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Managing Water in the West

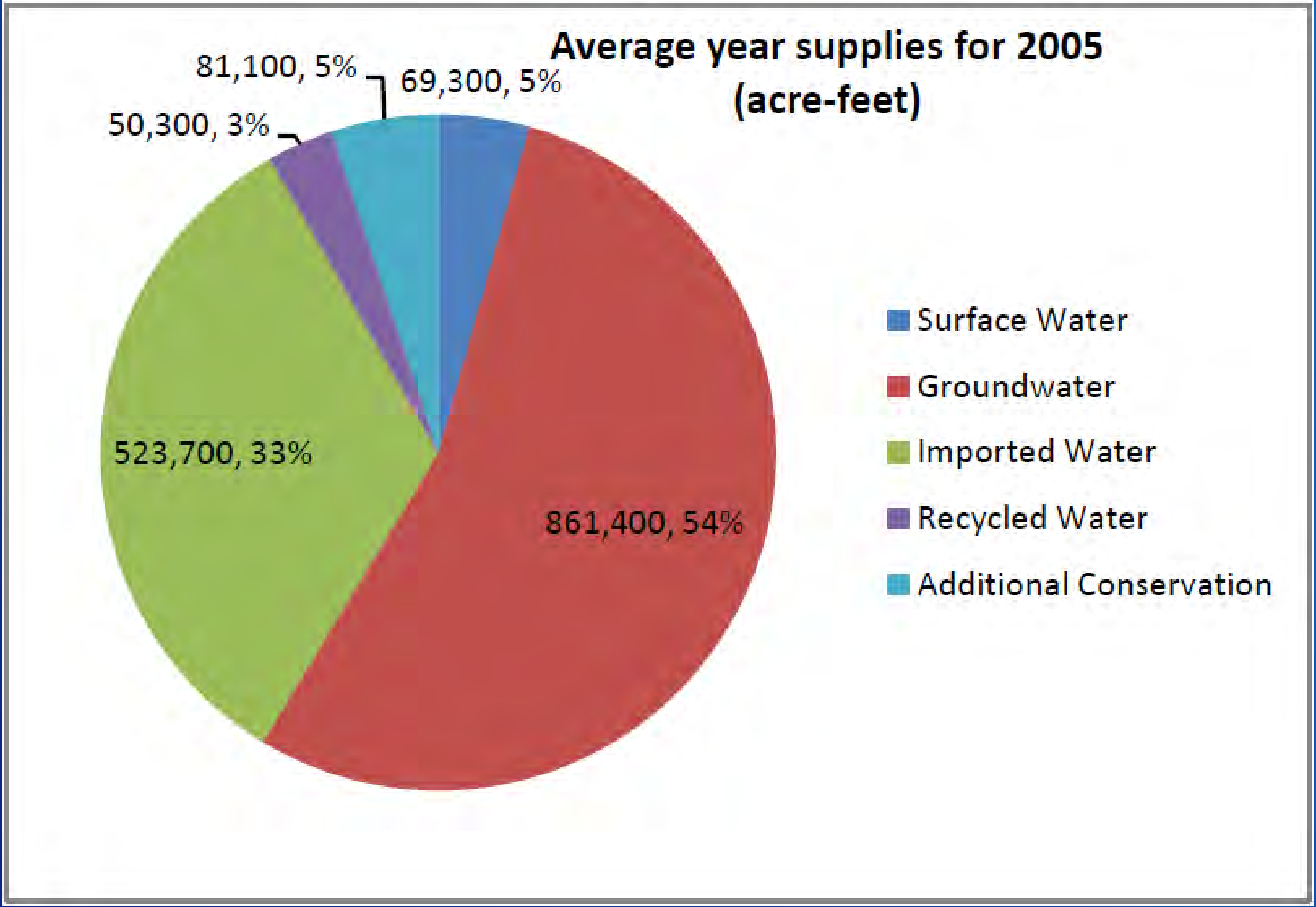
Groundwater Modeling:

A Simplified Approach for Modeling Climate Change Impacts on Groundwater Resources in the Santa Ana Watershed

U.S. Department of the Interior
Bureau of Reclamation

Introduction

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



SAWPA 2010

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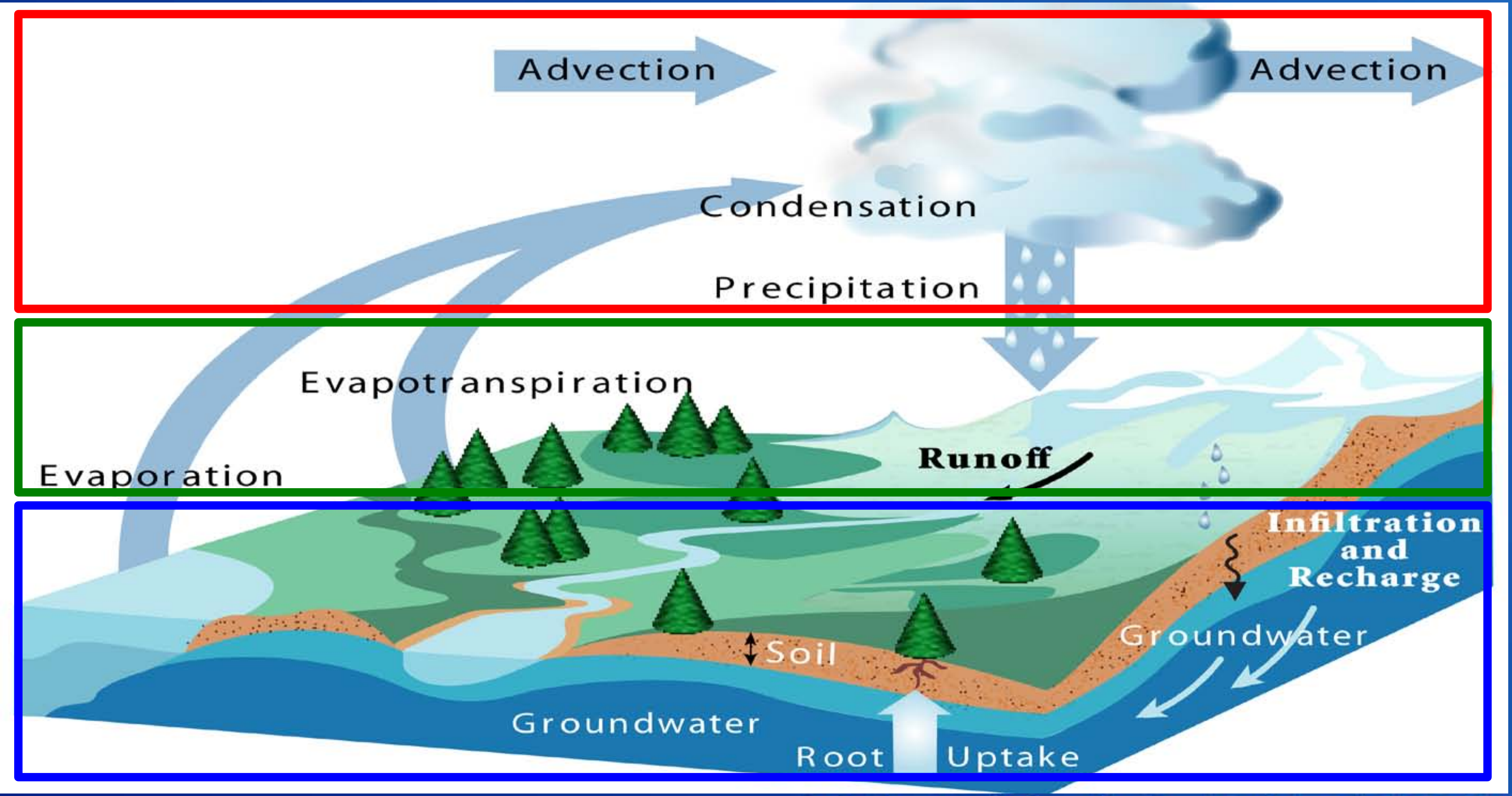
Introduction

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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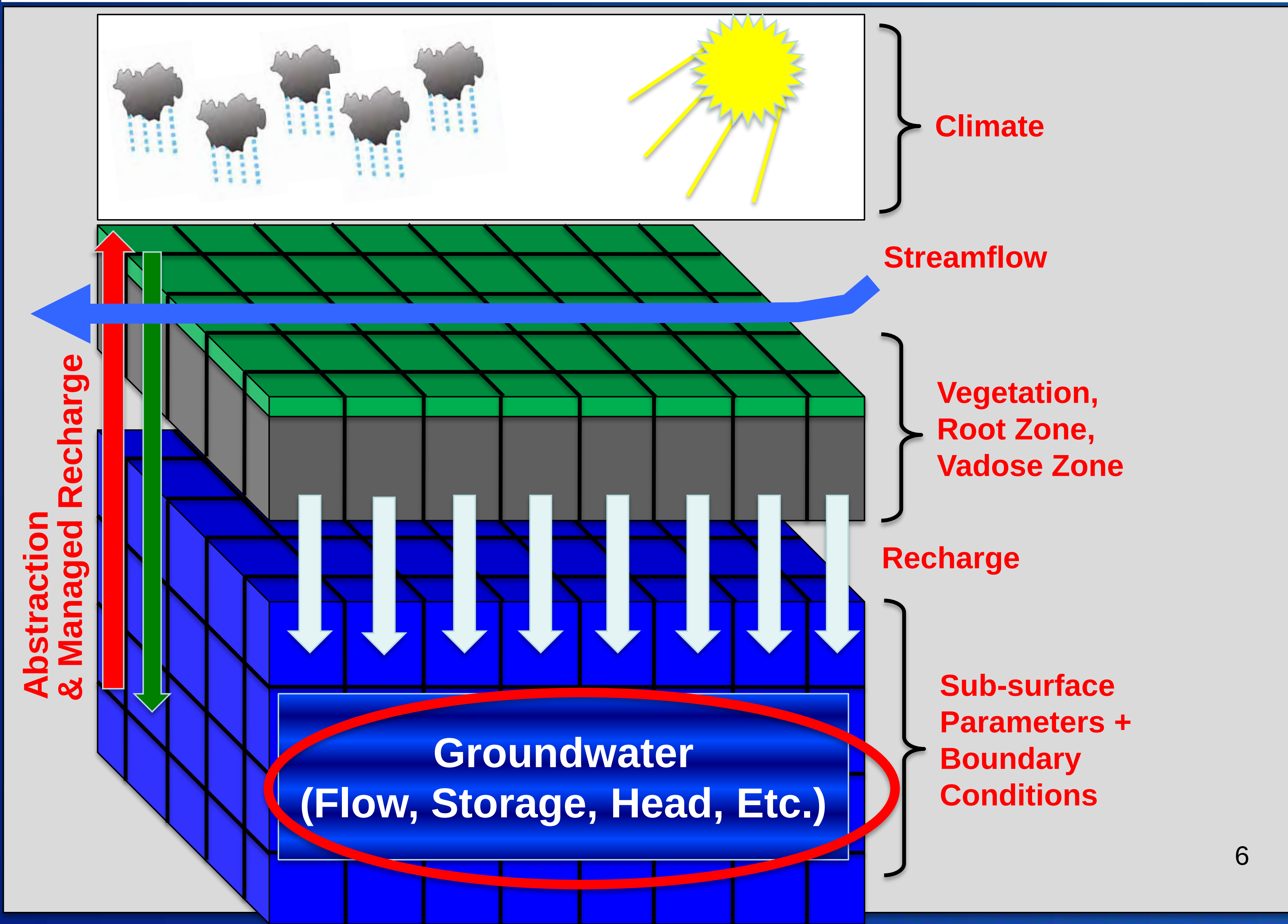
Outline

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

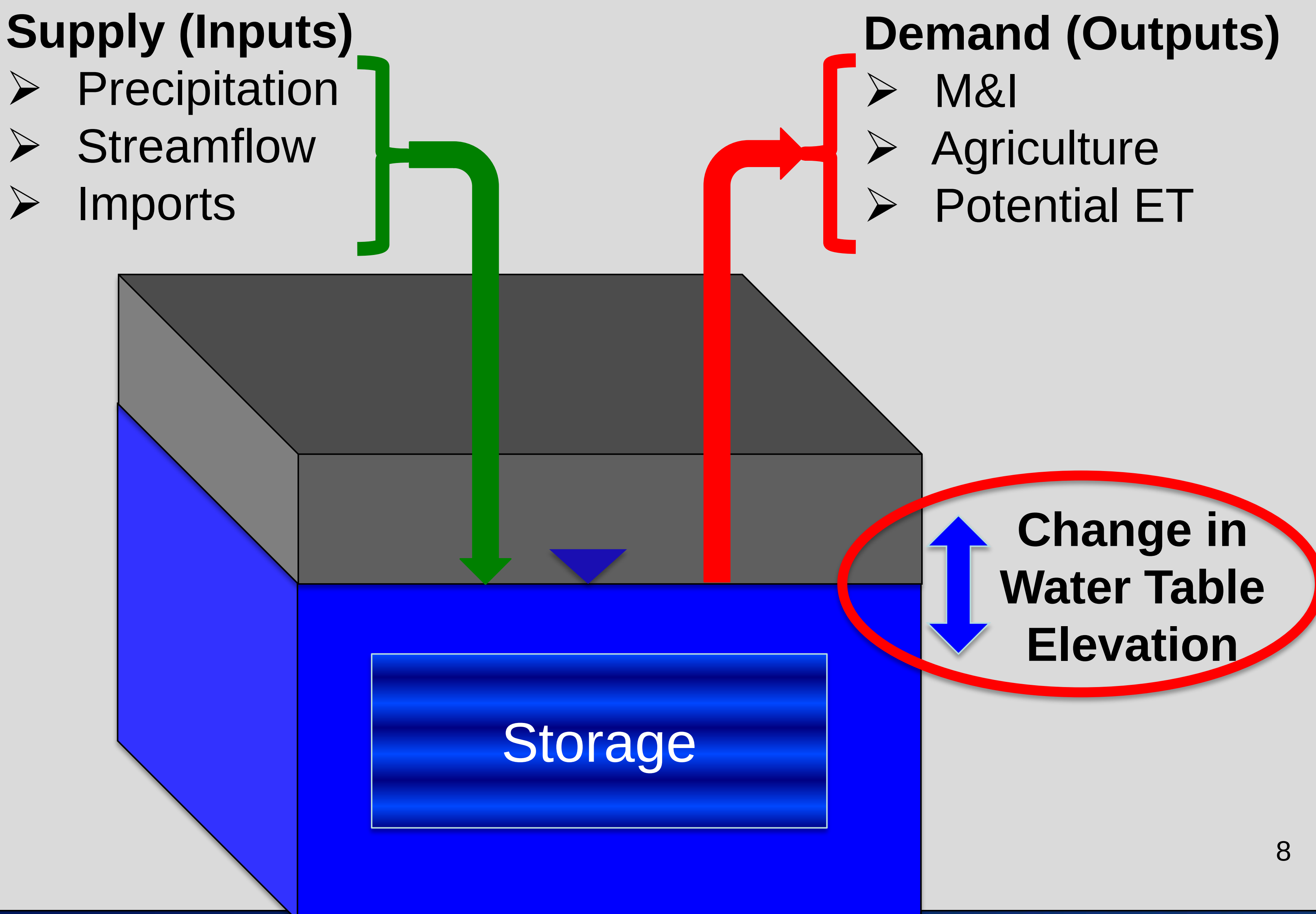
"Traditional" Groundwater Modeling



"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

ΔS = Inputs - Outputs

Change in Basin-Average GW Elevation	=	*f*{Precipitation} + *f*{Streamflow} + *f*{Imports}	-	*f*{Potential ET} + *f*{M&I Demand} + *f*{Ag Demand}

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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.)

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

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

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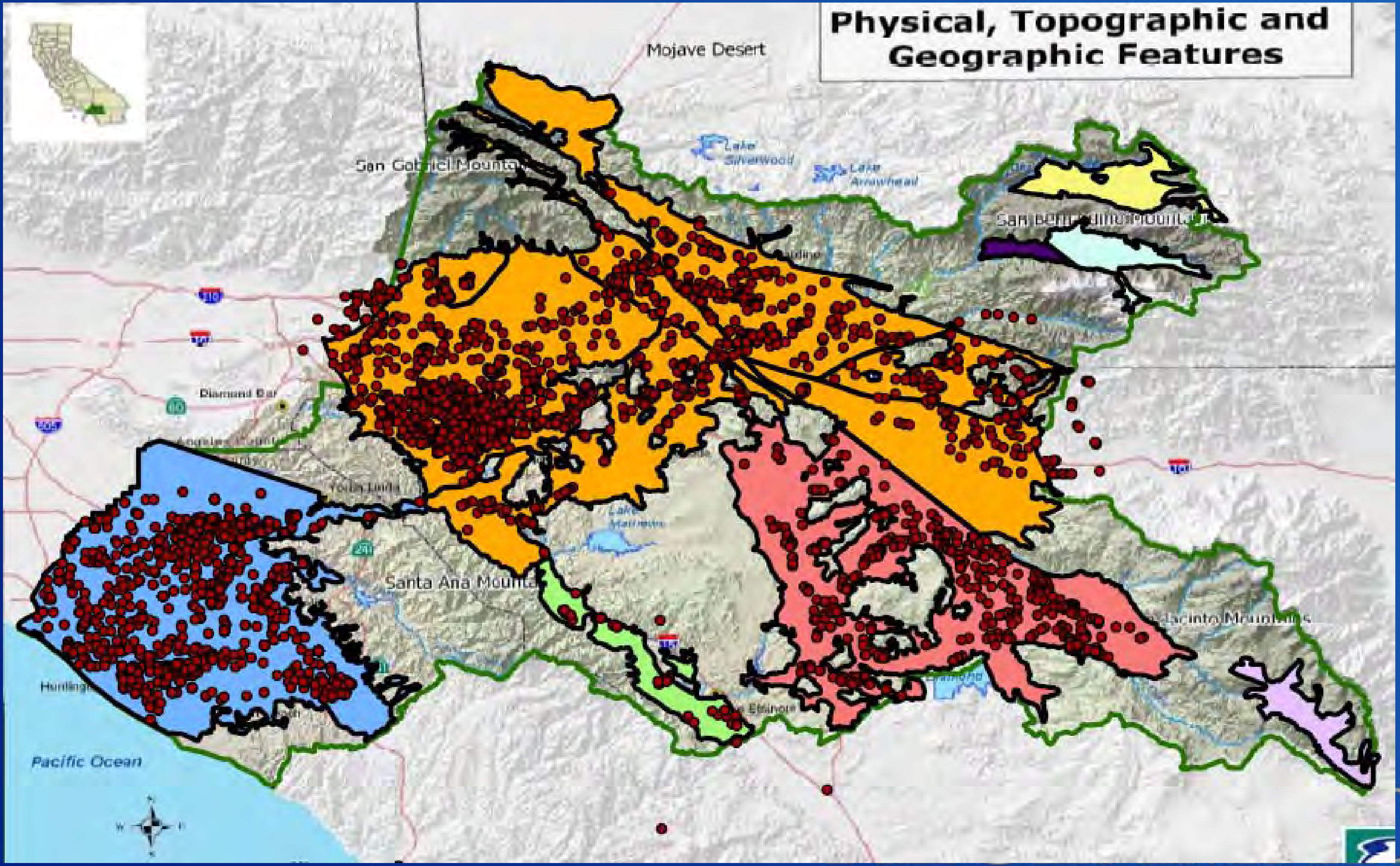
Data Collection & Pre-Processing

Groundwater Elevation

- Source: SAWPA groundwater database



Data Collection & Pre-Processing

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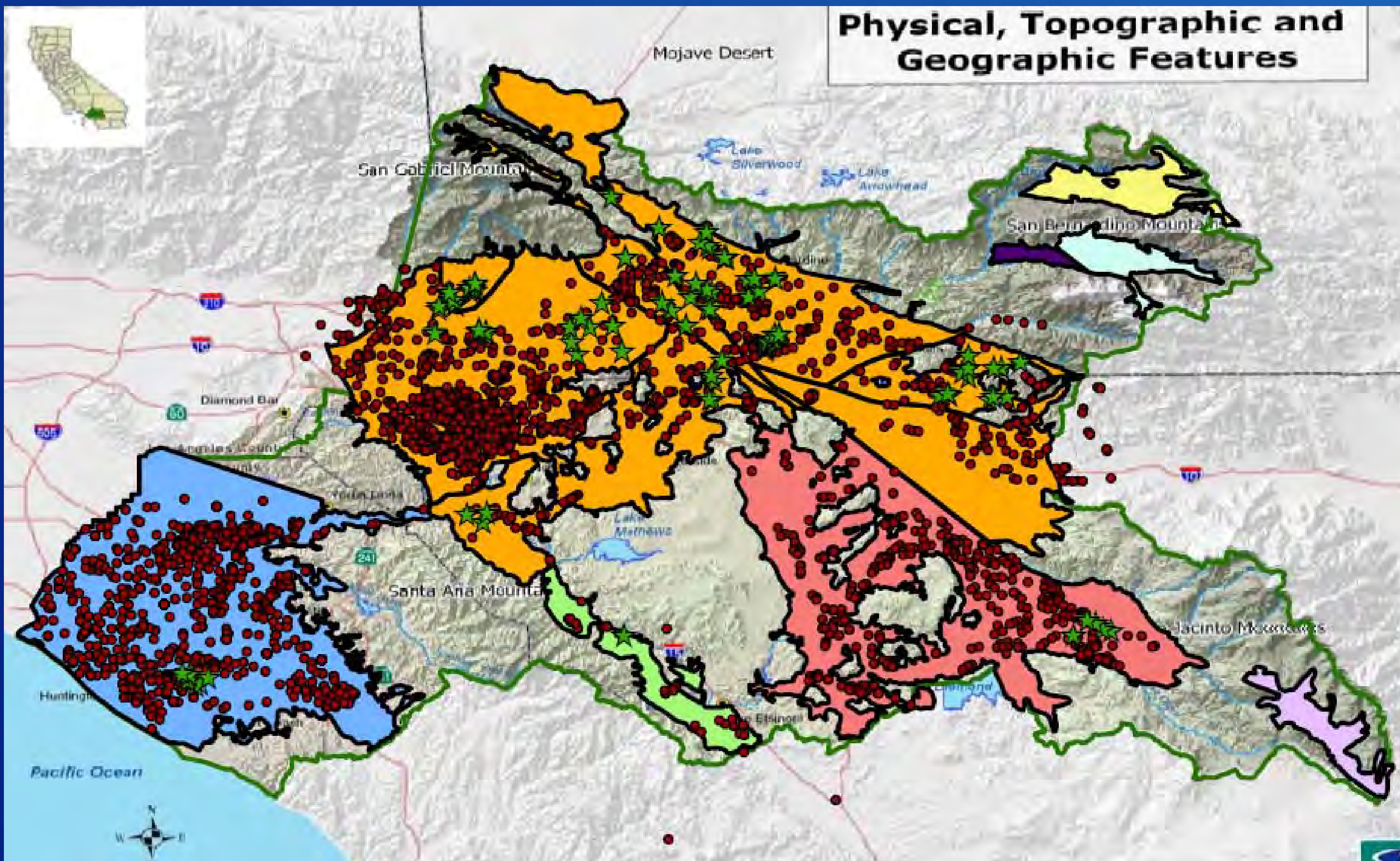


Data Collection & Pre-Processing

Groundwater Elevation

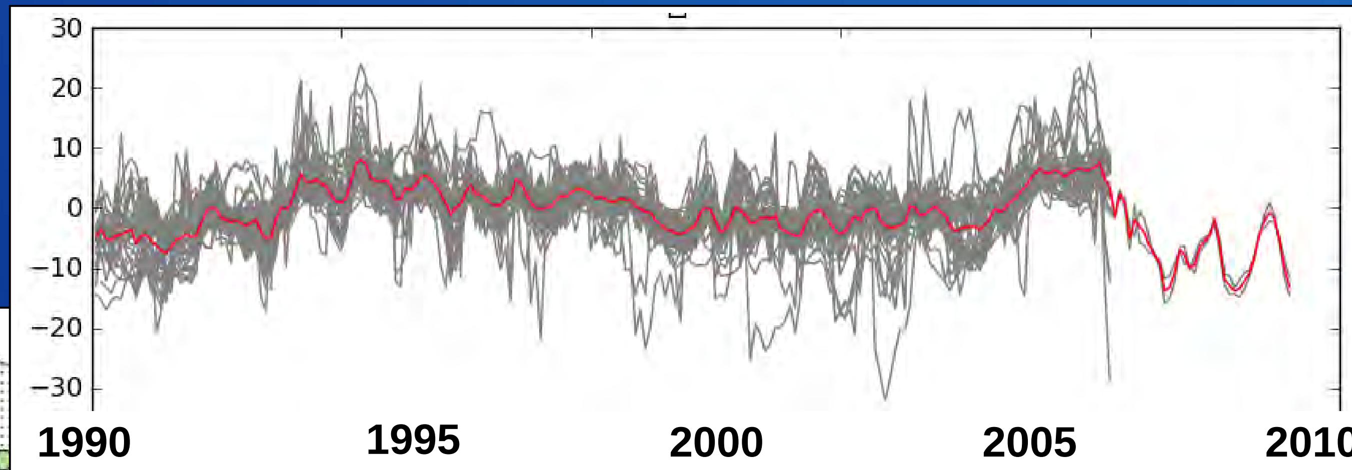
- Eliminate records with greater than 50% missing (by month)
- Eliminate individual outlier points
- Compute monthly mean GW levels for all months in record
- Interpolate to fill missing data (no extrapolation)

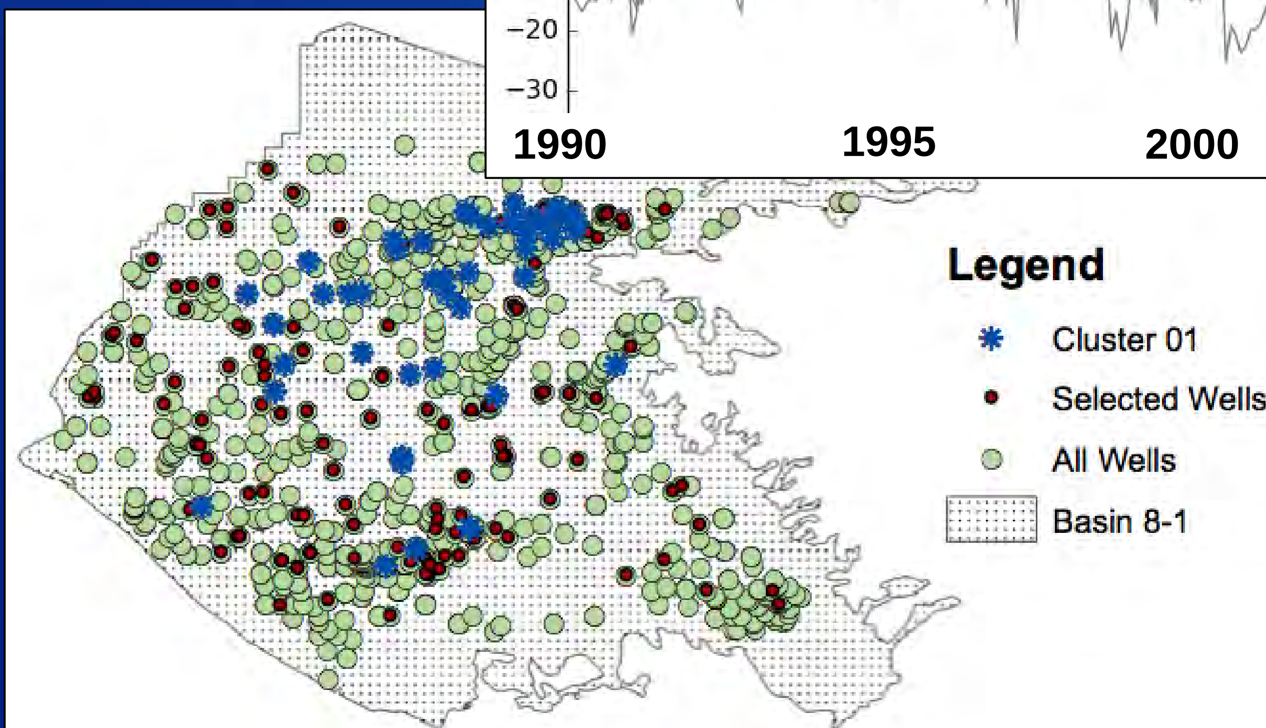
495 well records over four groundwater basins

Data Collection & Pre-Processing

Groundwater Elevation

- Clustering routine to identify wells with similar behavior



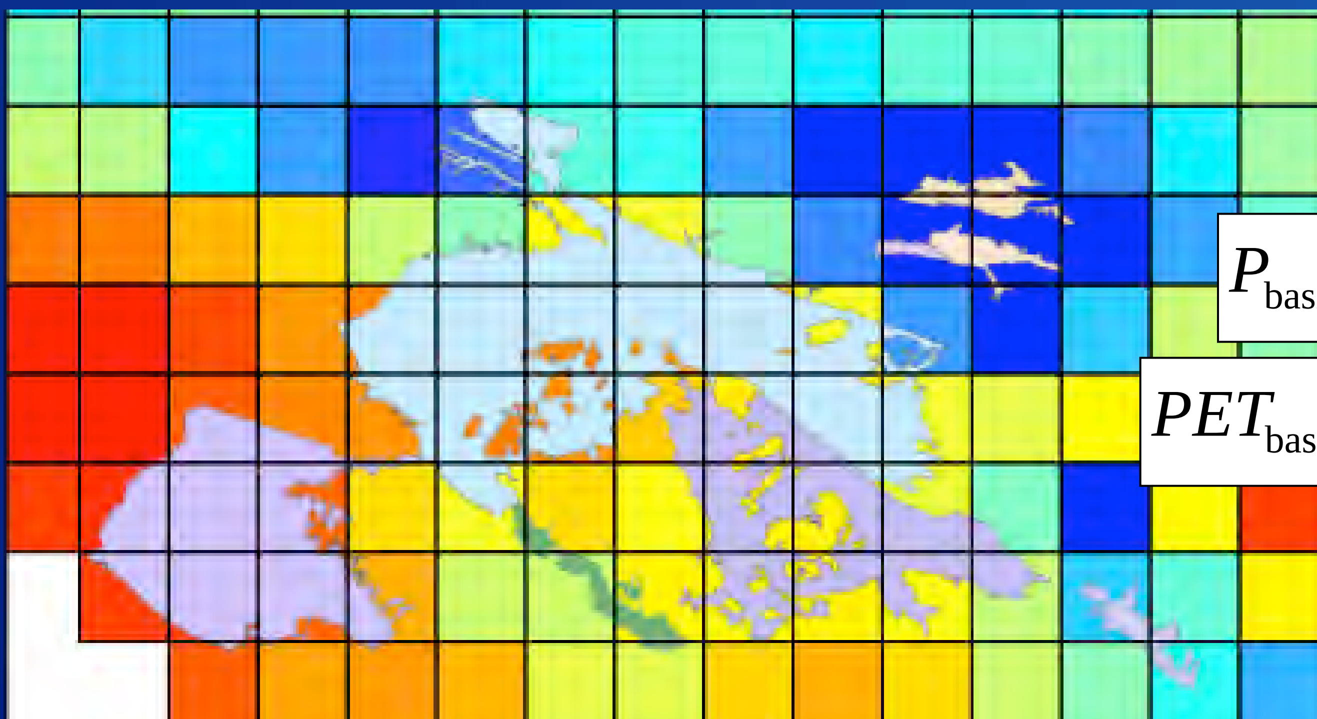


Data Collection & Pre-Processing

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)



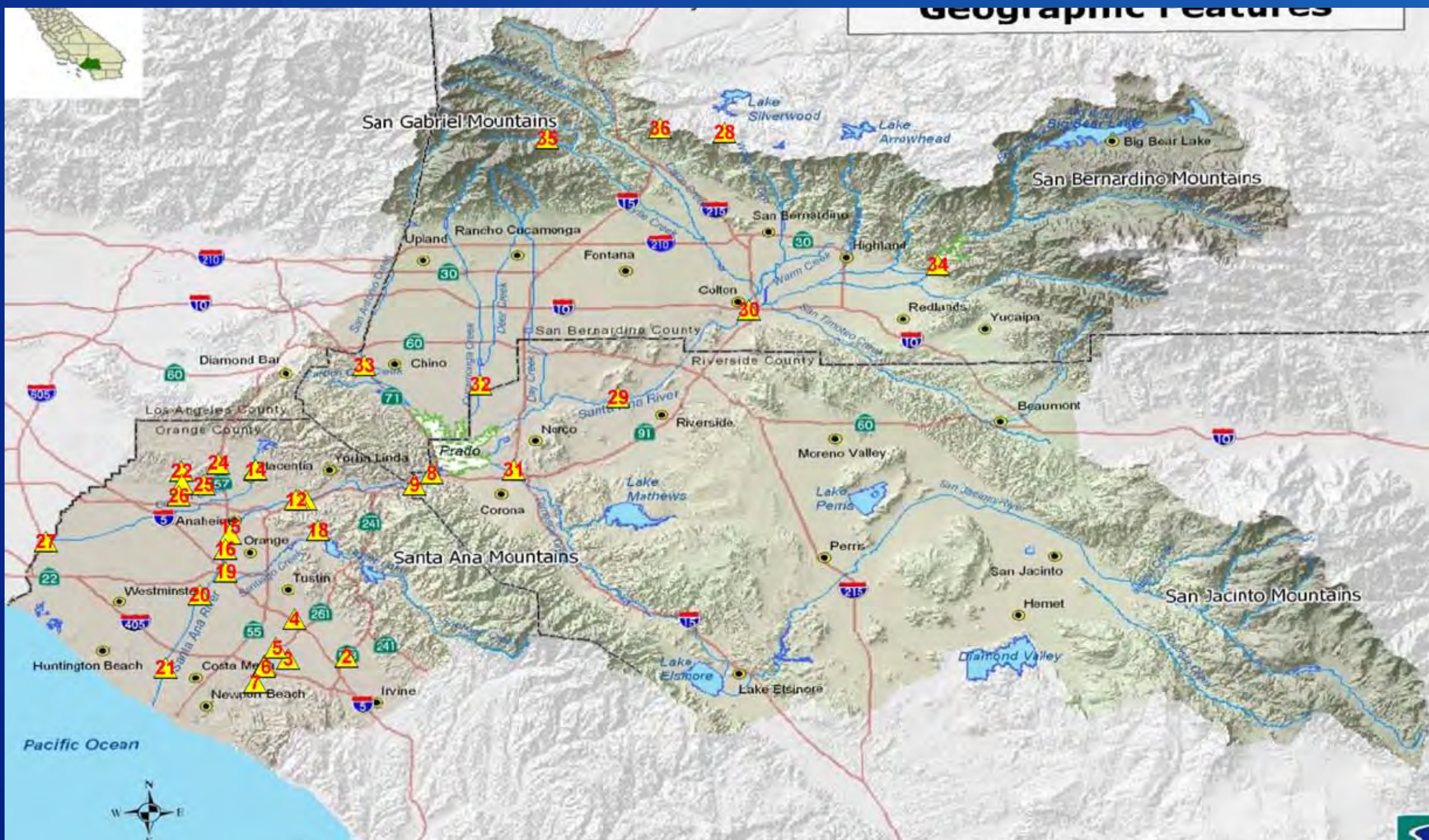
$$P_{\text{basin}} = \sum_i \sum_j P_{ij} \cdot f_{ij}$$

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

Data Collection & Pre-Processing

Streamflow

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

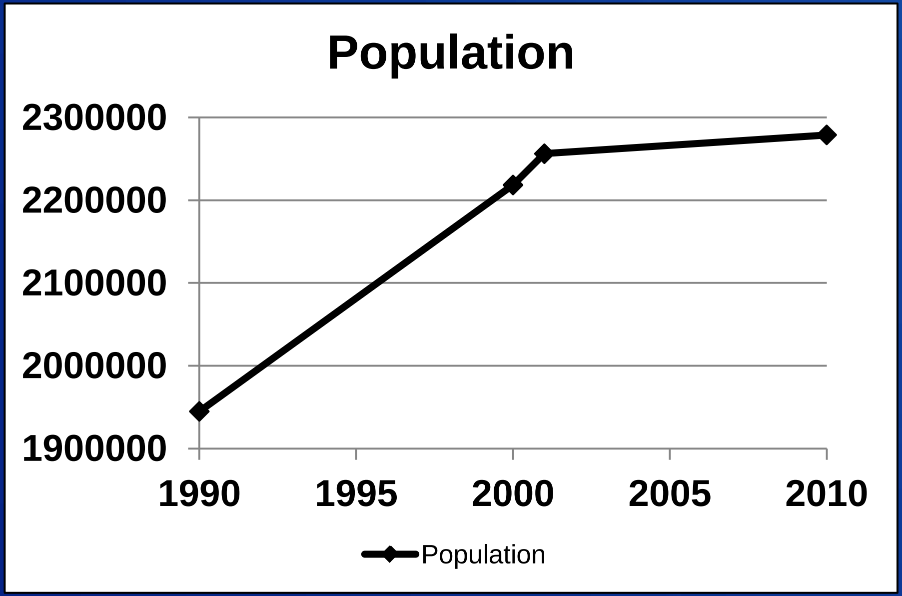


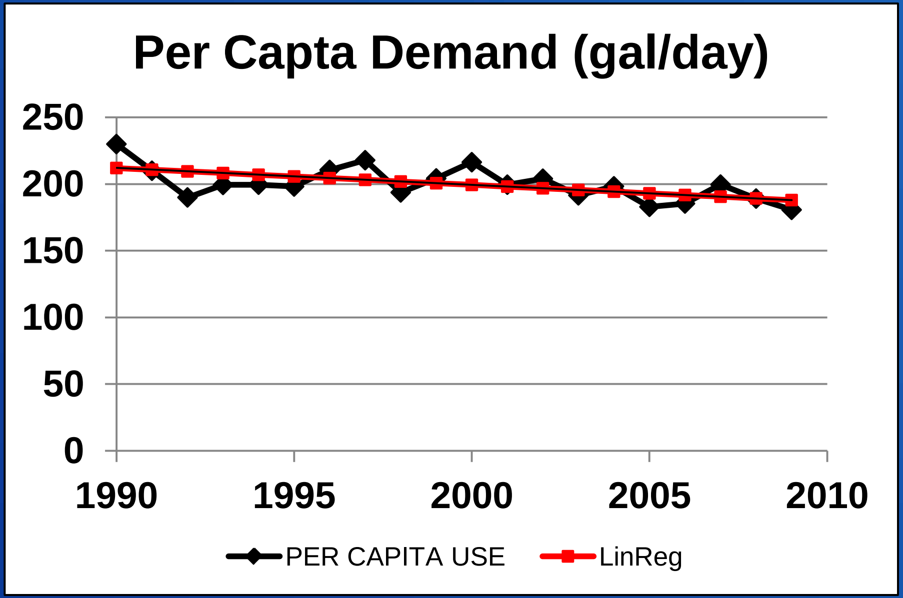
Data Collection & Pre-Processing

M&I Demand

- Population x Per Capita Demand
- Sources: population – Census tract data;

  per capita demand – 2000 & 2010 UWMPs





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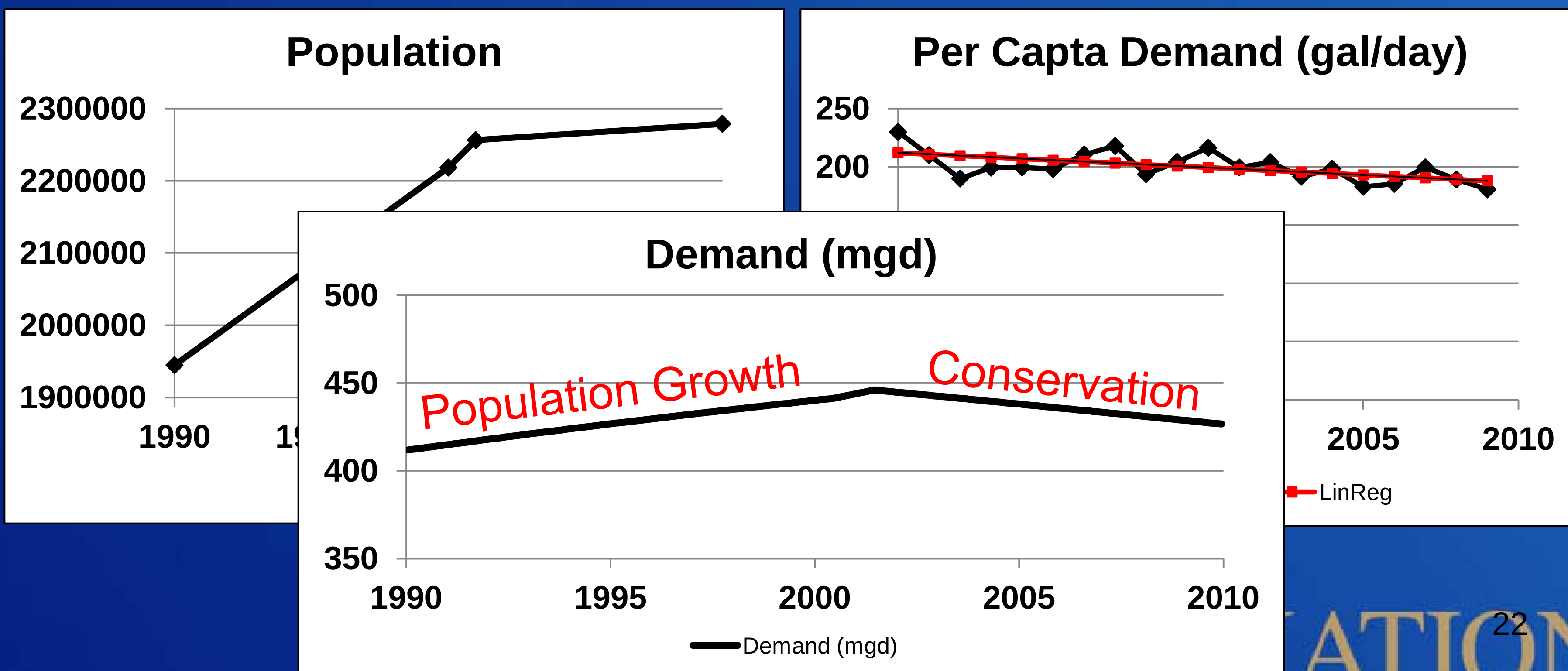
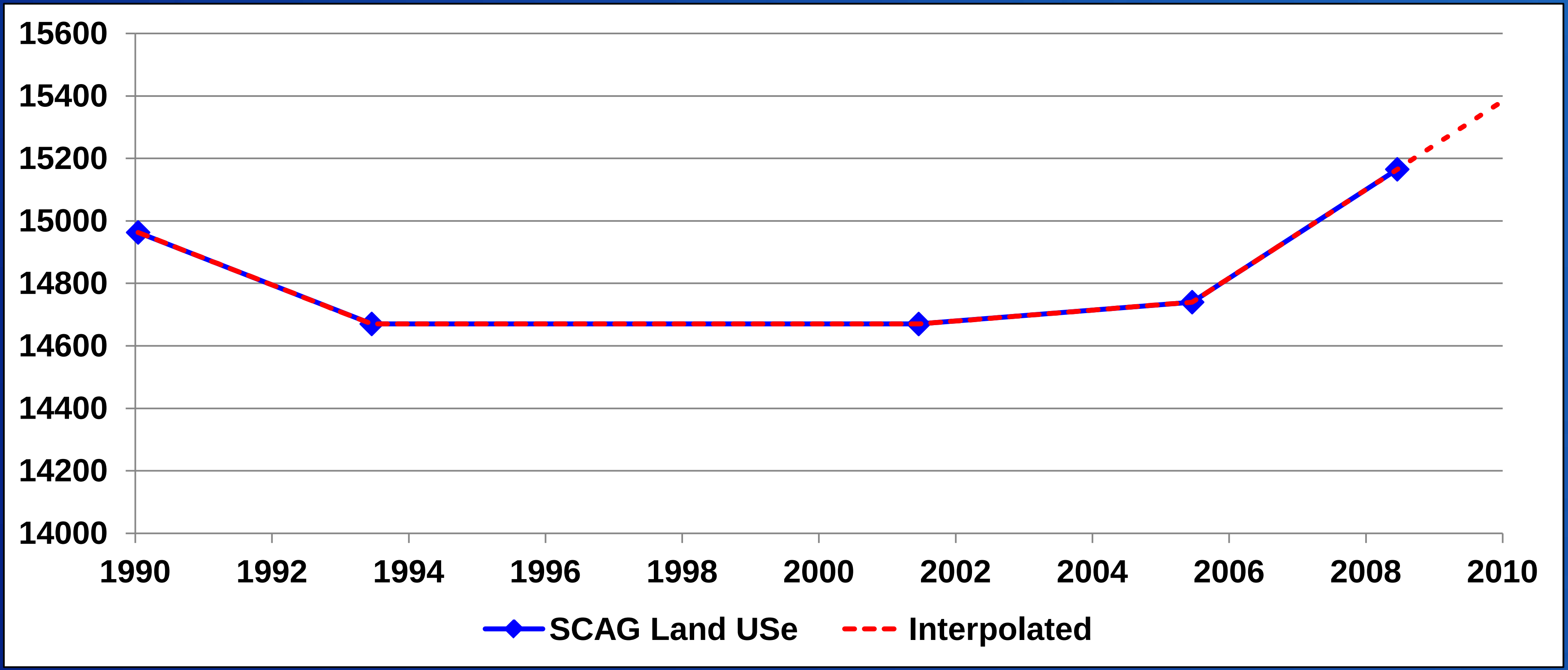


Data Collection & Pre-Processing

Agricultural Demand

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



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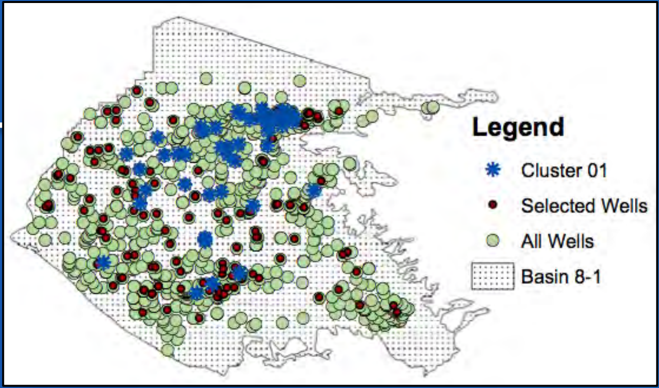
Data Collection & Pre-Processing

Augmented Supplies – Imports & Reuse

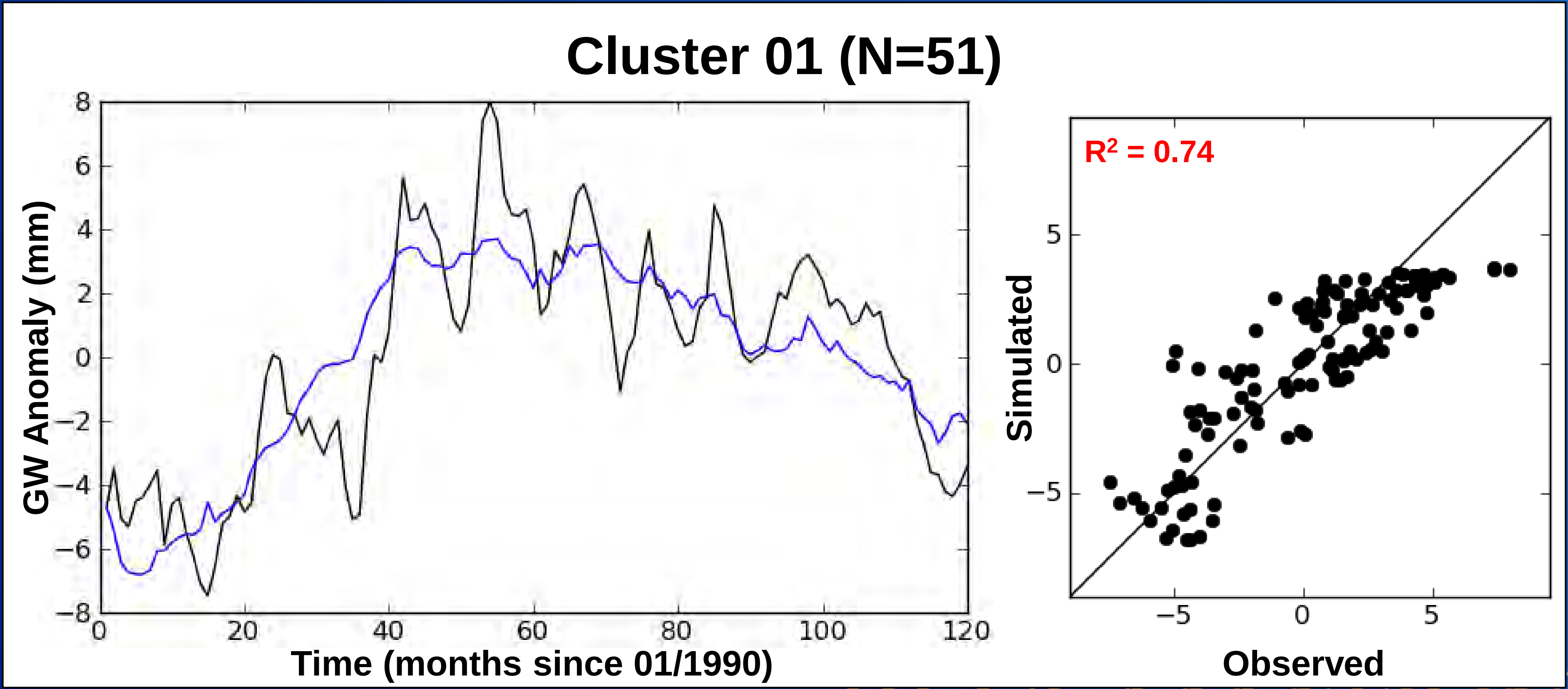
- Incomplete…
- Source: 2000 & 2010 UWMPs (insufficient data)

Preliminary Results



8-1: Coastal Plain of Orange County

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



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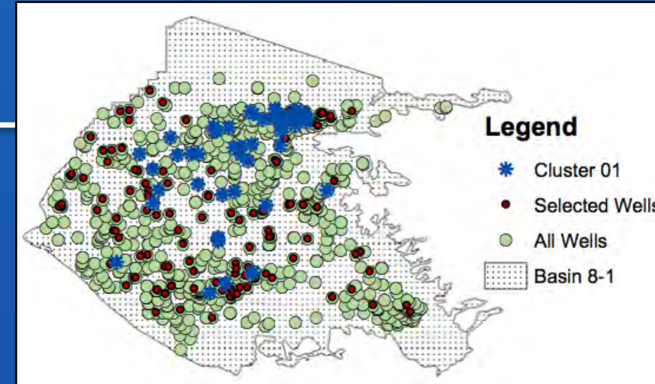

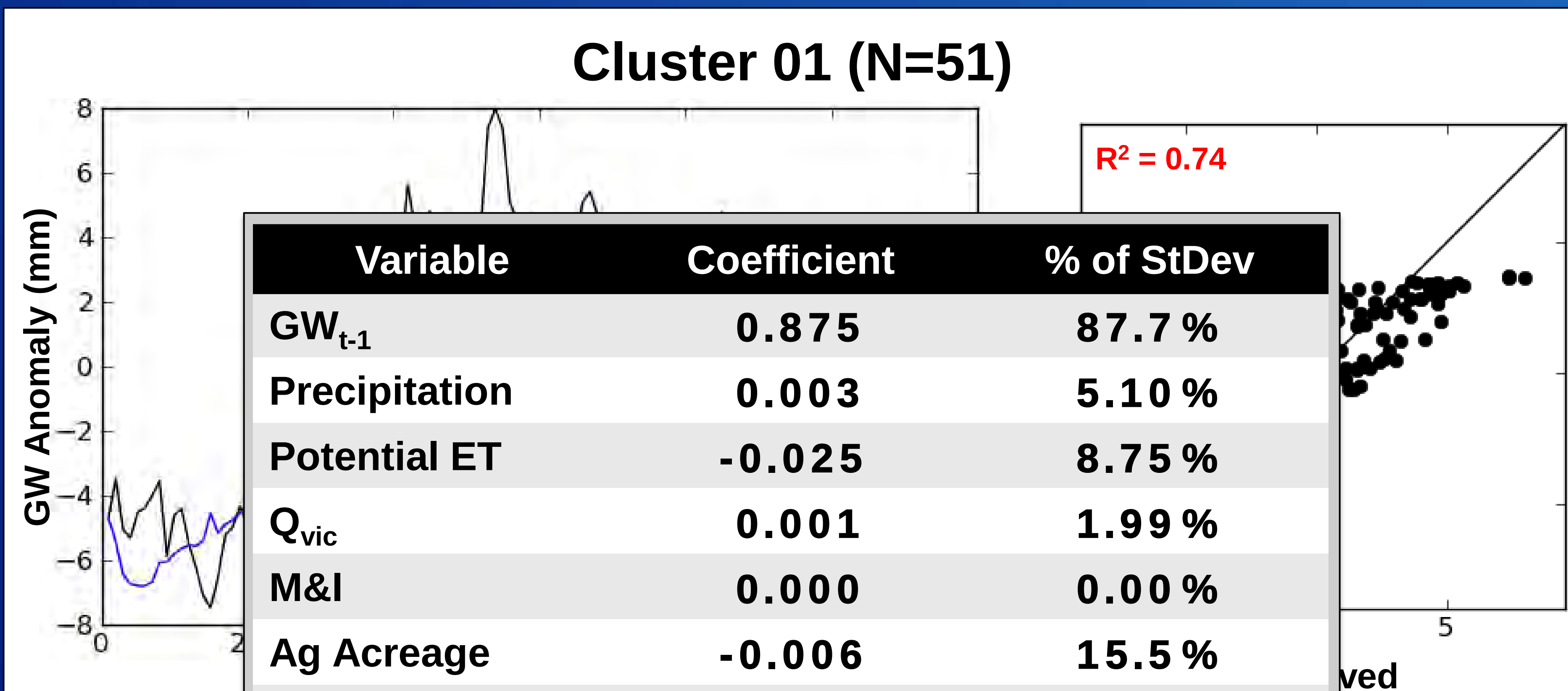

Variable	Coefficient	% of StDev
GW_{t-1}	0.875	87.7%
Precipitation	0.003	5.10%
Potential ET	-0.025	8.75%
Q_{vic}	0.001	1.99%
M&I	0.000	0.00%
Ag Acreage	-0.006	15.5%
Q_{import}	-----	-----

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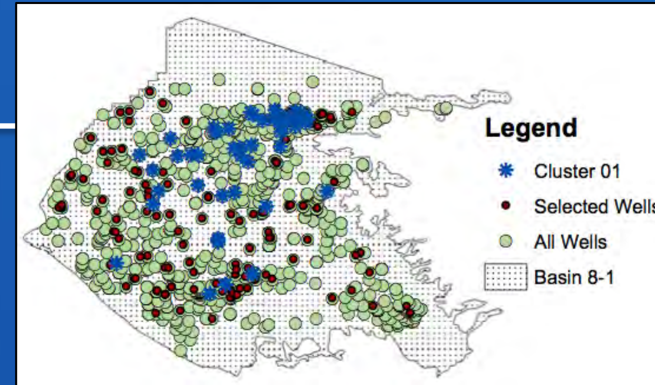
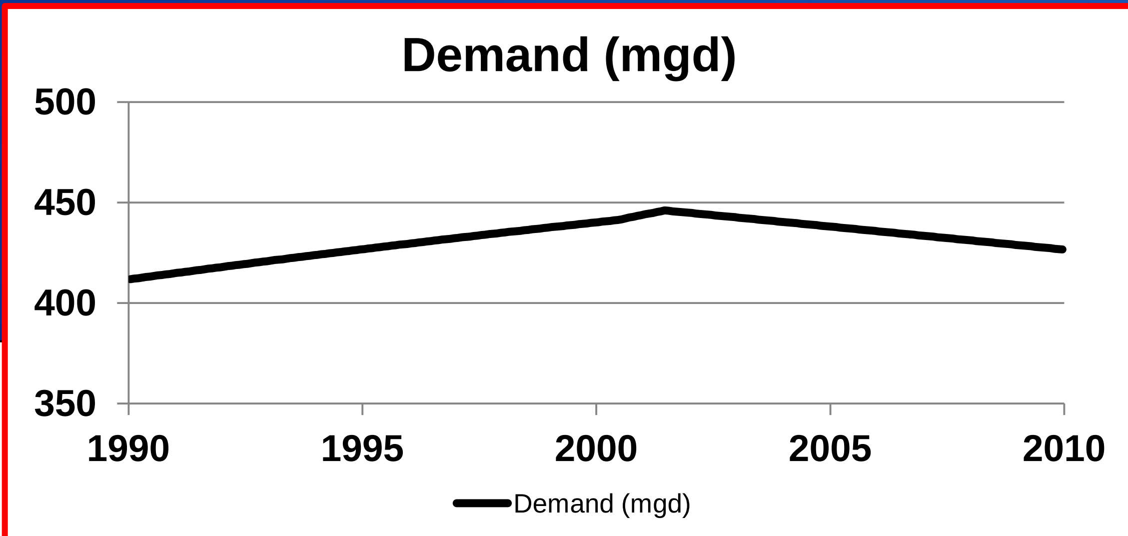
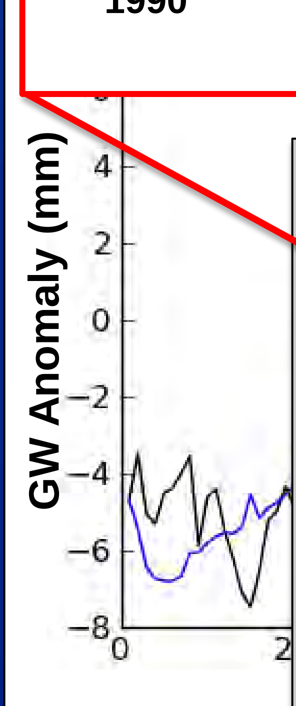
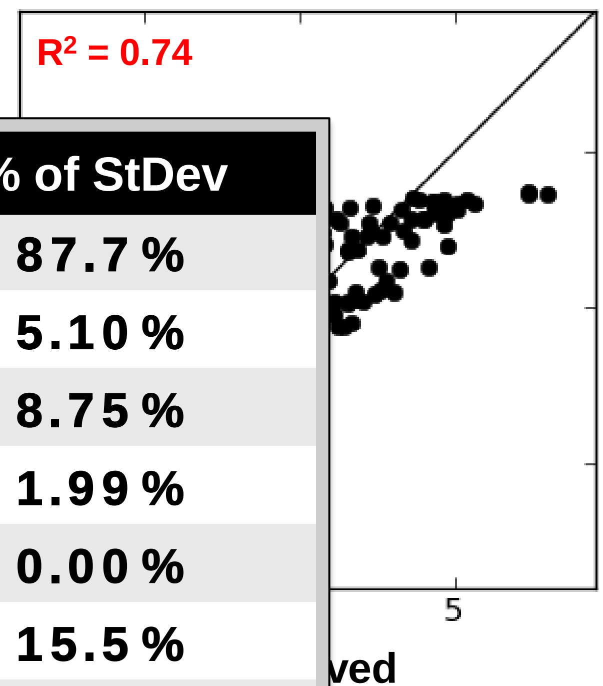




wells/cluster)

1)





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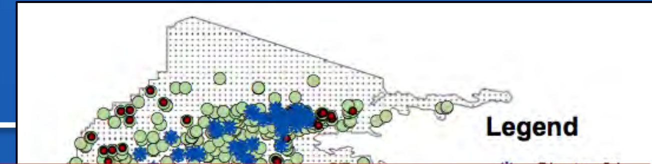

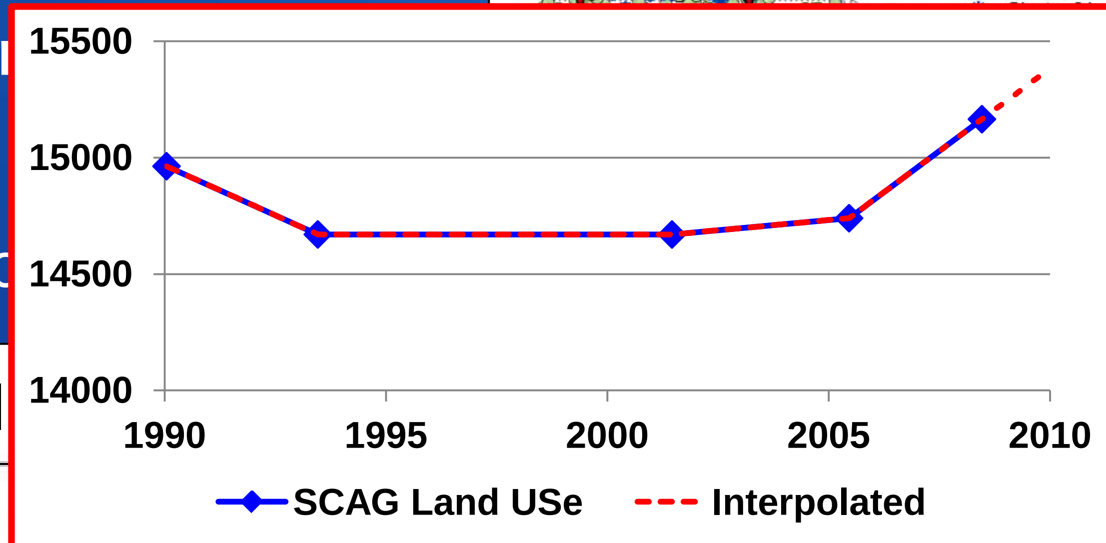

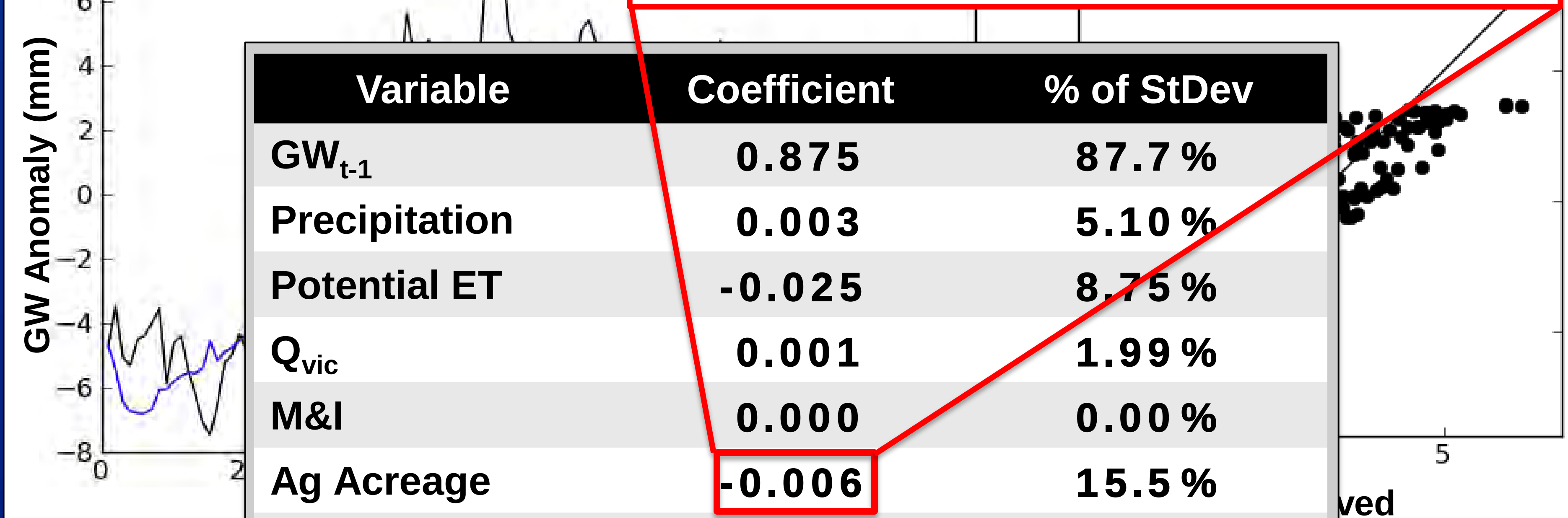

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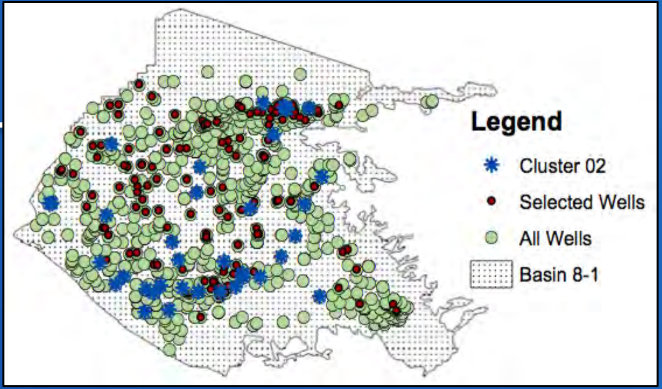

8-1: Coastal Plain of Orange County

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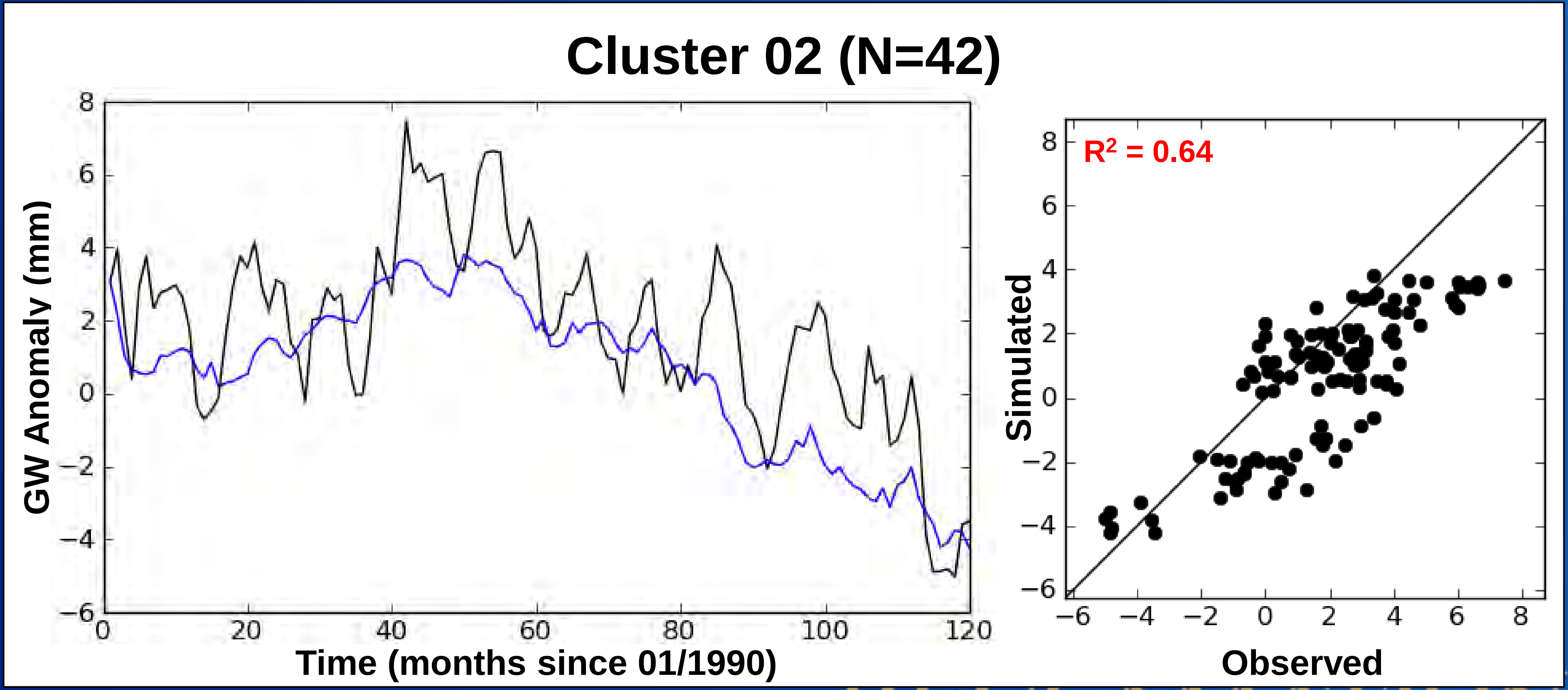

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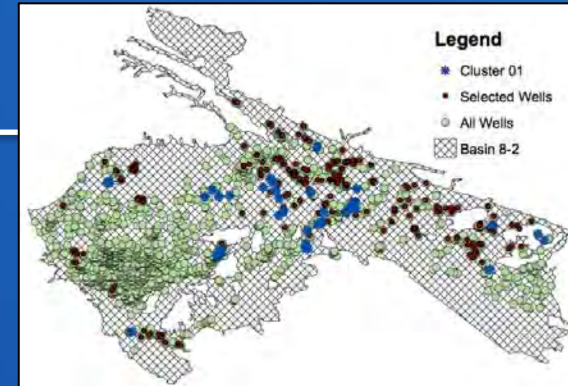
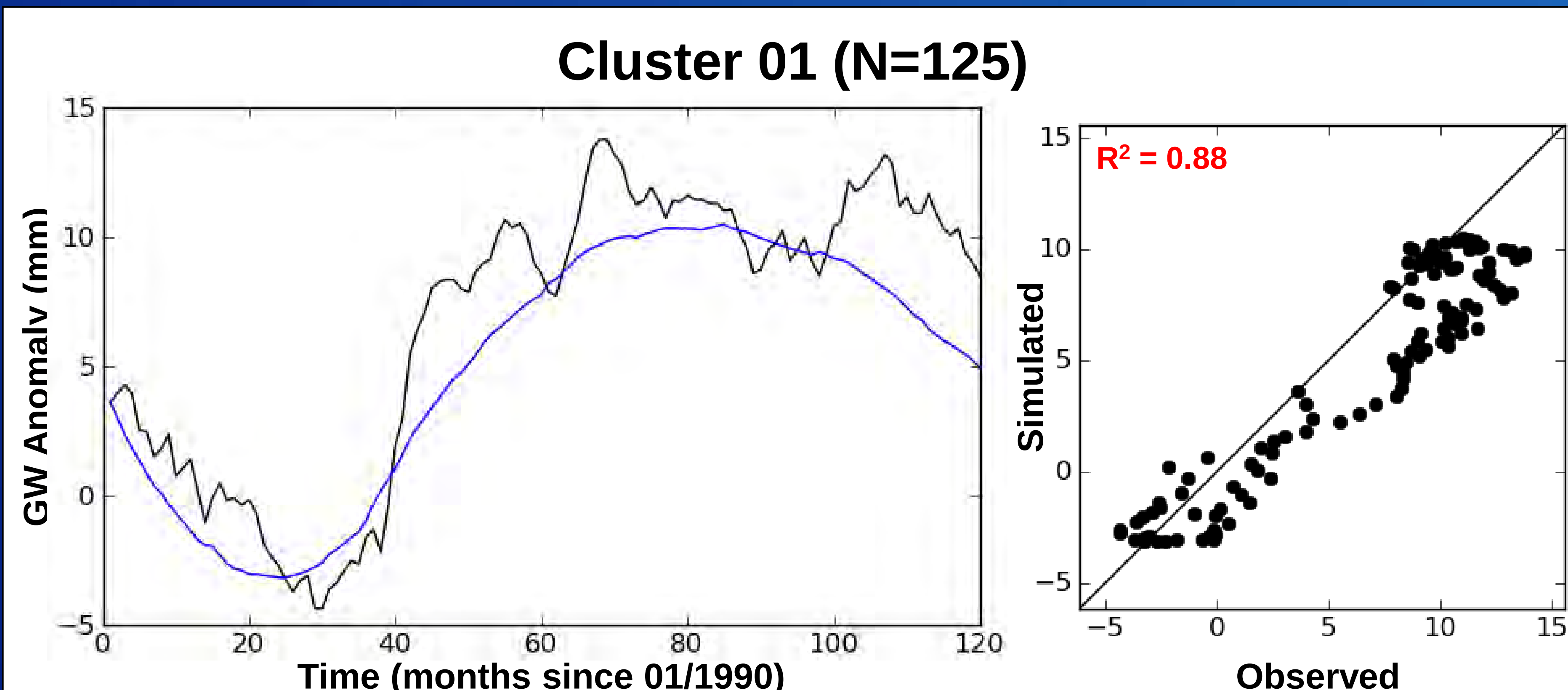


8-2: Upper Santa Ana Valley

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



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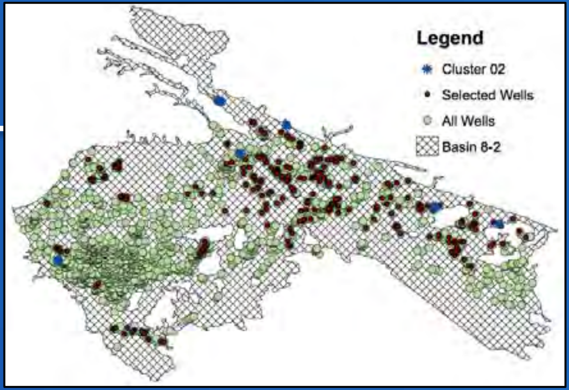

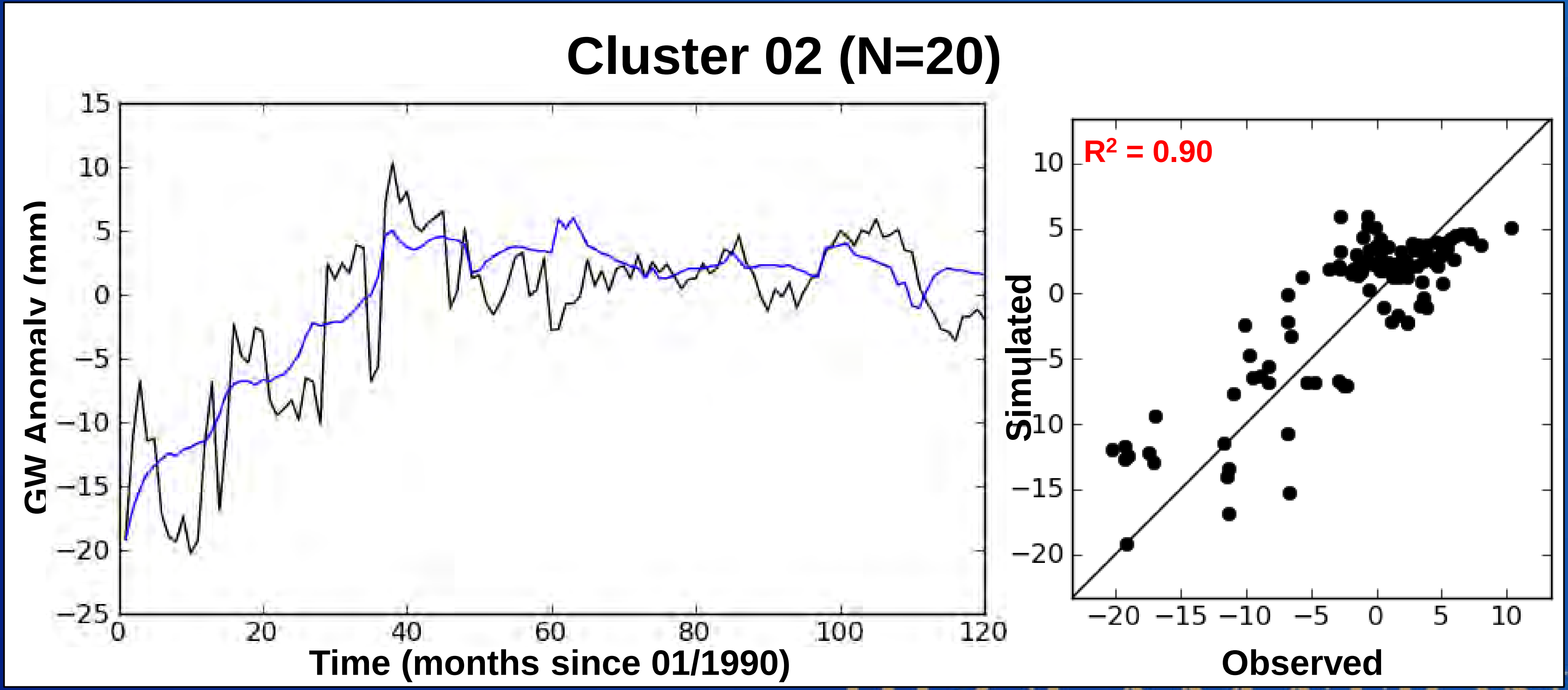

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Preliminary Results

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

Next Steps

Data Refinement

- Imports & Reuse
- Population & Per Capita Demand
- USGS stream gage data

Model Refinement & Cross Validation

- Assess value/contribution of each input variable
- Validate model outside of calibration period
  (fit model to data from 1990-1999;
  validate with data from 2000-2009)

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Next Steps

Comparison to "Traditional" Groundwater Modeling

- Work with Roy Herndon (OCWD) to compare results between simple modeling approach and sophisticated numerical model analysis for OC groundwater basin

Analysis of Sea Level Rise

- Simplified approach used here does not address issue of sea level rise
- Work with Roy Herndon (OCWD) to analyze potential impacts of sea level rise on sea water intrusion and salinity management

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?