

MODFLOW-OWHM Hydrologic Budgets and Case Studies

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Outline

- ▶ SGMA overview
- ▶ Types of hydrologic budgets generated by MF-OHWM
- ▶ Examples from case studies scattered within
 - ▶ CVHM (Claudia Faunt)
 - ▶ SJJRPBW (Jon Traum)
 - ▶ MERSTAN (Steve Philips)
 - ▶ SBFTM (Scott Paulinski)
 - ▶ PVHM (Randy Hanson)
 - ▶ Example Problems (Scott Boyce)

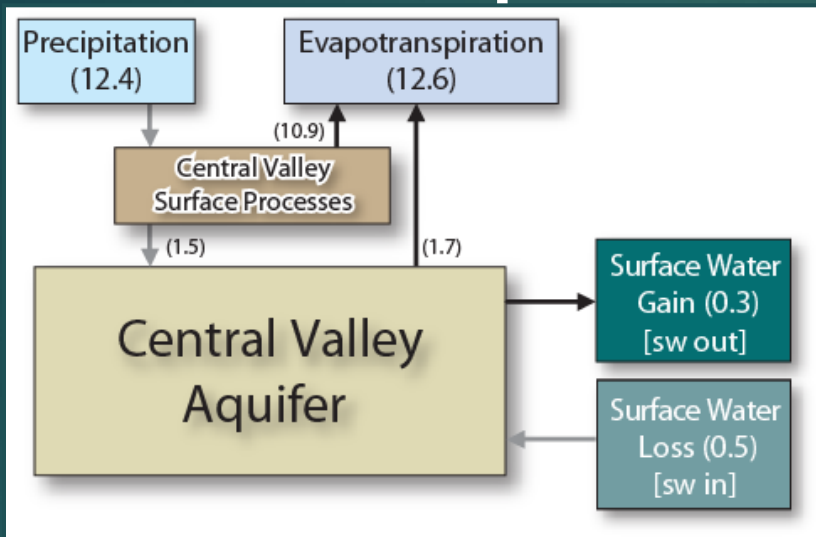
SGMA Undesirable Results

- ▶ Lowering of groundwater levels
- ▶ Reduction of groundwater storage
- ▶ Degraded water quality
- ▶ Seawater intrusion
- ▶ Land subsidence
- ▶ Depletions of interconnected surface water

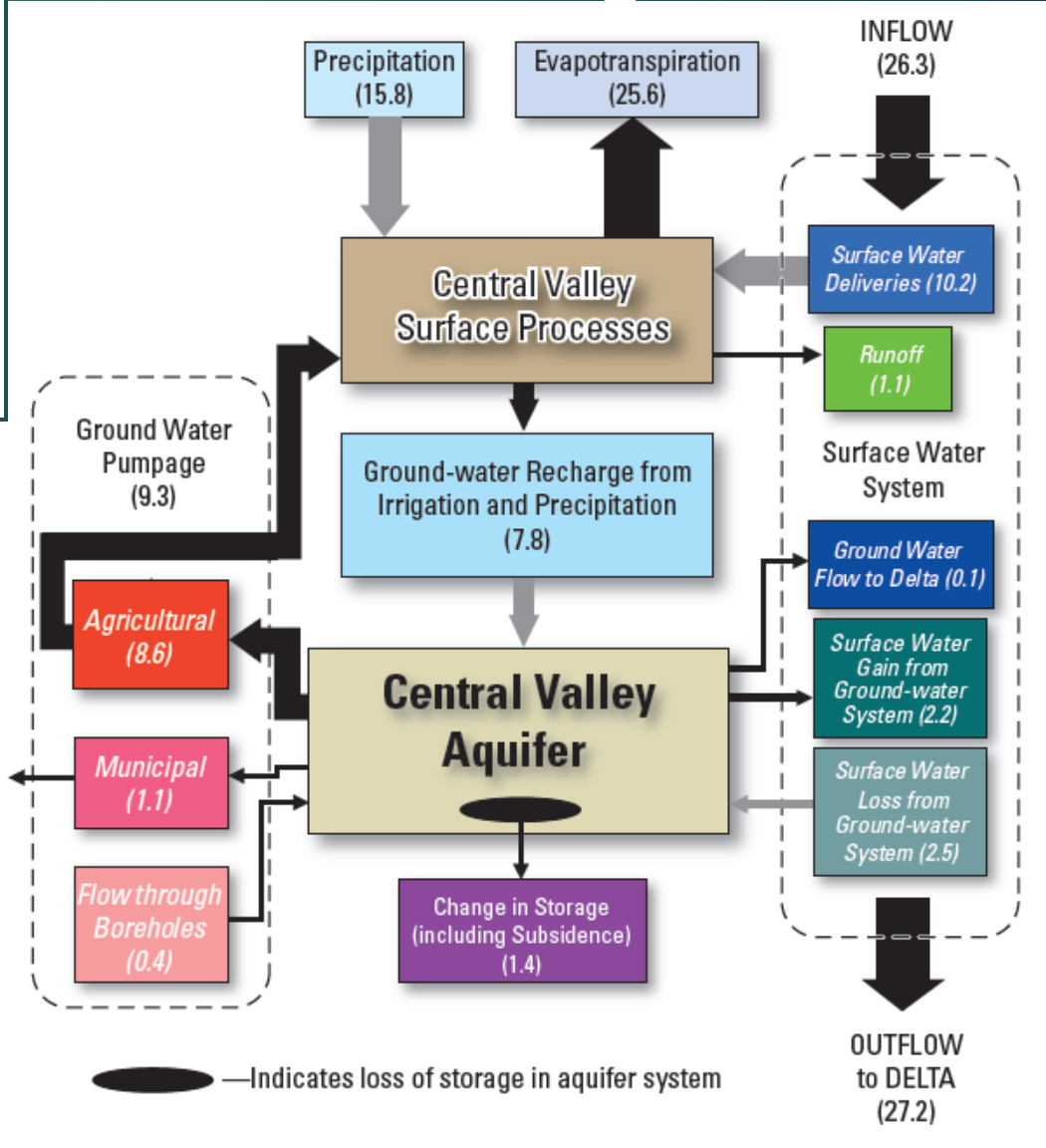
Hydrologic Budgets

- ▶ SGMA definition of hydrologic budget
 - ▶ Total groundwater and surface water entering and leaving a basin
- ▶ MF-OWHM Budgets
 - ▶ Groundwater budget
 - ▶ Water use budget
 - ▶ Streamflow budget
 - ▶ MNW2 budget
 - ▶ UZF budget

Pre-development



1962-2003/Engineered



Natural → Engineered

Simple → Complex

2 million acre-feet/year recharge/discharge → 12 million acre-feet/year recharge/discharge

Processing Budgets

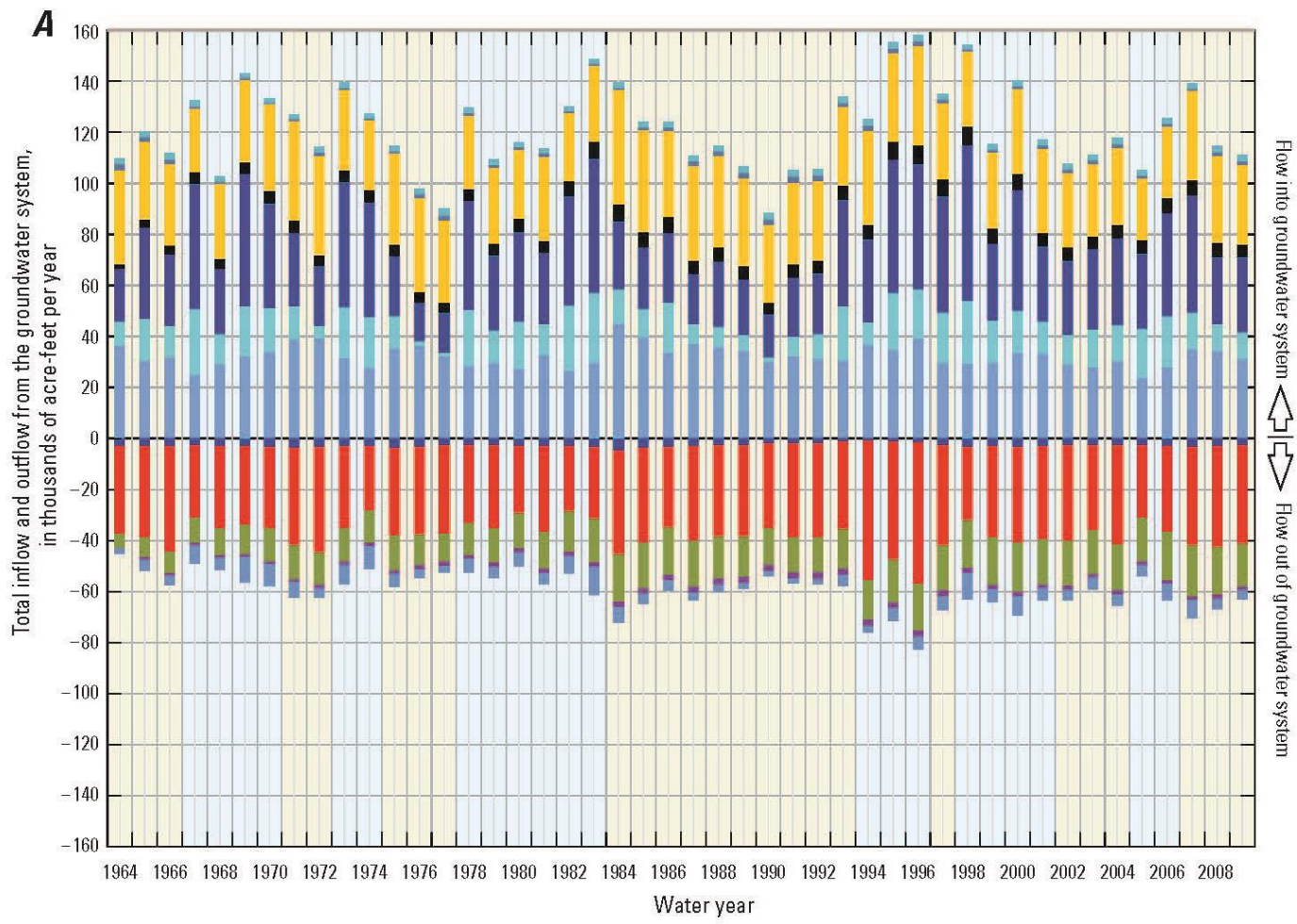
- ▶ Many different ways to temporally or spatially aggregate budget
 - ▶ Available for every model time step
 - ▶ Available at detailed spatial scales (GW Budget by cell, SW Budget by stream reach)
 - ▶ Some stored in binary format
- ▶ Tools to help
 - ▶ Zone Budget: subregional aggregation
 - ▶ ModelMuse: visualization
 - ▶ GW_Chart: convert to text

Groundwater Budget

- ▶ Used to determine reduction of groundwater storage
- ▶ Provides the flows into and out of each model cell in binary format
- ▶ Also called cell-by-cell budget

[Values in acre-feet; totals may not sum because of rounding]

Water-balance subregion	Area (square miles)	Net storage from specific yield and compressibility of water ¹	Net elastic and inelastic storage ¹	Net stream leakage ²	Net pumpage	Net recharge from landscape ³	Precipitation	Evapotranspiration	Surface-water deliveries
1	611	36,000	13,000	-144,000	45,000	453,000	1,063,000	547,000	46,000
2	1,163	-17,000	23,000	-294,000	557,000	768,000	1,496,000	1,269,000	129,000
3	1,112	-39,000	3,000	-212,000	49,000	508,000	1,125,000	1,300,000	717,000
4	560	-34,000	0	-494,000	6,000	-19,000	562,000	635,000	78,000
5	957	-34,000	-1,000	-200,000	65,000	466,000	1,200,000	1,101,000	439,000
6	1,044	-47,000	10,000	34,000	506,000	522,000	1,137,000	1,315,000	329,000
7	534	2,000	4,000	-38,000	186,000	222,000	590,000	512,000	172,000
Sacramento Valley	5,981	-99,000	52,000	1,348,000	1,414,000	2,920,000	7,173,000	6,6799,000	1,910,000
Eastside Streams (8)	1,362	-26,000	7,000	95,000	850,000	721,000	1,365,000	1,444,000	205,000
Delta (9)	1,026	-218,000	3,000	705,000	467,000	-200,000	975,000	1,603,000	64,000
10	1,083	-36,000	29,000	64,000	60,000	89,000	588,000	1,465,000	983,000
11	664	-21,000	0	-98,000	85,000	251,000	509,000	901,000	643,000
12	540	-56,000	1,000	39,000	45,000	131,000	384,000	702,000	440,000
13	1,648	43,000	67,000	163,000	754,000	474,000	1,092,000	2,233,000	936,000
San Joaquin Basin	3,935	-70,000	97,000	168,000	944,000	945,000	2,573,000	5,301,000	3,002,000
14	1,071	179,000	165,000	6,000	934,000	418,000	432,000	1,631,000	716,000
15	1,423	26,000	146,000	239,000	1,603,000	708,000	607,000	2,225,000	757,000
16	478	89,000	35,000	33,000	202,000	212,000	299,000	518,000	358,000
17	569	54,000	28,000	170,000	445,000	348,000	358,000	852,000	442,000
18	1,358	158,000	198,000	104,000	1,135,000	710,000	715,000	2,237,000	821,000
19	1,365	85,000	133,000	0	754,000	334,000	494,000	1,275,000	367,000
20	705	74,000	92,000	19,000	252,000	240,000	295,000	892,000	610,000
21	1,105	83,000	81,000	130,000	324,000	272,000	414,000	1,333,000	1,096,000
Tulare Basin	8,074	748,000	878,000	701,000	5,649,000	3,188,000	3,614,000	10,963,000	5,167,000
Total	20,378	300,000	1,000,000	300,000	9,300,000	7,600,000	15,700,000	25,900,000	10,300,000



EXPLANATION

INFLOWS

- South groundwater underflow
- North groundwater underflow
- Multi-aquifer well pumpage (In)
- Groundwater recharge/
Evapotranspiration-groundwater (In)
- Stream leakage (In)
- Aquifer storage (In)

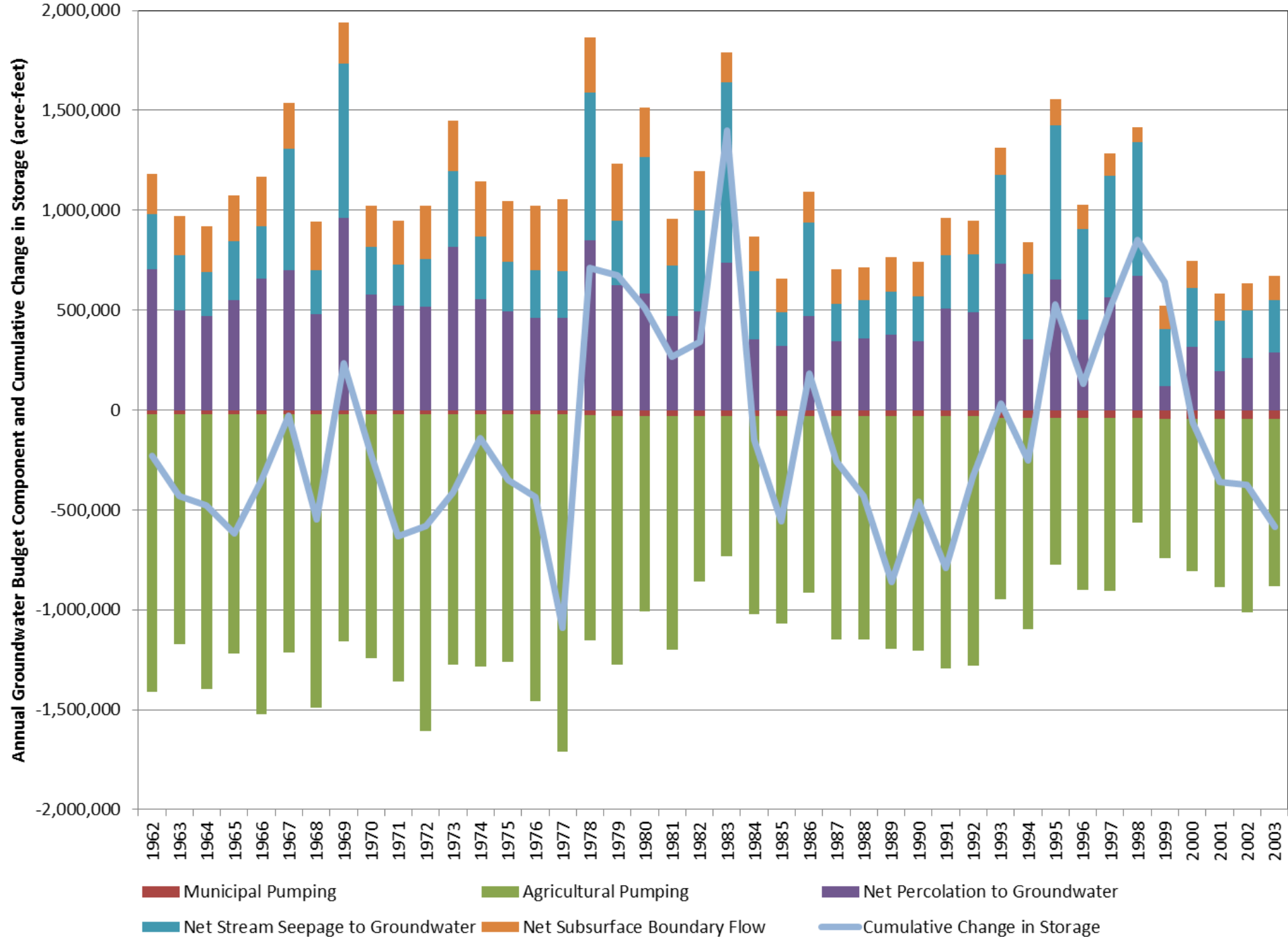
OUTFLOWS

- Aquifer storage (Out)
- Stream leakage (Out)
- Groundwater recharge/
Evapotranspiration-groundwater (Out)
- Agricultural pumpage (Out)
- Multi-aquifer well pumpage (Out)
- Wells (Out)
- Tile drains (Out)

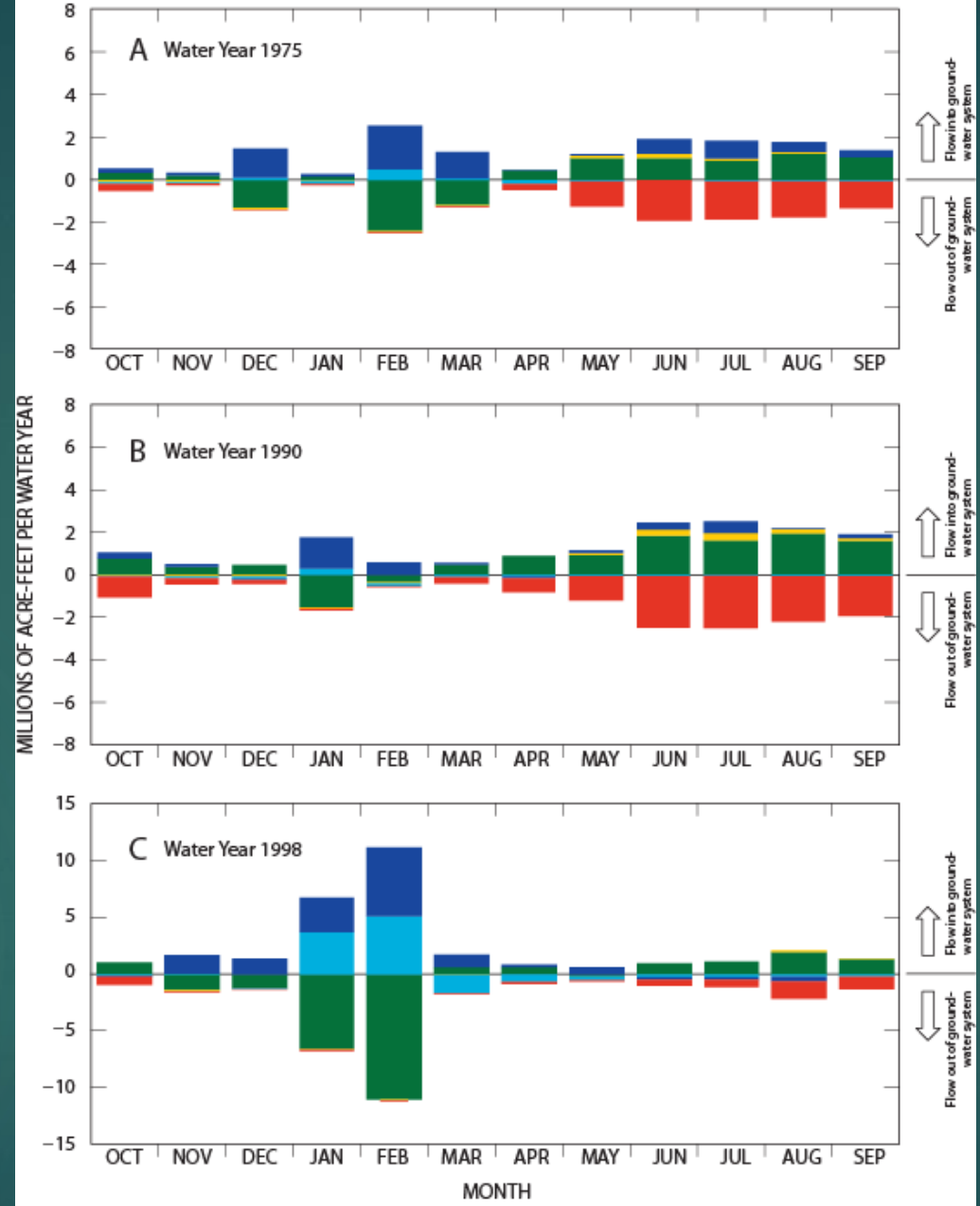
Recent precipitation cycles

- Dry
- Wet

Annual totals

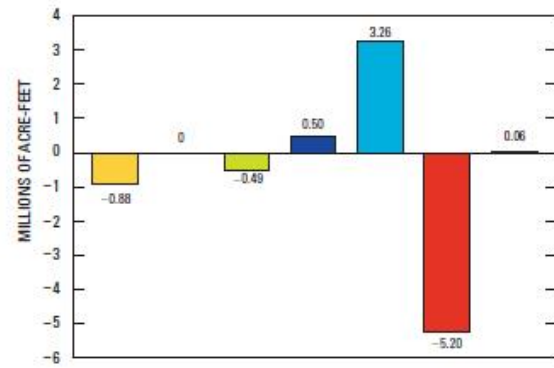
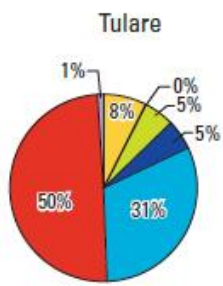


Annual totals



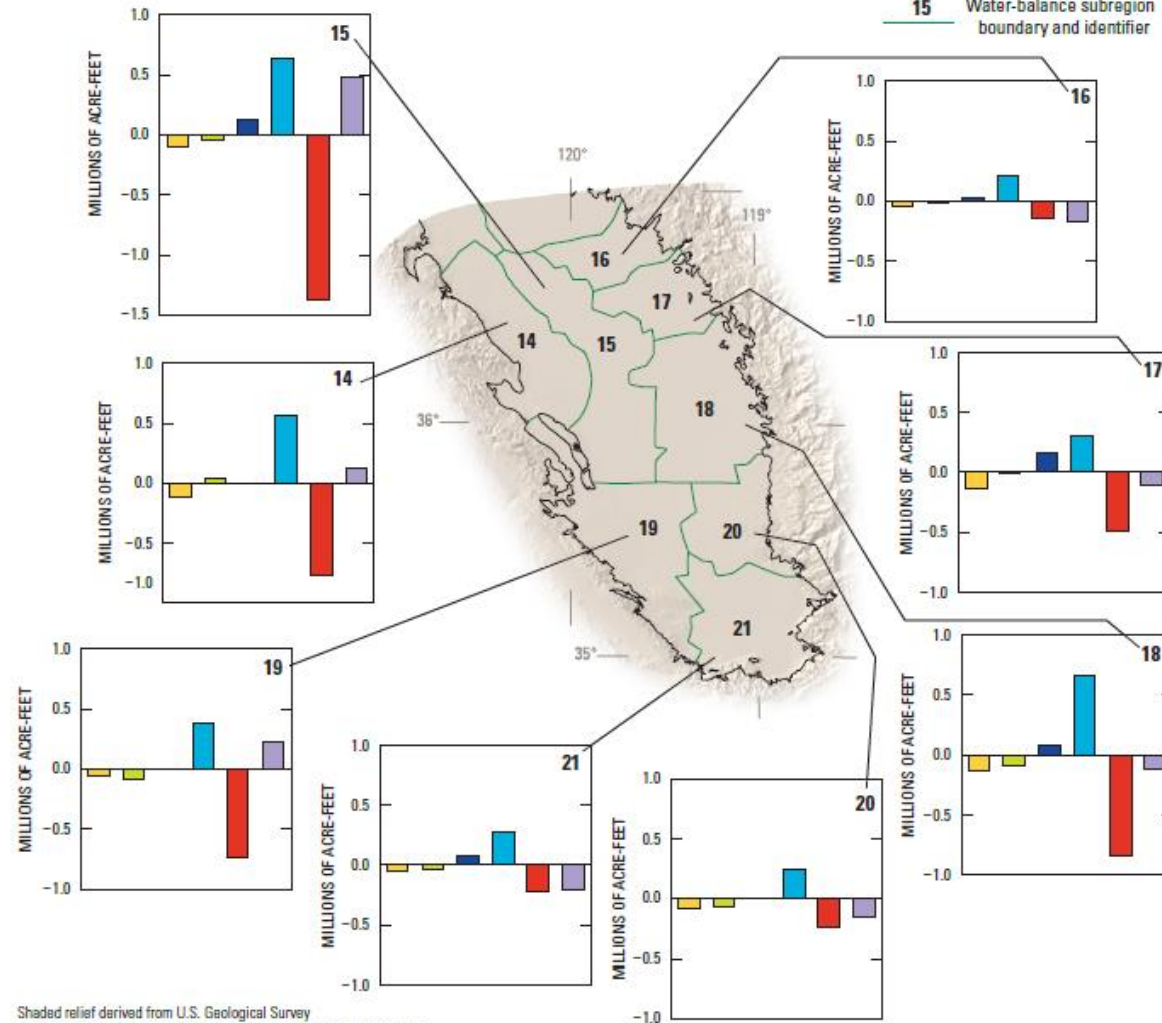
Monthly for selected year types

D



EXPLANATION

- Specific yield and compressibility of water
- Flow of groundwater to Delta
- Elastic and inelastic matrix storage
- Stream interaction
- Landscape recharge
- Pumpage
- Flow between regions or water-balance subregion
- Central Valley boundary
- 15 Water-balance subregion boundary and identifier

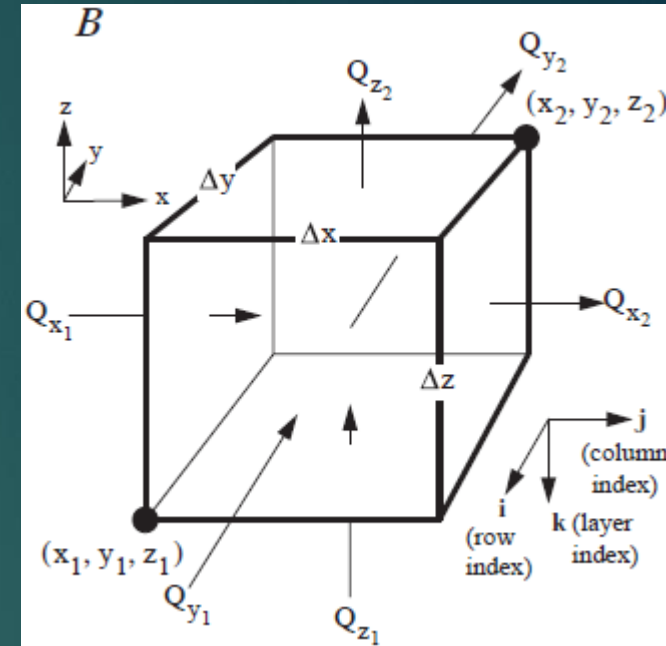


Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006. Albers Equal Area Conic Projection

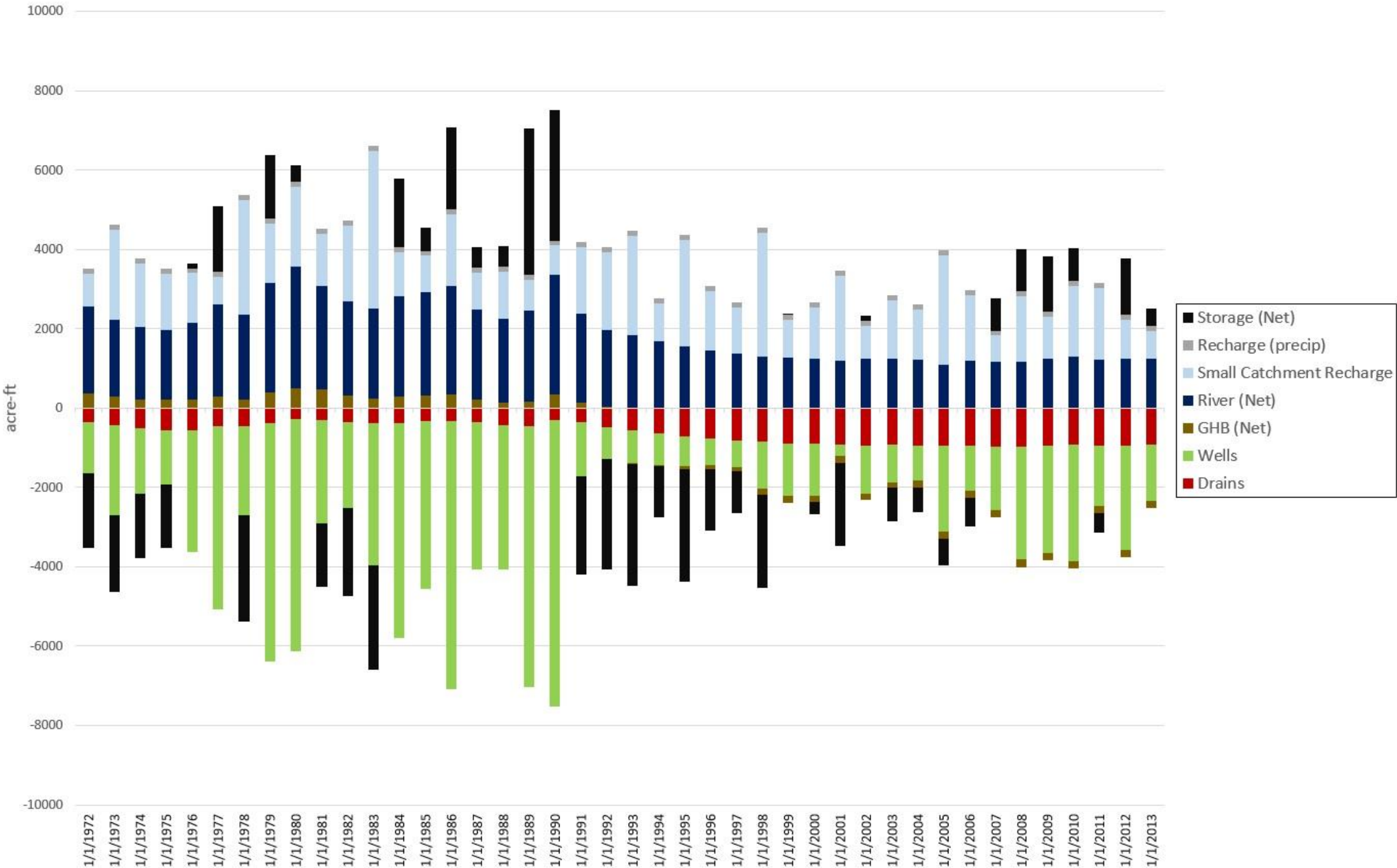
Average annual totals by subregion

Groundwater Flow Paths

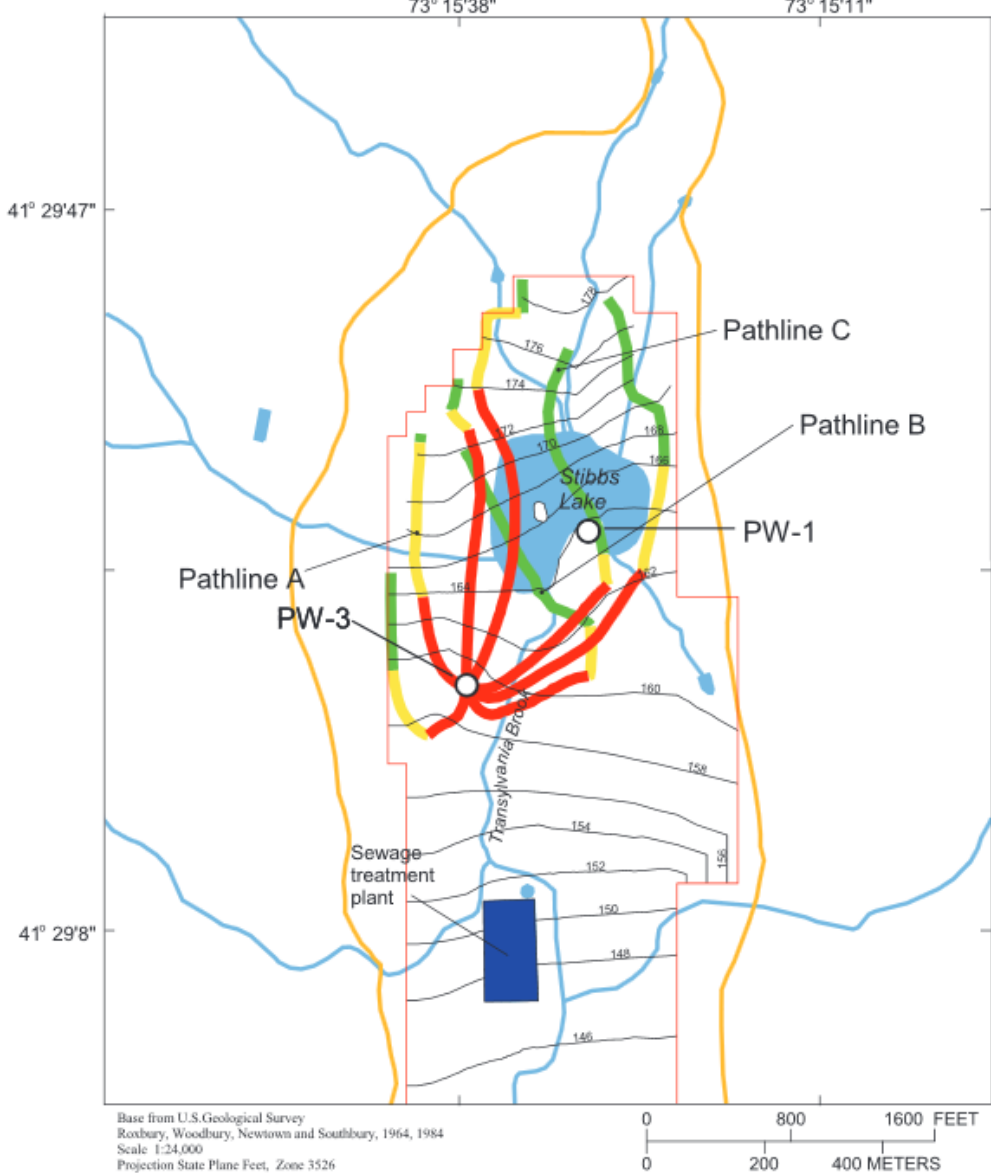
- ▶ Cell to cell flow (also called subsurface flow) is a key component of the groundwater budget
- ▶ Used to analyze water quality issues including seawater intrusion
- ▶ MODPATH post-processor to estimate groundwater flow paths from cell-by-cell output
- ▶ MODPATH-OBS post-processor for MODPATH to get concentrations
- ▶ MT3DMS and SEAWAT










Santa Barbara Annual Water Budget in Acre-ft per Year (1972 - 2013)



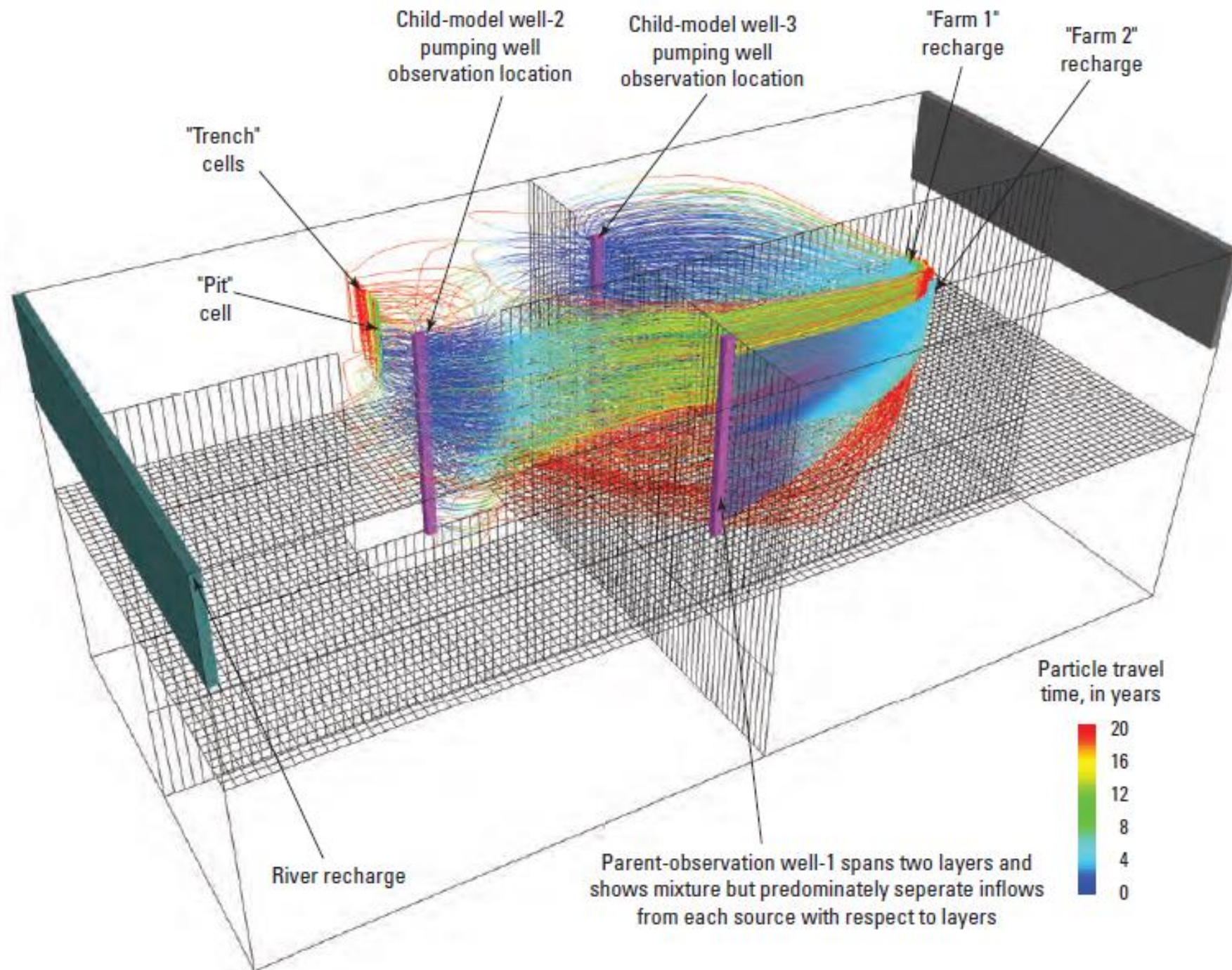
Annual totals



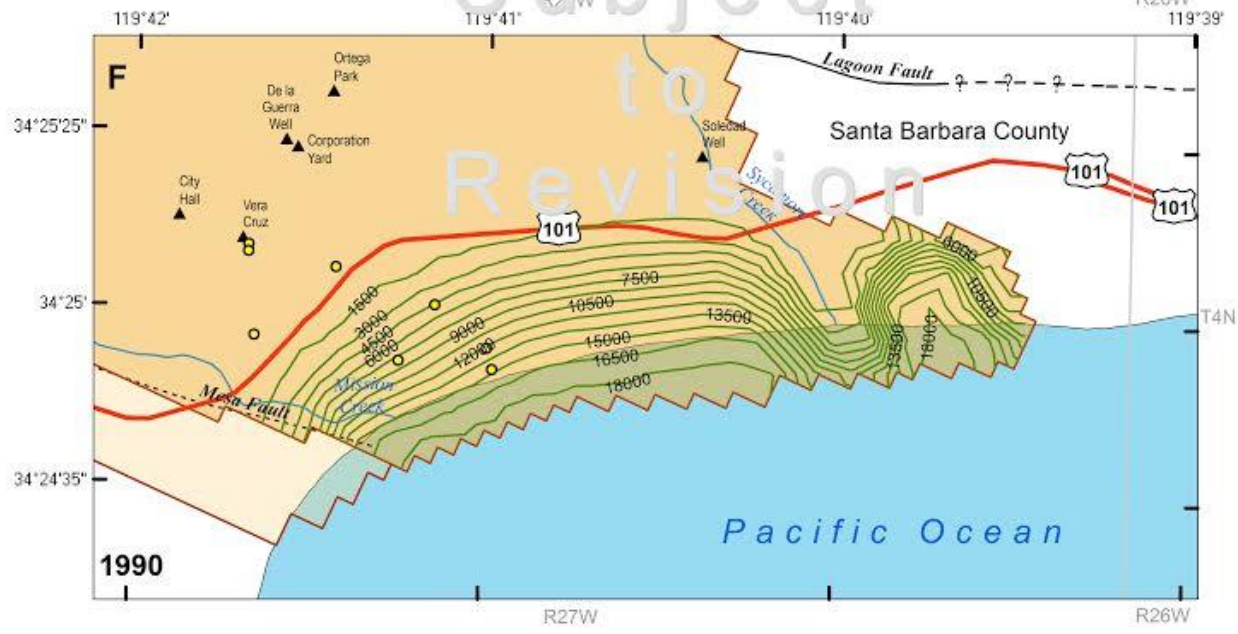
EXPLANATION

- | | | | |
|---|--|---|---------|
|  | LIMIT OF STRATIFIED
GLACIAL DEPOSITS |  | Layer 1 |
|  | EXTENT OF MODELED AREA |  | Layer 2 |
|  | CONTOURS ON SIMULATED WATER TABLE
Simulated drought conditions. Contour interval 2 feet.
Datum is sea level. |  | Layer 3 |
|  | WATER-SUPPLY WELLS with identifier | | |
- SELECTION PARTICLE PATHLINES
Color indicates layer of pathline.

Simulated flow paths



Simulated travel times



Preliminary
Subject
to
Revision

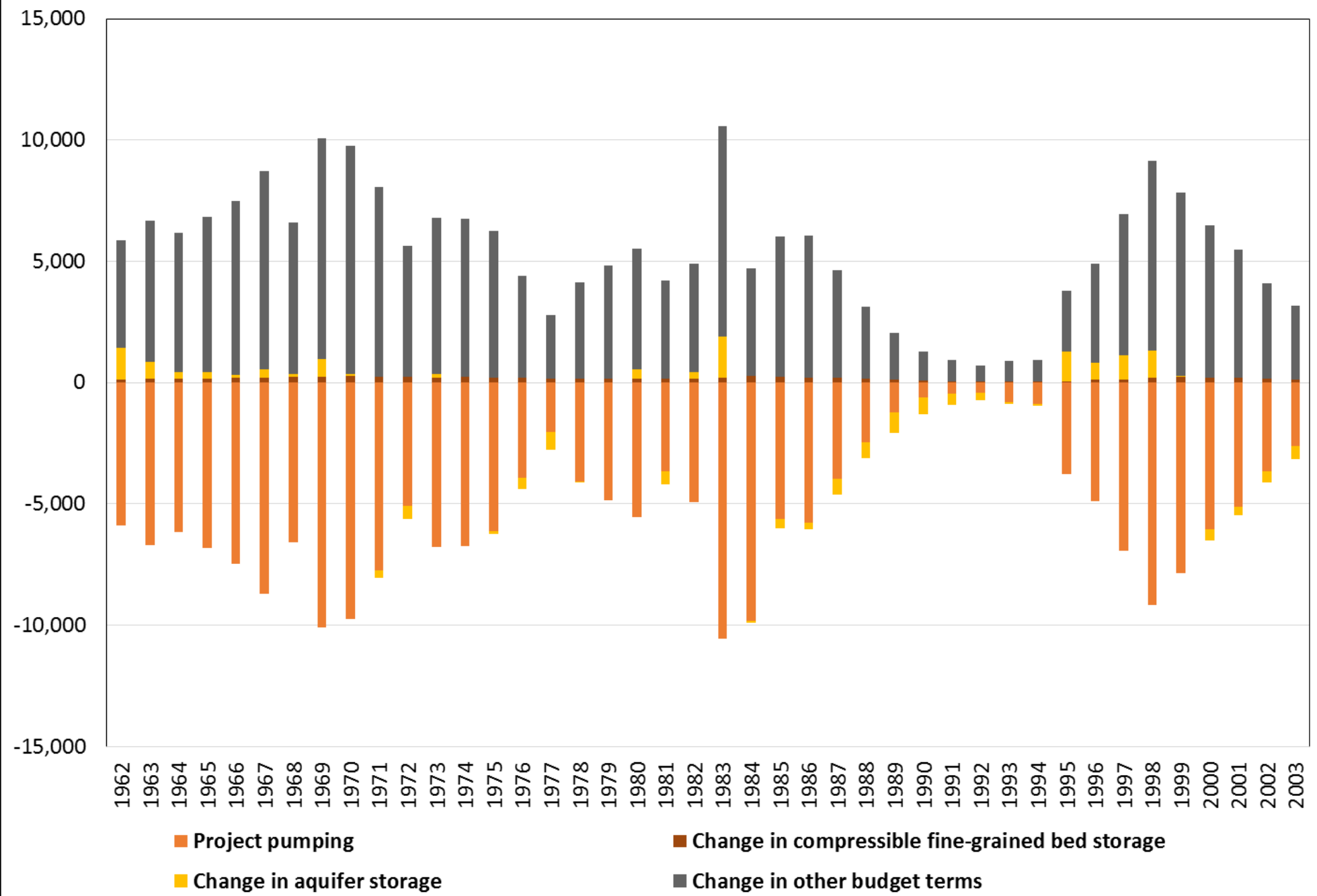
- Explanation**
- Key observation well
 - ▲ Production well
 - Simulated chloride level contour (mg/L)
 - Storage units
 - Highways
 - Major streams
 - Lower producing zone
 - Faults
 - Existence certain, location concealed
 - Existence certain, location inferred
 - Existence certain, location accurate
 - Existence questionable, location inferred

Simulated
chloride
concentrations

Subsidence Term in Groundwater Budget

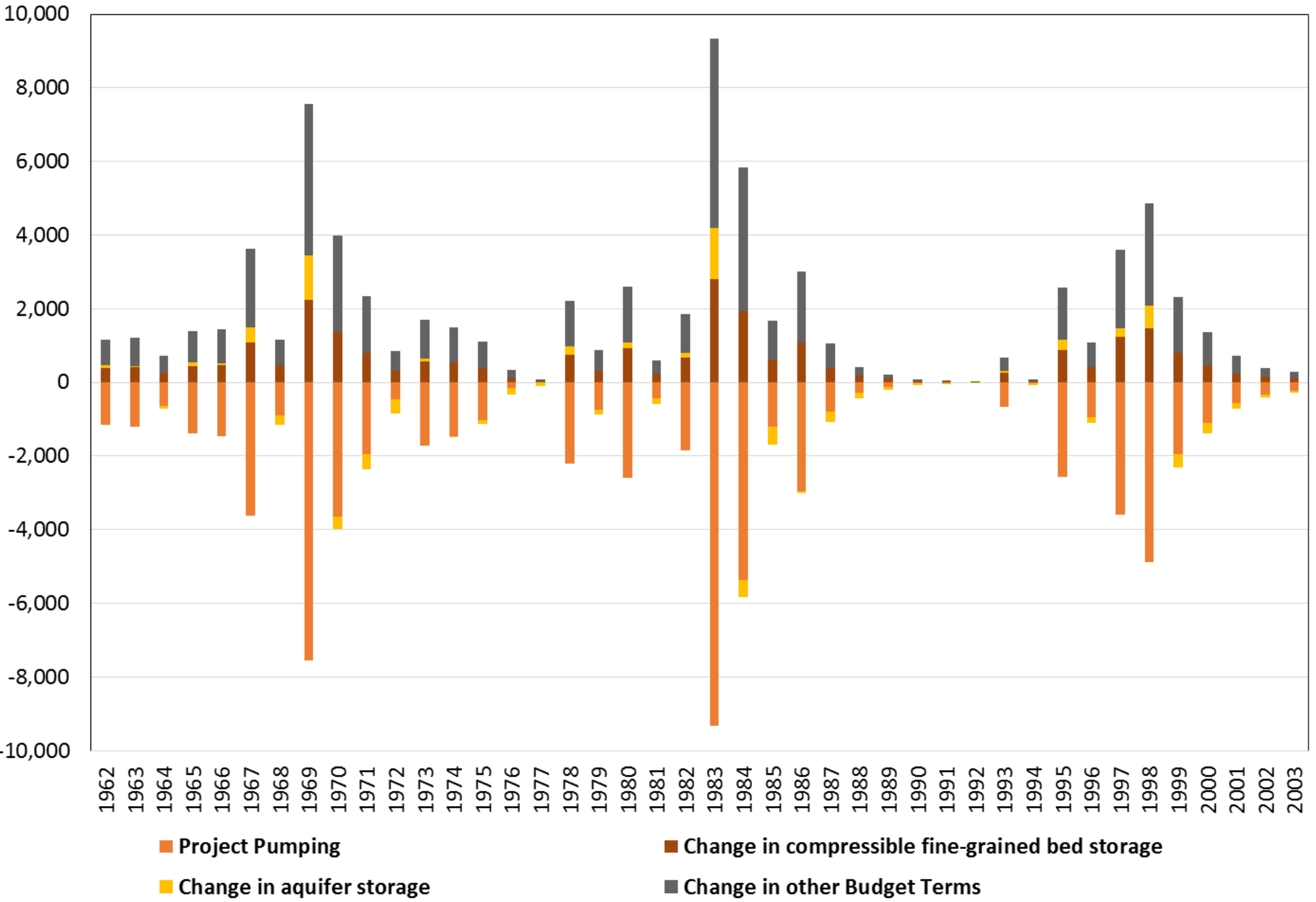
- ▶ Subsidiographs are used to determine location and magnitude of subsidence
- ▶ However, budget can be helpful for determining if subsidence is “significant and unreasonable”

Change in groundwater budget due to additional pumping - shallow wells



Change in storage due to pumping shallow wells

Change in groundwater budget due to additional pumping - deep wells



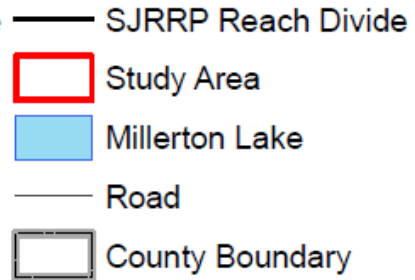
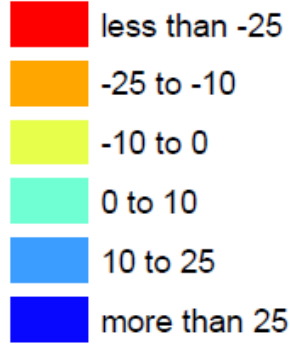
Change in storage due to pumping deep wells

Streamflow Budget

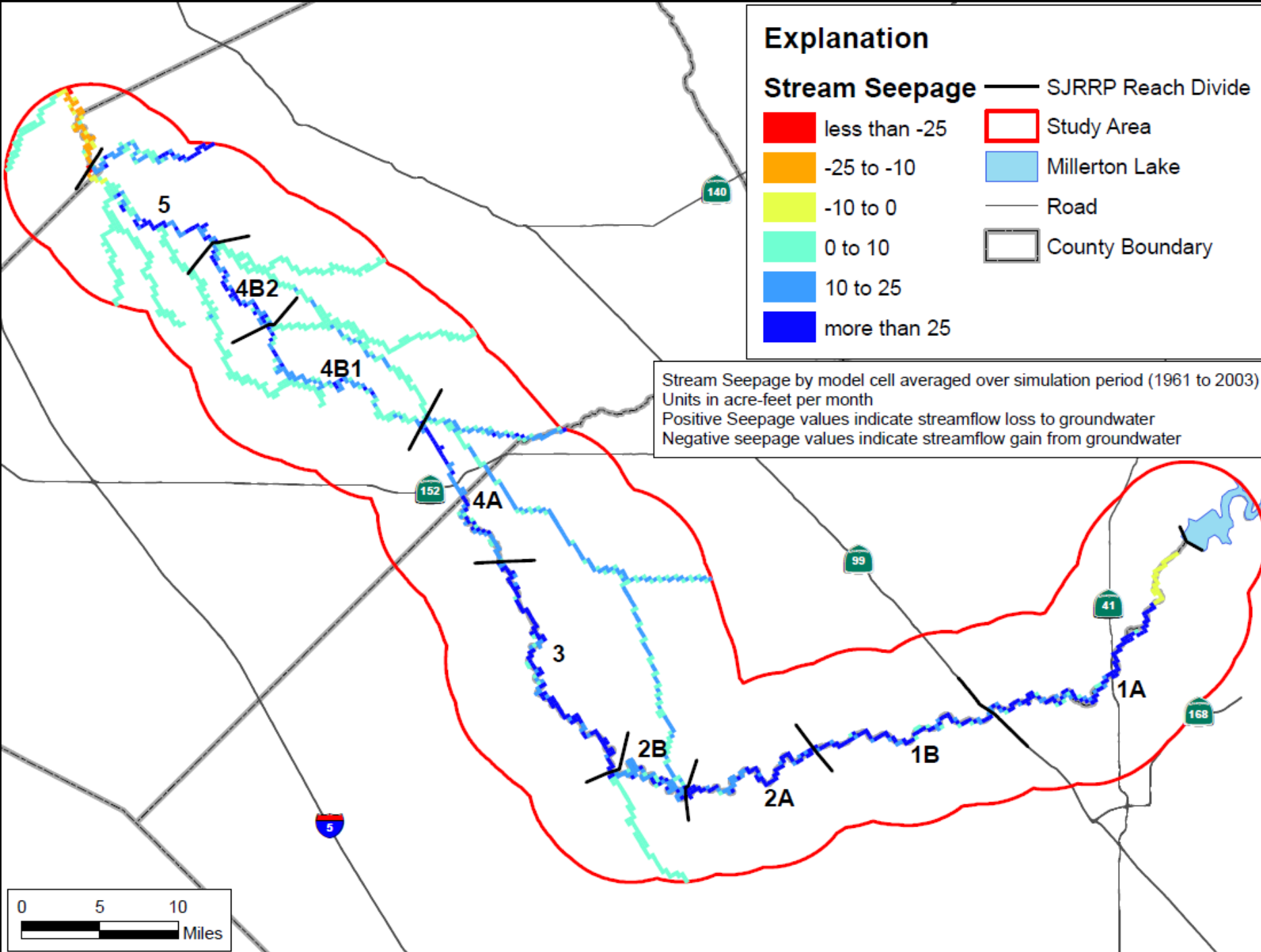
- ▶ Provides the inflows and outflows to the stream network by stream reach
- ▶ Can be used to determine depletion of interconnected surface water

Explanation

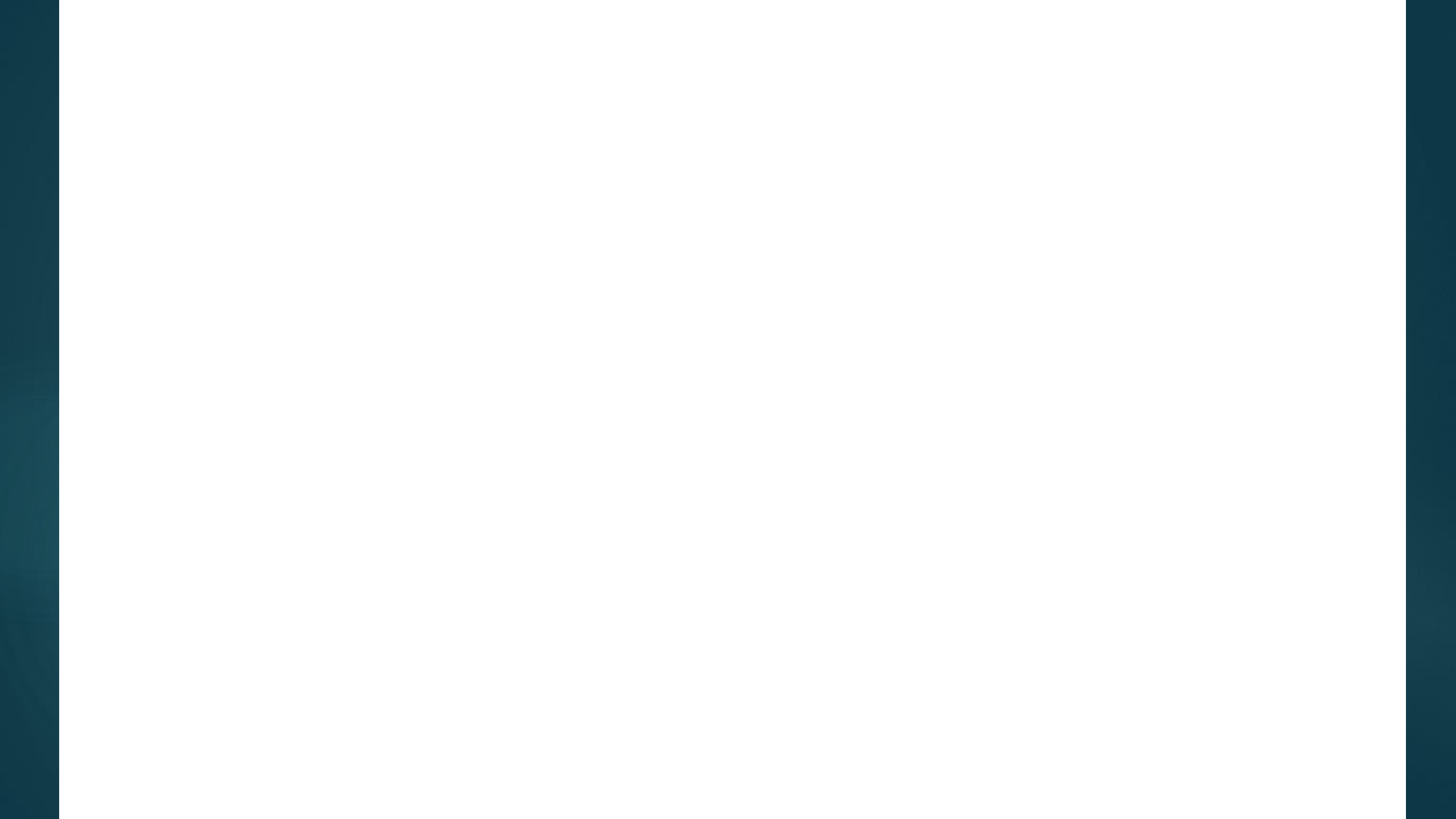
Stream Seepage



Stream Seepage by model cell averaged over simulation period (1961 to 2003)
Units in acre-feet per month
Positive Seepage values indicate streamflow loss to groundwater
Negative seepage values indicate streamflow gain from groundwater

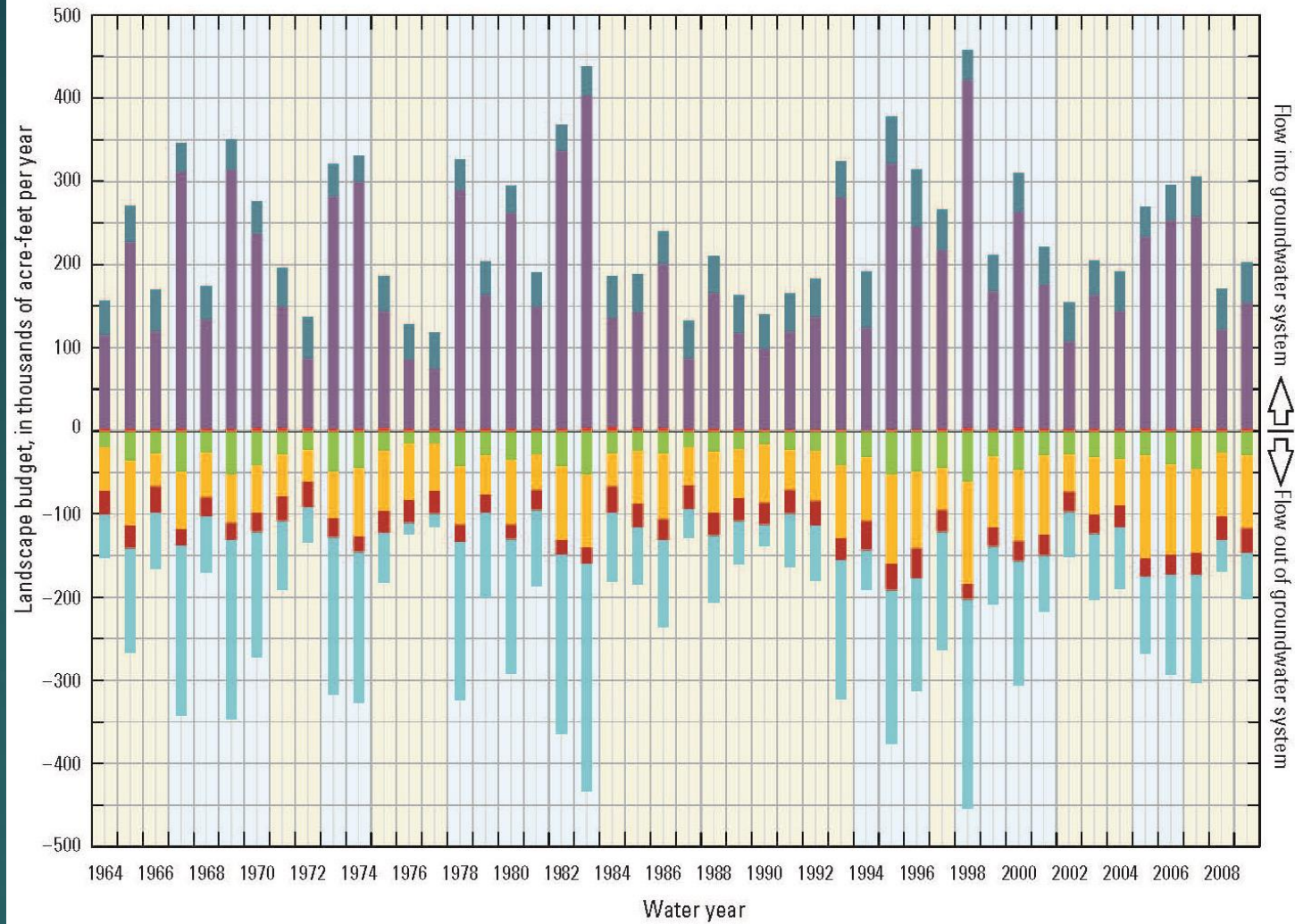


Annual
Average
groundwater
and surface
water
exchange



Water Use Budget

- ▶ Provides the flow components related to the supply and demand of crops and other plants for each water balance subregion
- ▶ Also called landscape budget, supply and demand budget, or farm budget
- ▶ Includes groundwater pumping and recharge which are significant components of the groundwater budget
- ▶ Includes the atmospheric budget components of precipitation and evapotranspiration

A**EXPLANATION**

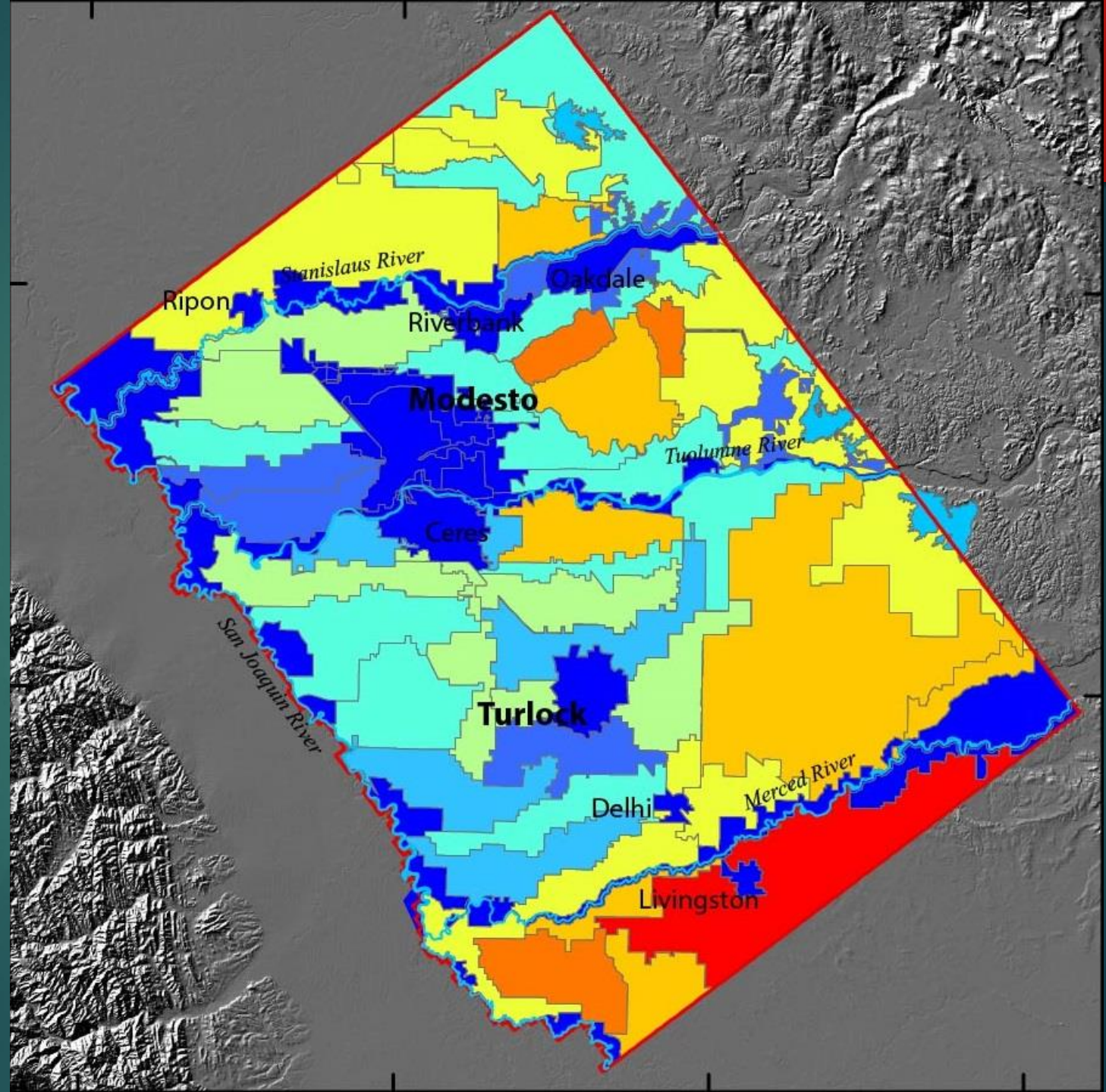
Landscape budget through time for Pajaro Valley, California

- Pumpage
- Precipitation
- Evapotranspiration from groundwater
- Deep percolation
- Evapotranspiration from precipitation
- Evapotranspiration from irrigation
- Runoff

Annual totals

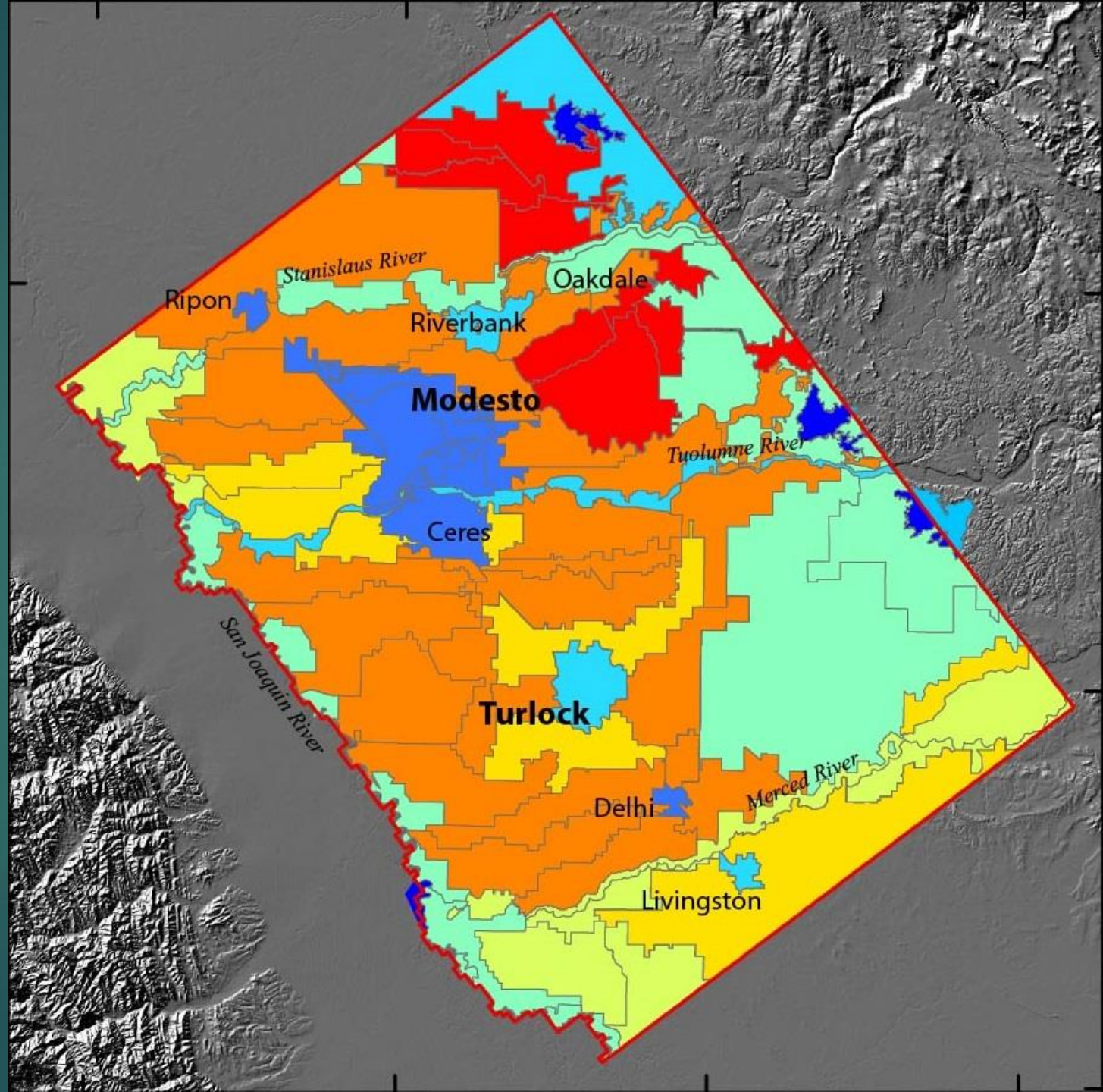
Simulated
agricultural
pumping

Hotter color
= more Ag
pumping



Simulated
areal
recharge

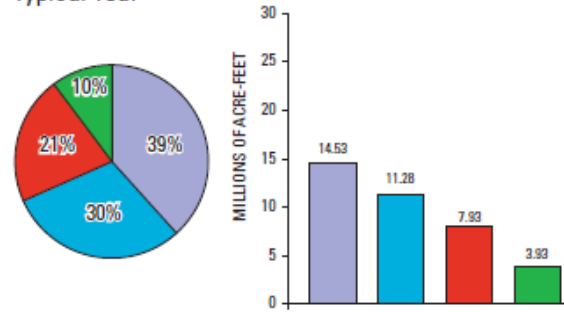
Hotter color
= more
recharge



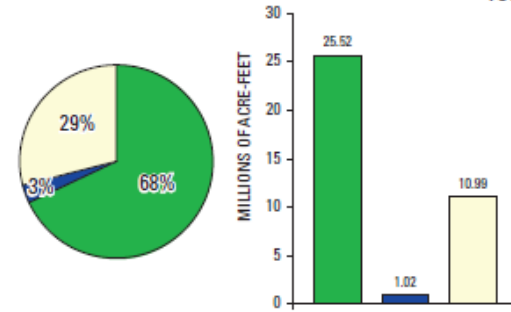
INPUT

OUTPUT

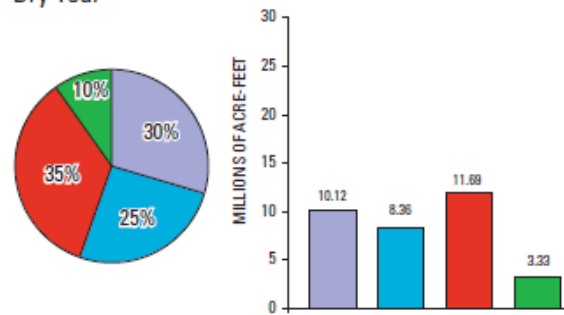
Typical Year



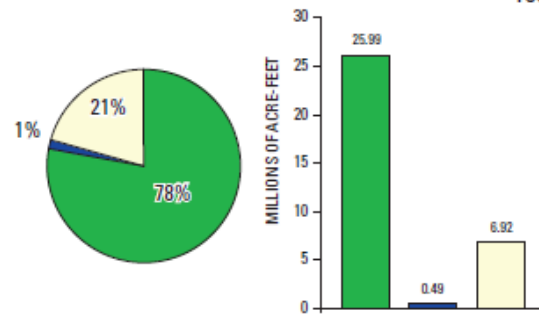
1975



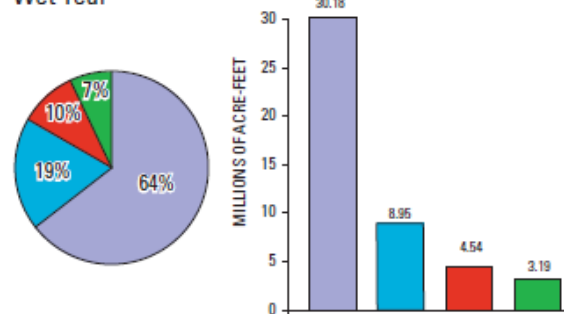
Dry Year



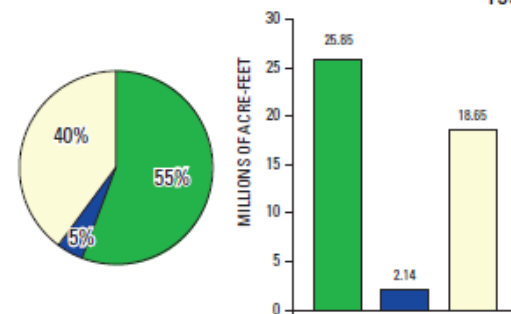
1990



Wet Year



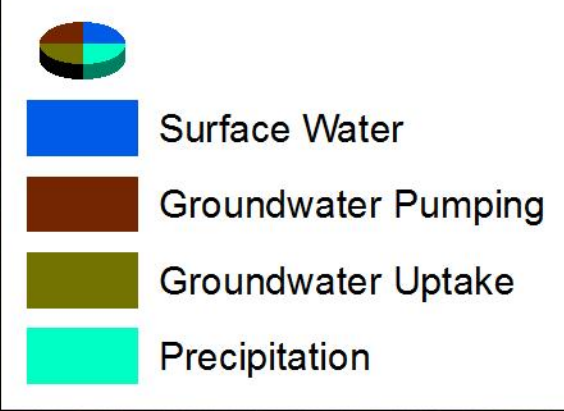
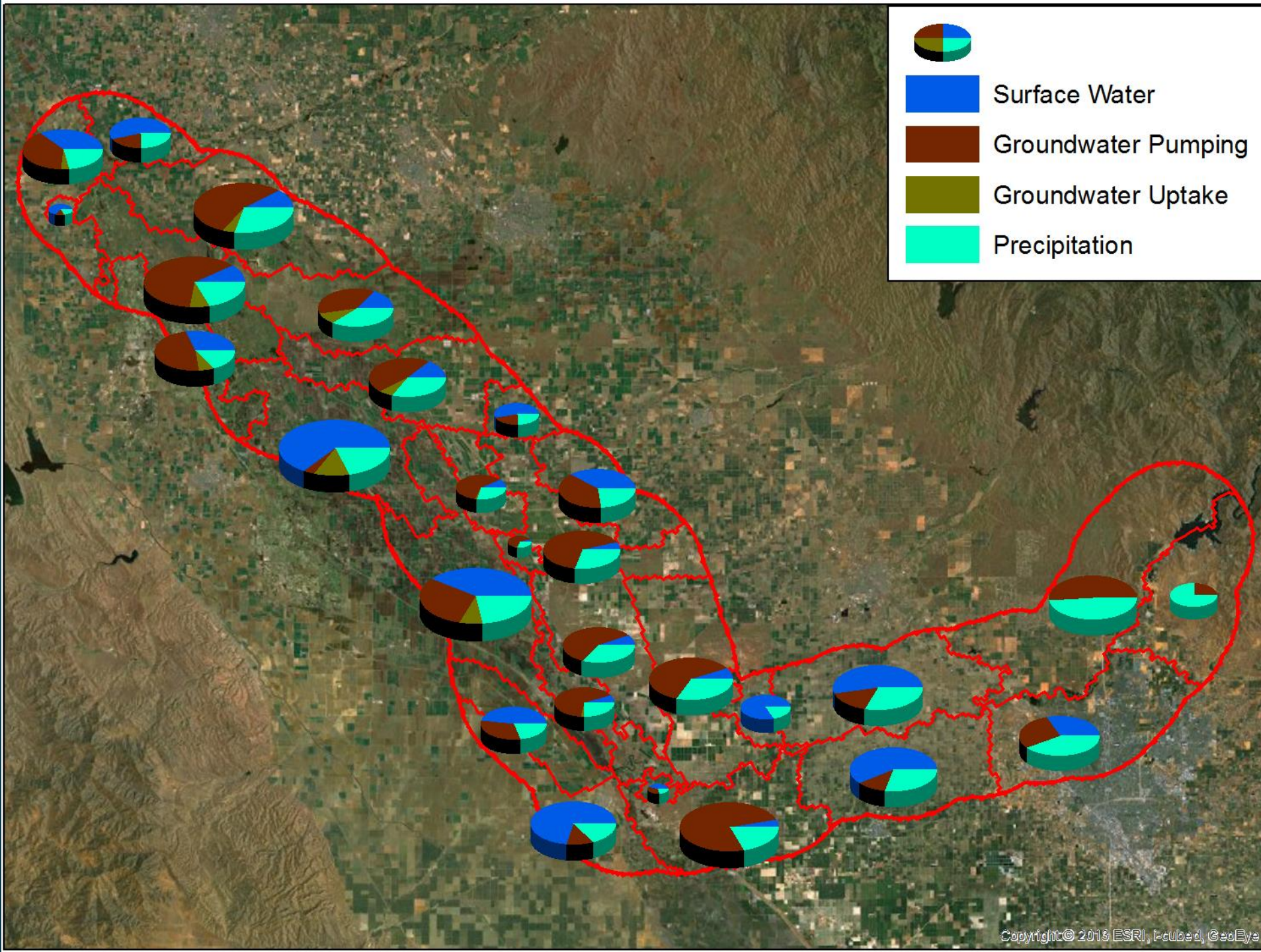
1998



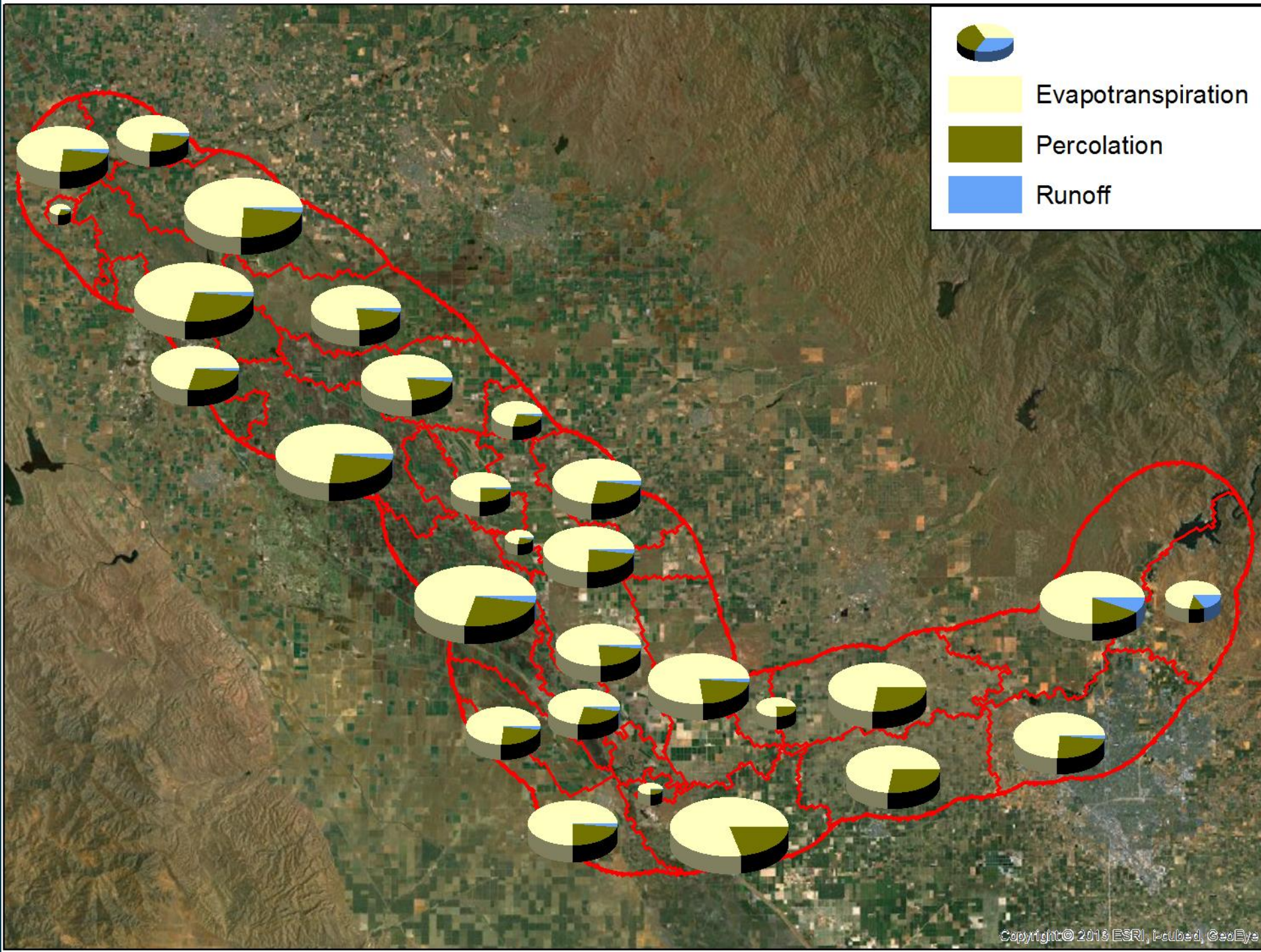
EXPLANATION

- | | | | |
|--------------------------|--------------------------------------|--------------------|--------|
| Precipitation | Groundwater pumpage | Evapotranspiration | Runoff |
| Surface-water deliveries | Evapotranspiration from ground water | Deep percolation | |

For hydrologic year types

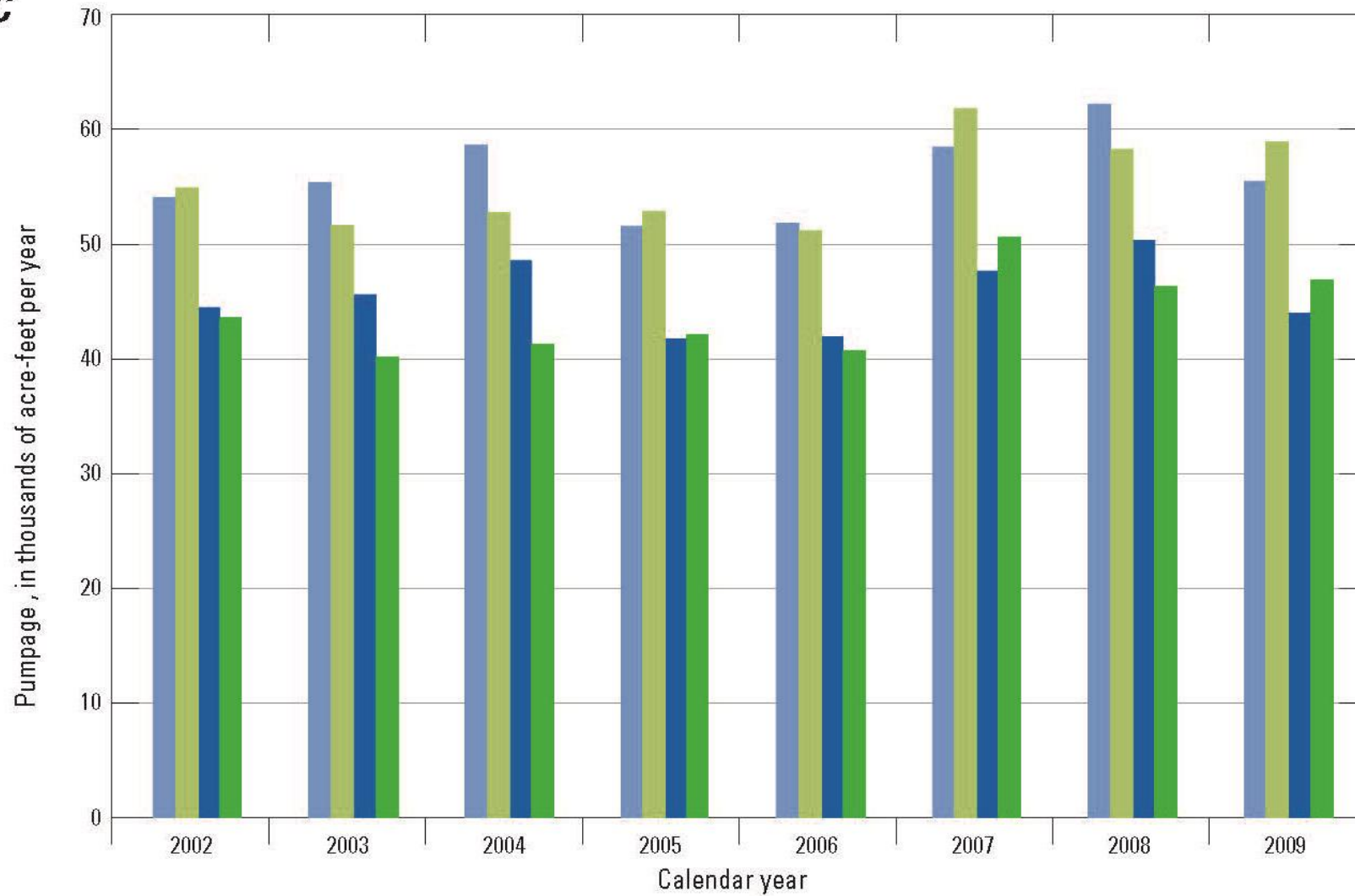


Simulated water supply



Simulated
water
demand

c



EXPLANATION

Total pumpage—

- Reported from Pajaro Valley Water Management Agency
- Simulated in the PVWMA region of the Pajaro Valley Hydrologic Model

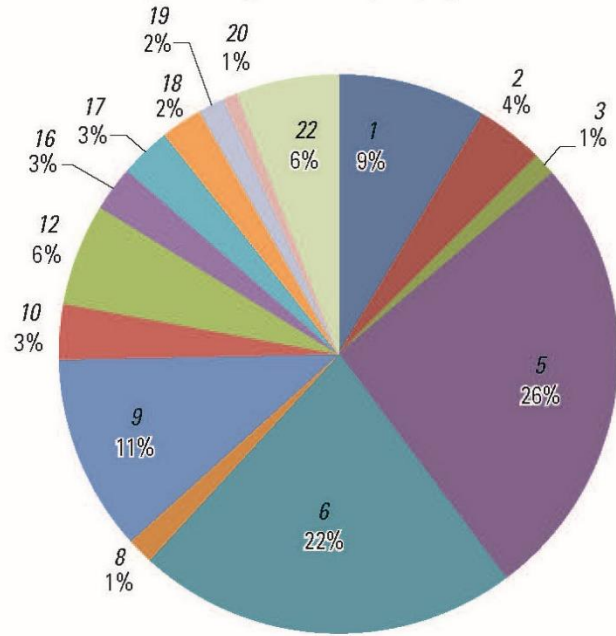
Total agricultural pumpage—

- Reported from Pajaro Valley Water Management Agency
- Simulated in the PVWMA region of the Pajaro Valley Hydrologic Model

Comparing simulated and reported pumpage – annual totals

B

Reported agricultural pumpage 2006–09

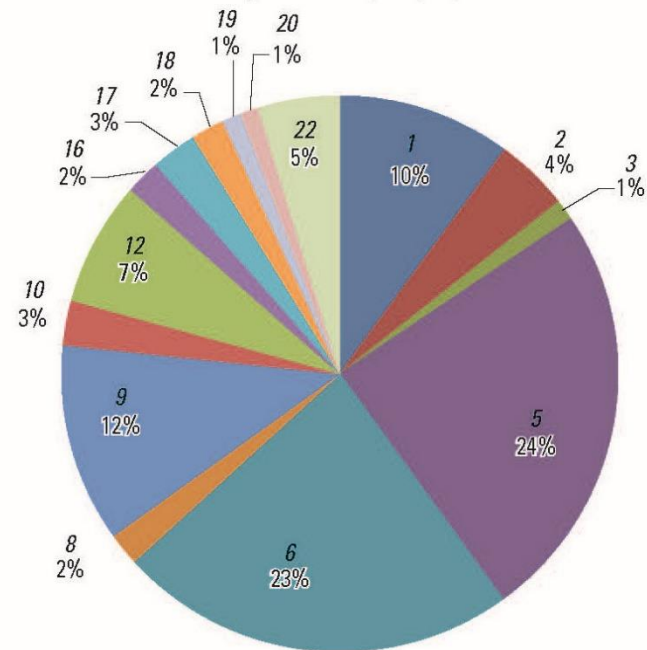


EXPLANATION

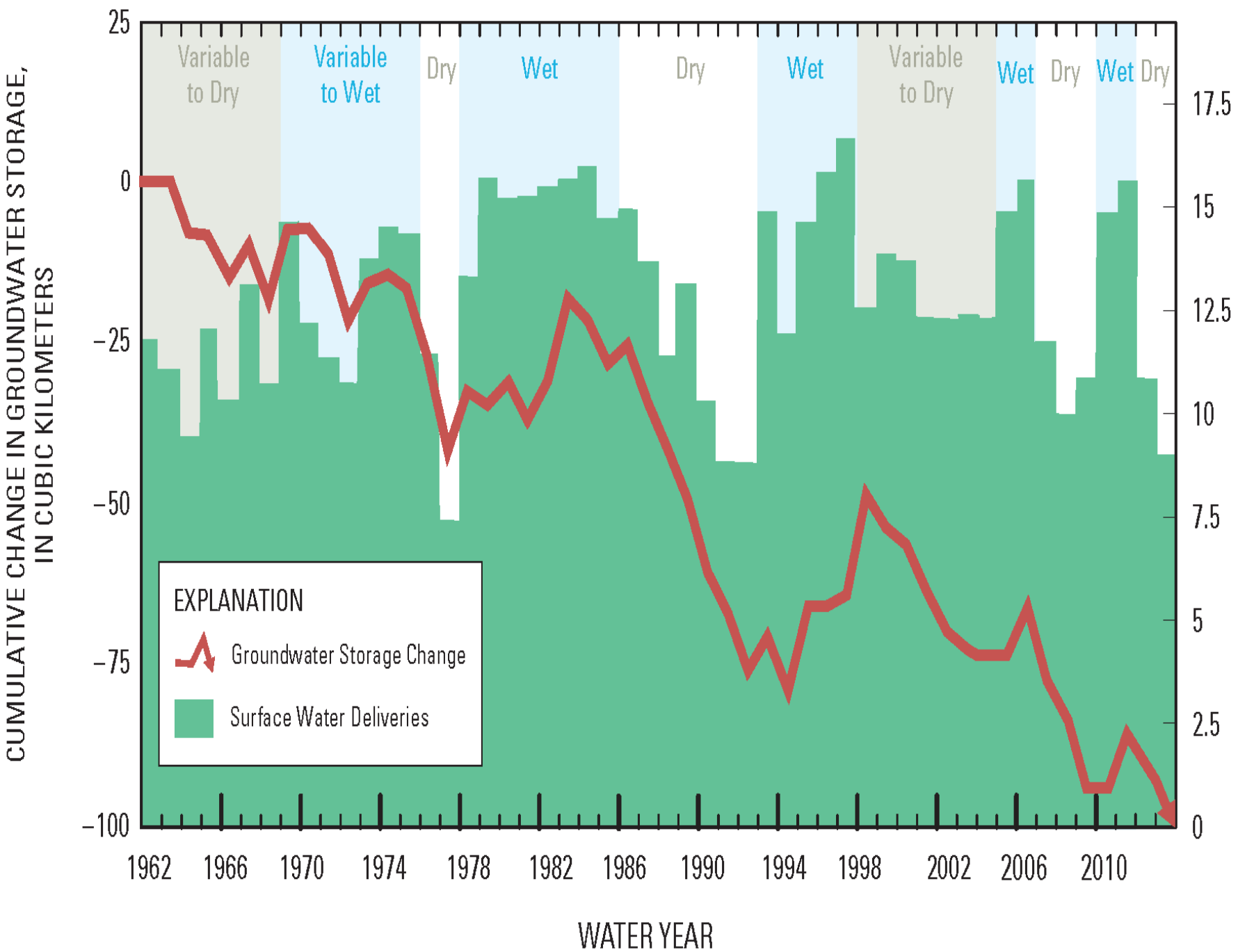
WBS ID Water balance subregion

- 1 Corralitos
- 2 Harkins Slough
- 3 San Andreas
- 5 Salsipudes
- 6 Pajaro
- 8 Pajaro River Mouth
- 9 Springfield Terrace
- 10 Beach Road
- 12 Highlands North
- 16 San Andreas
- 17 Beach Road
- 18 Springfield Terrace E
- 19 Springfield Terrace W
- 20 Springfield Terrace SE
- 22 San Andreas

Simulated agricultural pumpage 2006–09



Comparing simulated and reported pumping – by subregion



Combining budget types can help understand effects

References – MODFLOW and Tools

- ▶ Hanson, R.T., Boyce, S.E., Schmid, Wolfgang, Hughes, J.D., Mehl, S.M., Leake, S.A., Maddock, Thomas, III, and Niswonger, R.G., 2014, *One-Water Hydrologic Flow Model (MODFLOW-OWHM)*: U.S. Geological Survey Techniques and Methods 6-A51, 120 p., <http://dx.doi.org/10.3133/tm6A51>.
- ▶ Harbaugh, A.W., 1990, *A computer program for calculating subregional water budgets using results from the U.S. Geological Survey modular three-dimensional ground-water flow model*: U.S. Geological Survey Open-File Report 90-392, 46 p.
- ▶ Höffmann, J., Leake, S.A., Galloway, D.L., and Wilson, A.M., 2003, *MODFLOW-2000 Ground-Water Model—User Guide to the Subsidence and Aquifer-System Compaction (SUB) Package*: U.S. Geological Survey Open-File Report 03-233, 44 p.
- ▶ Konikow, L.F., Hornberger, G.Z., Halford, K.J., and Hanson, R.T., 2009, *Revised multi-node well (MNW2) package for MODFLOW ground-water flow model*: U.S. Geological Survey Techniques and Methods 6-A30, 67 p.
- ▶ Niswonger, R.G., and Prudic, D.E., 2005, *Documentation of the Streamflow-Routing (SFR2) Package to include unsaturated flow beneath streams—A modification to SFR1*: U.S. Geological Survey Techniques and Methods 6-A13, 50 p.
- ▶ Niswonger, R.G., Prudic, D.E., and Regan, R.S., 2006, *Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005*: U.S. Geological Survey Techniques and Methods 6-A19, 62 p.
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<http://pubs.usgs.gov/pp/1766/>
- ▶ Hanson, R.T., Schmid, Wolfgang, Faunt, C.C., Lear, Jonathan, and Lockwood, Brian, 2014, Integrated hydrologic model of Pajaro Valley, Santa Cruz and Monterey Counties, California: U.S. Geological Survey Scientific Investigations Report 2014–5111, 166 p., <http://dx.doi.org/10.3133/sir20145111>.
- ▶ Paulinski, Scott, and others. Santa Barbara and Foothill Groundwater Basins Geohydrology and Optimal Water Resources Management using Density Dependent Solute Transport and Optimization Models. In Preperation.
- ▶ Phillips, S.P., Rewis, D.L., and Traum, J.A., 2015, Hydrologic model of the Modesto Region, California, 1960–2004: U.S. Geological Survey Scientific Investigations Report, 2015–5045, 69 p., <http://dx.doi.org/10.3133/sir20155045>
- ▶ Traum, J.A., Phillips, S.P., Bennett, G.L., Zamora, Celia, and Metzger, L.F., 2014, Documentation of a groundwater flow model (SJRRPGW) for the San Joaquin River Restoration Program study area, California: U.S. Geological Survey Scientific Investigations Report 2014–5148, 151 p., <http://dx.doi.org/10.3133/sir20145148>