Updates to the Central Valley Hydrologic Model, with an Emphasis on Improving the Simulation of Land Subsidence in the San Joaquin Valley

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U.S. Geological Survey

In conjunction with Bureau of Reclamation

Outline:

- **Overview of Central Valley Hydrologic Model (CVHM)**
- **Updates and Refinements**
  - **(1) model code changes**
  - **(2) data updates**

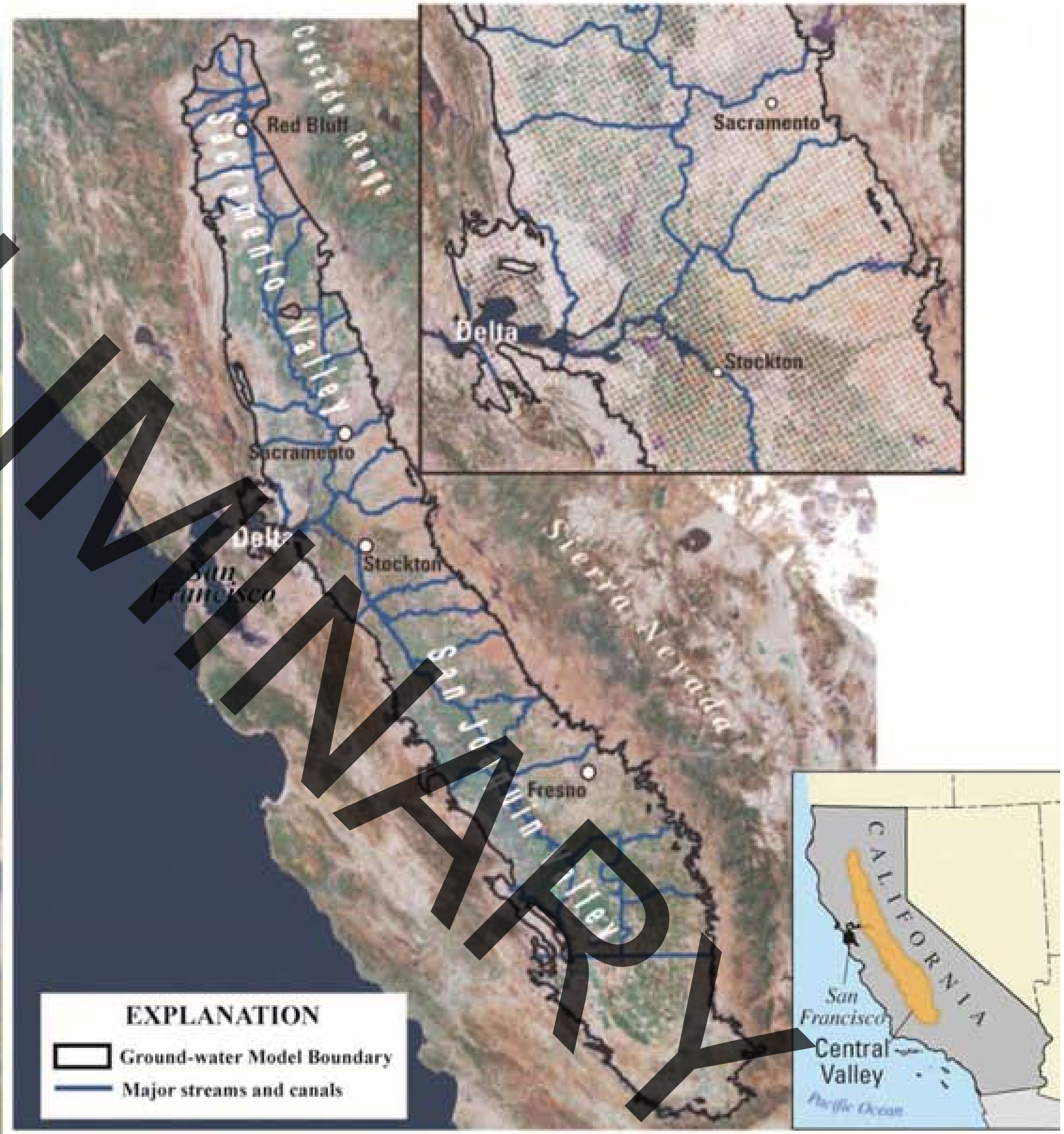
focused on more accurately simulating the locations and magnitudes of land subsidence

A Regional Hydrologic Model of California's Central Valley

- USGS Groundwater Resources Program
- Focus on groundwater availability and changes in storage
- Developed in consultation with CA-DWR
- Updates in conjunction with Reclamation

Central Valley Facts:

- 20,000 square miles
- More than 250 different crops with an estimated value of $17 billion /year
- Approximately 25 % of the table food consumed in the US is grown in the Central Valley
- Approximately 17 % of the Nation's irrigated land is in the Central Valley
- Approximately 20 % of the Nation's groundwater pumpage is from the Central Valley aquifer system



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CVHM – emphasis on groundwater availability and changes in storage

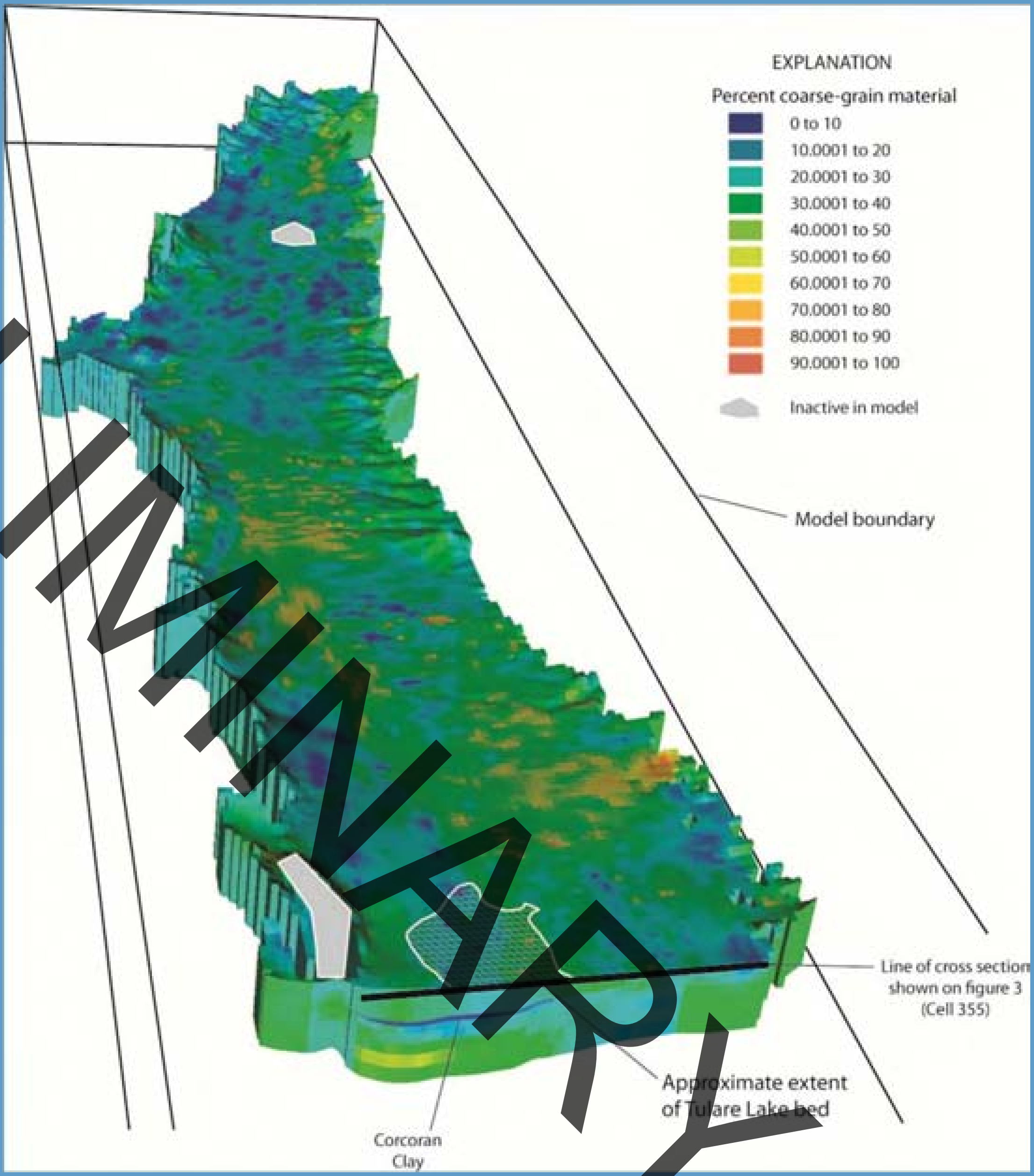
Objectives:

- **TEXTURE ANALYSIS**: Describe the sediment characteristics of the aquifer system to estimate hydraulic properties.
- **FARM PROCESS**: Develop an approach for systematically estimating water budget components for an aquifer system in an area dominated by irrigated agriculture.
- **GROUNDWATER MODEL**: Develop a model of the Central Valley aquifer system *capable of being accurate* at scales relevant to water management decisions.

Texture Analysis:

3D model

- Based on 8,500 drillers logs
- Interpolated to one-mile spatial grid at 50 foot depth intervals
- Coarse near river channels
- Finer in low energy environments (Corcoran Clay)



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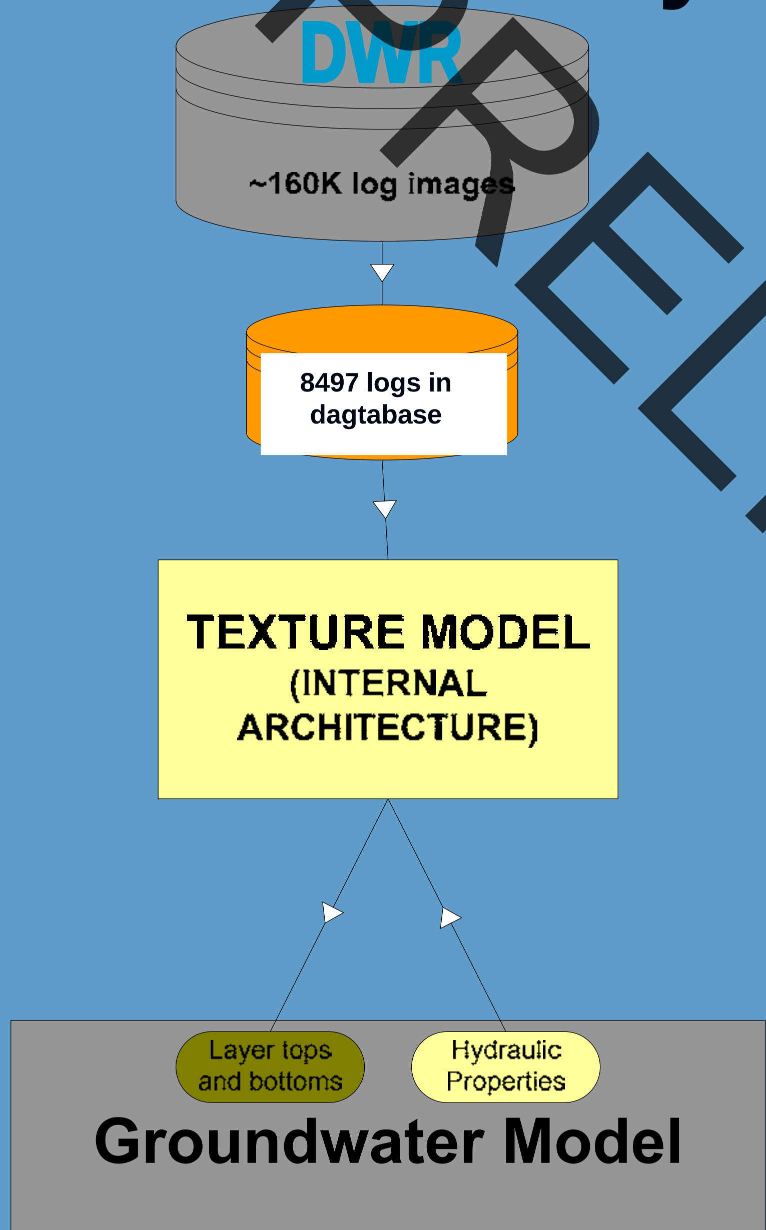
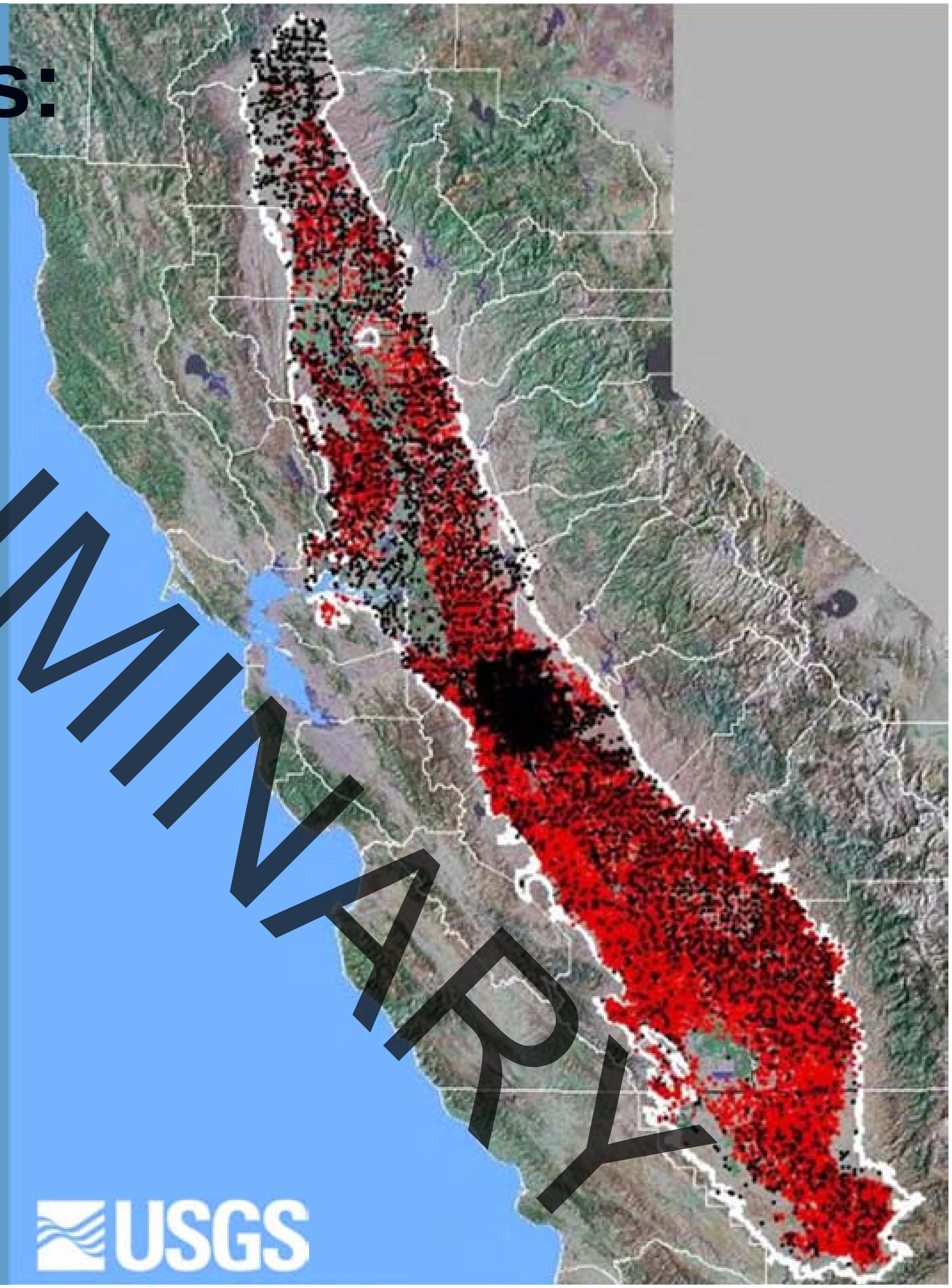
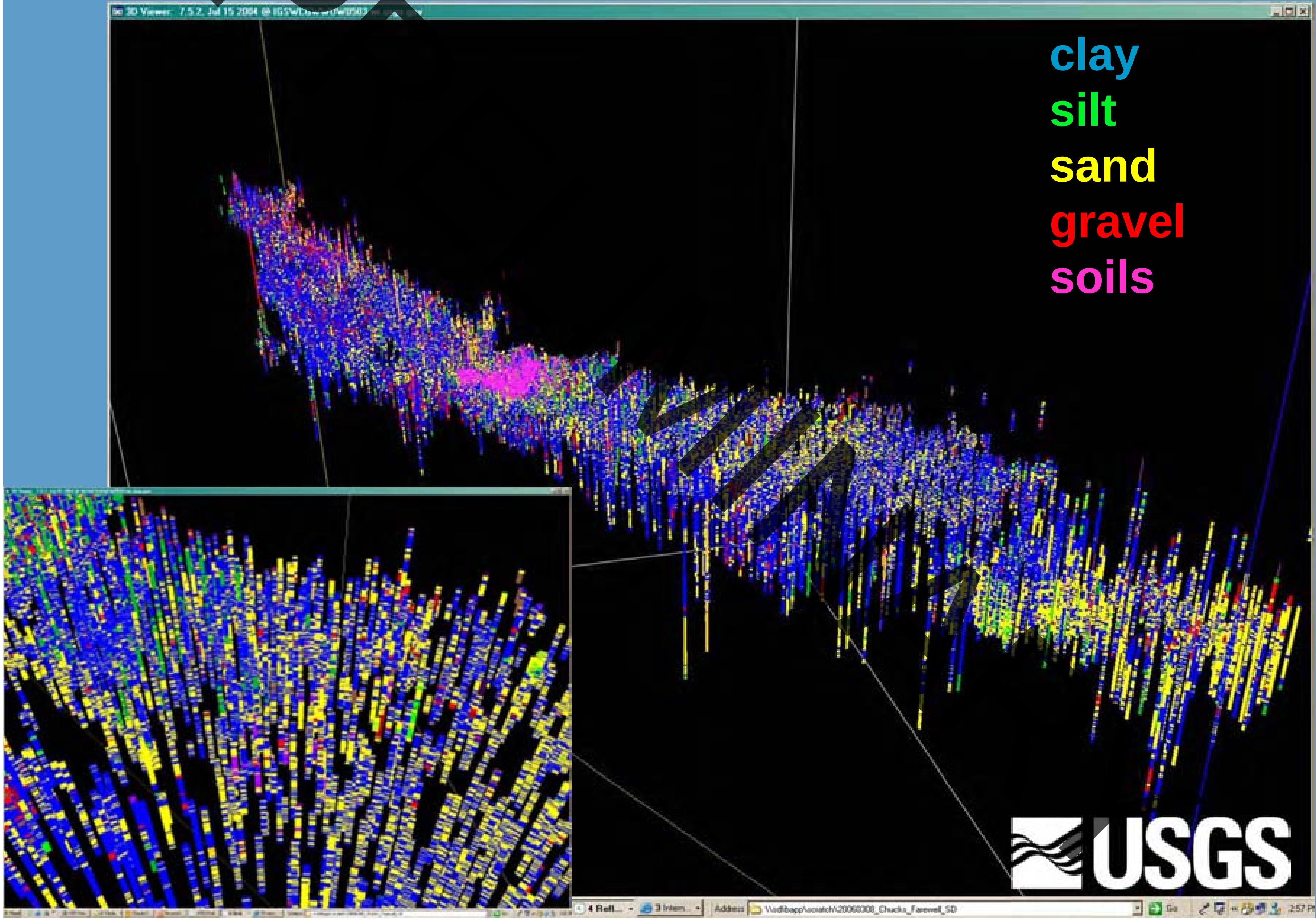
Texture Analysis:





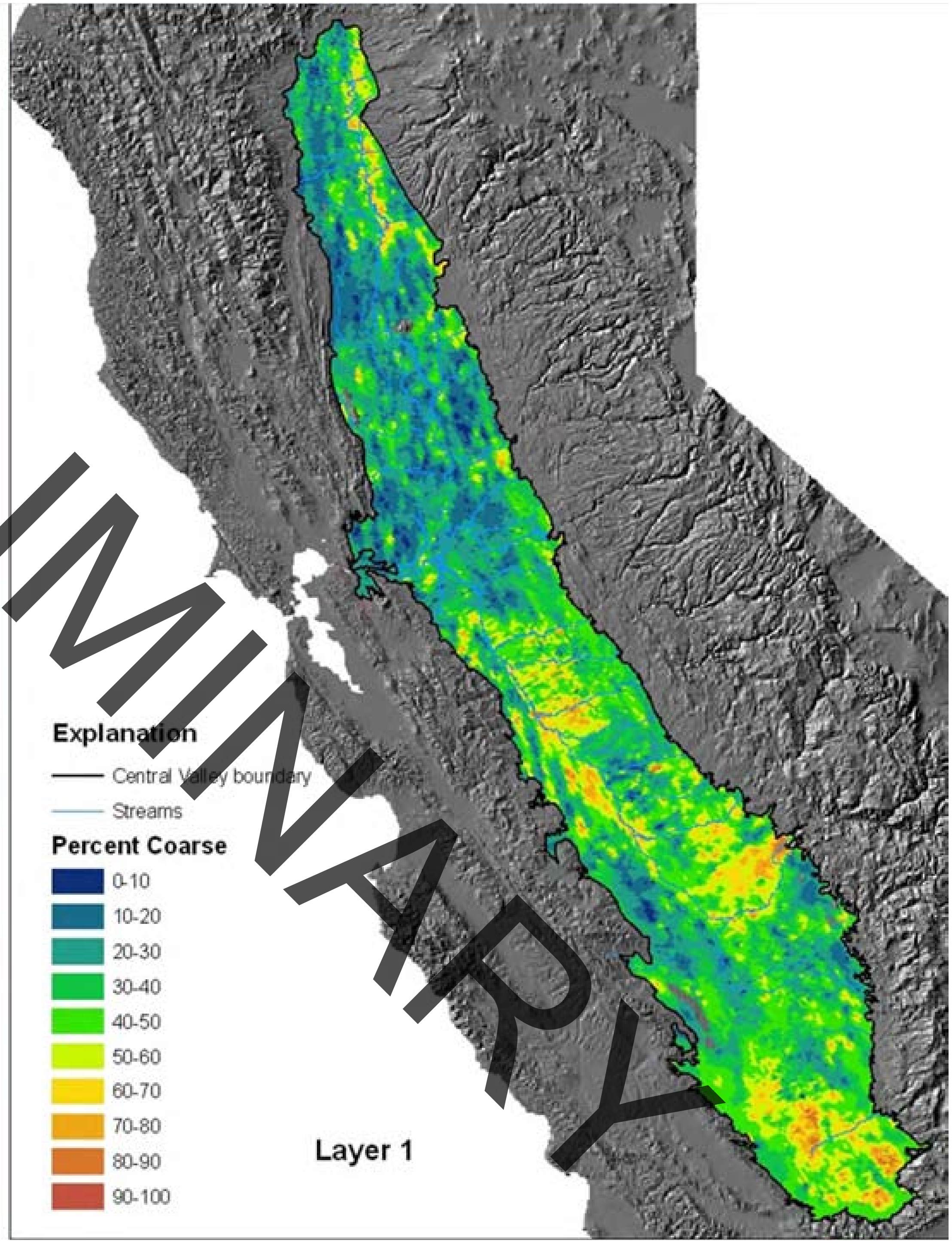
Central Valley well logs - lithology



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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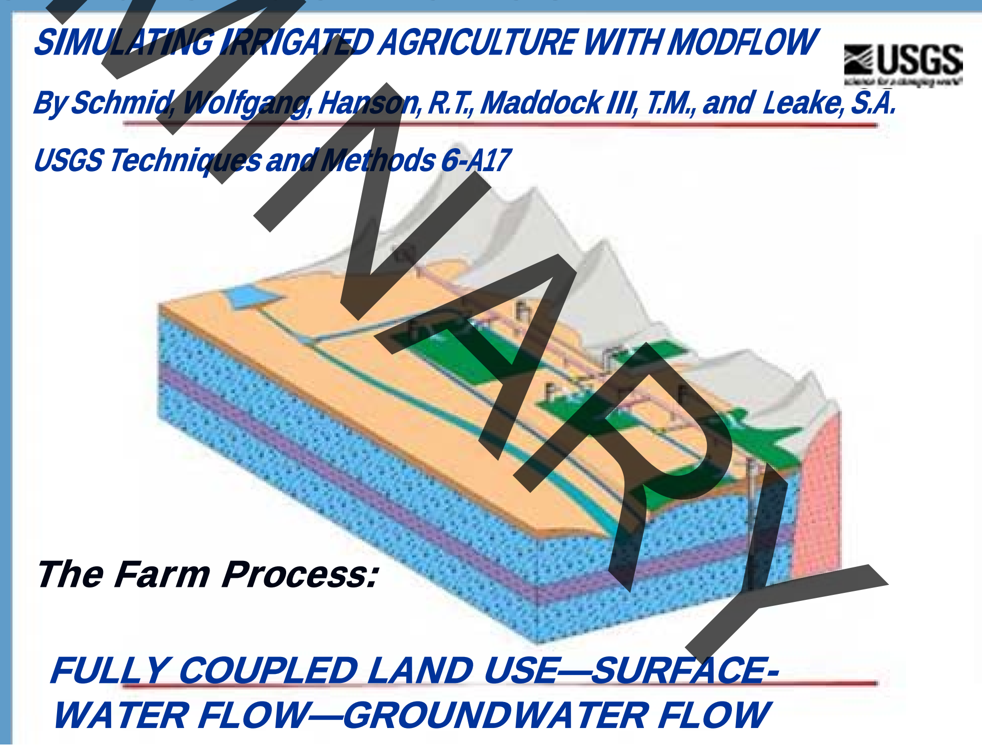
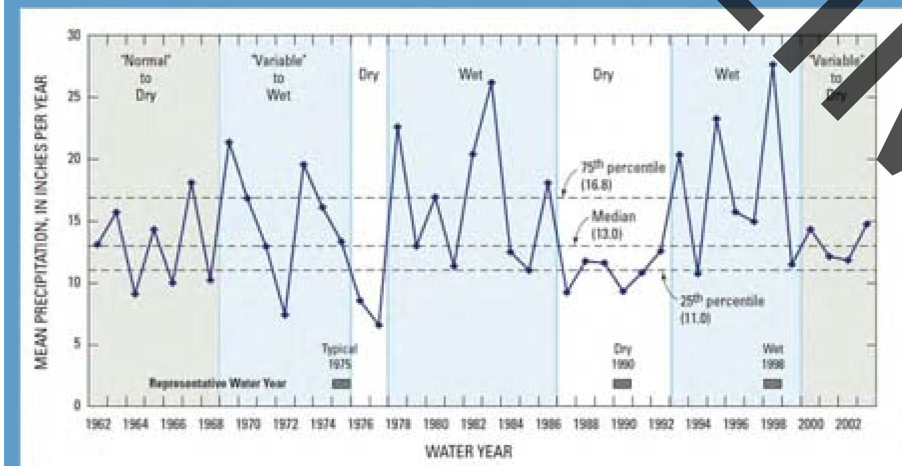
Farm Process:

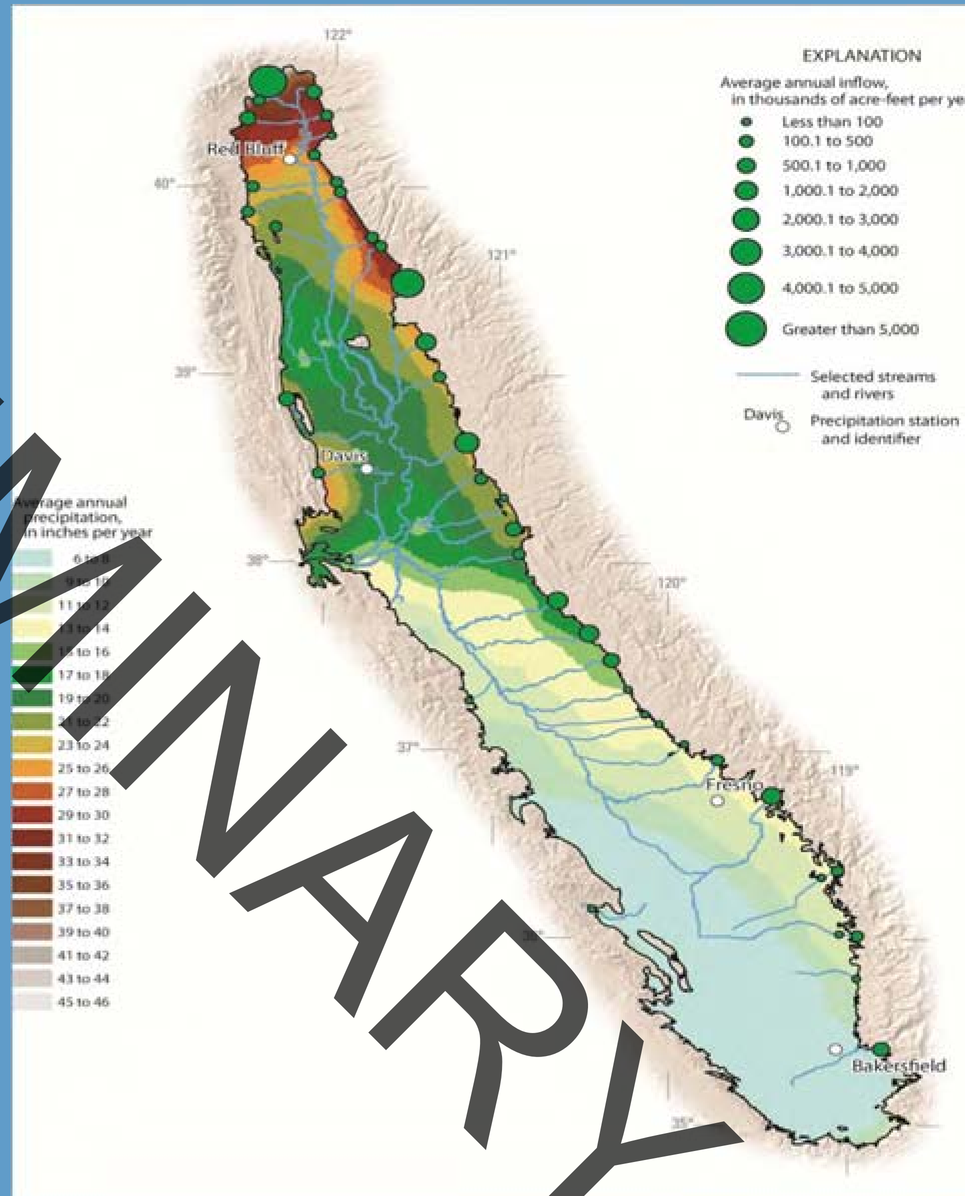
- Systematic approach for estimating water-budget components
- Based on:
  - the consumptive use of water by plants
  - available surface-water deliveries



Climate: Precipitation and Inflows

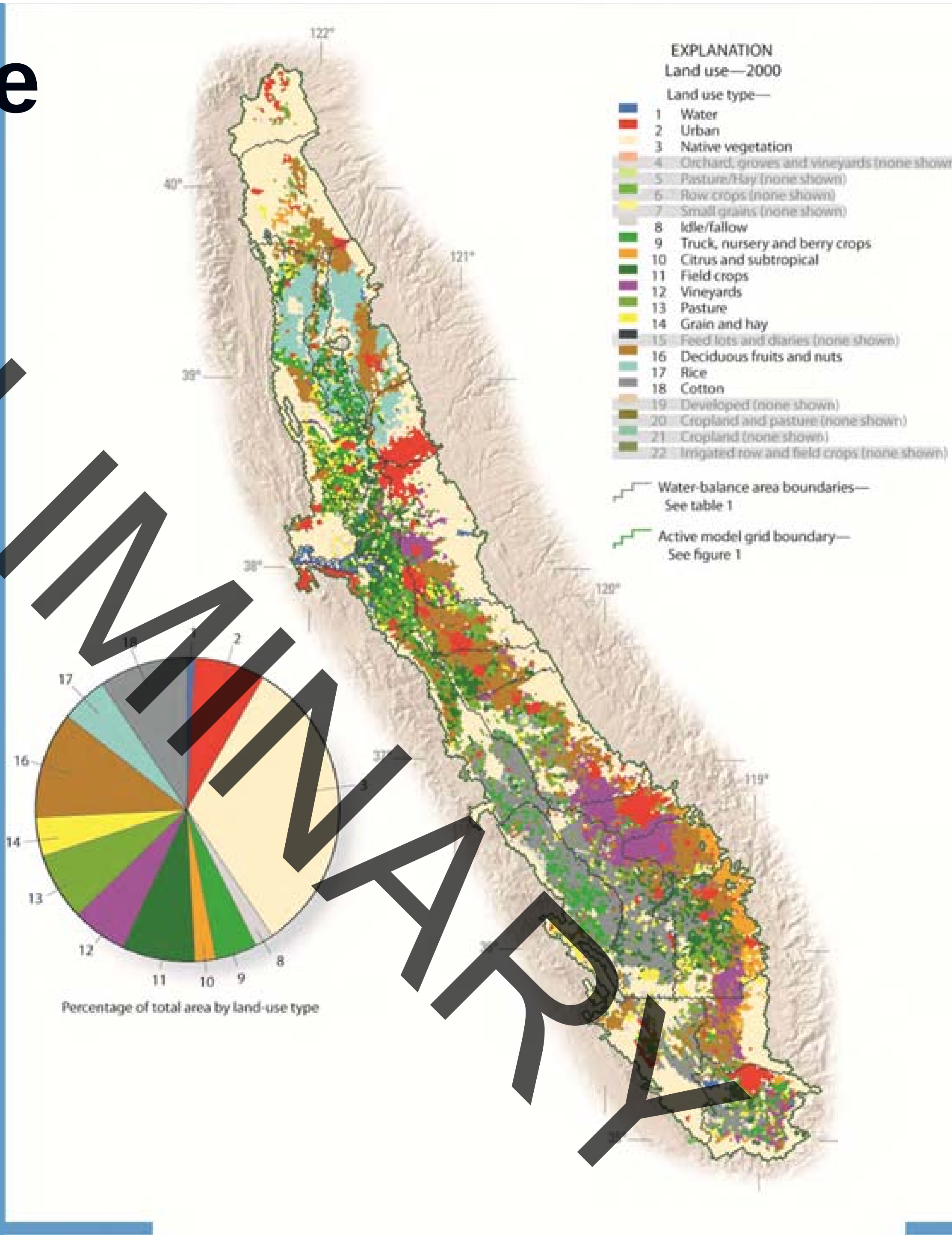
- Vary Geographically
- Vary with Time
  - Annually
  - Seasonally





Water-balance regions and Landuse

- 21 regions
  - CA-DWR collaboration
- 1962-2003
- Landuse categories:
  - Urban
  - Native
  - Crops



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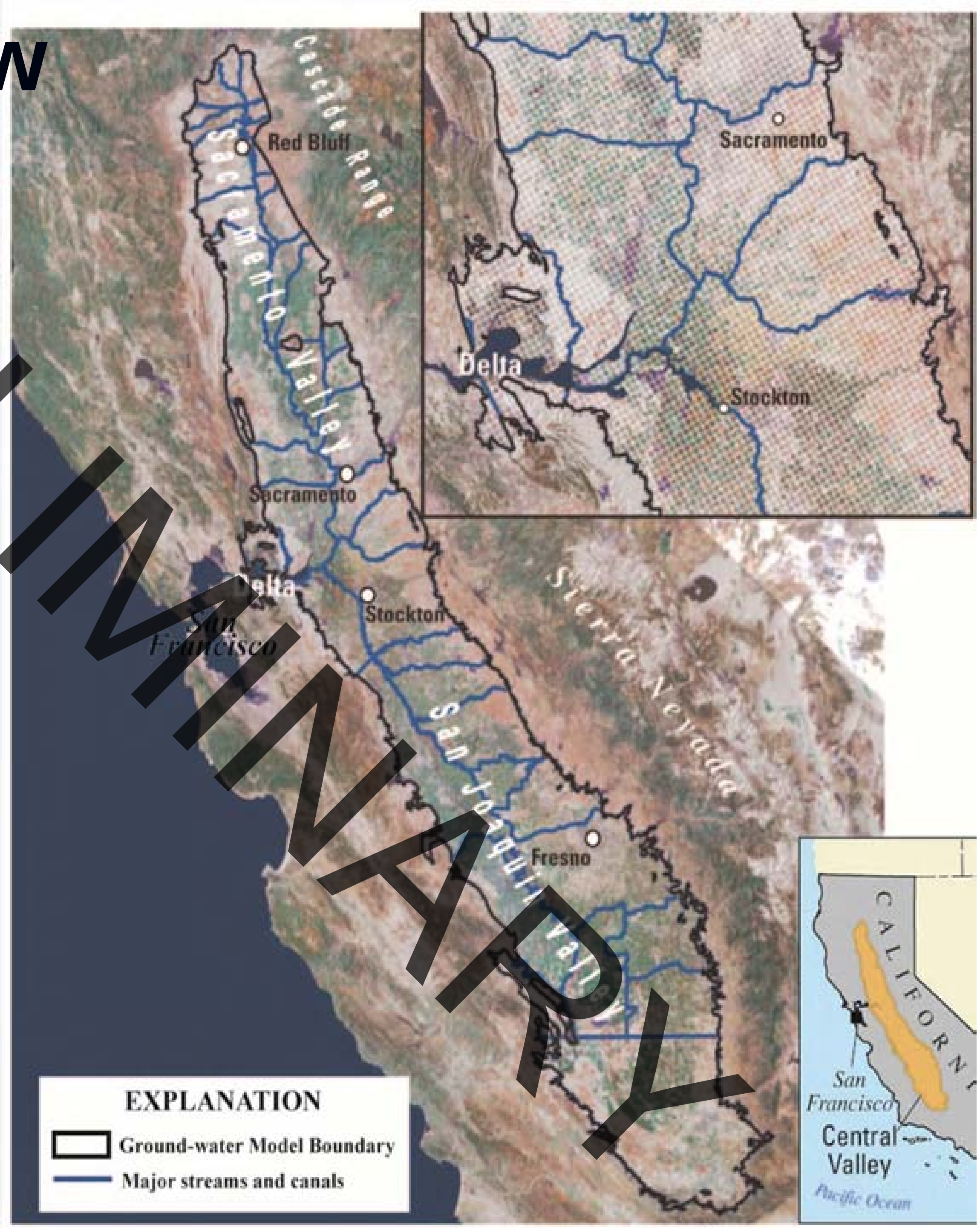
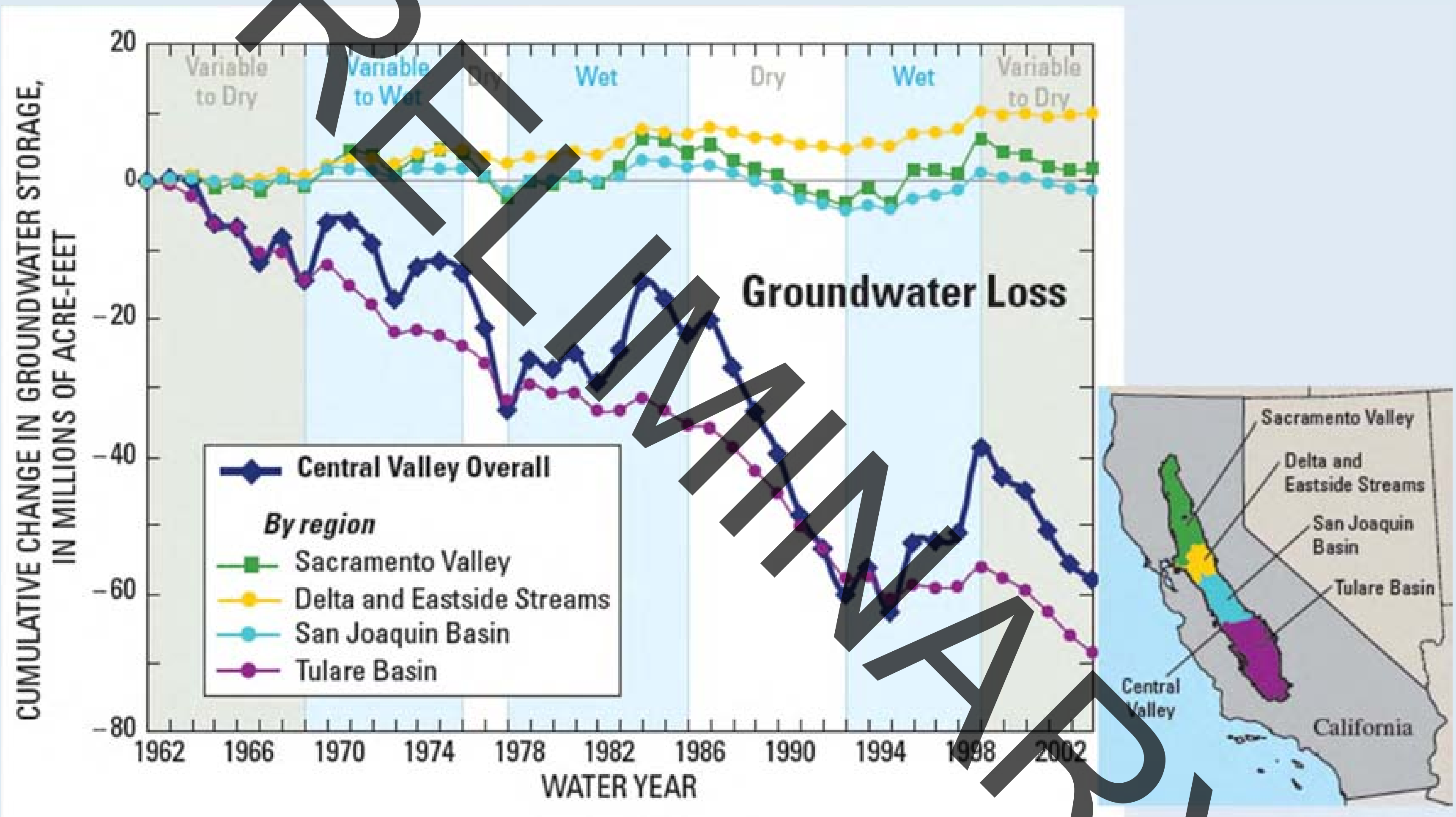
Model overview

- Uniform one sq. mile cells
- Water years 1962 – 2003 (monthly stress periods)
- MODFLOW-2000 with Farm Process (FMP)
  - Stream flow routing (SFR)
  - Wells (MNW) (municipal/ farm)
  - Subsidence (SUB)
  - Flow barriers (HFB)
- Sensitivity Analysis and Calibration with Parameter Estimation (UCODE/PEST)



Change in Storage with time



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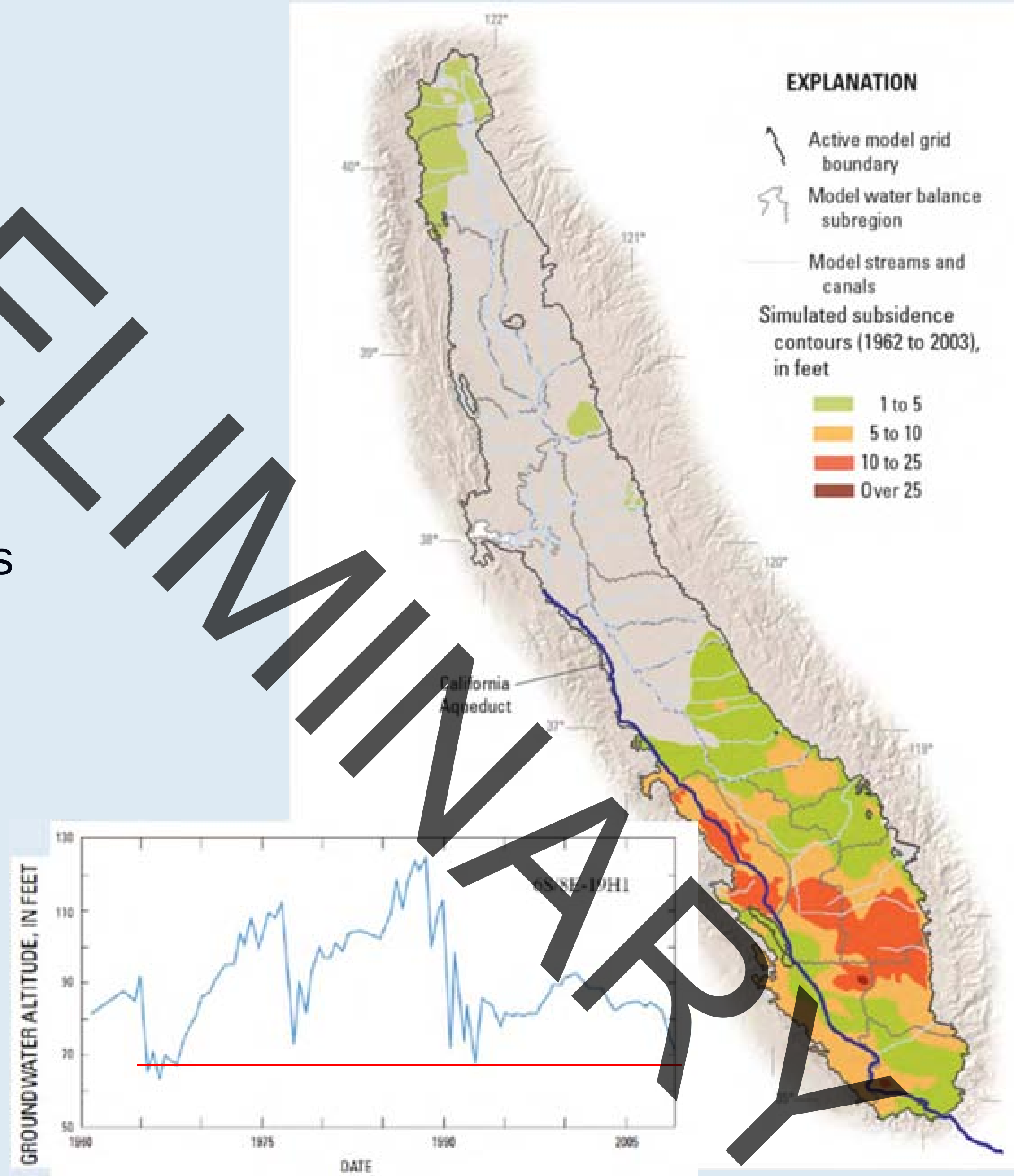
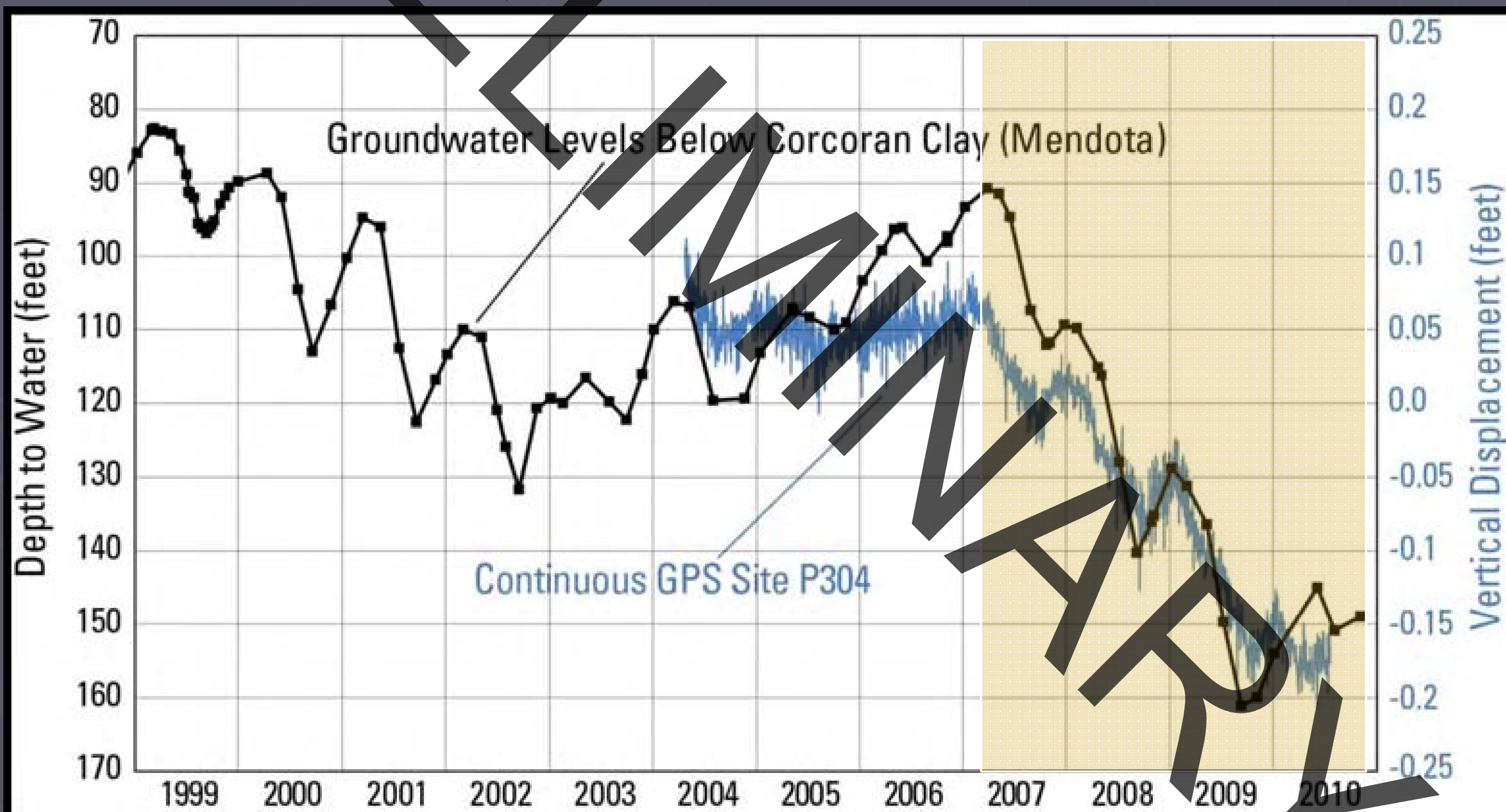
Subsidence:

- In1960s, groundwater pumping caused water levels to decline
- Water-level declines cause compaction of fine-grained deposits, which results in subsidence
- Surface-water deliveries since the late 1960s have reduced the dependence on groundwater
- Recently water levels were again reaching their historic lows and subsidence renewed
- Management constraint



Recent Water Level Changes and Subsidence

- Reduced surface water importation
- More reliance on the groundwater resources



P304 data from UNAVCO; water-level data from Luhdorff and Scalmanini Consulting Engineers

Subsidence Damages Natural Resources and Infrastructure

- Natural resources
  - Reduces aquifer-system storage capacity
  - Impacts to wetland, riparian, and aquatic ecosystems
  - Restricted land uses
- Infrastructure
  - Damage to water conveyance systems and other infrastructure
    - Lost freeboard, panel damage, water surface and liner misalignment, reduced conveyance capacity
    - Roads, rails, bridges, pipelines, wells, etc.

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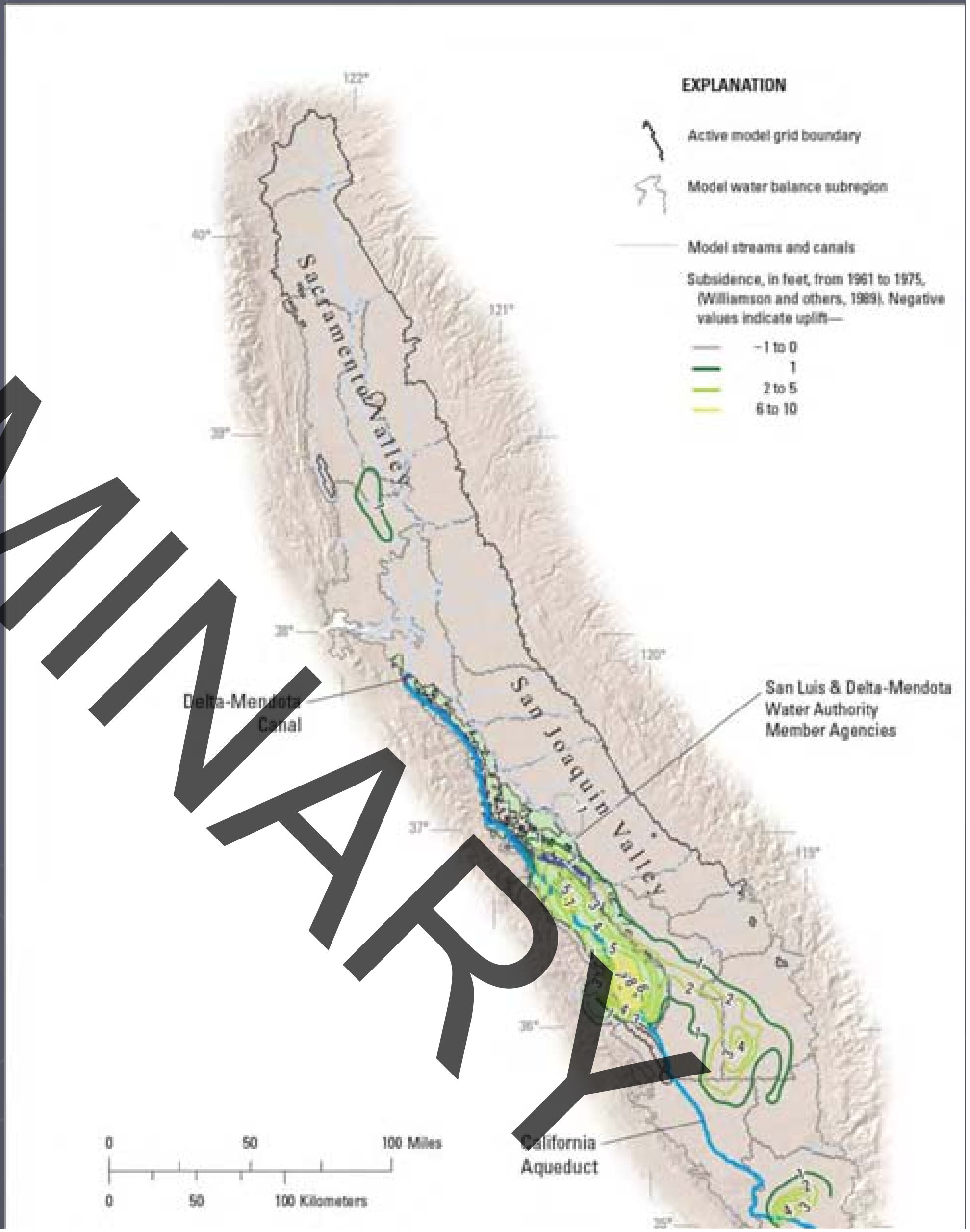
Updates and Refinements:

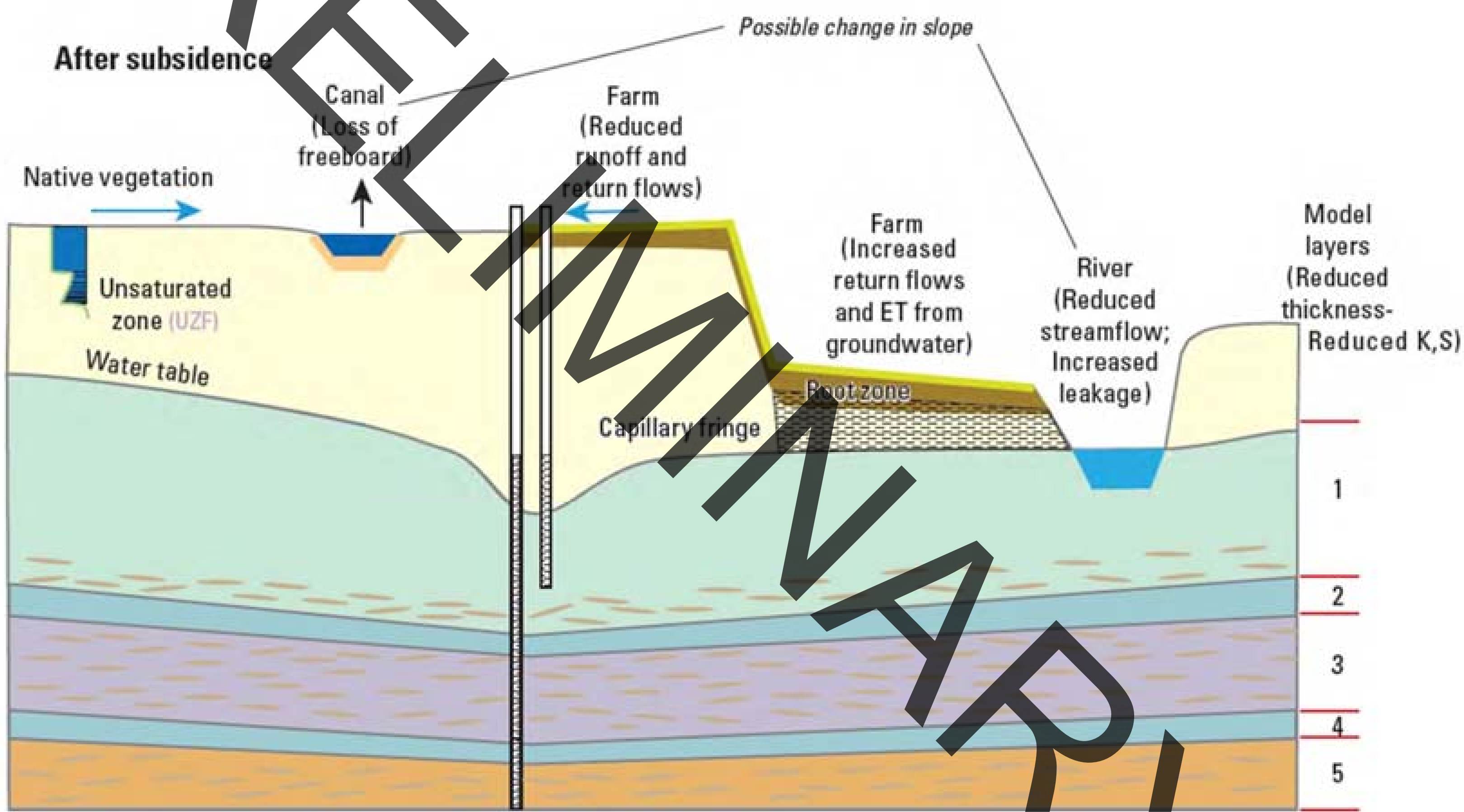
- Extend simulation through 2009
- Two categories:
  - (1) model code changes
  - (2) data updates



Model Code Changes :

- **MODFLOW and CVHM** updated to include:
  - (1) more accurate details in the timing of the subsidence by incorporating delay beds,
  - (2) separation of the inelastic and elastic portions of subsidence in the SUB package, and
  - (3) changes in land-surface altitudes caused by subsidence - deformable layers
  - (4) Simulation of water table (NWT solver)
  - (5) Adjustable sub-regions through time

Landscape processes	Subsurface processes
Farm Process (FMP)	Layer-Property Flow Package (LPF)
Streamflow Routing Package (SFR)	Subsidence Package (SUB)
Surface-Water Routing Process (SWR)	Multi-Node Well Package (MNW)
	Unsaturated-Zone Flow Package (UZF)



After subsidence
Possible change in slope
Canal
(Loss of
freeboard)
Farm
(Reduced
runoff and
return flows)
Native vegetation
Farm
(Increased
return flows
and ET from
groundwater)
River
(Reduced
streamflow;
Increased
leakage)
Model
layers
(Reduced
thickness-
Reduced K,S)
Unsaturated
zone (UZF)
Water table
Root zone
Capillary fringe
1
2
3
4
5

Data Updates

- Extend the model simulation period to September 2009 (from Sept. 2003)
- Update to the stream network
- Update surface water delivery data
- Increase the number of subregions (particularly western San Joaquin Valley)
- Add additional land use types
- Add agricultural drains
- Add ungaged watershed inflow
- Add water banks
- Add observations (subsidence, stream flow, drain flow, water levels)

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Extension of Model Simulation Period

- Surface water deliveries
- Subregions (now change through time)
- Municipal pumping
- Precipitation and evapotranspiration
- Crop water use parameters

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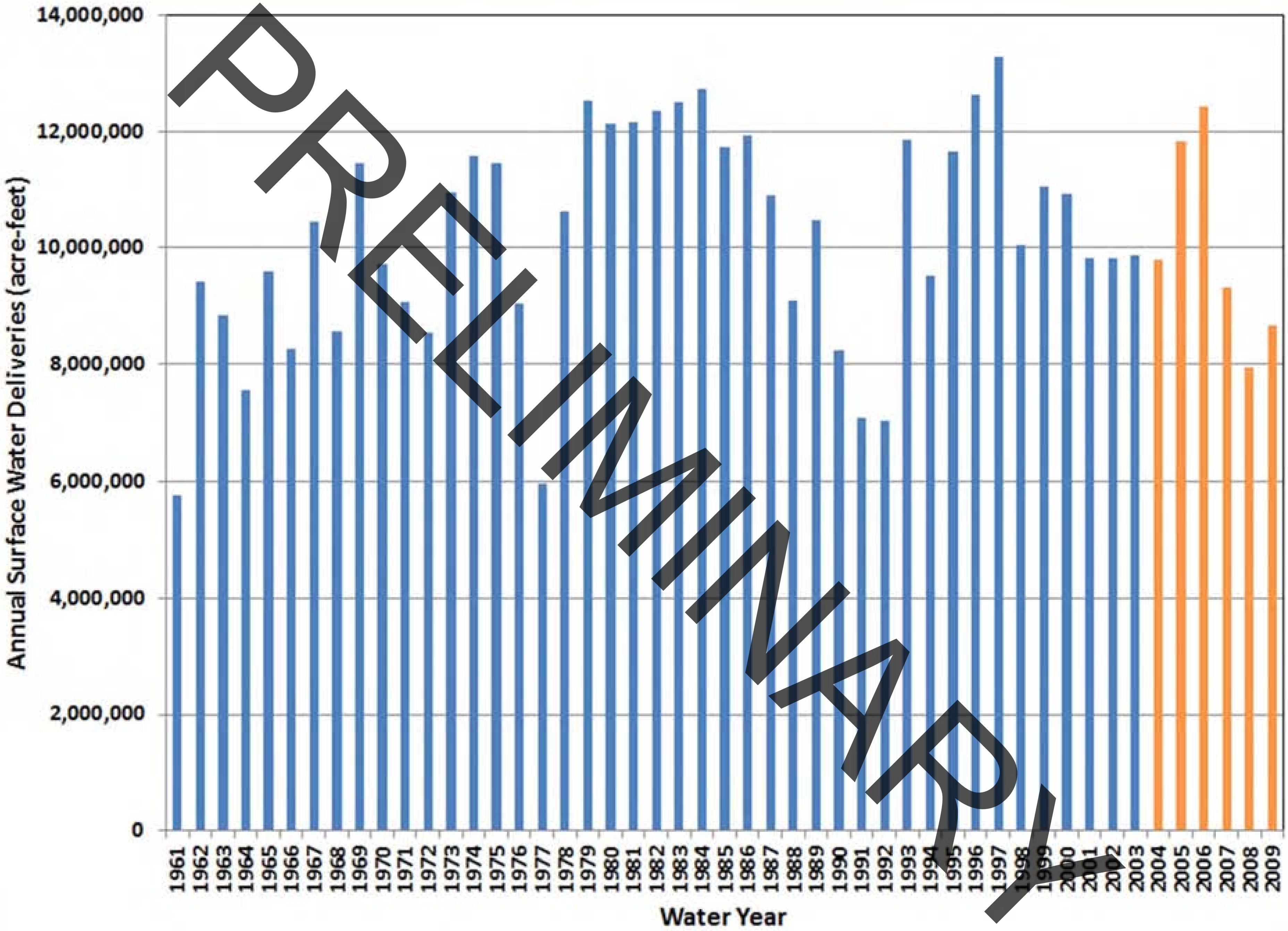
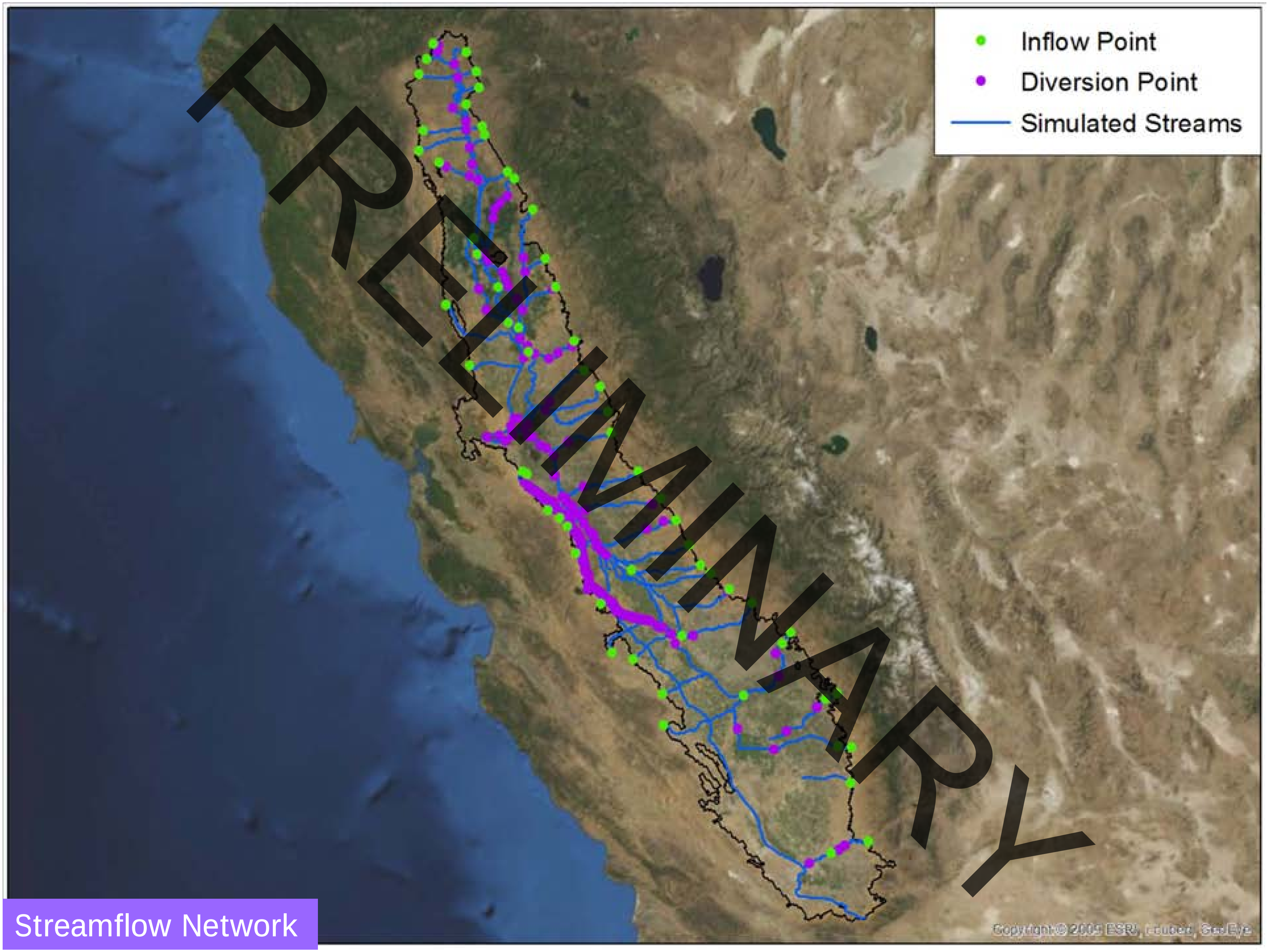


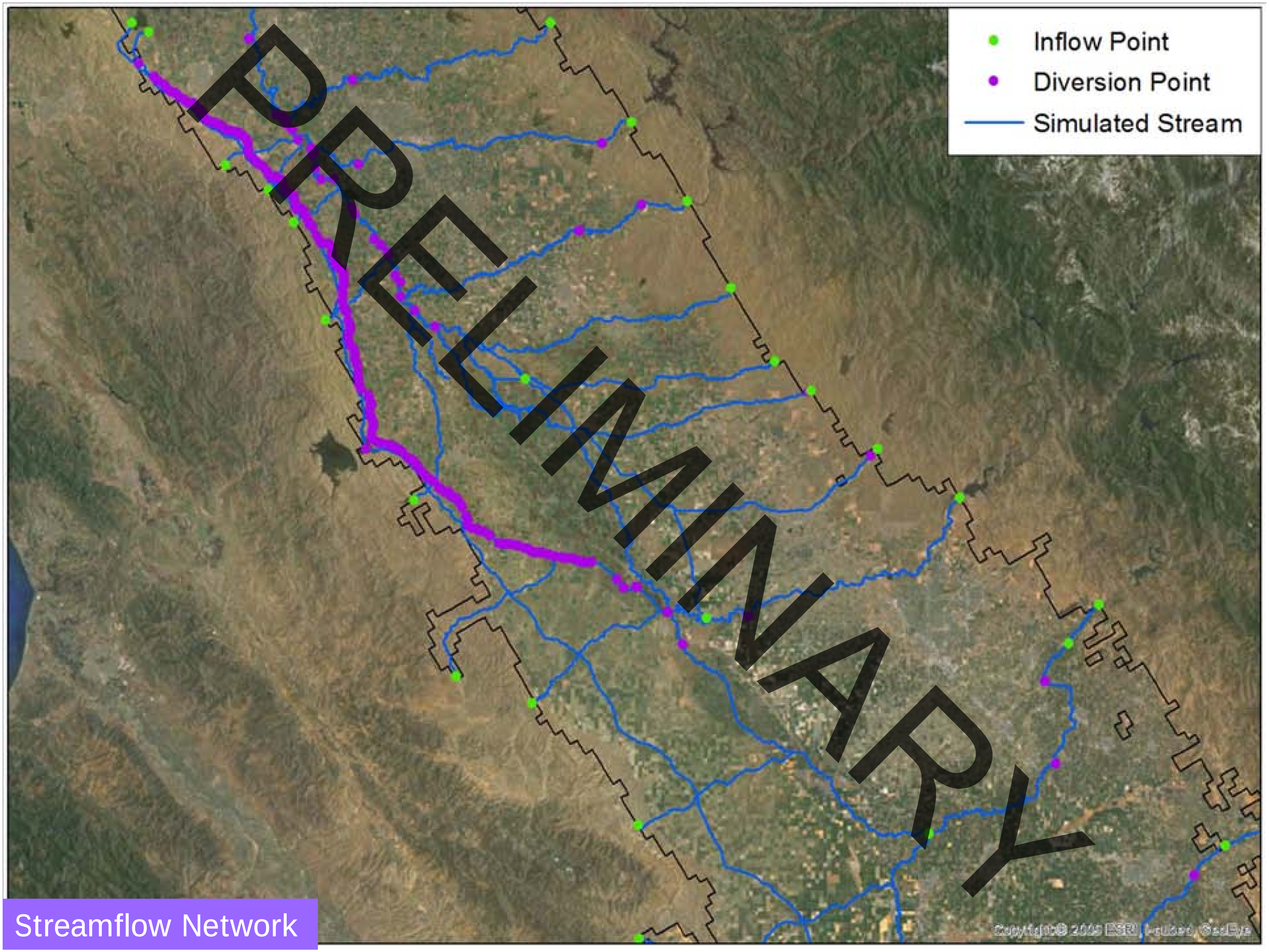
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Annual Surface Water Deliveries (acre-feet)
1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
Water Year
PRELIMINARY

Update on Streamflow Network

- Addition of Delta Mendota Canal and California Aqueduct
- Addition of San Joaquin and Sacramento River flood control bypasses
- Addition of other streams and creeks
- Detailed surface water Diversion Locations
  - Especially along DMC



Streamflow Network



Streamflow Network

Increase the Number of Subregions

- Additional breakdown of subregions in the Delta Mendota Canal area
- Allows the utilization of detailed surface water delivery data without the need to aggregate
- Improves distribution of groundwater pumping
- Addition of groundwater banking activities

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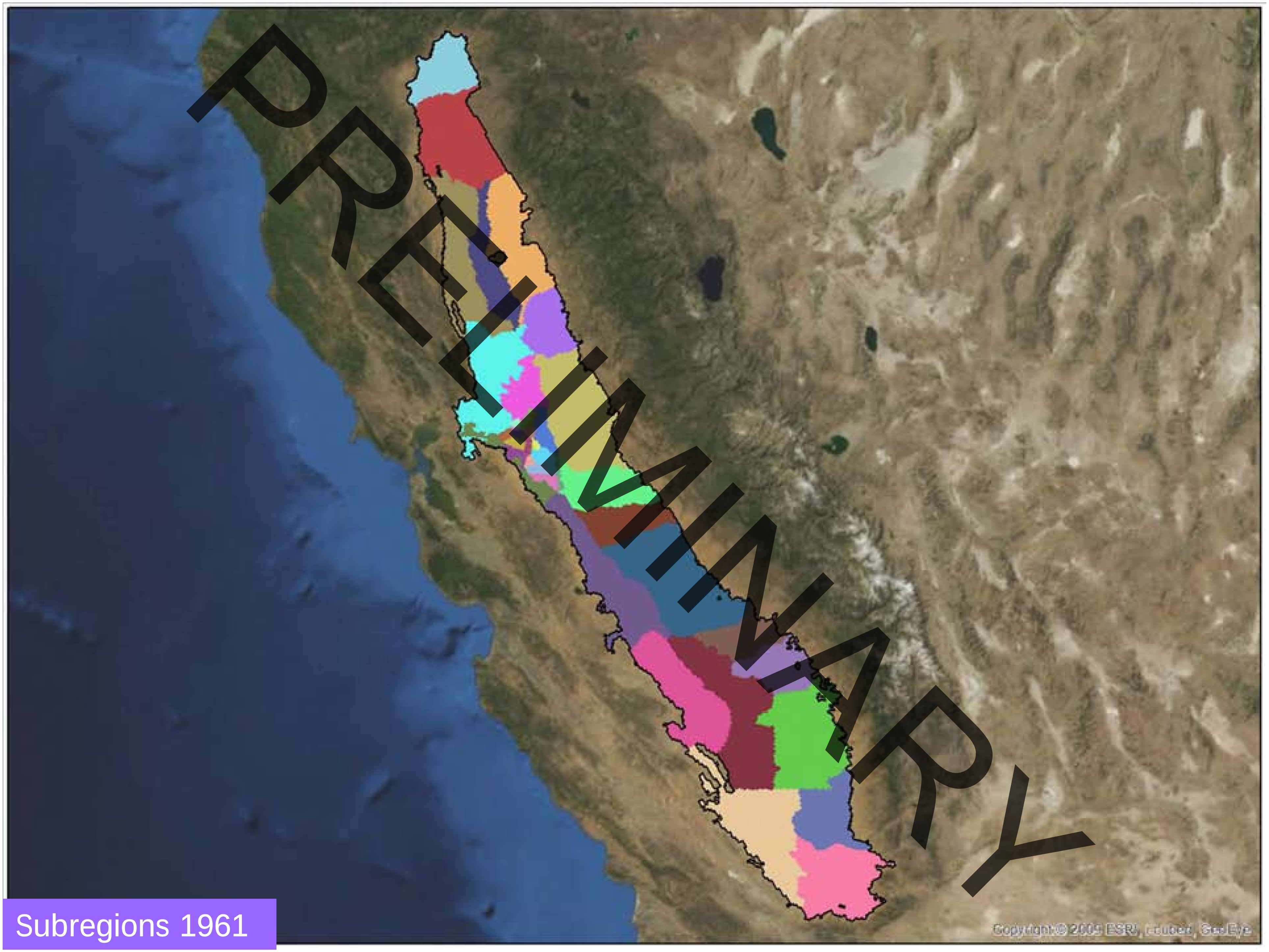
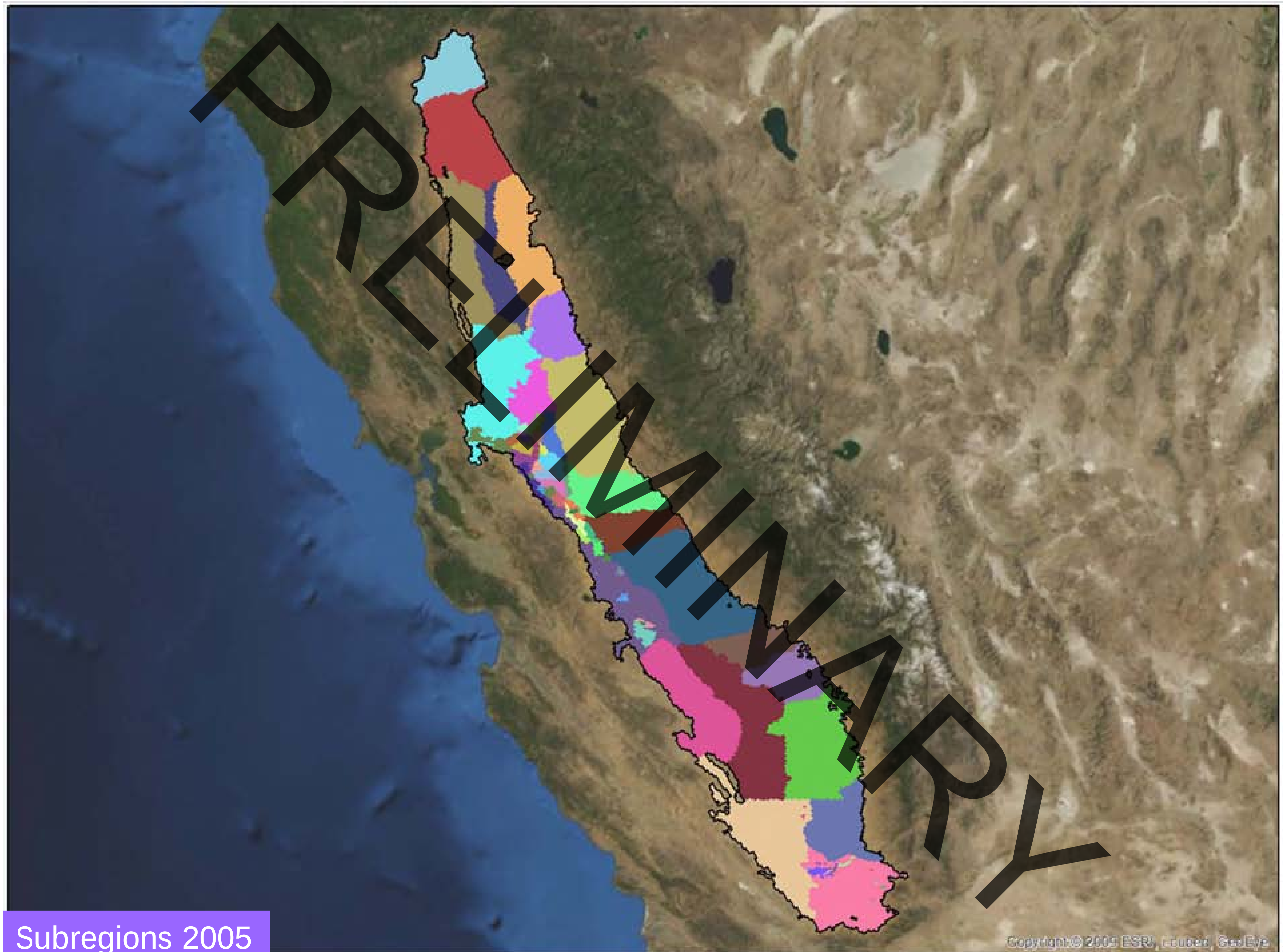


Subregions 1961



Subregions 2005

Other Enhancements

- Add additional land use types
  - Phreatophytes
  - Non-irrigated crops
- Add agricultural drains in DMC area
- Add ungaged watershed inflow
- Add recharge from water banking

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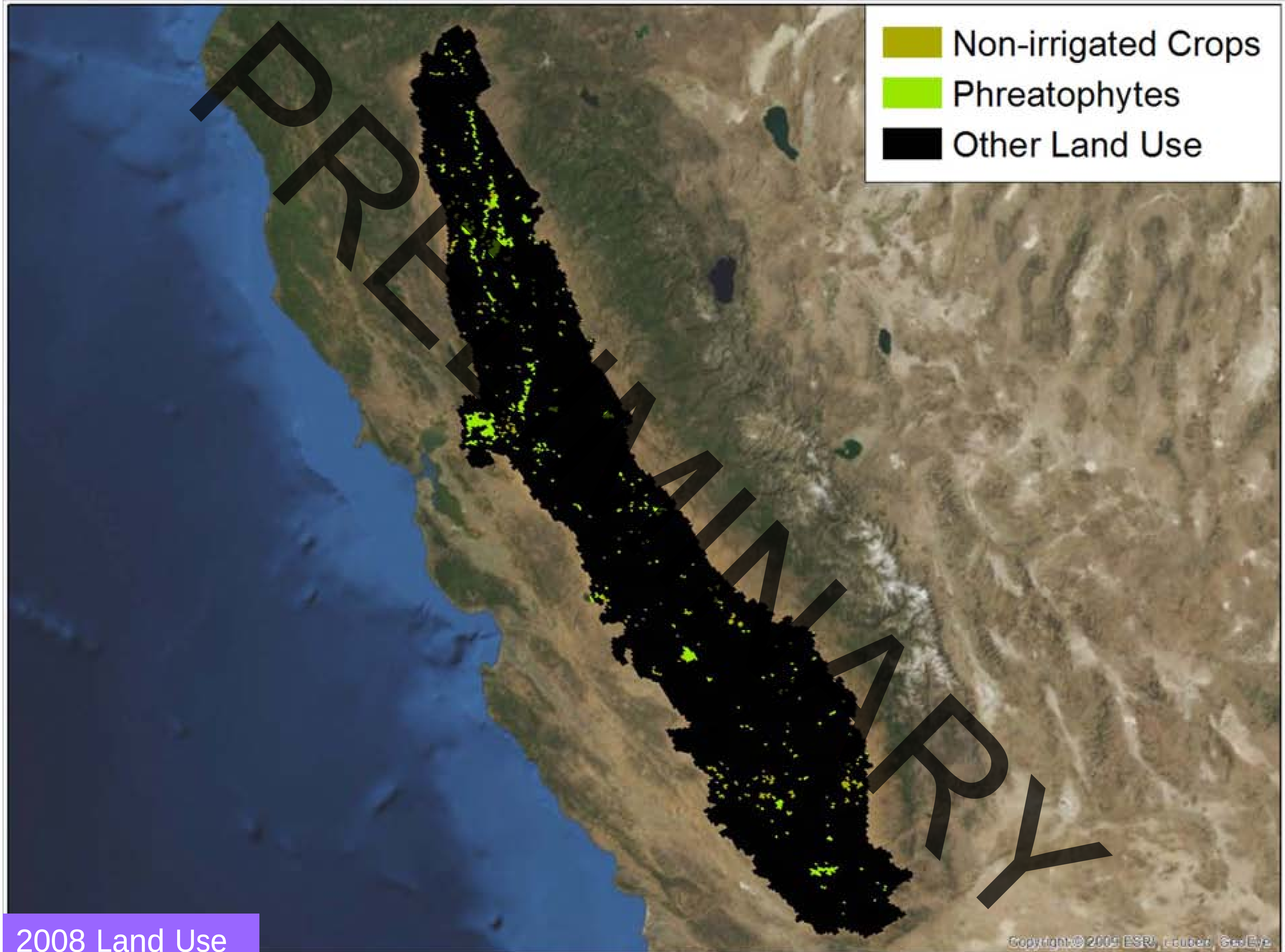
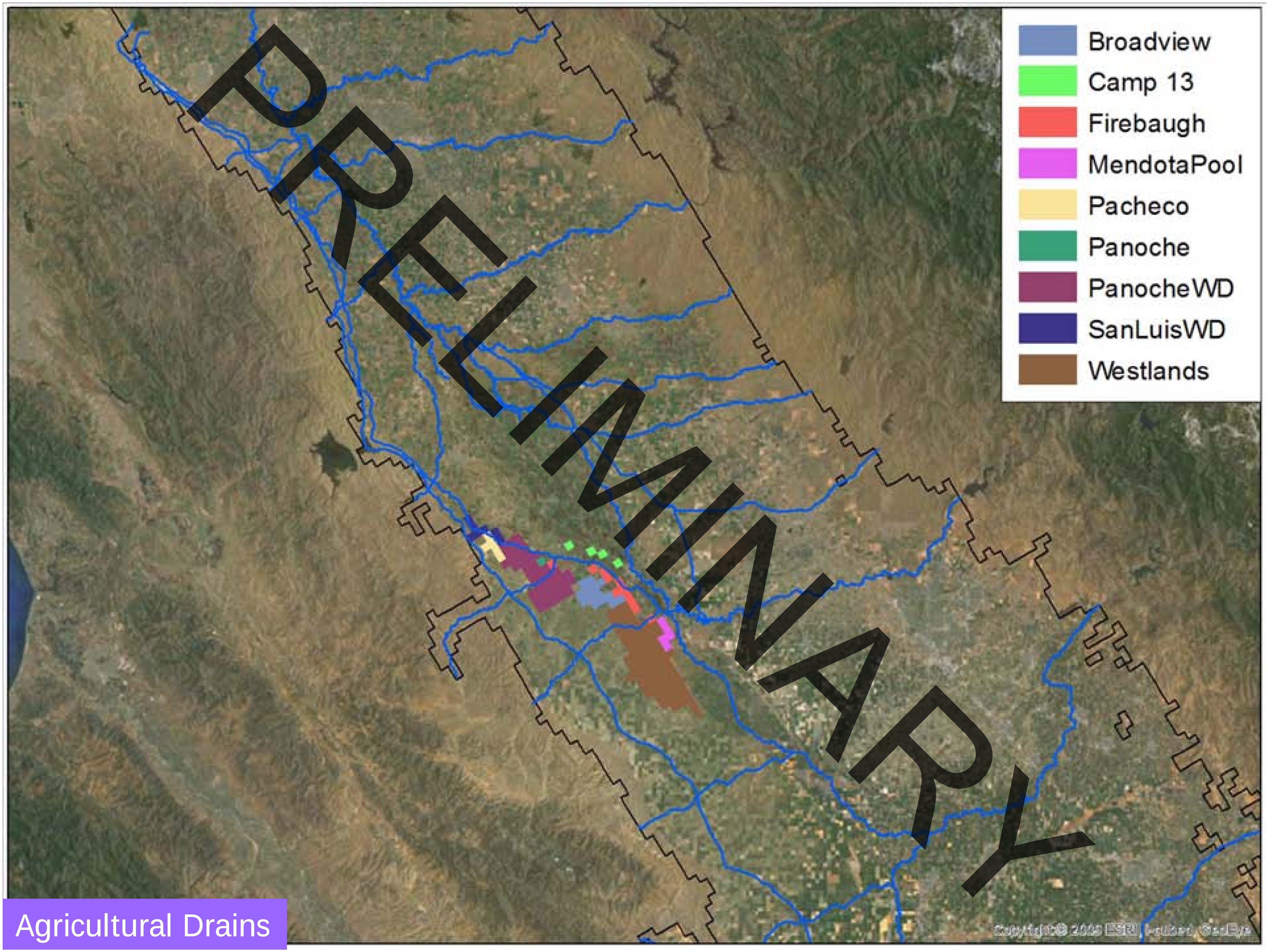
2008 Land Use



2008 Land Use



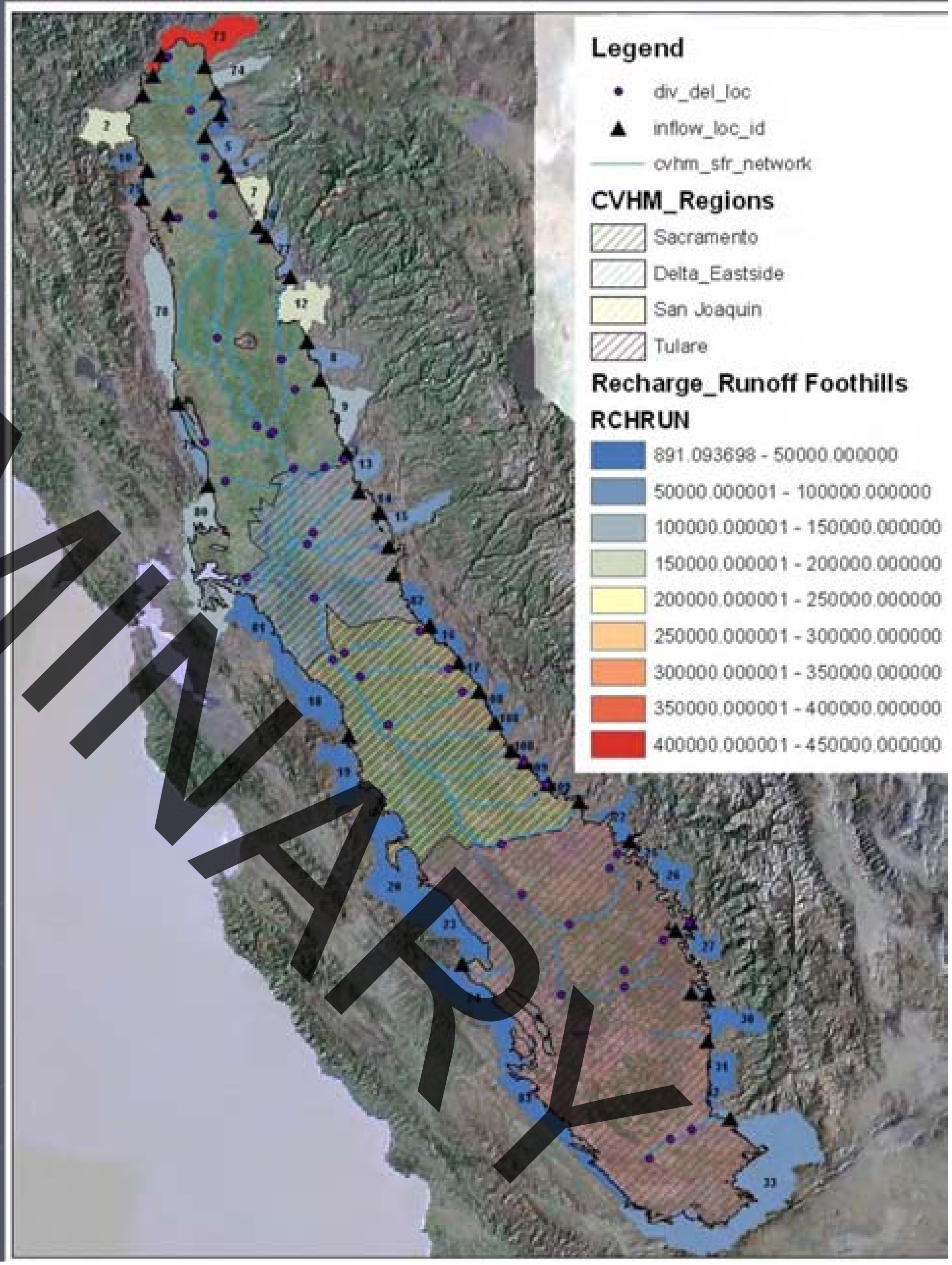
Agricultural Drains

Recharge from ungaged watersheds

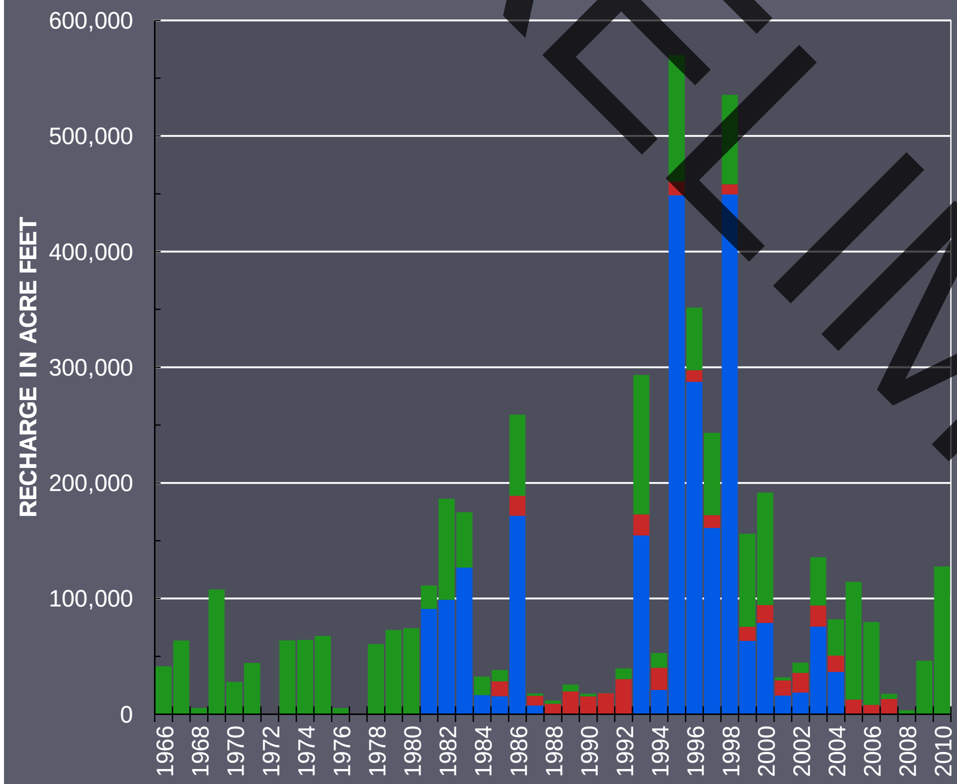
- Based on Basin Characteristic Model (Flint and Flint, 2007)
  - 2.6 MAF/yr

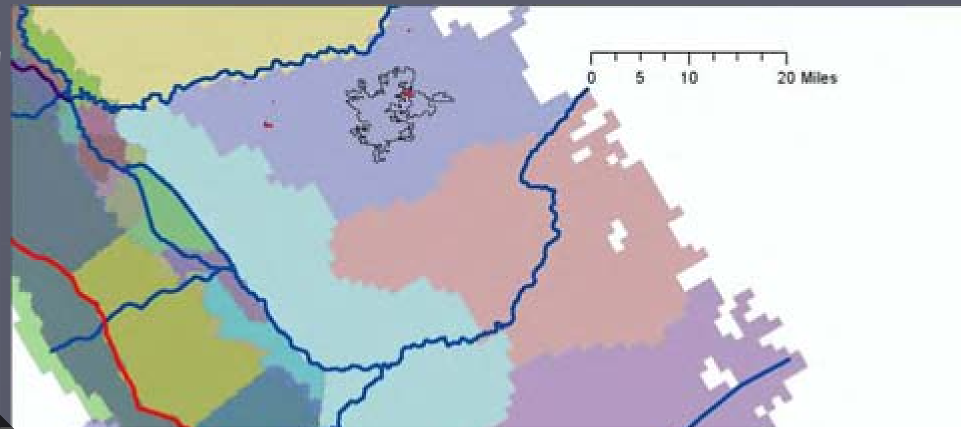
    (28. 9 MAF/yr gaged)

REGION	FREQUENCY	FLOW (AF/yr)
Delta_Eastside	4	181,307
Sacramento	19	2,027,001
San Joaquin	6	111,987
Tulare	12	277,608



Recharge from water banking

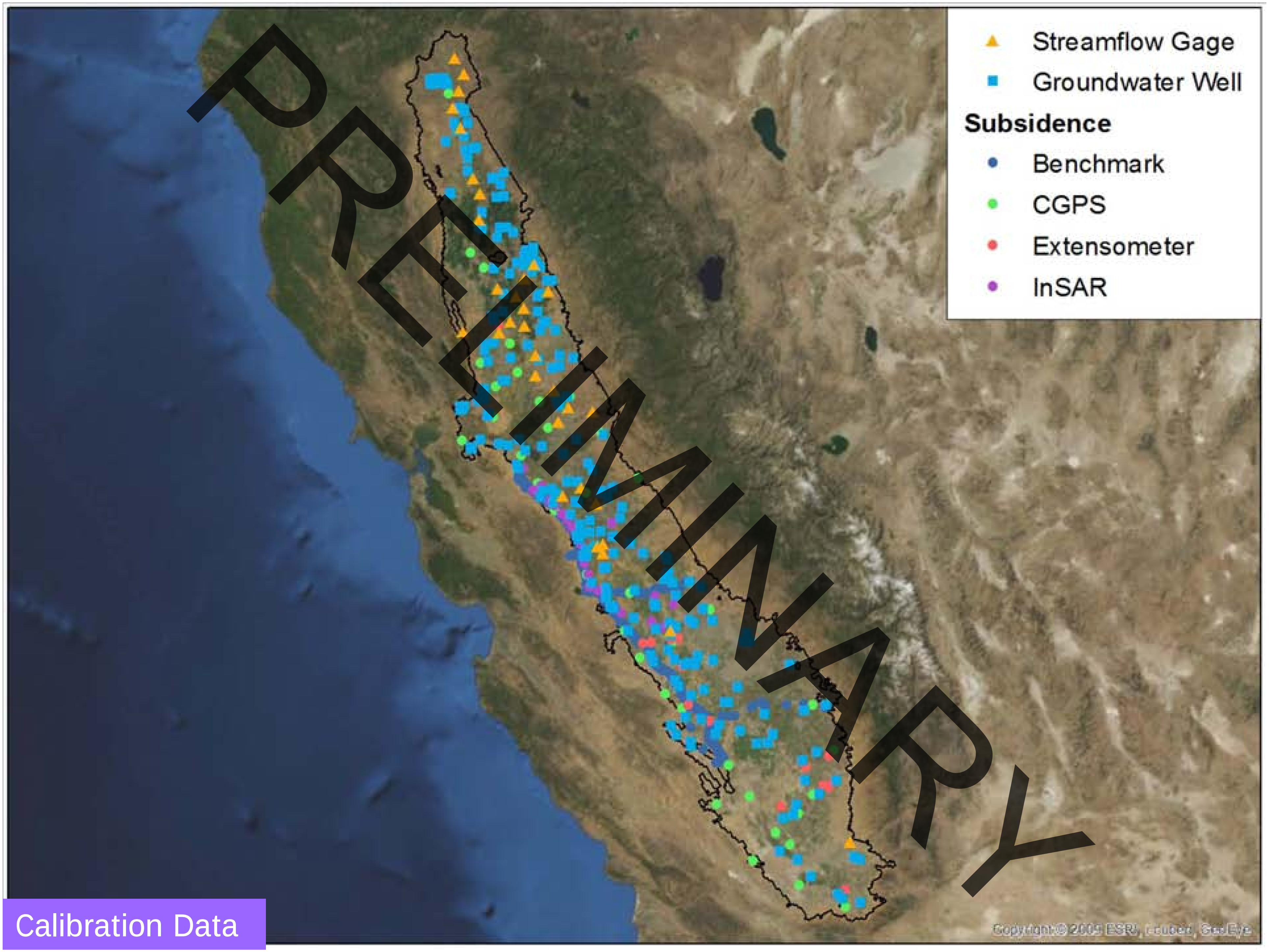




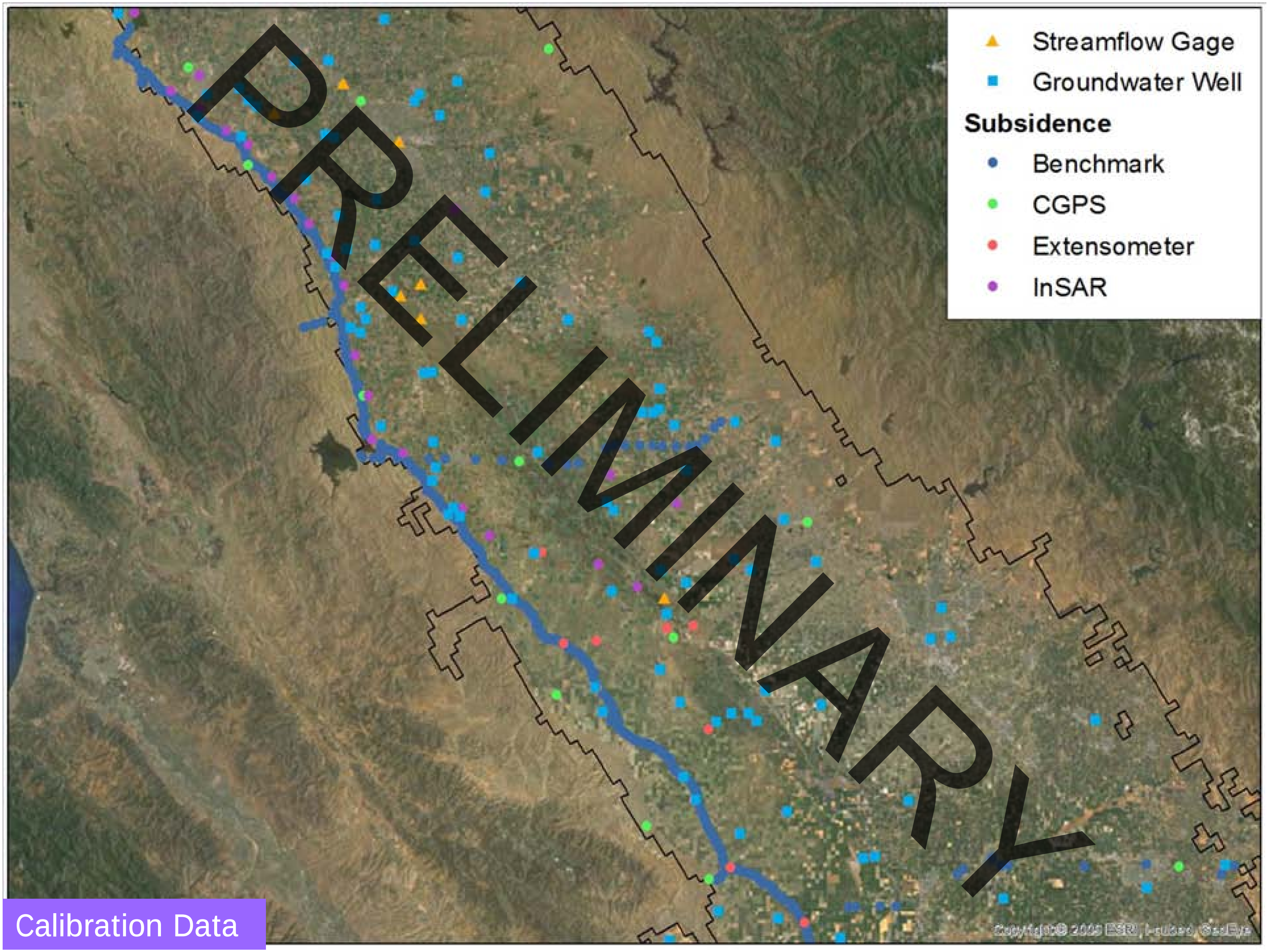
	Pond area	Period of Record	Average recharge	Total recharge
Arvin Edison	2,070	1966-2010	45,247	2,036,099
Fresno	420	1985-2007	14,530	334,194
Kern County	15,900	1981-2004	97,456	2,338,940

Calibration Data

- All datasets extended through 2009
- Groundwater elevation (260 sites - 24,801 obs)
- Streamflow (32 sites - 11,997 monthly averaged obs)
- Subsidence
  - Benchmark (829 sites - 2,837 obs)
  - Extensometer (25 sites - 30,213 obs)
  - Continuous GPS (40 sites - 56,547 obs)
  - InSAR (27 sites - 77 obs)
- Drainflow (7 sites - 1,056 monthly averaged obs)



Streamflow Gage
Groundwater Well
Subsidence
Benchmark
CGPS
Extensometer
InSAR
PRELIMINARY
Calibration Data



Calibration Data

Calibration Methodology

- Semi-automated calibration using a state of the art model-independent parameter estimation software called PEST
- 49 Model parameters
  - End Member Hydraulic Conductivity (4)
  - Power Mean Exponent (2)
  - Zonal Horizontal Hydraulic Conductivity (5)
  - Zonal Vertical Hydraulic Conductivity (5)
  - Hydraulic Conductivity Depth Decay (6)
  - Specific Storage (4)
  - Specific Yield (1)
  - Streambed Hydraulic Conductivity (11)
  - Drain Hydraulic Conductivity (1)
  - Boundary Conductance (1)
  - Ungagged Watershed Conductance (1)
  - Crop Coefficients (Kc) (2)
  - Irrigation Efficiency (4)
  - Runoff Coefficients (2)

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Subsidence Observations:

Subsidence/Aquifer-System Deformation Measurement Methods

- Land Survey
  - Spirit leveling: usually along highways, railroads, and canals
  - Global Positioning System (GPS)
- Extensometer
- Interferometric Synthetic Aperture Radar (InSAR)
- Hydrogeologic framework (water levels, geology, etc.)

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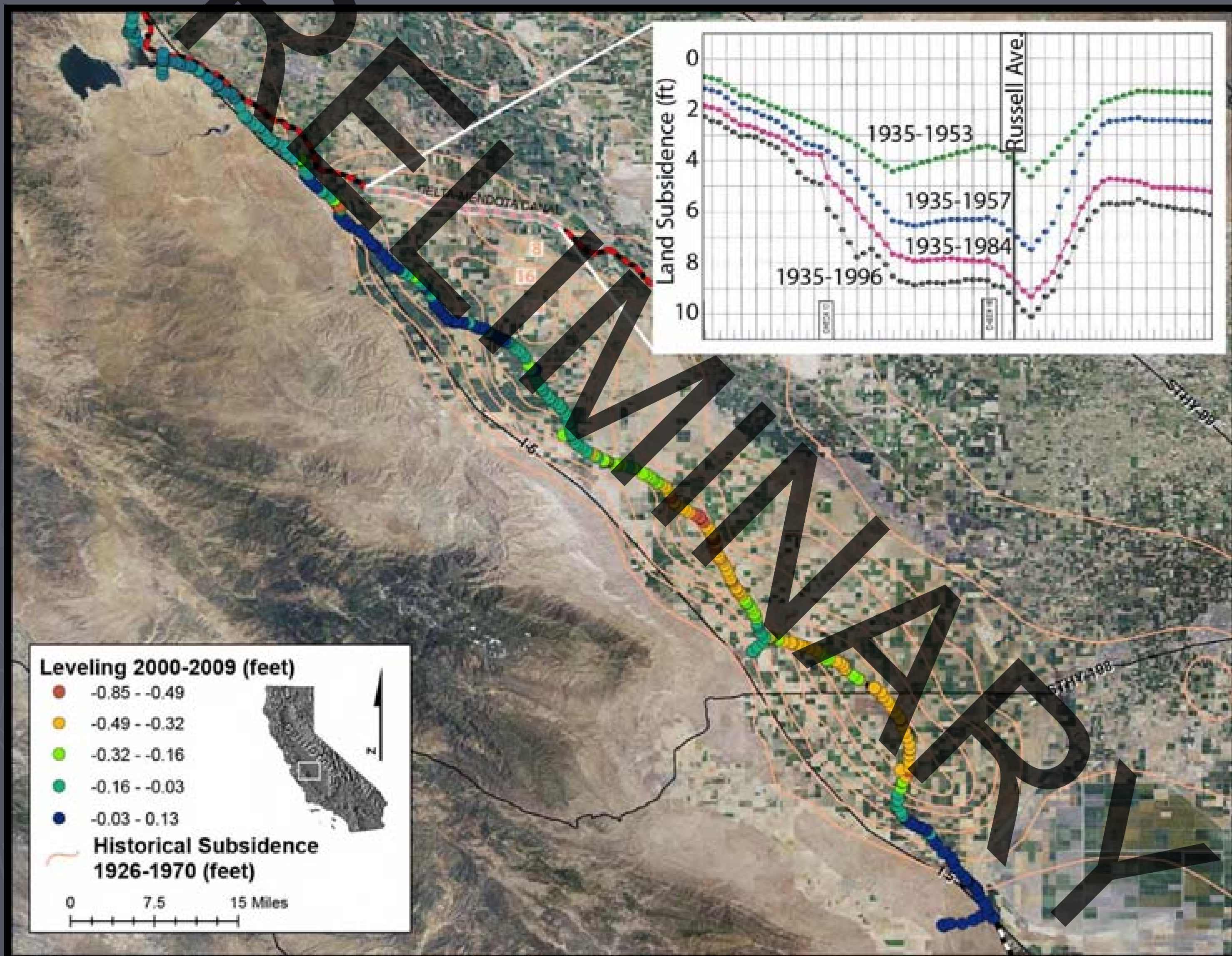
Leveling Along Aqueducts



Aqueduct leveling data from DWR; DMC leveling data from SLDMWA

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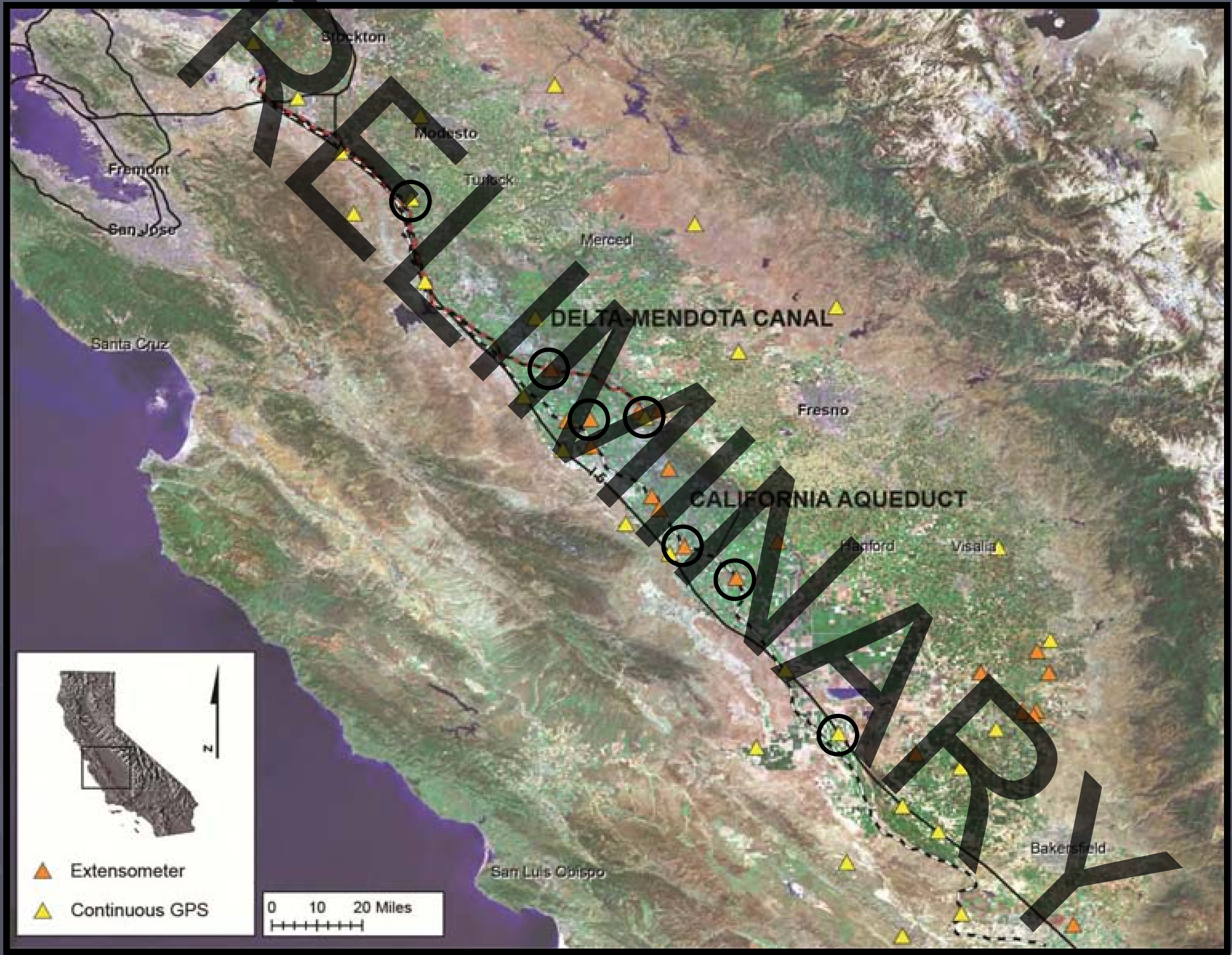
Extensometers and Continuous GPS



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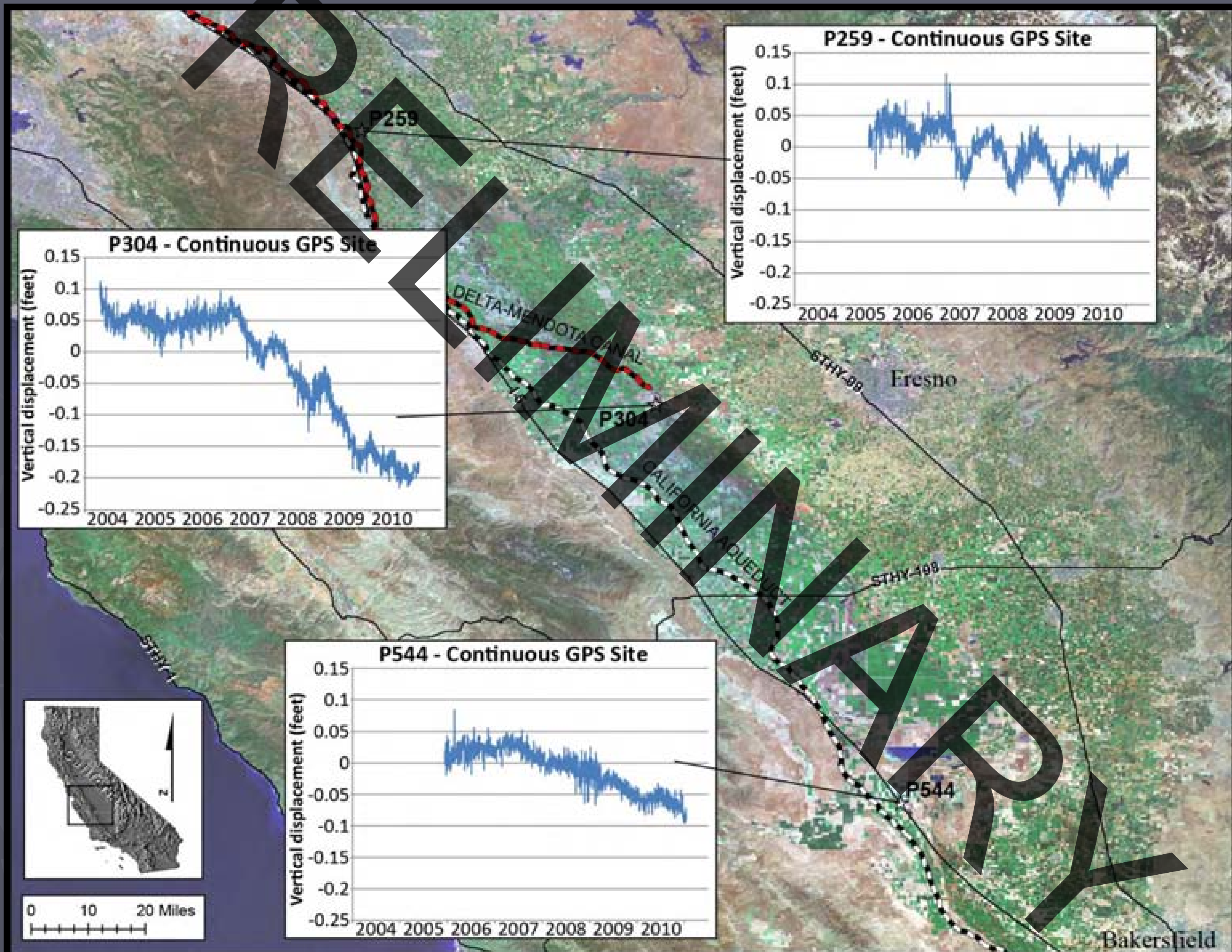
Continuous GPS data Along Aqueducts



GPS data from UNAVCO

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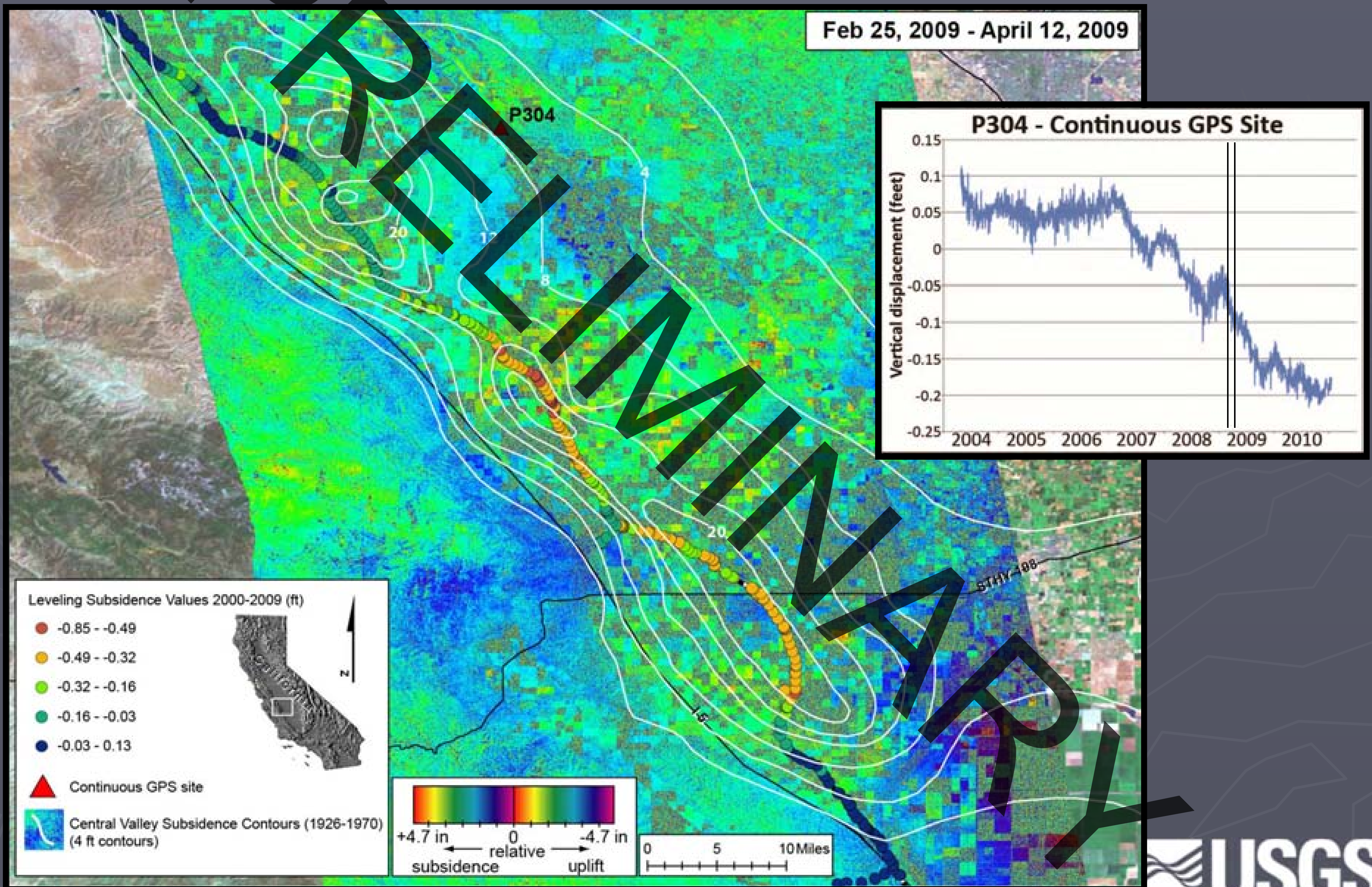
InSAR



GPS data from UNAVCO

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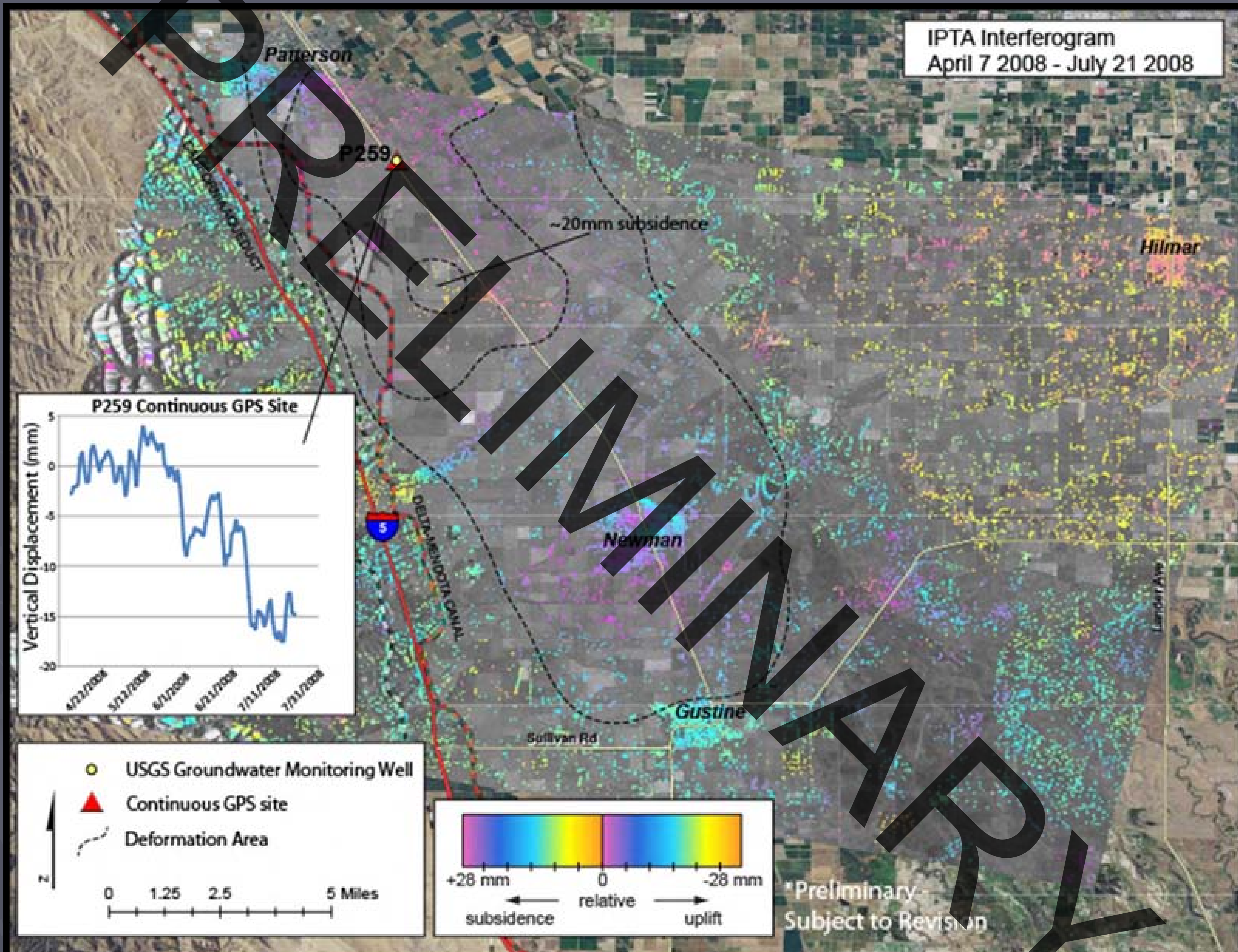
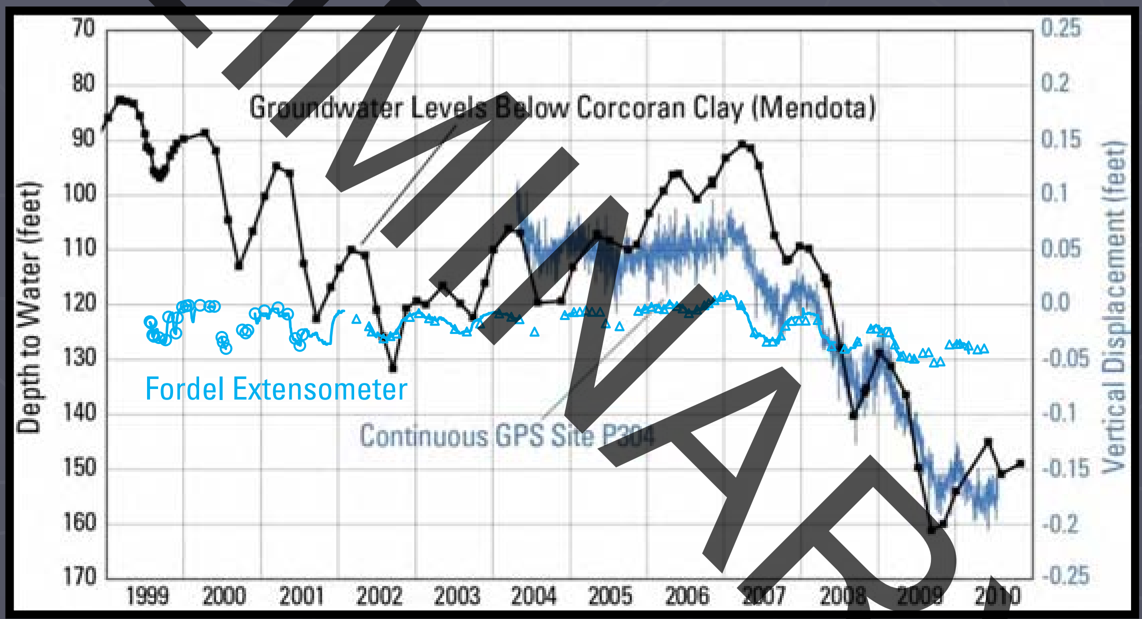

IPTA Interferogram
April 7 2008 - July 21 2008
Patterson
P259
~20mm subsidence
Hilmar
Newman
Gustine
Sullivan Rd
DELTA-MENDOTA CANAL
Lander Ave
P259 Continuous GPS Site
Vertical Displacement (mm)
4/22/2008
5/12/2008
6/1/2008
6/21/2008
7/11/2008
7/31/2008
USGS Groundwater Monitoring Well
Continuous GPS site
Deformation Area
0 1.25 2.5 5 Miles
+28 mm 0 -28 mm
subsidence relative uplift
*Preliminary -
Subject to Revision
PRELIMINARY

Where is subsidence happening?

- Nearly all of the compaction has occurred below the Corcoran Clay
  - GPS, extensometer, leveling, and water-level data were already cluing us in…



- Implication: CC not particularly important for simulating historical subsidence, but important for future scenarios

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Model Results

- Farm budget
- Groundwater budget
- Groundwater elevation map
- Subsidence map
- Lots of ways to slice and dice the model output

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Farm Budget Components

- Supply
  - Precipitation
  - Surface water (semi-routed and non-routed)
  - Groundwater pumping
  - Root uptake of shallow groundwater
- Demand
  - Crop evapotranspiration
  - Runoff
  - Percolation
  - Injection

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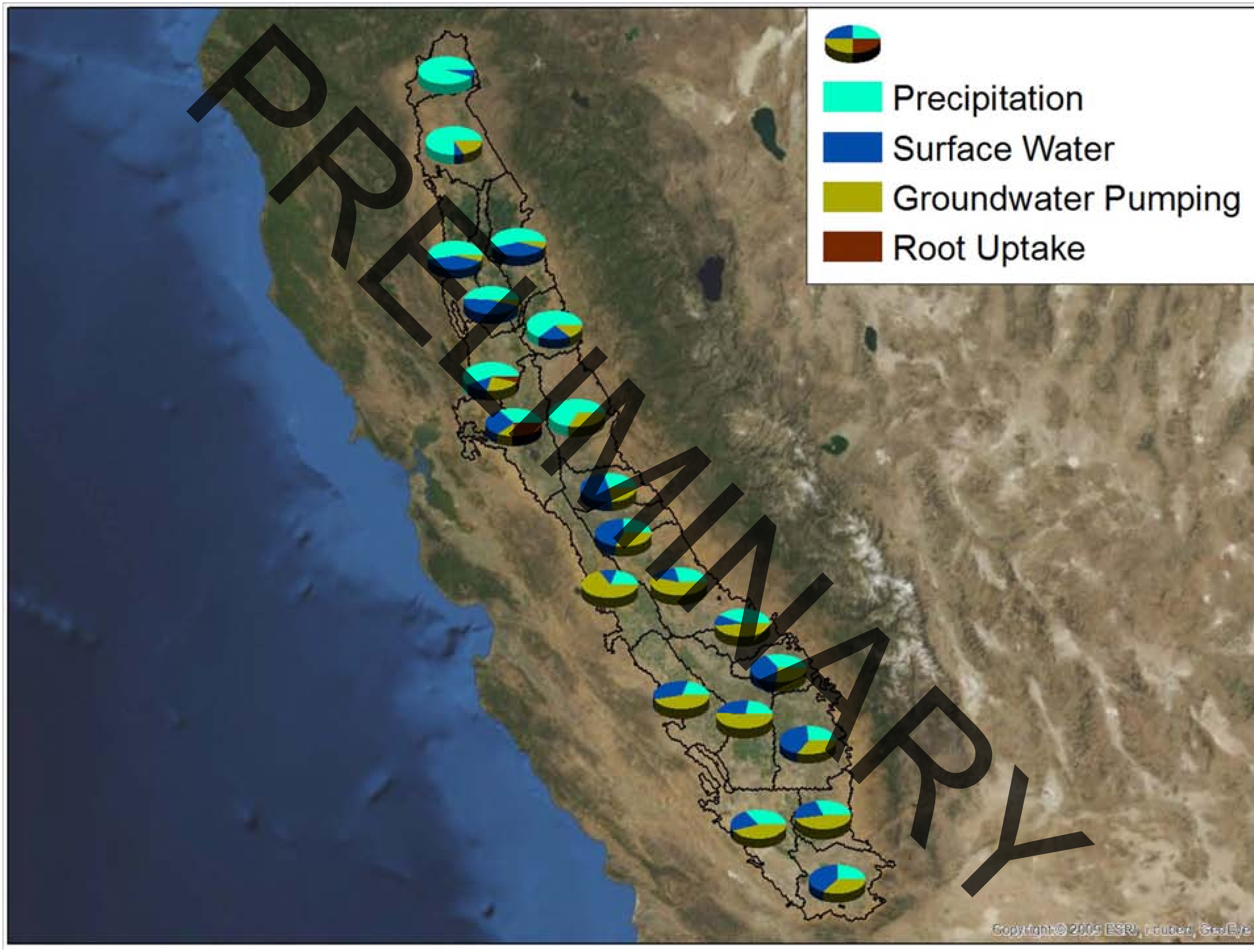
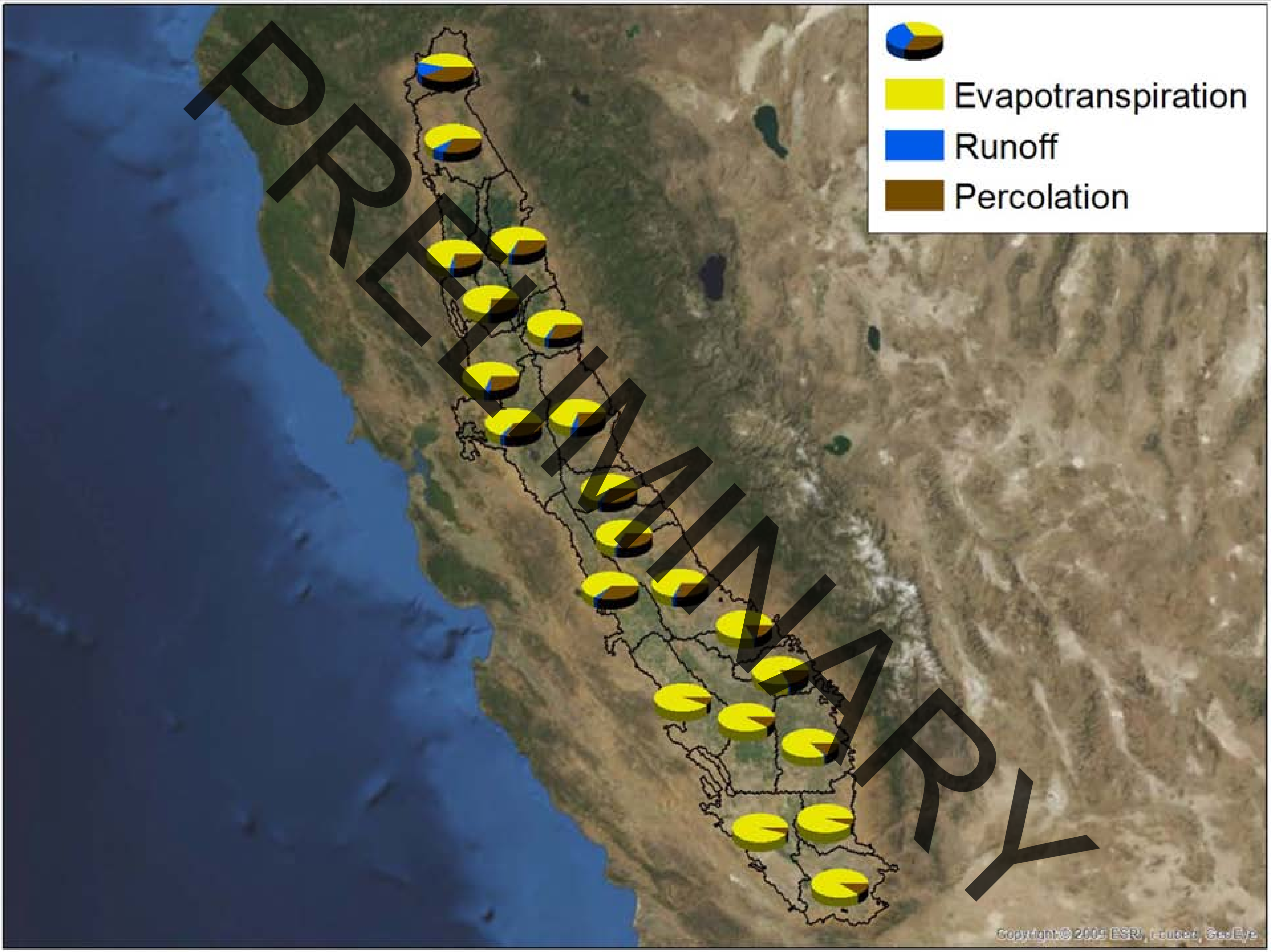

Precipitation
Surface Water
Groundwater Pumping
Root Uptake
PRELIMINARY



Evapotranspiration
Runoff
Percolation
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Groundwater Budget Components

- Inflows
  - Subsurface inflow from delta
  - Released water from clay compaction (inelastic and elastic)
  - Stream loss to groundwater
  - Ungagged watershed inflows
  - Percolation of precipitation and irrigation
- Outflows
  - Municipal pumping
  - Agricultural pumping
  - Clay rebound (elastic)
  - Subsurface outflow to delta
  - Stream gain from groundwater
  - Root uptake of shallow groundwater

Model Applications

- Simulate future scenarios including
  - Extended drought
  - Climate change
  - Reduced surface water deliveries
- Predict groundwater elevations
- Predict location and amount of land subsidence

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Child Model (SJWHM)

- ¼ mile by ¼ mile cells (4x refinement from CVHM)
- 5 layers simulated above Corcoran clay (3 in CVHM)
- Same input data as CVHM
- Uses the CVHM as boundary conditions
- Can be used to more accurately simulate water-management scenarios with effects that are within the SJWHM

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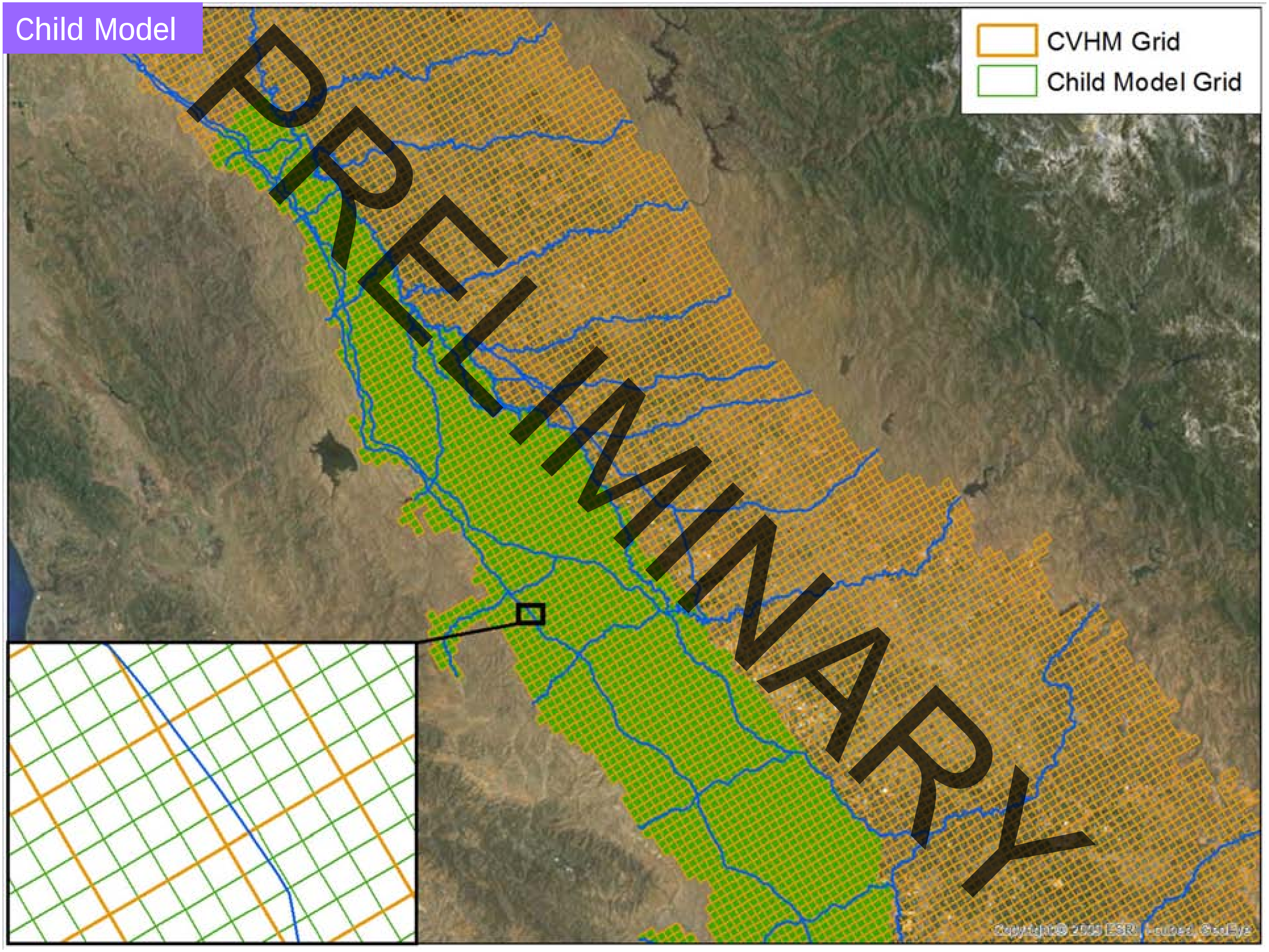
Child Model
CVHM Grid
Child Model Grid
PRELIMINARY

Summary and Conclusions:

- ► Recent modifications to MODFLOW are helping the CVHM to better characterize the entire hydrologic system
- ► Updated data sets and recalibrated model(s)
  - provides a detailed analysis of changes in hydrologic system and subsidence
  - helps us better understand water resources and the interaction of groundwater with subsidence
- ► Updated model(s) more accurately forecast water level changes and the anticipated locations and magnitudes of subsidence based on alternative future scenarios