Applying MODFLOW's Farm Process to California's Central Valley

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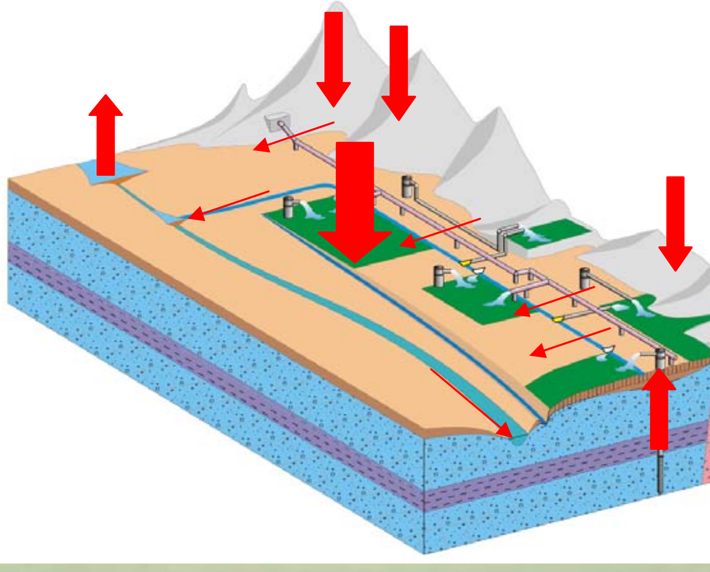
USGS Groundwater Resources Program

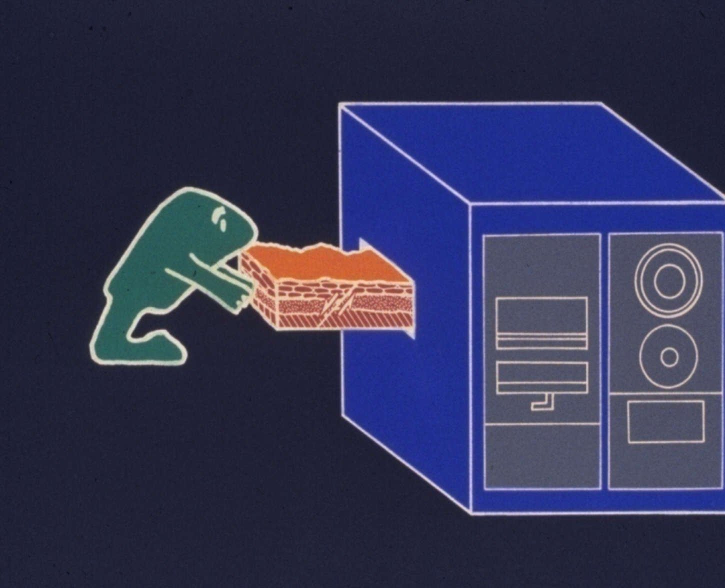
Focus on ground-water availability and changes in storage

Acknowledge DWR: Share some common data and model comparison

Overview:

- Study Objectives
- System Conceptualization
- Farm Process
- Texture Model
- Hydrologic Model
- Conclusions





Objectives:

- **TEXTURE MODELING**: Develop a better understanding of the internal architecture of the freshwater bearing deposits of the Central Valley.
- **FARM PROCESS**: Develop an approach for systematically estimating water budget components for the ground water flow system in areas dominated by irrigated agriculture.
- **GROUND-WATER MODEL**: Develop a model of the Central Valley ground-water flow system *capable of being accurate* at scales relevant to water management decisions.

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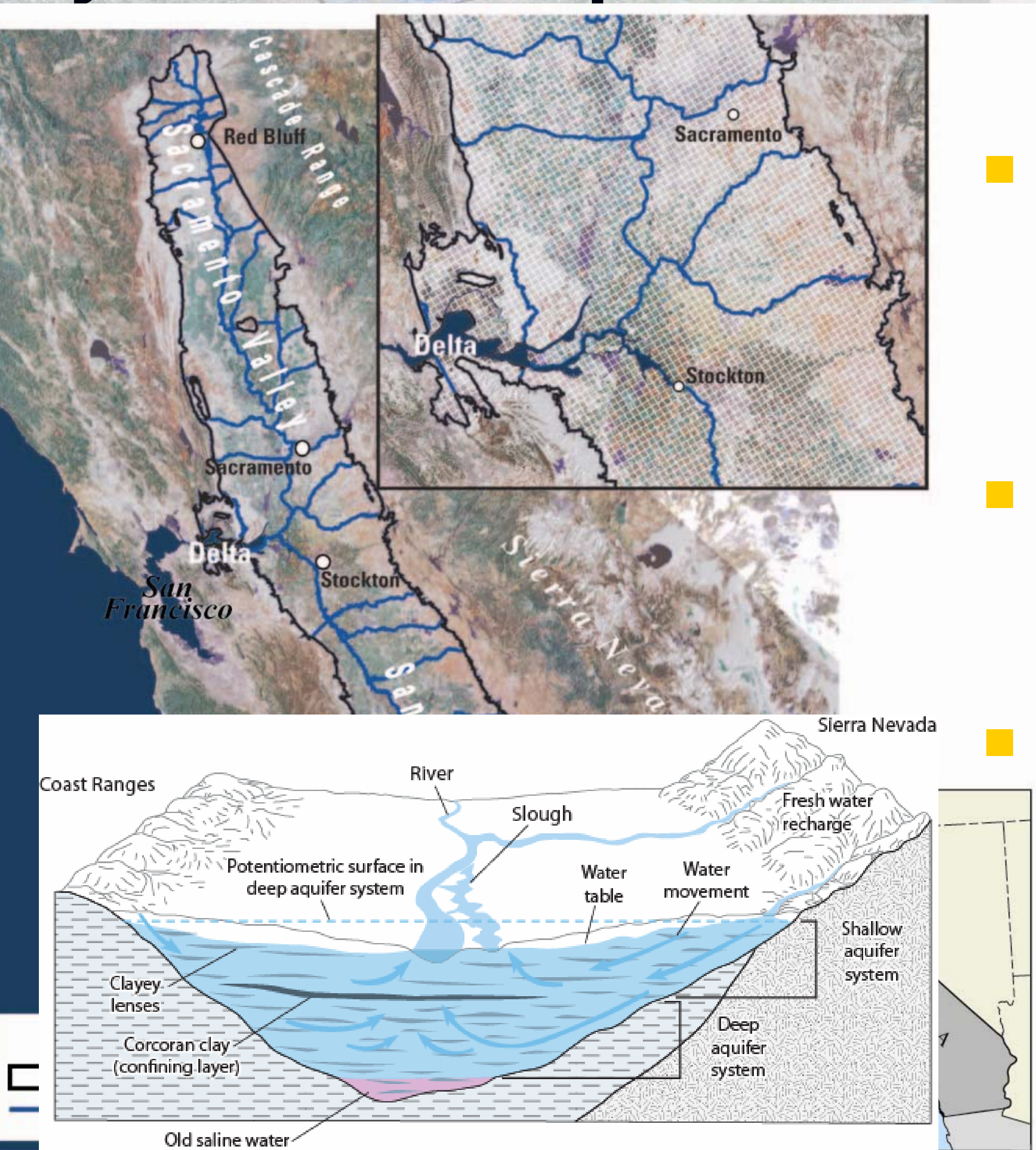
System Conceptualization:

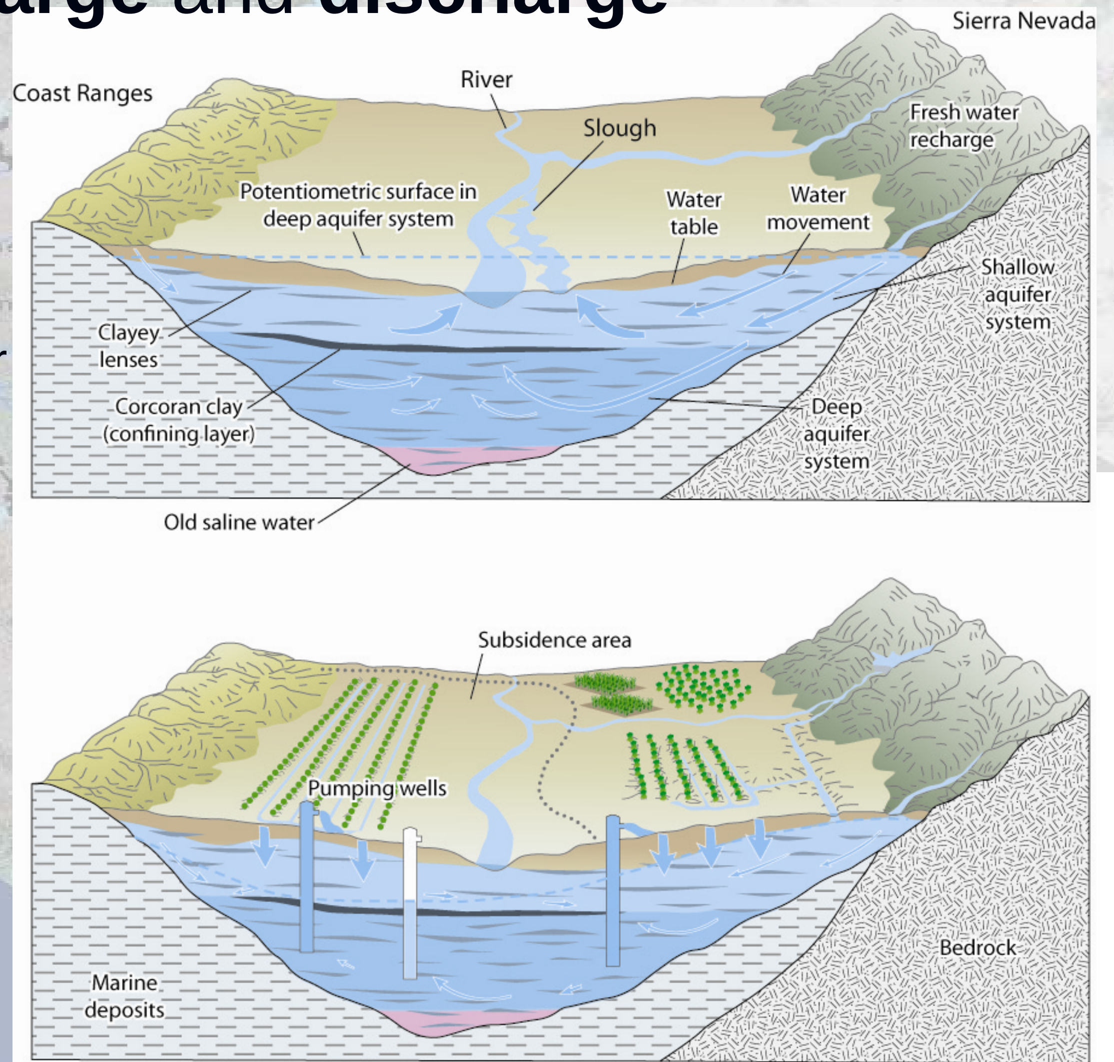


- Approx. 20,000 mi^2 (50,000 km^2) sediment filled structural trough
- Average thickness of sediments = 2,400 feet (732 m)
- Generally surrounded by relatively impermeable rock (except Delta)

System Conceptualization:

- **DEVELOPMENT AND IRRIGATED AGRICUTURE**
  - Major effects on **volume** and **distribution** of ground-water **recharge** and **discharge**
  - PRE-DEVELOPMENT
    - Recharge and discharge approx. 2 million acre-ft/yr
  - DEVELOPMENT
    - Began in about 1850
    - Most hydrologic data after major hydrologic changes
  - POST-DEVELOPMENT
    - Engineered system –
      - Canal network
      - Diversions
      - Reservoirs

      control inflows
    - Discharge increased to 12 million acre-ft/yr
    - Recharge increased to 11 million acre-ft/yr



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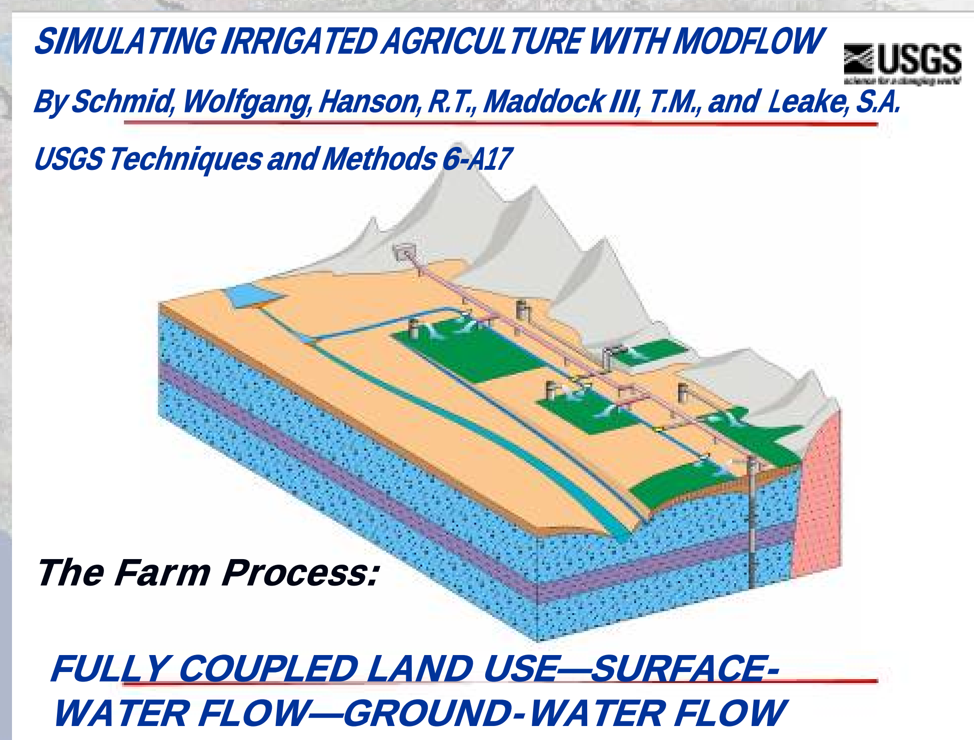
Farm Process:

- Systematic approach for estimating water-budget components (fully coupled)
- Based on:
  - the consumptive use of water by plants
  - available surface-water deliveries
- Misnomer
  - Landscape Process?



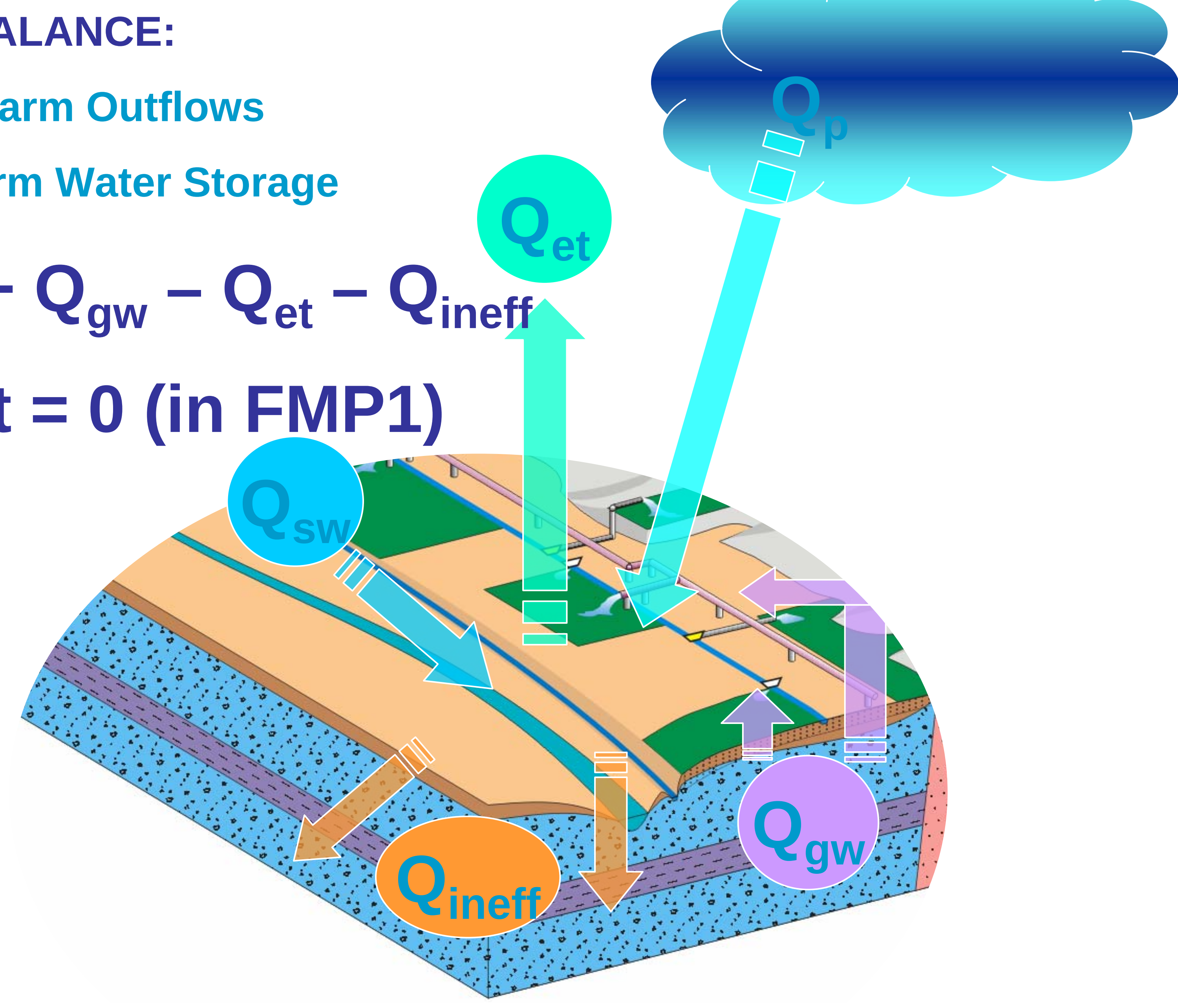
FARM MASS BALANCE:

Farm Inflow – Farm Outflows

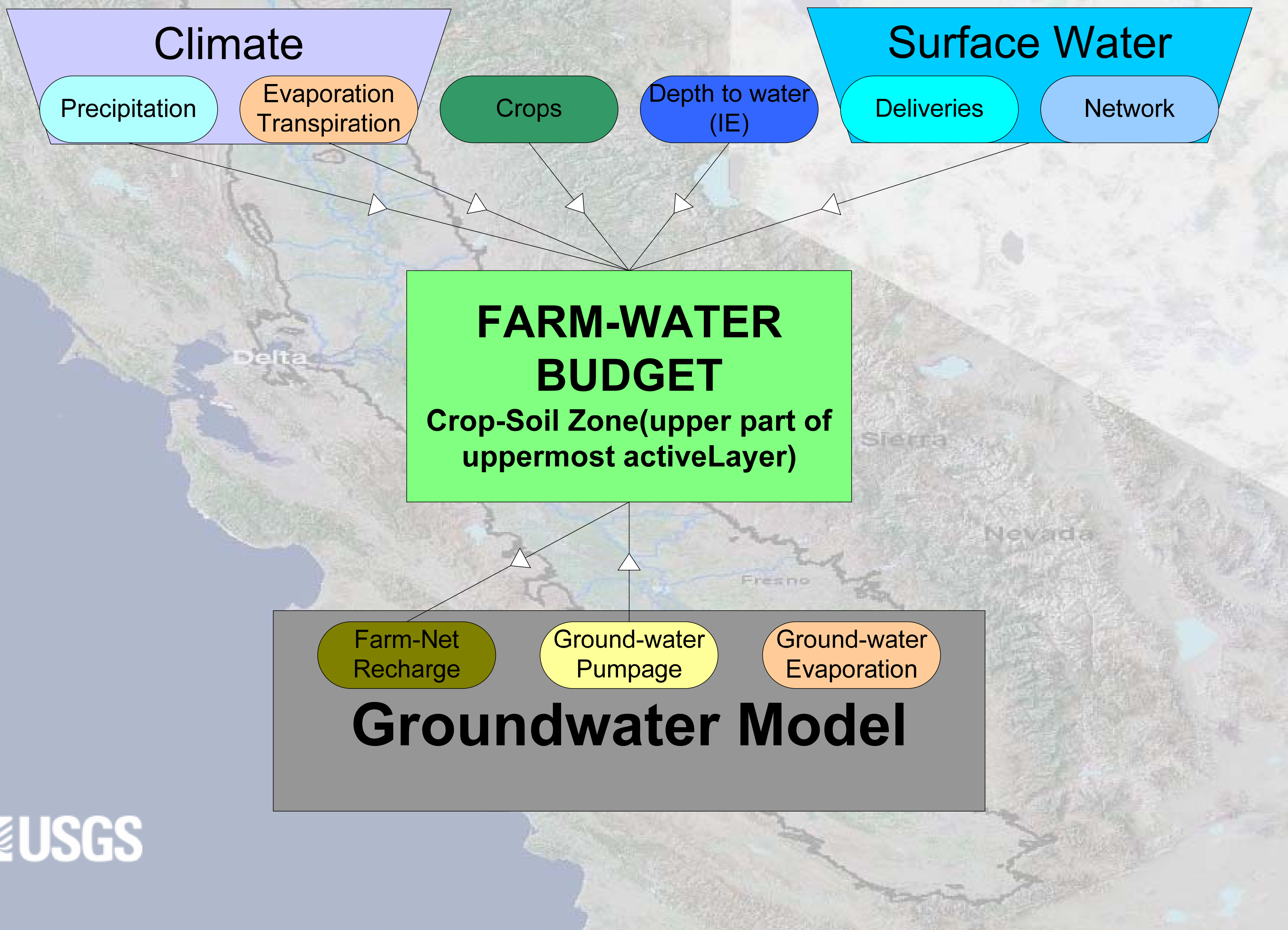
= Change in Farm Water Storage

$$Q_p + Q_{sw} + Q_{gw} - Q_{et} - Q_{ineff}$$

$$= dS_{farm}/dt = 0 \text{ (in FMP1)}$$



FARM PROCESS COMPONENTS



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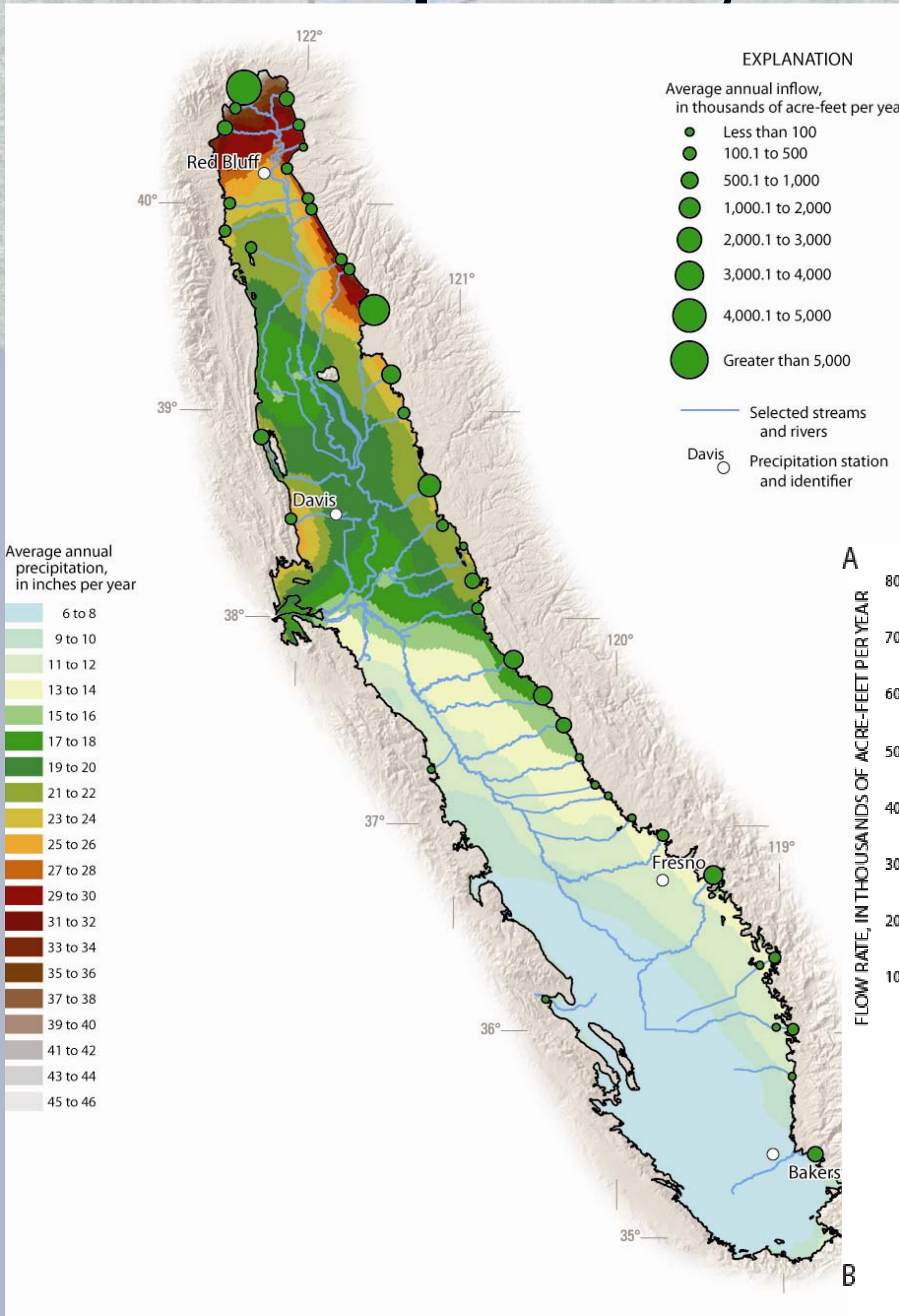
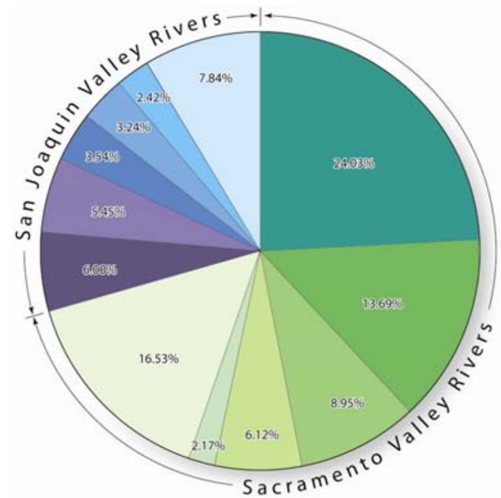
Precipitation, Inflows, and Climate





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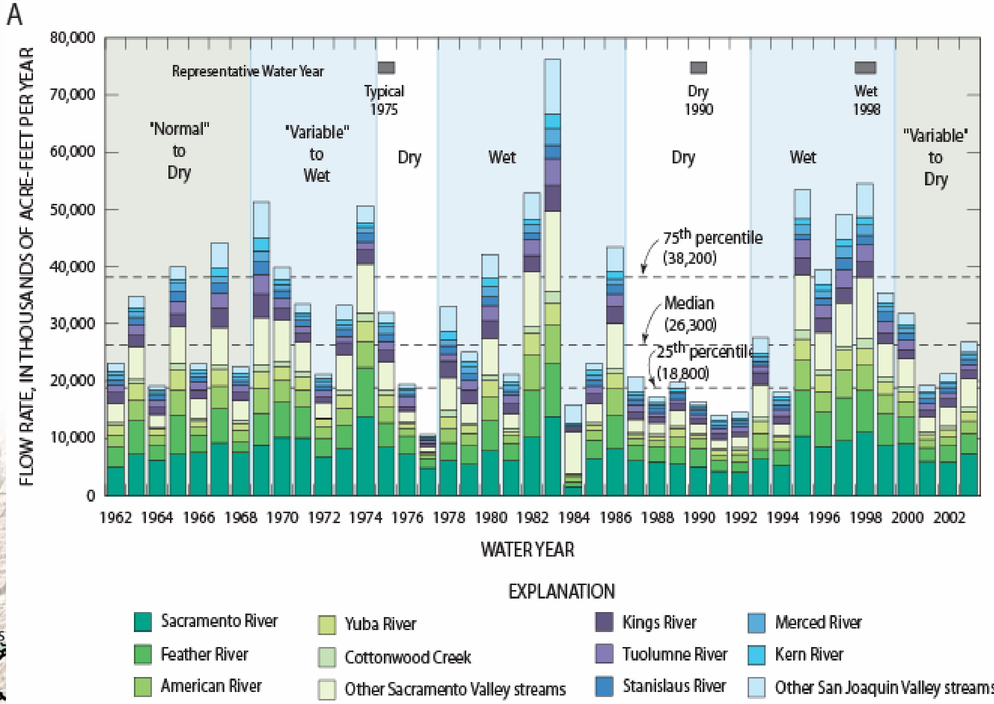

B

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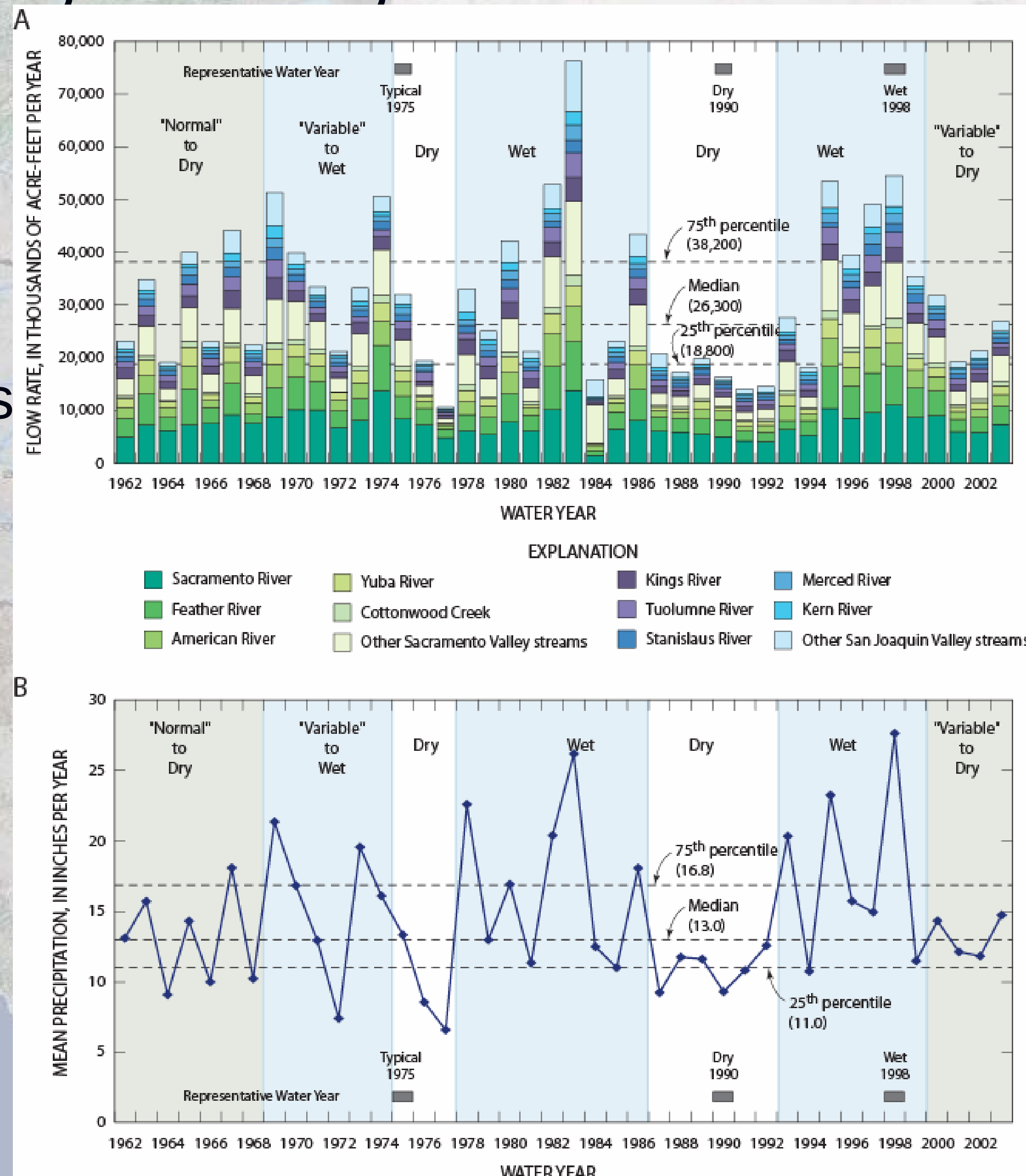
Precipitation, Inflows, and Climate

- Vary Spatially
- Vary Temporally
  - Annually
  - Seasonally
- Characteristic years
  - Typical
  - Wet
  - Dry



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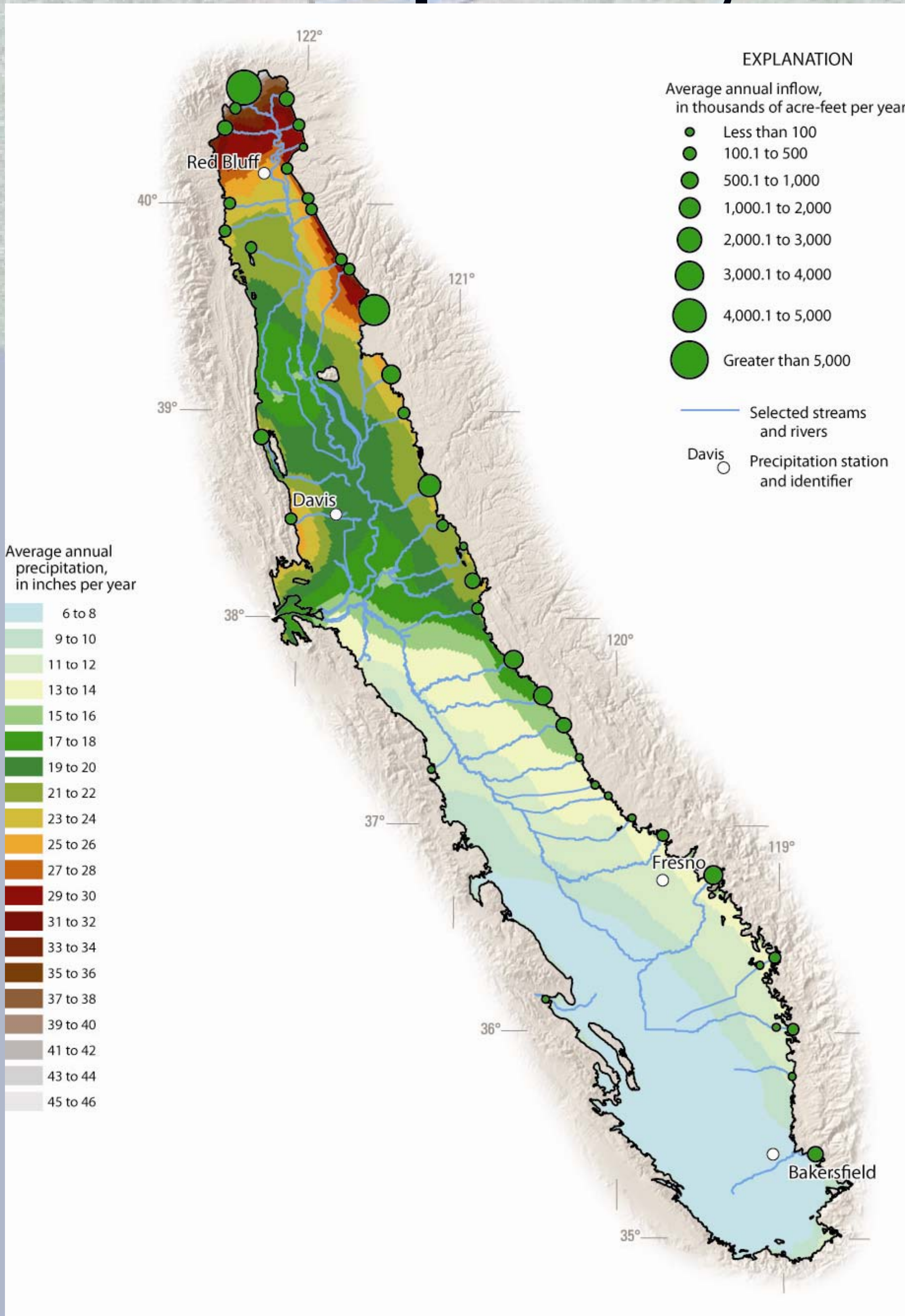
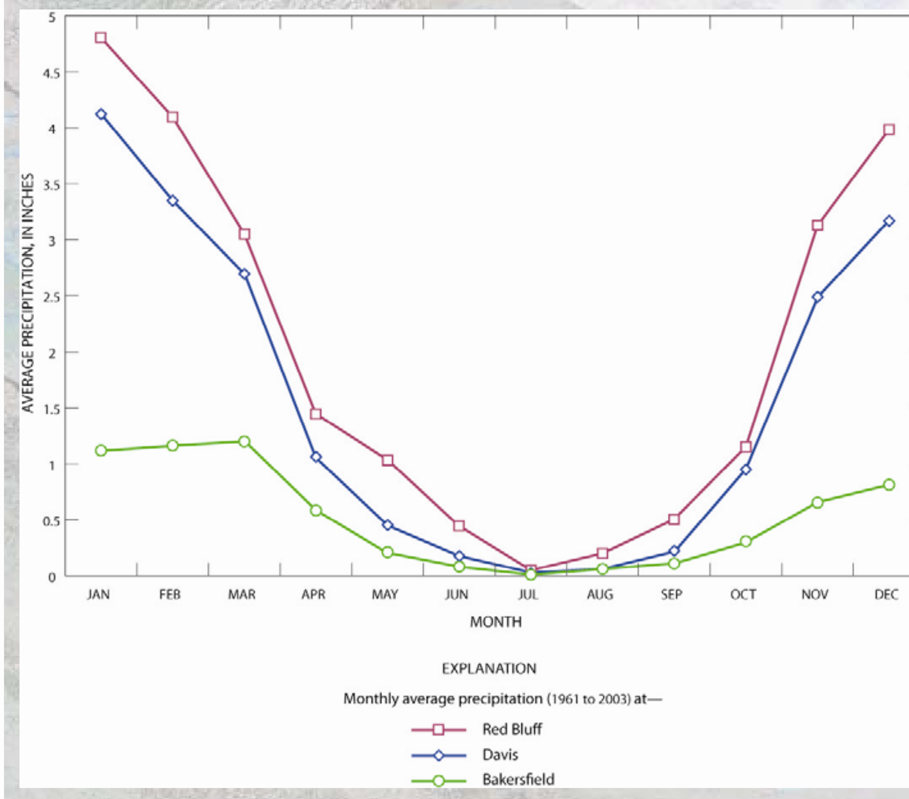


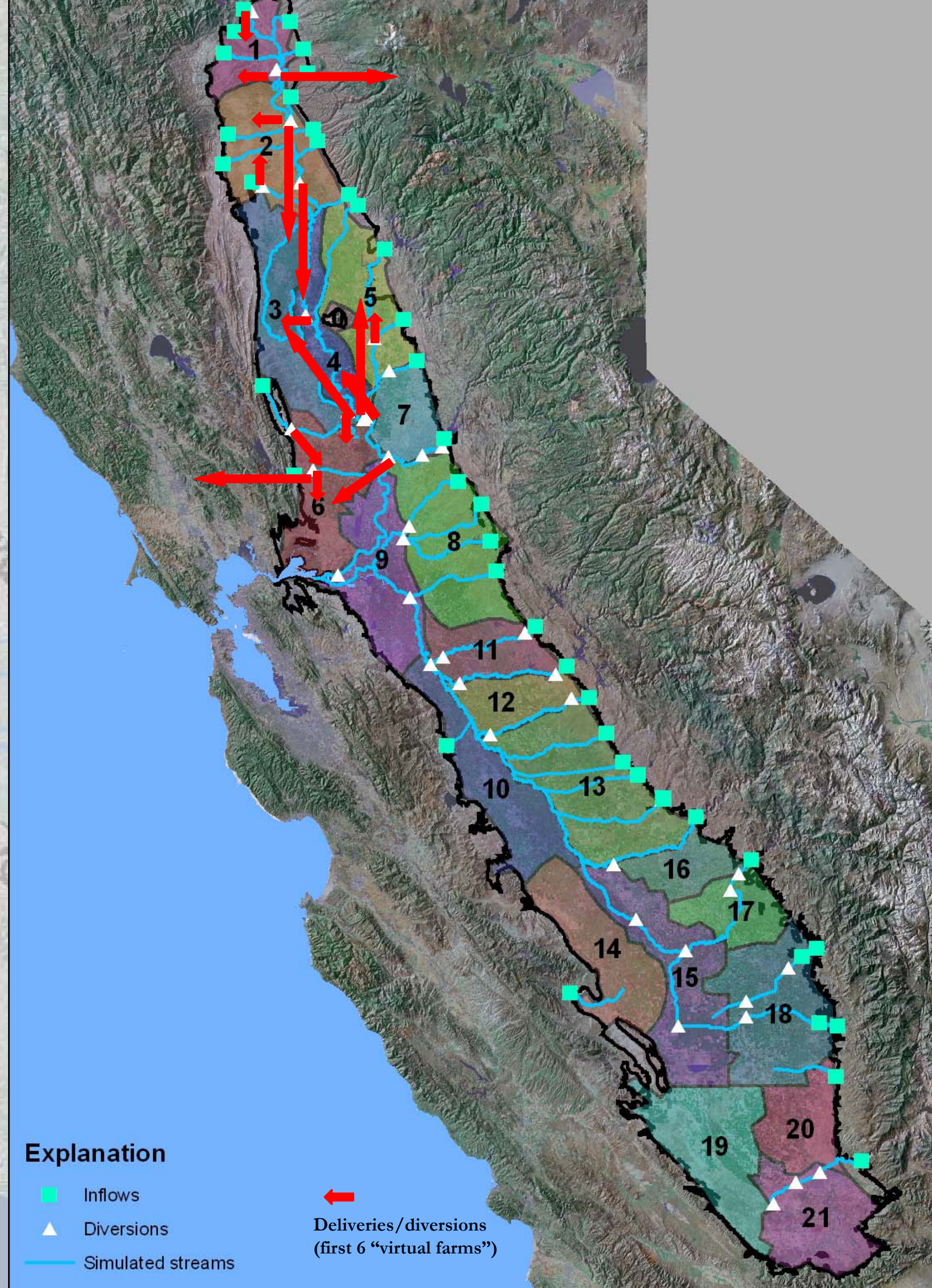
- Inflows, Precipitation, and ET
  - Vary Spatially
  - Vary Temporally
    - Annually
    - Seasonally



Stream Network

- Inflows (43)
  - Source:
    - DWR – 40 sites (many USGS measurements)
    - USGS – 3 sites
- Diversions (66) – Deliveries
  - Source: DWR
  - 64 to farm process
  - 2 diverted outside of model

USGS



Virtual farms & Landuse

- 21 virtual farms
- 5 landuse maps for 1961-2003 period
- 22 landuse categories
- Including
    - Urban
    - Native
    - Crops

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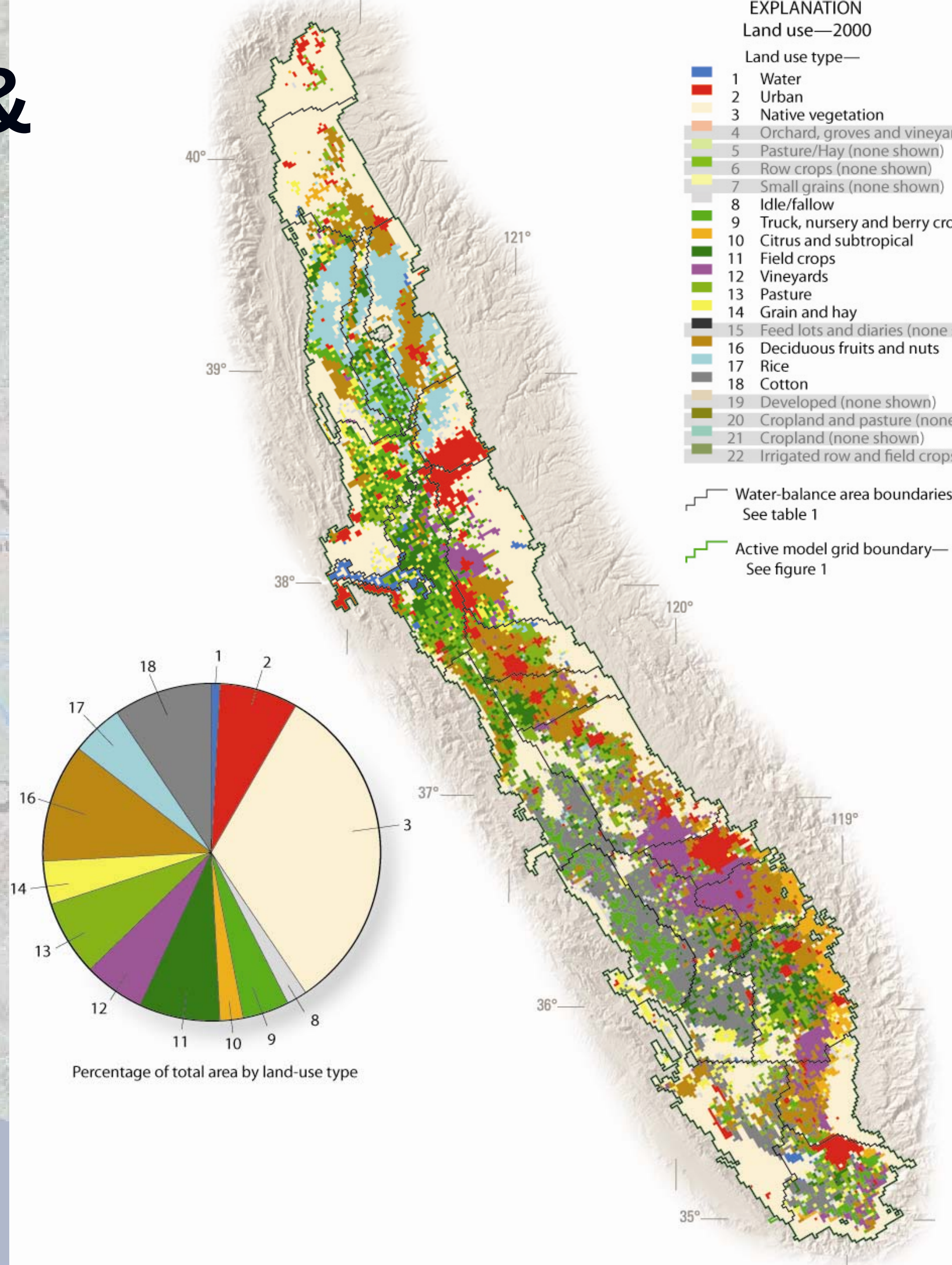
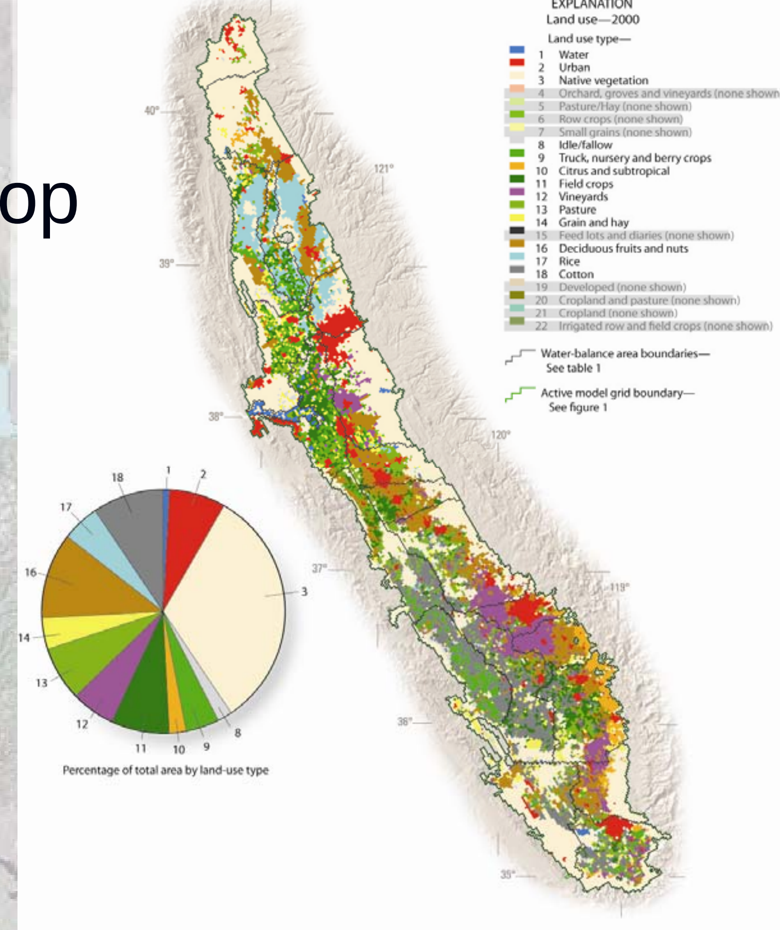
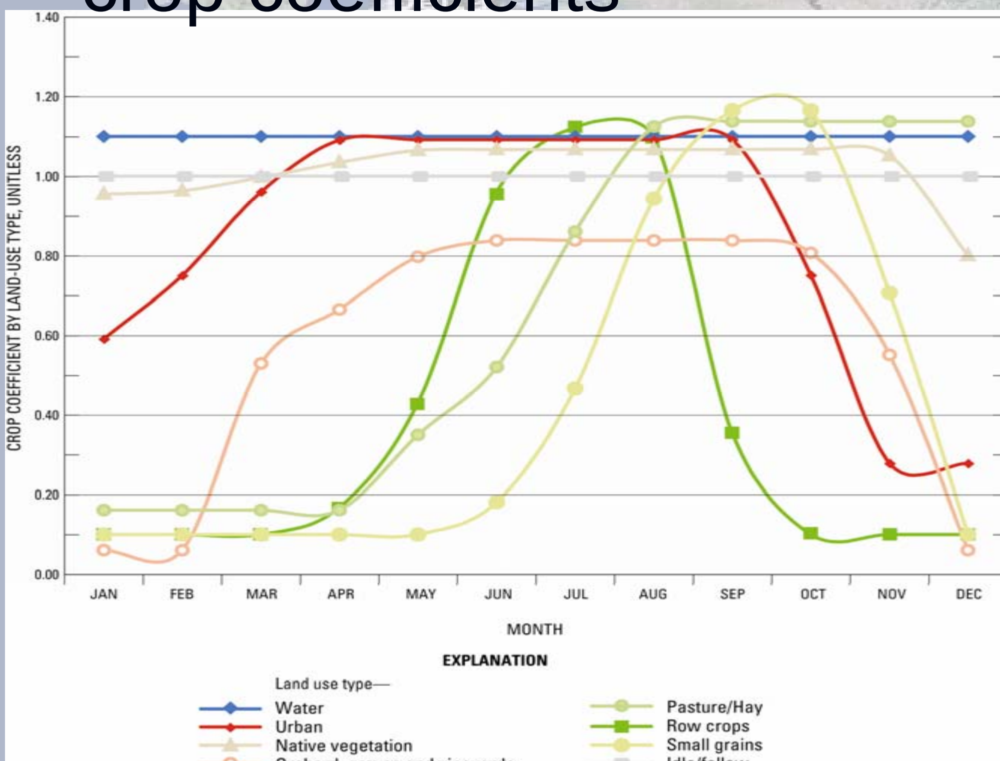


Landuse and Crops

- Landuse category = virtual crop
- Virtual crop coefficients attributed to virtual crops
- Area-weighted averages of crop coefficients





Model overview

- Uniform one sq. mile cells
- 1961 – 2003
  (monthly stress periods)
- Packages\Processes
  - Farm (water budget)
  - Stream flow routing (SFR)
  - Wells (MNW) (municipal/ farm)
  - Subsidence (SUB)
  - Flow barriers (HFB)
- Sensitivity Analysis and Calibration with Parameter Estimation (UCODE)

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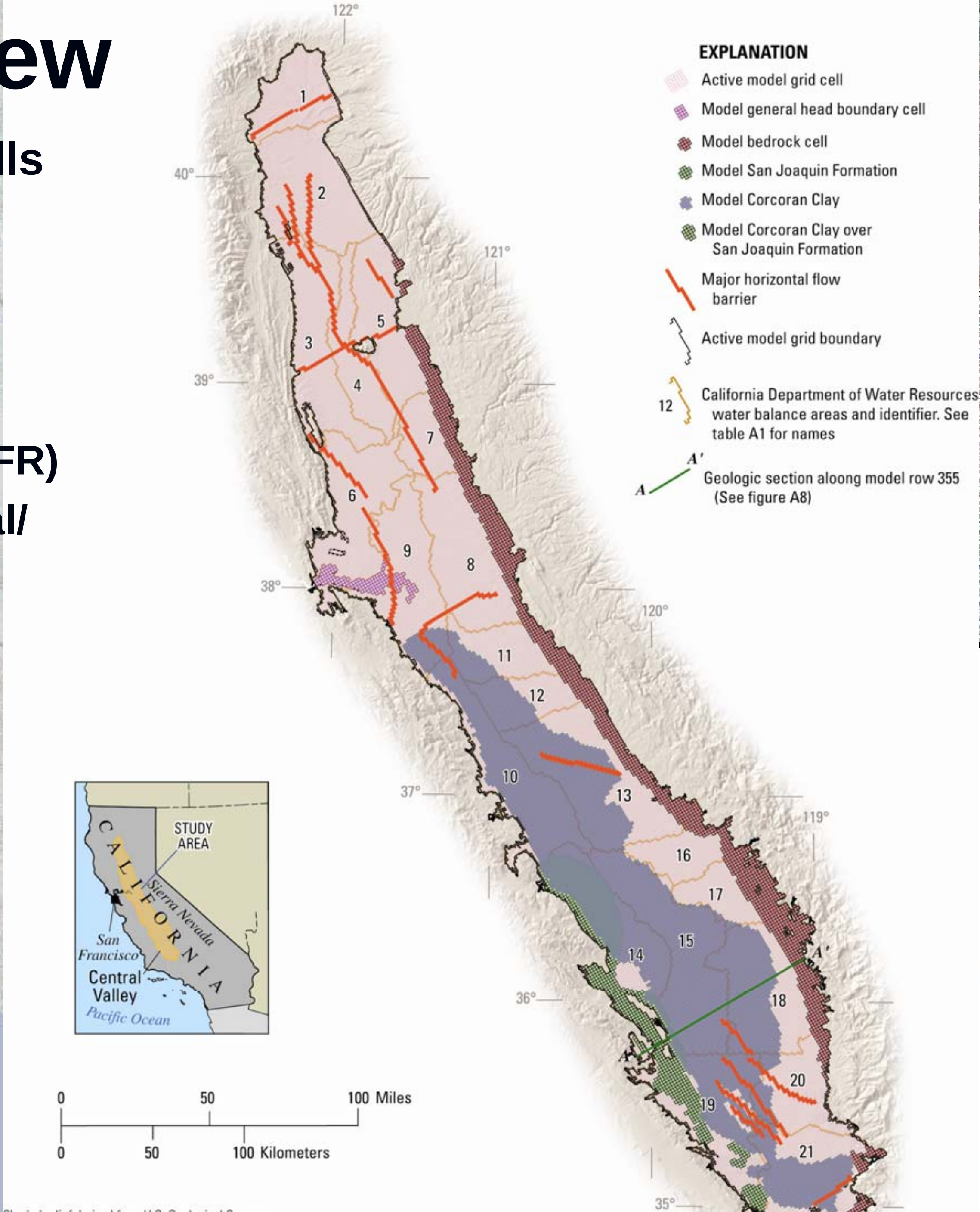
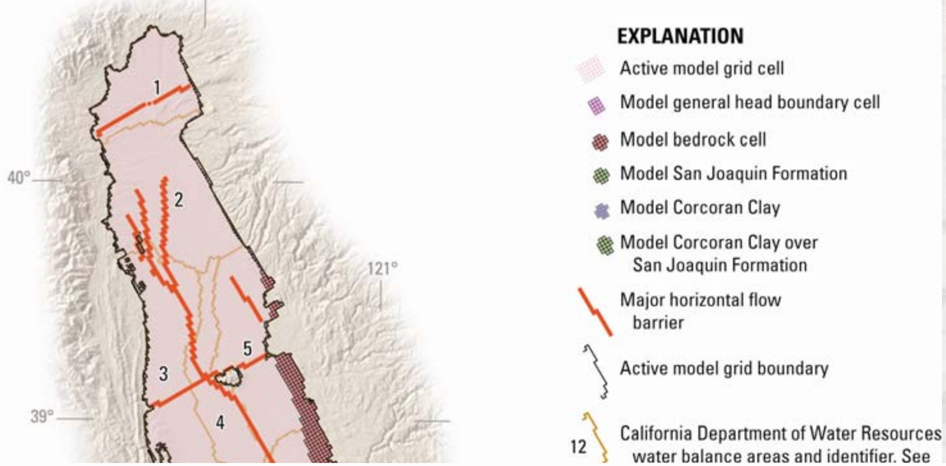
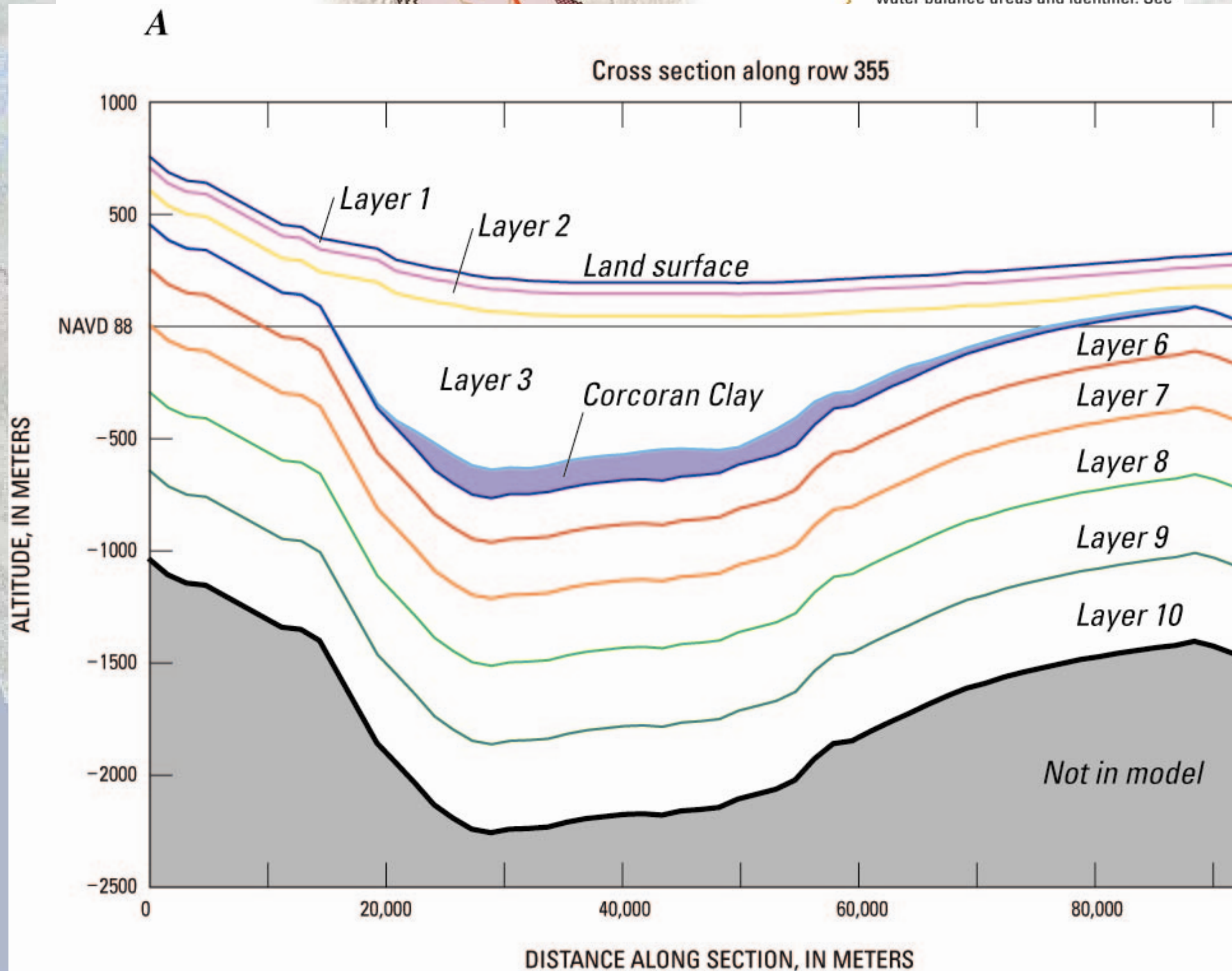


Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006, Albers Equal Area Conic Projection

Discretization

- 10 layers
- Thinner near surface
- Generally equal thickness in multiples of 50 ft increments
  1. 50
  2. 100
  3. 150
  4. Upper Corcoran Clay
  5. Lower Corcoran Clay
  6. 200
  7. 250
  8. 300
  9. 350
  10. 400
- Total Thickness Outside Corcoran: 1800 ft (550 m)
- Dummy layers outside Corcoran Clay





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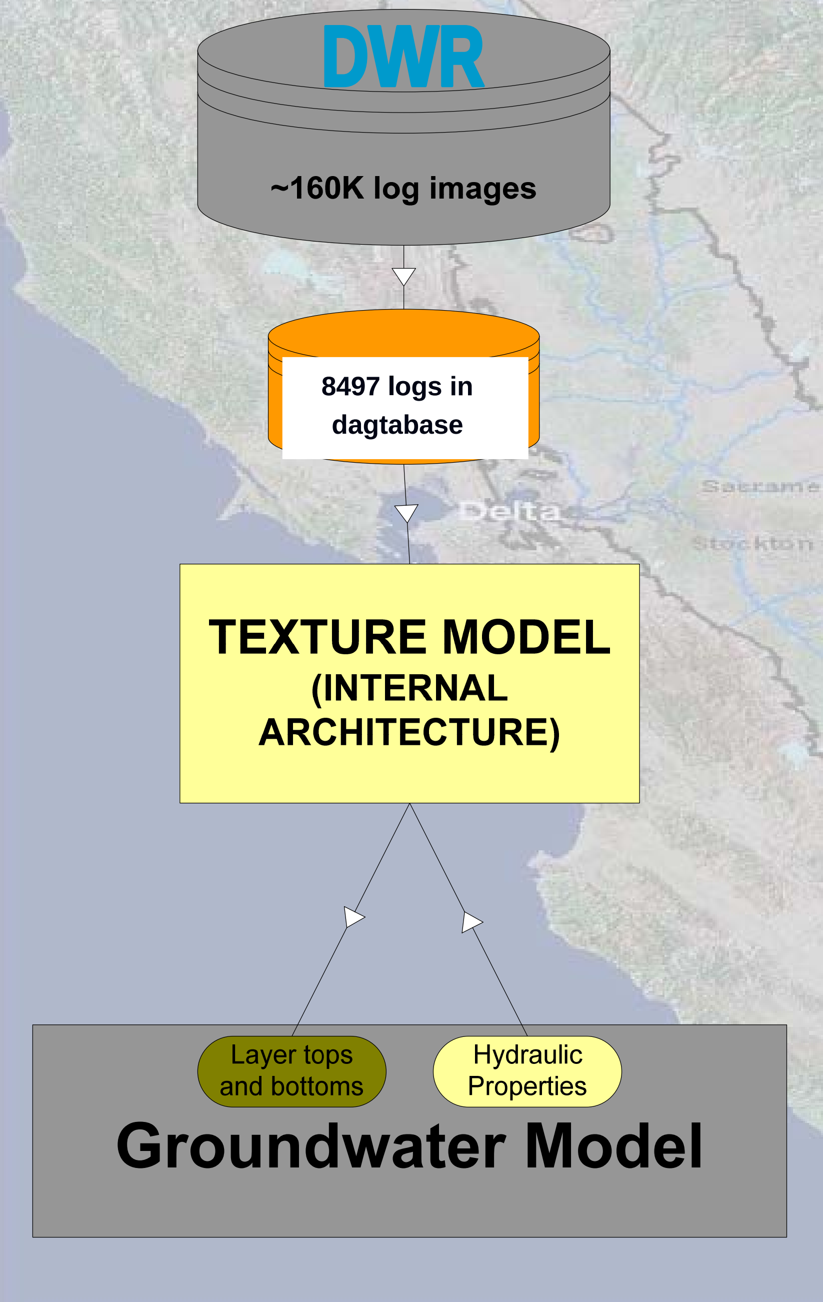
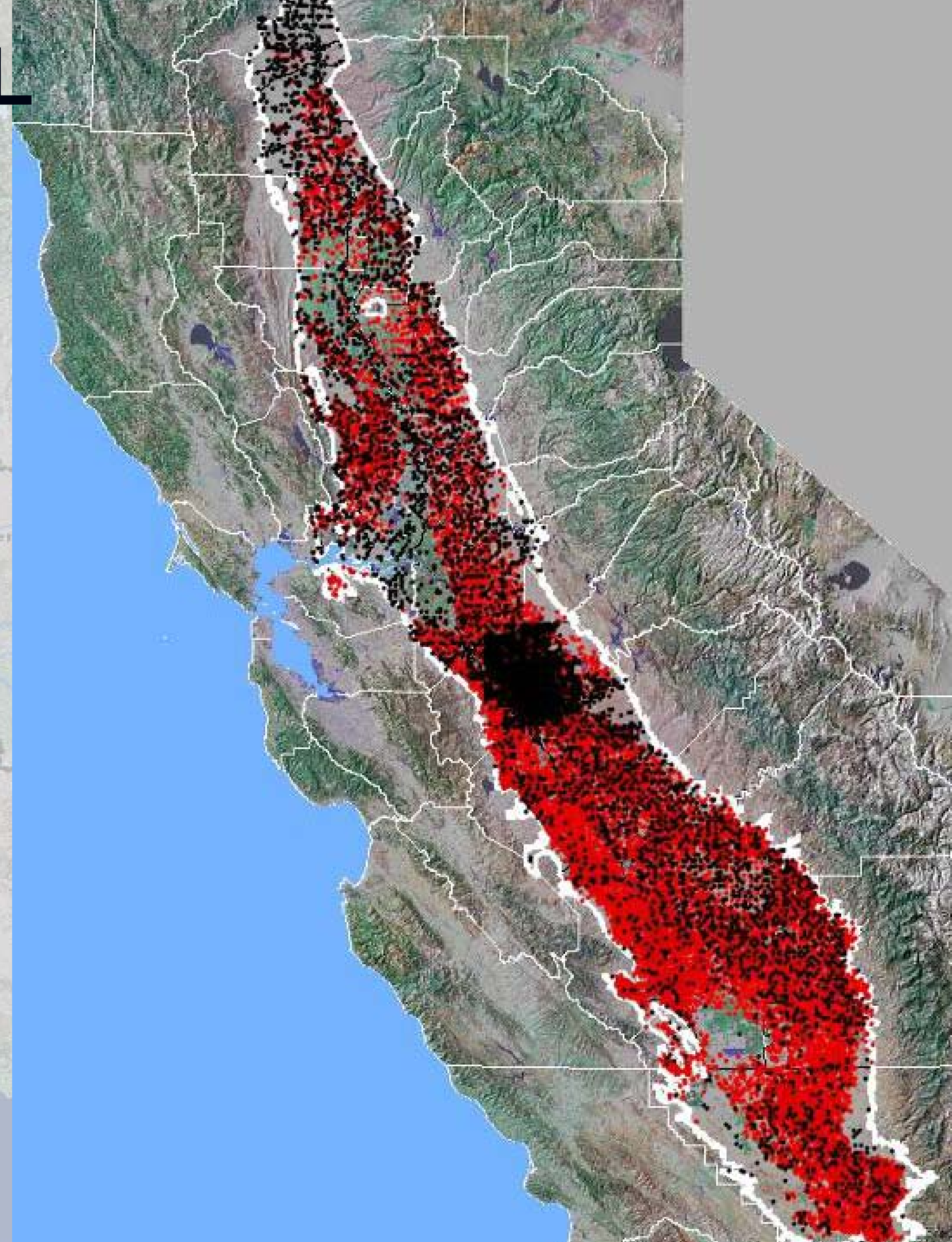
TEXTURE MODEL





Well database:

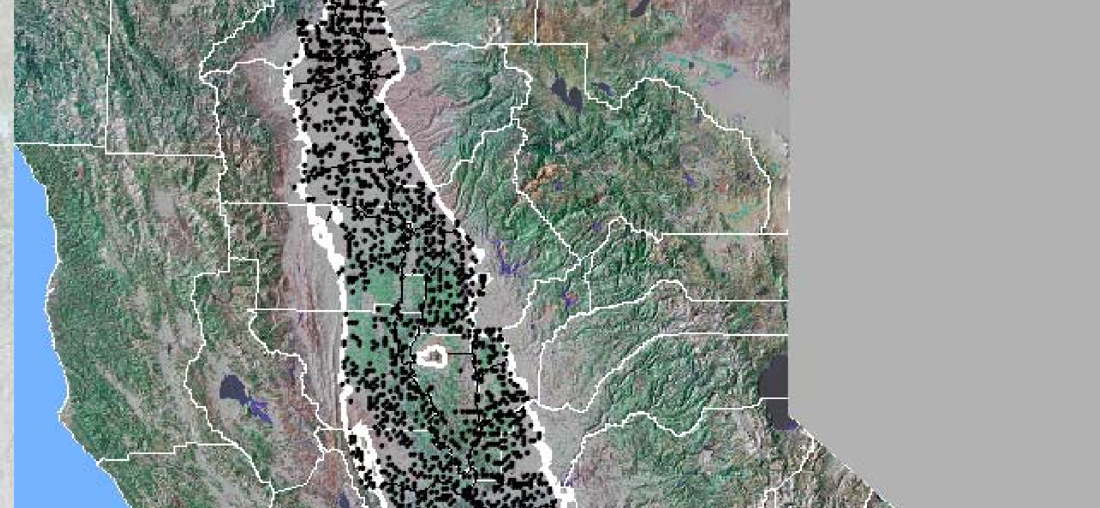
Properties within stratigraphy based on textural analysis

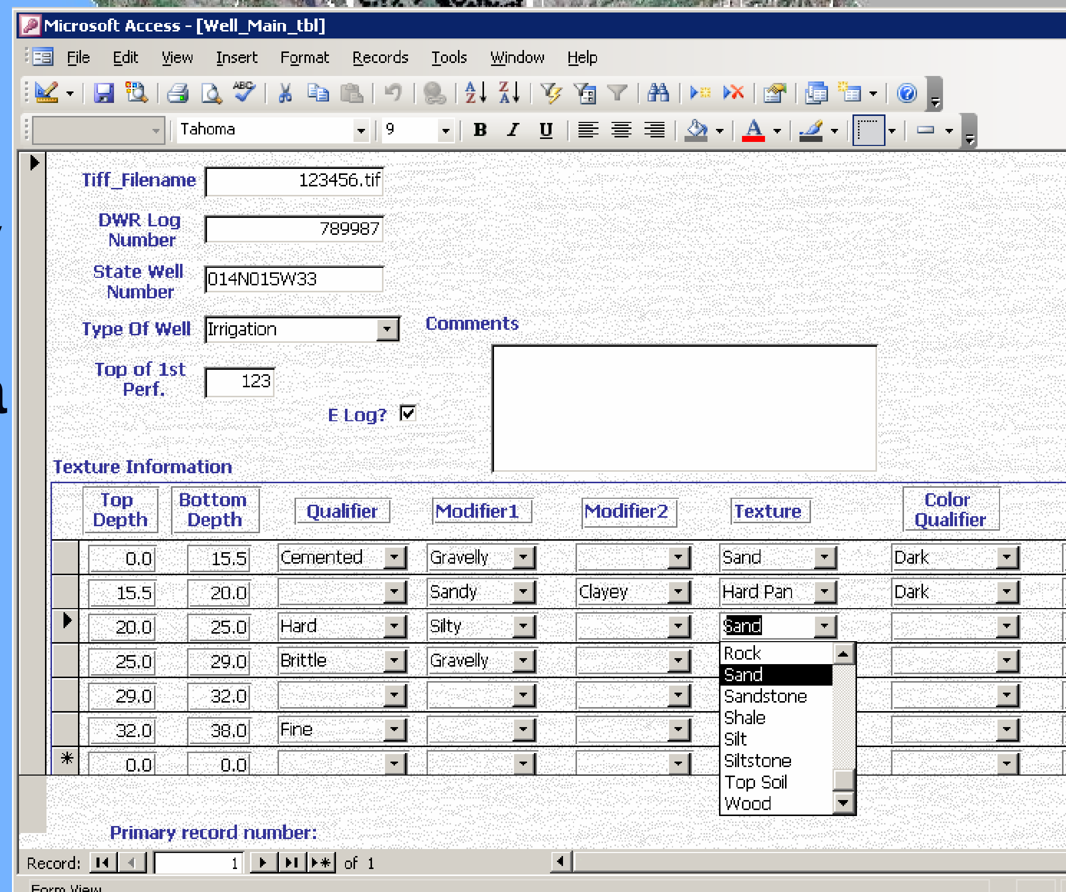
Digitized DWR well logs

8497 logs digitized

2598 in Stanislaus county (Burow and others work)

5899 in rest of model area





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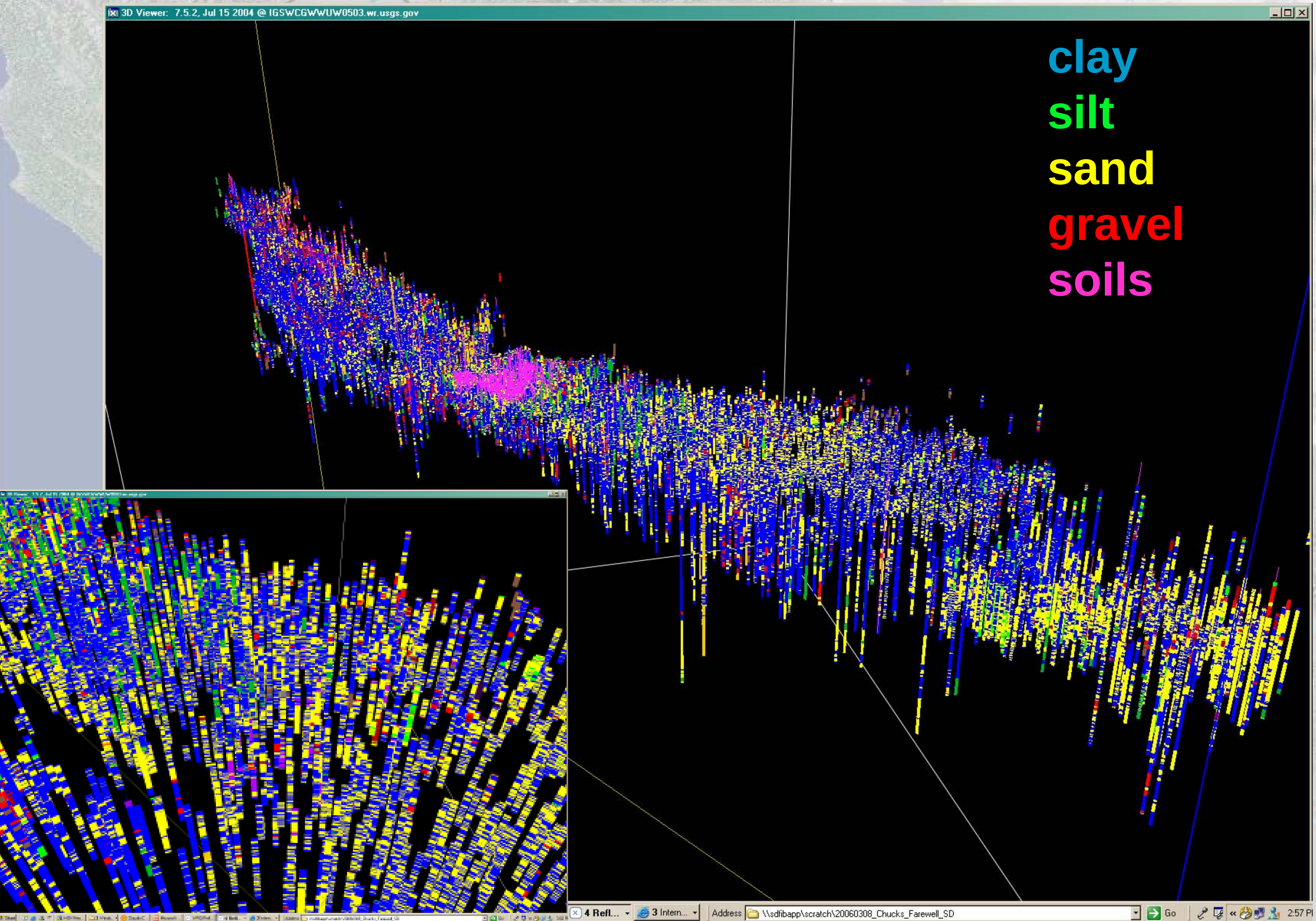
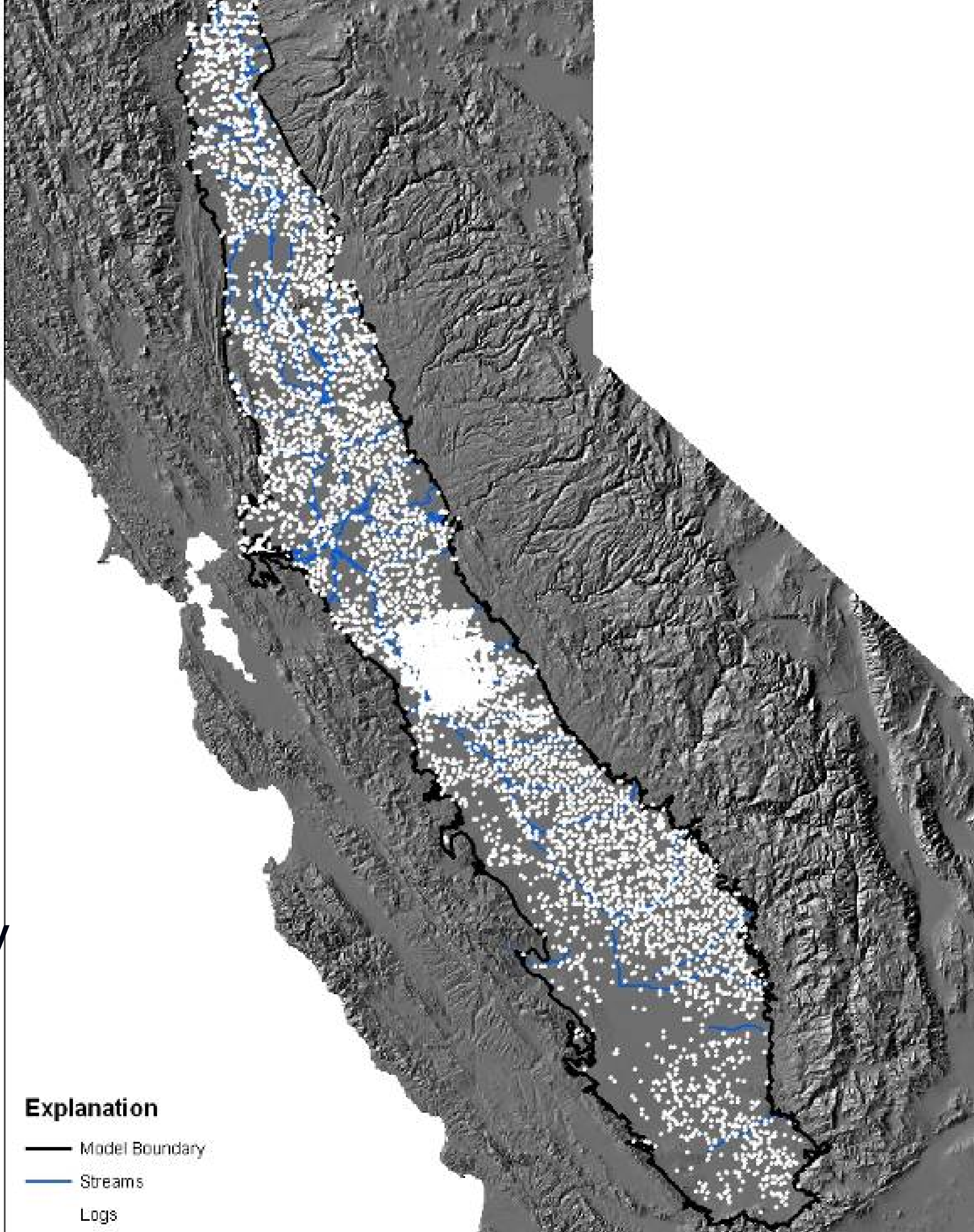
Central Valley well logs - lithology



Data Analysis and Post Processing

Three-dimensional kriging (ISATIS)

- 50 foot depth intervals
- 1 mile spatial grid
- Coarse near river channels
- Finer in low energy environments (Corcoran Clay)



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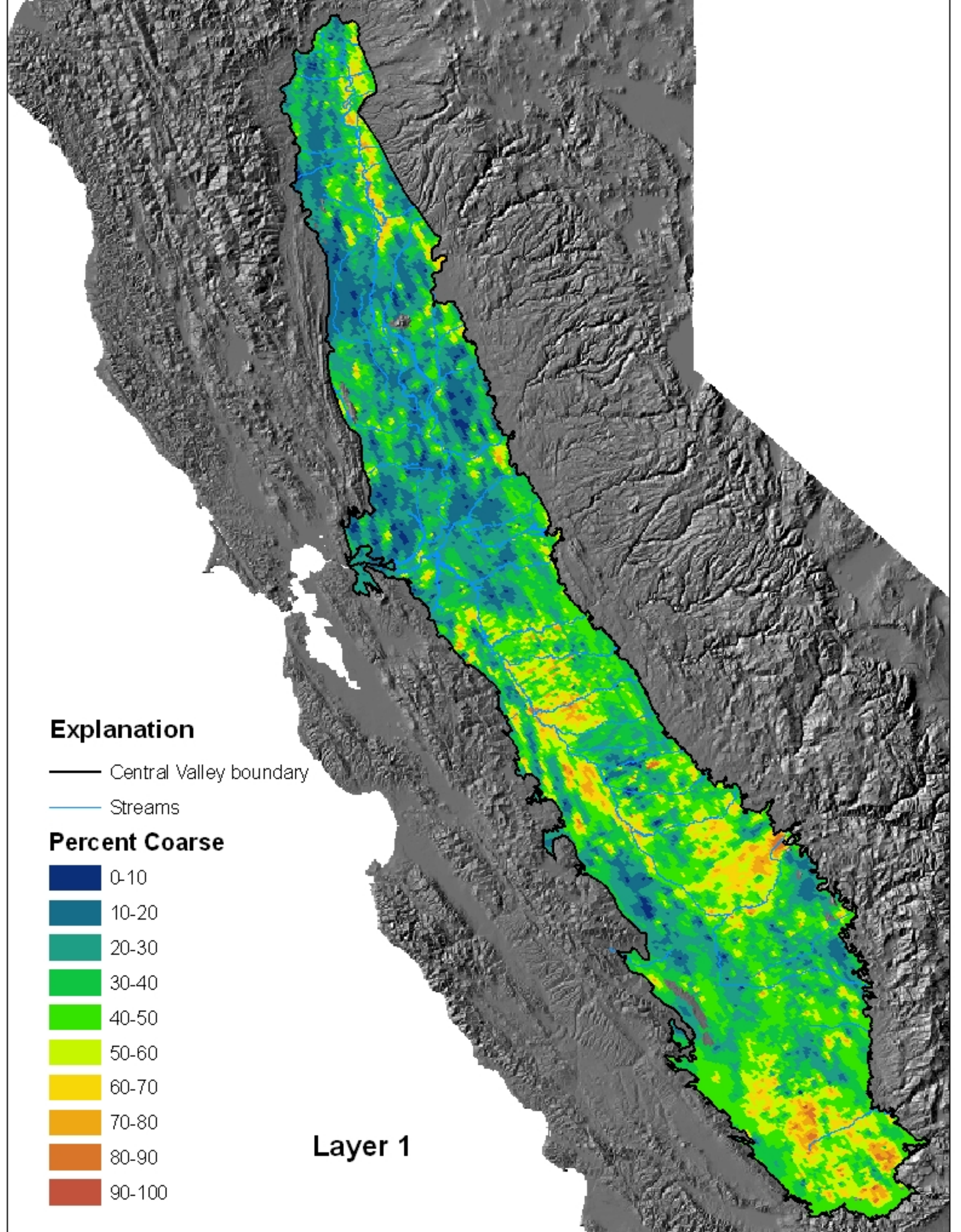

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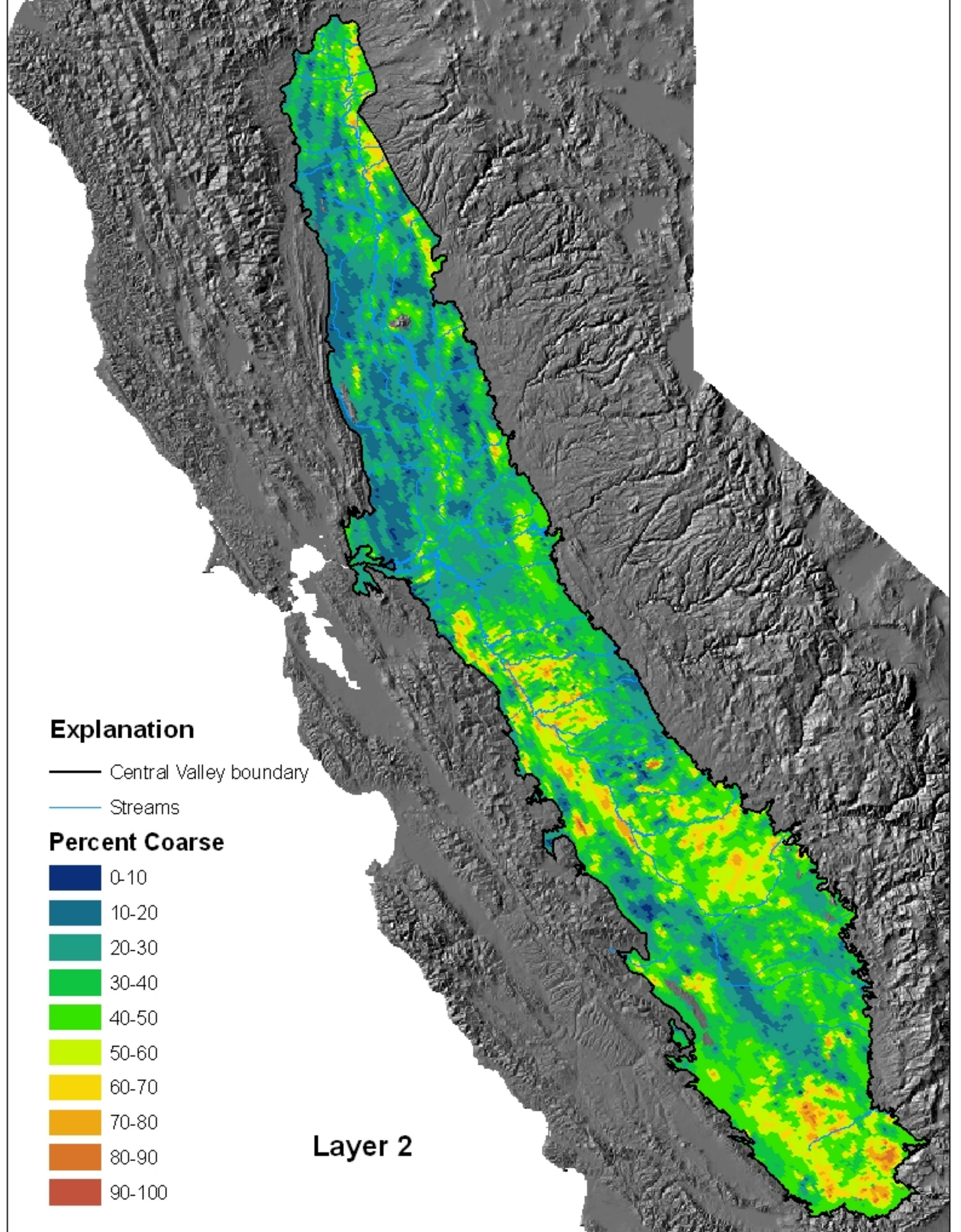

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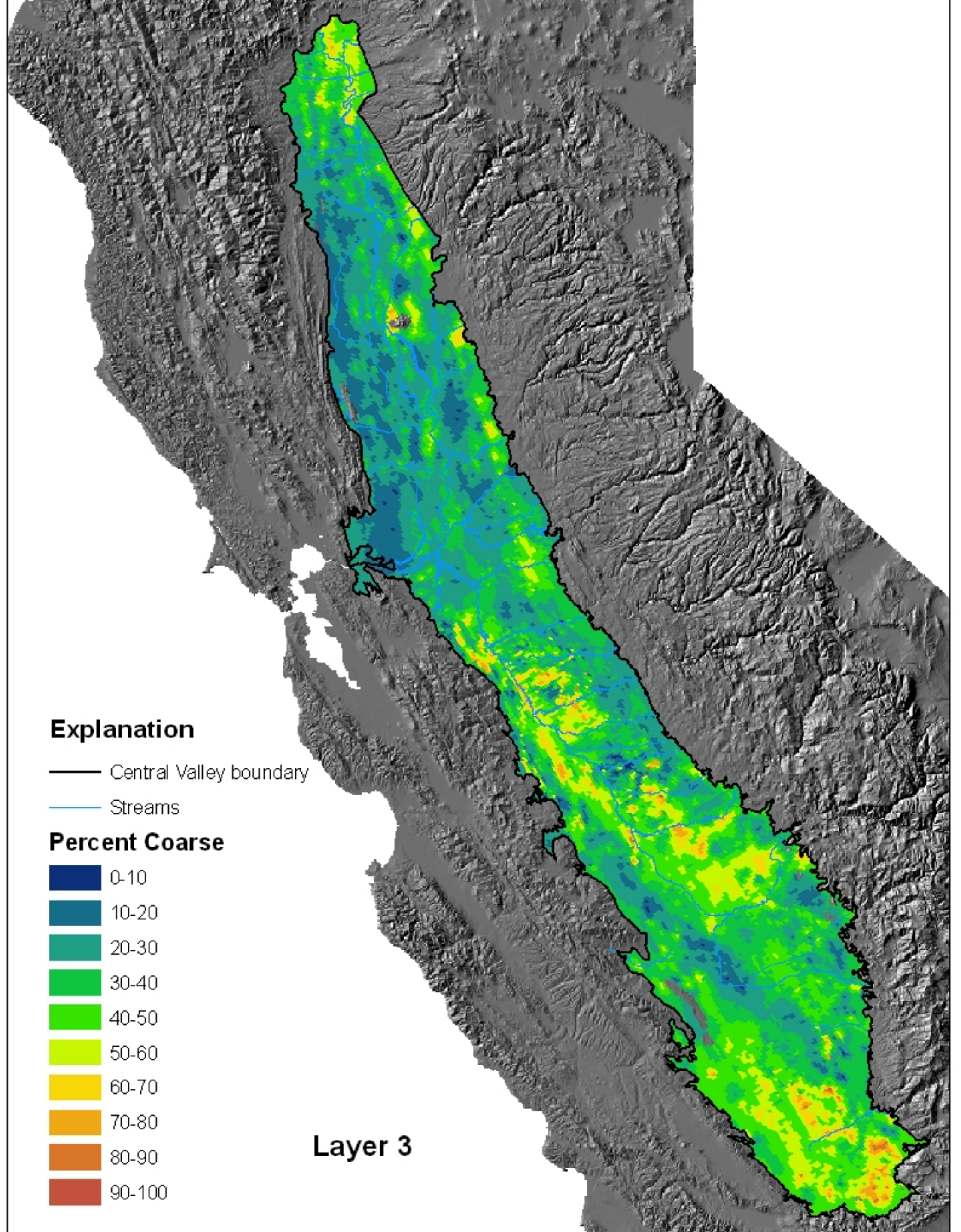

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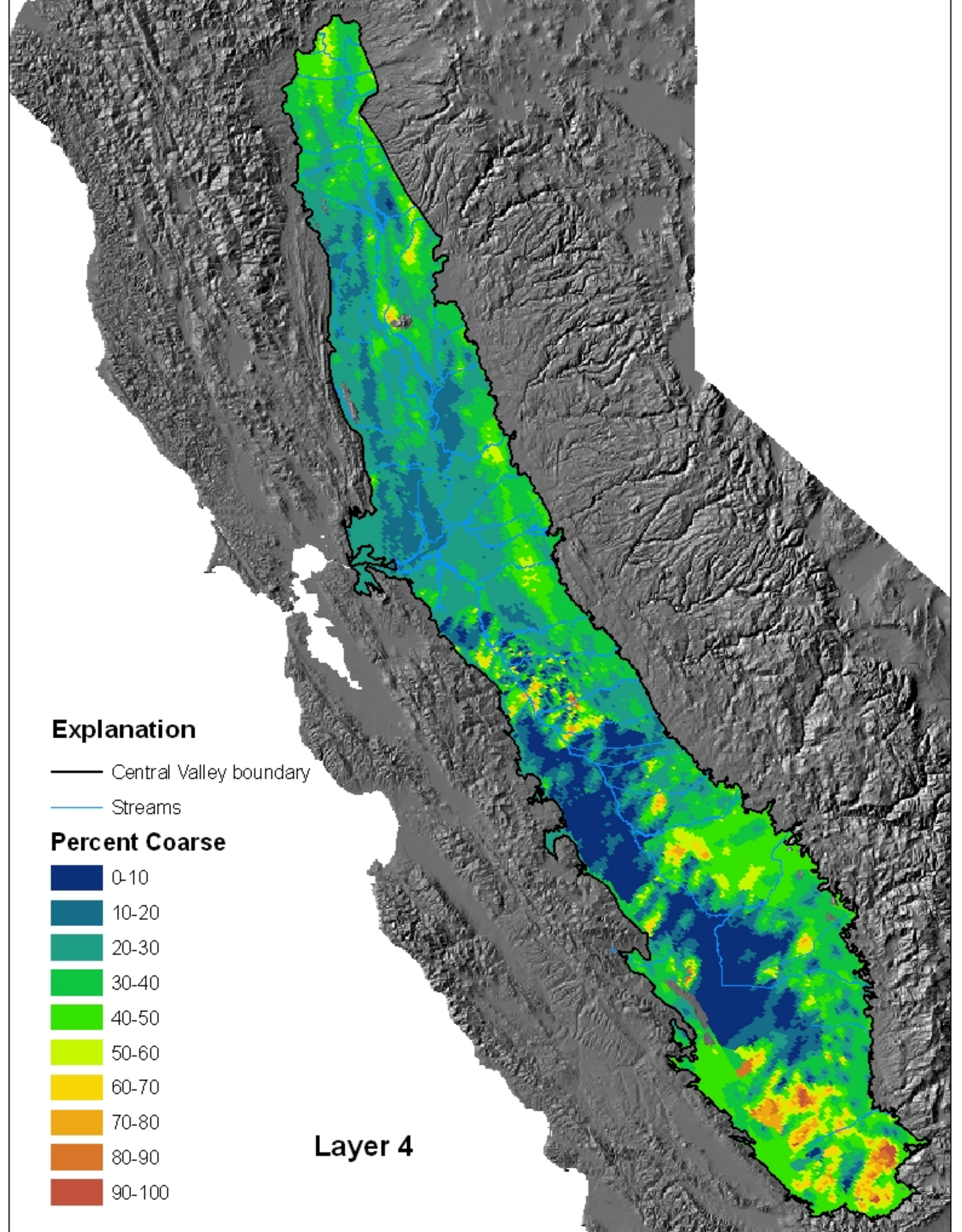

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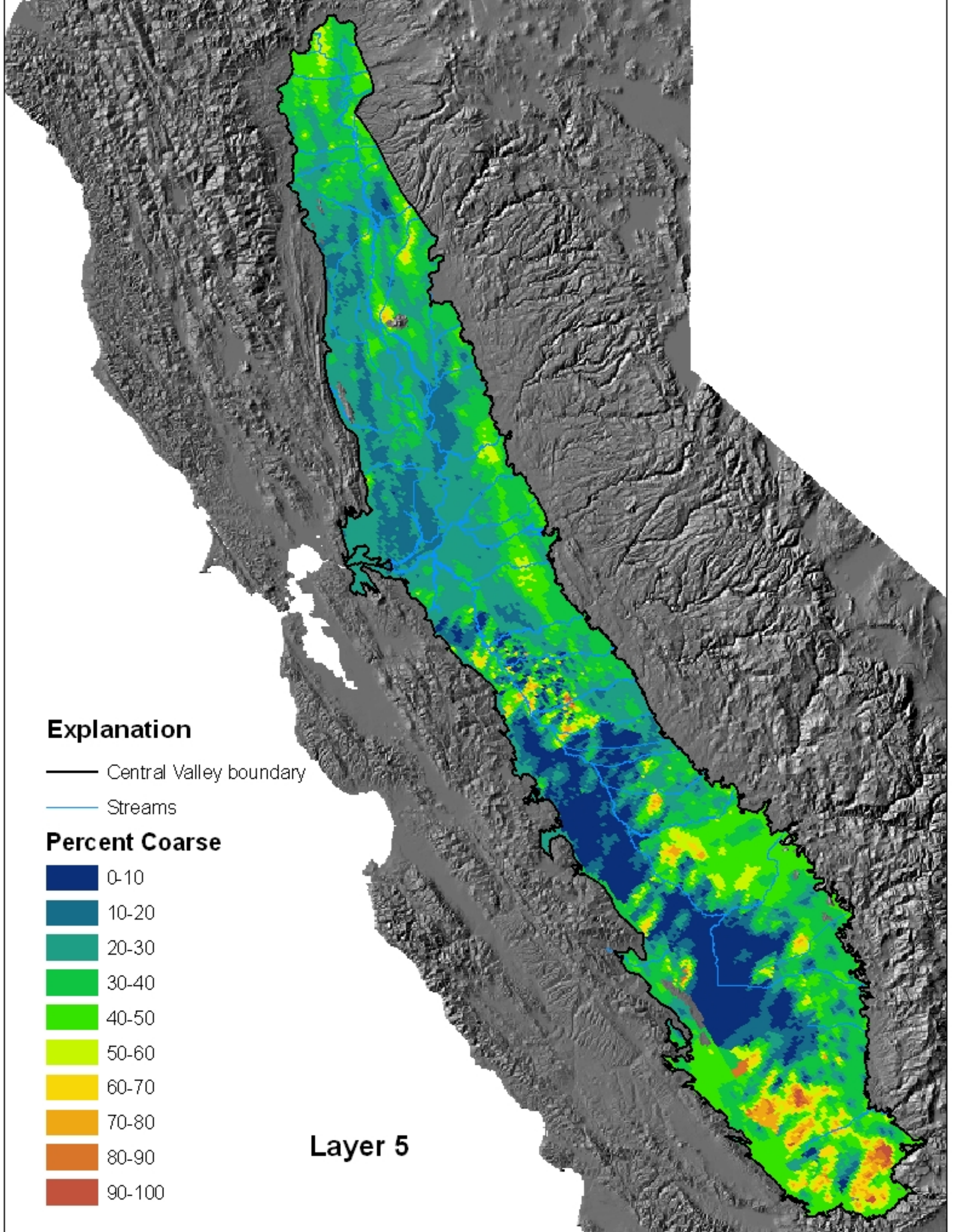

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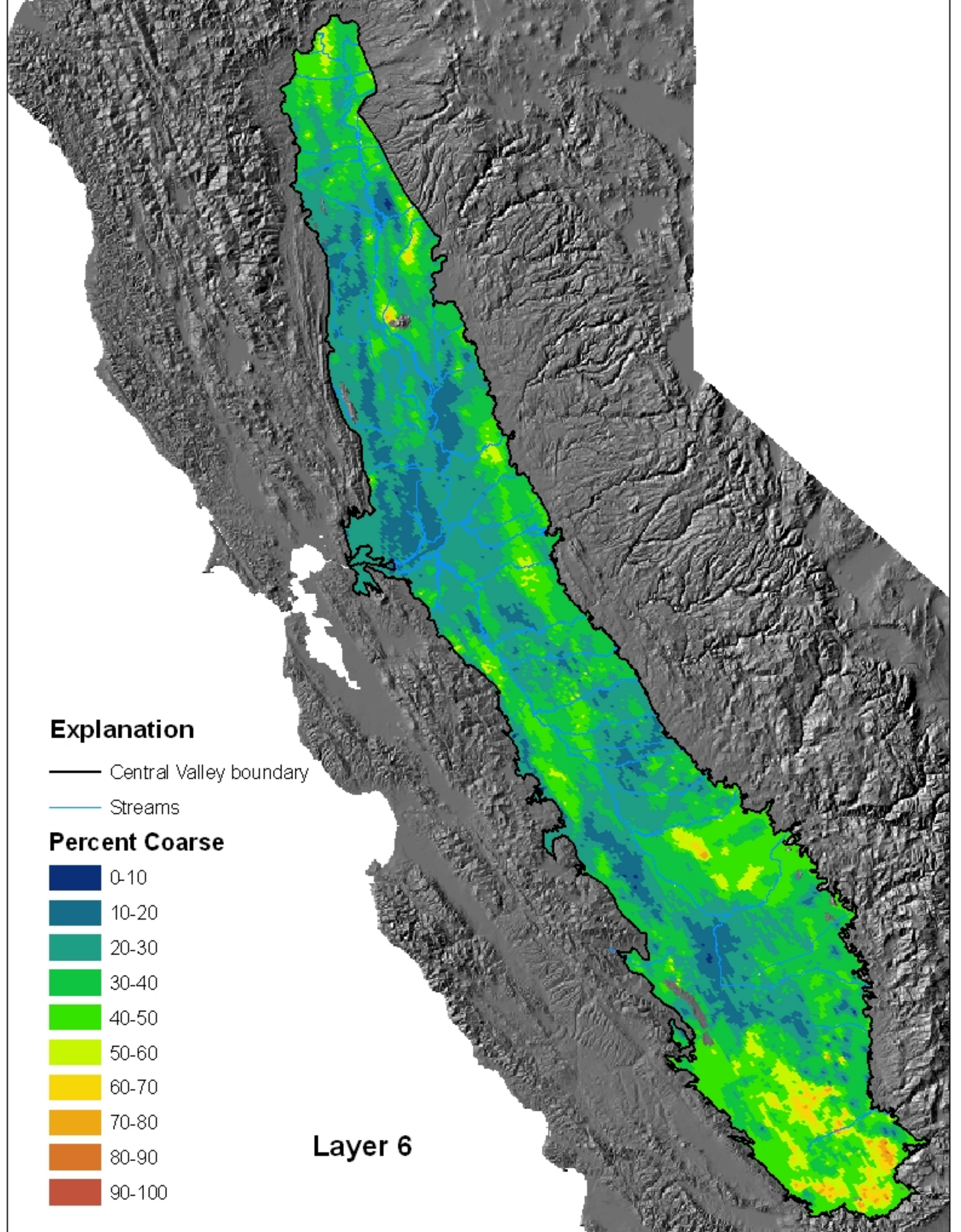

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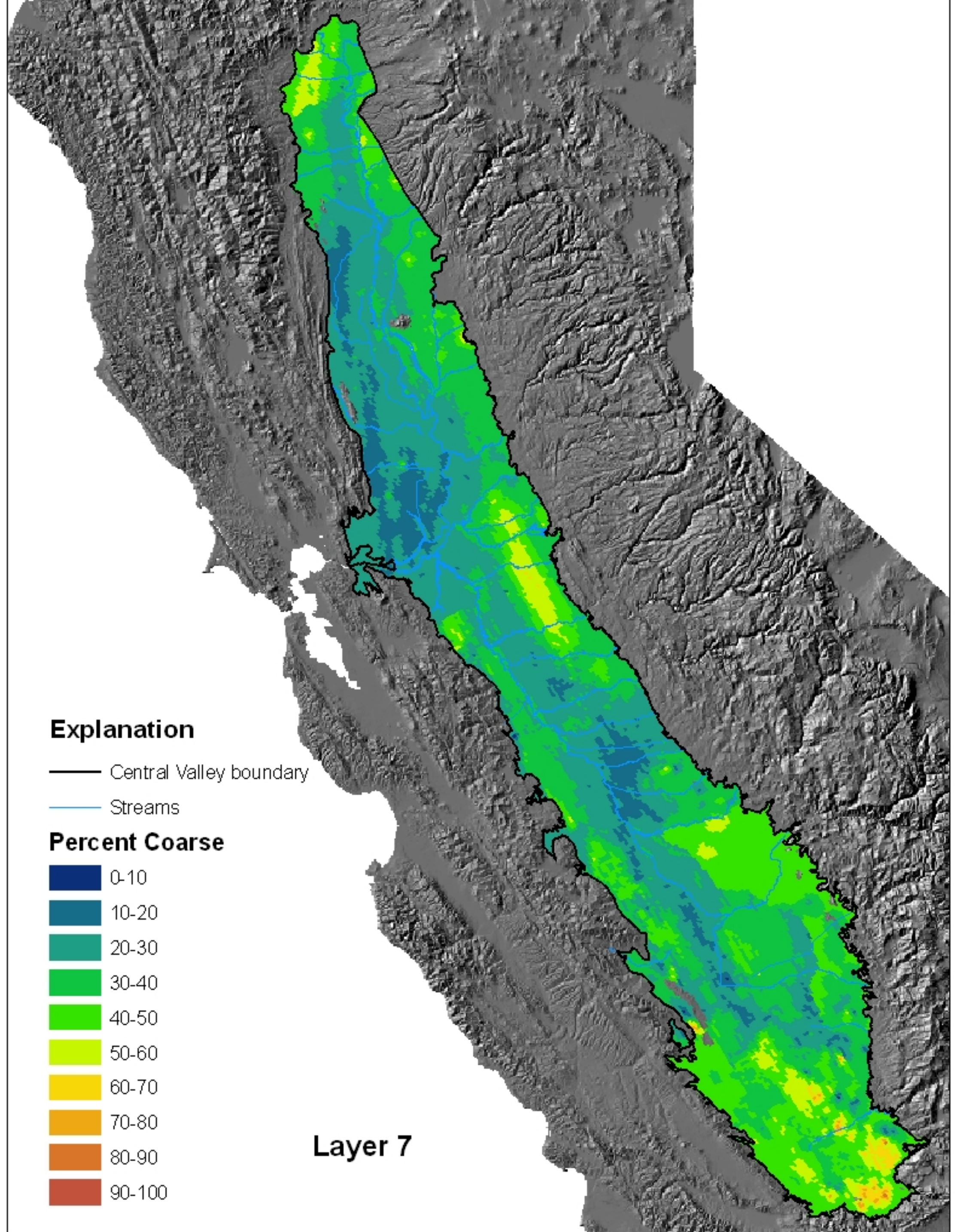

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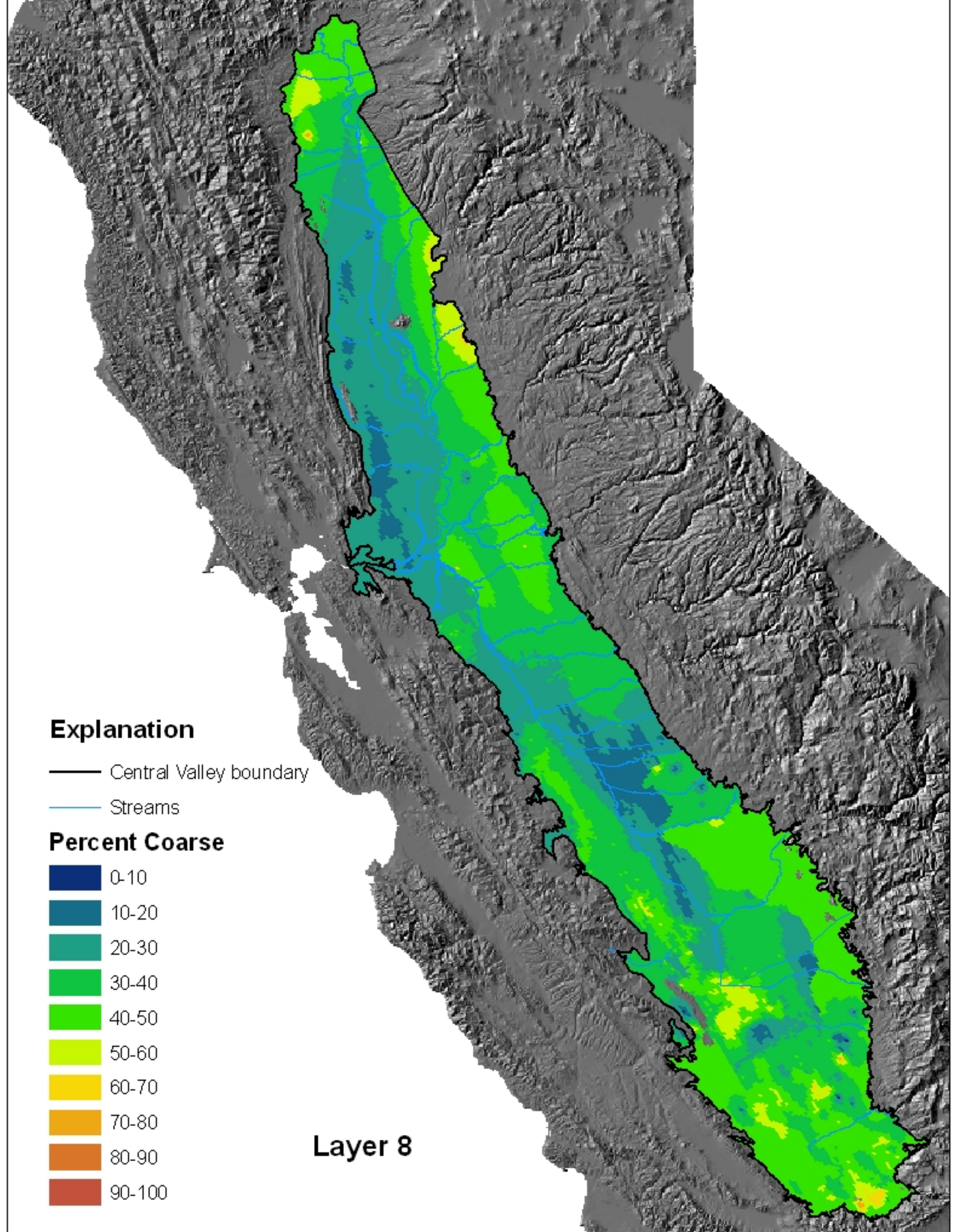

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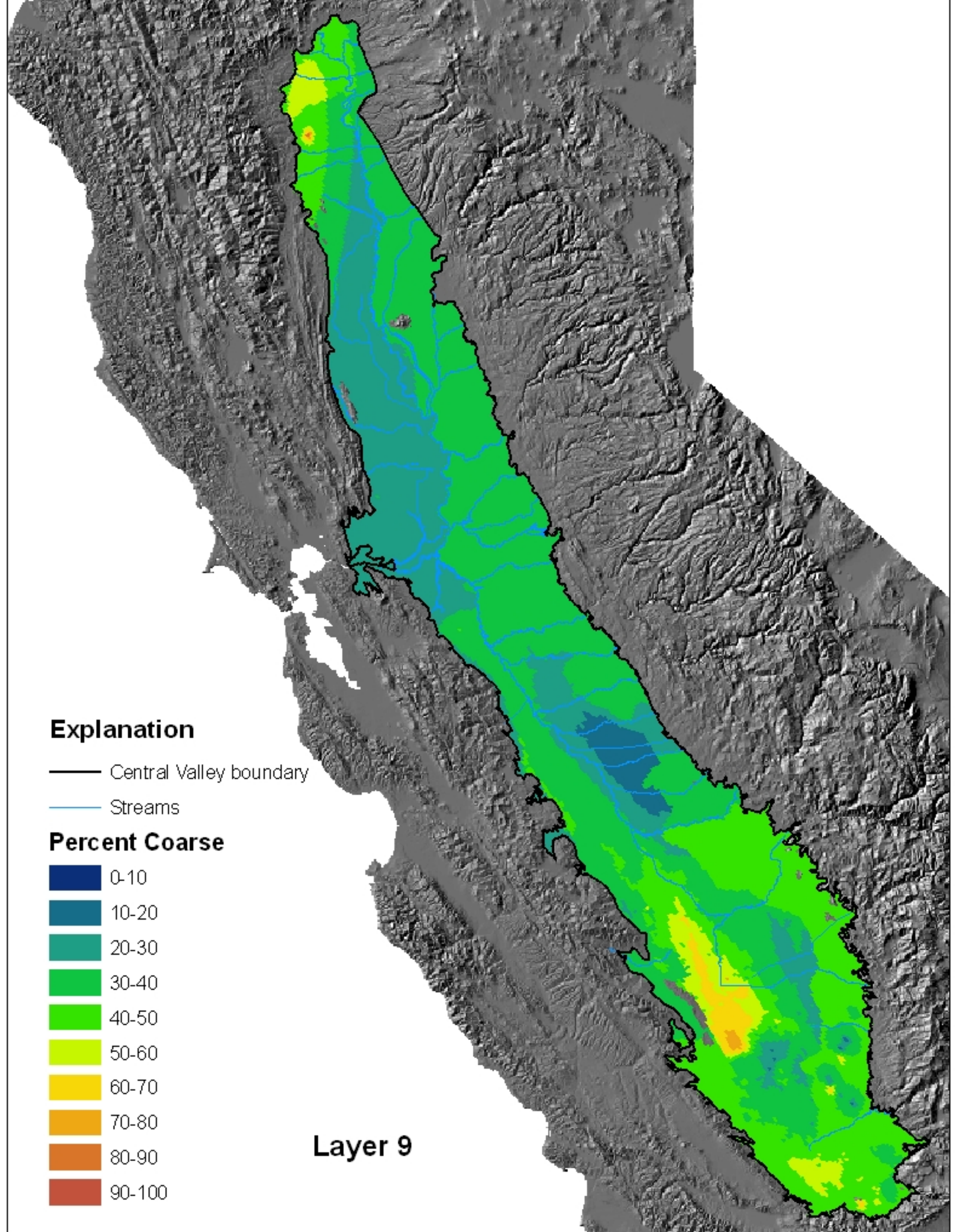

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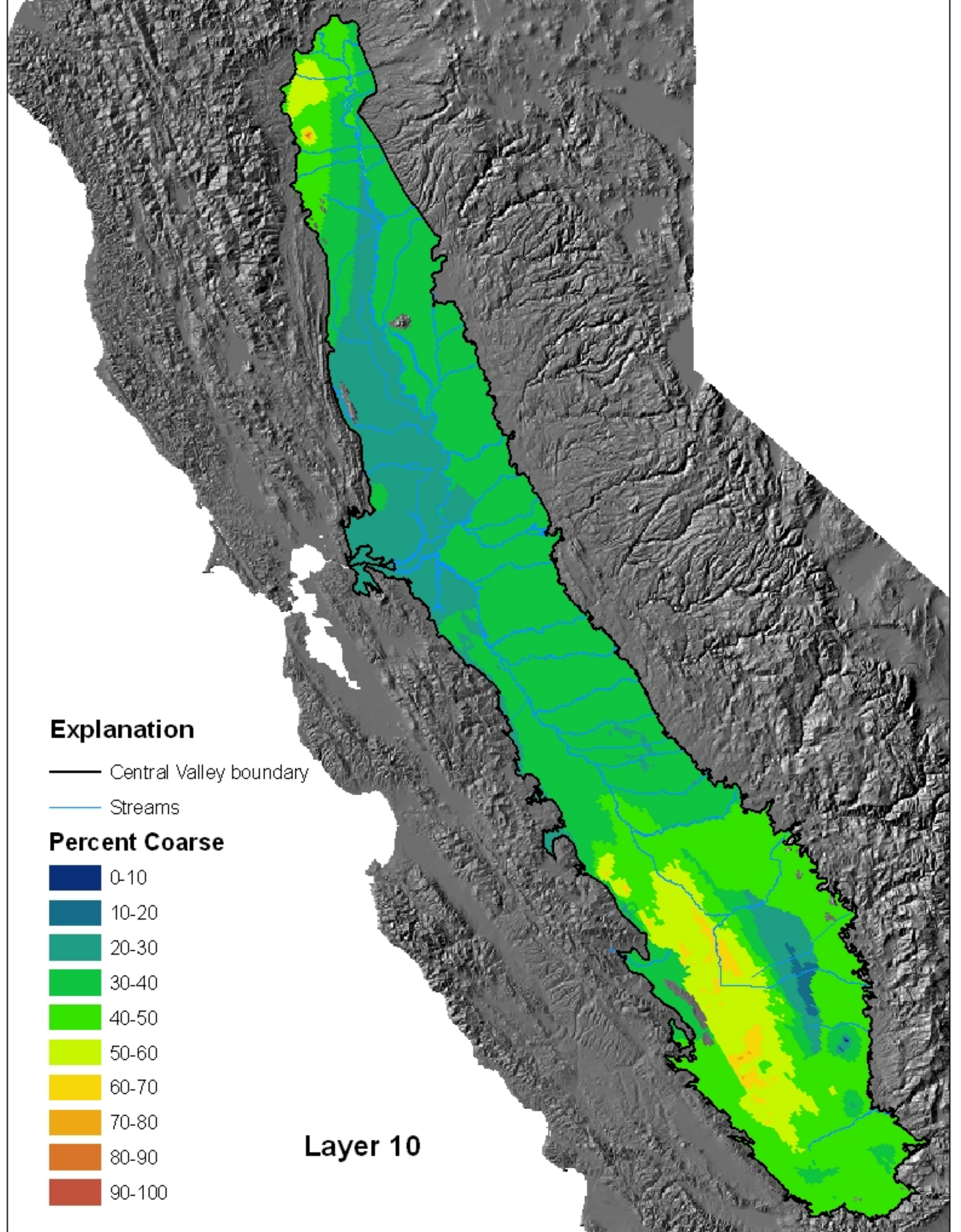
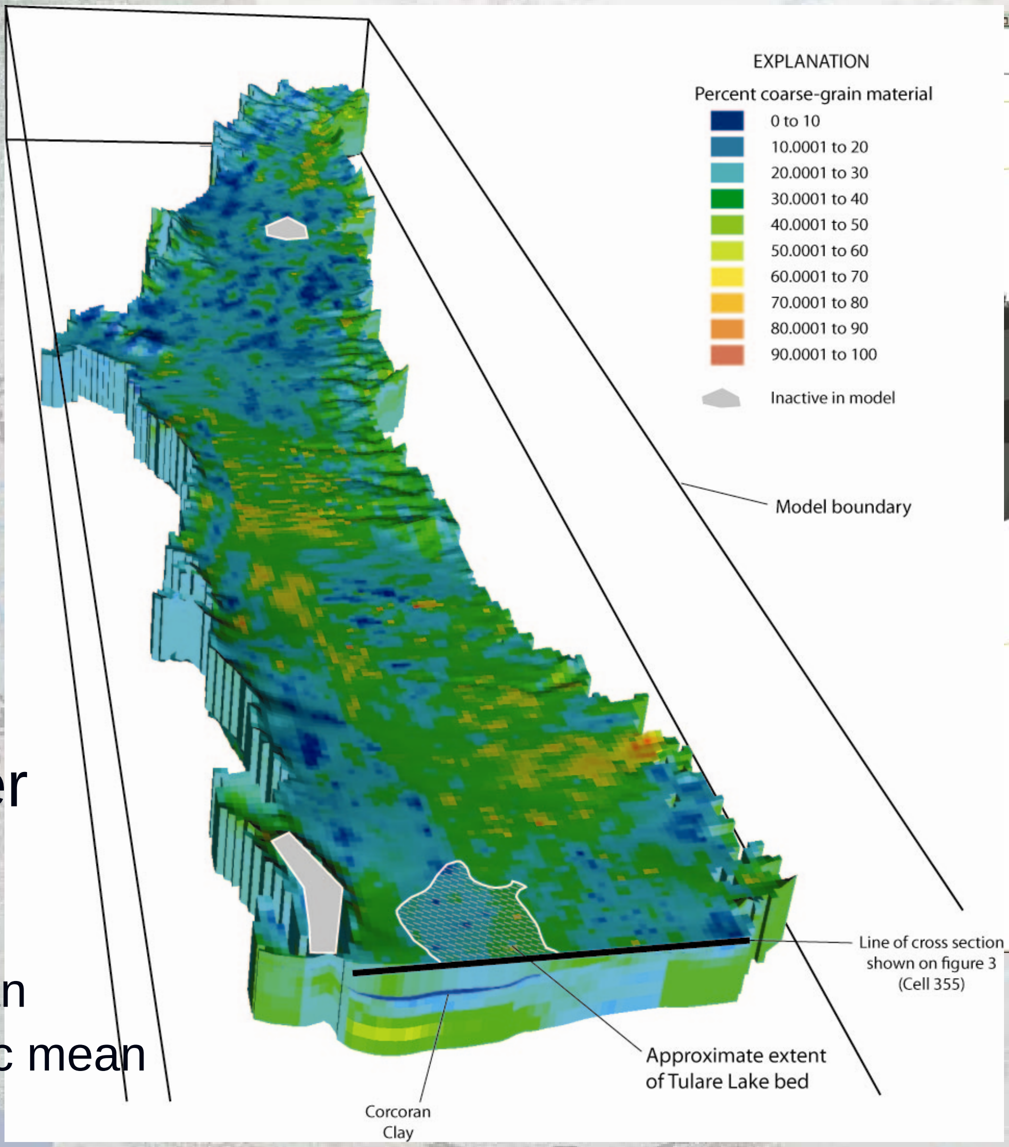


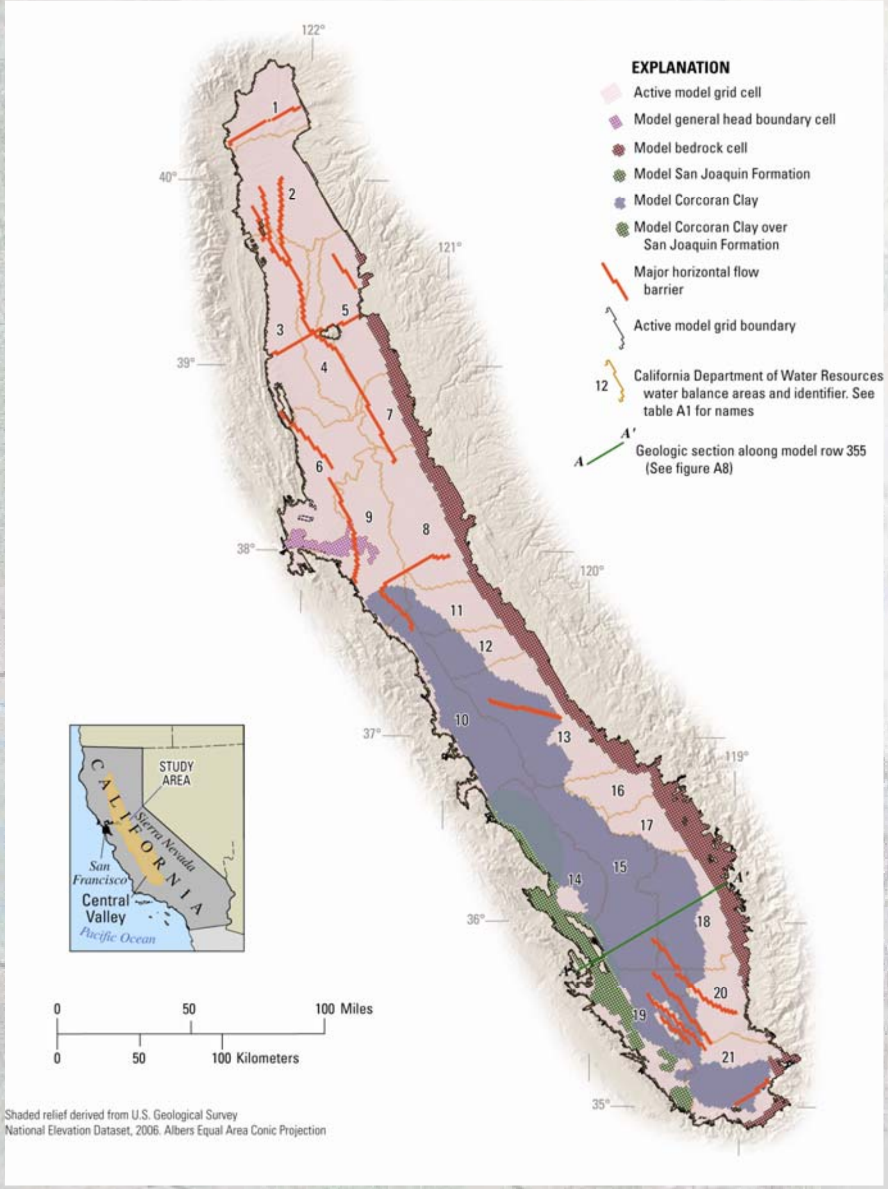
Texture based approach for hydraulic properties:

- Hydraulic conductivity is a function of
  - Stratigraphy
  - Texture – Coarse vs. fine-grained
- Stratigraphy
  - 3D geologic model
- Texture
  - Percent coarse each layer
    - Hydraulic conductivity
      - Power mean
        Horizontal – arithmetic mean
        Vertical – approx. geometric mean
    - Subsidence (% fine)



Parameters

- 65 total
  - Hydraulic Properties (17)
    - K coarse
    - K fine
    - 8 horizontal multipliers
    - 3 vertical multipliers
    - 4 storage
  - Stream Conductances (9)
  - Farm Process (39)
    - 10 Irrigation efficiencies
    - 4 Crop coefficients
    - 4 Root depths and capillary fringe
    - 21 Runoff percents (precipitation and irrigation)



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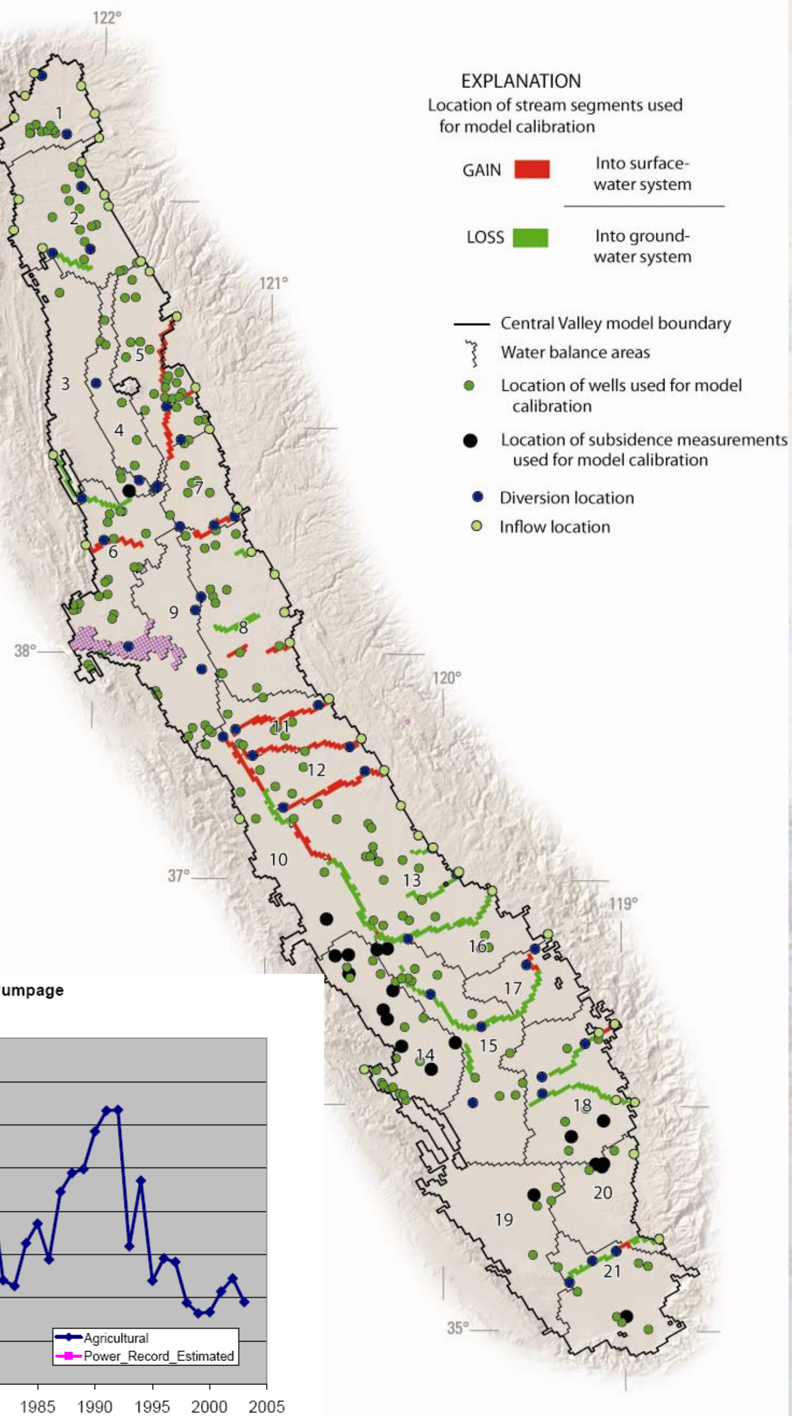
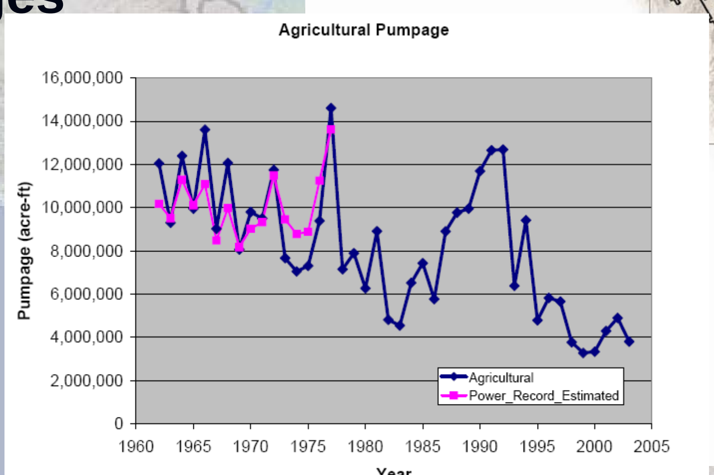
Observations

- **23,493 total estimated**
- **Water levels and water level change**
  - **206 wells – 19,931 obs.**
- **Streamflow**
  - **40 segments – 782 obs.**
- **Subsidence**
  - **24 locations – 2,780 obs.**
- **Other comparisons**
  - **Power records (pumpage)**
  - **103 stream-flow gages**
  - **66 diversion sites**





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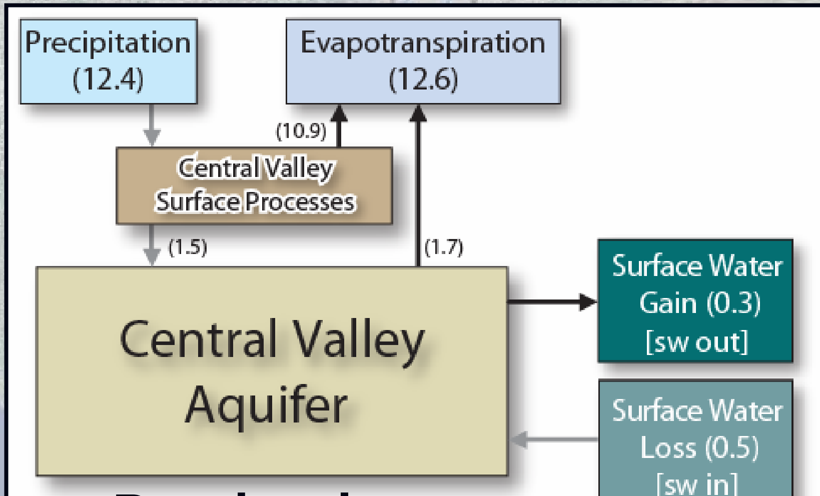
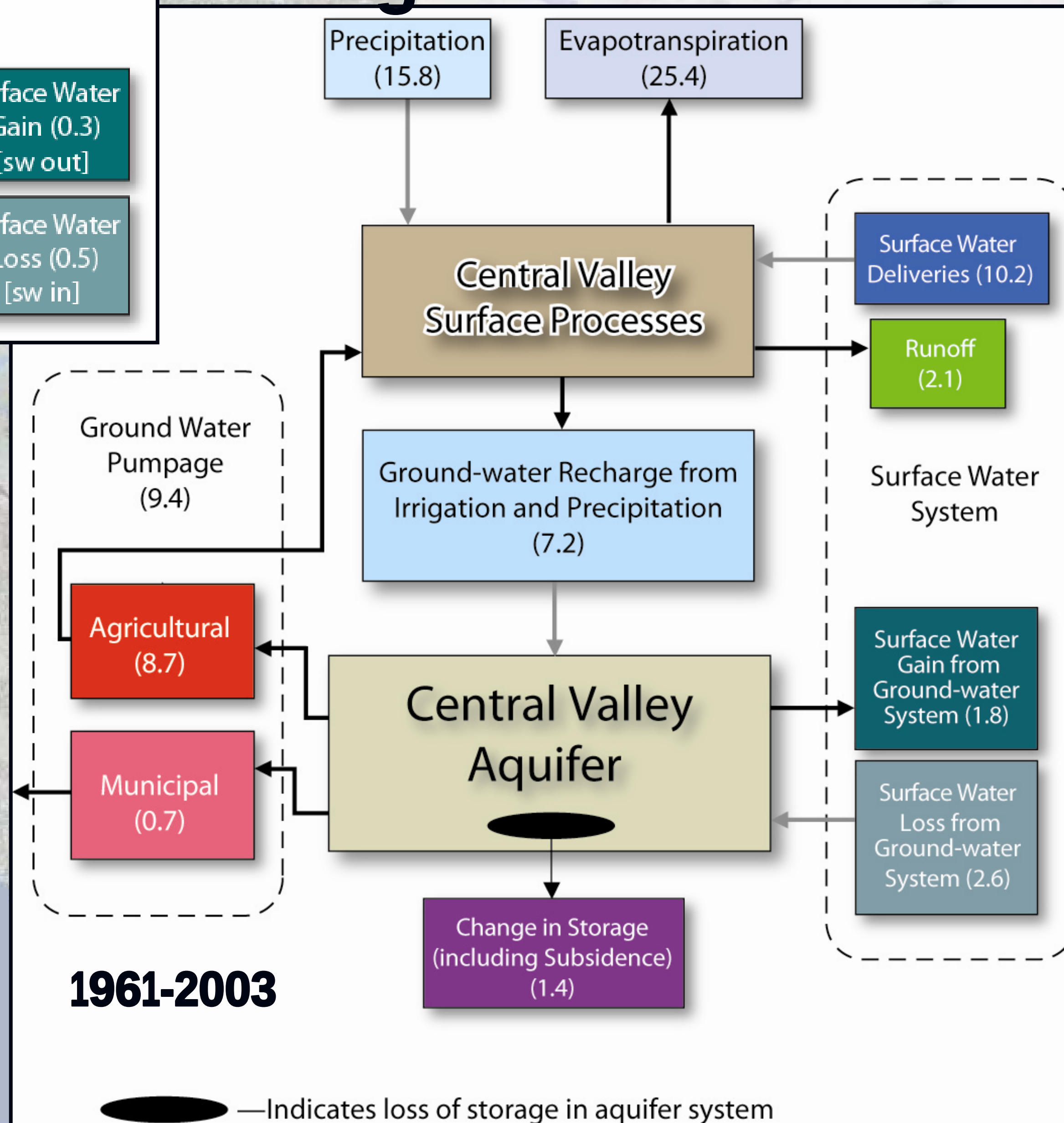
Hydrologic Budgets



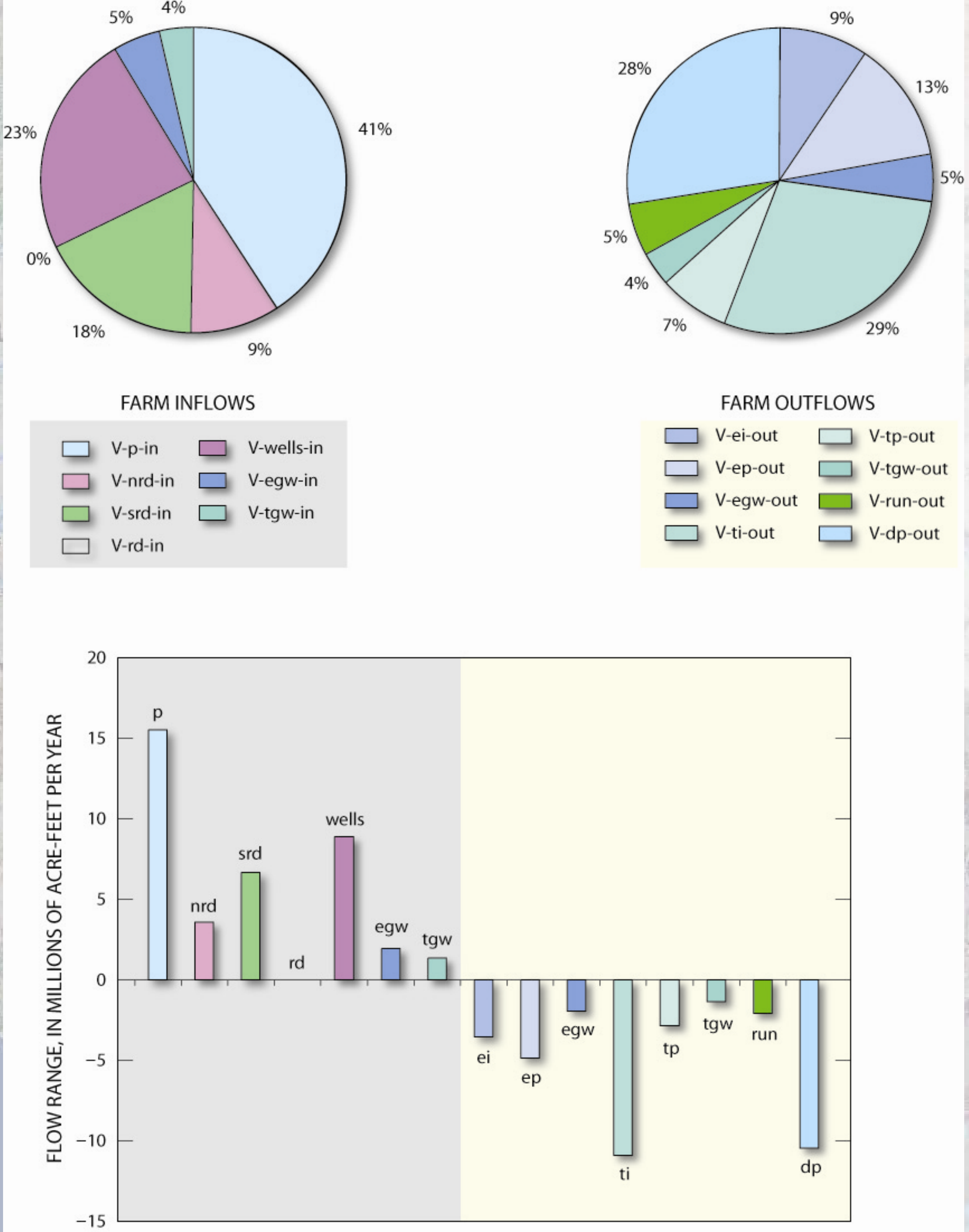
Pre-development



1961-2003

Farm Process (Landscape) Budget

- "Farm" inflows
  - Precipitation
  - Surface-water deliveries
  - Pumping
- "Farm" outflows
  - Deep percolation
  - Transpiration from irrigation



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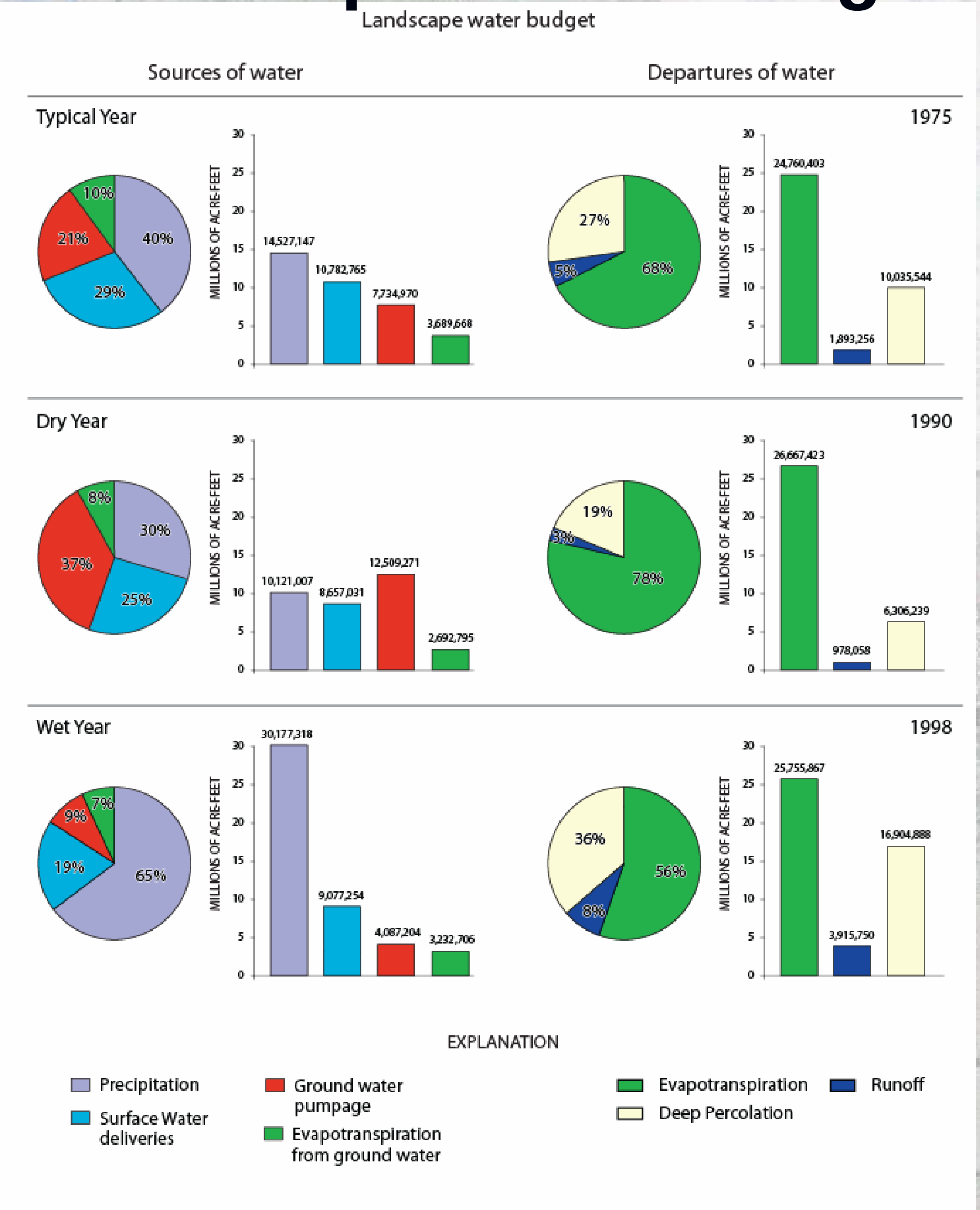
Landscape Water Budget



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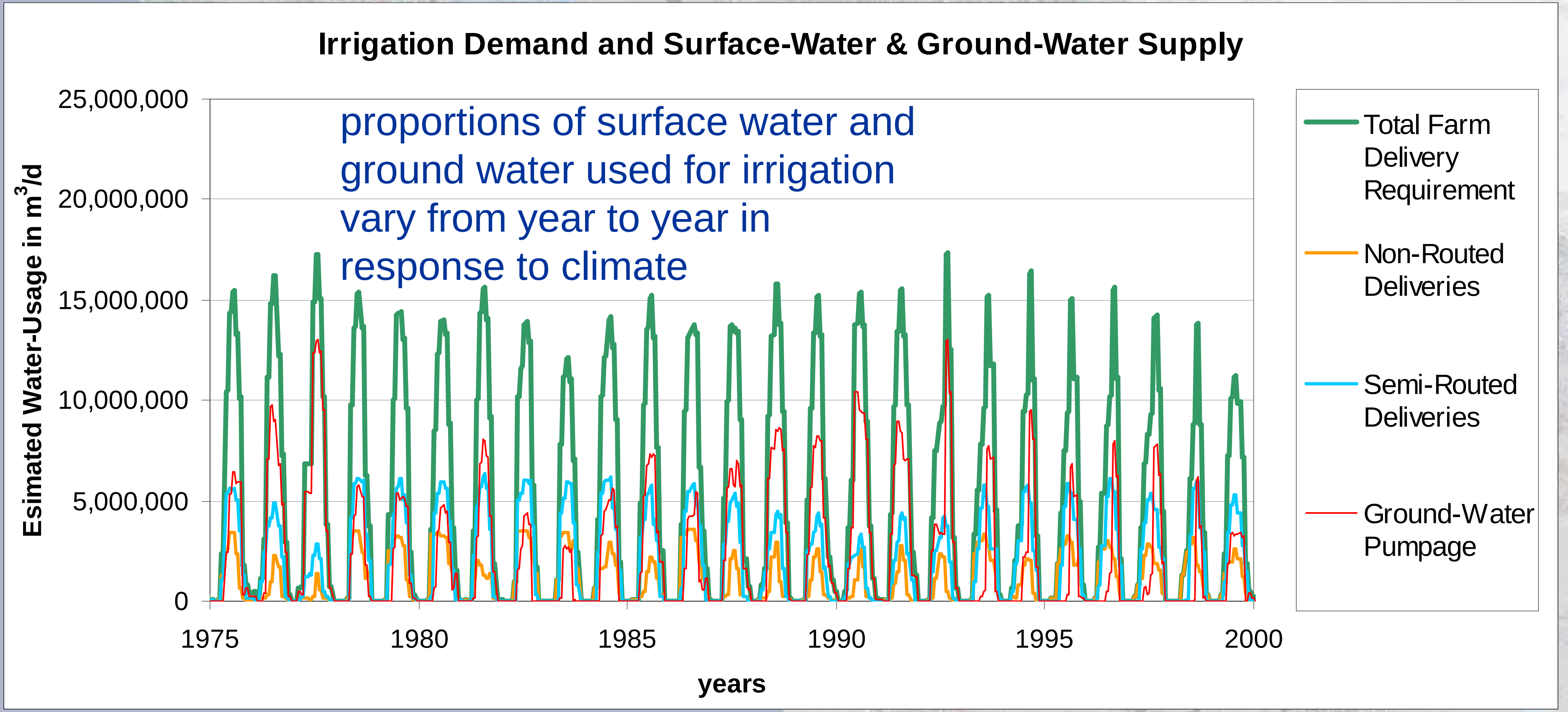
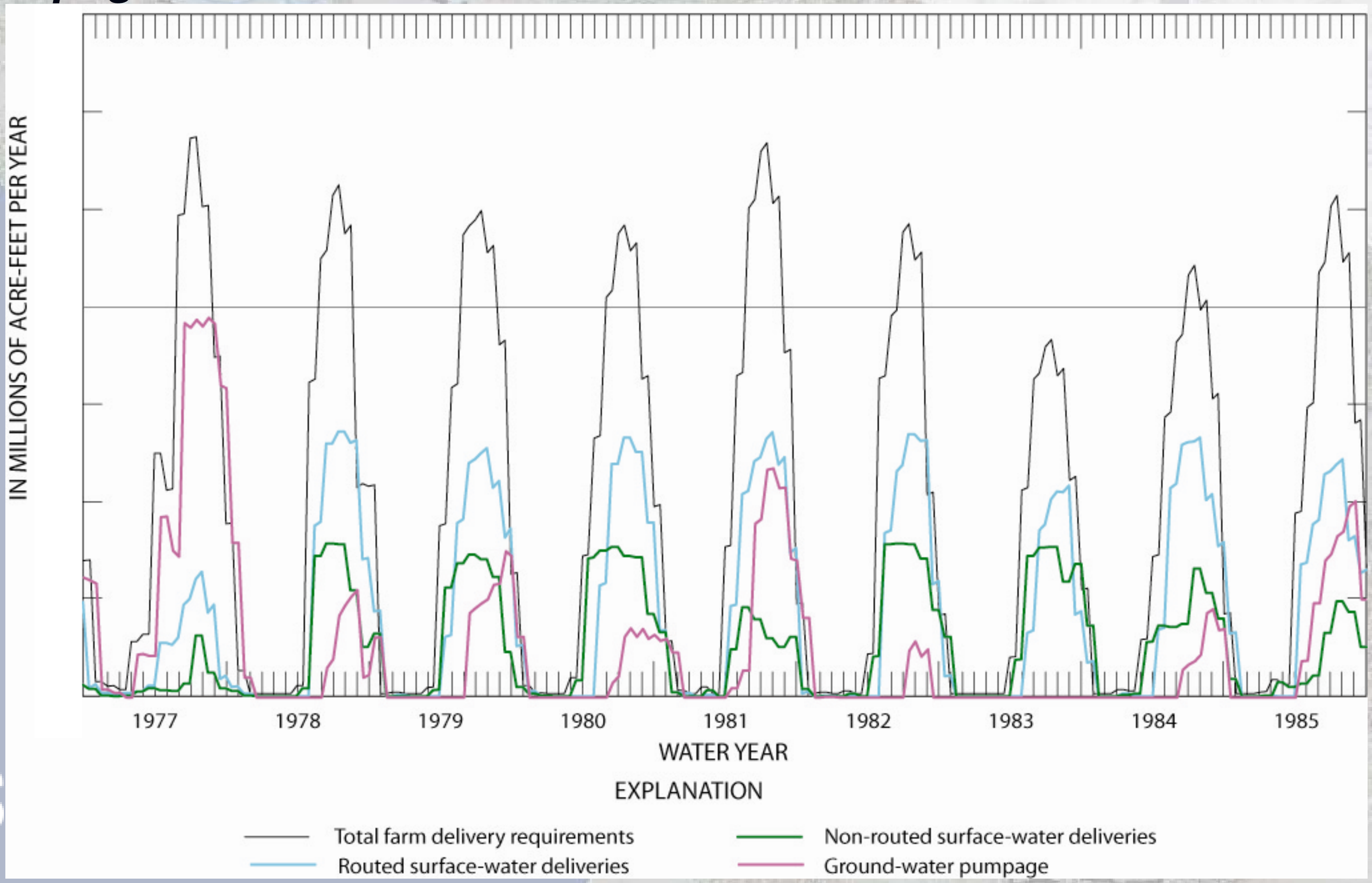
Example of FMP and Response of Climate Changes built into CVHM

- *Drought '76-'77, '88-'92*
- *Wet Period '83, '99*



Example of FMP Seasonal Changes

- *Drought '77*
  - *High pumping all growing season*
- *Typically*
  - *Early in growing season dominantly surface water deliveries*
  - *Later in growing season, surface-water shortfall made up by ground-water pumpage*



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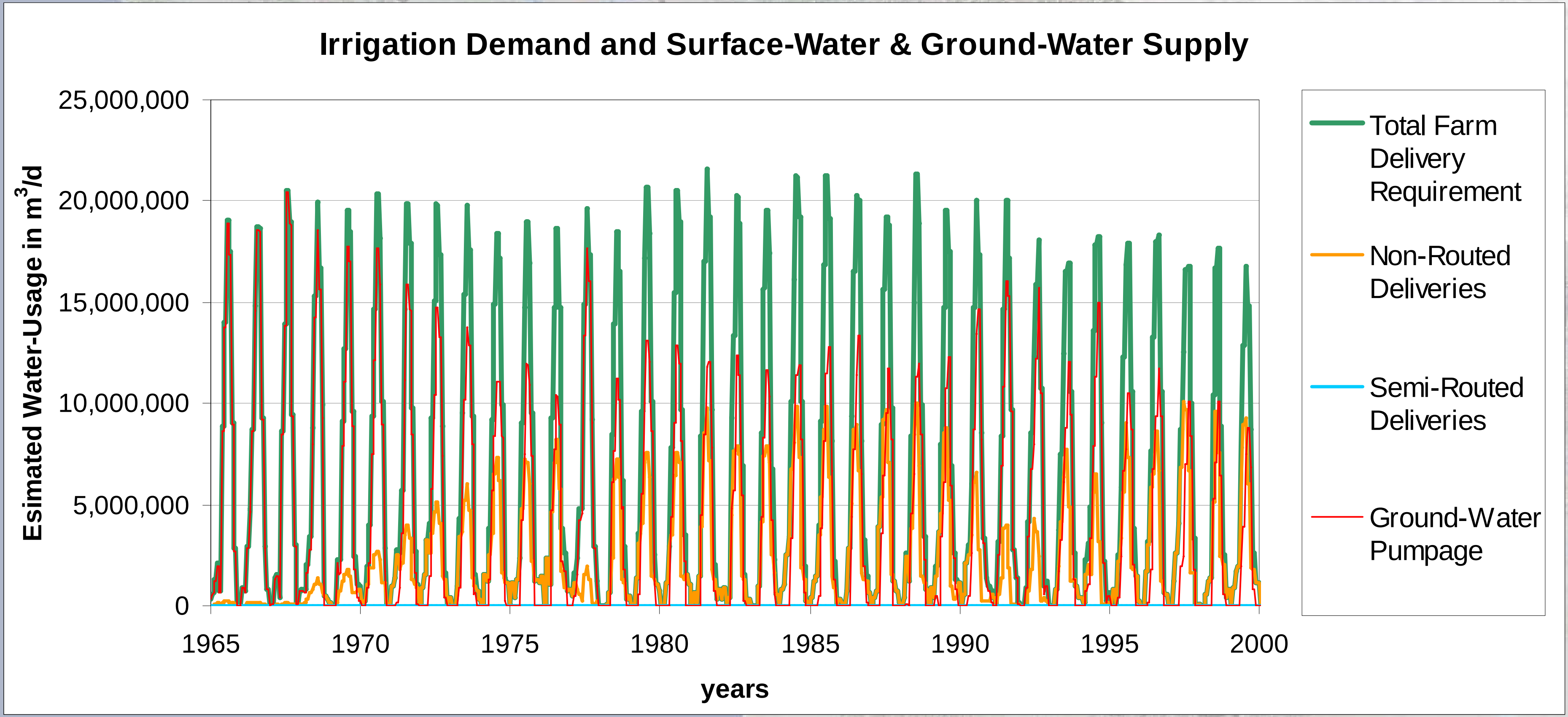
Example of FMP

- *Change of Dominant Water Source*
- *Non-routed Water Transfers start in late 60s*



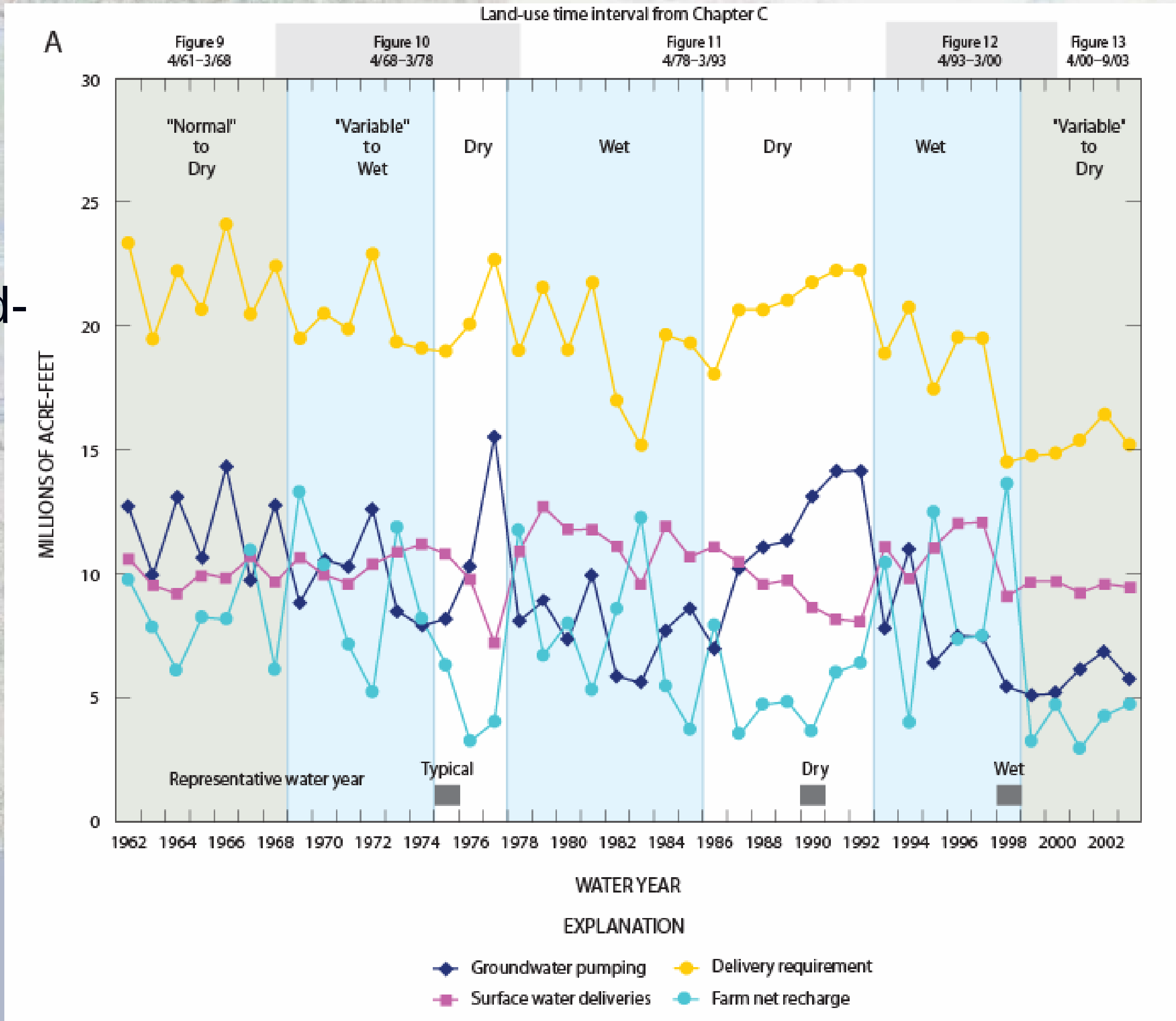
Changes in Landscape Budget through time

- 1960s pumping > surface-water deliveries
- Majority of delivery system in place by mid-1970s
- Surface-water deliveries > pumpage since then except during droughts
- Decreased TFDR

  -increased efficiency

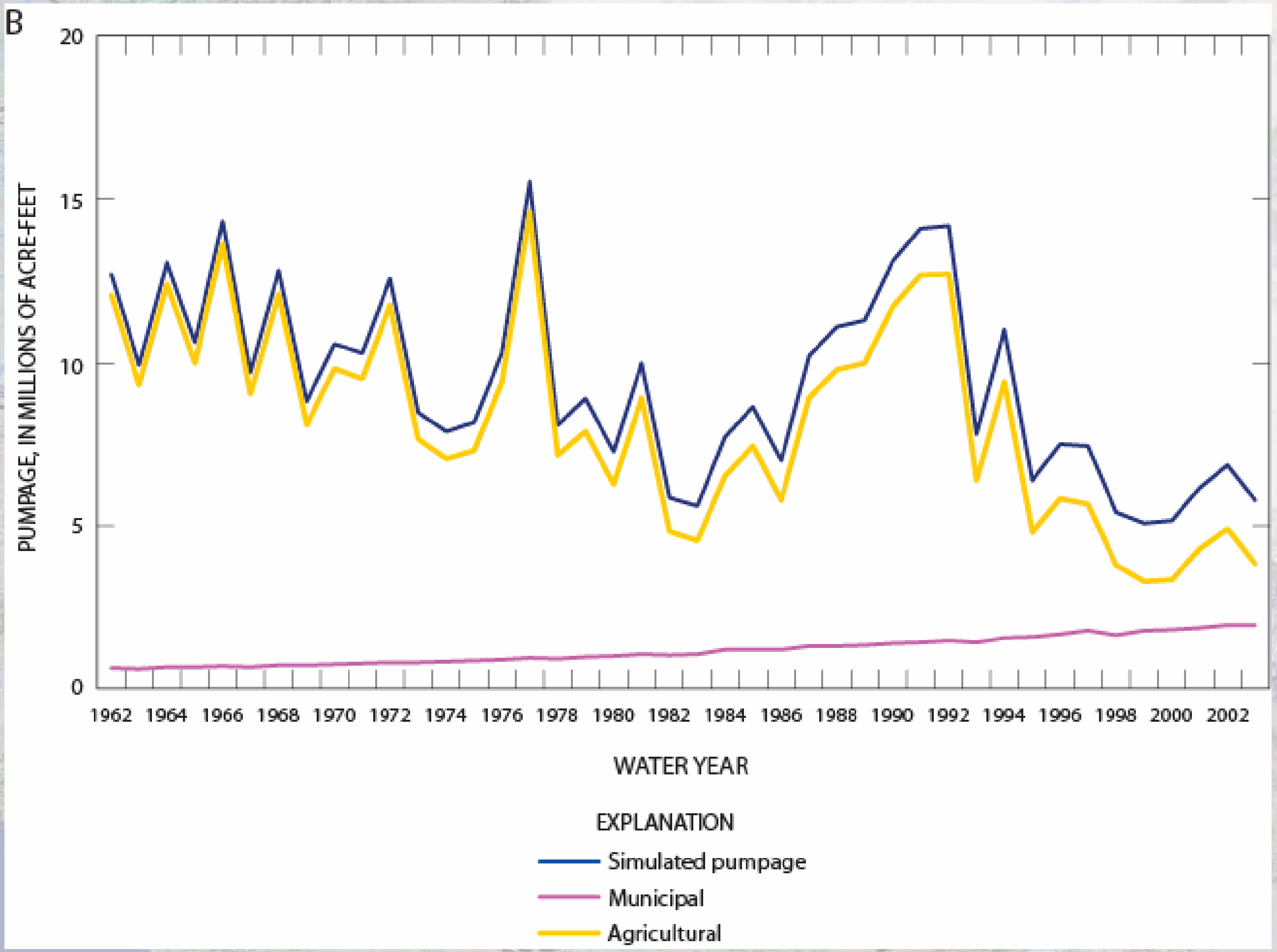
  -crop changes

  -conversion of farm-land to urban (about the same water use, but simulated differently)



Simulated Pumpage:

- Since about 1970, general trend in decrease in total amount of ground-water pumped
- Throughout time period, general increase in proportion of ground-water pumped used for municipal uses



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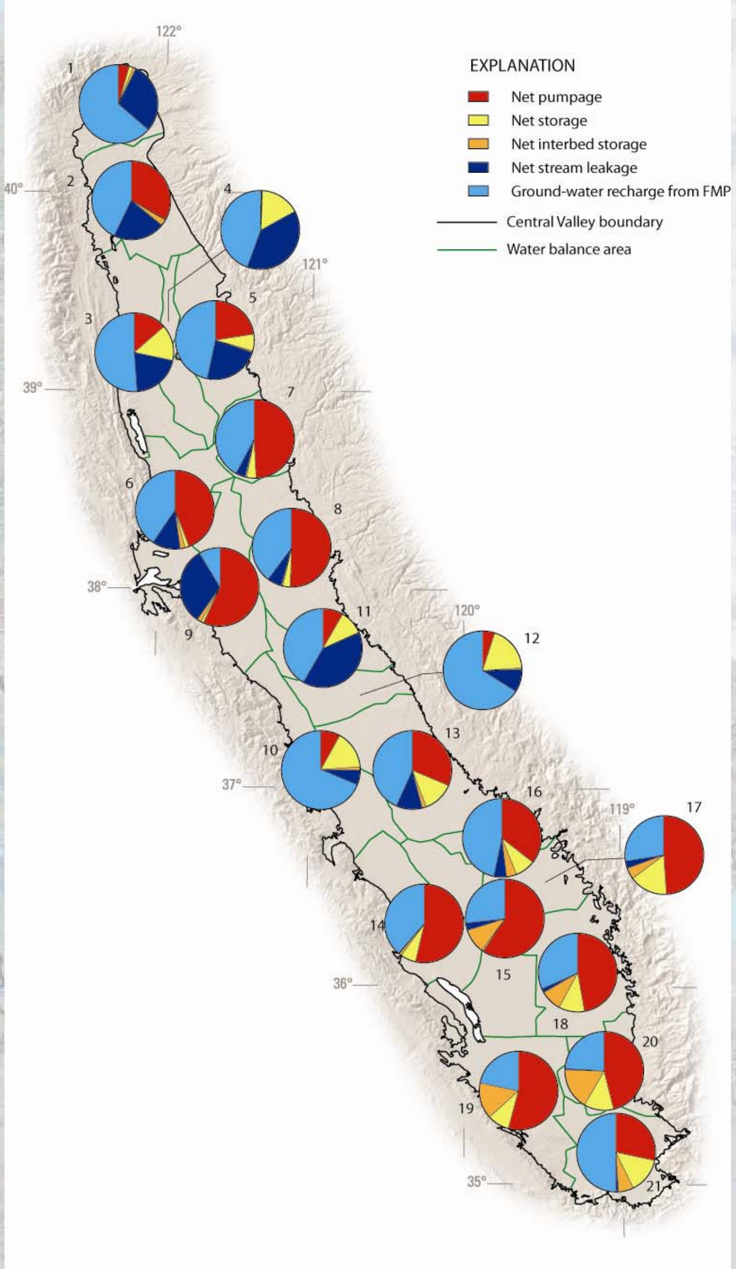
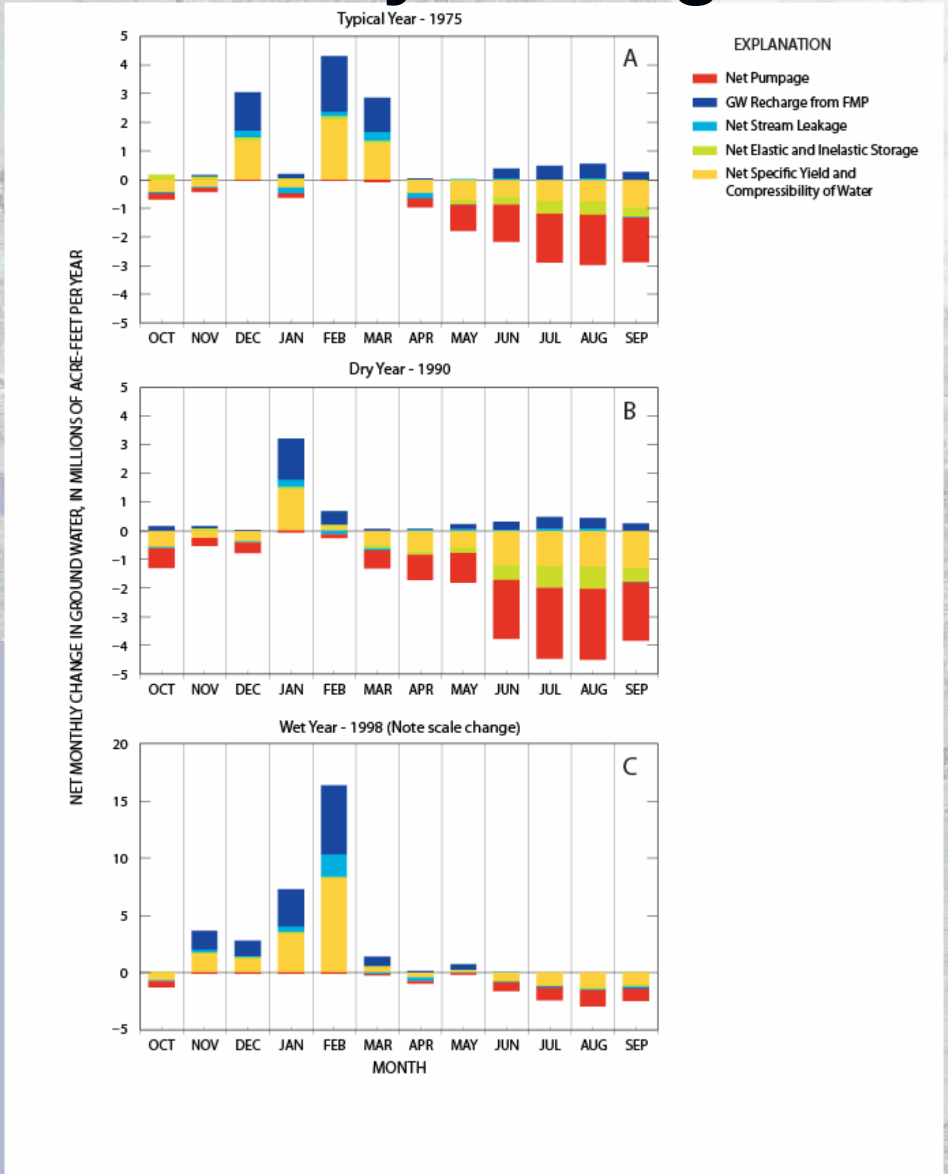
Ground-Water Budget

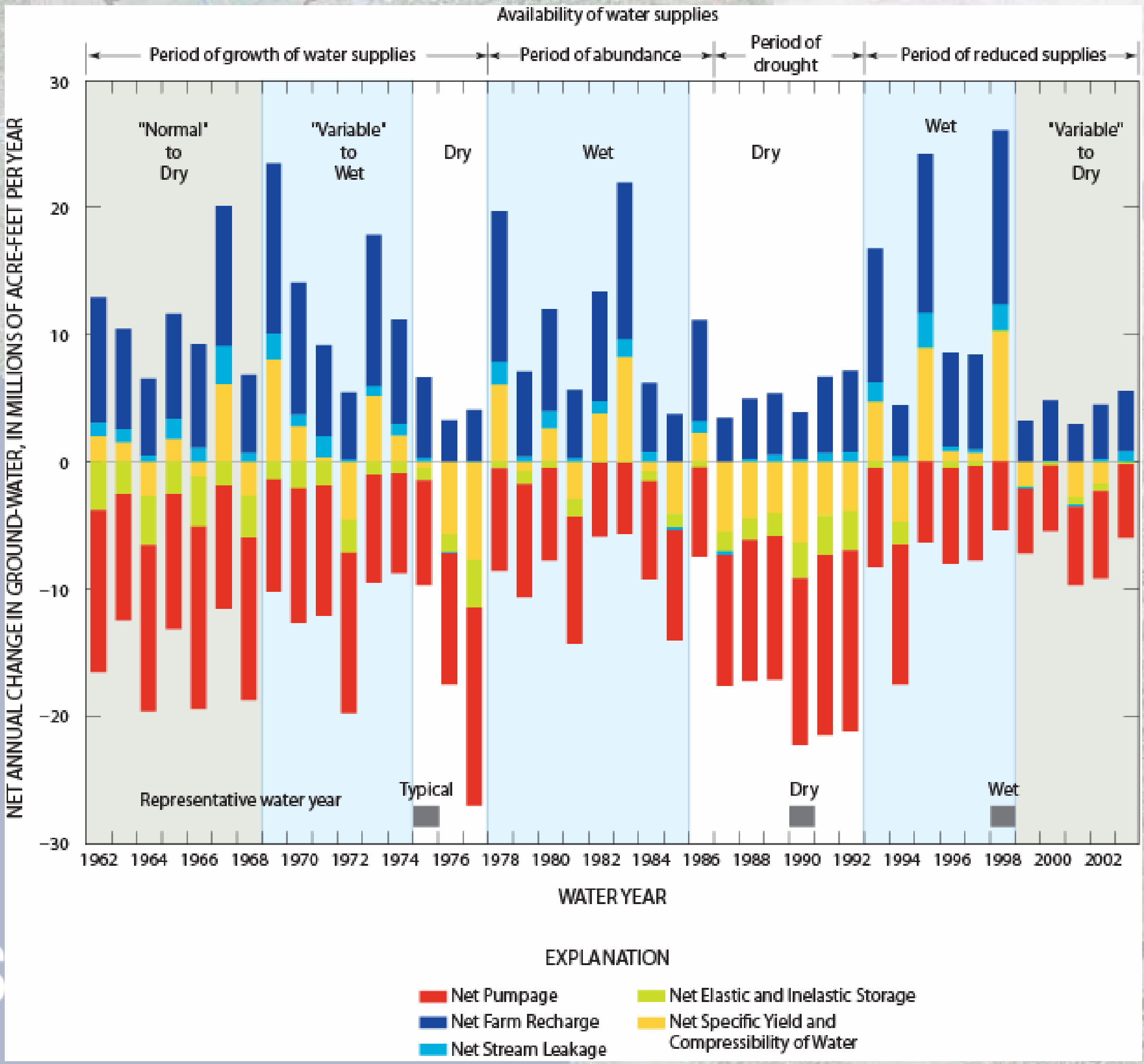
- Ultimate goal to see how landuse affects ground-water system
- Significant stream-flow infiltration north and around delta
- Significant pumpage and change in storage to the south
- Subsidence predominantly in the south (magnitude of pumping much higher)



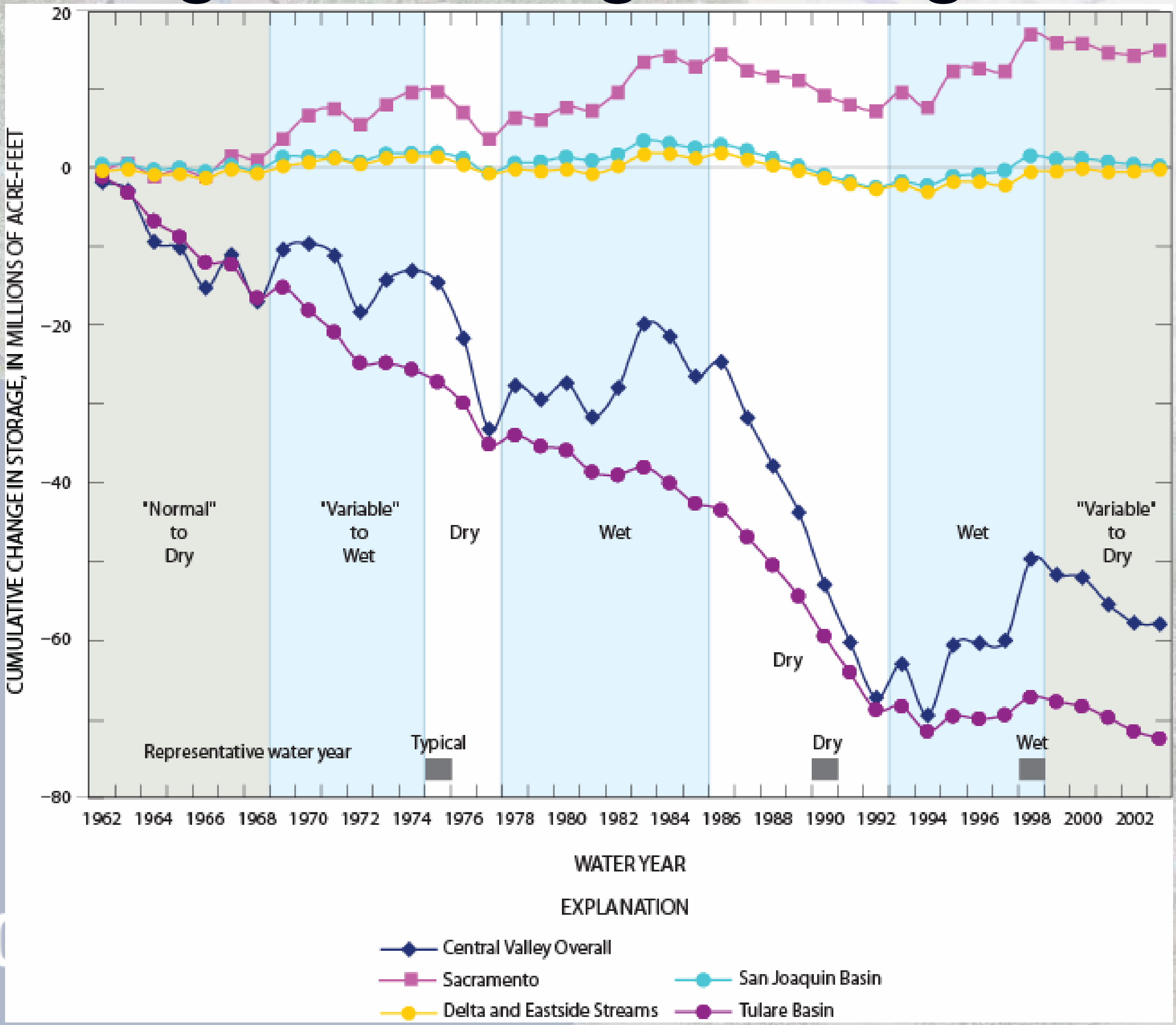
Change in Groundwater Availability through time



Change in Groundwater Availability through time



Change in Storage through time



Summary/Conclusions

Coupled farm-process and ground-water model is being used to estimate un-metered historical pumpage and to simulate the delivery of surface water

Surface-water deliveries supply most of the consumption in the initial part of the growing season, whereas increased ground-water pumpage augments these supplies later in the season

Proportions of surface water and ground water used for irrigation vary from year to year in response to climate and landuse changes

Numerical model is a useful tool for assessing ground-water availability and sustainable management of both ground water and surface water