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Managing Water in the West

Groundwater Hydrology in West-Wide Climate Risk Assessment: No Standard Practice

February 24, 2012, Riverside, CA

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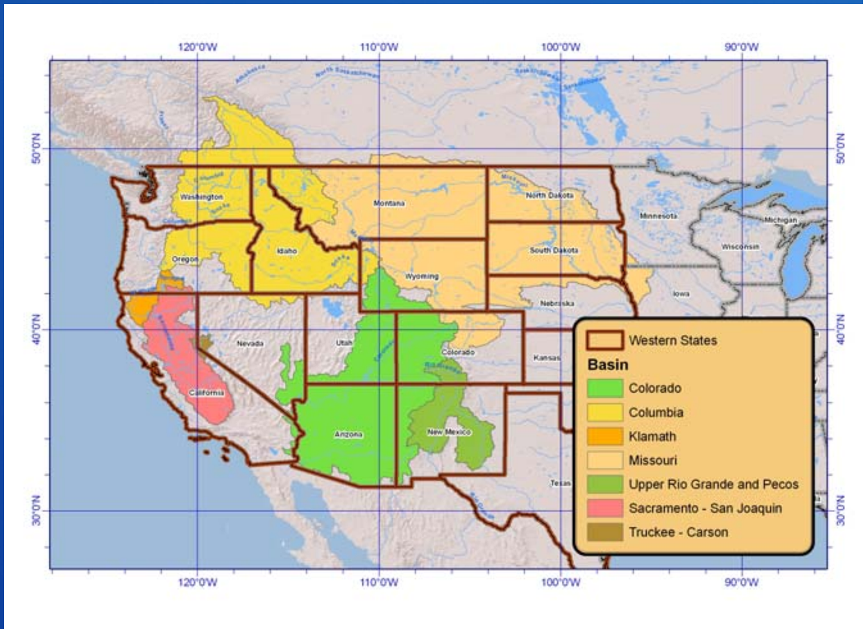
U.S. Department of the Interior
Bureau of Reclamation

Background

- Public Law 111-11, Subtitle F (SECURE Water Act, SWA, 2009) § 9503.
- Climate change risks for water and environmental resources in "major Reclamation river basins."
- Reclamation's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Basin Study Program
  1. Basin Studies
  2. West-Wide Climate Risk Assessments (WWCRAs)
  3. Landscape Conservation Cooperatives (LCCs)



8 major Reclamation River Basin

SECURE – Science and Engineering to Comprehensively Understand and Responsibly Enhance

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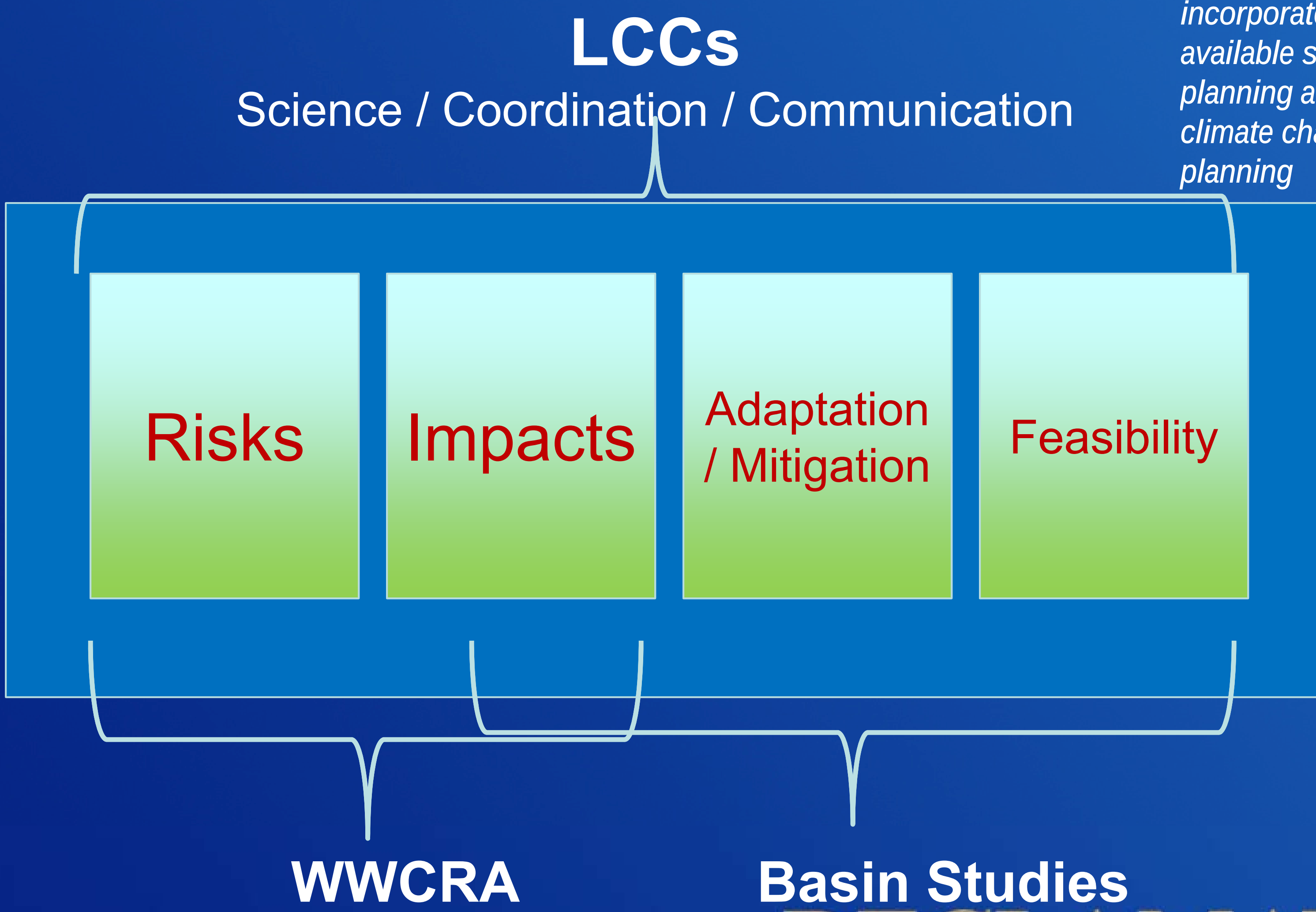
Reclamation WaterSMART Program

Comprehensive approach to incorporate the best available science into planning activities for climate change adaptation planning



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Outline

- West-Wide Climate Risk Assessments (WWCRAs) - foundation for Basin Studies
- Groundwater Hydrology in the context of Basin Studies – selected examples : Santa Ana Watershed (CA), and ongoing Basin Studies with a GW component
- Groundwater Hydrology Research and Development Office efforts – Science and Technology (S&T) Program

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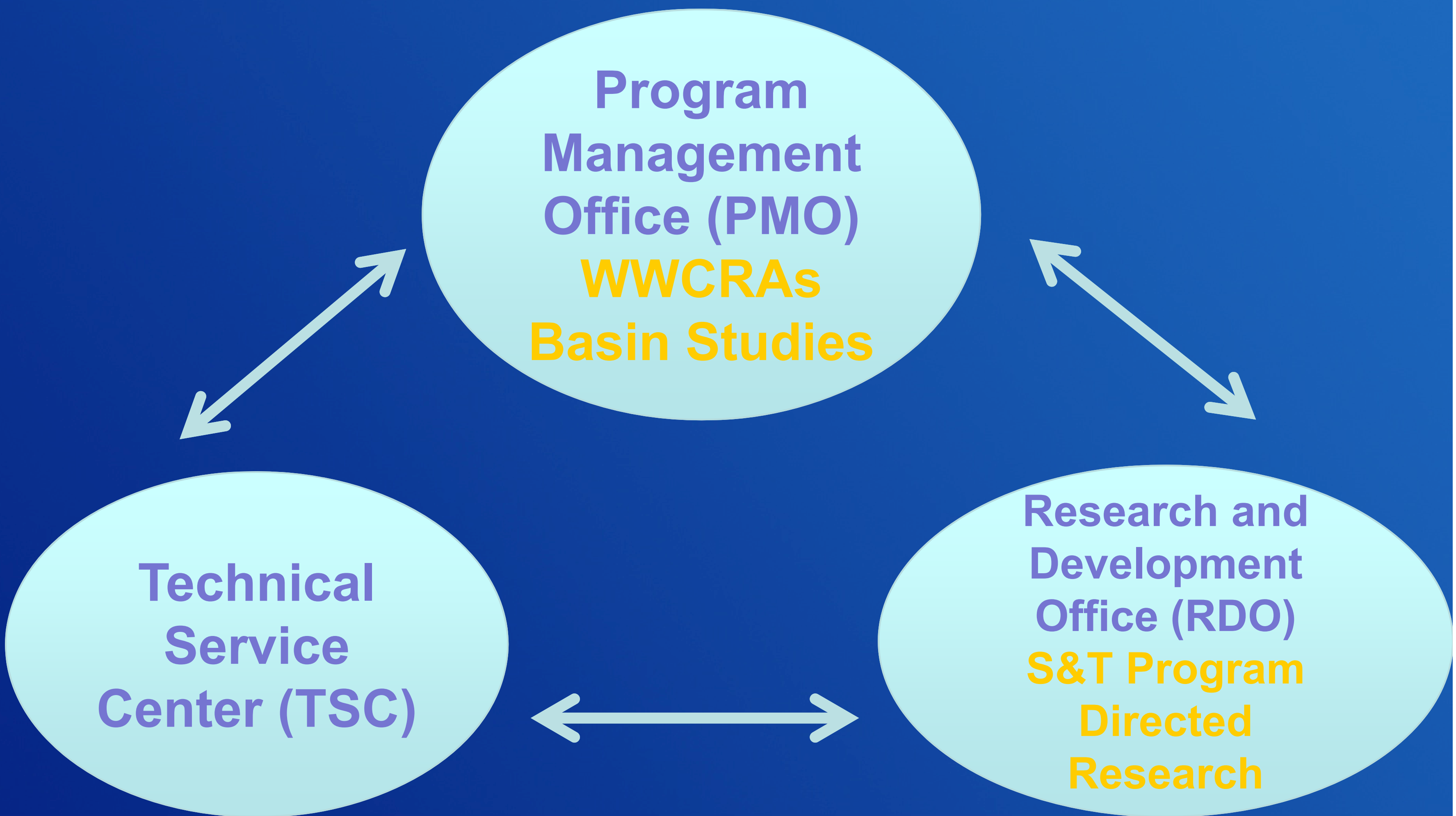
Institutional Layout



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Water Resources Planning and Operations Support Group and Economics Team

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- Jon Platt (Economics)
- Steve Piper (Economics)
- Rob Davis (Economics)
- Linux Cluster

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West-Wide Climate Risk Assessments (WWCRAs) - foundation for Basin Studies

Groundwater Hydrology in the context of Basin Studies – selected examples : Santa Ana Watershed (CA), and ongoing Basin Studies with a GW component

Groundwater Hydrology Research and Development Office efforts – Science and Technology (S&T) Program

WEST-WIDE CLIMATE RISK ASSESSMENTS

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SECURE Water Act, 2009

Coordination

Risks

Impacts

Adaptation / Mitigation

Feasibility

Monitoring

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SECURE Water Act, 2009

- Risks
  - Change in snowpack
  - Groundwater recharge and discharge
  - Increases in water demand or reservoir evaporation as result of increasing temperature
- Impacts
  - Ability to deliver water
  - Hydroelectric power generation
  - Recreation at Reclamation facilities
  - Fish and wildlife habitat
  - Endangered, threatened, candidate species
  - Water quality issues
  - Flow dependent ecological resiliency
  - Flood control management

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West Wide Climate Risk Assessments

Baseline Assessments of Risks and Impacts

- Transforming General Circulation Model information into a spatial and temporal scale relevant to a planning context
- Projections of Future Water Supply
- Projections of Future Water Demand
- Simulating future operations of Reclamation facilities
  - Hydropower, flood control, … etc.
- Determining Ecosystem Responses and Resiliency

* Consistent approach across 8 major Reclamation River Basins

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WWCRA Activities

CMIP3 & Updates

BCSD 2008 & Updates

With Stakeholders e.g. CO Basin Study

FY 2011 Rio Grande

FY 2010 - 2011

FY 2011 - 2012

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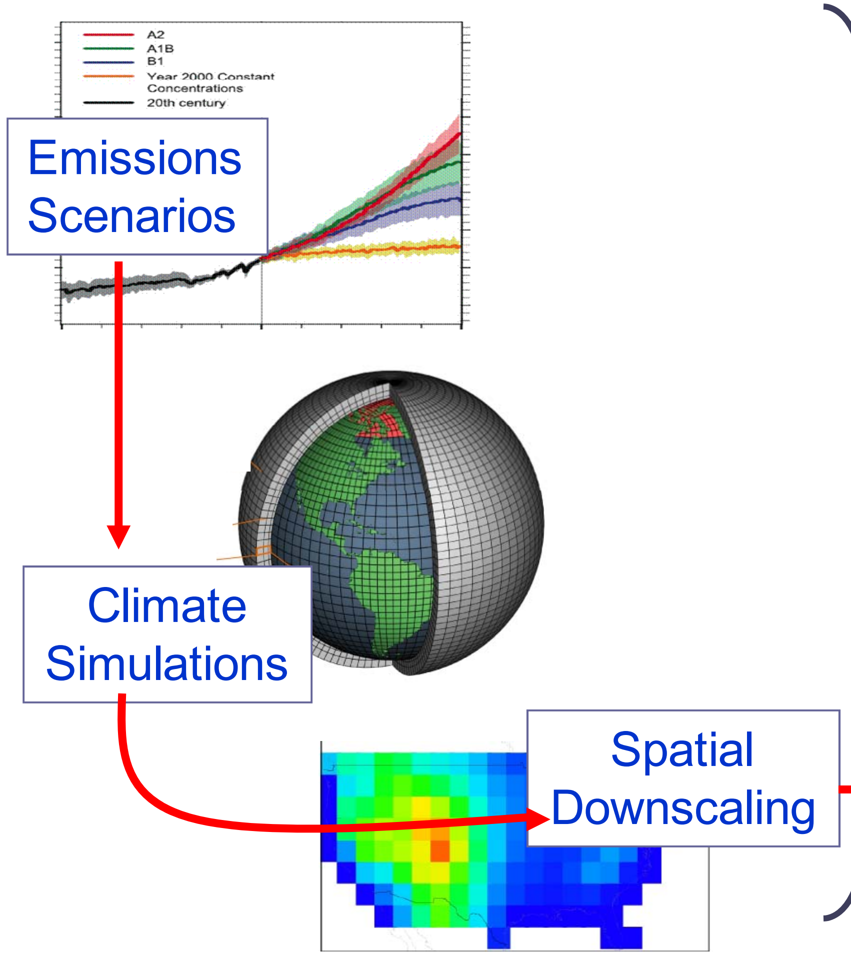
Downscaled GCM Output



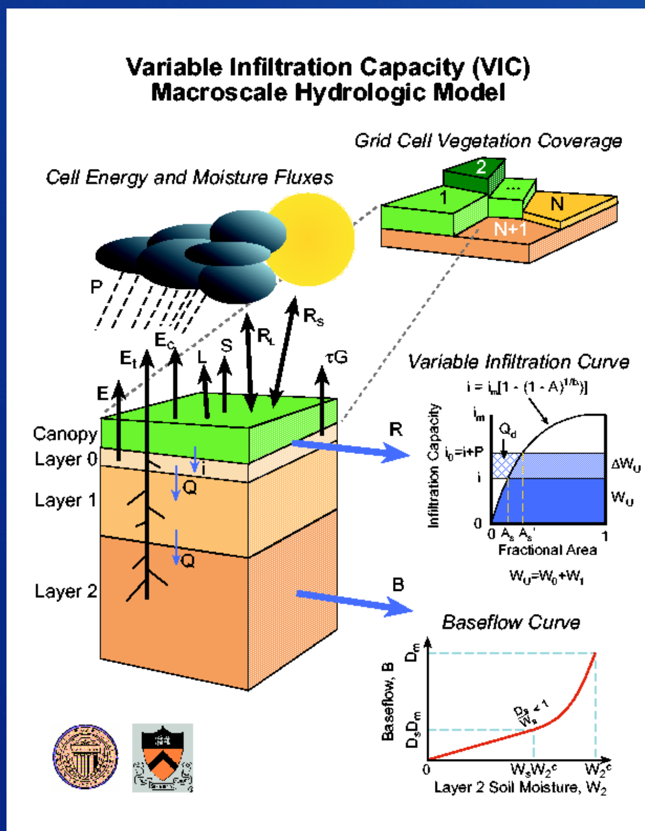
- **3 emissions scenarios**
  - **A1b, A2, B1**
- **Monthly P&T 1950-2099**
- **1/8° (12 km) gridded data**

Santa Clara Univ. (Maurer)
Reclamation
LLNL

Hydrologic Modeling – VIC Setup, 2 Steps

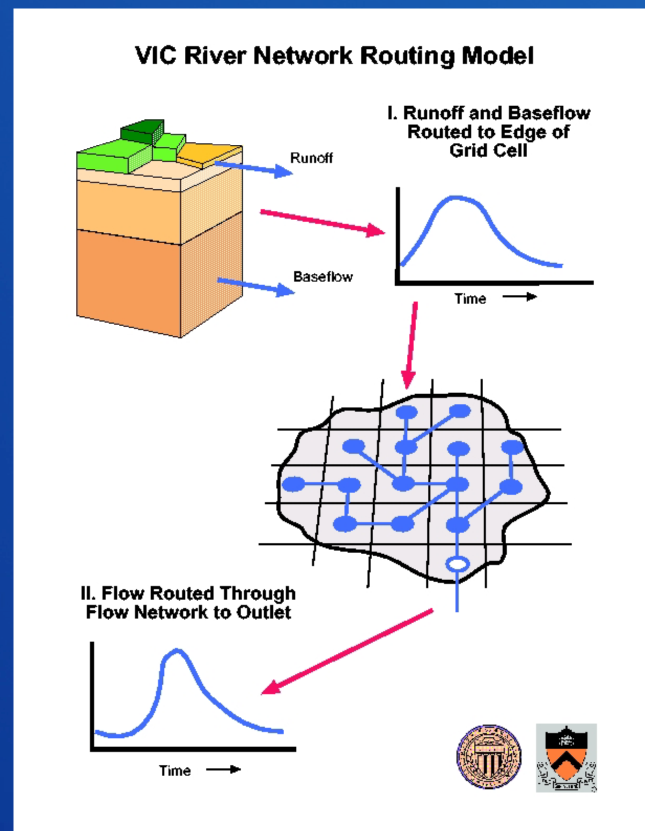
1.Land Surface Simulation

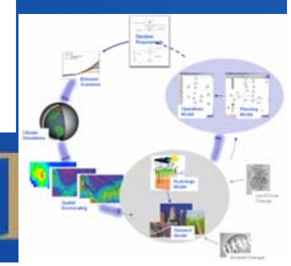
• simulate runoff (and other fluxes) at each grid cell



2. Streamflow Routing

• transport runoff from grid cell to outlet





What's being simulated

- 112 gridded climate projections → 112 gridded hydrology projections (runoff, swe, et, pet)
- Time Period: daily 1950-2099
- ~36,000 grid cells at 1/8th degree (~12 km) spatial resolution

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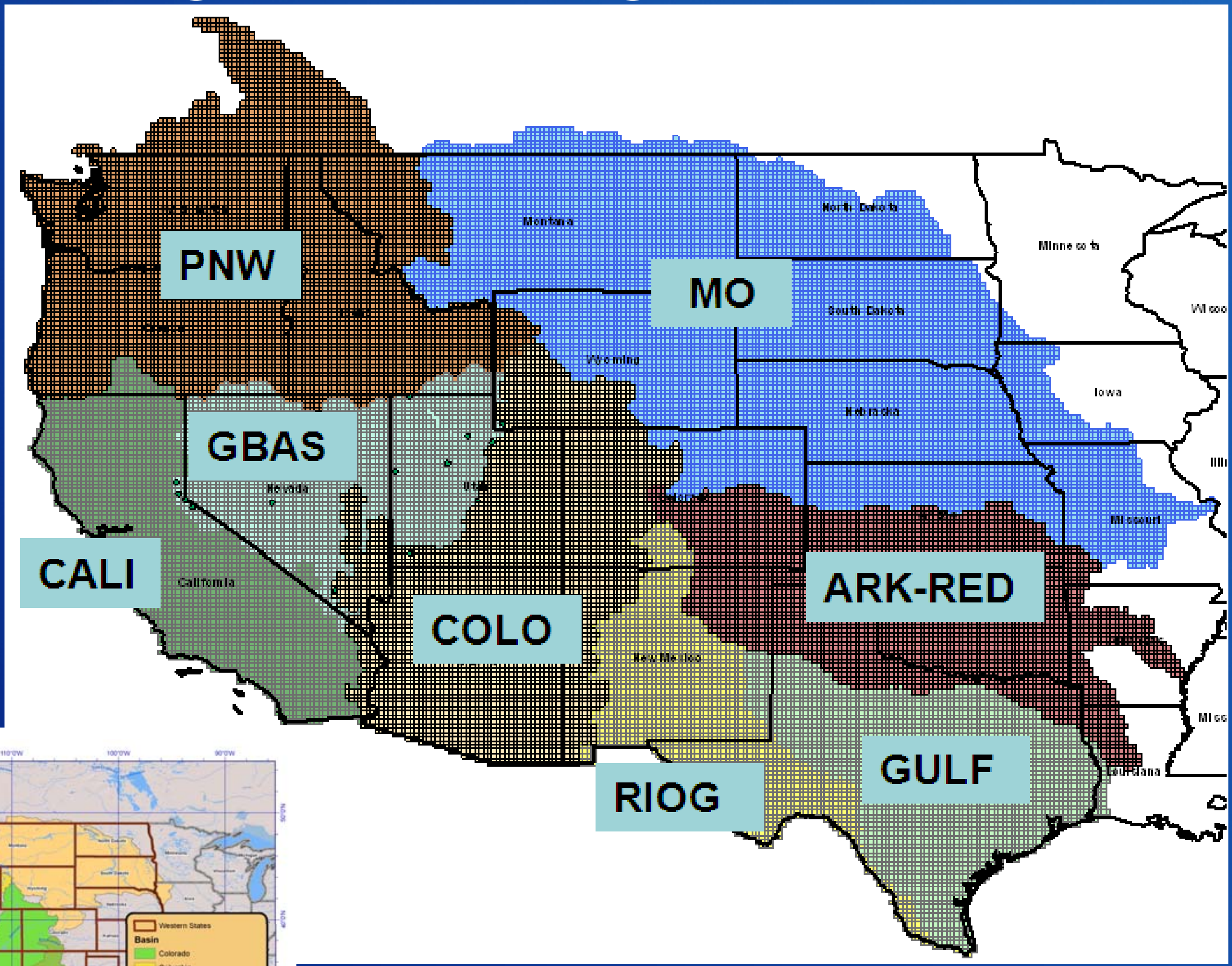
Hydrologic Modeling - VIC Applications



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Results - WWCRA

- **Precipitation and temperature trends**
- **Change in snowpack – SWE**
- **Timing of runoff**
- **For reporting**
  - **43 WWCRA locations spanning the major Reclamation basins**
  - **152 HCDN (Hydroclimate Data Network) sites spanning the western US**

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Results – West-Wide Summary

- Precipitation is expected to increase from the 1990s level during the 2020s and 2050s, but declines nominally during the 2070s.(though the early to middle 21st century increases could be artifacts of the BCSD climate projections development leading to slightly wetter projections).
- Temperature shows a persistent increasing trend from the 1990s level.
- April 1st SWE shows a persistent decreasing trend from the 1990s level.
- Annual runoff shows some increase for the 2020s decade from the 1990s level, but shows decline moving forward to the 2050s and 2070s decade from the 1990s reference, suggesting that although precipitation changes are projected to remain positive through the 2050s, temperature changes begin to offset these precipitation increases leading to net loss in the water balance through increased evapotranspiration losses.
- Winter season (December-March) runoff shows an increasing trend.
- Spring-summer season (April-July) runoff shows a decreasing trend.

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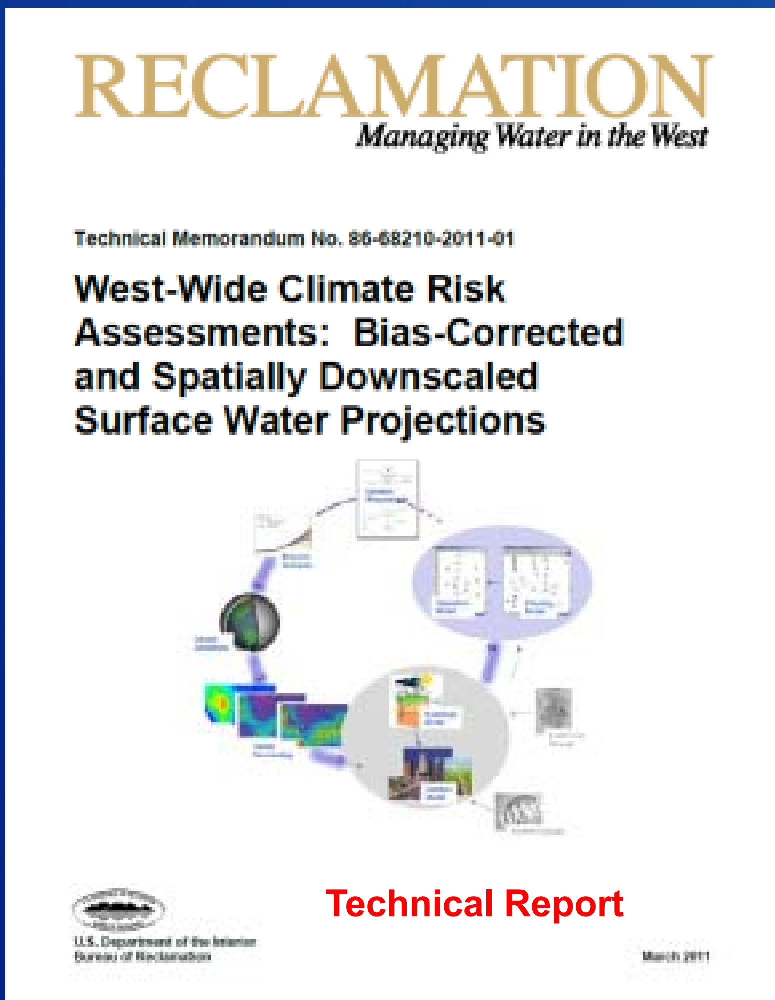
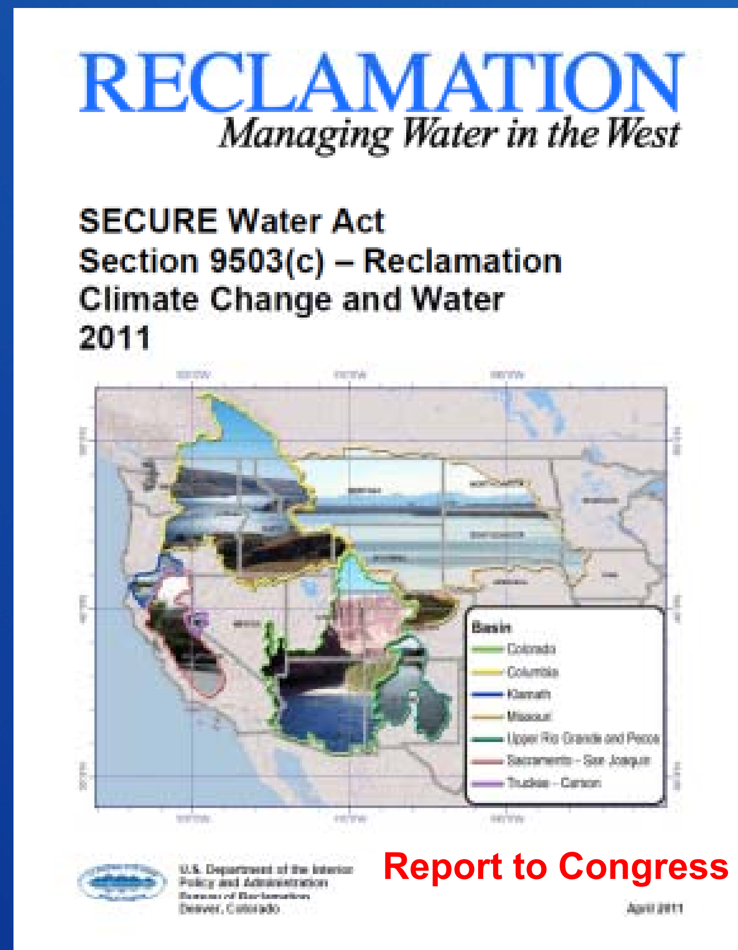
Reporting

http://www.usbr.gov/climate





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Online Data Access

Bias Corrected and Downscale ×

gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

RECLAMATION USGS CLIMATE CENTRAL Santa Clara University SCRIPPS INSTITUTION OF OCEANOGRAPHY

Bias Corrected and Downscaled WCRP CMIP3 Climate and Hydrology Projections

This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.

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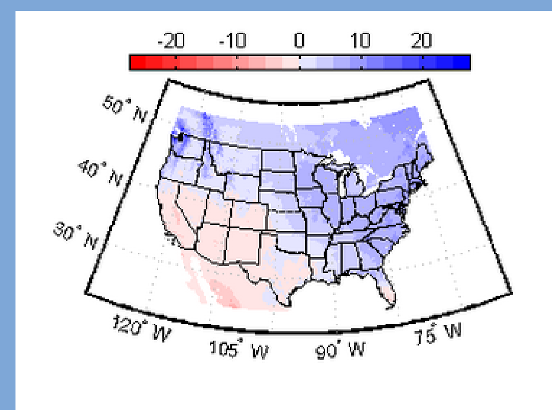
Summary

This archive contains fine spatial-resolution translations of:

- climate projections over the contiguous United States (U.S.) developed using two downscaling techniques (monthly BCSD Figure 1, and daily BCCA Figure 2), and
- hydrologic projections over the western U.S. (roughly the western U.S. Figure 3) corresponding to the monthly BCSD climate projections.

Archive content is based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report. Please see the "About" page for information on projection development, including the methodology to perform climate model bias-correction and spatial downscaling.

Figure 1: BCSD CMIP3 Monthly Climate Analysis example - Median projected change in average-annual precipitation (cm/year), 2041-70 versus 1971-2000.



Purpose

The archive is meant to provide access to climate and hydrologic projections at spatial and temporal scales more relevant to some of the watershed and basin-scale decisions facing water managers and planners dealing with climate change. Such access permits several types of analyses, including:

- assessment of local to regional climate projection uncertainty.
- assessment of potential climate change impacts on natural and social systems (e.g., watershed hydrology, ecosystems, water and energy demands).
- risk-based exploration of planning and policy responses framed by potential climate changes exemplified by these

Figure 2. BCCA CMIP3 Daily Climate Analysis example -

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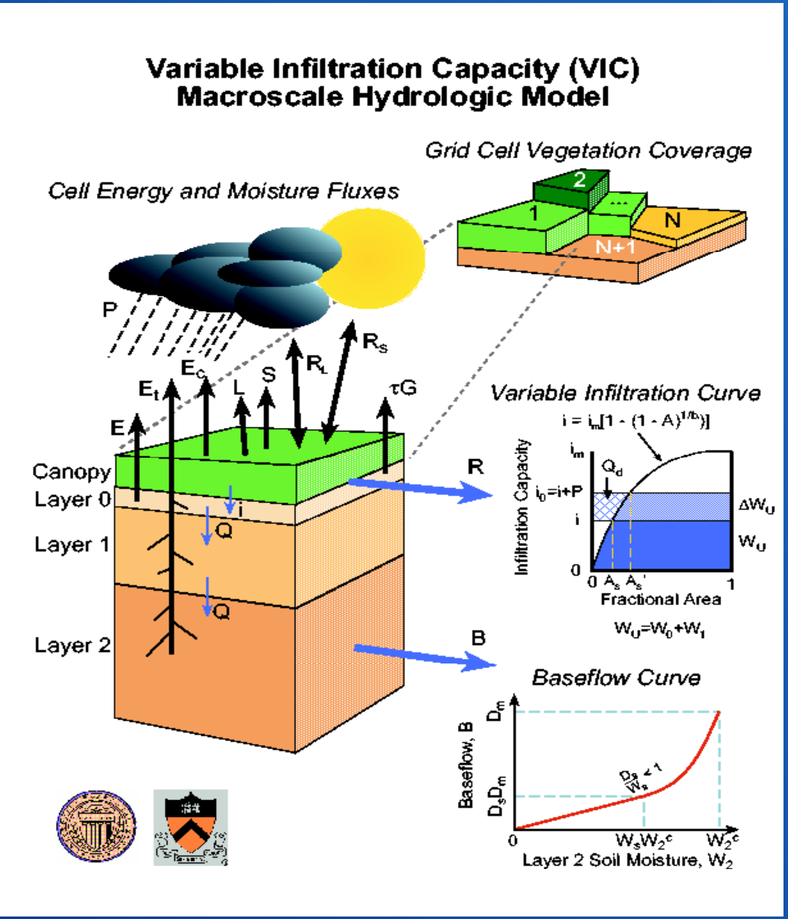
Step 1 – Land Surface Simulation

- For each grid cell VIC simulates daily fluxes:
  - surface runoff
  - baseflow
  - evapotranspiration
  - etc.



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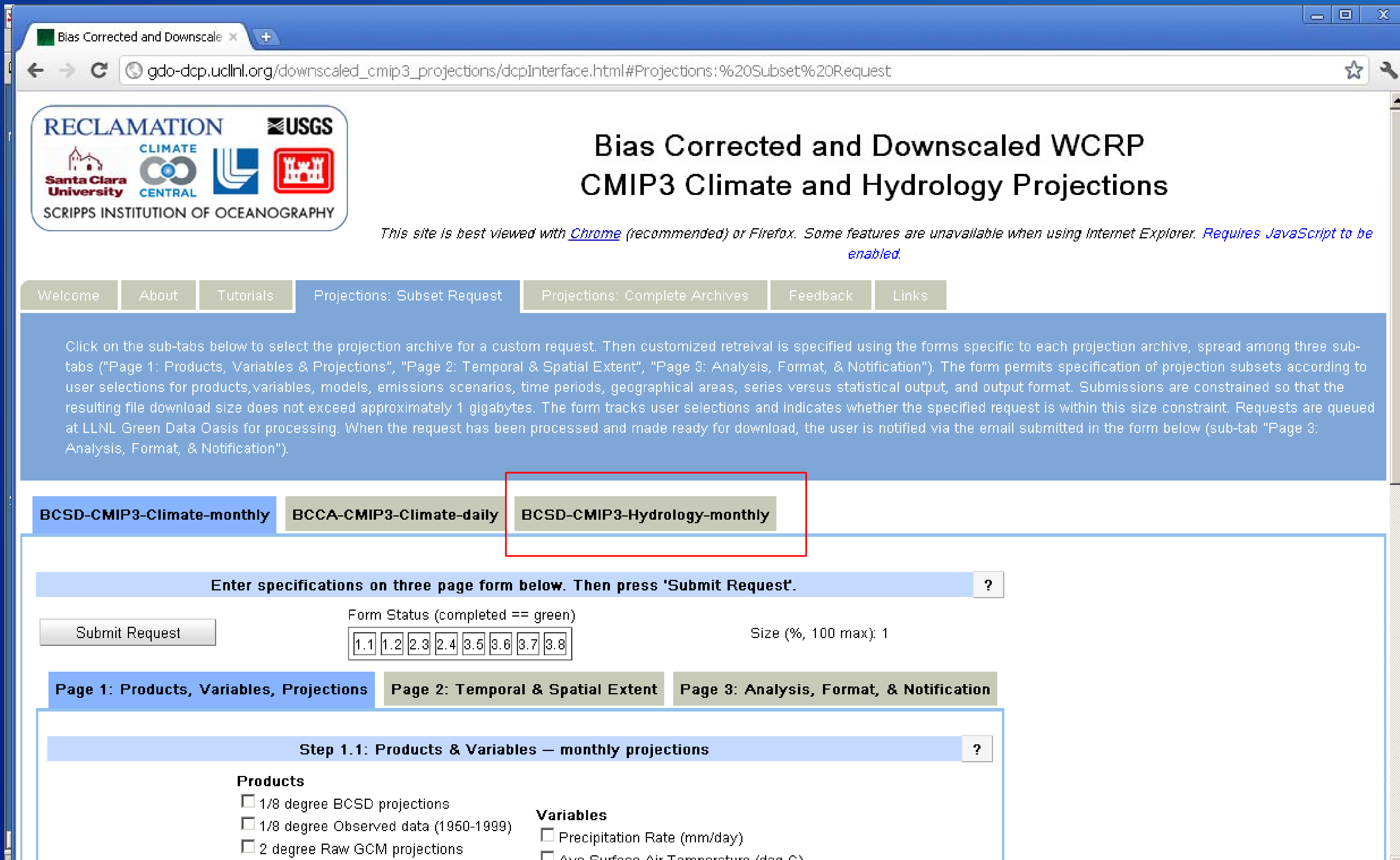
Online Data Access



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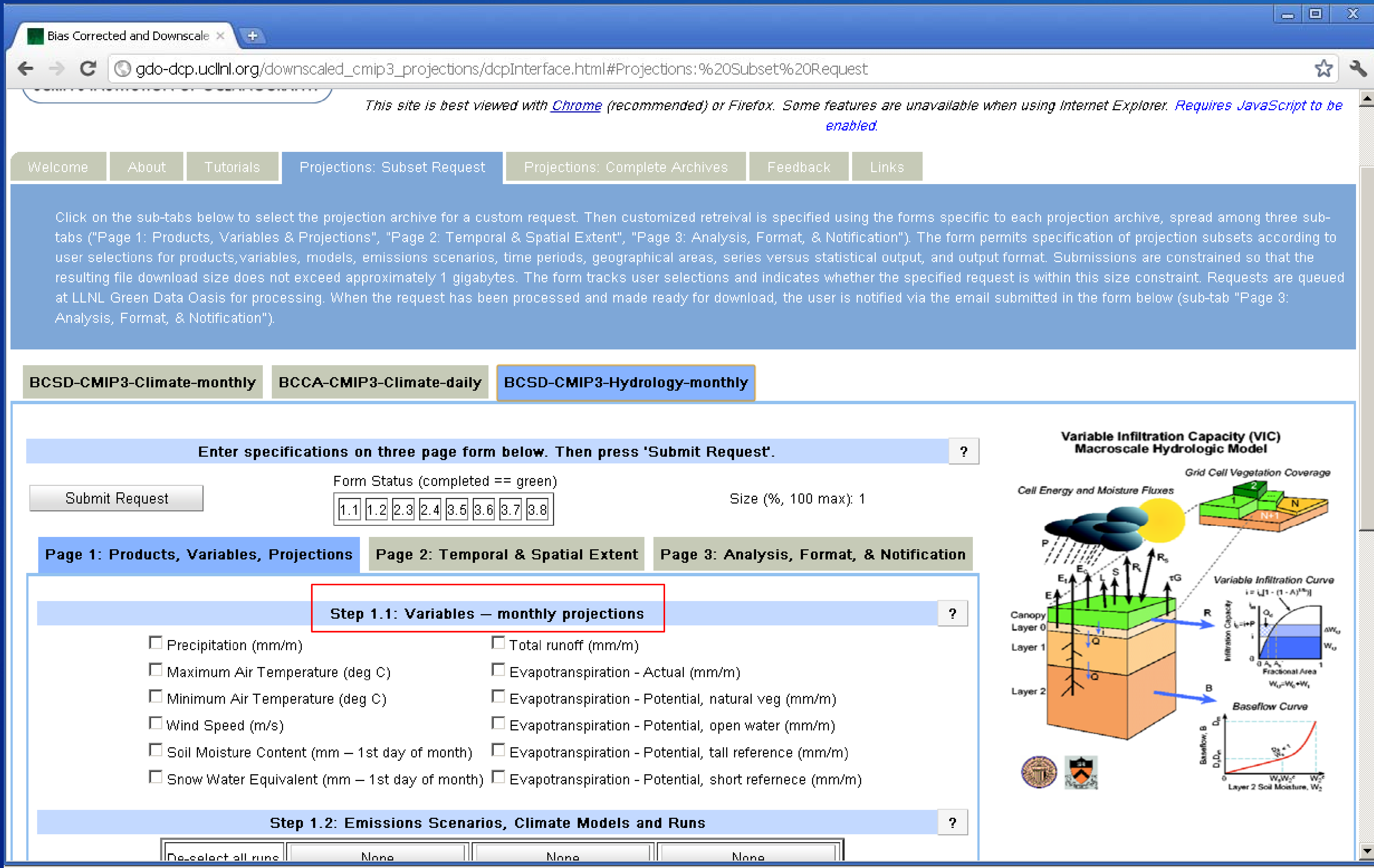
Online Data Access



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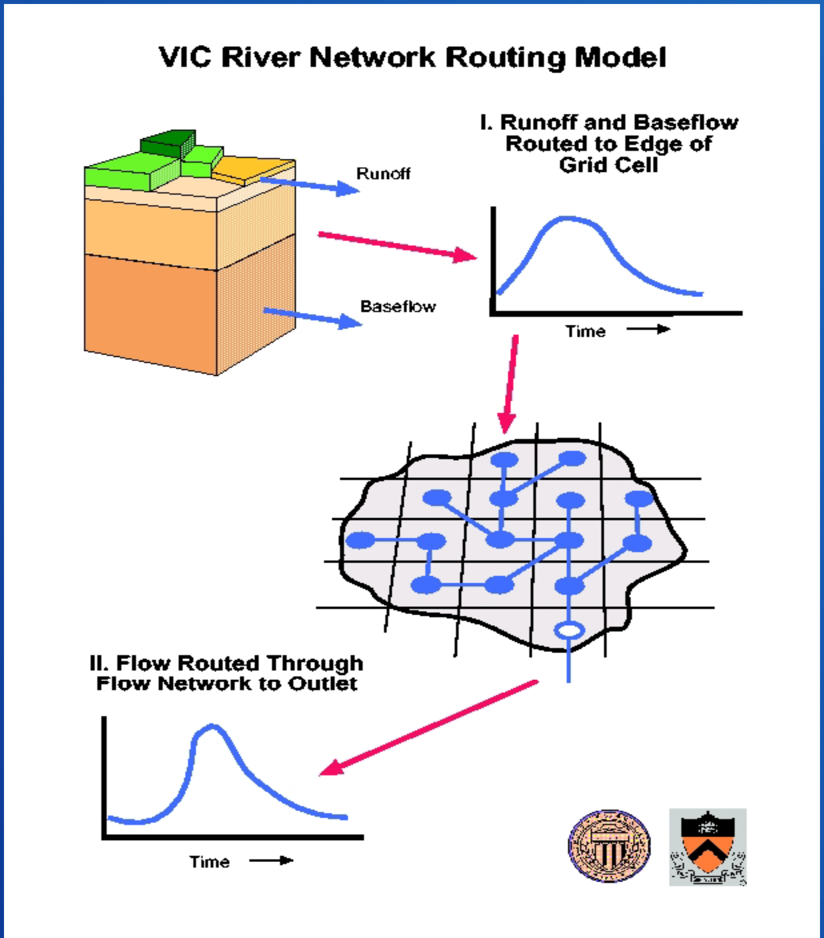
Step 2- Streamflow Routing

- Transport runoff (surface runoff and baseflow) - move water from the grid cells through the flow network to the outlet or routing locations of interest



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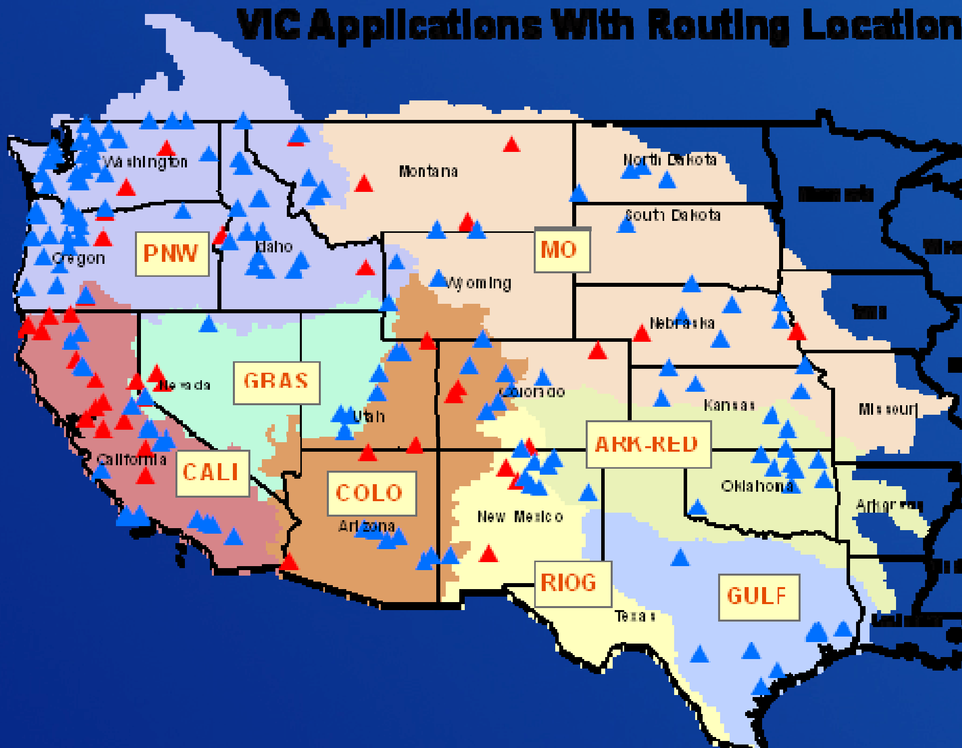
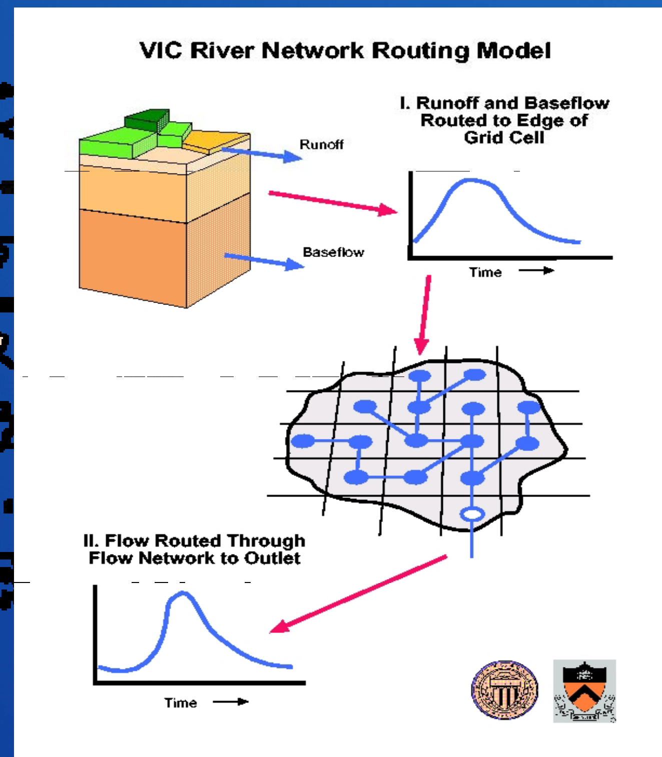
VIC Applications With Routing Locations





Red triangles – WWCRA Locations (total 43)

Blue triangles – HCDN locations (total 152)

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Online Data Access

Daily and Monthly Streamflow Projections

Jan 1, 1950 – Dec 31, 2099

195 locations West-Wide

http://gis.usbr.gov/streamflow_projections/

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Data Dissemination

- Gridded hydroclimate co-hosted with the current CMIP-3 archive at LLNL

  http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections

- Time-series of streamflow projections, Reclamation GIS/WaterSMART website

  http://gis.usbr.gov/streamflow_projections/

- American Geophysical Union (AGU) Eos Article describing the online gridded hydroclimate archive (… more than 61,000 Earth and space scientists worldwide …)

  Gangopadhyay, S., T. Pruitt, L. Brekke, and D. Raff (2011), Hydrologic projections for the western United States, Eos Trans. AGU, 92(48), 441, doi:10.1029/2011EO480001.

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West-Wide Climate Risk Assessments (WWCRAs) - foundation for Basin Studies

Groundwater Hydrology in the context of Basin Studies – selected examples : Santa Ana Watershed (CA), and ongoing Basin Studies with a GW component

Groundwater Hydrology Research and Development Office efforts – Science and Technology (S&T) Program

GROUNDWATER HYDROLOGY IN THE CONTEXT OF BASIN STUDIES – SELECTED EXAMPLES

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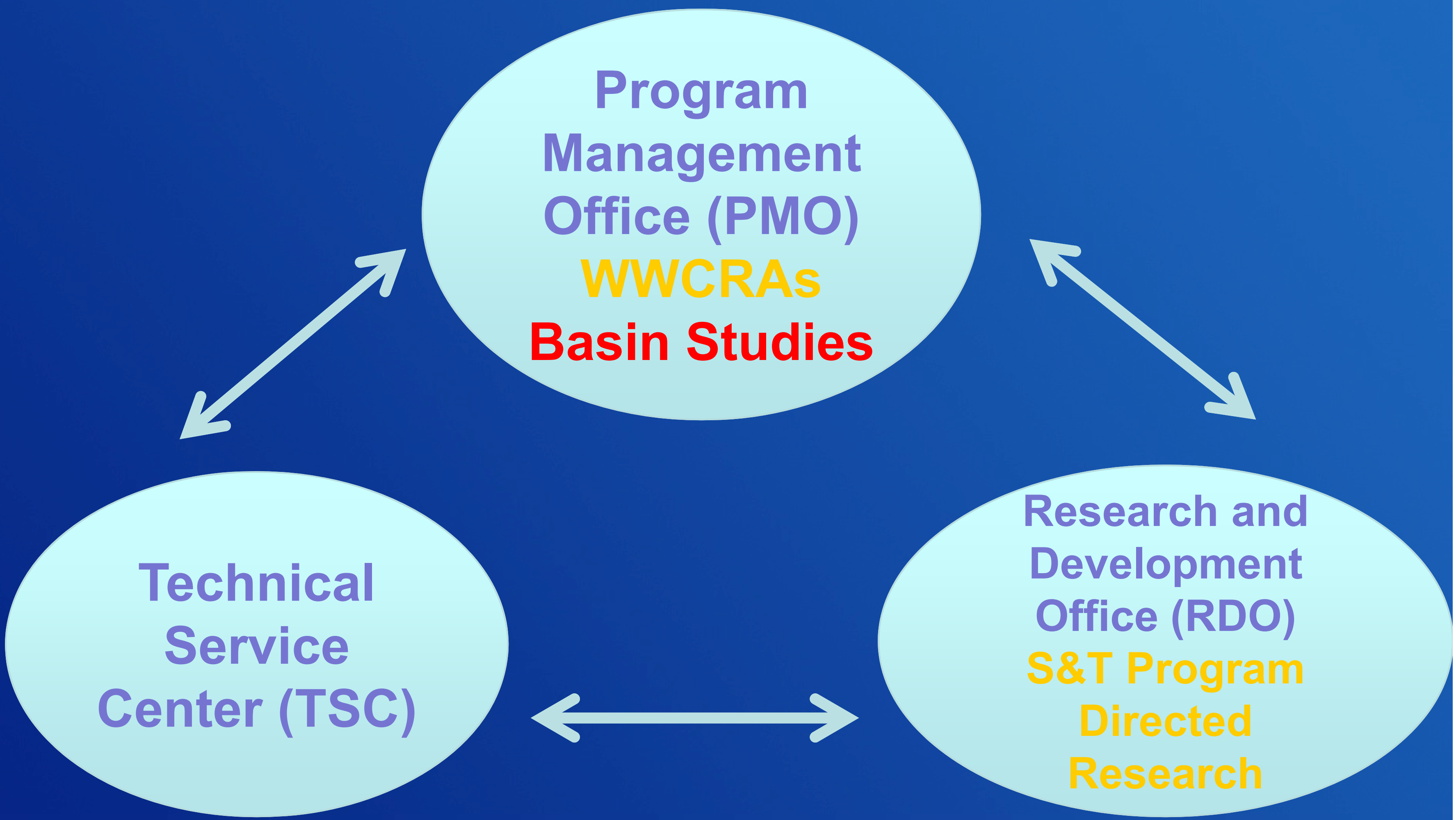
Institutional Layout



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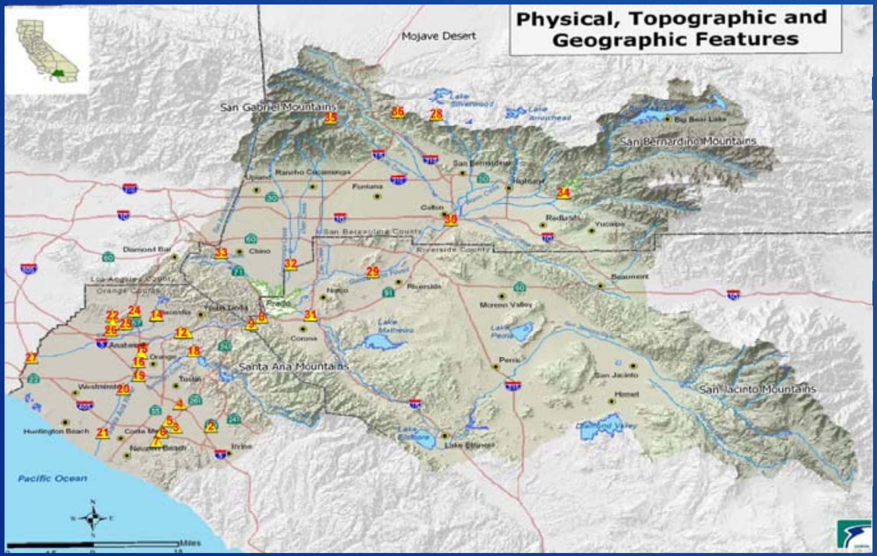
Basin Study Examples

- Water supply projections - surface water and ground water
- Santa Ana Watershed, Southern California



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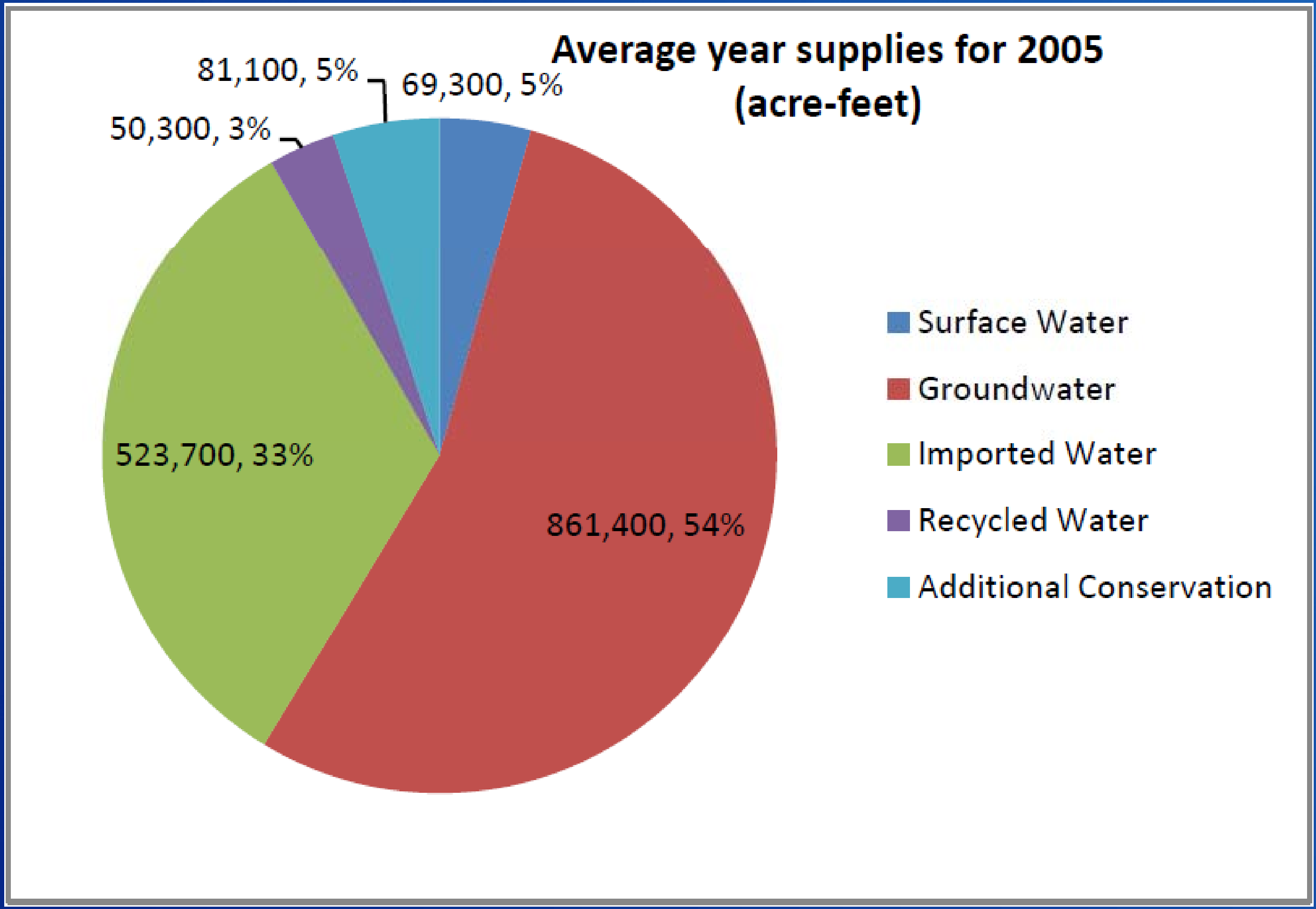
Introduction

Groundwater is the single largest water source within the Santa Ana Watershed



SAWPA 2010

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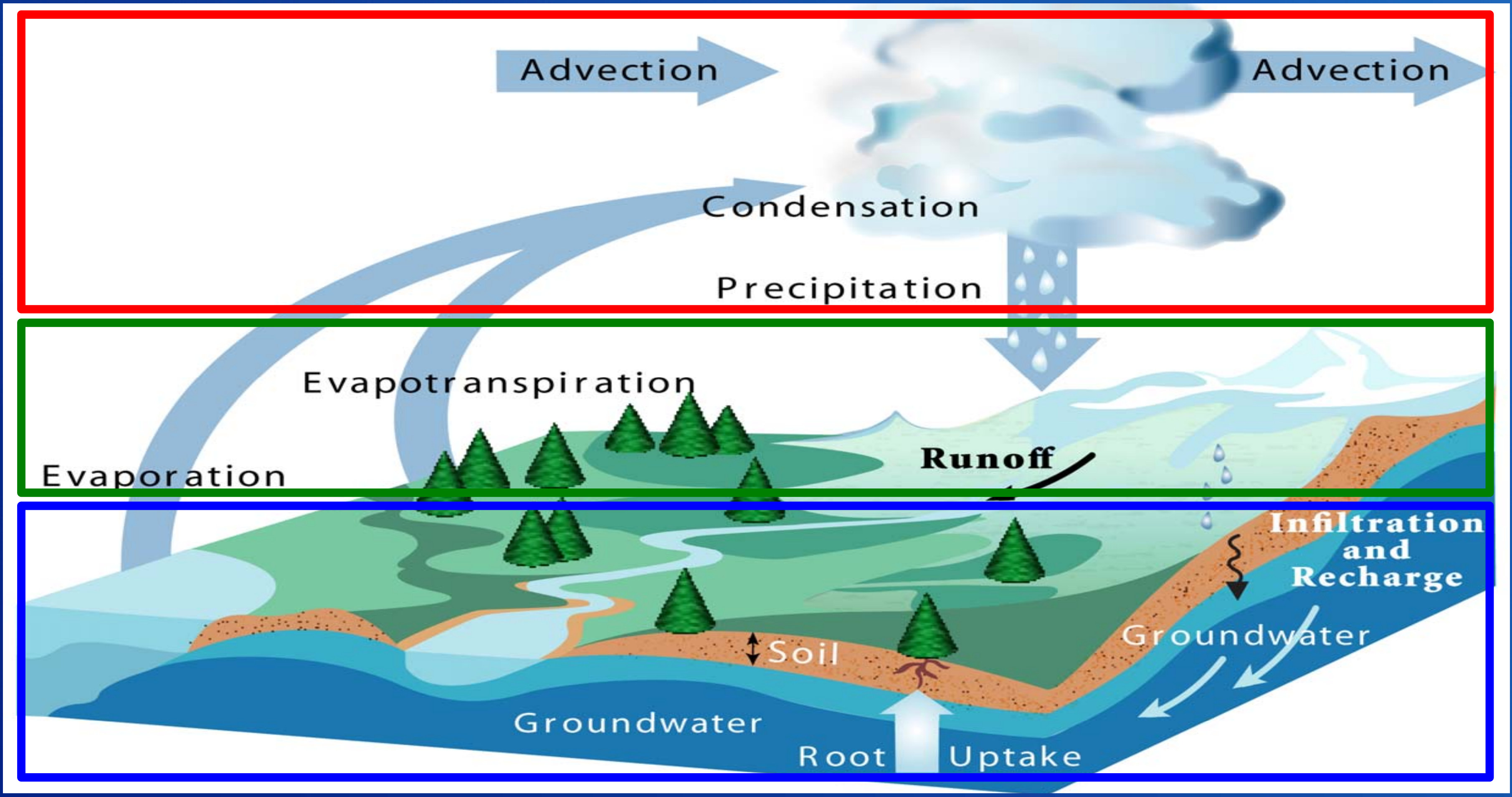
Introduction

Climate change will affect the hydrologic processes that govern water resources – including groundwater



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Introduction

The objective of this work is to

- Develop a simplified modeling framework for evaluating climate change impacts on groundwater levels
- Apply this framework to evaluate potential impacts of climate change, as well as mitigation/adaptation alternatives

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Outline

- Brief overview of “traditional” groundwater modeling
- Development of simplified modeling framework
- Model input data and pre-processing
- Preliminary results
- Ongoing work

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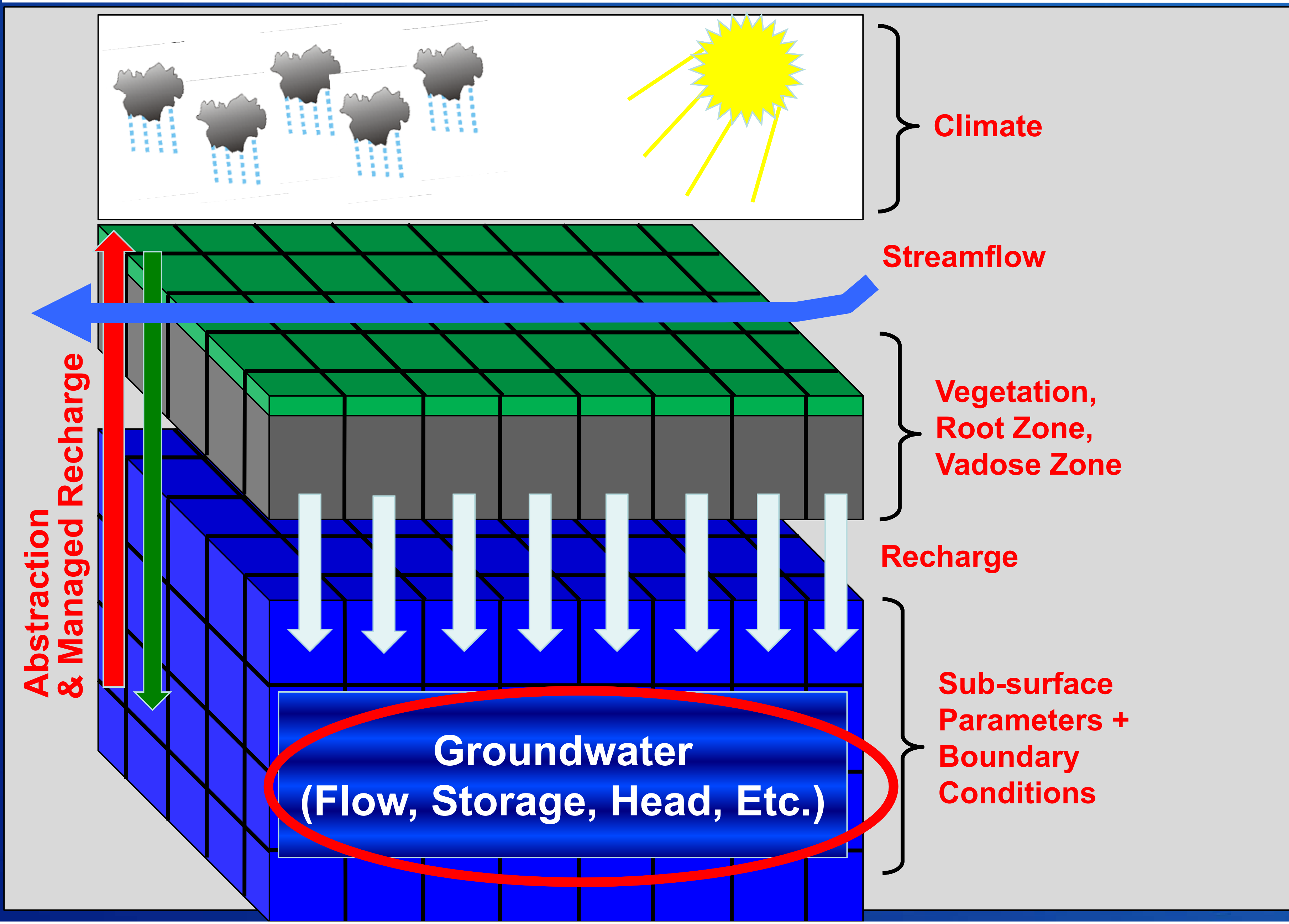
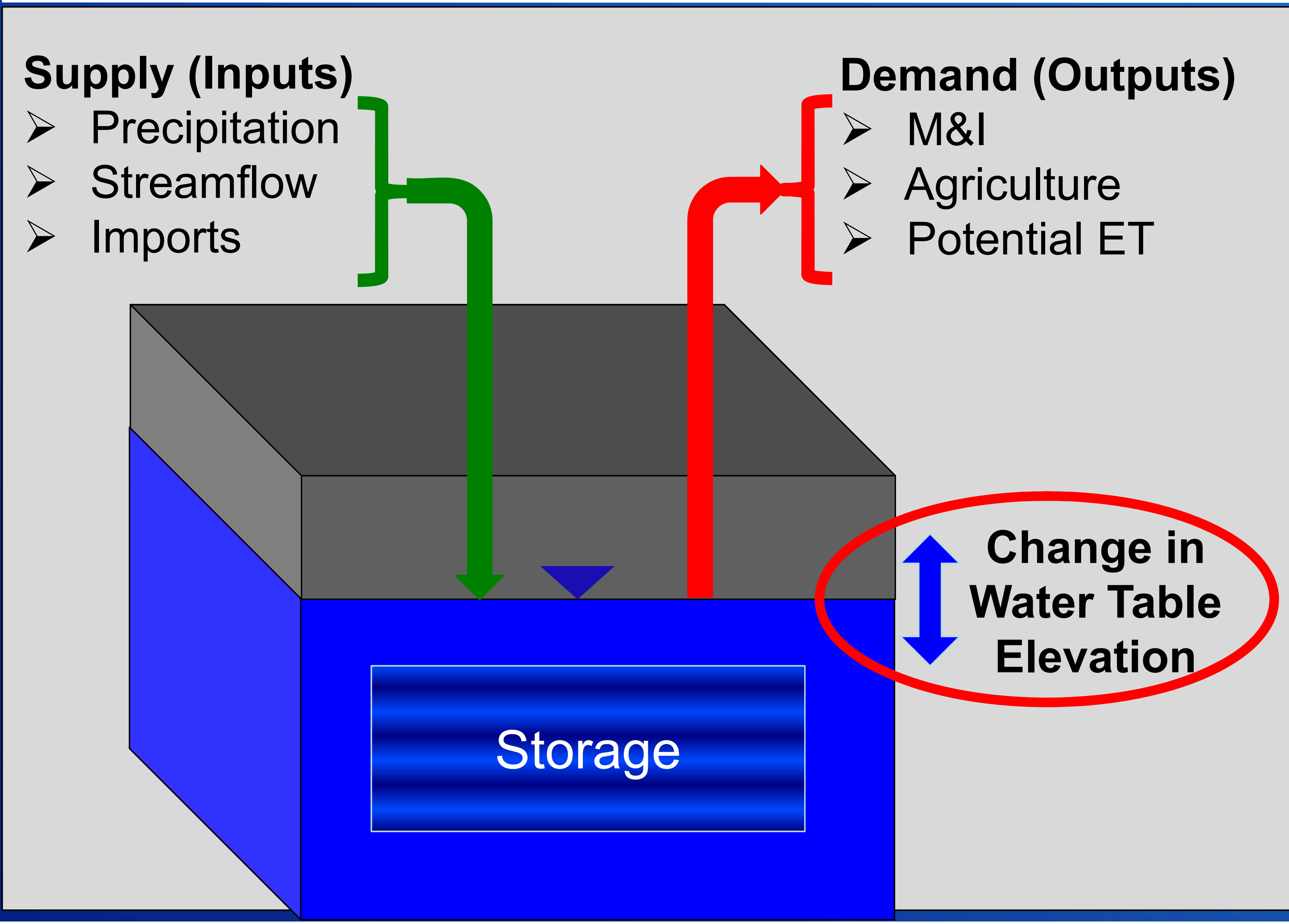
"Traditional" Groundwater Modeling



“Traditional” Groundwater Modeling

- **Advantages**
  - Explicitly considers all groundwater inflows and outflows – e.g., recharge, loss, abstraction, etc.
  - Spatially distributed (gridded) information – e.g., change in water table distribution
- **Disadvantages**
  - Data requirements – spatially distributed climate, vegetation, land cover/use, soils, geology, etc., etc.
  - Computational expense – pre-processing to compute recharge, model calibration, simulation of 2D/3D flow
  - Accumulation of uncertainties during each step

Simplified Modeling Framework



Simplified Modeling Framework

$$\Delta S = \text{Inputs} - \text{Outputs}$$

$$\left(\begin{array}{c}\text{Change in}\\ \text{Basin-Average}\\ \text{GW Elevation}\end{array}\right) = \left(\begin{array}{c}f\{\text{Precipitation}\}\\ +\\ f\{\text{Streamflow}\}\\ +\\ f\{\text{Imports}\}\end{array}\right) - \left(\begin{array}{c}f\{\text{Potential ET}\}\\ +\\ f\{\text{M\&I Demand}\}\\ +\\ f\{\text{Ag Demand}\}\end{array}\right)$$

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Simplified Modeling Framework

ΔS = Inputs - Outputs

ΔS ≈ Change in Basin-Average Groundwater Elevation

- Fluctuation in groundwater levels represents change in groundwater storage
- But…
  - Does not require specific information regarding soil properties (porosity, permeability, specific yield)
  - Does not require actual volume of groundwater gains (recharge) and losses (abstraction, baseflow, ET, etc.)

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Simplified Modeling Framework

ΔS = Inputs - Outputs

Inputs ≈ *f*{precipitation}
+ *f*{streamflow}
+ *f*{imports}

- Precipitation – contributes to recharge within basin; reduces GW abstraction for irrigation
- Streamflow – may contribute to recharge within basin; SW use reduces GW abstraction; SW may be used for recharge
- Imports – imports reduce GW abstraction; imports may be used for managed recharge

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Simplified Modeling Framework

ΔS = Inputs - Outputs

Outputs ≈ *f*{Potential ET}
+ *f*{M&I Demand}
+ *f*{Ag Demand}

- Potential ET – high evaporative demand increases water use by natural, landscaping, & agricultural; reduces recharge
- M&I Demand – high demand increases abstraction; decreases SW available for recharge
- Ag Demand – high demand increases abstraction; decreases SW available for recharge

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Simplified Modeling Framework

Representative Quantities

Inputs ≈ *f*{precipitation}
+ *f*{streamflow}
+ *f*{imports}

Outputs ≈ *f*{Potential ET}
+ *f*{M&I Demand}
+ *f*{Ag Demand}

$$f\{x_{ym}\} = C_x \cdot x'_{ym} = C_x \cdot \left(\frac{x_{ym} - \bar{x}_m}{\sigma_{x_m}} \right)$$

The use of <u>standardized representative values</u> – rather than actual volumes – for each term significantly reduces data collection and pre-processing requirements and provides a more flexible modeling framework

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Simplified Modeling Framework

Model Formulation:
Autoregressive + Multiple Linear Regression

$$h'_t = \rho_1 \cdot (h'_{t-1}) + C_1 \cdot (P') + C_2 \cdot (Q'_{local}) + C_3 \cdot (Q'_{import}) + C_4 \cdot (PET') + C_5 \cdot (D'_{AG}) + C_6 \cdot (D'_{MI}) + \varepsilon$$

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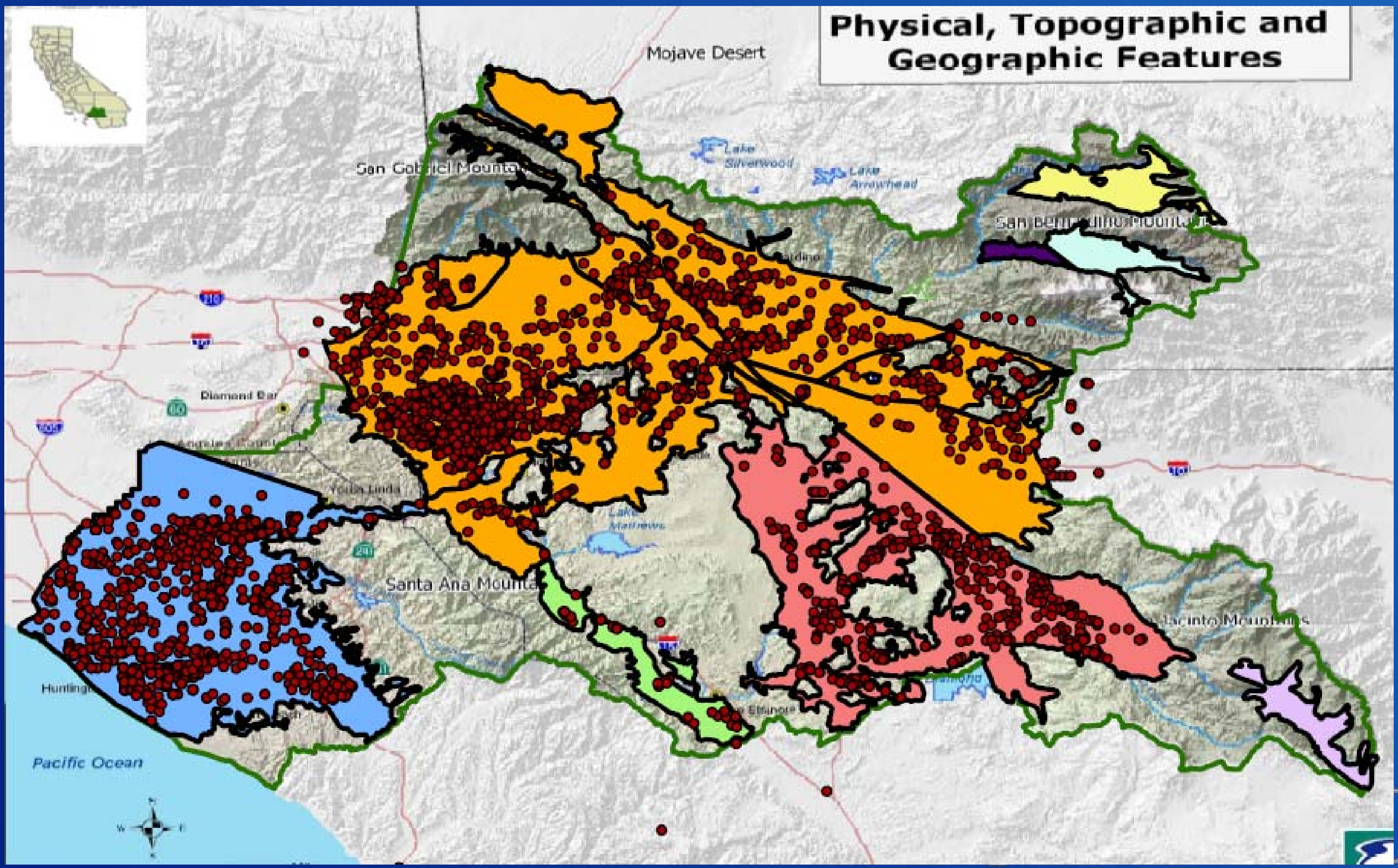
Data Collection & Pre-Processing

Groundwater Elevation

- Source: SAWPA groundwater database



Data Collection & Pre-Processing

Groundwater Elevation

- Eliminate records with greater than 50% missing (by month)
- Eliminate individual outlier points
- Compute monthly mean GW levels for all months in record
- Interpolate to fill missing data (no extrapolation)

495 well records over four groundwater basins

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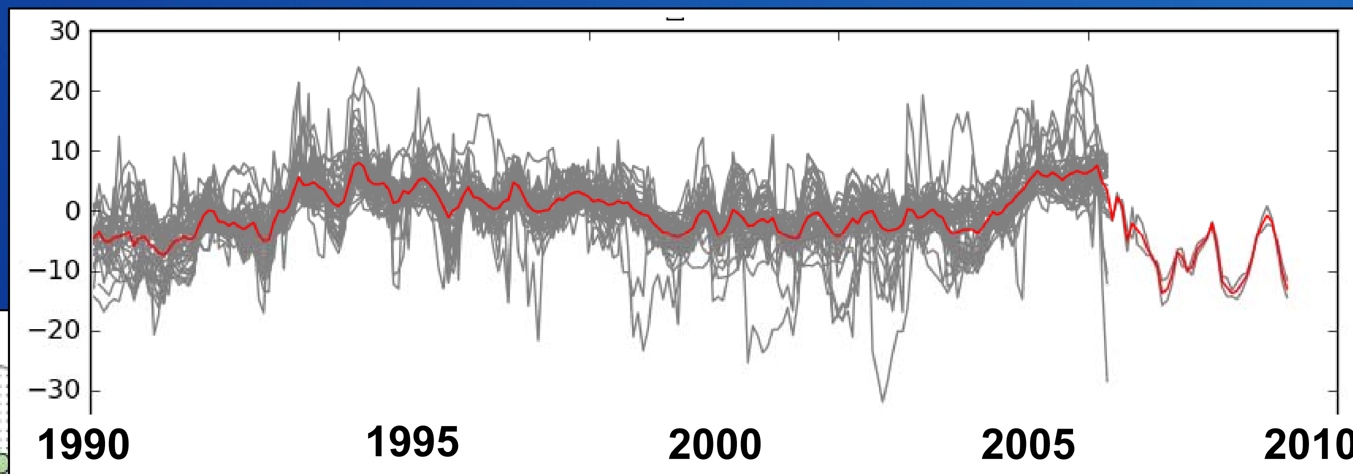
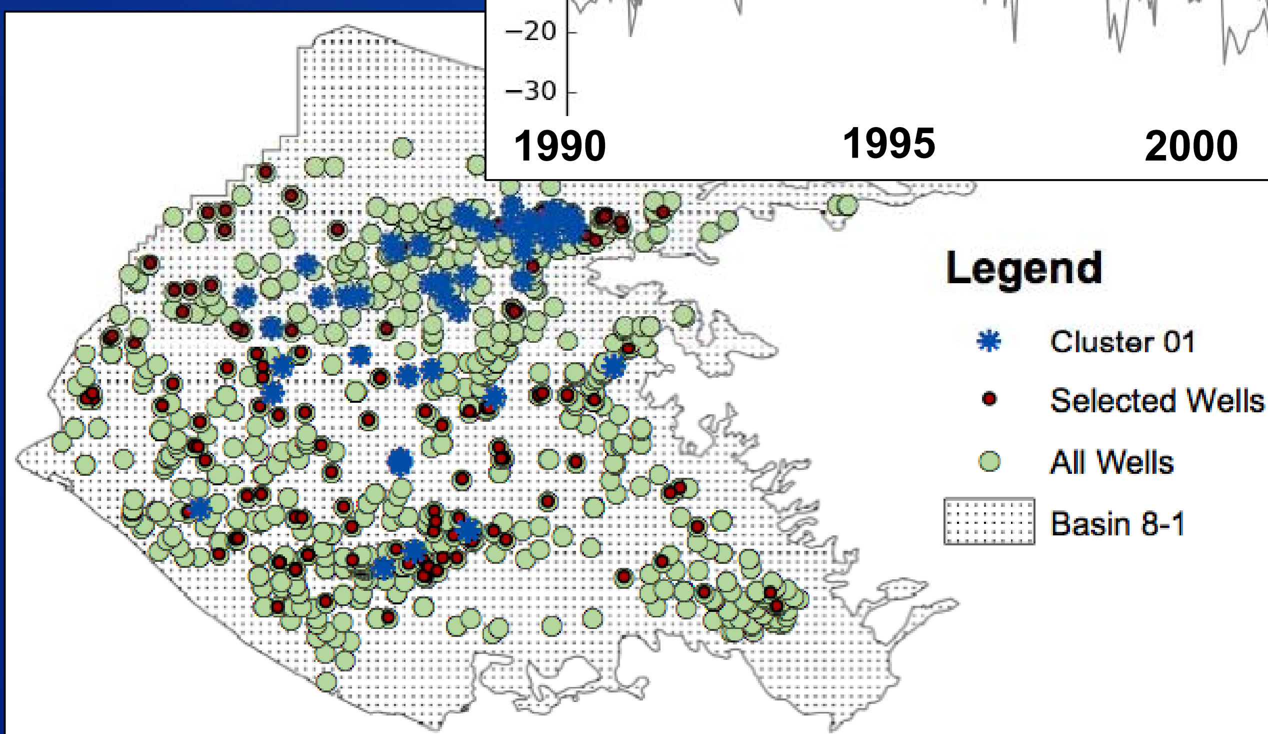
Data Collection & Pre-Processing

Groundwater Elevation

- Clustering routine to identify wells with similar behavior



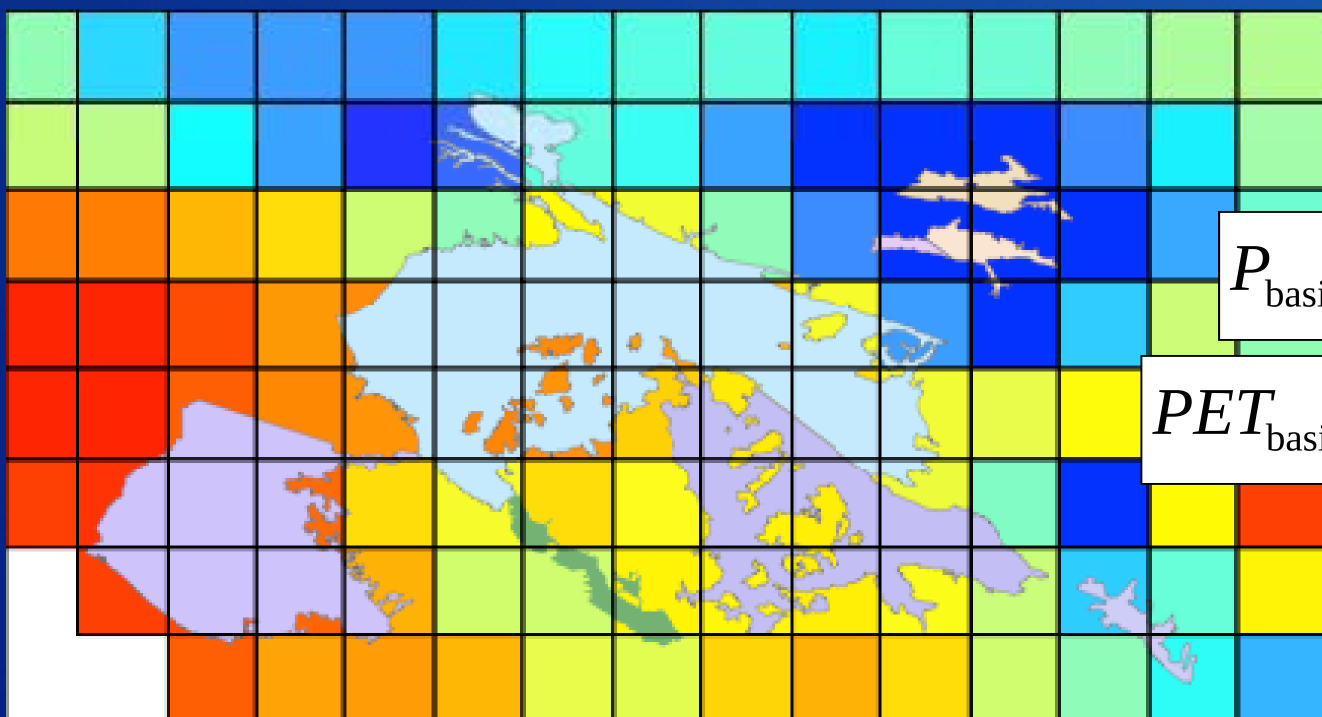


Data Collection & Pre-Processing

Basin-Average Precipitation & Potential ET

- Weighted average of gridded historical datasets over individual groundwater basins
- Source: Maurer et al. (2002) gridded climate dataset;

  Reclamation (2011) hydrologic simulations (PET)



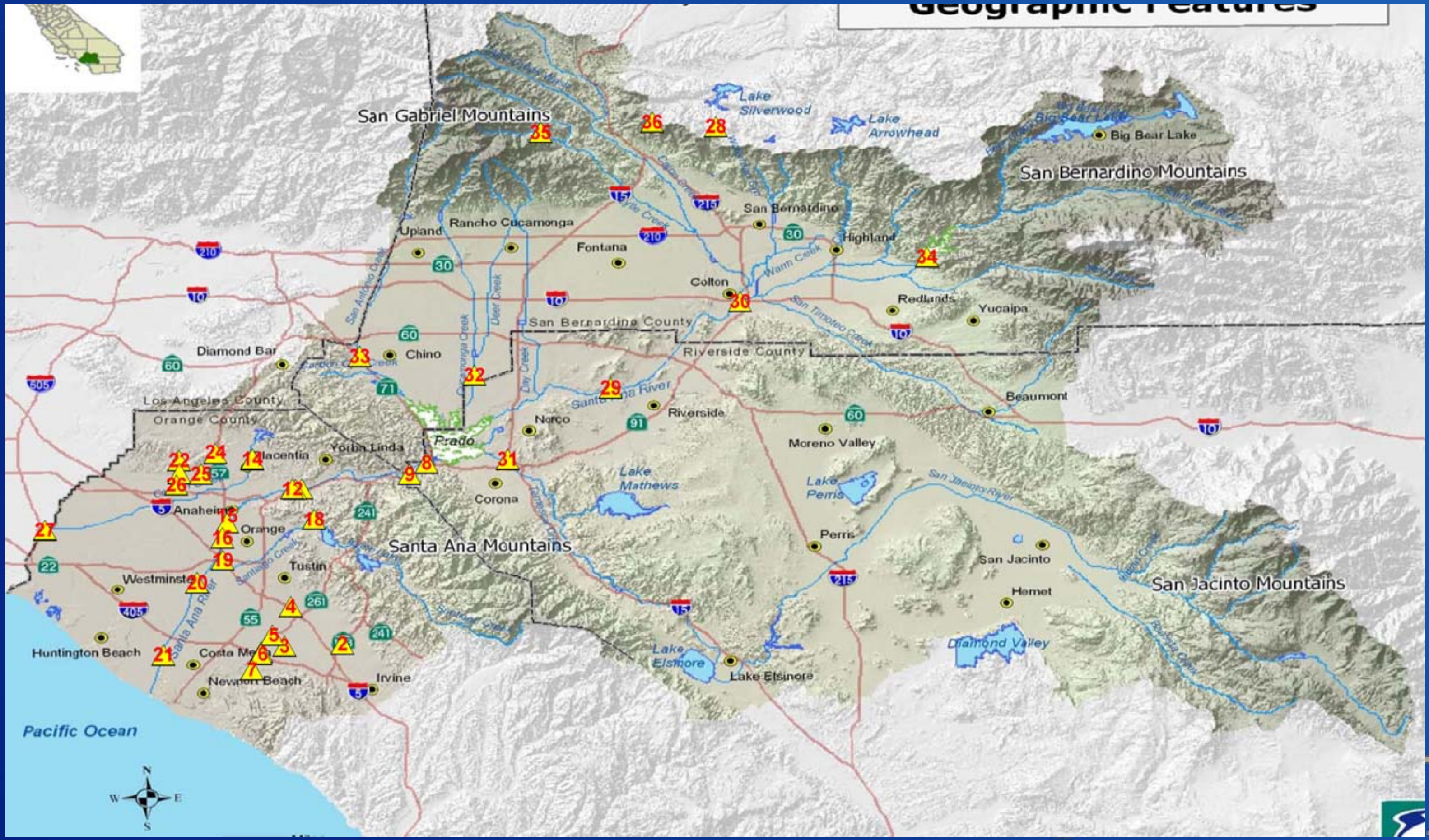
$$P_{\text{basin}} = \sum_i \sum_j P_{ij} \cdot f_{ij}$$

$$PET_{\text{basin}} = \sum_i \sum_j PET_{ij} \cdot f_{ij}$$

Data Collection & Pre-Processing

Streamflow

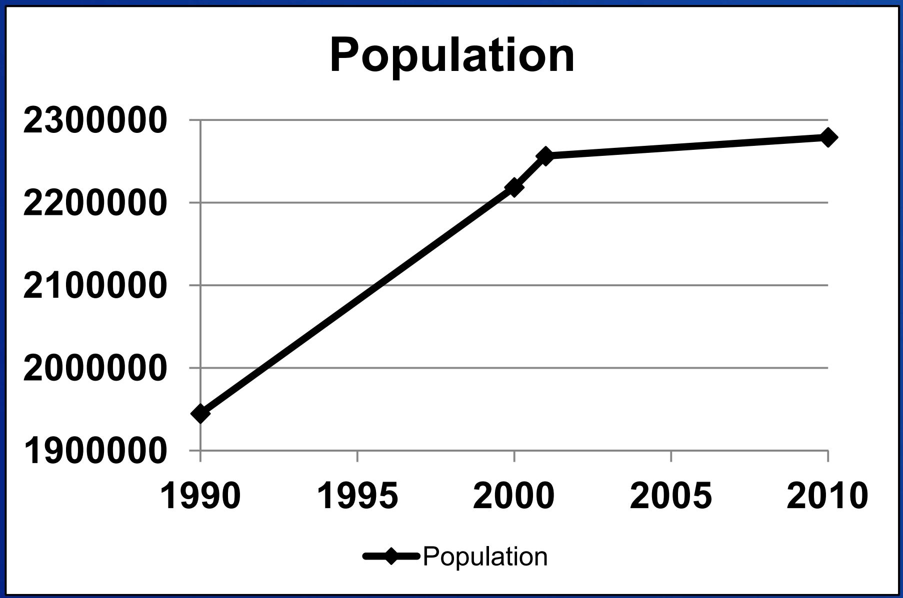
- Simulated natural streamflow at selected locations
- Source: Reclamation (2011) hydrologic simulations

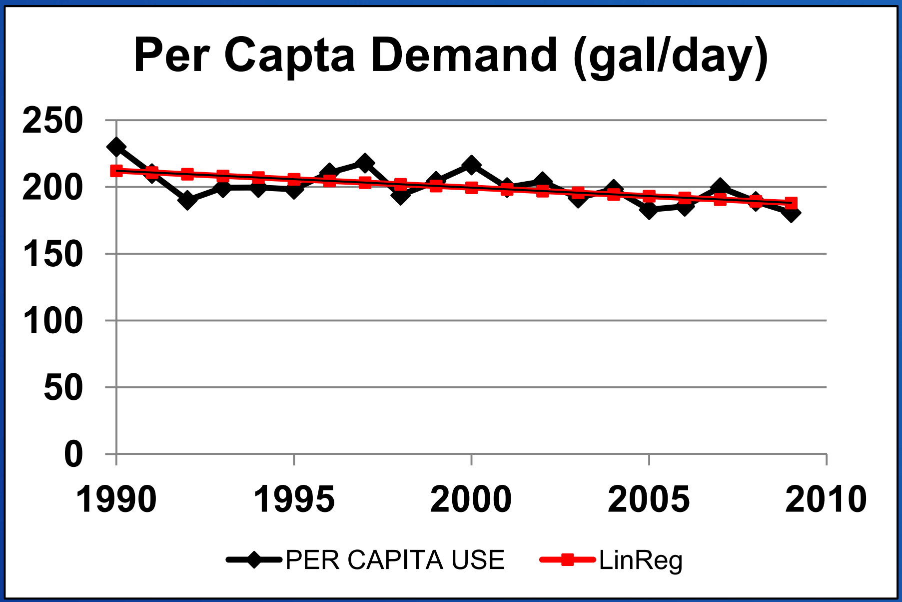


Data Collection & Pre-Processing

M&I Demand

- Population x Per Capita Demand
- Sources: population – Census tract data;
  per capita demand – 2000 & 2010 UWMPs





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Data Collection & Pre-Processing

M&I Demand

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- Sources: population – Census tract data;
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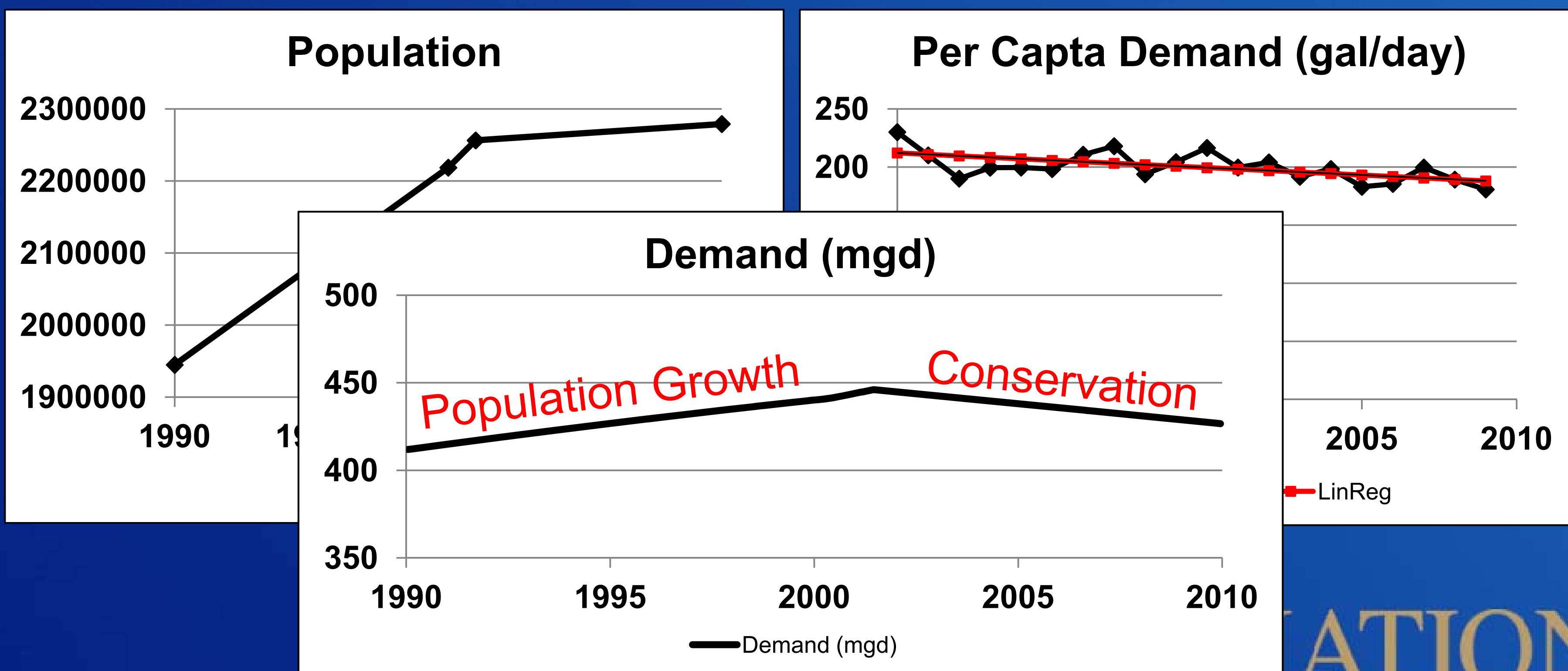
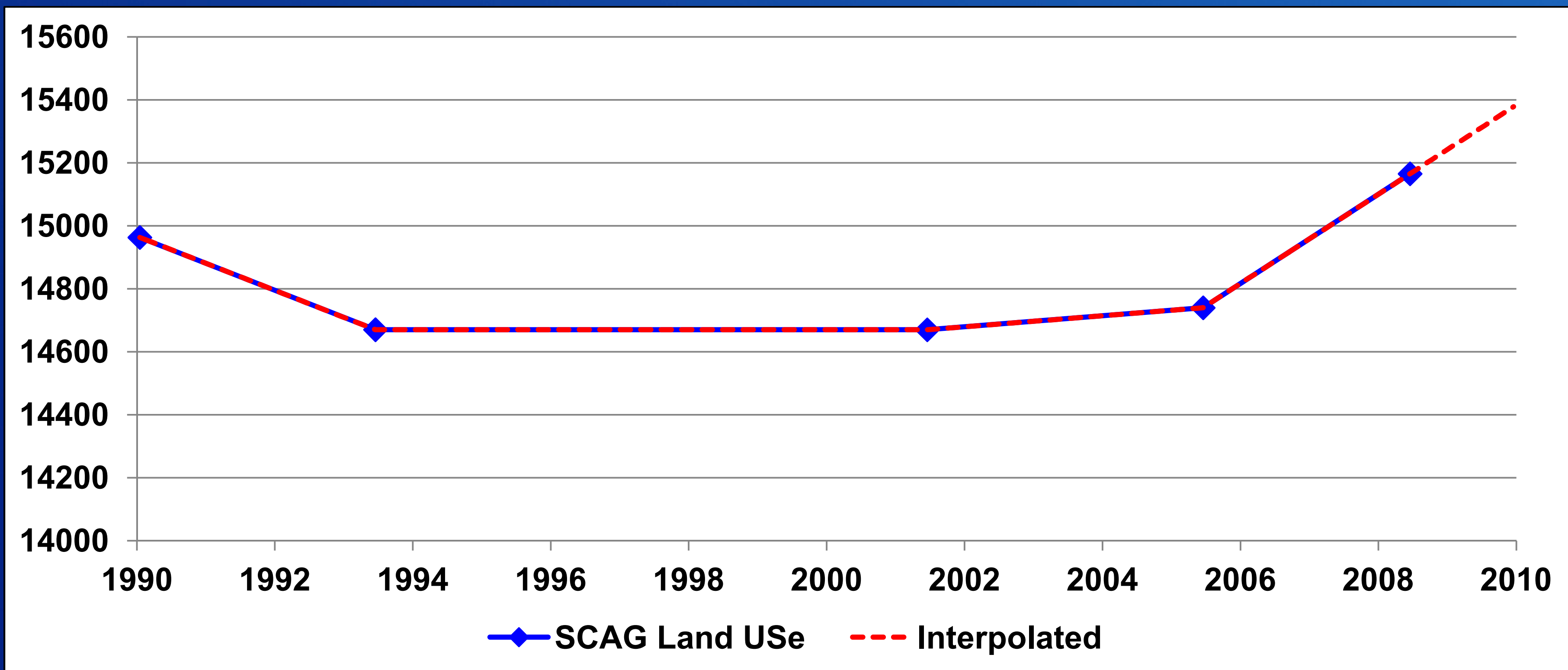


Data Collection & Pre-Processing

Agricultural Demand

- Irrigated acreage as surrogate for irrigation water demand
- Source: SCAG land use database



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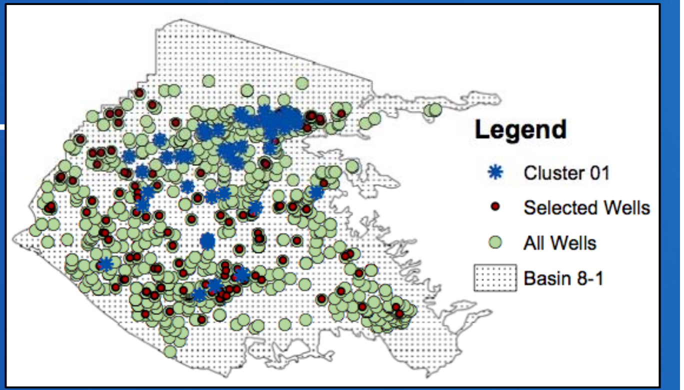
Data Collection & Pre-Processing

Augmented Supplies – Imports & Reuse

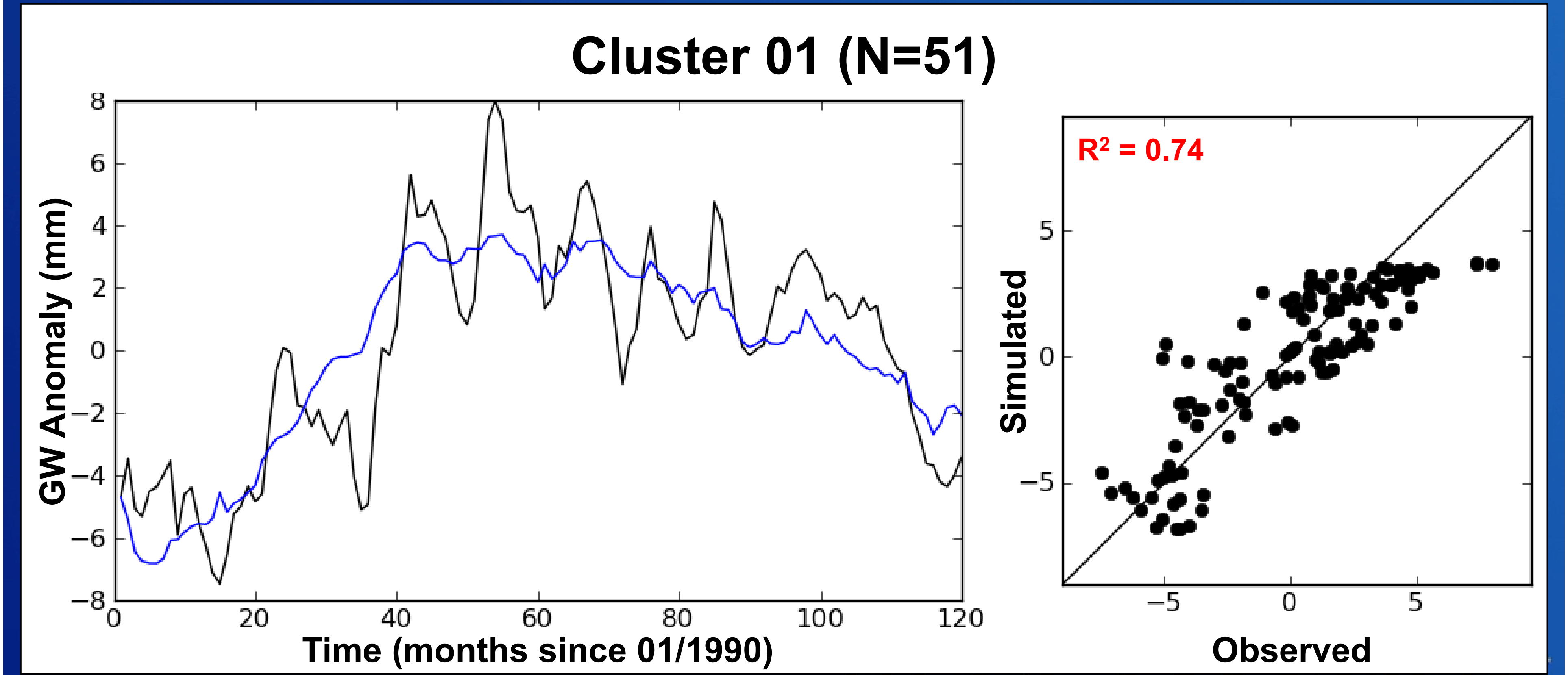
- Incomplete…Ongoing …
- Source: 2000 & 2010 UWMPs (insufficient data)

Preliminary Results



8-1: Coastal Plain of Orange County

- 199 wells
- 20 independent well clusters (1-51 wells/cluster)



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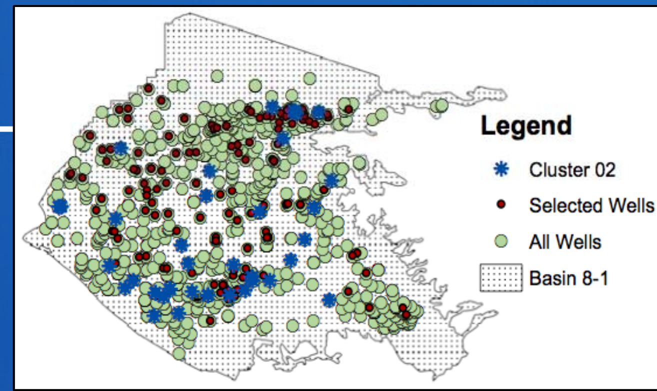
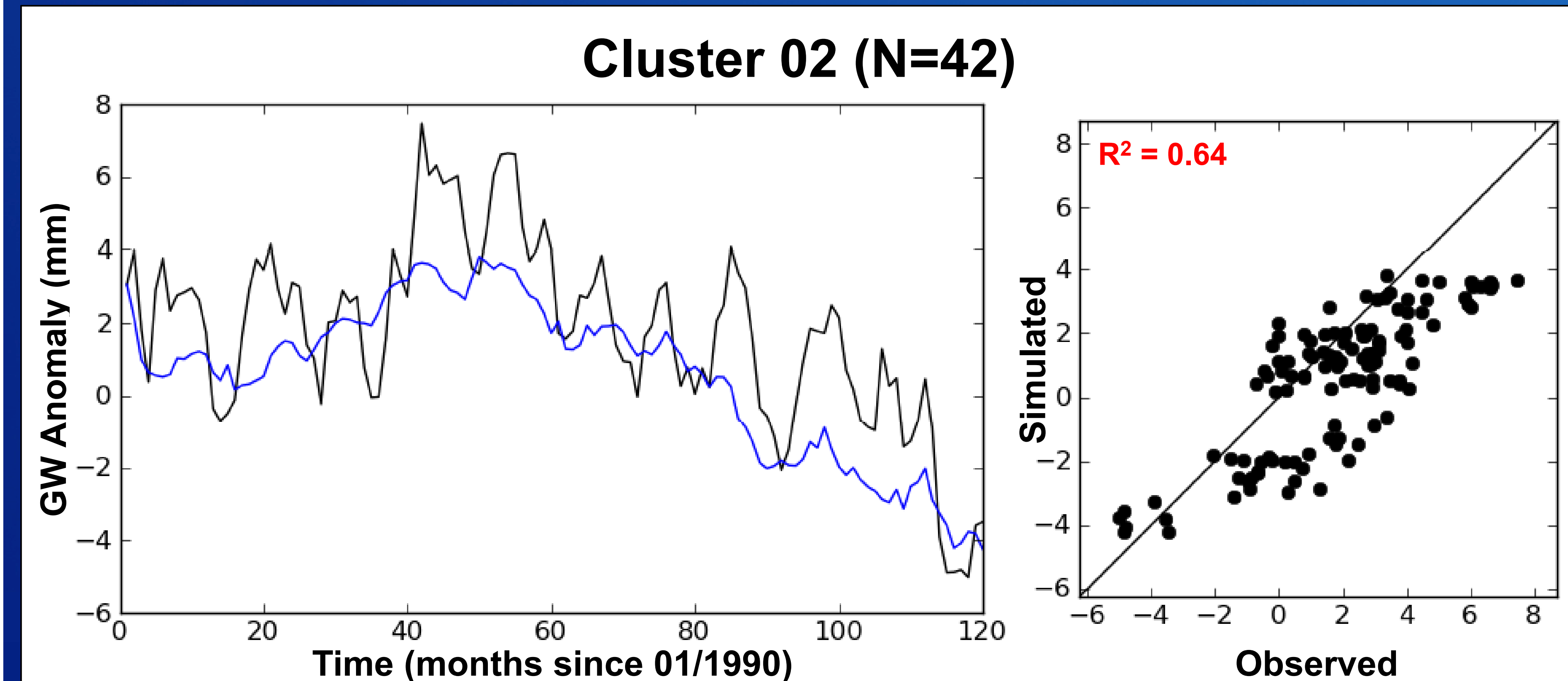
Preliminary Results



8-1: Coastal Plain of Orange County

- 199 wells
- 20 independent well clusters (1-125 wells/cluster)



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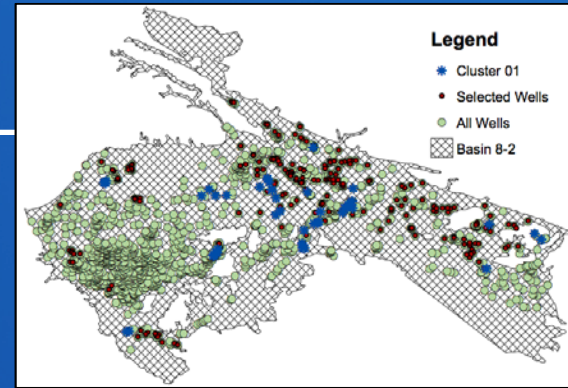
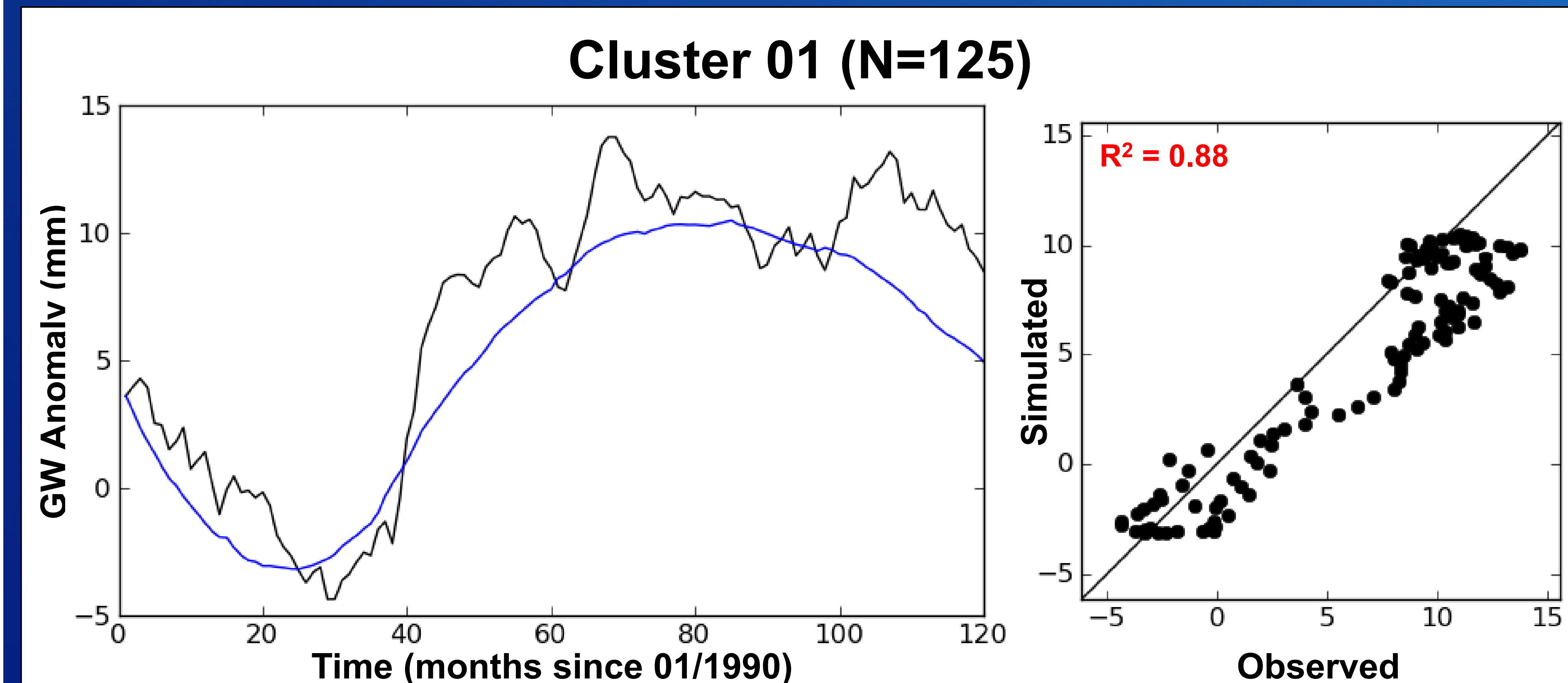
Preliminary Results



8-2: Upper Santa Ana Valley

- 284 wells
- 10 independent well clusters (1-125 wells/cluster)



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Preliminary Results

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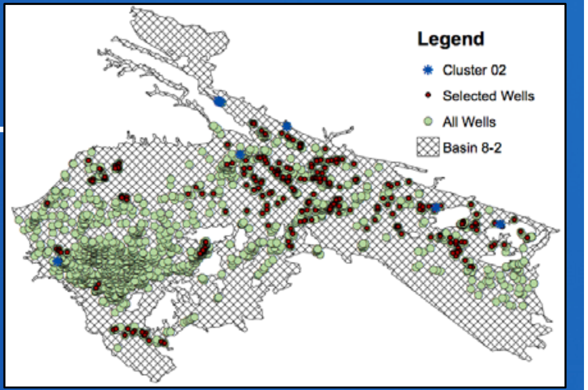

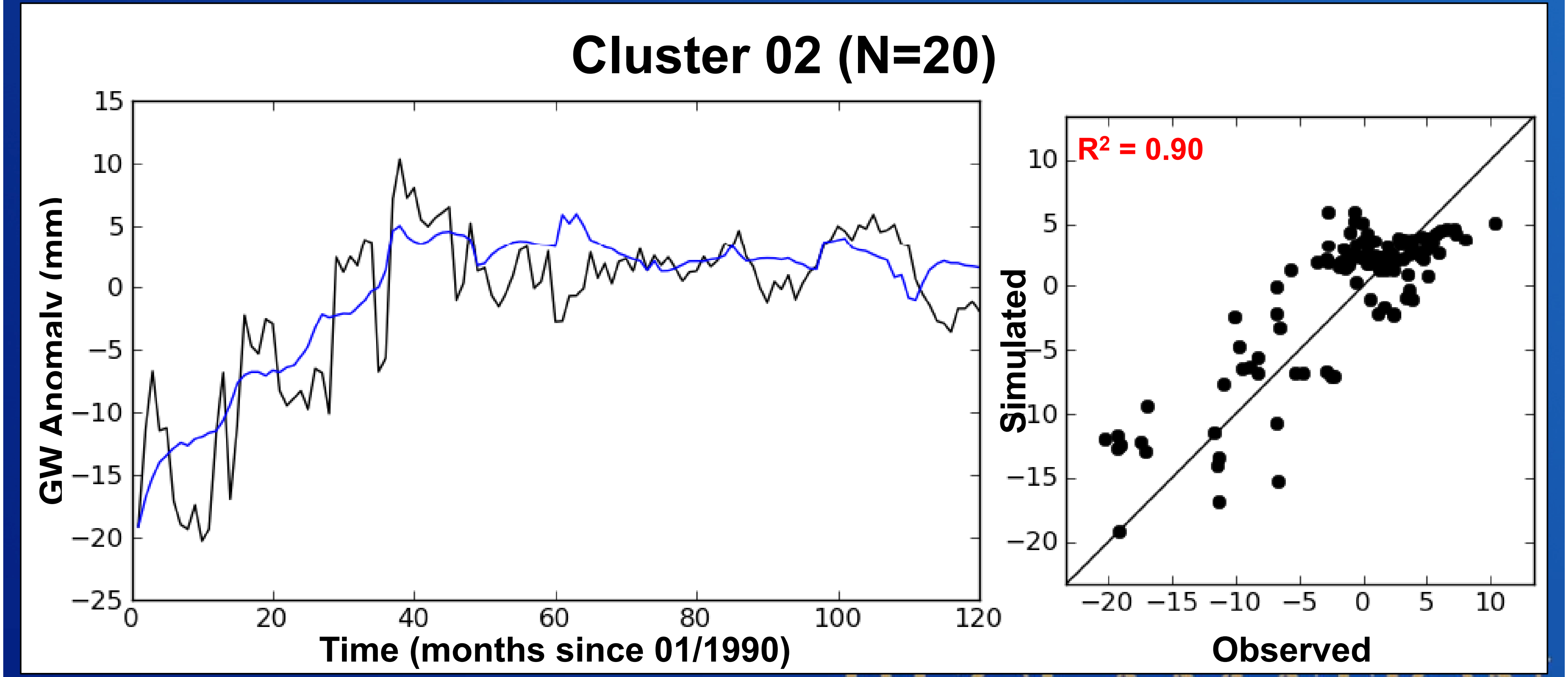

Preliminary Results

Summary

- Developed a simplified modeling framework
- Collected and pre-processed large amount of data
- Identified well clusters in each groundwater basin with similar behavior
- Fit regression models for each well cluster

Initial results demonstrate that the simple modeling framework developed here is able to reproduce key features of year-to-year variations in observed GW levels

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Next Steps

Implement within decision support system

- Projections

  Evaluate changes in GW level under projected climate, M&I demand, agricultural acreage, etc.

- Trade-off analysis

  Given projected changes in climate, population, & land use

  … what changes in per capita demand, water imports, and water re-use are required to maintain GW above a given level?

Basin Studies with a Groundwater Hydrology Component

- Santa Ana Watershed (CA)
- Hood River Basin (OR)
- Niobrara Basin Study (WY/SD/NE)
- Lower Rio Grande Basin Study (TX)
- Klamath River Basin (CA/OR)

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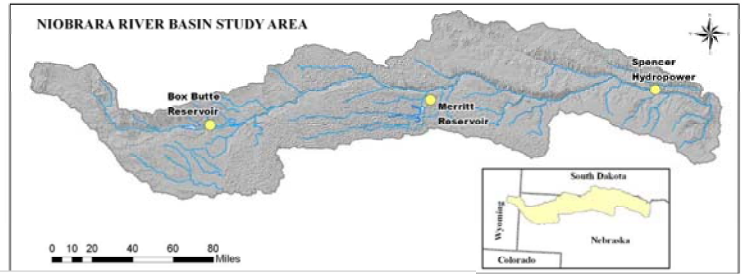
Niobrara Basin Study



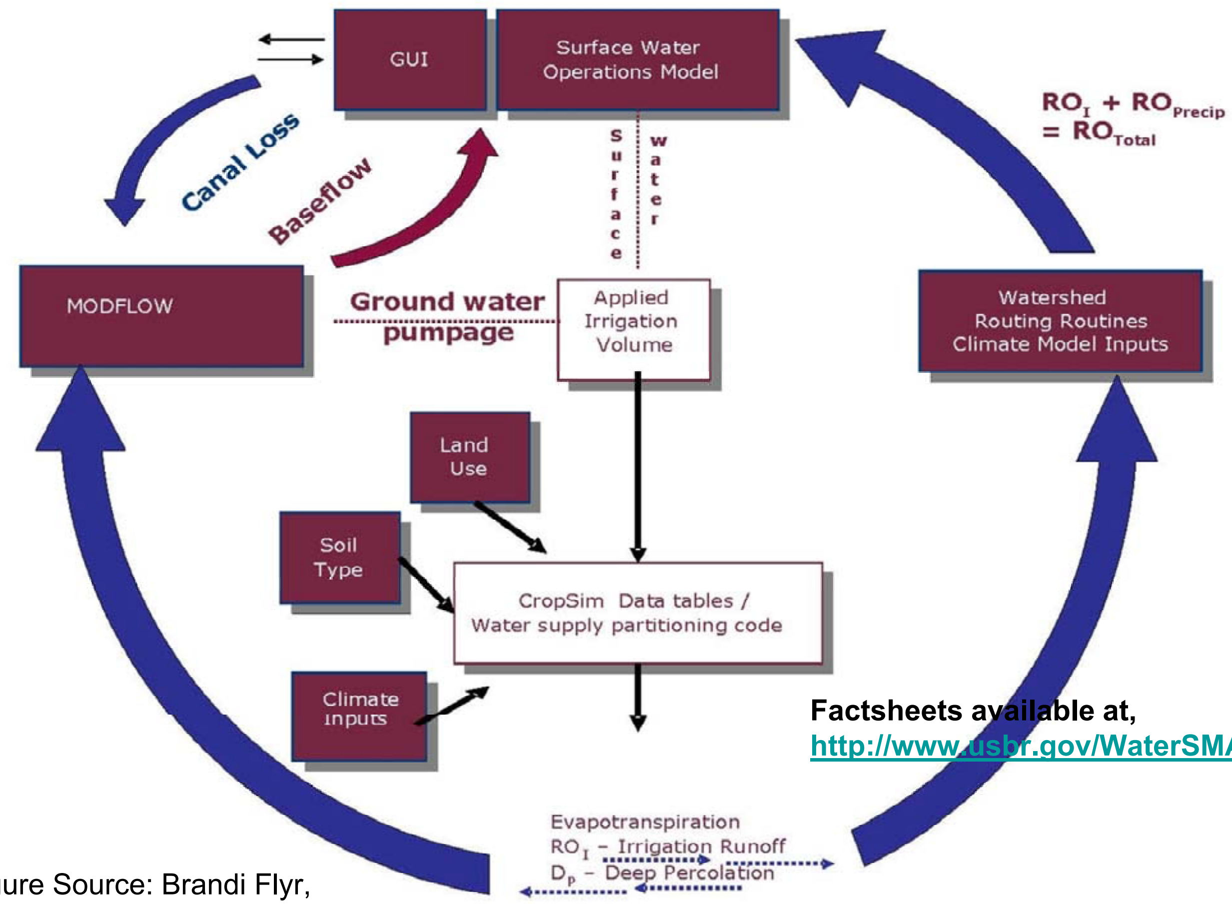


Figure Source: Brandi Flyr, NE DNR

Factsheets available at, http://www.usbr.gov/WaterSMART/bsp/studies.html

West-Wide Climate Risk Assessments (WWCRAs) - foundation for Basin Studies

Groundwater Hydrology in the context of Basin Studies – selected examples : Santa Ana Watershed (CA), and ongoing Basin Studies with a GW component

Groundwater Hydrology Research and Development Office efforts – Science and Technology (S&T) Program

GROUNDWATER HYDROLOGY RESEARCH AND DEVELOPMENT OFFICE EFFORTS – S&T PROGRAM

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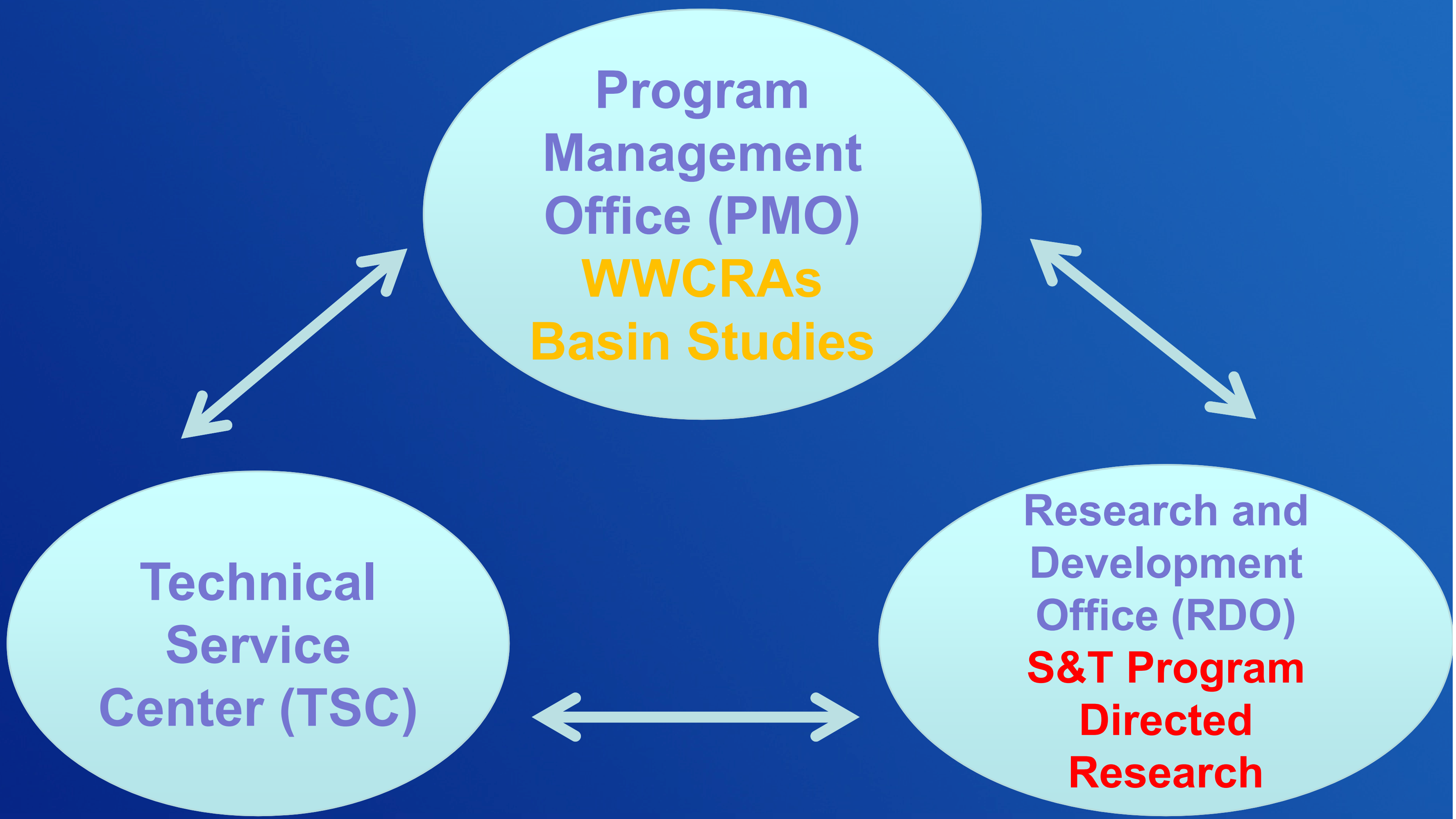
Institutional Layout



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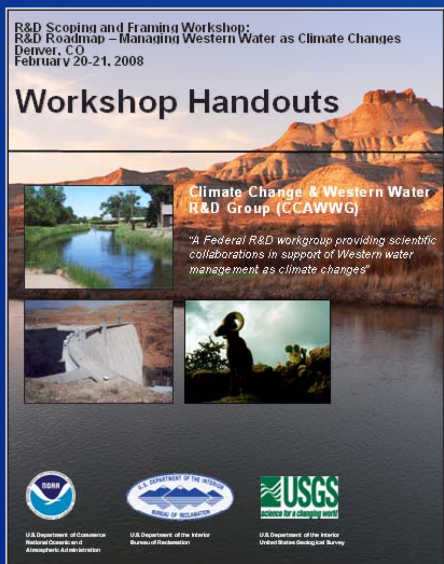
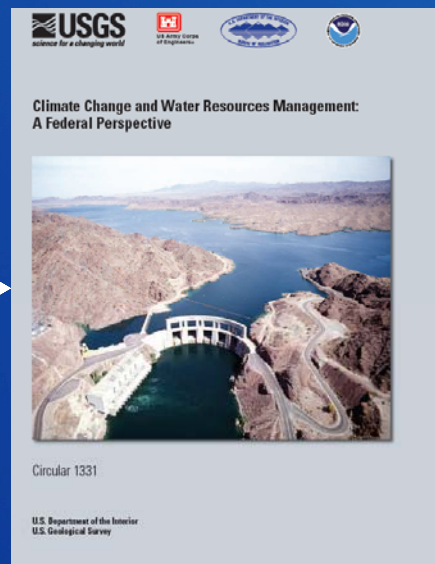
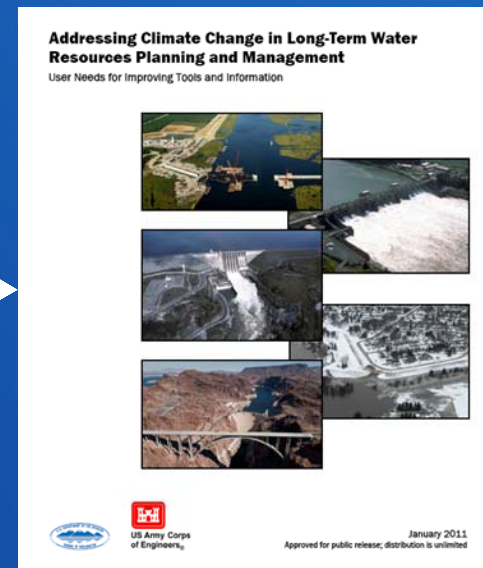
LTdoc: Development Pathway, co-authored by USACE & Reclamation







C-CAWWG
February 2008
Workshop

USGS Circular
1331
January 2009

CCAWWG User
Needs Document

http://www.usbr.gov/climate/userneeds/

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LTdoc "gaps" are organized by eight technical areas

Preliminaries

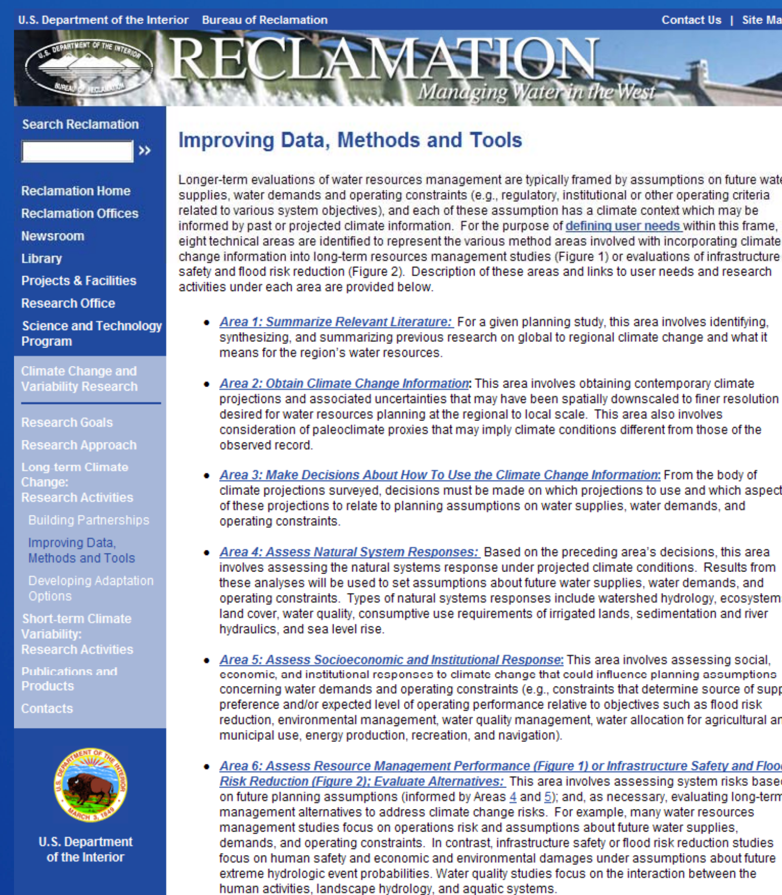
1. Summarize Relevant Literature
2. Obtaining Climate Projections Data

Making Planning Assumptions

3. Make Decisions about How to Relate Climate Projections Data to Planning
4. **Assess Natural Systems Response**
5. Assess Socioeconomic and Institutional Response (highlighted)

Conducting Planning Evaluations and Supporting Decisions

6. Assess Systems Risk and Evaluate Alternatives
7. Assess and Characterize Uncertainties
8. Communicate Results and Uncertainties to Decision-Makers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Managing Water in the West

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U.S. Department of the Interior

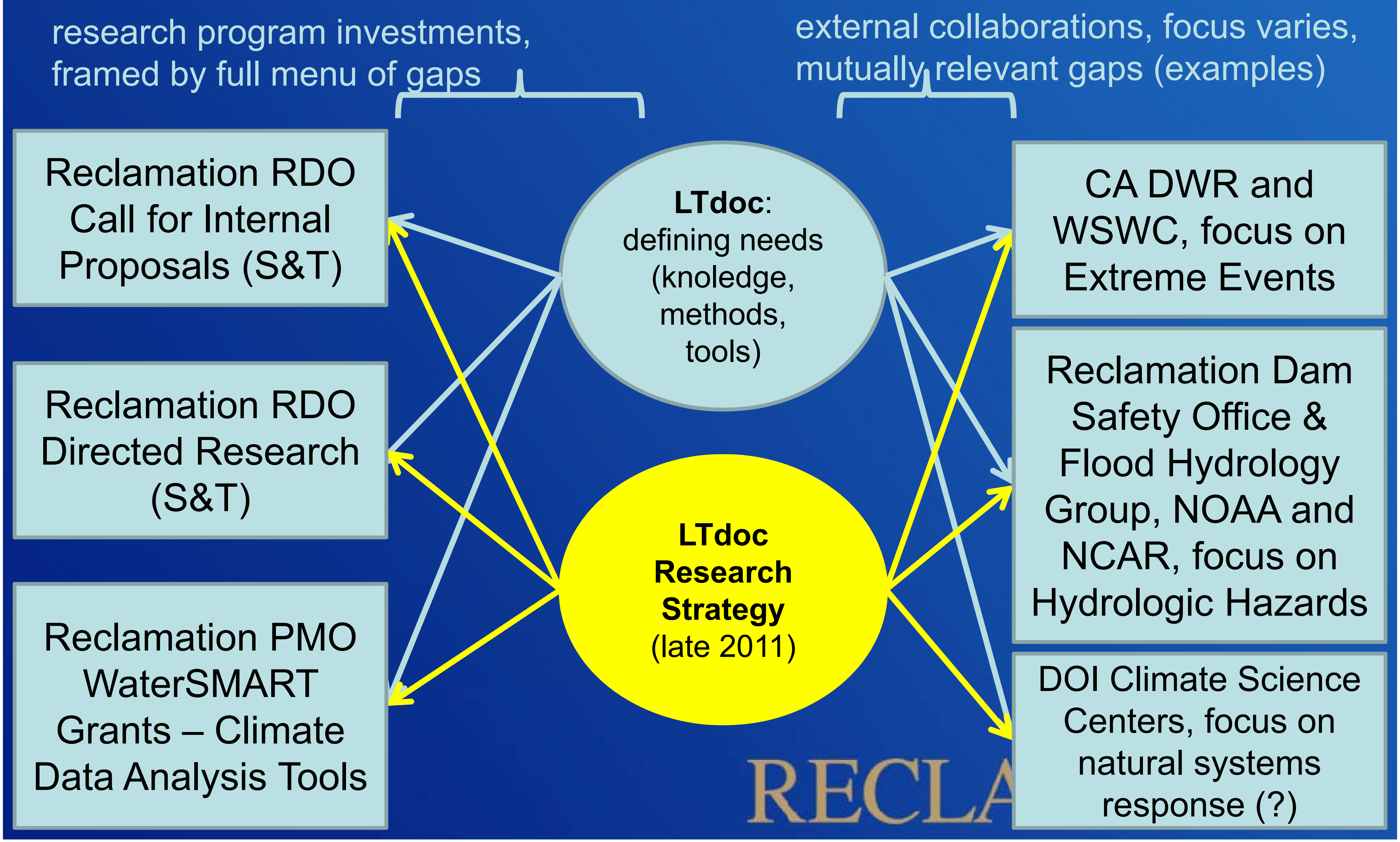
Improving Data, Methods and Tools

Longer-term evaluations of water resources management are typically framed by assumptions on future water supplies, water demands and operating constraints (e.g., regulatory, institutional or other operating criteria related to various system objectives), and each of these assumption has a climate context which may be informed by past or projected climate information. For the purpose of defining user needs within this frame, eight technical areas are identified to represent the various method areas involved with incorporating climate change information into long-term resources management studies (Figure 1) or evaluations of infrastructure safety and flood risk reduction (Figure 2). Description of these areas and links to user needs and research activities under each area are provided below.

- *Area 1: Summarize Relevant Literature:* For a given planning study, this area involves identifying, synthesizing, and summarizing previous research on global to regional climate change and what it means for the region's water resources.
- *Area 2: Obtain Climate Change Information*: This area involves obtaining contemporary climate projections and associated uncertainties that may have been spatially downscaled to finer resolution desired for water resources planning at the regional to local scale. This area also involves consideration of paleoclimate proxies that may imply climate conditions different from those of the observed record.
- *Area 3: Make Decisions About How To Use the Climate Change Information*: From the body of climate projections surveyed, decisions must be made on which projections to use and which aspects of these projections to relate to planning assumptions on water supplies, water demands, and operating constraints.
- *Area 4: Assess Natural System Responses:* Based on the preceding area's decisions, this area involves assessing the natural systems response under projected climate conditions. Results from these analyses will be used to set assumptions about future water supplies, water demands, and operating constraints. Types of natural systems responses include watershed hydrology, ecosystems, land cover, water quality, consumptive use requirements of irrigated lands, sedimentation and river hydraulics, and sea level rise.
- *Area 5: Assess Socioeconomic and Institutional Response*: This area involves assessing social, economic, and institutional responses to climate change that could influence planning assumptions concerning water demands and operating constraints (e.g., constraints that determine source of supply preference and/or expected level of operating performance relative to objectives such as flood risk reduction, environmental management, water quality management, water allocation for agricultural and municipal use, energy production, recreation, and navigation).
- *Area 6: Assess Resource Management Performance (Figure 1) or Infrastructure Safety and Flood Risk Reduction (Figure 2); Evaluate Alternatives:* This area involves assessing system risks based on future planning assumptions (informed by Areas 4 and 5); and, as necessary, evaluating long-term management alternatives to address climate change risks. For example, many water resources management studies focus on operations risk and assumptions about future water supplies, demands, and operating constraints. In contrast, infrastructure safety or flood risk reduction studies focus on human safety and economic and environmental damages under assumptions about future extreme hydrologic event probabilities. Water quality studies focus on the interaction between the human activities, landscape hydrology, and aquatic systems.

http://www.usbr.gov/research/climate/long-term/improvements.html

Reclamation RDO is using LTdoc to steer research engagements on multiple fronts



Knowledge Gaps

1. What is the present role of groundwater as a multi-use supply source in the Western States?
2. How will natural recharge in groundwater basins of the West be affected by climate change?
3. Can paleohydrology be used to understand climate variability implications on groundwater resources of the West?
4. How is water quality impacted by climate change and what are its implications on groundwater resources of the West?
5. What tools are available and necessary to study groundwater-surface water management in a changing climate?
6. Can there be a proactive communication and institutional strategy with the science strategy?
7. What is the role of groundwater in defining tribal interests and in evaluation of cultural value? Understand climate change implications and risk.
8. How will climate change affect the water-energy nexus, and cascading effects on groundwater-surface water management?

Source: AZ Water Inst., USBR 2009 workshop

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Thought Process

1. What are the questions of interest to Reclamation where GW-SW interaction has a prominent role?
2. Where are the sites where these questions are currently relevant and where the answers would be helpful now and in the future?
3. What would be a plan of action (define needs, tasks to address needs) that gets at the answers.
4. Define some tractable pilot projects to demonstrate action in producing information.
5. Answers that can inform policy making or changes to existing policy.

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Questions of Interest to Reclamation

1. Infrastructure management
2. Operations management
3. Interaction between infrastructure and operations management

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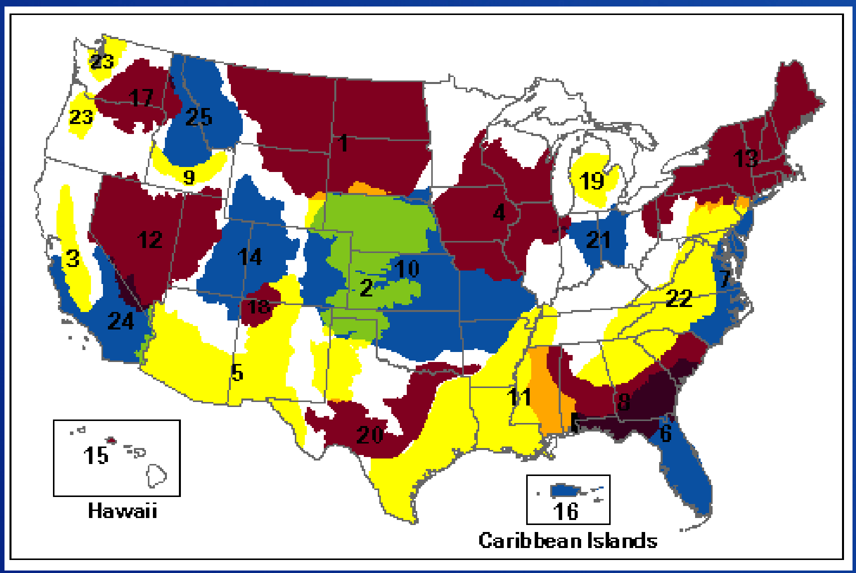
Supply-Demands-Issues

Groundwater Resources - SUPPLY



Source: USGS RASA study
http://water.usgs.gov/cgi/rasabiblio/?form=map

USBR Service Areas - DEMANDS

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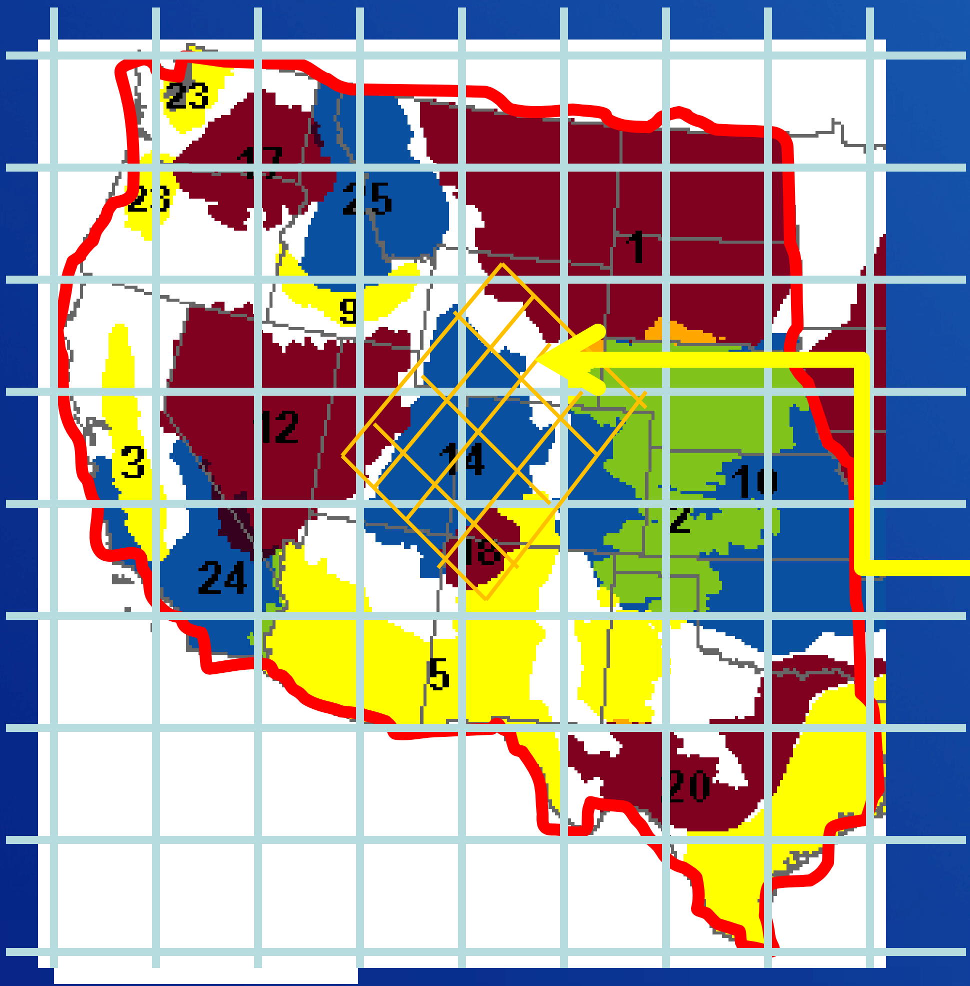
Supply-Demands-Issues



What are the <u>questions</u> of interest to Reclamation where GW-SW interaction has a prominent role?

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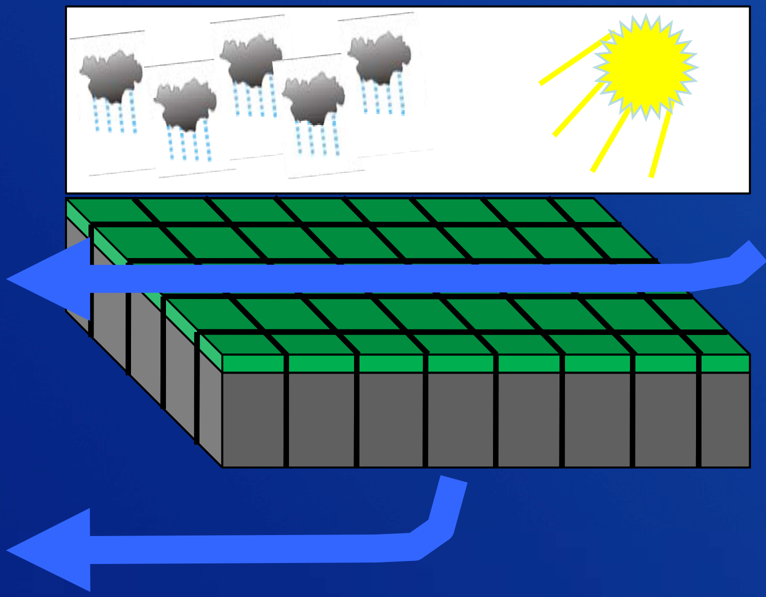
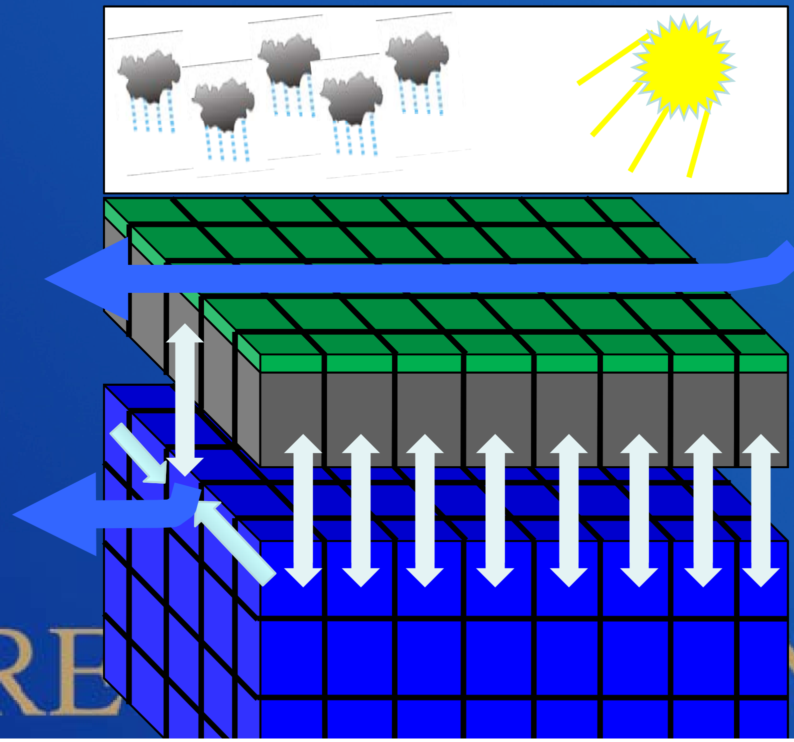
Research:

Can “traditional” hydrologic models be used to evaluate hydrologic response to climate change in regions where baseflow is a significant component of discharge?

“Traditional” LSM with
1D baseflow parametization



Coupled LS/GW Model with
3D groundwater flow



Research:

Can "traditional" hydrologic models be used to evaluate hydrologic response to climate change in regions where baseflow is a significant component of discharge?

- Compare model biases between basins with high/low baseflow (uncalibrated and calibrated)
- Compare model biases and hydrologic projections between model structures:
  - LSM with 1D baseflow parameterization (VIC)
  - LSM with unconfined aquifer model (VIC-GW)
  - LSM loosely coupled with GW model (VIC+MODFLOW)
  - Fully-coupled SW-GW-LSM (ParFlow, HydroGeoSphere)

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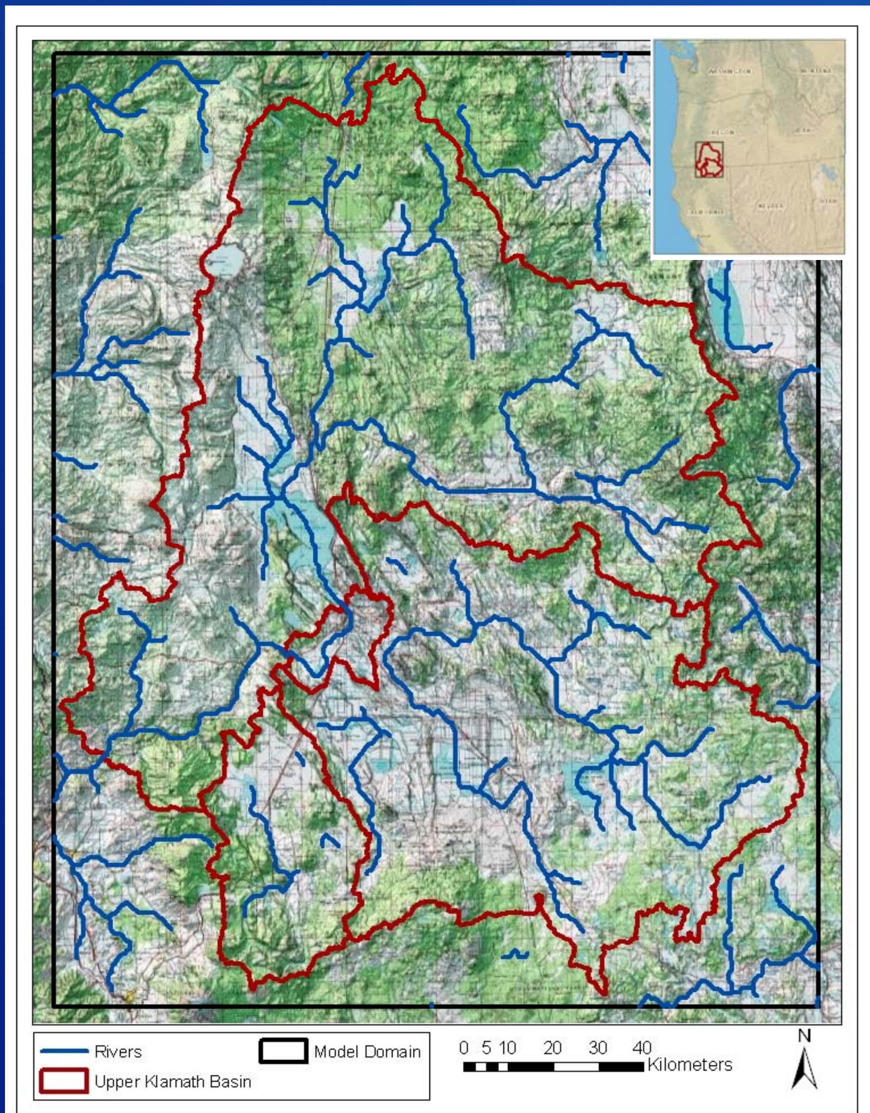
The Upper Klamath Basin



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Research Goals

- **Build a regional model of the Upper Klamath Basin using ParFlow (brief model description in next slides)**

- **Assess the impact of subsurface characterization on land energy fluxes and the regional water budget**

- **Fully integrated groundwater-surface water processes embedded within operations models**

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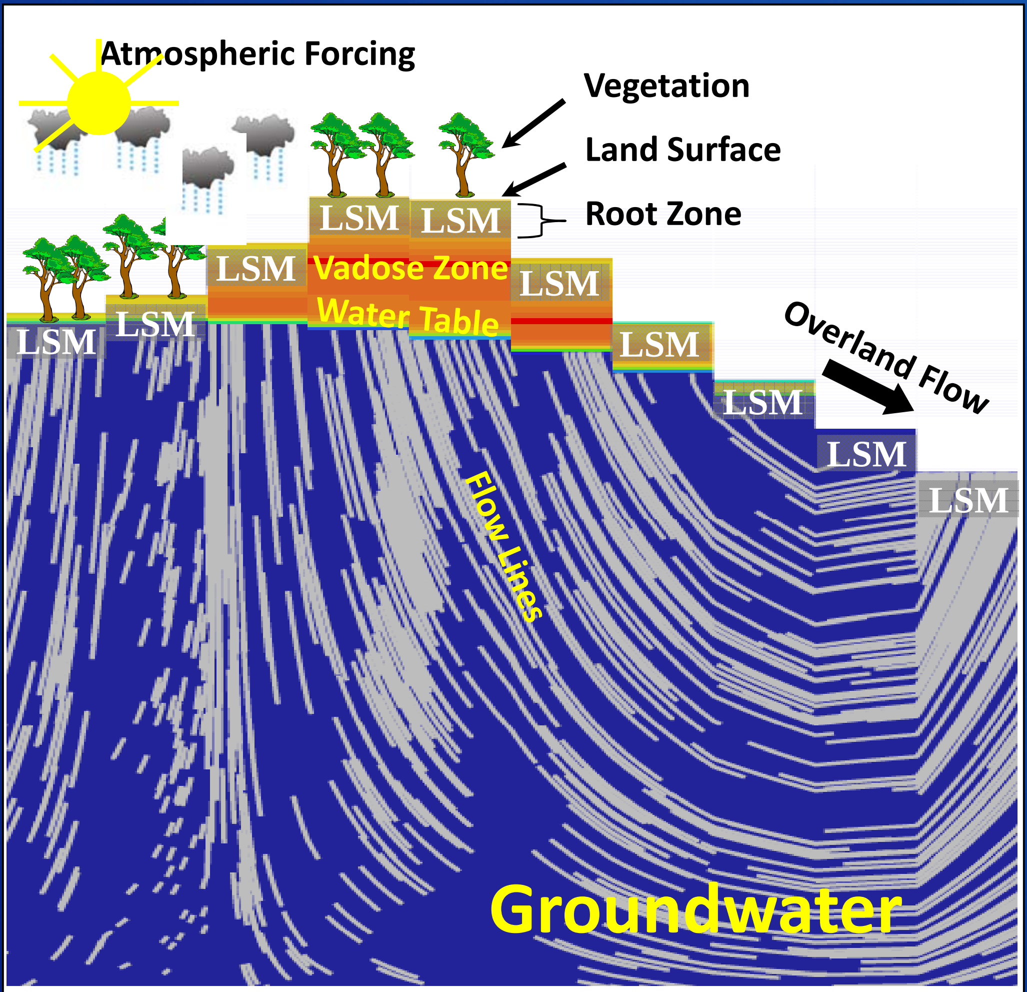
ParFlow

Fully-integrated hydrology model



- **Groundwater flow:** variably-saturated, three-dimensional Richards equation
- **Overland flow/surface runoff:** free-surface overland flow boundary condition (Mannings + kinematic wave)
- **Land surface water and energy fluxes:** Common Land Model (CLM), includes infiltration, canopy and vegetation processes, and coupled water-energy balance
- **Fully-coupled, mass conservative, parallel implementation**

ParFlow References: Kollet and Maxwell (2008), Kollet and Maxwell (2006), Maxwell and Miller (2005), Dai et al. (2003), Jones and Woodward (2001); Ashby and Falgout (1996)

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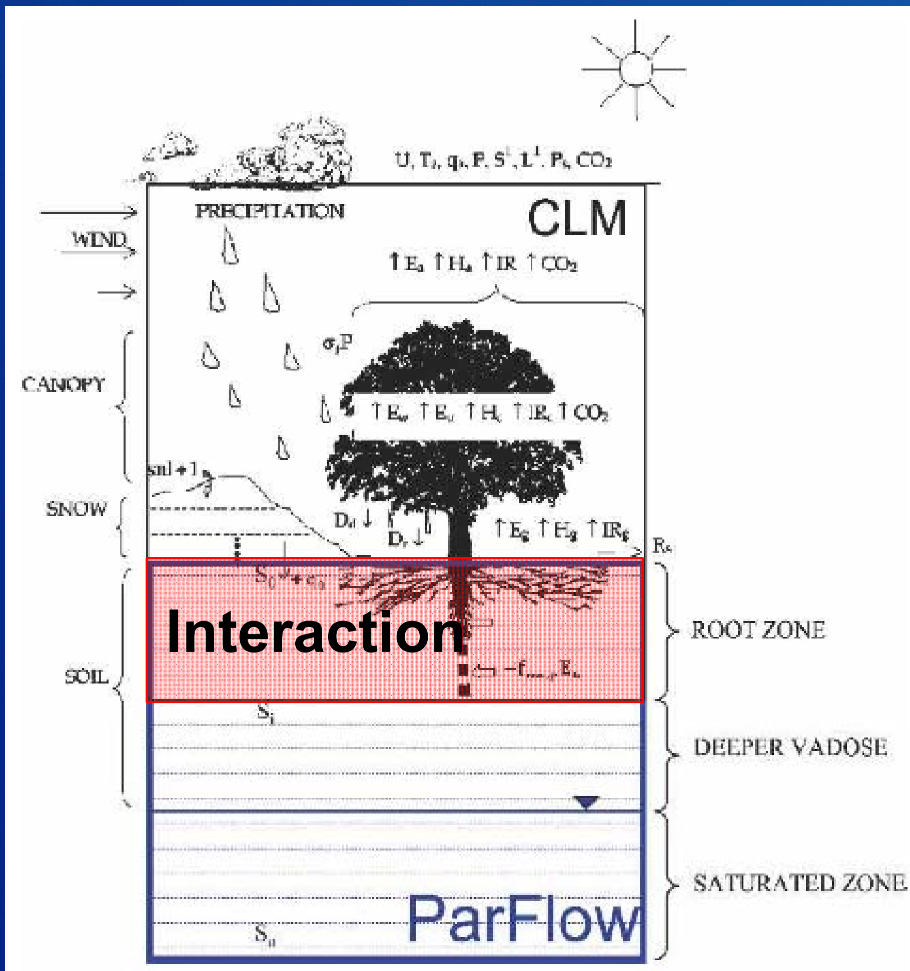
ParFlow

Groundwater-Surface Water-Land Surface Coupling



Maxwell and Miller, JHM, 2005

PF solves coupled SW/GW flow @ [**t**]

(soil moisture/ pressure)

CLM computes EB & ET @ [**t+1**]

ET fluxes

PF solves coupled SW/GW flow @ [**t+1**]

(soil moisture/ pressure)

CLM computes EB & ET @ [**t+2**]

Research Questions

1. When considering regional water budgets on a spatiotemporal resolution relevant for water management is the variability between subsurface characterizations sufficient to impact decision making?

2. What is the relative importance of subsurface heterogeneity or topography in controlling the spatial structure of land energy fluxes and hydrologic variables on a regional scale?

3. Do relationships remain stationary given a range of realistic subsurface parameterizations?

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Goals

- Integrate management algorithms into ParFlow
- Develop an application for a subset of the Upper Klamath domain
- Analyze several management scenarios
- Time permitting, compare integrated model results to a stand alone WEAP model

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Methodology

- Analyze WEAP algorithms and integrate into ParFlow
- Define a simplified domain including a reservoir, groundwater pumping and surface irrigation
- Test integrated model with simple scenarios
- Define management scenarios to test
- Analyze several management scenarios using the integrated model

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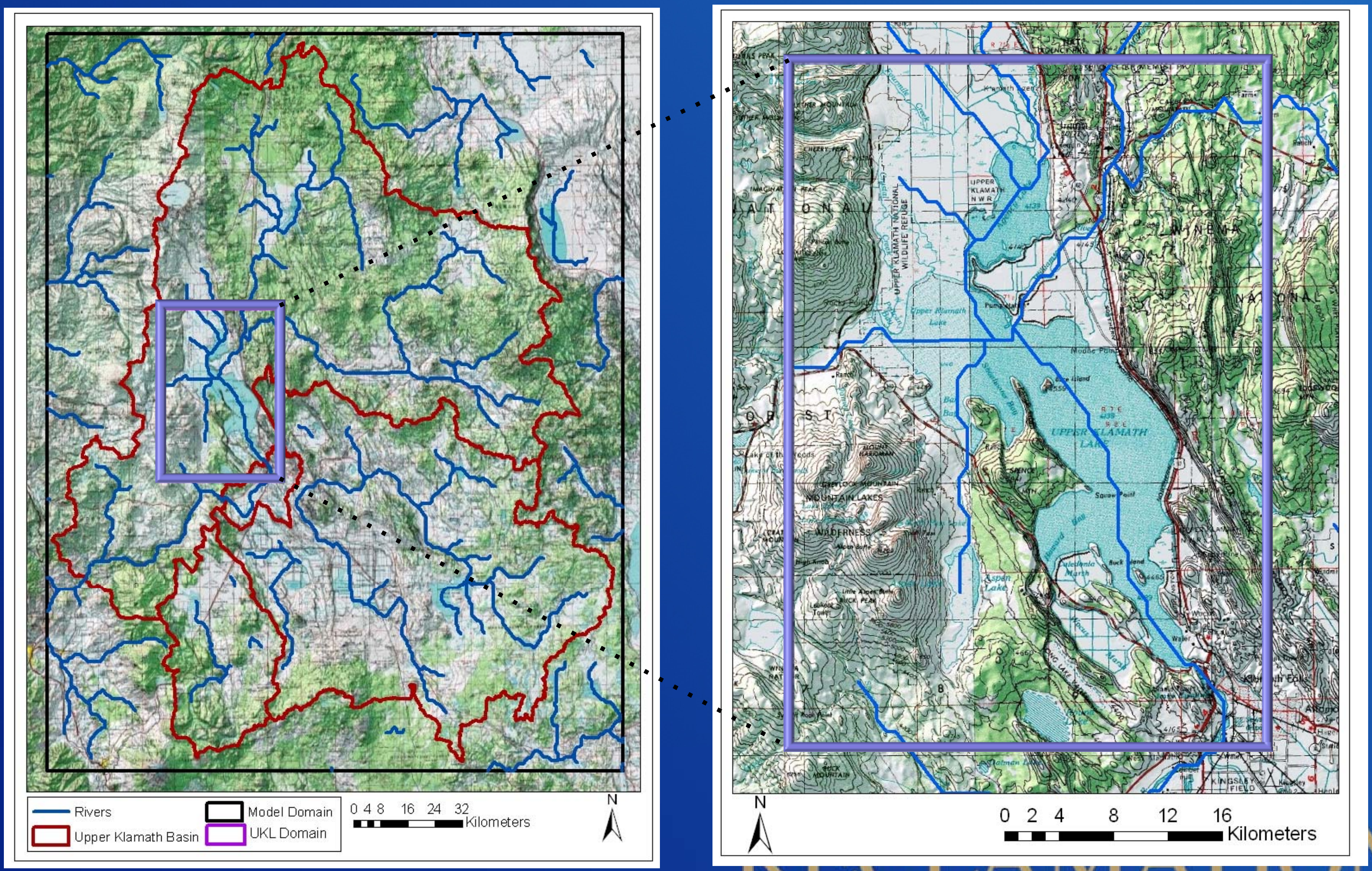
Management Domain



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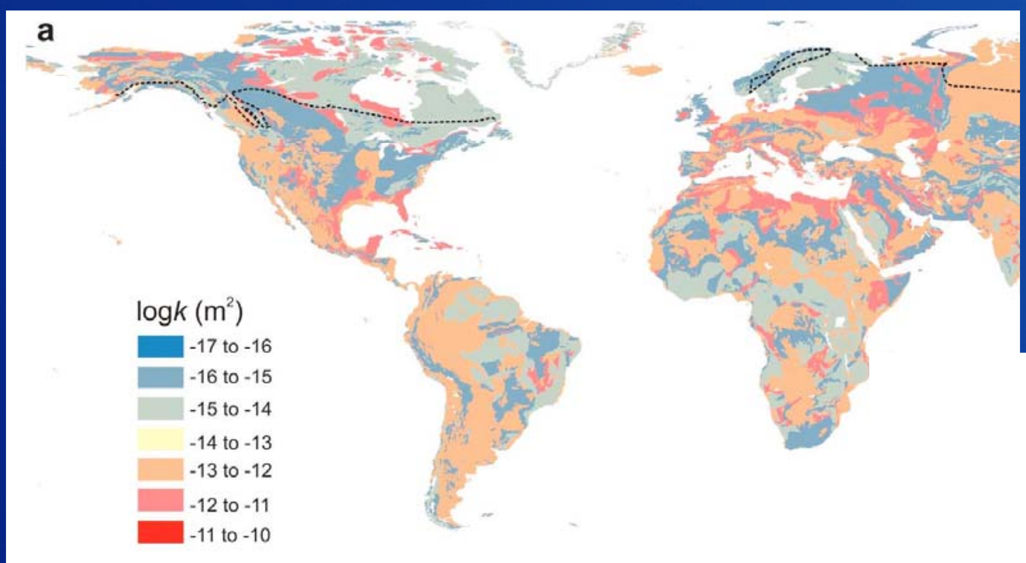
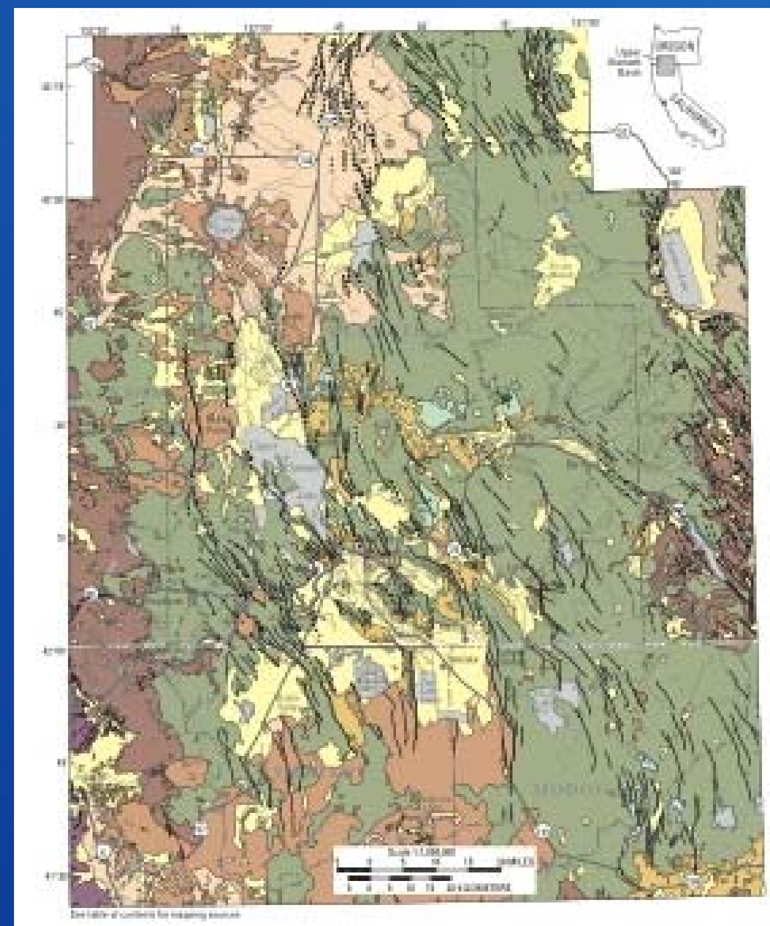
Subsurface Characterization

- Sources of conductivity data
  - USGS hydrogeologic strata map
  - US permeability from Gleeson et al., 2010
  - Well logs



Subsurface Permeability
(Gleeson et al., 2010)



Upper Klamath Hydrogeologic Units
(USGS, 2005)

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Summary

- Broad-based approach
- Basin Studies (PMO + Regions + Area Offices) – best actionable science
- Applied Research (RDO) – S&T program, and Directed Research Activities

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Groundwater Hydrology in West-Wide Climate Risk Assessment: No Standard Practice

Groundwater Hydrology in West-Wide Climate Risk Assessment: Towards Standard Practice

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Subhrendu Gangopadhyay, TSC, sgangopadhyay@usbr.gov

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