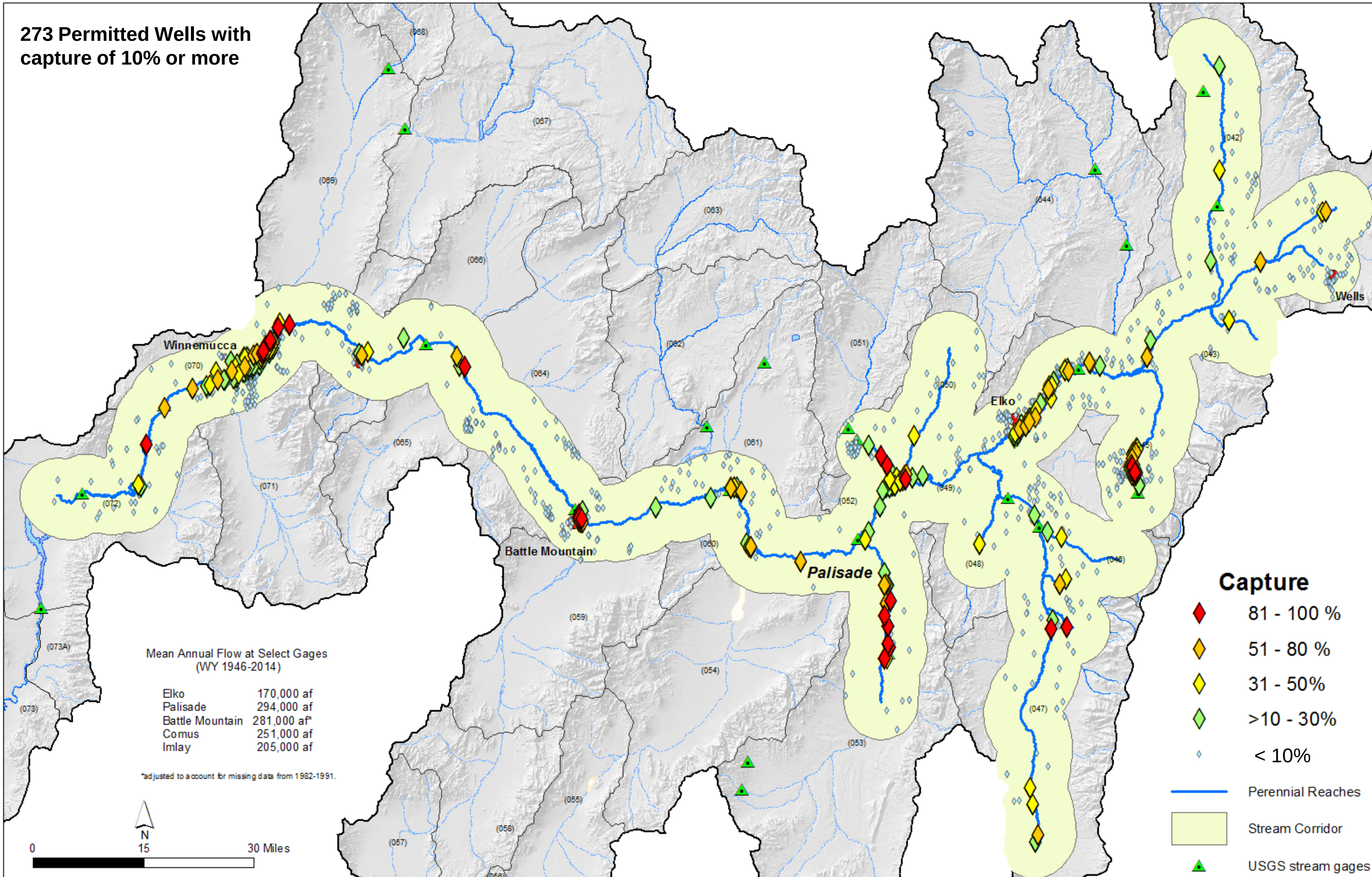


GLOVER'S SOLUTION



1852 Wells




273 Permitted Wells with capture of 10% or more
Winnemucca
Battle Mountain
Palisade
Elko
Wells
Mean Annual Flow at Select Gages (WY 1946-2014)
Elko 170,000 af
Palisade 294,000 af
Battle Mountain 281,000 af*
Comus 251,000 af
Imlay 205,000 af
*adjusted to account for missing data from 1982-1991.
N
0 15 30 Miles
Capture
81 - 100 %
51 - 80 %
31 - 50%
>10 - 30%
< 10%
Perennial Reaches
Stream Corridor
USGS stream gages

Glover's Results

Total Groundwater ***Duty*** with >10% Capture (AFA)	37,650
Estimated Groundwater ***Pumping*** during Irrigation Season (AF)*	7,480
Additional Flow in Humboldt River over 2015 Irrigation Season if all Pumping Ceased (AF)	1,480

*Based on 2013 records

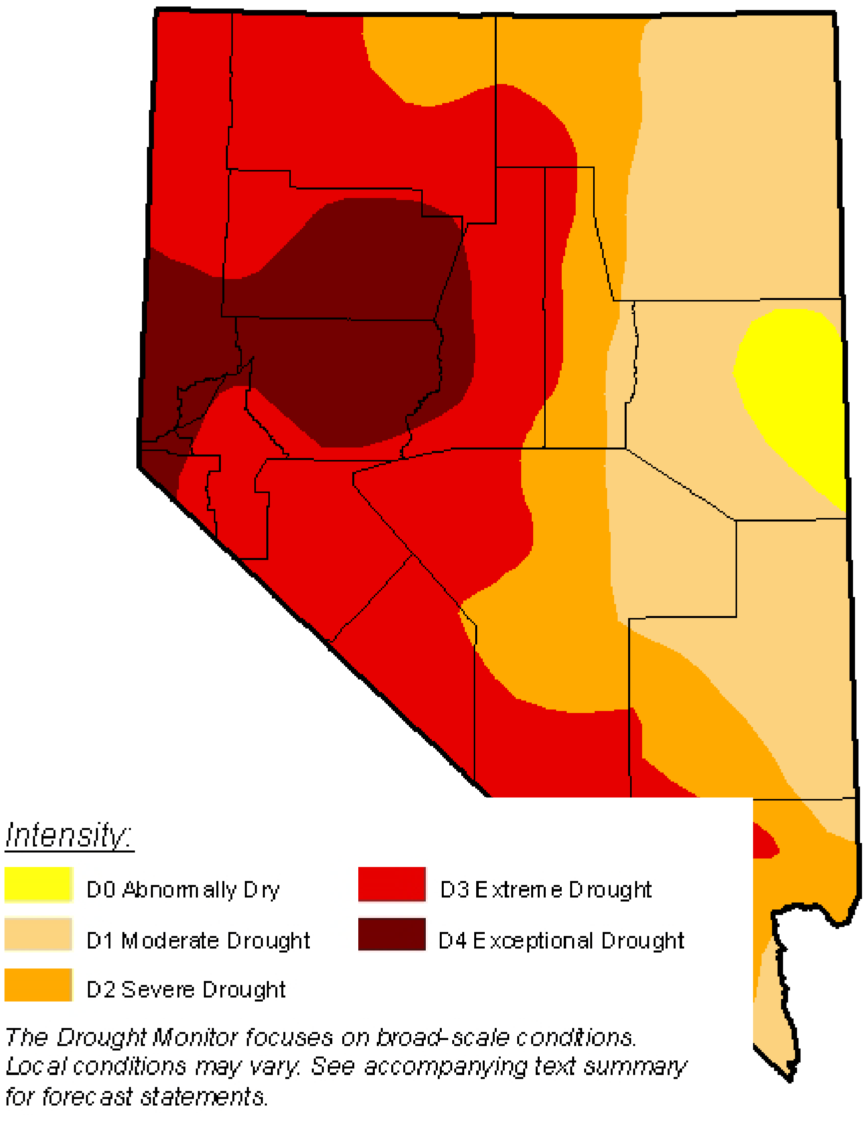
Hydrologic Conditions

&

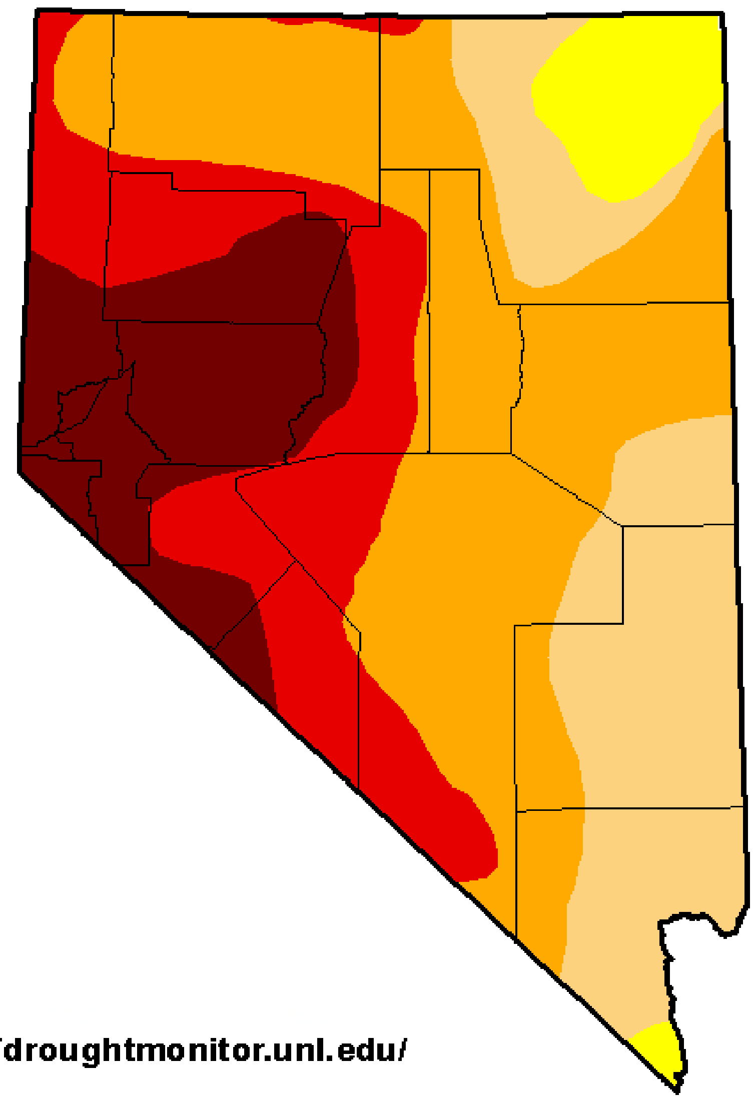
Climate Forecast

Current Drought Conditions

October 7, 2014

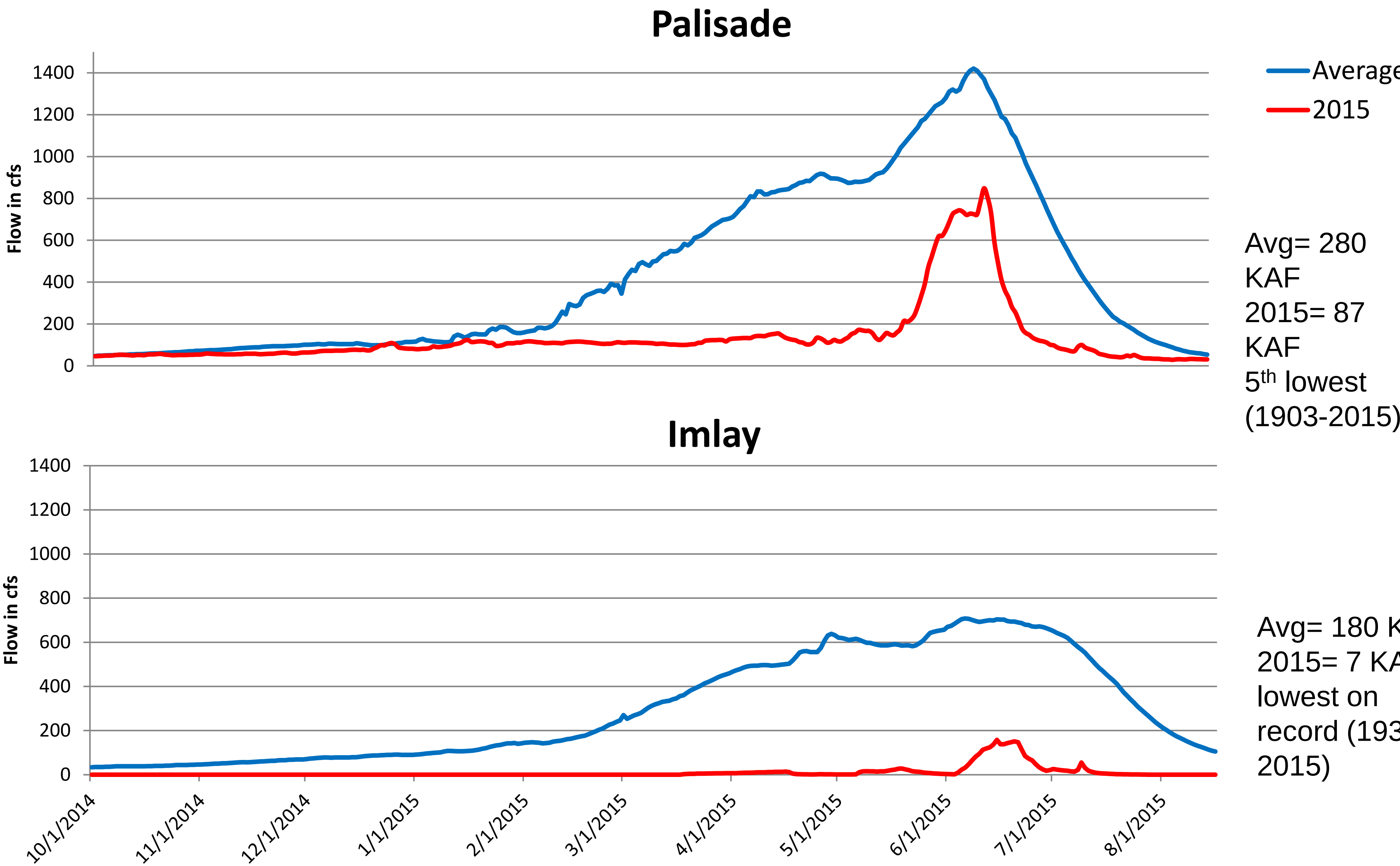


October 27, 2015



http://droughtmonitor.unl.edu/

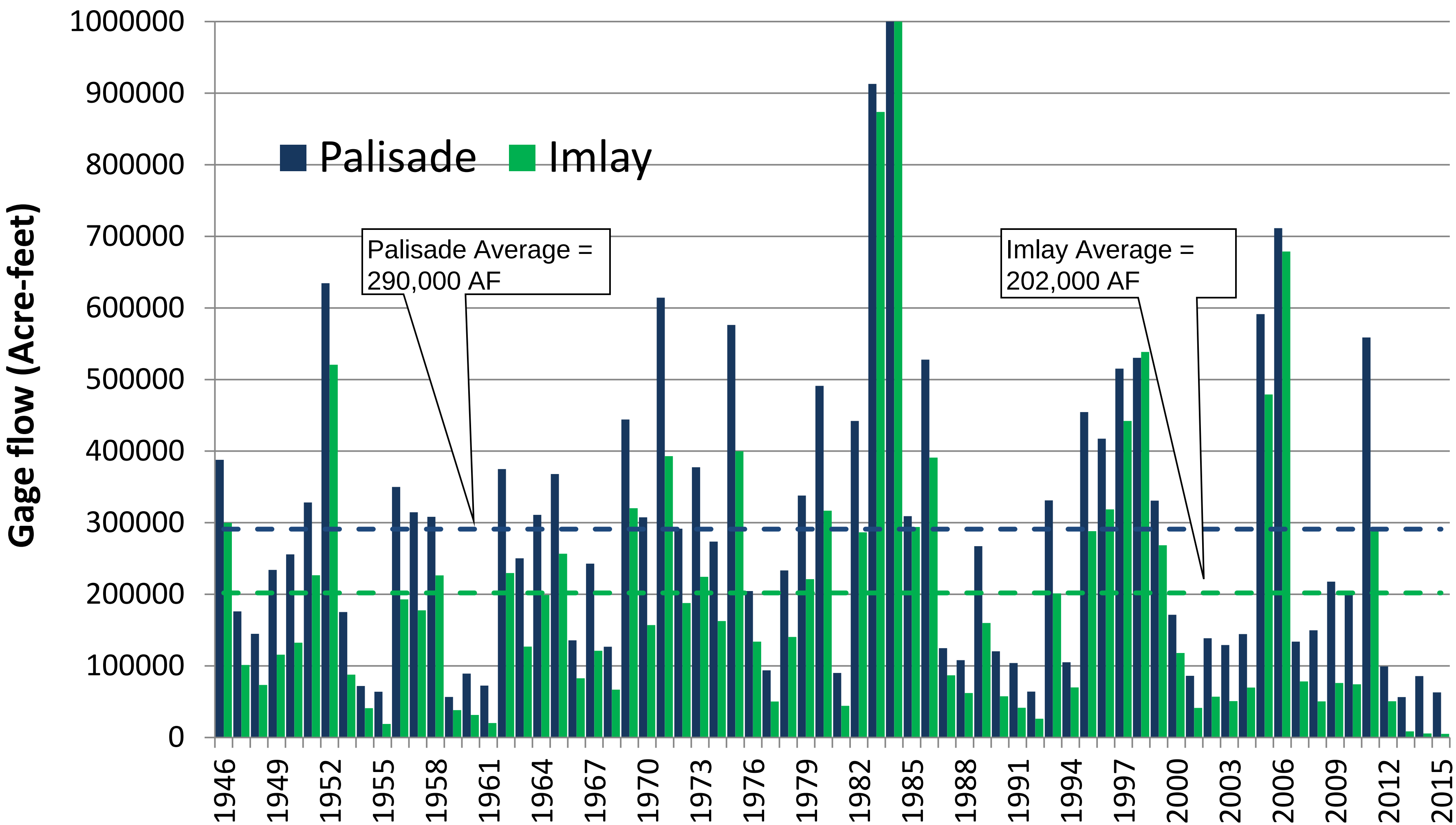
2015 Humboldt River streamflow



Avg= 280 KAF
2015= 87 KAF
5th lowest (1903-2015)

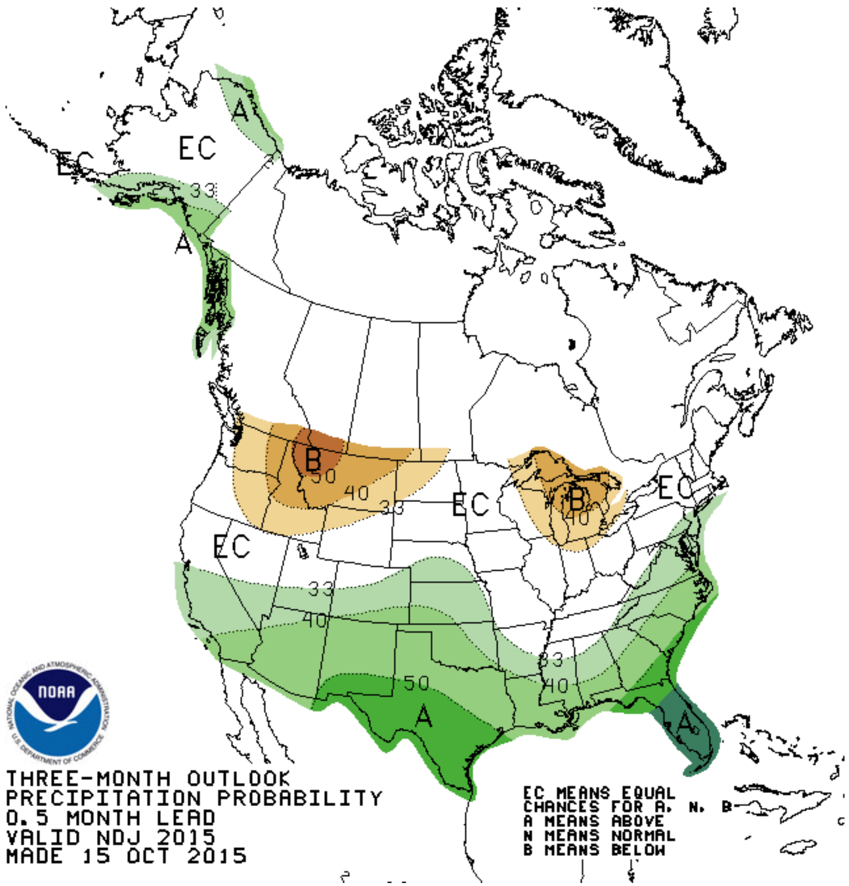
Avg= 180 KAF
2015= 7 KAF
lowest on record (1937-2015)

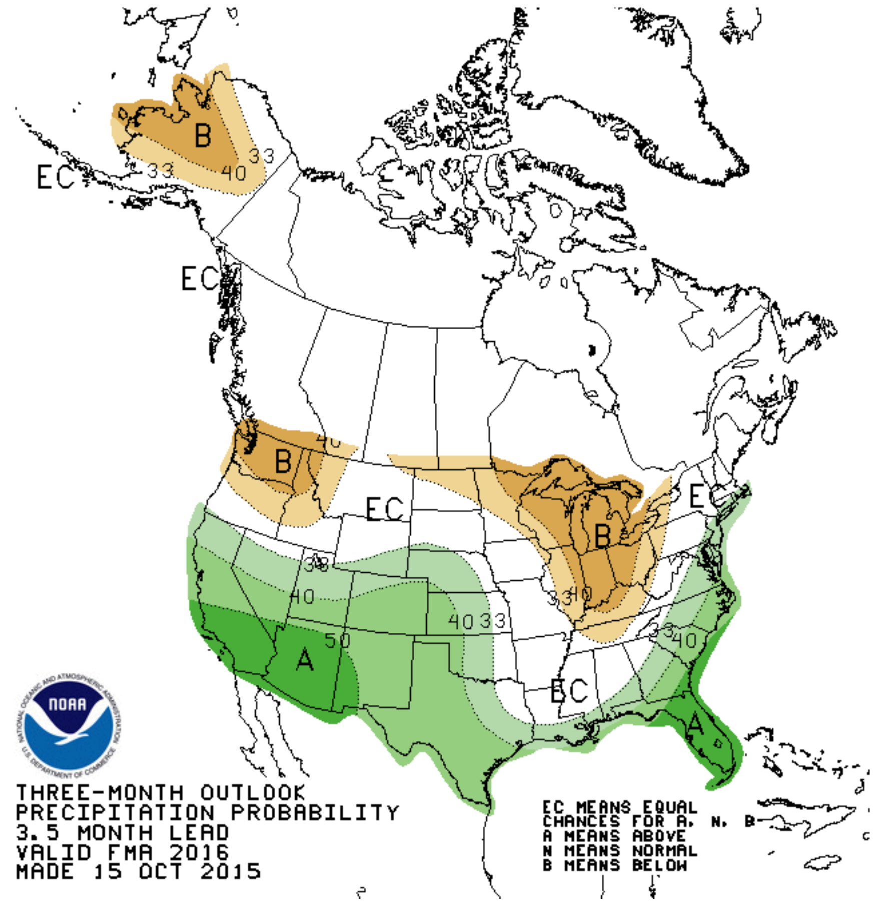
Humboldt River Flow, 1946-2015



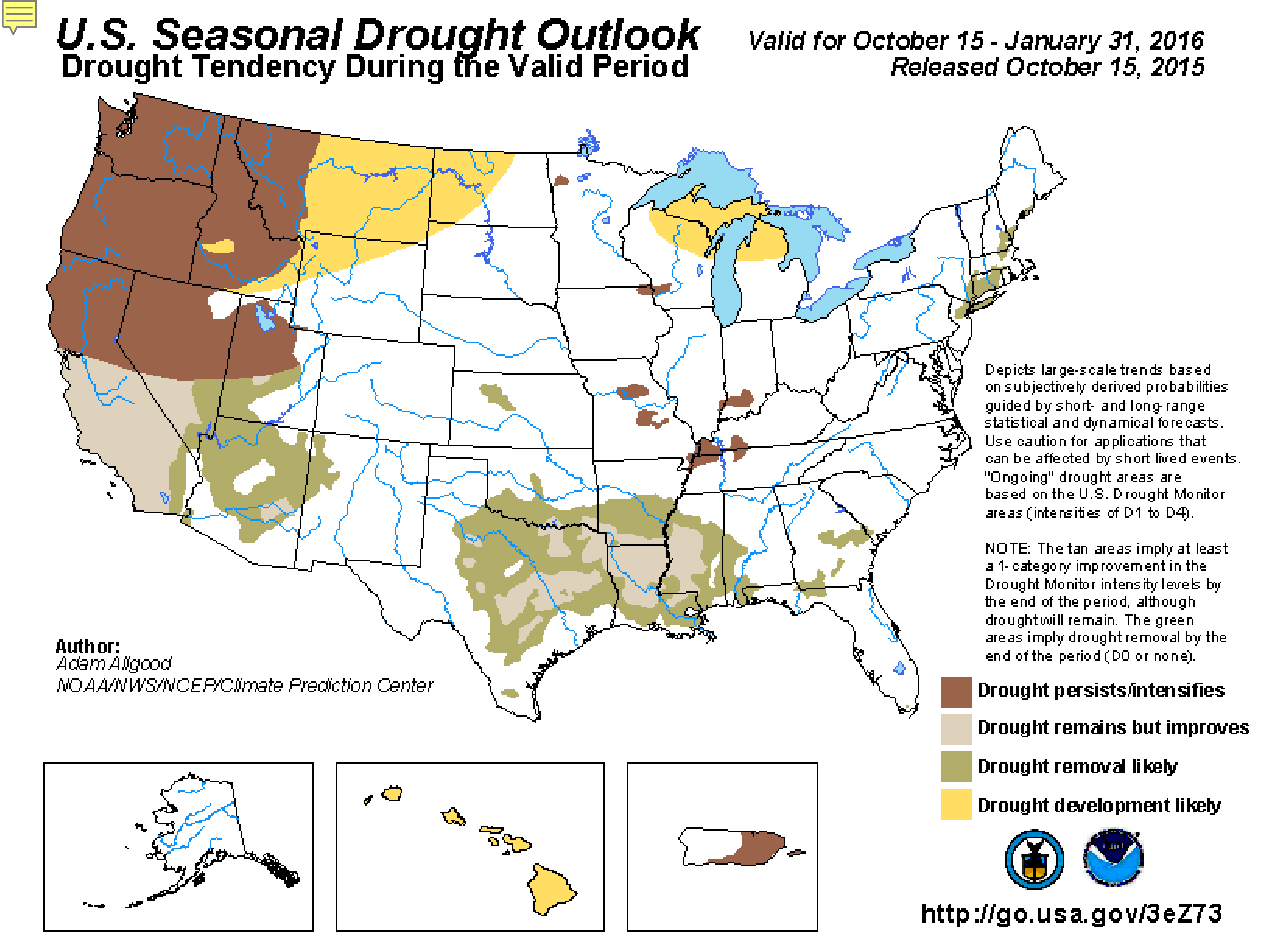
Weather/Climate Forecast

Three-Month Outlook - Precipitation





http://www.cpc.ncep.noaa.gov/products/predictions/long_range/


U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period
Valid for October 15 - January 31, 2016
Released October 15, 2015
Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Use caution for applications that can be affected by short lived events. "Ongoing" drought areas are based on the U.S. Drought Monitor areas (intensities of D1 to D4).
NOTE: The tan areas imply at least a 1-category improvement in the Drought Monitor intensity levels by the end of the period, although drought will remain. The green areas imply drought removal by the end of the period (D0 or none).
Drought persists/intensifies
Drought remains but improves
Drought removal likely
Drought development likely
Author:
Adam Allgood
NOAA/NWS/NCEP/Climate Prediction Center
http://go.usa.gov/3eZ73

Humboldt River

Capture Modeling

Overview

Humboldt River Capture Modeling

- Groundwater pumping affects flow in the Humboldt River, but the magnitude and timing are not well understood.

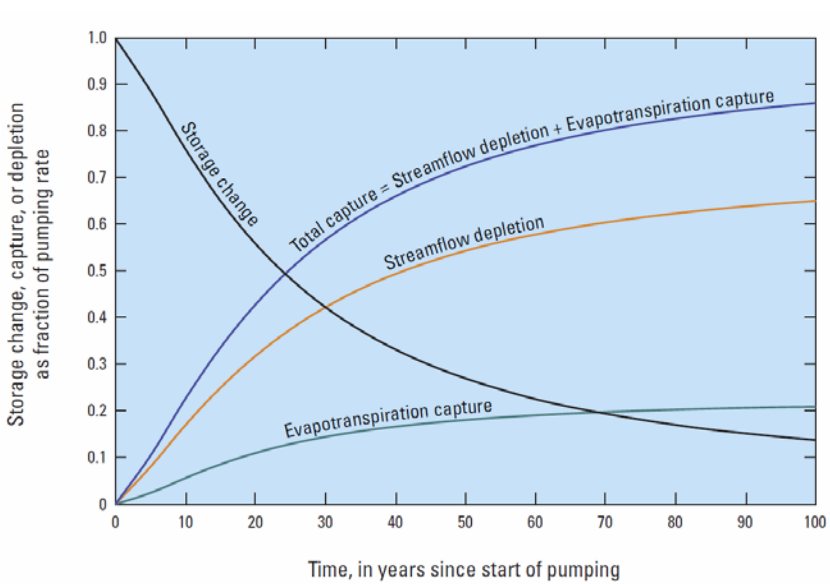
- We need to know this as a basis for equitable, accurate and legally defensible water management strategies.

- State Engineer's Office contracting with USGS and DRI for calibrated basin-scale groundwater – surface water models from pre-development through 2015.

What is Streamflow capture?

- Also commonly referred to as Streamflow depletion.
- In 1940, C.V. Theis published paper on “The source of water derived from wells”

CHARLES V. THEIS
1900-1987



1. All water discharged by wells is balanced by a loss of water somewhere.

2. This loss is always to some extent and in may cases largely from storage in the aquifer. Some ground water is always mined. The reservoir from which the water is taken is in effect bounded by time and by the structure of the aquifer as well as by material boundaries. The amount of water removed from any area is proportional to the drawdown, which in turn is proportional to the rate of pumping. Therefore, too great concentration of pumping in any area is to be discouraged and a uniform areal distribution of development over the area where the water is shallow should be encouraged, so far as is consistent with soil and marketing or other economic conditions.

3. After sufficient time has elapsed for the cone to reach the area of recharge, further discharge by wells will be made up at least in part by an increase in the recharge if previously there has been rejected recharge. If the recharge was previously rejected through transpiration from non-beneficial vegetation, no economic loss is suffered. If the recharge was rejected through springs or refusal of the aquifer to absorb surface waters, rights to these surface waters may be injured.

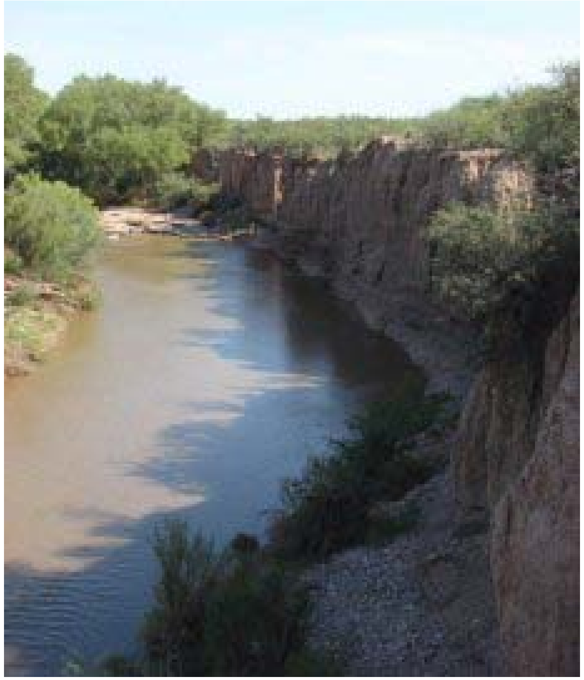
4. Again, after sufficient time has elapsed for the cone to reach the areas of natural discharge, further discharge by wells will be made up in part by a diminution in the natural discharge. If this natural discharge fed surface streams, prior rights to the surface water may be injured.

Humboldt River Capture Modeling

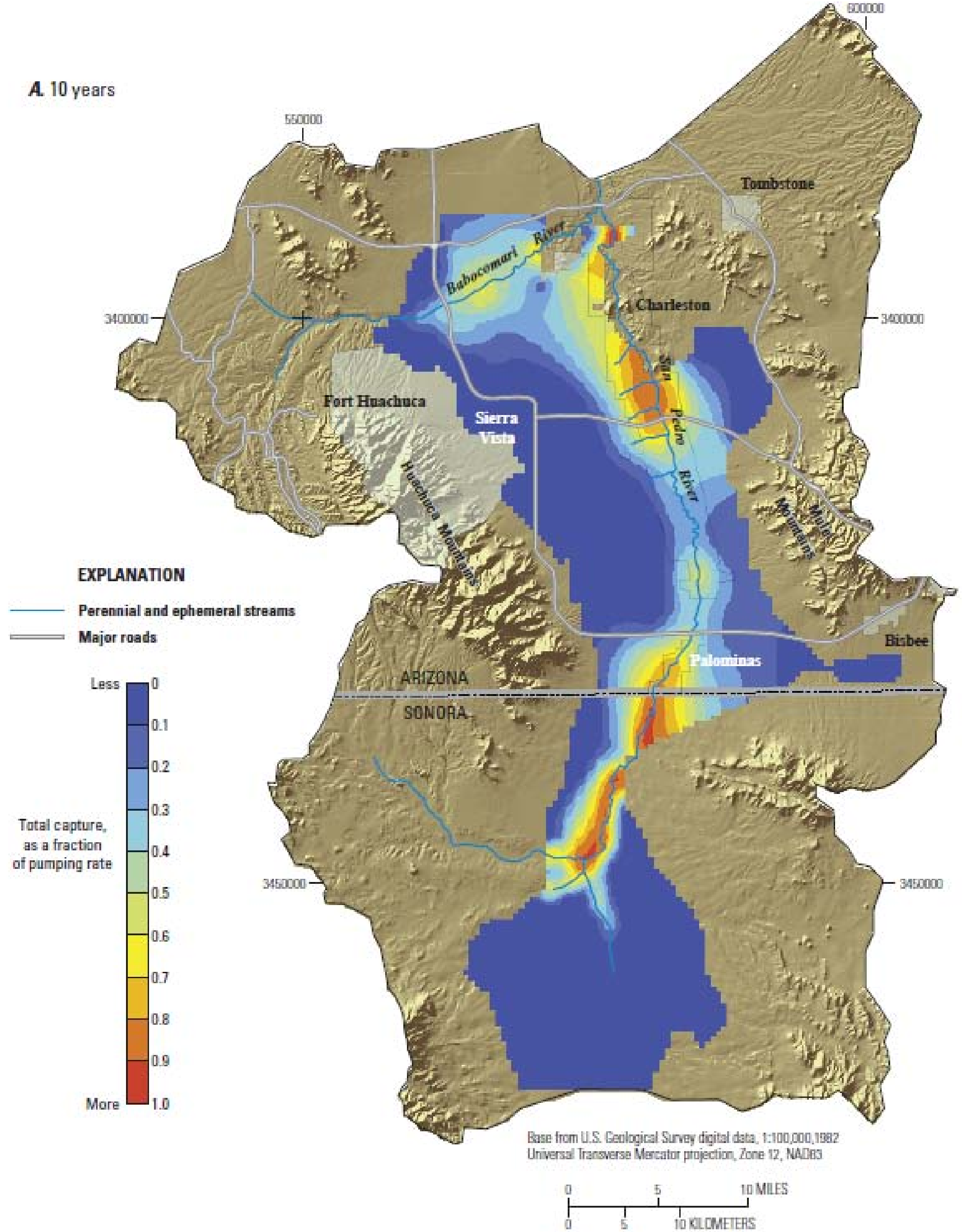
- What is a capture model?
- Groundwater flow model is foundation
  - Simulates surface and groundwater system
  - Calibrated to actual conditions (water levels, flows)
- Used to estimate and predict river capture by groundwater pumping anywhere in the basin
- Model products are capture maps for selected time periods
- Necessary for future conjunctive management of surface and groundwater in the basin

Capture Map Example: San Pedro River, AZ

- Developed by the USGS
- Effects of groundwater pumping and aquifer storage projects on streamflow

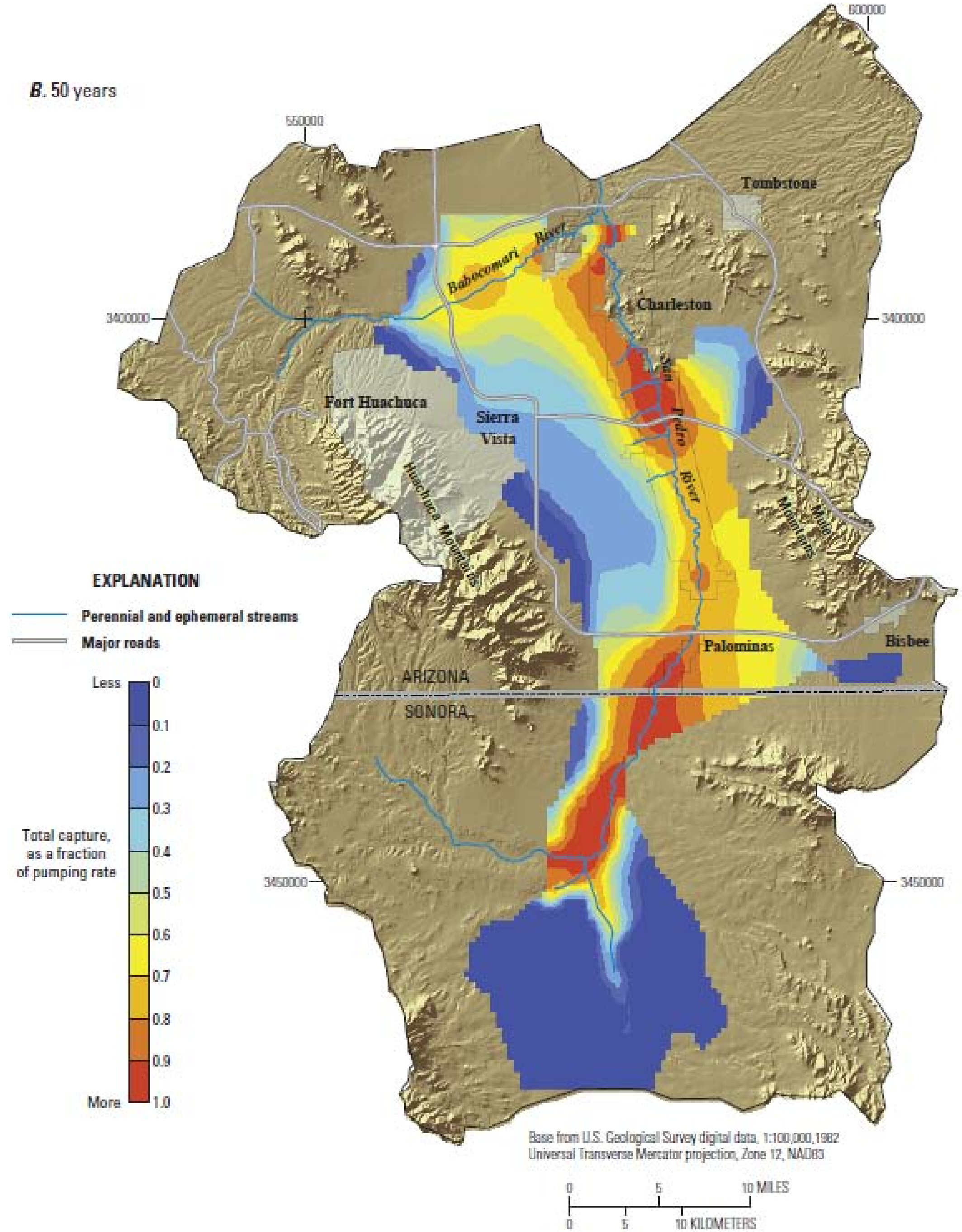


San Pedro River Capture Map



USGS SIR 2008-5207

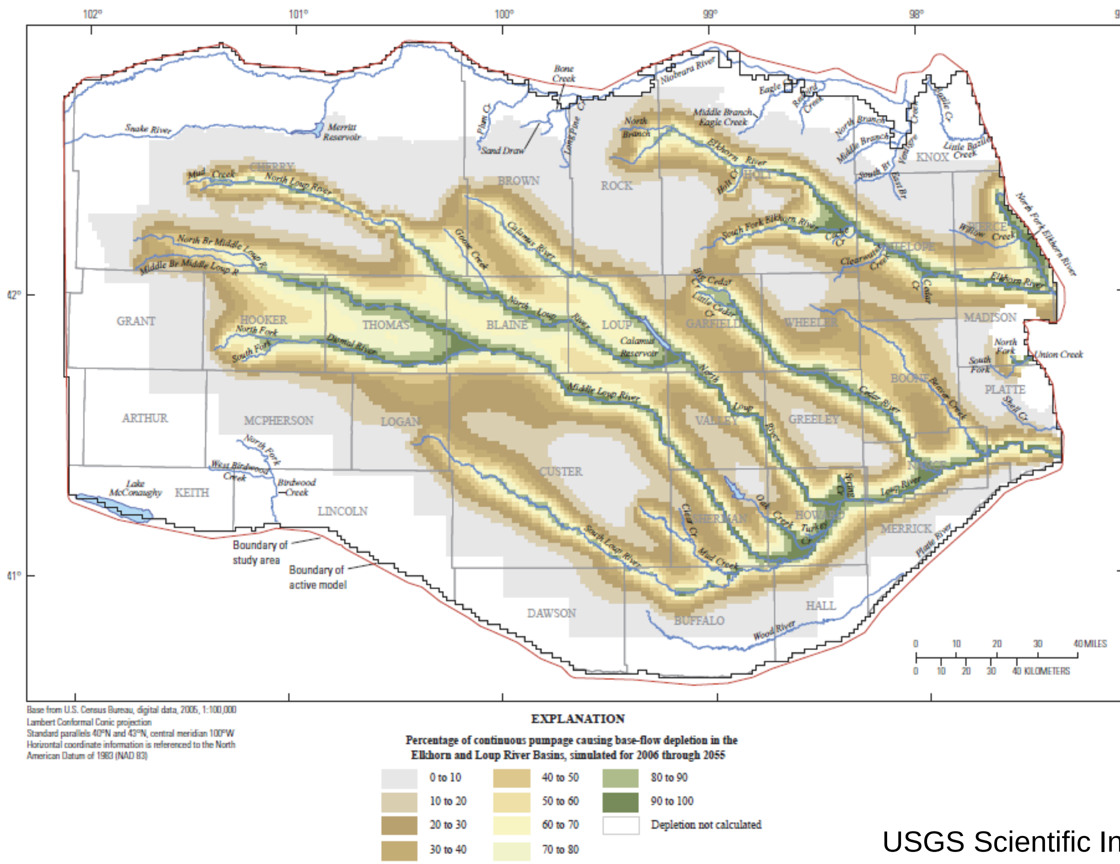
San Pedro River Capture Map



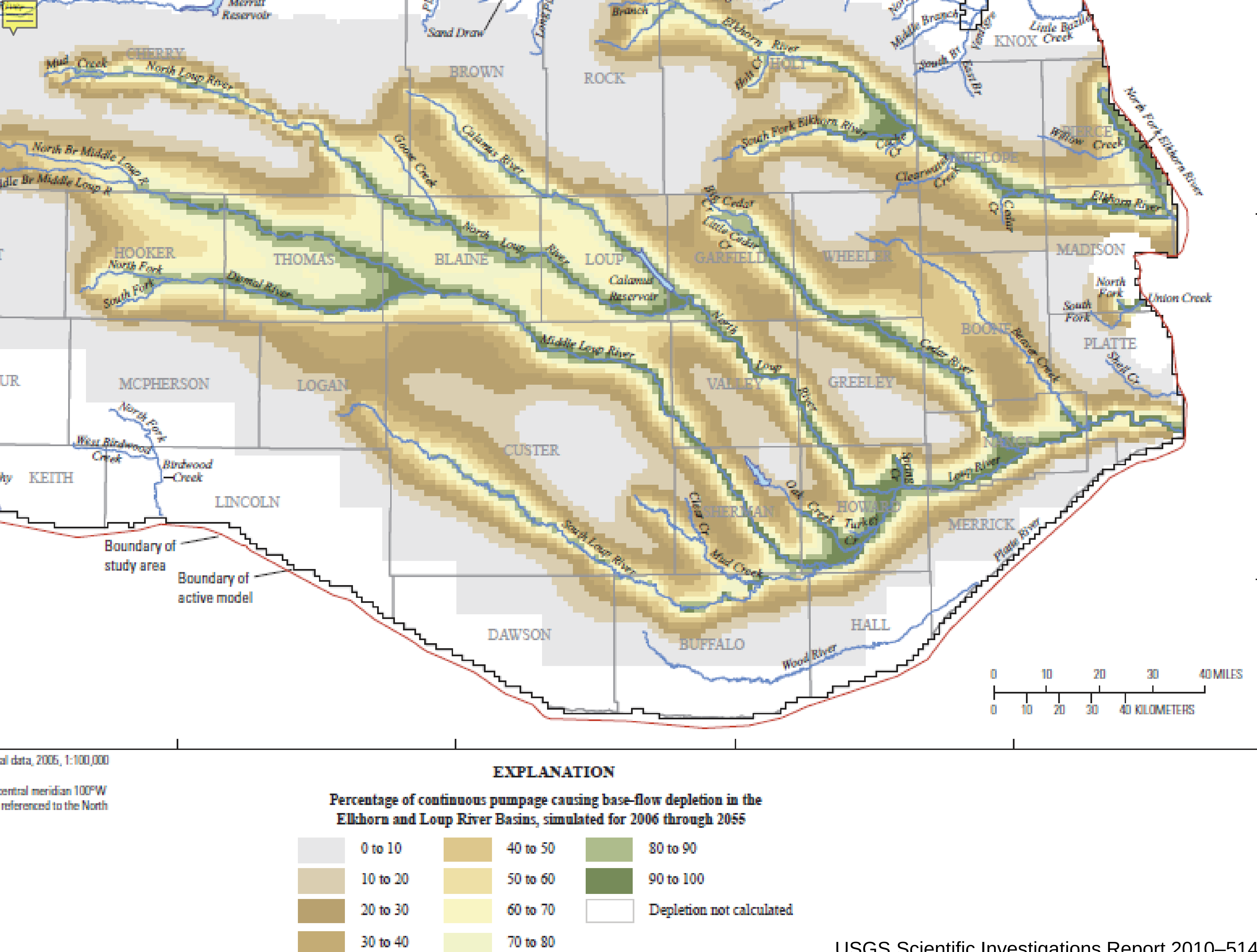
USGS SIR 2008-5207

Capture Map Example: Elkhorn-Loupe River Basin, Nebraska

– No new groundwater appropriations
– Applications to change pumping location are reviewed for capture %, and duty is adjusted so the effect on streamflow is neutral.



USGS Scientific Investigations Report 2010–5149



…al data, 2005, 1:100,000

…central meridian 100°W
…referenced to the North

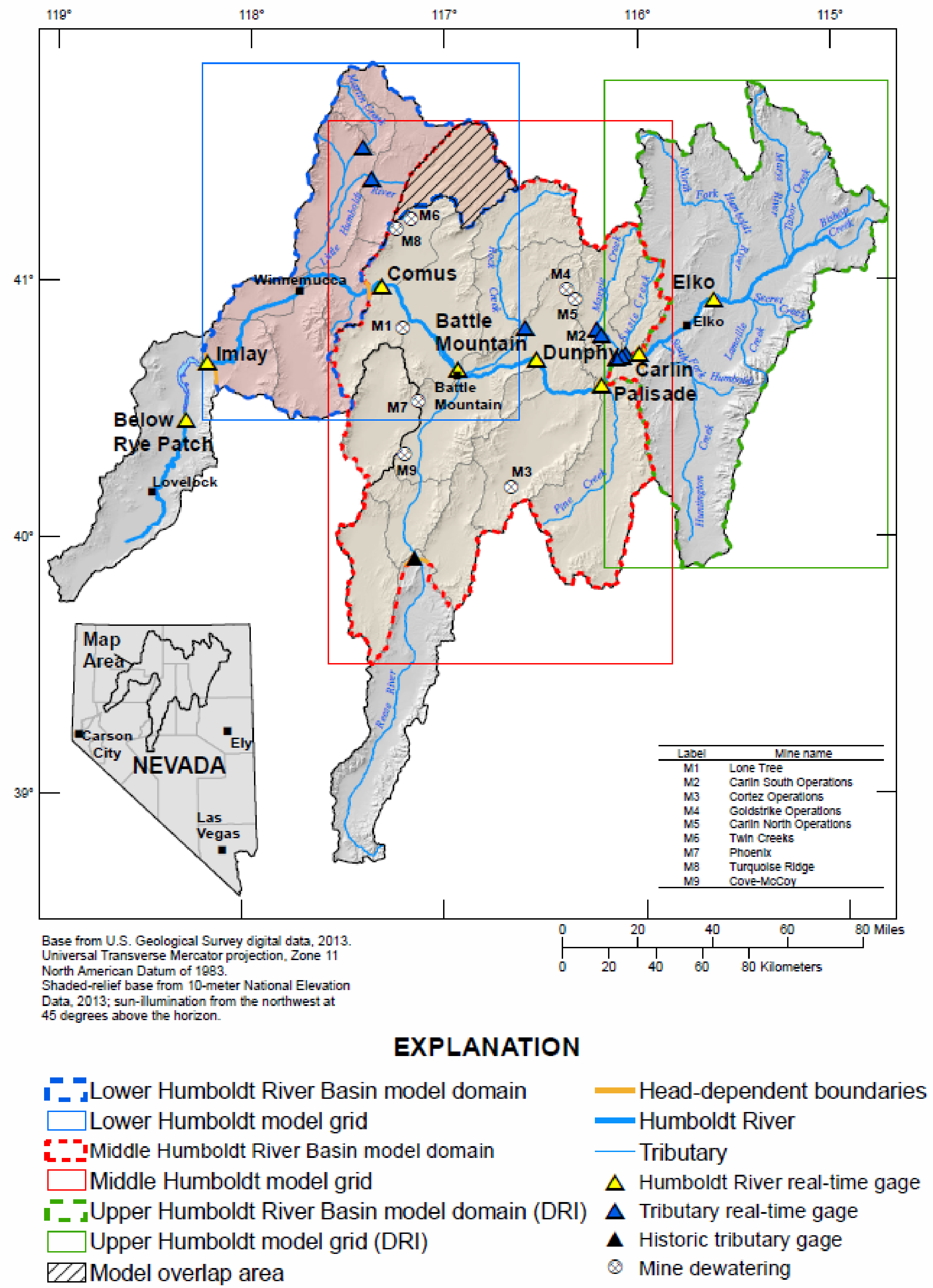
Humboldt River

Capture Modeling

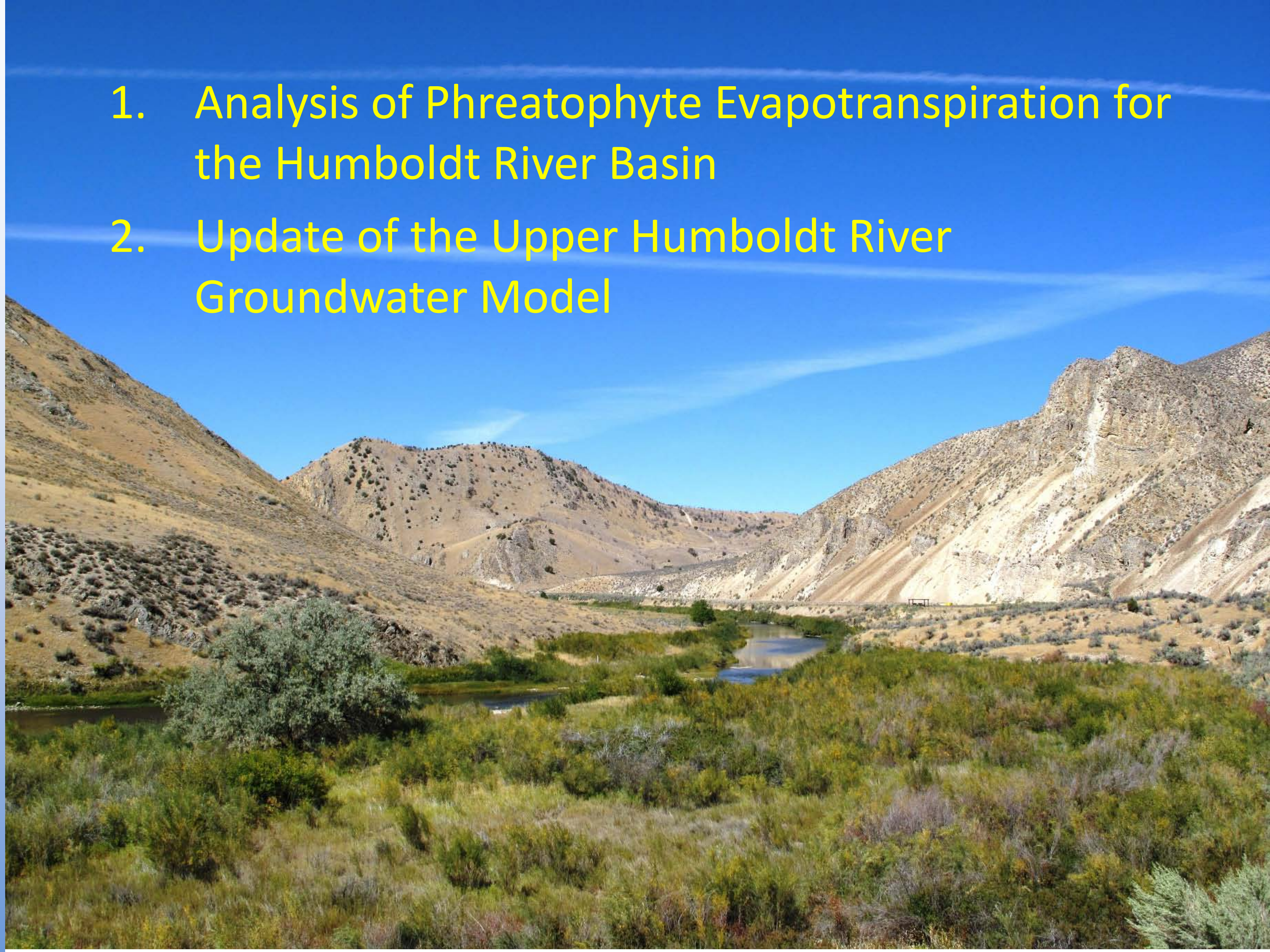
USGS and DRI

Planned Models

- Three separate but connected models
- DRI Upper Humboldt - update of existing model
- USGS Middle Humboldt - update of existing model
- USGS Lower Humboldt - new model



1. Analysis of Phreatophyte Evapotranspiration for the Humboldt River Basin
2. Update of the Upper Humboldt River Groundwater Model

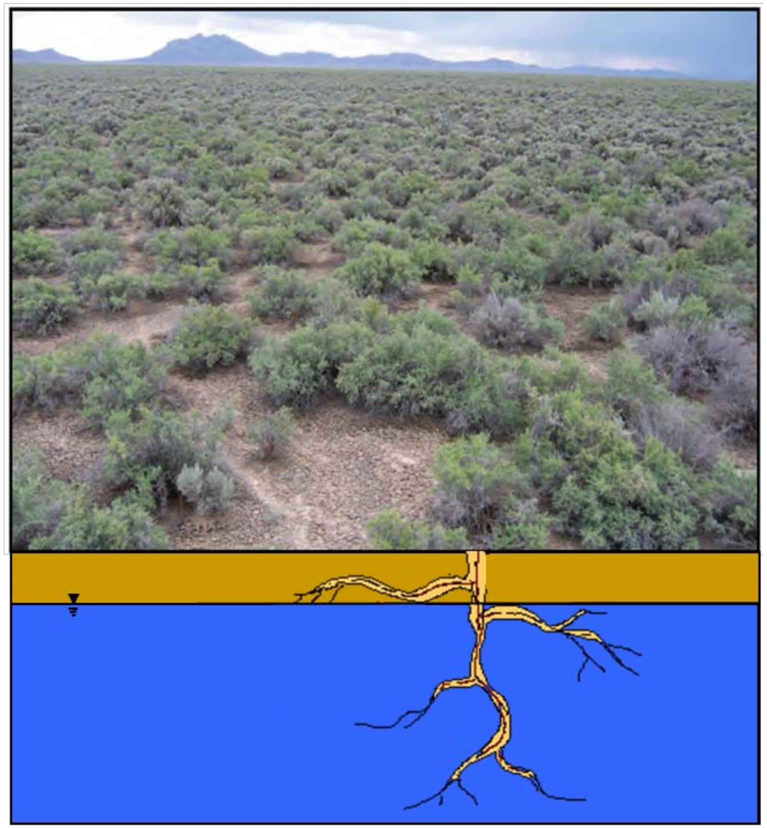


Desert Research Institute

Greg Pohll
Justin Huntington

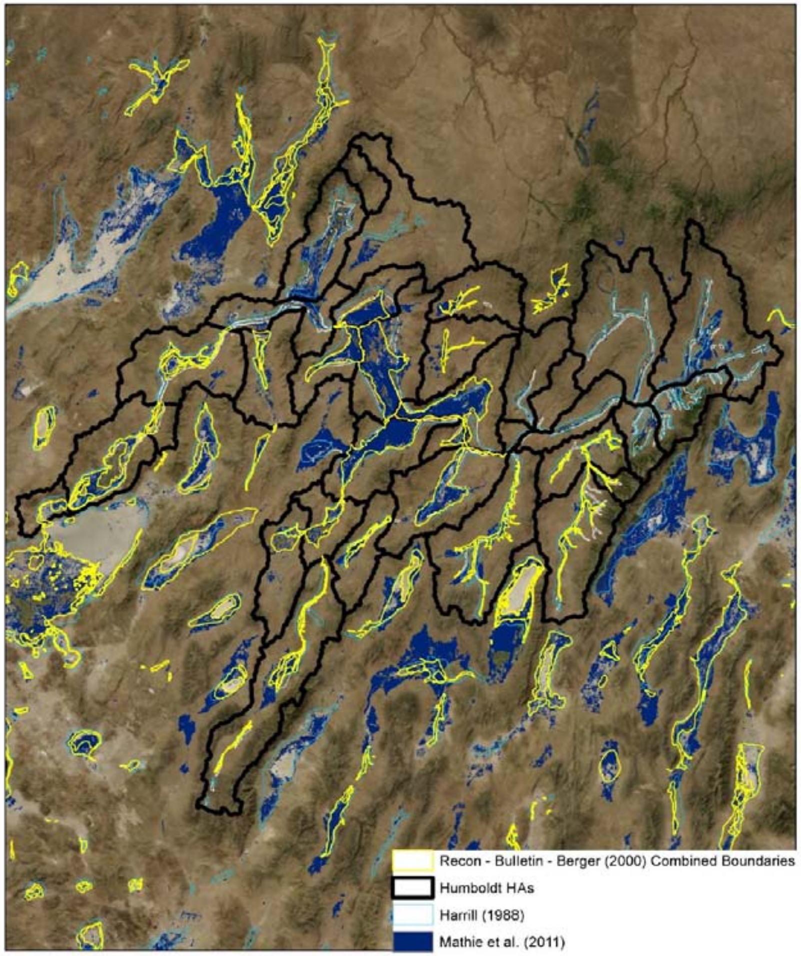
Phreatophyte ET

- Humboldt River groundwater models rely on accurate estimates of phreatophyte ET
- Field work and areal and satellite imagery will be used to refine existing phreatophyte groundwater discharge boundaries in each HA

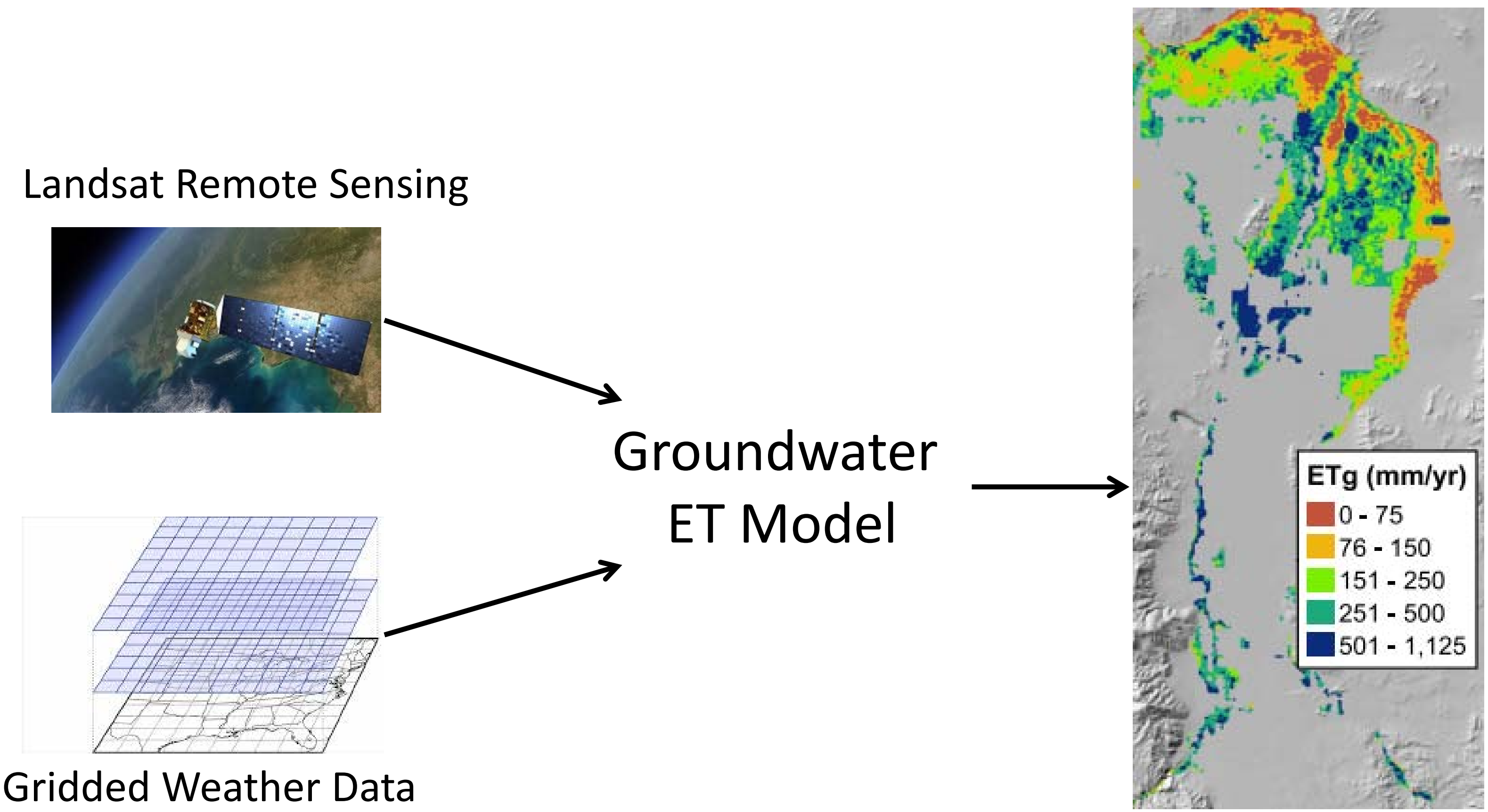


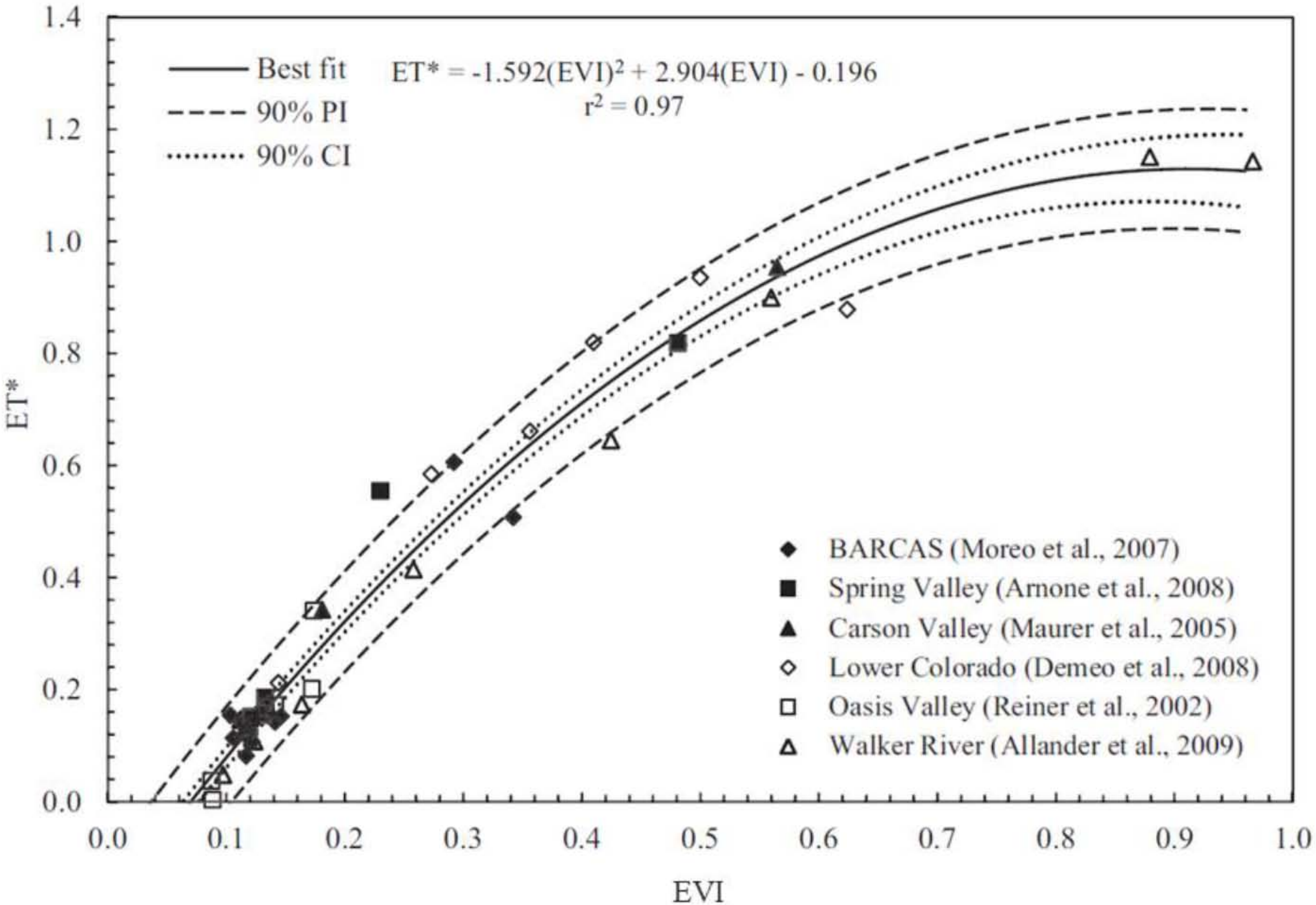
Delineate Phreatophyte ET Areas

- Many different phreatophyte boundary datasets are available for the Humboldt Basin
- Phreatophyte areas will be field verified, and refined to determine the most accurate and appropriate boundaries



- Local climate data will be organized into gridded database
- Climate data will be paired to the Landsat imagery (1985-2015) to estimate groundwater ET

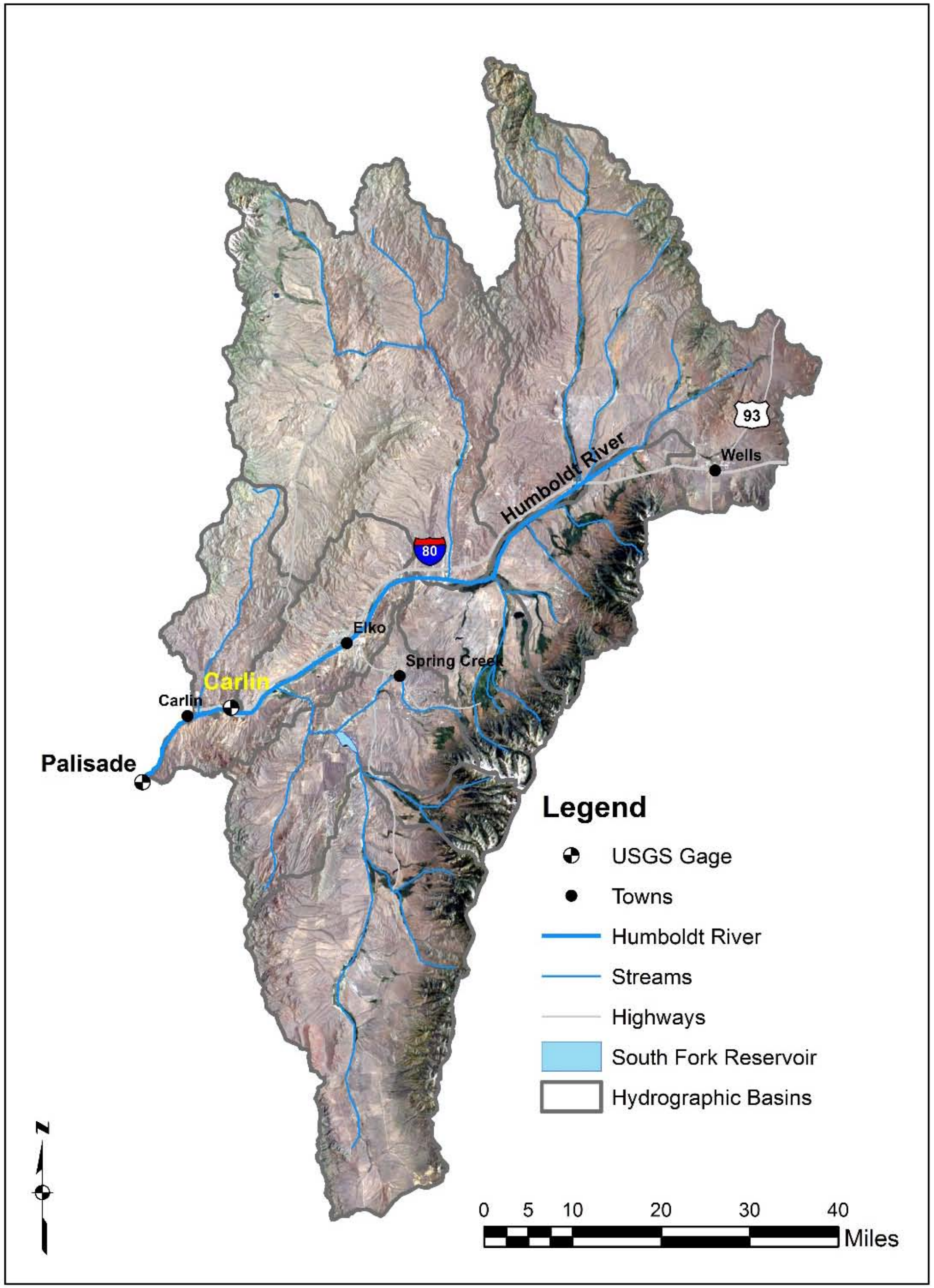




Beamer et al., 2013

Upper Humboldt Groundwater Model

- Update AQUA Program groundwater flow model
- Simulates hydrographic basins 42 - 50

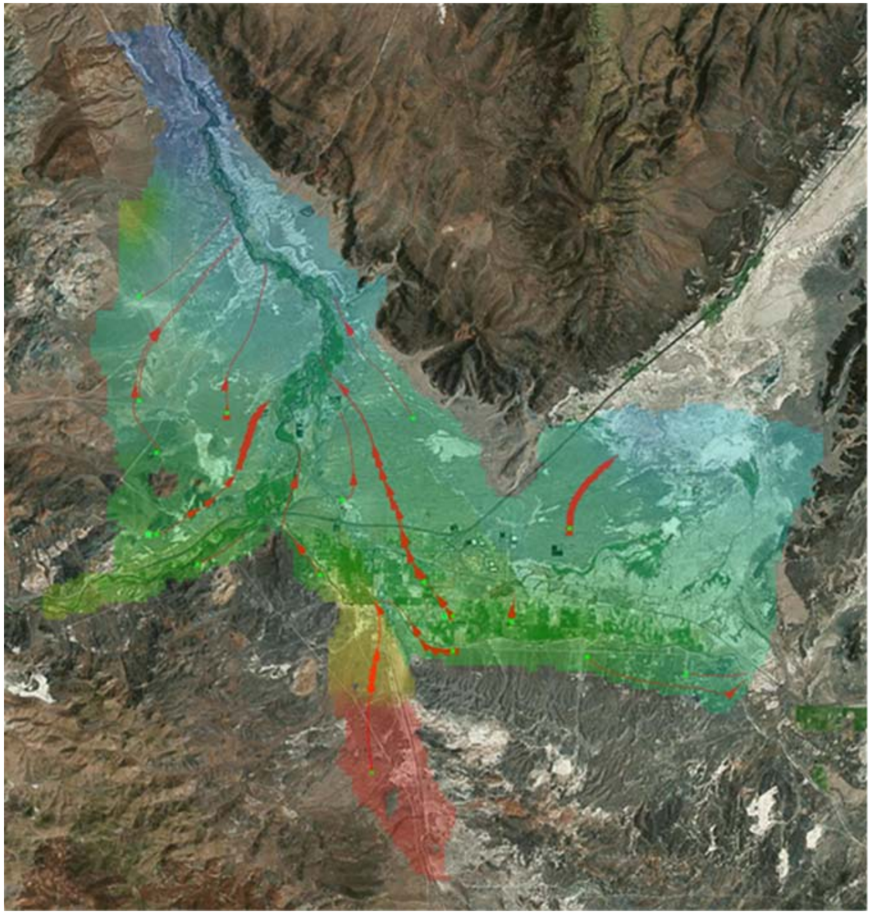


Groundwater Modeling Tasks

1. Assess non-linear bias
2. Update hydrogeologic database
3. Reconstruct model to focus on groundwater and surface water interactions along the upper Humboldt River
4. Capture analysis
5. Reporting

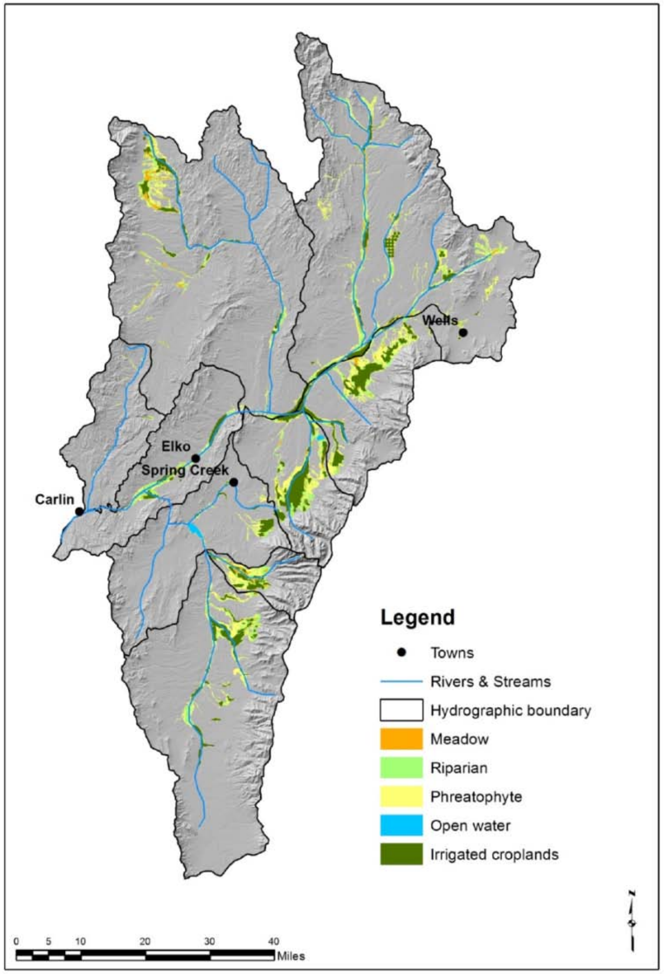
Task #1 – Nonlinear Bias

- Stream capture calculations are dependent on groundwater levels, pumping and evapotranspiration rates
- Stream capture calculations are not necessarily additive
- The bias associated with the non-additive nature of the calculations will be evaluated using hypothetical test models and an existing model of the Fernley groundwater system



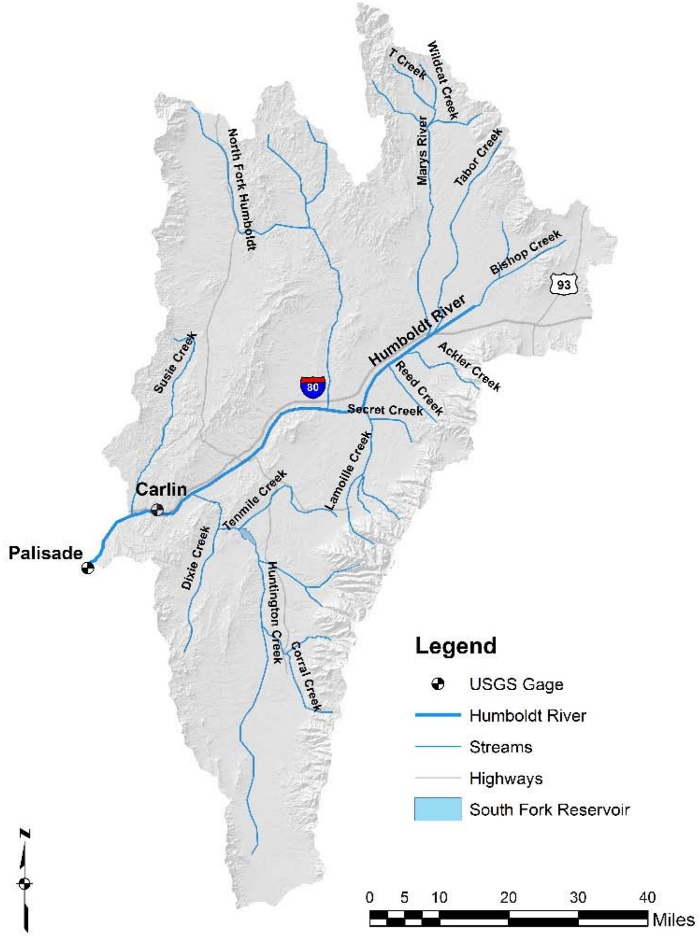
Task #2 – Update Database

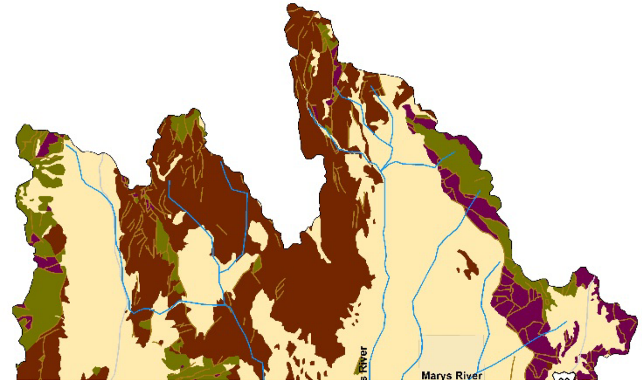
- Groundwater pumping
- Phreatophyte ET
- Surface water flows and spatial and temporal distribution of gains and losses
- Hydraulic parameters (e.g. hydraulic conductivity and storage parameters)
- Groundwater recharge

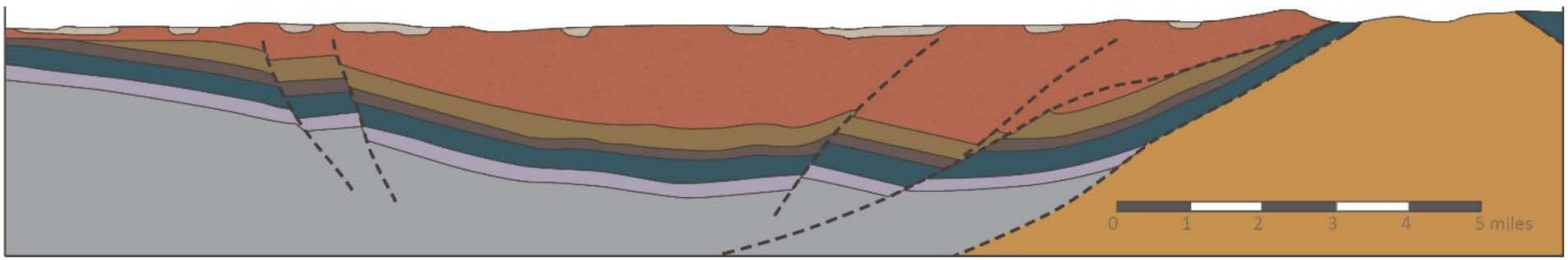


Task #3 – Update Model

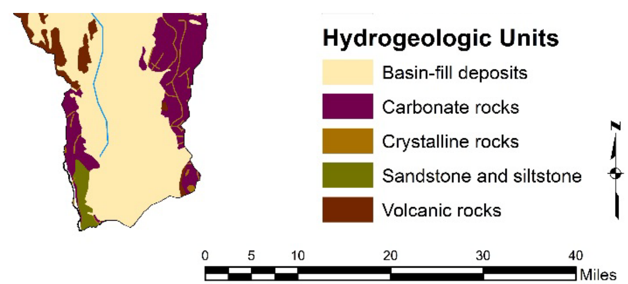
- Enhance simulation of groundwater/surface water interactions
- Stream package for Humboldt River
- Tributaries (18) will be included as specified head boundary conditions





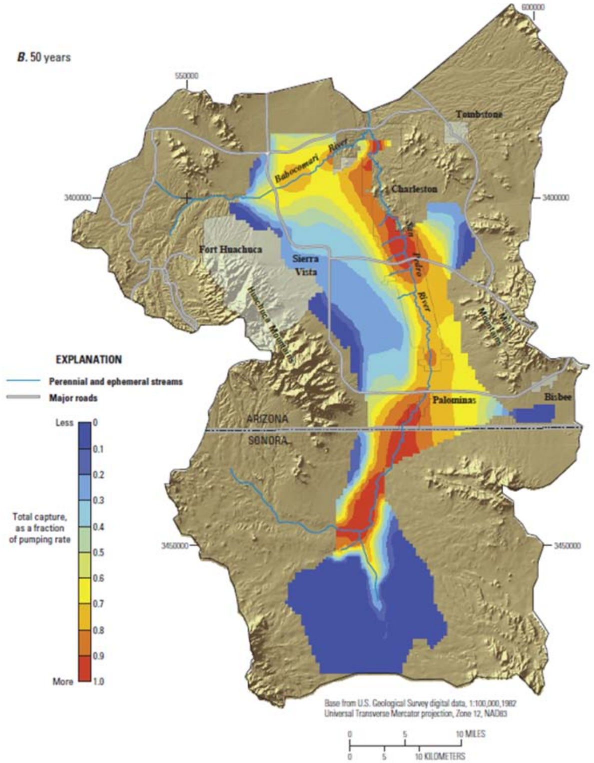


- **Qa** — ALLUVIUM – Silt, sand, and gravel along present streams
- **Ts3** — SEDIMENTARY AND VOLCANIC ROCKS – Tuff, vitric ash, tuffaceous siltstone and sandstone, conglomerate, and limestone. Includes the Humboldt Formation.
- **Tiw** — INDIAN WELL FORMATION – Tuffaceous fluvial conglomerate, siltstone, and sandstone, andesitic flows and lahars, tuff and ash-flow tuff
- **Te** — ELKO FORMATION – Brown and black shale containing interbedded limestone, dolomite, siltstone, tuff, and conglomerate
- **PIPl** — UPPER PALEOZOIC CARBONATES – Lower Permian and Upper Pennsylvanian limestone
- **IPMdp** — DIAMOND PEAK FORMATION – Bouldery and pebbly conglomerate, sandstone, and limestone
- **Mc** — CHAINMAN FORMATION – Conglomerate, sandstone, and shale
- METAMORPHIC CORE COMPLEX



Task 4 – Stream Capture

- Historical depletions will be calculated for the main stem of the Humboldt River (above Palisade gage) and tributaries
- Capture maps will be developed for entire model area at 10, 25, 50 and 100 years



USGS SIR 2008-5207

Task #5 - Reporting

- A peer-reviewed DRI report will document all model updates and stream capture analysis
- A peer-reviewed journal article will be written in collaboration with the USGS to document the nonlinear bias analysis

DRI
Desert Research Institute

Interim Final
in the Upper
Quality Ass

Greg Pohll
Jenny Chapman
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Rishi Parashar
Susan Rybarski
Ronald L. Hershey
Wyatt Fereday
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James M. Thomas

October 2015

Publication No

Modeling Ground Water Flow and Radioactive Transport in a Fractured Aquifer

by Greg Pohll[a], Ahmed E. Hassan[a], Jenny B. Chapman[a], Charalambos Papelis[a], and Roko Andricevic[a]

Abstract

Three-dimensional numerical modeling is used to characterize ground water flow and contaminant transport at the Shoal nuclear test site in north-central Nevada. The fractured rock aquifer at the site is modeled using an equivalent porous medium approach. Field data are used to characterize the fracture system into classes: large, medium, and no/small fracture zones. Hydraulic conductivities are assigned based on discrete interval measurements. Contaminants from the Shoal test are assumed to all be located within the cavity. Several challenging issues are addressed in this study. Radionuclides are apportioned between surface deposits and volume deposits in nuclear melt glass, based on their volatility and previous observations. Surface-deposited radionuclides are released hydraulically after equilibration of the cavity with the surrounding ground water system, and as a function of ground water flow through the higher-porosity cavity into the low-porosity surrounding aquifer. Processes that are modeled include the release functions, retardation, radioactive decay, prompt injection, and ingrowth of daughter products. Prompt injection of radionuclides away from the cavity is found to increase the arrival of mass at the control plane but is not found to significantly impact calculated concentrations due to increased spreading. Behavior of the other radionuclides is affected by the slow chemical release and retardation behavior. The transport calculations are sensitive to many flow and transport parameters. Most important are the heterogeneity of the flow field and effective porosity. The effect of porosity in radioactive decay is crucial and has not been adequately addressed in the literature. For reactive solutes, retardation and the glass dissolution rate are also critical.

Introduction

Ground water flow and transport modeling is a tool that combines all of the information collected into a single "model" of how the ground water system behaves. An essential prerequisite for a successful application of such modeling is an understanding of the transport mechanisms and good estimates of the governing parameters (Jussel et al. 1994). These parameters usually contain a large degree of uncertainty due to imperfections in data collection and in the modeling structure. Some of the uncertainty can be addressed directly with powerful tools such as Monte Carlo analysis, which quantifies the uncertainty (Graham and McLaughlin 1989; Jussel et al. 1994; Valocchi 1990; Bellin et al. 1992, 1994; Hassan et al. 1998). Because the number of uncertain parameters can be large, not all of the uncertain parameters can be addressed in the Monte Carlo analysis. However, a less rigorous analysis can be used to address these additional uncertainties.

The purpose of this work is to characterize ground water flow and contaminant transport at the Project Shoal area (near Fallon, Nevada) through numerical modeling that uses site-specific hydrologic and geochemical data. This will allow hydrologists, site managers, and regulators to develop a better understanding of the system and assess future work.

The specific objectives of the study were:

1. To construct a ground water flow model that uses site-specific data. The development of the flow model uses indicator simulation techniques to simulate the spatial distribution of fracture classes and associated equivalent hydraulic conductivities observed via video logging, geophysical logging, surficial fracture mapping, and hydraulic testing.
2. To construct a radionuclide transport model that incorporates processes uniquely associated with nuclear test activities (melt glass dissolution, prompt injection, and ingrowth of daughter products).
3. To determine which parameters are most sensitive in terms of radionuclide transport through a multicomponent sensitivity analysis. This type of sensitivity analysis incorporates the method of Monte Carlo analysis with the adjustment of mean parameters for each sensitivity case.

During the course of this analysis, several challenging practical issues arose and needed to be addressed. These issues represent features that are not commonly encountered in analytical or numerical studies. For example, the source conditions do not follow either of the two extremes usually employed in theory: the instantaneous source and the continuous release conditions. The contaminant release from the source is controlled by hydraulic as well as chemical release conditions, which result in a source that is not amenable to description by any of those two extremes. The chemical release conditions involved dissolution of nuclear melt glass, for which limited data are available. In addition, prompt injection, which is the instantaneous transport away from the source due

[a]Water Resources Center, Desert Research Institute, University and Community College System of Nevada, 2215 Raggio Pkwy., Reno, NV 89512.

Received May 1998, accepted April 1999.

USGS Models

Evaluation of streamflow depletion related to groundwater withdrawals

Middle and Lower Humboldt River basins

Objectives

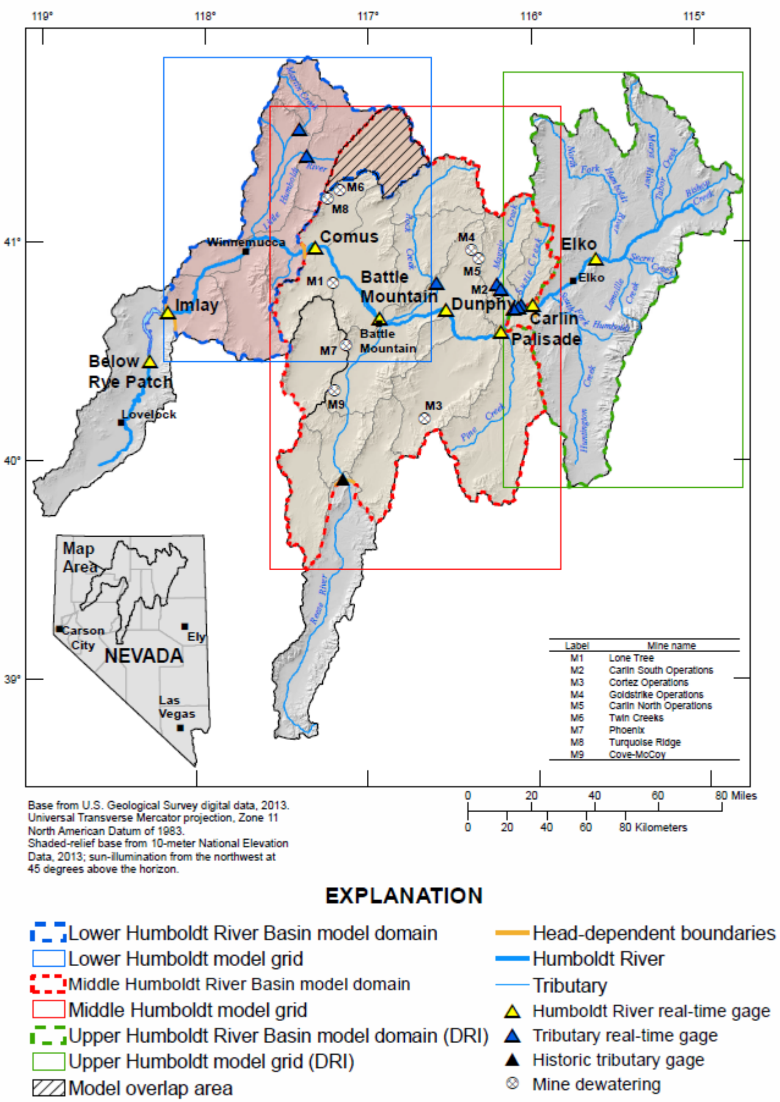
1. Estimate Humboldt River depletion caused by groundwater withdrawals between Carlin and Imlay gages (Capture Maps).

2. Estimate effect of mine dewatering on Humboldt River streamflows as a result of mine-dewatering operations through 2015.

3. Estimate effect of groundwater withdrawals from individual hydrographic areas on Humboldt River depletion.

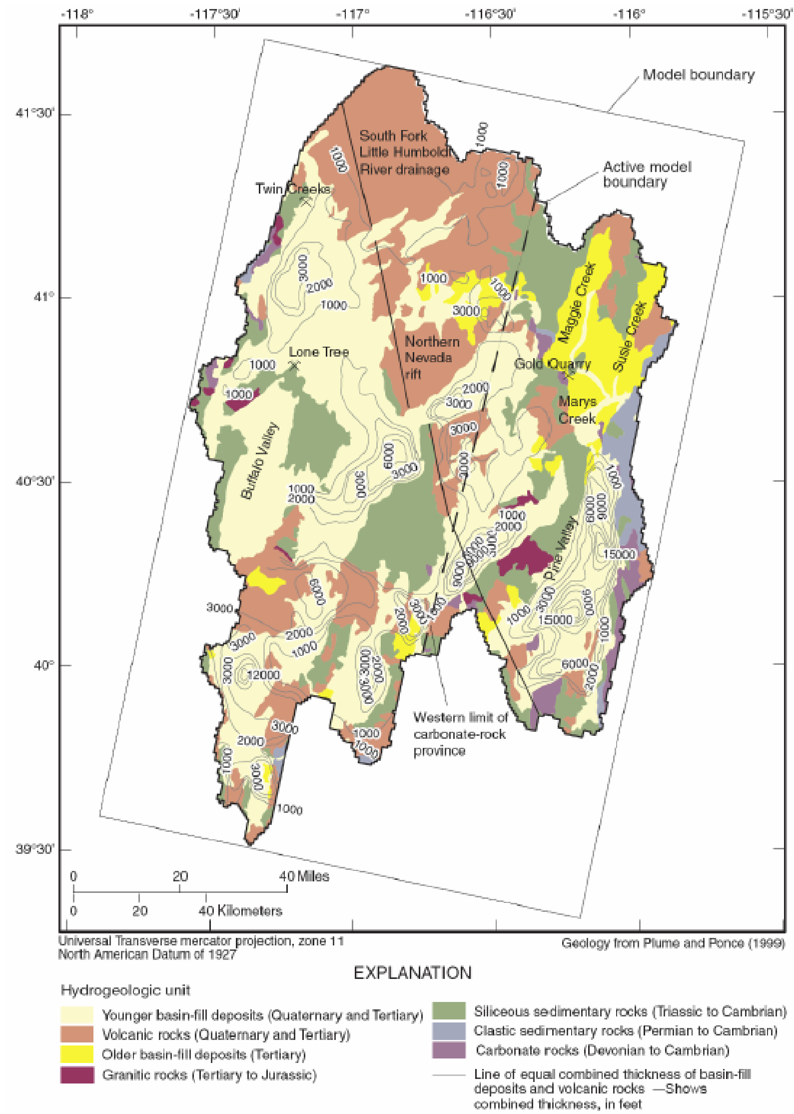
General Approach

- Revise and recalibrate existing Middle HRB MODFLOW model.
- Build and calibrate new Lower HRB MODFLOW model.
- Similar construction, design, and calibration approach.
- Middle HRB model receives flow from Upper HRB model at Carlin gage.
- Middle HRB model transfers flow to Lower HRB model at Comus gage.



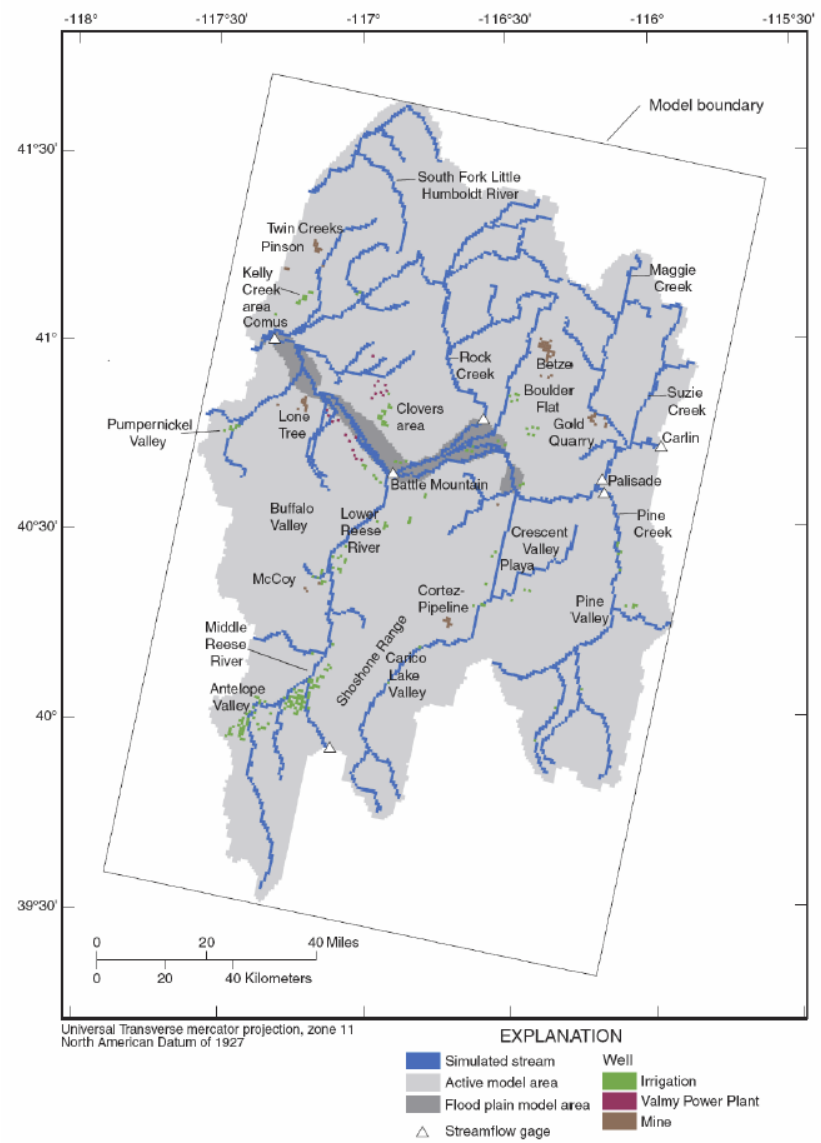
General Approach (cont)

- Determine/refine hydraulic properties through model calibration.
- Reformulate calibrated models to answer questions and address objectives.
- Develop reference scenario where groundwater is not pumped.
- Develop capture maps.
- Evaluate mine dewatering.



Model Design – Discretization

- Middle HRB model
  - 2,500 ft square grid cells
  - 4 layers including bedrock.
- Lower HRB model
  - 1,500 ft square grid cells
  - 3 layers, does not include bedrock.



Model Design – Steady state and transient models

Steady State model

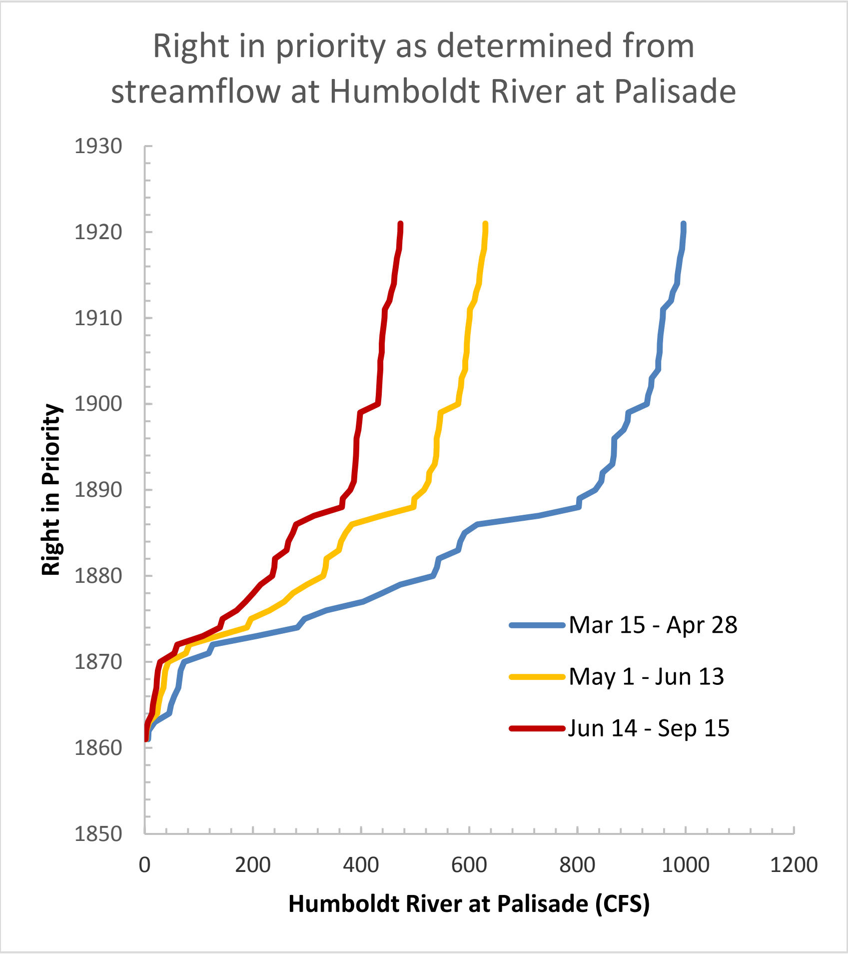
- Simulates average conditions of early 1960's.
- Assumes no long-term changes in groundwater storage.
- Represents a period of dynamic equilibrium.

Transient model

- Simulates changing conditions from 1961 through 2015.
- Simulates changes in groundwater storage.
- Stresses (pumping rates) varied semi-annually.
- Simulates on a monthly time step.

Simulated processes

- Recharge (includes intermittent streams).
- Groundwater flow and levels.
- Tributary streams with year-round flow.
- Humboldt River flow and diversions.
- Evapotranspiration of groundwater.
- Groundwater pumping.

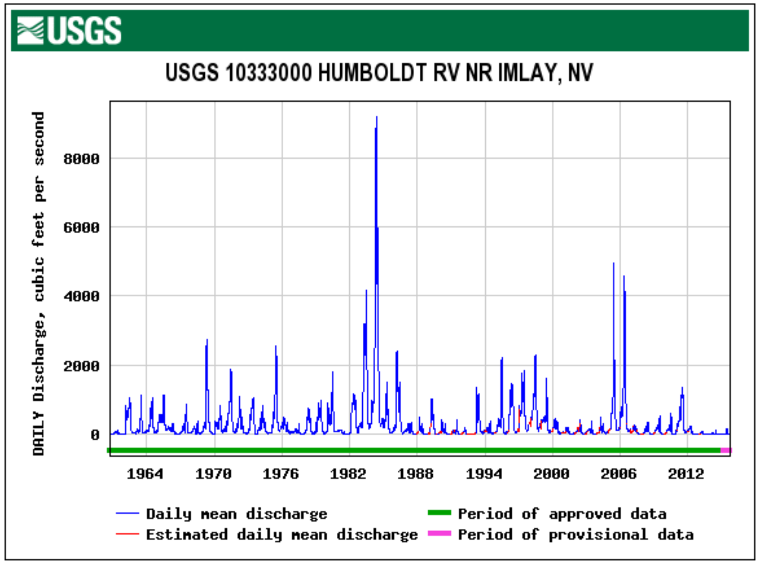


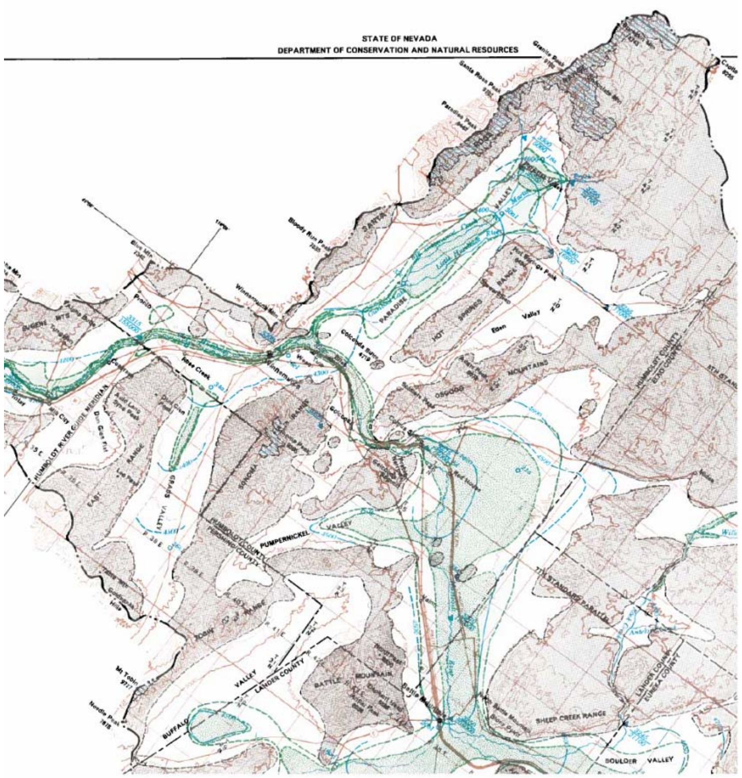
Model Calibration

- Calibration is the process of adjusting hydraulic properties (parameters) in the model and model construction to improve simulation of observed conditions.
- 100’s to 1000’s of parameters.
- Ultimate goal is satisfactory determination of hydraulic properties governing the hydrologic system.

Model Calibration – Observation data

- Synthesizes known data for the system.
- Groundwater levels.
- Streamflows.
- Water budgets.
- Evapotranspiration rates.
- Areas of phreatophyte discharge.
- Transmissivity estimates.





Eakin and Lamke, 1966, Bulletin 32

Model Calibration – Strategy and approach

- Automated calibration procedure known as Parameter ESTimation (PEST).
- PEST systematically adjusts properties to minimize differences between simulated and observed data.
- Will use existing hydrogeologic frameworks to distribute and constrain properties in hydrogeo units.
- Transmissivity and storage properties will be allowed to vary within units to better represent variability of the properties within hydrogeologic units.

Model Calibration – related to mine dewatering

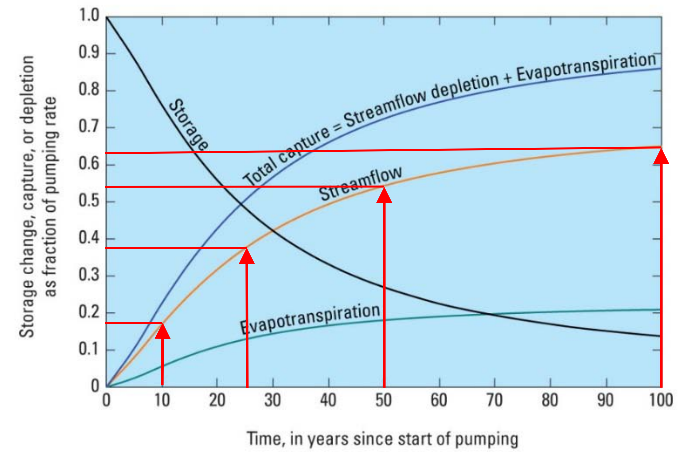
- Start with hydraulic property solutions found in existing mine groundwater flow models.
- Simulate mine-dewatering and compare with observed water level data near mines.
- Adjust properties if necessary to optimize a solution that minimizes differences between simulated and observed conditions.

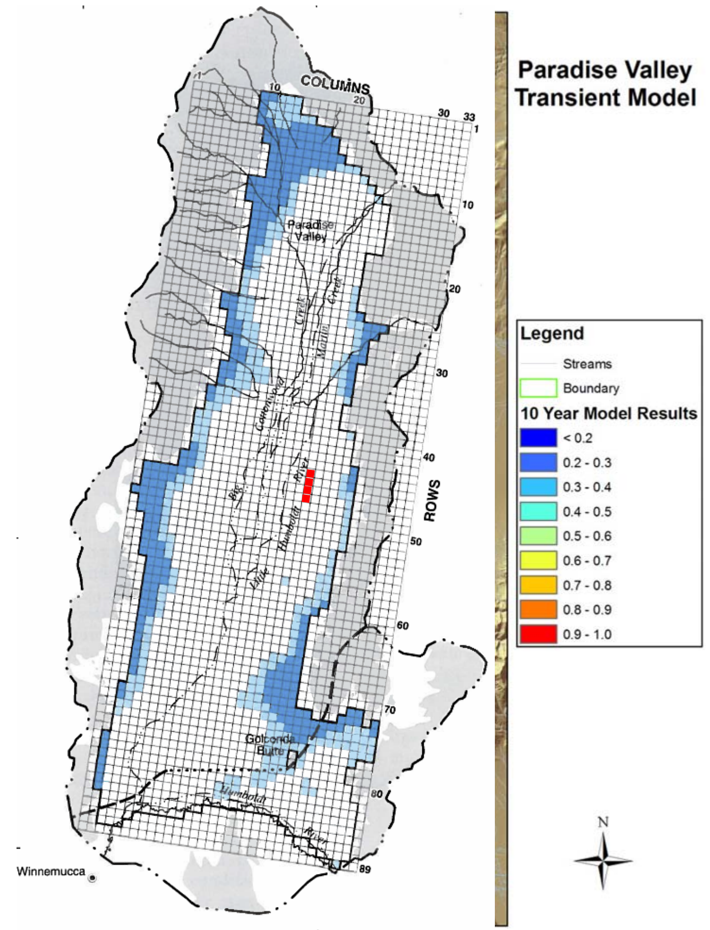
Develop reference scenario

- Reference scenario represents the hydrologic system where groundwater is not pumped.
- Provides a reference from which to evaluate impacts of groundwater pumping on streamflow.
- Will use 50-yr reference period 1966 – 2015.
- Repeat reference period once to simulate 100 year period.

Develop capture maps

- Start with reference scenario (no pumping).
- Systematically pump one model cell at a time.
- Evaluate change in streamflow (stream depletion) as result of pumping from each cell for durations of 10, 25, 50, and 100 years.
- Develop a contour map of stream depletion for each pumping duration evaluated (capture map).





Mine Dewatering

- All within the Middle Humboldt model domain.
- Criteria for evaluation is pumped more than average of 1,000 acre-ft/yr for 5 or more years.
- 9 mine dewatering operations to be evaluated.
- Non-consumptive portion of water routed to areas of irrigation, injection, or stream discharge.

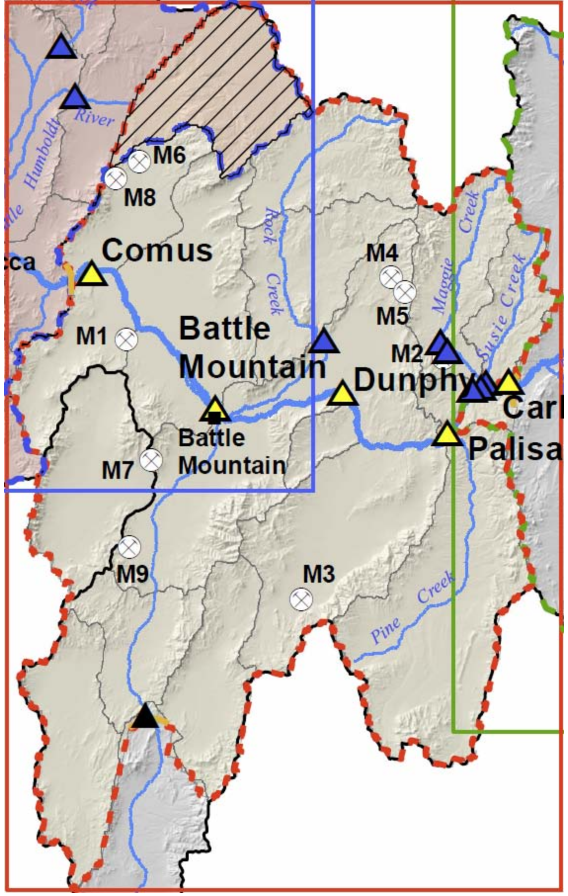


Fig. 1 No.	Mine Operation	Basin	2015 Mine status
M1	Lone Tree	Clovers	Inactive
M2	Carlin South Operations	Maggie Creek	Active
M3	Cortez Operations	Crescent Valley	Active
M4	Goldstrike Operations	Boulder Flat	Active
M5	Carlin North Operations	Boulder Flat	Active
M6	Twin Creeks	Kelly Creek	Active
M7	Phoenix	Buffalo Valley	Active
M8	Turquoise Ridge	Kelly Creek	Surface Inactive, Underground Active
M9	Cove-McCoy	Lower Reese River Valley	Inactive/Exploration

Mine Dewatering

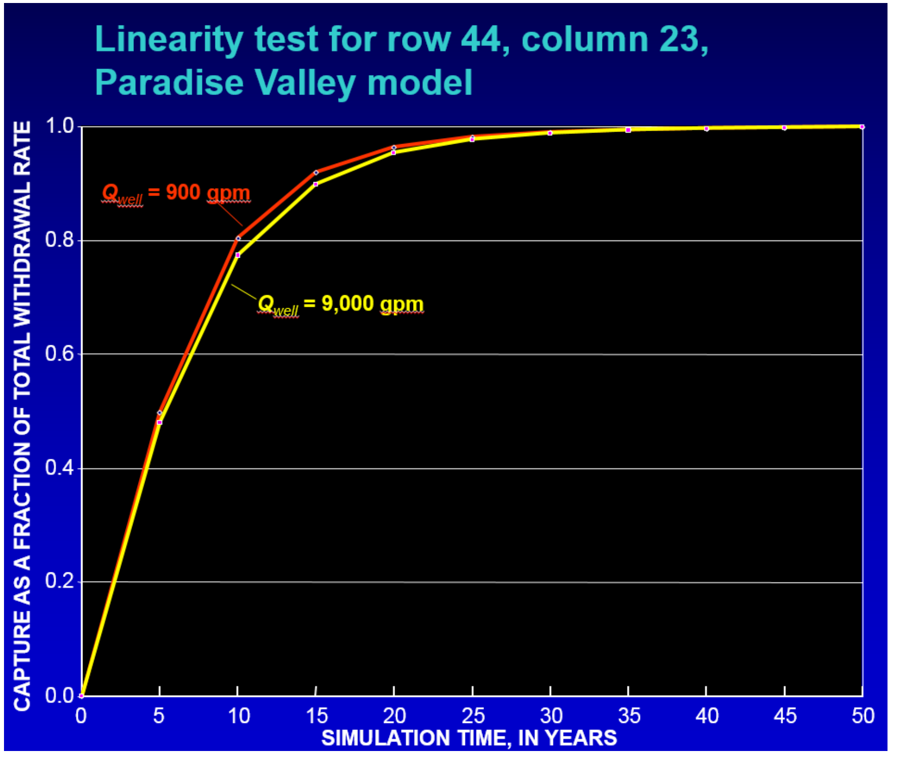
- Create mine-dewatering scenario for each mine-dewatering operation.
- Scenarios will only simulate pumping associated with dewatering operation.
- Evaluate stream depletion (and accretion) by differencing streamflows between mine dewatering scenarios and reference scenario.
- Produce plots showing streamflow accretion and depletion over time for each dewatering operation evaluated and all operations together.

Effect of existing pumping from each HA on Humboldt River depletion

- Simulate impact of existing pumping from each HA on streamflow depletion.
- Create pumping scenario for each HA by removing pumping from all other HA's in calibrated models.
- Evaluate stream depletion by differencing streamflows between HA pumping scenarios and reference scenario.

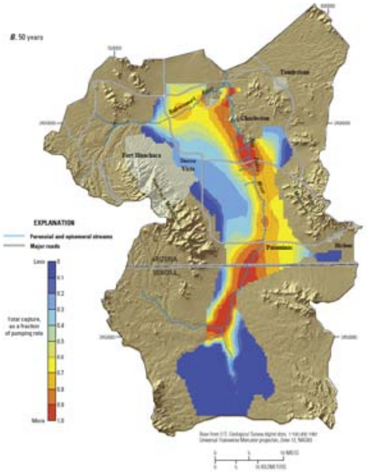
Potential limitation

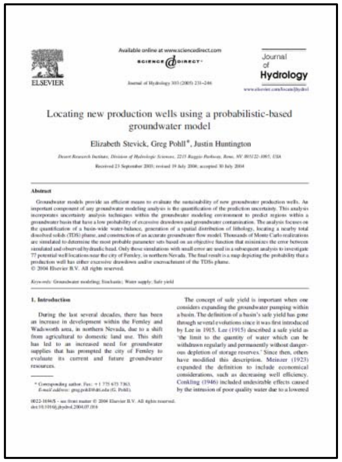
- Do models respond linearly to groundwater pumping?
- In other words – Does simulated capture fraction at a given location vary with pumping rate and/or other nearby pumping?
- Will be some degree of non-linearity which will be tested.
- Anticipated to be small enough to ignore.
- To be verified by further study (with DRI)



Peer Reviewed Products

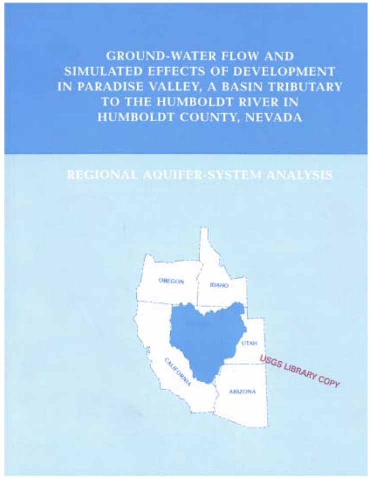
- Publically available models.
- Interactive capture maps.
- Journal article on use of non-linear models for evaluating stream depletion.
- USGS professional-series report.





Locating new production wells using a probabilistic-based groundwater model

Elizabeth Stevick, Greg Pohll*, Justin Huntington



Timeline

Task	FY16				FY17				FY18				FY19			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Field work	x				x											
Develop model input datasets	x	x	x	x	x	x										
Model calibration					x	x	x	x								
Journal Article draft		x	x	x												
Journal Article Acceptance								x								
PP Chapters 1 - 3 draft		x	x	x	x	x	x	x								
PP chapters review and processing									x	x	x	x				
Depletion map development									x	x						
Mine dewatering evaluation										x	x					
HA evaluation										x	x					
PP Chapter 4 draft									x	x	x	x				
PP Ch 4 report review and processing													x	x	x	
Final PP report publication																x
Quarterly progress reports to NSE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Annual progress update to stakeholders	x				x				x				x			x


Questions