

An aerial view of a large-scale irrigation system with numerous long, straight lines of water spraying across a green agricultural field.

The California Central Valley Groundwater-Surface Water Simulation Model

Groundwater Process

C2VSim Training

A large, dark bird, possibly a crane or heron, is captured in mid-flight against a background of tall, green grass. The bird's wings are fully extended, and its long neck is stretched forward.

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California Department of Water Resources, Sacramento, CA





Outline

IWFM Groundwater Process

Groundwater Budget

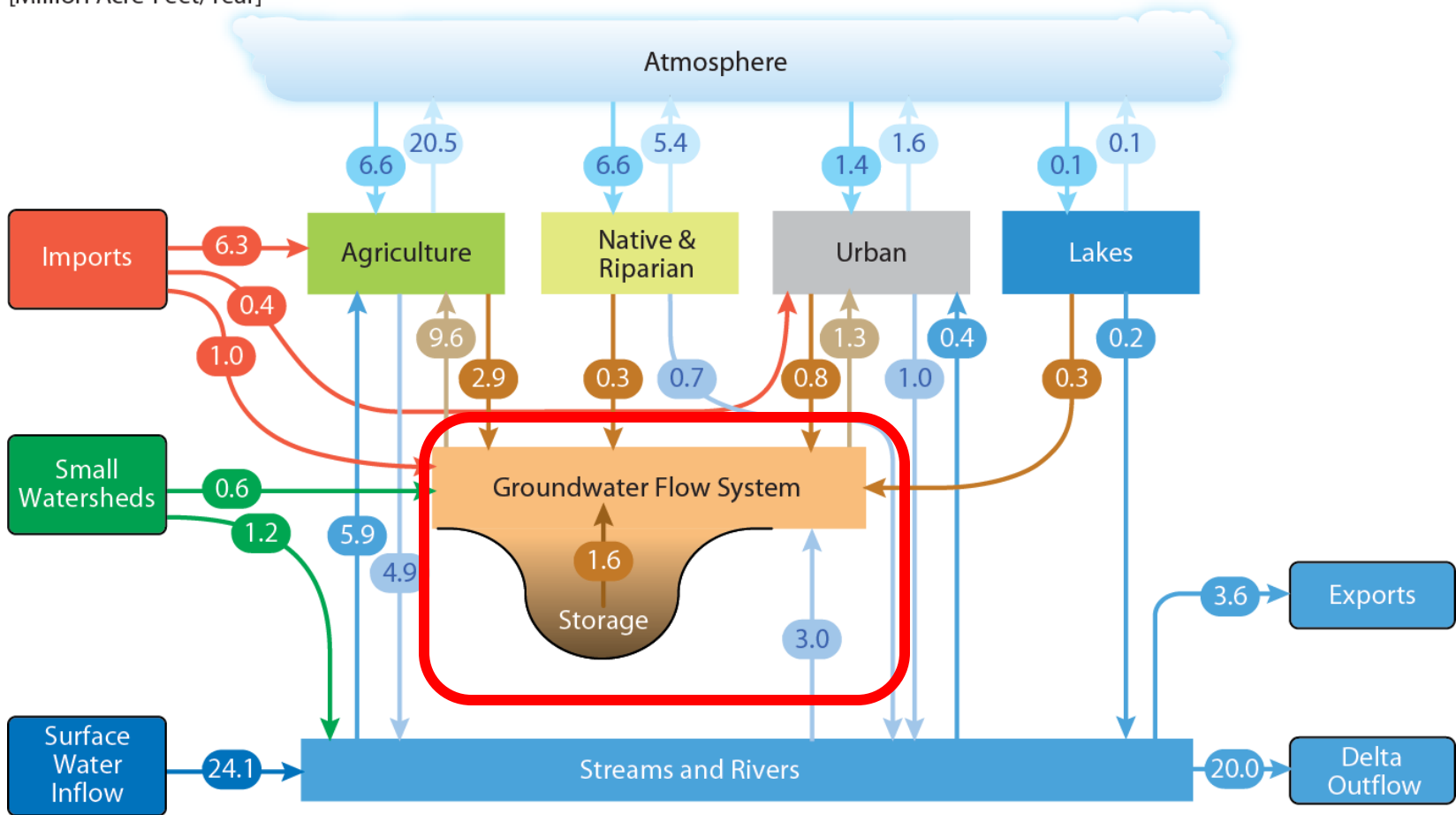
Z-Budget

C2VSim Results

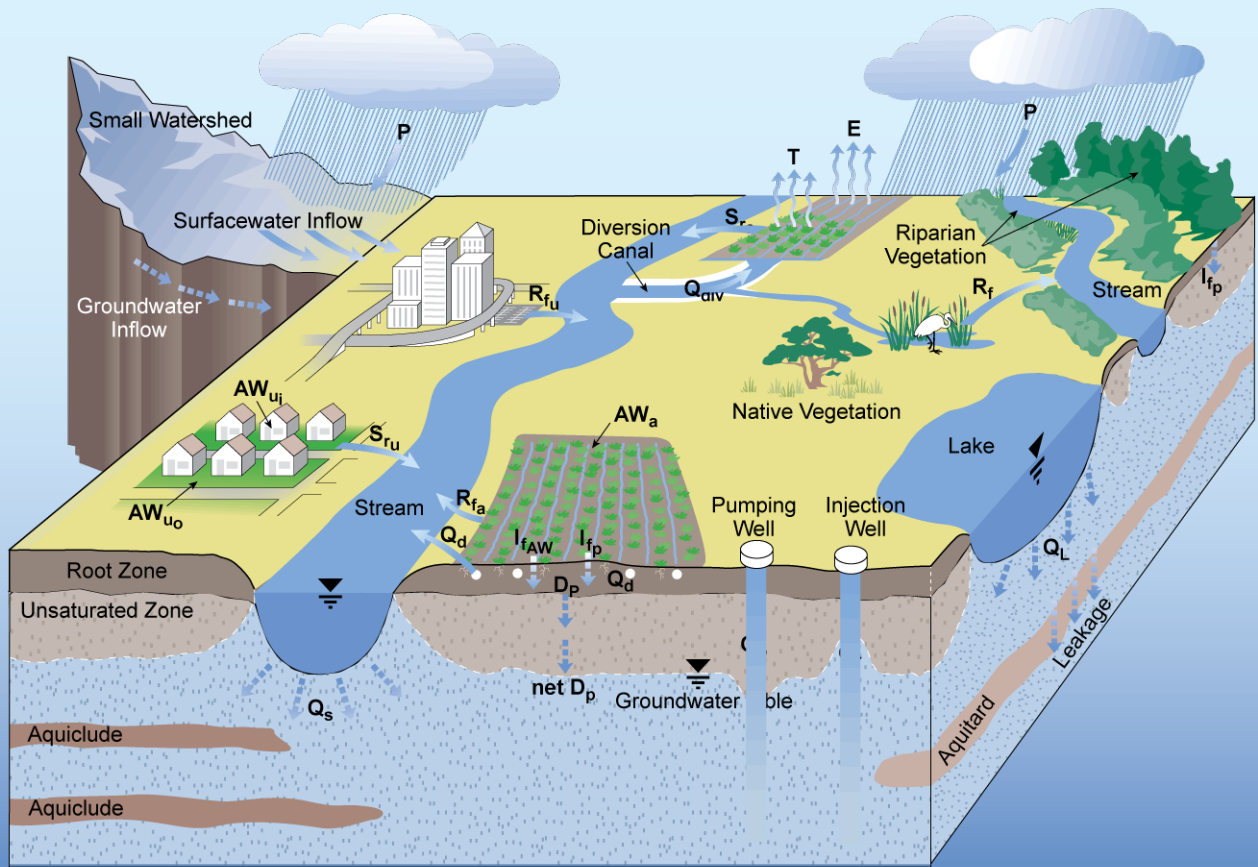
IWFM Groundwater Process

Simulated Annual Water Budget

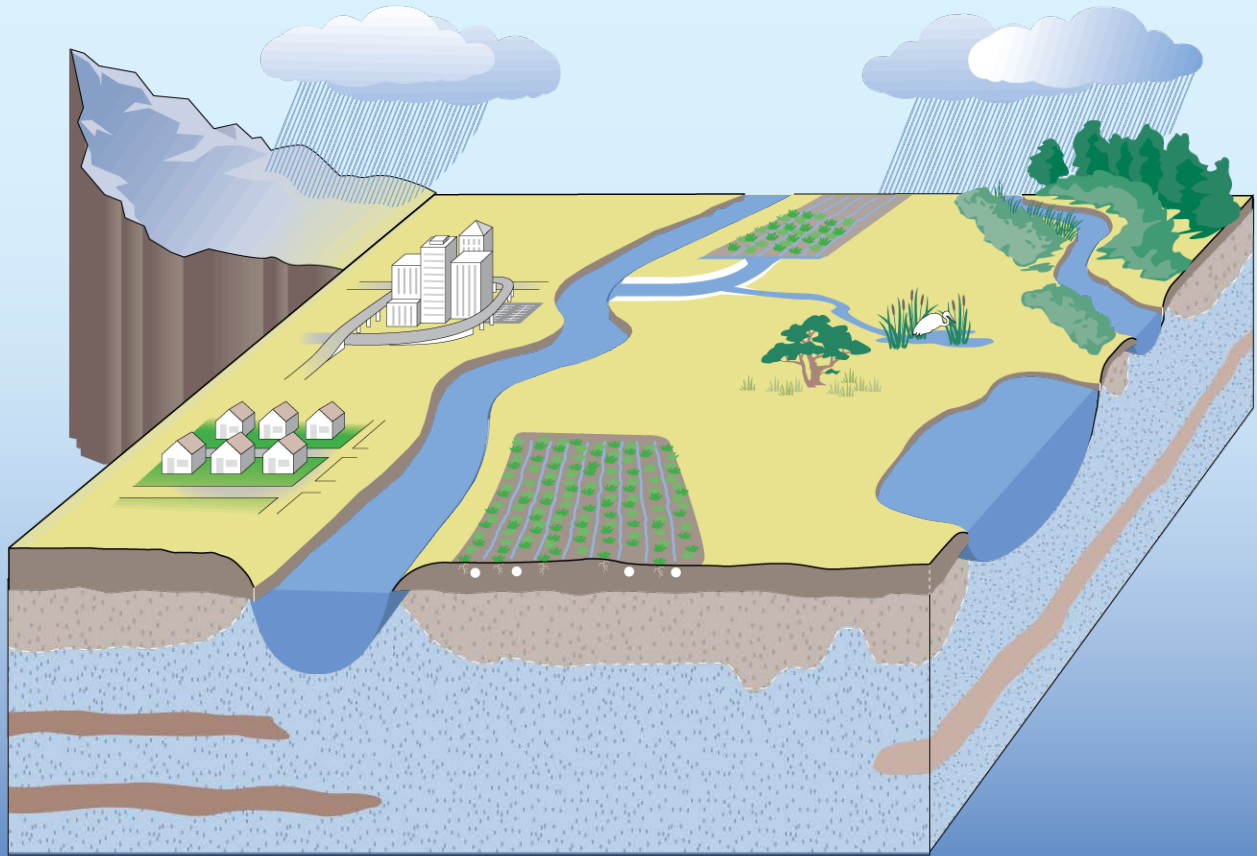
Average Flows for Water Years 2000-2009
[Million Acre-Feet/Year]



IWFM



IWFM Groundwater Process



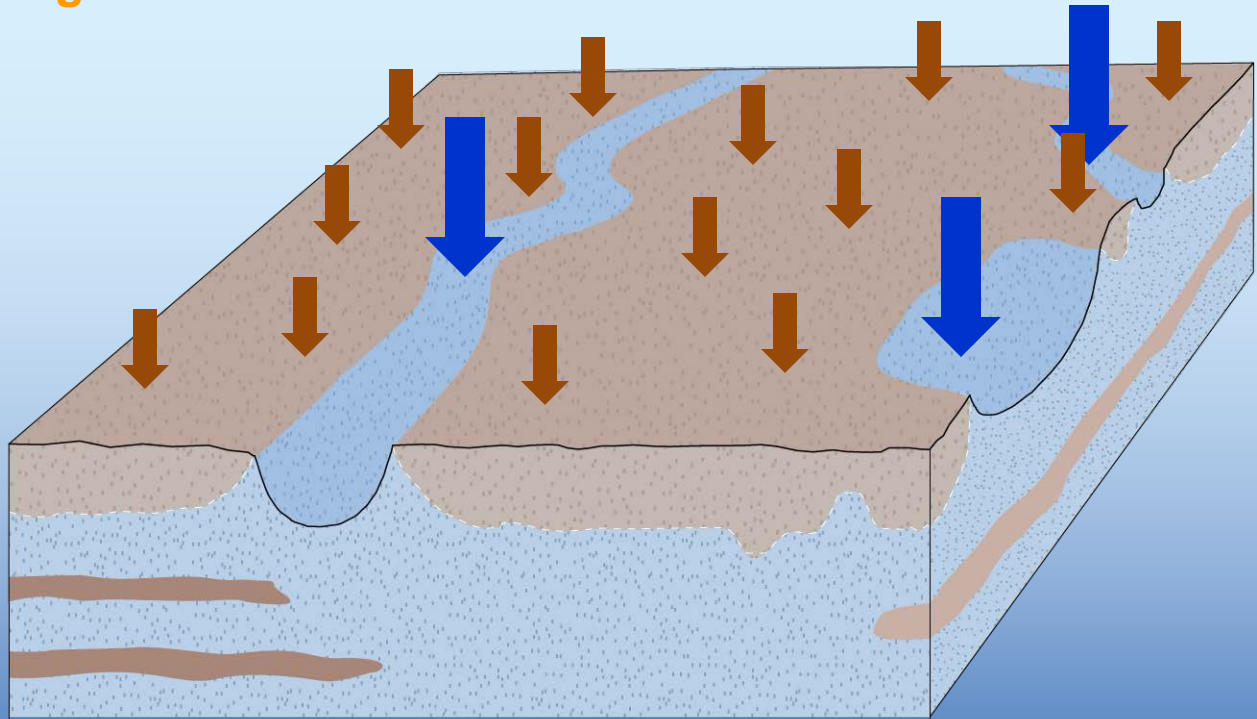
IWFM Groundwater Process

Inflows:

Deep Percolation

Surface Water

Storage



IWFM Groundwater Process

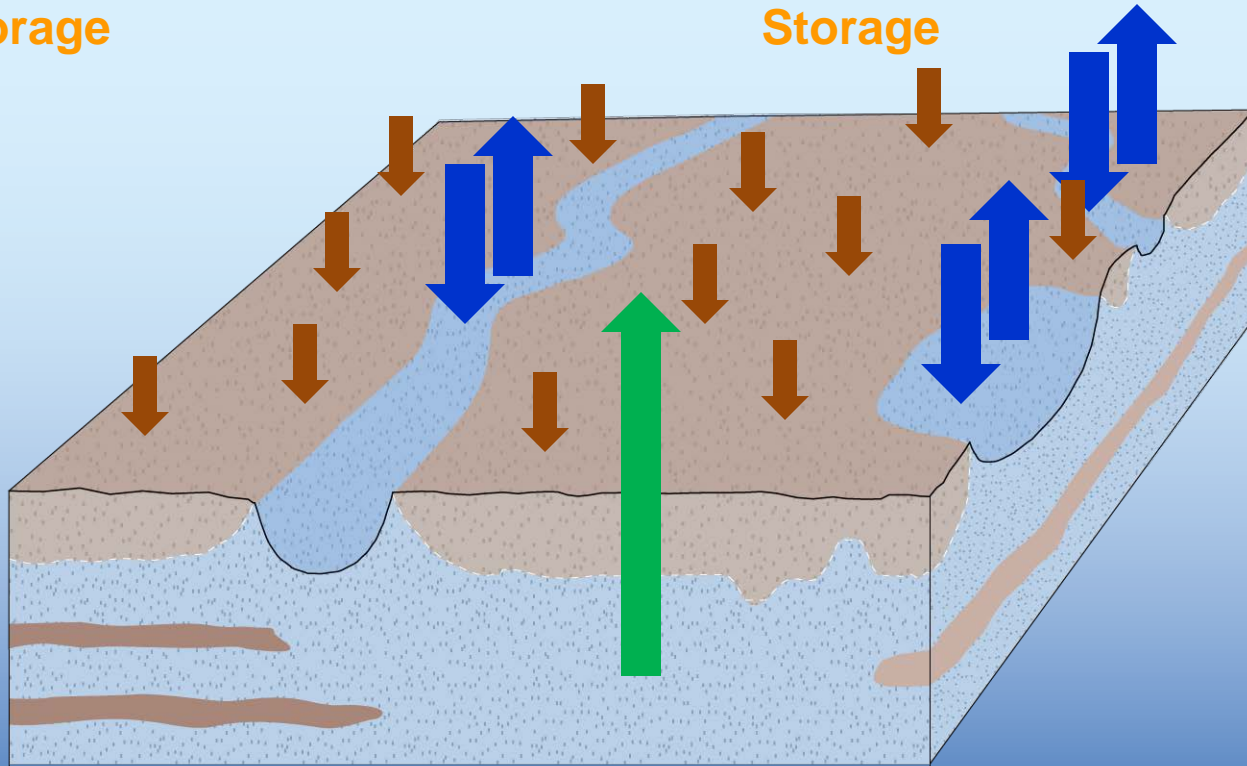
Inflows:

Deep Percolation
Surface Water
Storage

=

Outflows:

Pumping
Surface Water
Storage



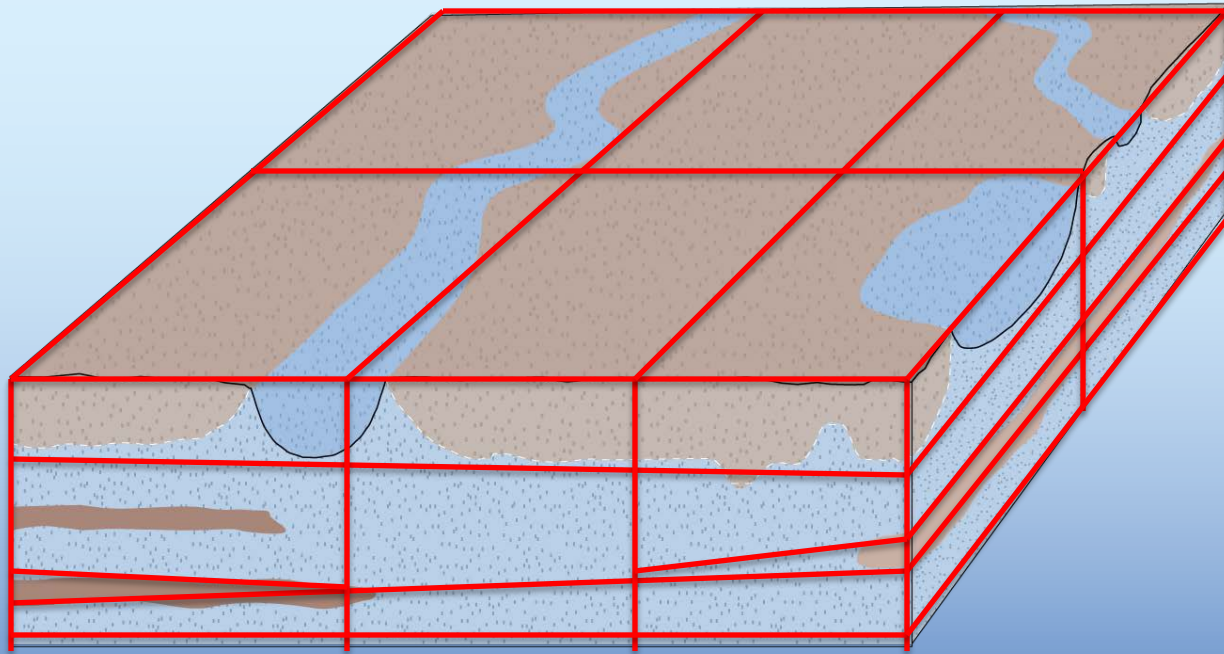


IWFM Groundwater Process

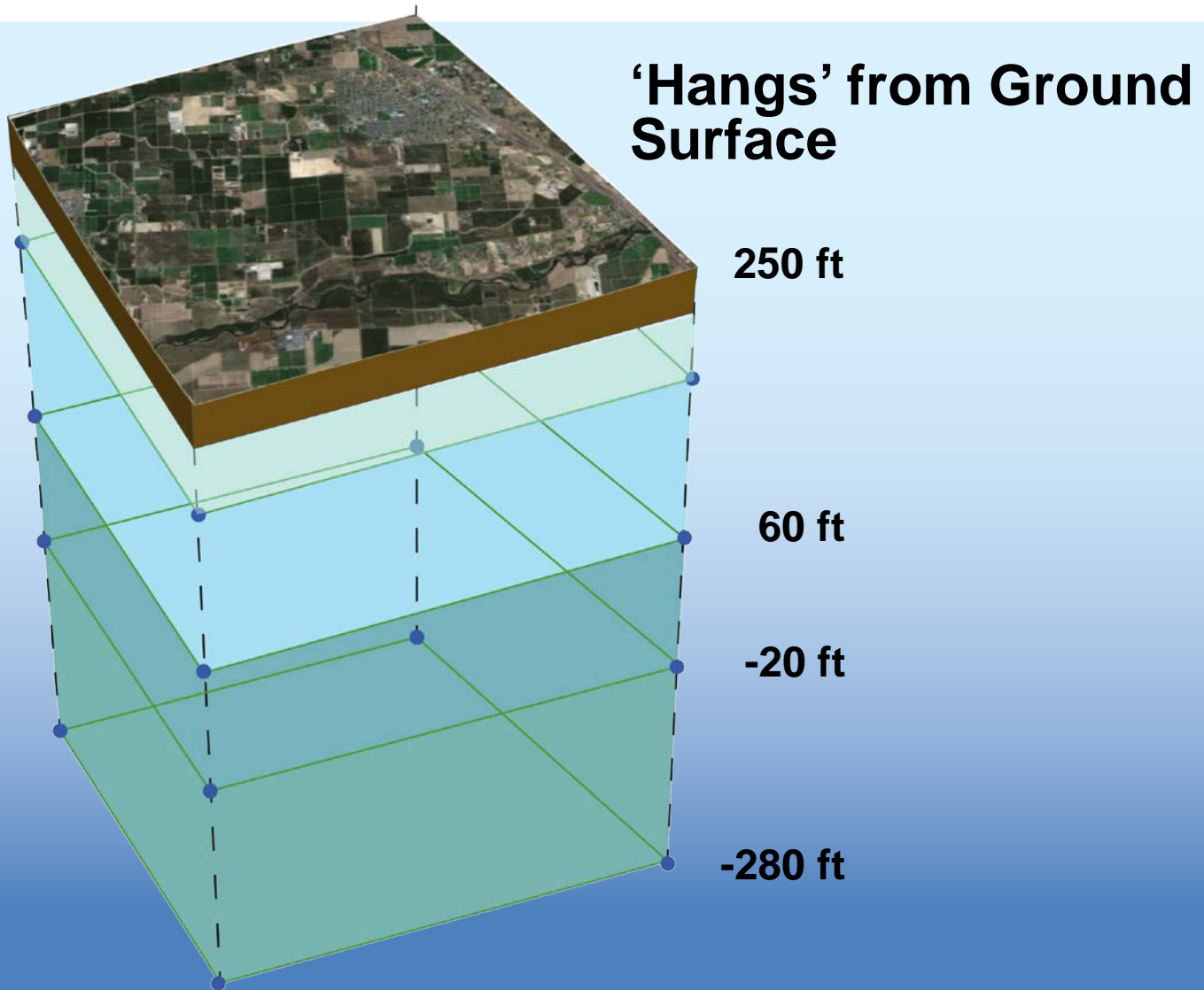
- Simulate a combination of confined, unconfined, and leaky aquifer layers separated by aquitards or aquicludes
- Simulate changing aquifer conditions and subsidence
- Employ a quasi 3-D approach
- Use the Galerkin finite element method for the numerical solution of the governing equation

IWFM Groundwater Process

Simulate the aquifer as unconfined, leaky and confined aquifers separated by aquitards or aquicludes



Stratigraphy



Groundwater Flow Equation

$$\frac{\partial S_s h}{\partial t} - \nabla \cdot (\mathbf{T} \nabla h) + I_u L_u (h - h_u) + I_d L_d (h - h_d) - Q = 0$$

S_s = Storativity, (dimensionless);

h = Groundwater head, (L);

T = Transmissivity = Kh , (L^2/T);

K = Hydraulic conductivity; (L/T);

h_s = Saturated thickness of aquifer, (L);

t = Time (T);

I_u, I_d = Indicator functions for top and bottom aquifer, (dimensionless);

h_u, h_d = Groundwater head at adjacent upper and lower aquifer layers, (L/T);

L_u, L_d = Leakage coefficients of adjacent upper and lower aquifer layers, ($1/T$);

Q = Source/sink term, (L/T).

Groundwater Parameters

```

C  OPTIONS 1 & 2 : The following lists the factors to convert the aquifer parameters and grid coordinates to the appropriate units
C
C  FX      ; Conversion factor for parametric grid coordinates
C  FKH     ; Conversion factor for horizontal hydraulic conductivity - It is used to convert only the spatial component of the unit;
C  FS      ; Conversion factor for specific storage coefficient
C  FN      ; Weighting factor for specific yield value
C  FV      ; Conversion factor for aquitard vertical hydraulic conductivity - It is used to convert only the spatial component of the unit;
C  FL      ; Conversion factor for aquifer vertical hydraulic conductivity - It is used to convert only the spatial component of the unit;
C  FSCE    ; Conversion factor for elastic storage coefficient
C  FSCI    ; Conversion factor for inelastic storage coefficient
C  FDC     ; Conversion factor for interbed thickness
C  FDCMIN  ; Conversion factor for minimum interbed thickness
C  FHC     ; Conversion factor for pre-compaction hydraulic head
C  TUNITKH; Time unit of horizontal hydraulic conductivity. This should be one of the units recognized by HEC-DSS that are listed in the Main Control File.
C  TUNITV  ; Time unit of aquitard vertical conductivity. This should be one of the units recognized by HEC-DSS that are listed in the Main Control File.
C  TUNITL  ; Time unit of aquifer vertical conductivity. This should be one of the units recognized by HEC-DSS that are listed in the Main Control File.
C
C-----
C  FX      FKH      FS      FN      FV      FL      FSCE    FSCI    FDC      FDCMIN  FHC
C-----
C  3.281   1.       1.       1.       1.       1.       1.       1.       1.       1.       1.
C-----
C  VALUE      DESCRIPTION
C-----
C  1mon       / TUNITKH
C  1mon       / TUNITV
C  1mon       / TUNITL
C*****

```

Groundwater Parameters

```

C
C List the groundwater nodes, and aquifer parameters for each layer
C
C ID ; Groundwater node number
C PKH ; Hydraulic conductivity; [L/T]
C PS ; Specific storage; [1/L]
C PN ; Specific yield; [L/L]
C PV ; Aquitard vertical hydraulic conductivity; [L/T]
C PL ; Aquifer vertical hydraulic conductivity; [L/T]
C SCE ; Elastic storage coefficient (Use SCE*DC if DC=0); [1/L]
C SCI ; Inelastic storage coefficient (Use SCI*DC if DC=0); [1/L]
C DC ; Interbed thickness; [L]
C DCMIN; Minimum interbed thickness; [L]
C HC ; Pre-compaction hydraulic head (use 99999. to use initial heads); [L]
C *Note* The above land subsidence parameters are only for interbed layers (i.e. clay layers)
C

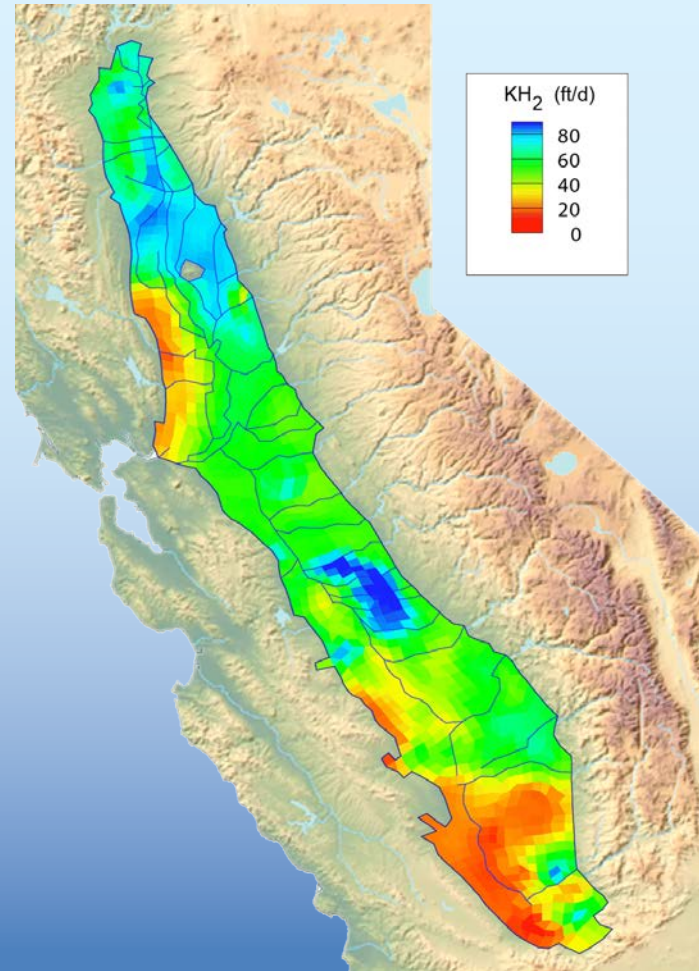
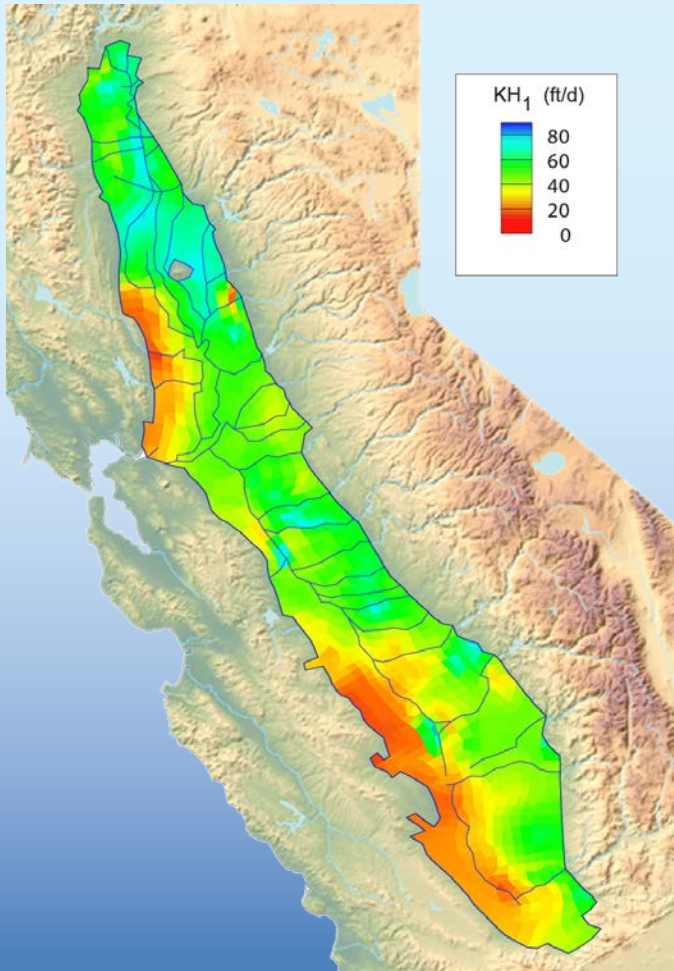
```

ID	Hydr. cond. PKH	Spec. Stor. PS	Spec. Yld. PN	Aquitard Vert. K PV	Aquifer Vert. K PL	Elastic Stg. Coef. SCE	Inelastic Stg. Coef. SCI	Interbed Thickness DC	Min. Intrbed Thickness DCMIN	Precomp Hyd. Head HC
1	1819.54	2.000E-05	0.1509	2.000E-01	1.821	4.500E-06	1.010E-06	13.0	2.0	605.7
	1978.15	1.930E-05	0.1220	3.000E-03	2.114	4.890E-06	1.010E-06	4.0	2.0	636.7
	194.44	1.710E-05	0.1680	1.740E+00	1.458	4.500E-06	1.010E-06	2.0	2.0	663.4
2	1869.77	2.000E-05	0.1417	2.000E-01	1.806	4.500E-06	1.010E-06	12.0	2.0	605.8
	2022.38	1.668E-05	0.1220	3.000E-03	2.103	4.760E-06	1.010E-06	4.0	2.0	635.3
	194.50	1.599E-05	0.1691	1.740E+00	1.496	4.500E-06	1.010E-06	2.0	2.0	661.9
3	1820.95	2.000E-05	0.1393	2.000E-01	1.796	4.500E-06	1.010E-06	12.0	2.0	622.8
	2109.67	1.588E-05	0.1220	3.000E-03	2.117	4.490E-06	1.010E-06	4.0	2.0	651.9
	191.29	1.658E-05	0.1680	1.730E+00	1.527	4.510E-06	1.010E-06	2.0	2.0	678.6
4	1845.00	2.000E-05	0.1539	2.000E-01	1.802	4.500E-06	1.010E-06	12.0	2.0	576.8
	2074.58	1.960E-05	0.1220	3.000E-03	2.099	4.760E-06	1.010E-06	5.0	2.0	610.0
	189.35	2.179E-05	0.1692	1.730E+00	1.477	4.500E-06	1.010E-06	2.0	2.0	636.7
5	2034.70	2.000E-05	0.1533	2.000E-01	1.771	4.500E-06	1.010E-06	12.0	2.0	453.0
	1863.64	2.370E-05	0.1220	3.001E-03	2.010	4.910E-06	1.010E-06	4.0	2.0	475.2
	195.13	2.080E-05	0.1698	1.750E+00	1.487	4.510E-06	1.010E-06	2.0	2.0	501.9
6	1342.19	2.000E-05	0.1368	2.000E-01	1.783	4.500E-06	1.010E-06	19.0	2.0	540.5
	1746.02	3.140E-05	0.1220	3.000E-03	2.040	4.870E-06	1.010E-06	3.0	2.0	572.4

Hydraulic Conductivity

Layer 1

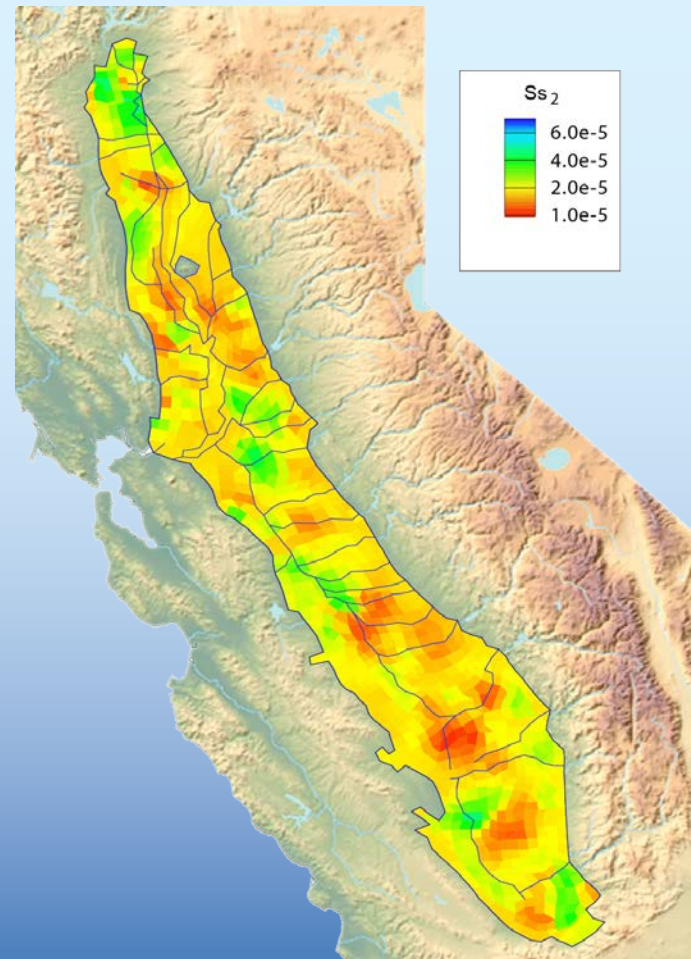
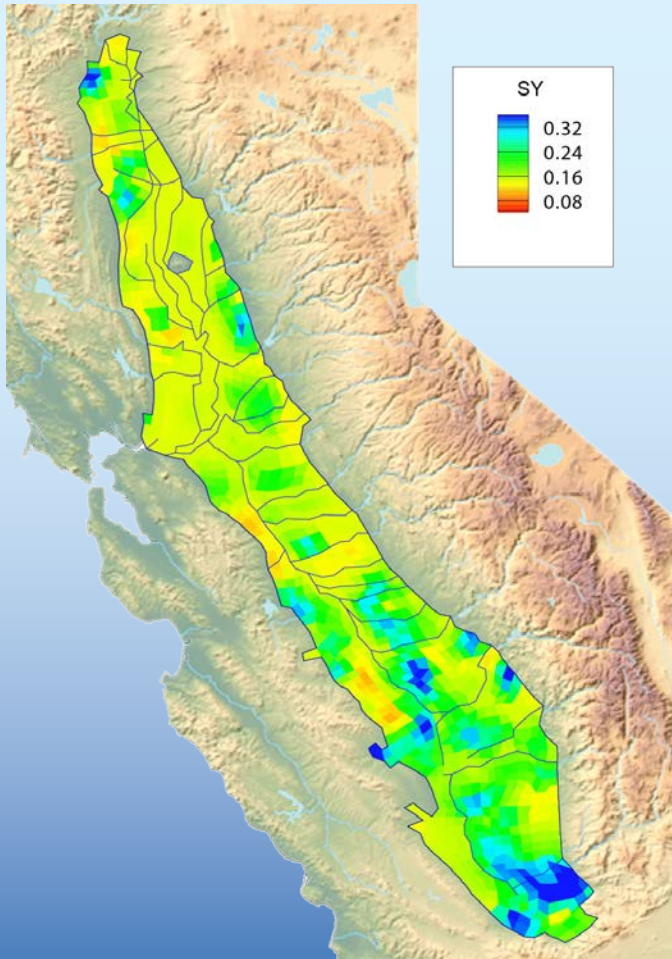
Layer 2



Storage Parameters

Layer 1

Layer 2



Faults

- Battle Creek Fault
- **Red Bluff Arch**
- Plainfield Ridge Anticline
- Pittsburgh – Kirby Hills – Vaca Fault
- Vernalis Fault
- Graveley Ford Faults
- Visalia Fault
- Pond-Poso Creek Fault
- **Edison Fault**
- **White Wolf Fault**

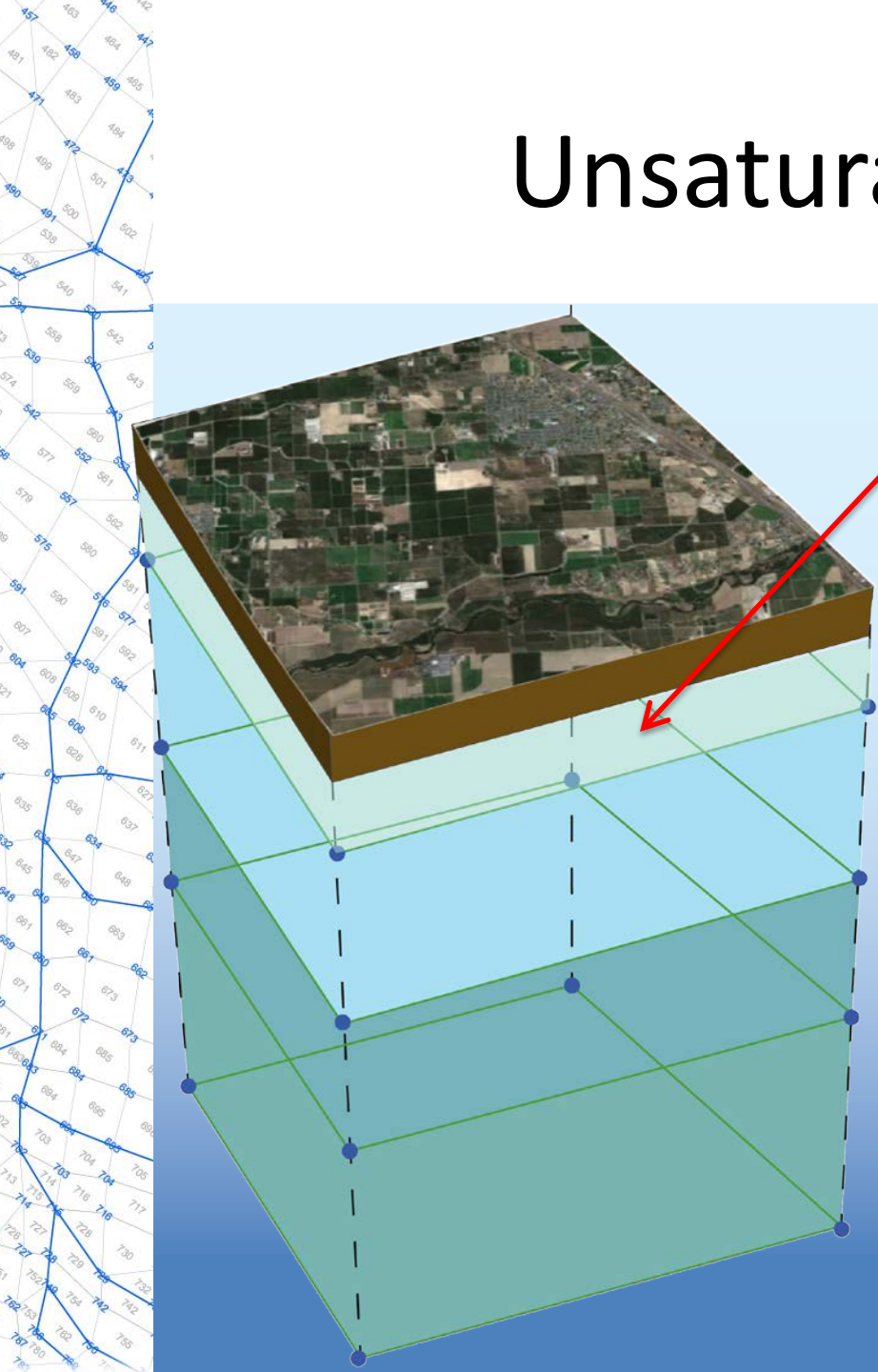


Flow Barrier Parameters

```
C*****
C
C          ANOMALY IN HYDRAULIC CONDUCTIVITY
C
C List the groundwater elements and corresponding aquifer parameters for nodes that will overwrite the above aquifer data
C
C NEBK; Number of elements where hydraulic conductivity values will be overwritten
C FACT; Conversion factor for the anomaly hydraulic conductivity - It is used to convert only the spatial component of the unit;
C TUNIT; Time unit of anomaly hydraulic conductivity. This should be one of the units recognized by HEC-DSS that are listed in the Main Control File.
C-----
C VALUE          DESCRIPTION
C-----
C 7              /NEBK
C 1.0           /FACT
C 1mon          / TUNIT
C-----
C
C IC ;          Counter for number of overwrite options
C IEBK;         Element number corresponding to counter IC
C BK ;         Hydraulic conductivity at the specified node; [L/T]
C-----
C
C          LAYER 1  LAYER 2  LAYER 3
C          IEBK    BK       BK       BK
C-----
C 1         55     1.0308900 1.0250100 1.0326100
C 2         56     1.0308900 1.0250100 1.0326100
C 3         57     1.0308900 1.0250100 1.0326100
C 4         58     1.0308900 1.0250100 1.0326100
C 5        1383    .029790000 .029950000 .030030000
C 6        1384    .029790000 .029950000 .030030000
C 7        1385    .029790000 .029950000 .030030000
C-----
C*****
```

Red Bluff Arch

Unsaturated Zone



- Vertical water flow between root zone and water table
 - In: Deep Percolation
 - Out: Net Deep Percolation
- Divide into two layers of equal thickness

Unsaturated Zone Parameters

```

C*****
C      OPTION 2 (for Unsaturated Zone Parameter Definition)
C*****
C
C List the groundwater elements and unsaturated zone parameters for
C each layer (skip if option 1 is used)
C
C IE;      Element number
C PD;      Thickness of unsaturated layer; [L]
C PN;      Total porosity; [L/L]
C PL;      Hydraulic conductivity; [L/T]
  
```

IE	LAYER 1			LAYER 2		
	Thickness PD	Porosity PN	Kv PL	Thickness PD	Porosity PN	Kv PL
1	21.1	0.11953	0.99997	21.1	0.11987	1.00010
2	43.8	0.11626	0.99981	43.8	0.11936	1.00004
3	58.1	0.10603	0.99828	58.1	0.11759	0.99807
4	65.3	0.11495	0.99882	65.3	0.11885	0.99907
5	35.8	0.11647	1.00002	35.8	0.11960	1.00000
6	66.1	0.11138	0.99962	66.1	0.11892	0.99930
7	20.1	0.11994	0.99929	20.1	0.11961	0.99934
8	34.7	0.11705	1.00007	34.7	0.11967	1.00007
9	51.1	0.11687	0.99975	51.1	0.11959	0.99964
10	92.0	0.11702	0.99956	92.0	0.11957	0.99927
11	103.6	0.09024	0.98848	103.6	0.11081	0.98629
12	71.8	0.11418	0.99625	71.8	0.11753	0.99678
13	29.9	0.11964	0.99986	29.9	0.11988	0.99990
14	21.1	0.11973	0.99999	21.1	0.11996	1.00001
15	35.6	0.11939	0.99989	35.6	0.11987	0.99994
16	73.5	0.11888	0.99974	73.5	0.11979	0.99975
17	84.5	0.08288	0.98602	84.5	0.11004	0.98142
18	106.0	0.09180	0.99129	106.0	0.11287	0.99144
19	79.5	0.11515	0.99806	79.5	0.11856	0.99826
20	38.3	0.11947	0.99969	38.3	0.11977	0.99967
21	46.0	0.11968	0.99989	46.0	0.11991	0.99992
22	29.8	0.11096	0.99901	29.8	0.11865	0.99801

Groundwater Boundary Conditions

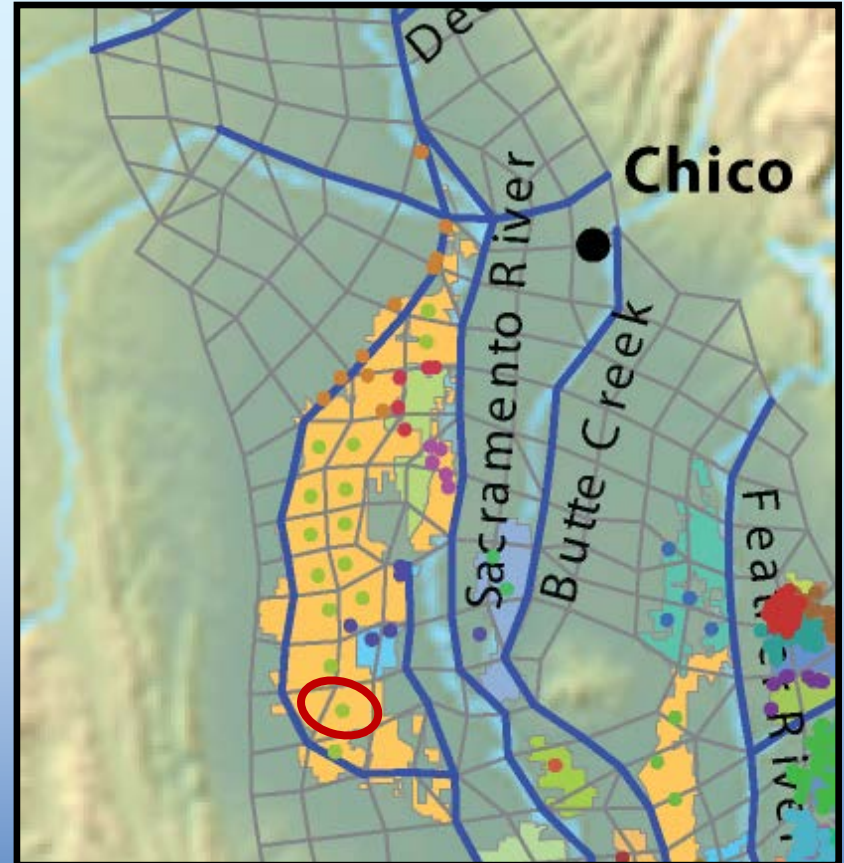


- x Specified head
- x Specified flow
- x General head boundary conditions
- **Small stream watersheds** as dynamically computed flow boundary conditions

Pumping

Pumping by well

- Used when exact location and construction details of wells are known
- Pumping at the well is distributed to aquifer layers based on the screened interval of the well in an aquifer layer
- Well locations described in Preprocessor Well Data File
- Well information specified in Pumping Specification File



Pumping Specification

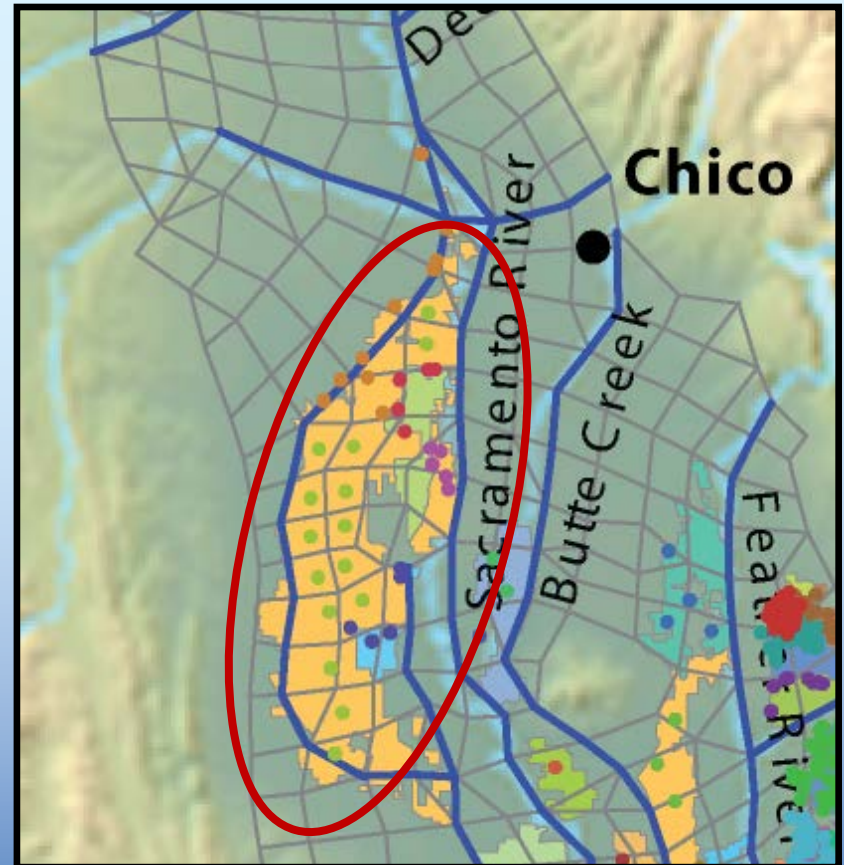
Urban Groundwater Pumping

```
C*****
C          Well Pumping Specifications
C (Skip if no wells are being modeled, ie, NWELL = 0 as specified in preprocessor)
C
C ID      ; Well identification number
C ICOLWL  ; Well pumping - this number corresponds to the appropriate data column in the pumping data file (Unit 24)
C ICFIRIGWL; Fraction of the pumping that is used for irrigation purposes - this number corresponds to the appropriate data column in the
C          irrigation fractions data file (Unit 27)
C FRACWL  ; Relative proportion of the pumping in column ICOLWL to be applied to well ID
C IRGWL   ; Subregion number where the pumping is delivered to;
C          Enter 0, if pumping is exported to outside the model area
C          Enter -1, if the pumping is used in the same element
C ICADJWL ; Supply adjustment specification - this number corresponds to the data column in the supply adjustment specifications data file (Unit 12)
C ICWLMAX ; Maximum pumping amount - this number corresponds to the appropriate data column in the pumping data file (Unit 24)
C FWLMAX  ; Fraction of data value specified in column ICWLMAX to be used as maximum pumping amount
C
C-----
C ID ICOLWL ICFIRIGWL FRACWL IRGWL ICADJWL ICWLMAX FWLMAX
C-----
1 22 22 0.1918 -1 1 22 0.2876
2 22 22 0.0404 -1 1 22 0.0606
3 22 22 0.3839 -1 1 22 0.5759
4 22 22 0.3839 -1 1 22 0.5759
5 23 22 0.2158 -1 1 23 0.3236
6 23 22 0.0666 -1 1 23 0.0998
7 23 22 0.0628 -1 1 23 0.0942
8 23 22 0.1857 -1 1 23 0.2785
9 23 22 0.4544 -1 1 23 0.6816
10 23 22 0.0147 -1 1 23 0.0221
11 24 22 0.1875 -1 1 24 0.2813
12 24 22 0.2253 -1 1 24 0.3379
13 24 22 0.5872 -1 1 24 0.8808
14 25 22 1.0000 -1 1 25 1.5000
15 26 22 0.0152 -1 1 26 0.0227
16 26 22 0.3841 -1 1 26 0.5761
17 26 22 0.0444 -1 1 26 0.0666
18 26 22 0.0414 -1 1 26 0.0621
19 26 22 0.1181 -1 1 26 0.1772
20 26 22 0.0933 -1 1 26 0.1400
21 26 22 0.0250 -1 1 26 0.0375
22 26 22 0.0156 -1 1 26 0.0234
```

Pumping

Pumping by element

- Used when detailed well information is not available, but pumping amounts for an area that is represented by multiple finite element cells are known
- Pumping is distributed horizontally to cells with respect to developed area in each cell (surrogate for water demand)
- In each cell, pumping is distributed to aquifer layers based on user specified fractions



Pumping Specification

Agricultural Groundwater Pumping

```

C *****
C           Elemental Pumping Specifications
C           (Skip if elemental pumping is not specified, ie, NSINK = 0)
C
C ID       ; Element identification number corresponding to the pumping
C ICOLSK   ; Element pumping - this number corresponds to the appropriate data
C           column in the pumping data file (Unit 24)
C ICFIRIGSK; Fraction of the pumping that is used for irrigation purposes -
C           this number corresponds to the appropriate data column in the
C           irrigation fractions data file (Unit 27)
C FRACSK   ; Relative proportion of the pumping in column ICOLSK to be applied
C           to element ID
C FRACSKL  ; The distribution factor of pumping for each aquifer layer; i.e. for
C           layers 1 to NL
C IRGSK    ; Subregion number where the pumping is delivered to
C           Enter 0, if pumping is exported to outside the model area
C           Enter -1, if the pumping is used in the same element
C ICADJSK  ; Supply adjustment specification - this number corresponds to
C           the data column in the supply adjustment specifications
C           data file (Unit 12)
C ICSKMAX  ; Maximum pumping amount - this number corresponds to the
C           appropriate data column in the pumping data file (Unit 24)
C FSKMAX   ; Fraction of data value specified in column ICSKMAX to be used as
C           maximum pumping amount
C

```

C ID	ICOLSK	ICFIRIGSK	FRACSK	FRACSKL			IRGSK	ICADJSK	ICSKMAX	FSKMAX
				(1)	(2)	(3)				
1	1	1	0.0000	0.677	0.323	0.000	-1	1	1	1
2	1	1	0.0037	0.677	0.323	0.000	-1	1	1	1
3	1	1	0.0437	0.677	0.323	0.000	-1	1	1	1
4	1	1	0.0124	0.677	0.323	0.000	-1	1	1	1
5	1	1	0.0060	0.677	0.323	0.000	-1	1	1	1
6	1	1	0.0317	0.677	0.323	0.000	-1	1	1	1
7	1	1	0.0237	0.677	0.323	0.000	-1	1	1	1
8	1	1	0.0176	0.677	0.323	0.000	-1	1	1	1
9	1	1	0.0639	0.677	0.323	0.000	-1	1	1	1
10	1	1	0.0533	0.677	0.323	0.000	-1	1	1	1
11	1	1	0.0011	0.677	0.323	0.000	-1	1	1	1
12	1	1	0.0094	0.677	0.323	0.000	-1	1	1	1
13	1	1	0.0096	0.677	0.323	0.000	-1	1	1	1
14	1	1	0.0075	0.677	0.323	0.000	-1	1	1	1
15	1	1	0.0675	0.677	0.323	0.000	-1	1	1	1
16	1	1	0.0459	0.677	0.323	0.000	-1	1	1	1
17	1	1	0.0000	0.677	0.323	0.000	-1	1	1	1
18	1	1	0.0058	0.677	0.323	0.000	-1	1	1	1
19	1	1	0.0332	0.677	0.323	0.000	-1	1	1	1
20	1	1	0.0207	0.677	0.323	0.000	-1	1	1	1
21	1	1	0.0130	0.677	0.323	0.000	-1	1	1	1

Tile Drains

- Tile drains are simulated as general head boundary conditions:

$$Q_{td} = C_{td}(z_{td} - h) \leq 0$$

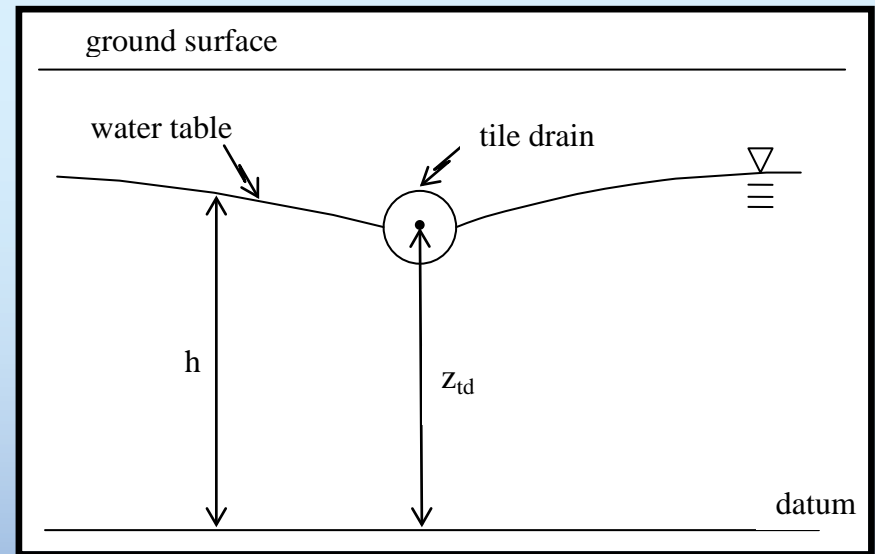
Q_{td} = tile drain flow, [L³/T]

C_{td} = conductance, [L²/T]

z_{td} = tile drain elevation, [L]

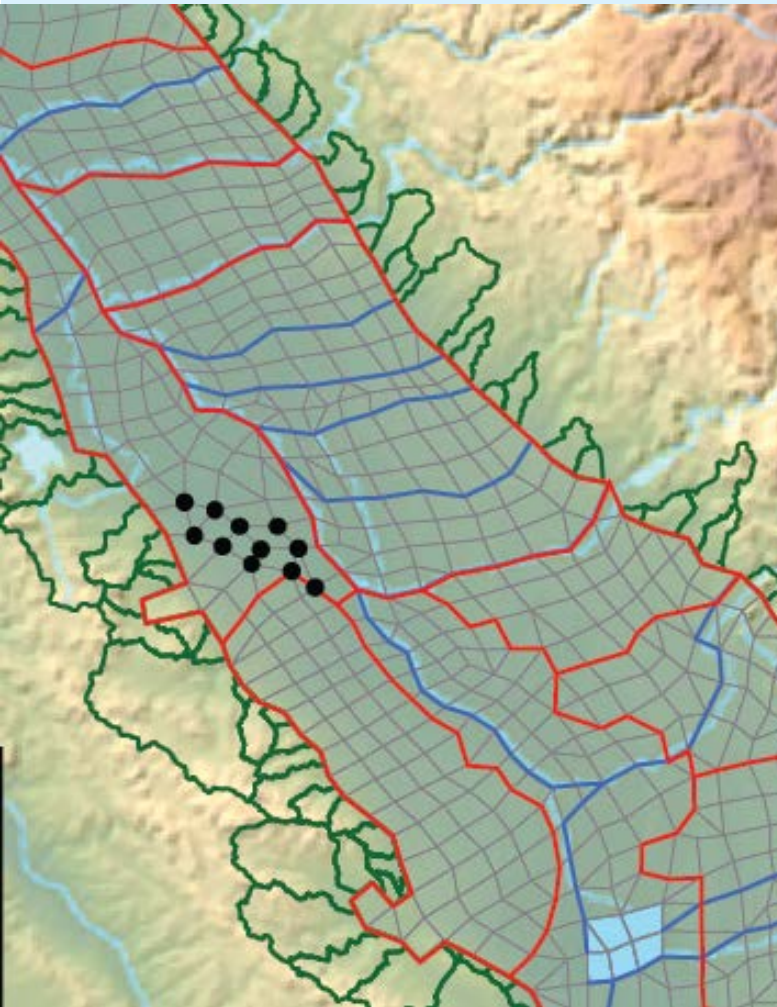
h = groundwater head, [L]

- Tile drain flows can be directed into specified stream nodes or outside the model area



Tile Drains

11 tile drains – water goes to San Luis Drain outlet



Tile Drains Data Specifications

NTD ; Number of groundwater nodes with tile drains
 FACTH ; Conversion factor for tile drain elevations
 FACTCDC; Conversion factor for tile drain conductances
 TUNIT ; Time unit of conductance. This should be one of the units recognized by HEC-DSS

VALUE	DESCRIPTION
11	/NTD
1.0	/FACTH
60.0	/FACTCDC (convert ft ² /sec to ft ² /min)
imin	/TUNIT

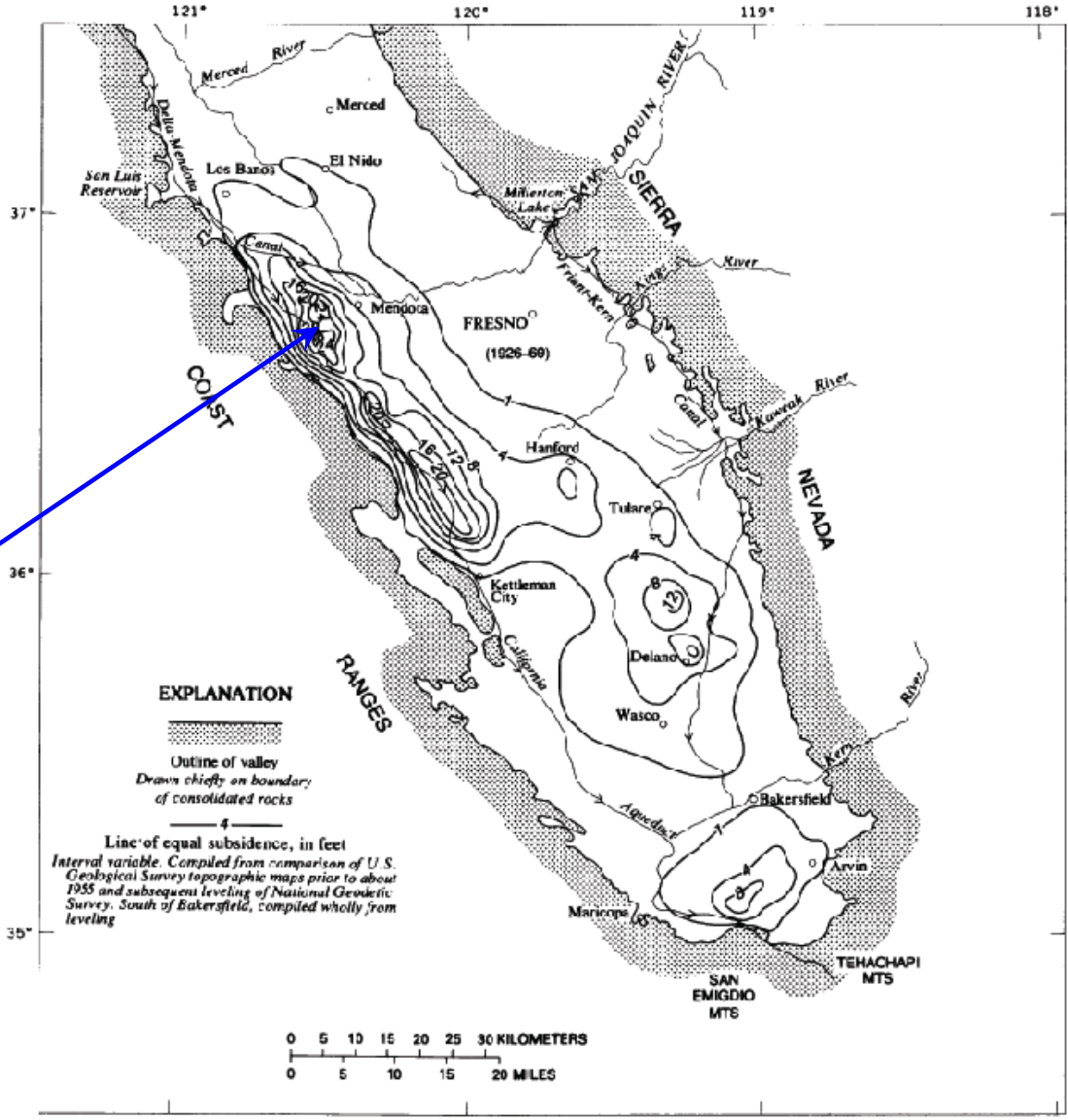
Tile Drain Parameters

The following lists the groundwater node number, elevation and conductance for each tile drain. The stream node that the tile drain flow contributes to is also listed.

NODEDR ; Groundwater node number corresponding to the tile drain
 Case 1: For drainage out of node, list the node number as a negative value. For example
 Case 2: For drainage into the node, list the node number as a positive value. For example
 ELEVDR ; Elevation of the drain; [L]
 CDCDR ; Hydraulic conductance of the interface between the aquifer and the drain; [L²/T]
 ISTRMDR; Stream node into which drain flows into (input 0 (zero) if the drain flows out of

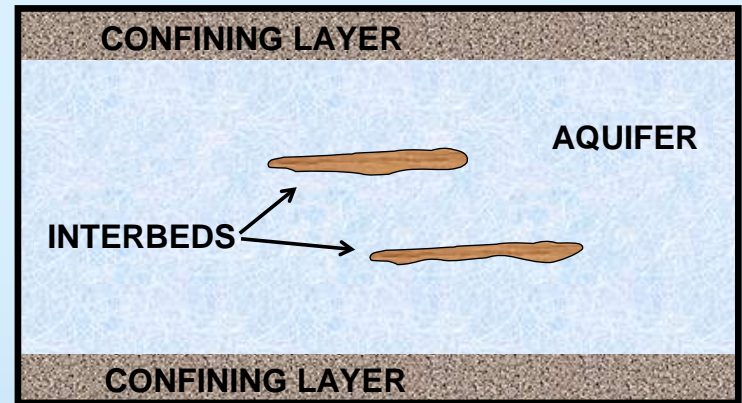
NODEDR	ELEVDR	CDCDR	ISTRMDR
-794	110.70	0.1000	114
-815	181.70	0.1000	114
-816	115.70	0.1000	114
-827	133.70	0.1000	114
-828	130.70	0.1000	114
-840	188.70	0.1000	114
-841	167.70	0.1000	114
-842	149.70	0.1000	114
-855	189.70	0.1000	114
-856	190.70	0.1000	114
-857	187.70	0.1000	114

Land Surface Subsidence



Aquifer Subsidence

- Optional simulation of elastic and inelastic compaction of interbed materials
- Storage change due to subsidence is added to the groundwater equation



$$q_s = S'_s \frac{\partial h}{\partial t} \quad ; \quad S'_s = \begin{cases} S_{se} b_o & \text{if } h > h_c \\ S_{si} b_o & \text{if } h \leq h_c \end{cases} \quad ; \quad \Delta b = \begin{cases} -\Delta h S_{se} b_o & \text{if } h > h_c \\ -\Delta h S_{si} b_o & \text{if } h \leq h_c \end{cases}$$

q_s = rate of inflow or outflow due to subsidence, (L/T)

S_{se} = elastic specific storage, (1/L)

S_{si} = **inelastic specific storage, (1/L)**

b_o = interbed thickness, (L)

h_c = **pre-consolidation head, (L)**

Δh = change in groundwater head, (L)

Δb = **change interbed thickness, (L)**

Subsidence Parameters

```

C
C List the groundwater nodes, and aquifer parameters for each layer (skip if option 1 is used)
C
C ID ; Groundwater node number
C PKH ; Hydraulic conductivity; [L/T]
C PS ; Specific storage; [1/L]
C PN ; Specific yield; [L/L]
C PV ; Aquitard vertical hydraulic conductivity; [L/T]
C PL ; Aquifer vertical hydraulic conductivity; [L/T]
C SCE ; Elastic storage coefficient (Use SCE*DC if DC=0); [1/L]
C SCI ; Inelastic storage coefficient (Use SCI*DC if DC=0); [1/L]
C DC ; Interbed thickness; [L]
C DCMIN; Minimum interbed thickness; [L]
C HC ; Pre-compaction hydraulic head (use 99999. to use initial heads); [L]
C
C *Note* The above land subsidence parameters are only for interbed layers (i.e. clay layers)

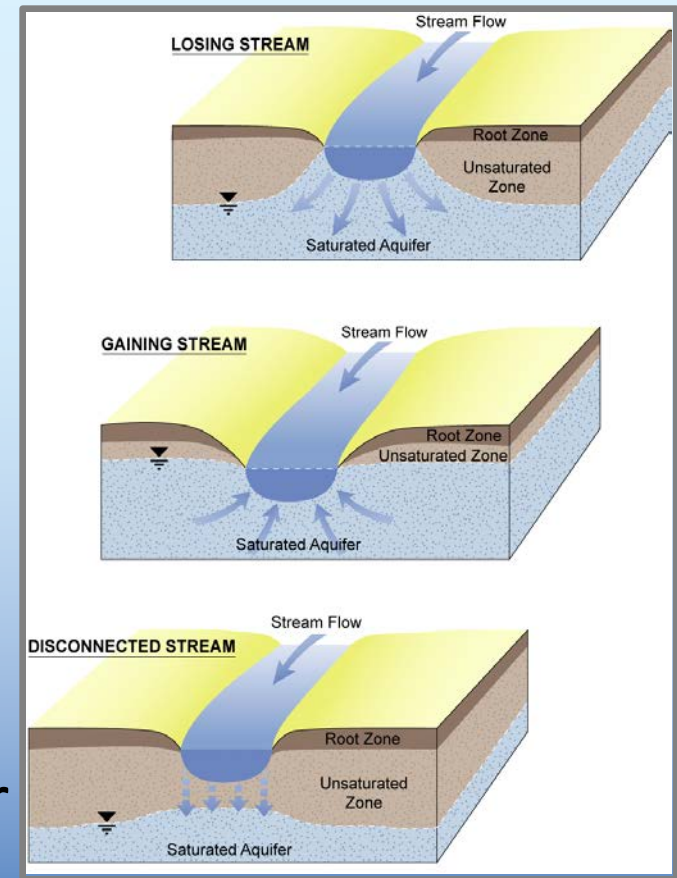
```

Layer 1										
Layer 2										
.										
.										
ID	Hydr. cond. PKH	Spec. Stor. PS	Spec. Yld. PN	Aquitard Vert. K PV	Aquifer Vert. K PL	Elastic Stg. Coef. SCE	Inelastic Stg. Coef. SCI	Interbed Thickness DC	Min. Intrbed Thickness DCMIN	Precompc Hyd. Head HC

1	1819.54	2.000E-05	0.1509	2.000E-01	1.821	4.500E-06	1.010E-06	13.0	2.0	605.7
	1978.15	1.930E-05	0.1220	3.000E-03	2.114	4.890E-06	1.010E-06	4.0	2.0	636.7
	194.44	1.710E-05	0.1680	1.740E+00	1.458	4.500E-06	1.010E-06	2.0	2.0	663.4
2	1869.77	2.000E-05	0.1417	2.000E-01	1.806	4.500E-06	1.010E-06	12.0	2.0	605.8
	2022.38	1.668E-05	0.1220	3.000E-03	2.103	4.760E-06	1.010E-06	4.0	2.0	635.3
	194.50	1.599E-05	0.1691	1.740E+00	1.496	4.500E-06	1.010E-06	2.0	2.0	661.9
3	1820.95	2.000E-05	0.1393	2.000E-01	1.796	4.500E-06	1.010E-06	12.0	2.0	622.8
	2109.67	1.588E-05	0.1220	3.000E-03	2.117	4.490E-06	1.010E-06	4.0	2.0	651.9
	191.29	1.658E-05	0.1680	1.730E+00	1.527	4.510E-06	1.010E-06	2.0	2.0	678.6
4	1845.00	2.000E-05	0.1539	2.000E-01	1.802	4.500E-06	1.010E-06	12.0	2.0	576.8
	2074.58	1.960E-05	0.1220	3.000E-03	2.099	4.760E-06	1.010E-06	5.0	2.0	610.0
	189.35	2.179E-05	0.1692	1.730E+00	1.477	4.500E-06	1.010E-06	2.0	2.0	636.7
5	2034.70	2.000E-05	0.1533	2.000E-01	1.771	4.500E-06	1.010E-06	12.0	2.0	453.0
	1863.64	2.370E-05	0.1220	3.001E-03	2.010	4.910E-06	1.010E-06	4.0	2.0	475.2
	195.13	2.080E-05	0.1698	1.750E+00	1.487	4.510E-06	1.010E-06	2.0	2.0	501.9
6	1342.19	2.000E-05	0.1368	2.000E-01	1.783	4.500E-06	1.010E-06	19.0	2.0	540.5
	1746.02	3.140E-05	0.1220	3.000E-03	2.040	4.870E-06	1.010E-06	3.0	2.0	572.4
	195.21	3.150E-05	0.1704	1.740E+00	1.509	4.510E-06	1.010E-06	2.0	2.0	599.1
7	1781.31	2.000E-05	0.1554	2.000E-01	1.785	4.500E-06	1.010E-06	12.0	2.0	540.1
	2082.88	2.549E-05	0.1220	3.000E-03	2.013	4.990E-06	1.010E-06	4.0	2.0	586.8
	193.58	2.429E-05	0.1700	1.730E+00	1.481	4.510E-06	1.010E-06	2.0	2.0	613.5
8	2218.52	2.000E-05	0.1524	2.000E-01	1.848	4.500E-06	1.010E-06	7.0	2.0	525.7
	2797.60	2.290E-05	0.1220	3.001E-03	2.093	4.920E-06	1.010E-06	4.0	2.0	554.0
	204.58	2.080E-05	0.1700	1.760E+00	1.499	4.500E-06	1.010E-06	2.0	2.0	580.7
9	2154.87	2.000E-05	0.1535	2.000E-01	1.678	4.500E-06	1.010E-06	14.0	2.0	430.4

Stream Flow and Stream-Aquifer Interaction

- Assumption of zero storage at a stream node in computing stream flows; i.e. total inflow equals total outflow
- Fully coupled stream and groundwater conservation equations
- Simultaneous solution of stream and groundwater equations results in the computation of stream-aquifer interaction



Initial Conditions

```
C*****
C                               Initial Aquifer Head Values
C
C   FACT; Conversion factor for initial heads
C   HP;   Initial head at corresponding groundwater node; [L]
C-----
C   Layer 1:
C
C   VALUE                DESCRIPTION
C-----
1
C-----
C   Initial Head at Layer 1
C   HP
C-----
5.7030000E+02
6.2990000E+02
7.9390000E+02
7.0810000E+02
3.8330000E+02
4.5620000E+02
7.1010000E+02
5.3840000E+02
4.2860000E+02
5.4040000E+02
3.7940000E+02
6.0530000E+02
5.9810000E+02
5.2580000E+02
4.0160000E+02
5.0770000E+02
4.2540000E+02
5.9350000E+02
1.2083000E+03
1.0729000E+03
6.6200000E+02
4.4320000E+02
2.9540000E+02
```


Initial Conditions

```
C*****
C
C           Interbed Thickness for Each Layer
C
C   The following lists the initial Interbed Thicknesses for each node (in
C   sequential order) to overwrite what is specified in the parameter file.
C
C   FACT;   Conversion factor for initial interbed thickness
C   DC ;    Initial interbed thickness; [L]
C-----
C   Layer 1:
C
C   VALUE           DESCRIPTION
C-----
C   0.0             / FACT
C-----
C   Initial interbed thickness at Layer 1
C   DC
C-----
* FACT = 0.0 so use values in Parameter Data File
```

```
C*****
C
C           Initial Preconsolidation Head Values for Land Subsidence
C
C   The following lists the preconsolidation head for each groundwater node
C   (in sequential order) to overwrite the values specified in parameter file.
C
C   FACT;   Conversion factor for preconsolidation head
C   HC ;    Initial preconsolidation head at corresponding groundwater node; [L]
C-----
C   Layer 1
C
C   VALUE           DESCRIPTION
C-----
C   0.0             / FACT
C-----
C   Initial preconsolidation head at Layer 1
C   HC
C-----
* FACT = 0.0 so use values in Parameter Data File
C-----
```

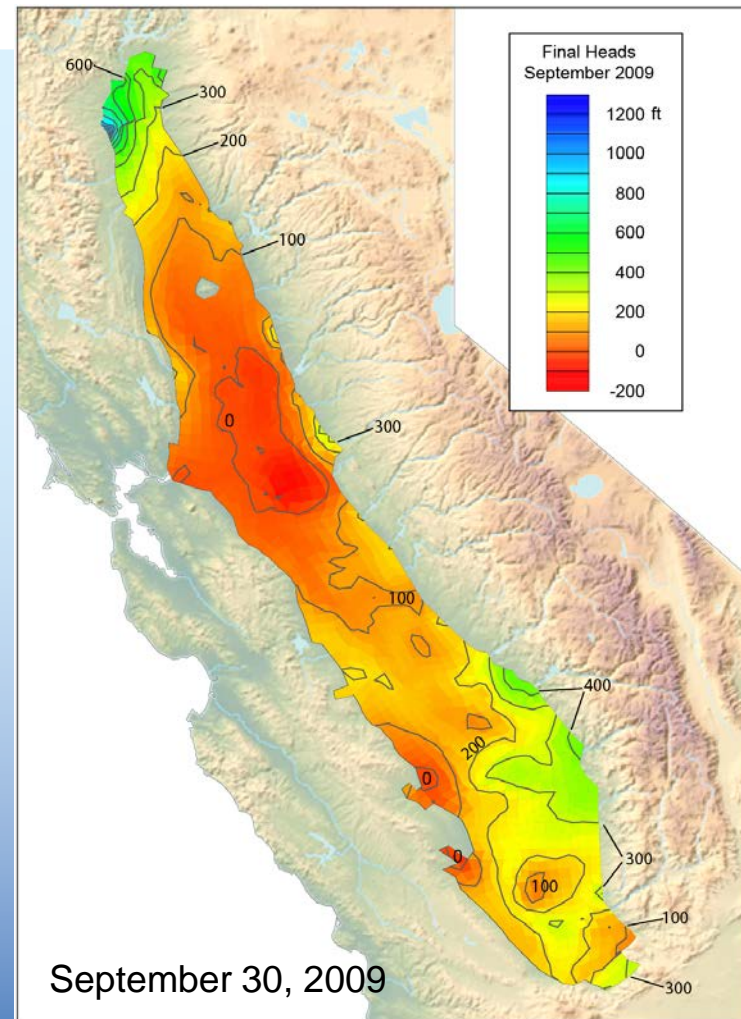
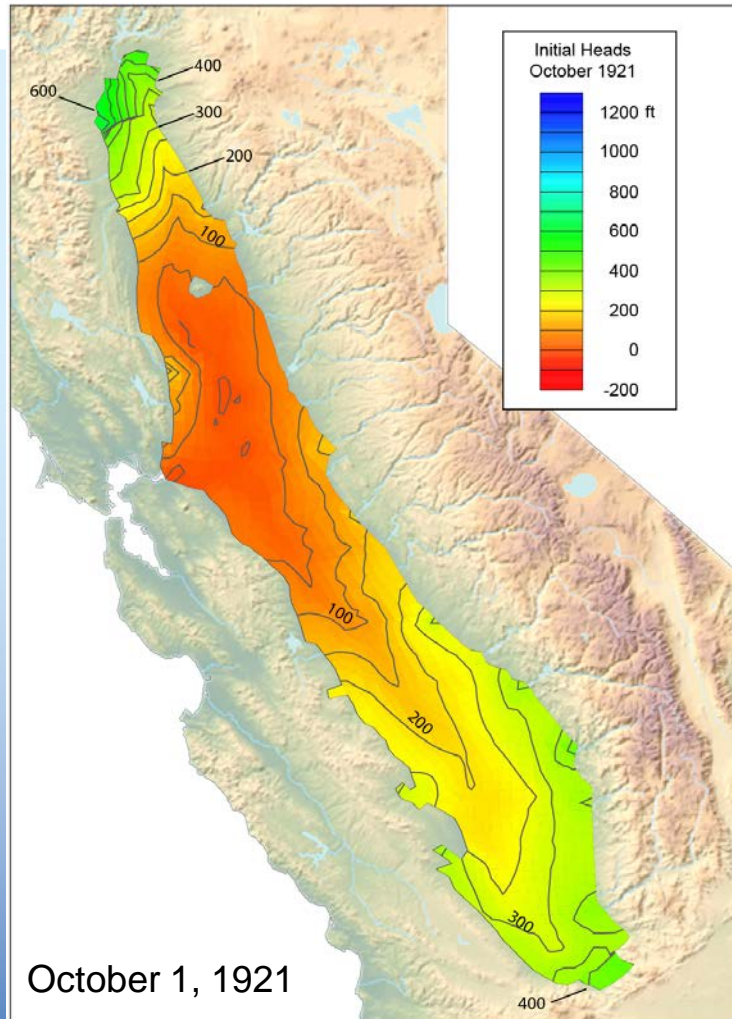


IWFM Groundwater Output

- Groundwater heads at each time step
 - Tabular file
 - Teclot file
- Hydrographs at specified locations
- Groundwater Budget Tables
- Z-Budget Tables
- Final condition (initial condition format)

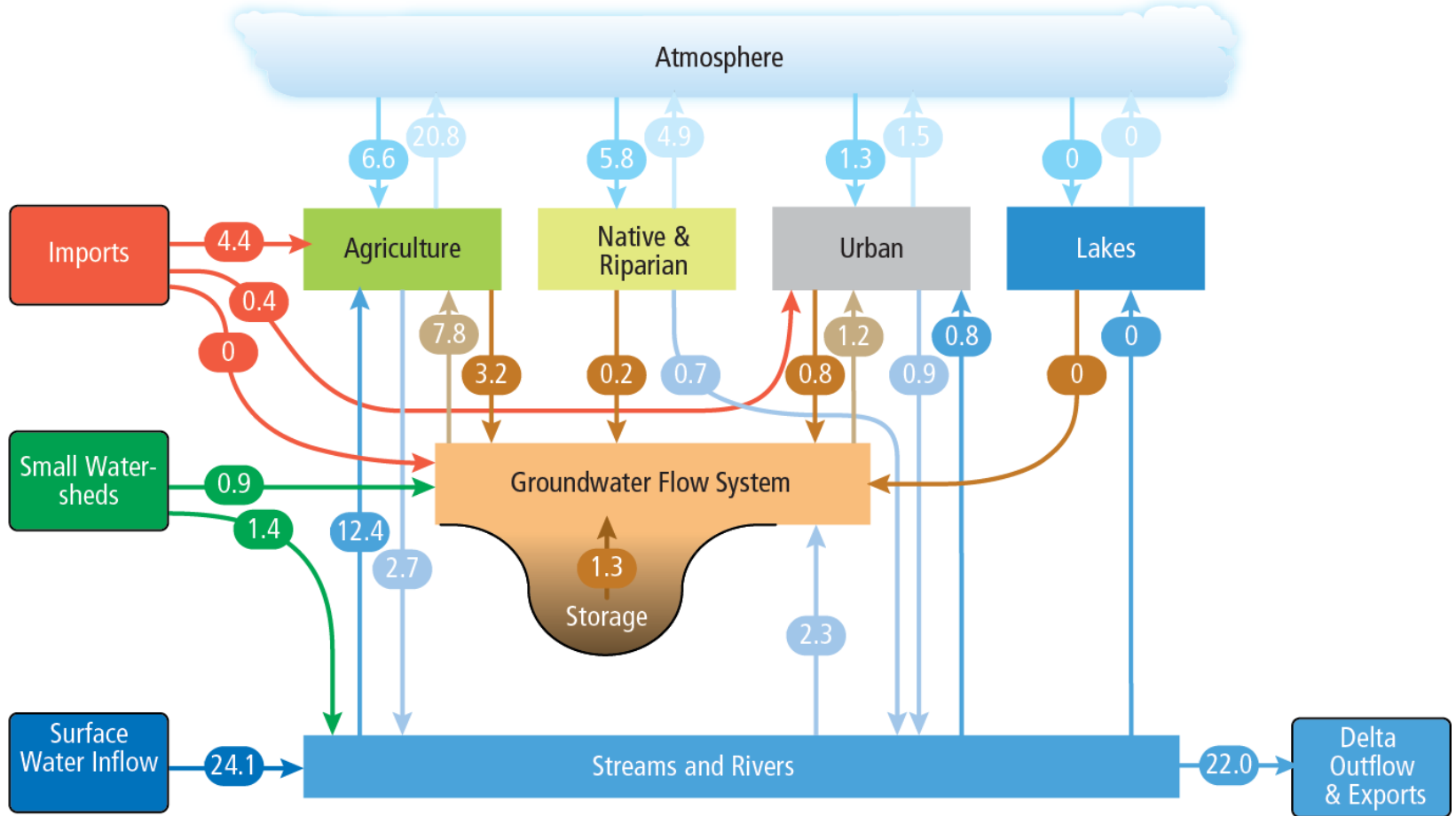
Water Table Altitude

Produced from IWFM's TecPlot[®] output files



Simulated Annual Water Budget

Average Flows for water years 2000-2009
[Million Acre-Feet/Year]



Groundwater Heads

***** * GROUNDWATER HEAD AT ALL NODES * * (UNIT=FEET) * *****												
TIME	NODE 1	2	3	4	5	6	7	8	9	10	11	
10/31/1921_24:00	566.5463	629.5031	788.6257	710.0800	391.2870	462.6835	706.7880	539.8874	431.8585	535.4416	385.7901	603.83
	539.7935	633.2230	763.7920	719.2746	428.0438	513.7184	672.6800	529.9162	462.5000	462.4243	437.3399	580.20
	536.1648	641.0350	760.2141	725.8688	431.7036	531.1812	675.8854	533.1477	461.3802	440.6458	448.3508	584.79
11/30/1921_24:00	562.9786	628.1120	783.6372	711.2241	398.2450	466.8200	703.8579	539.4566	432.9475	532.1847	390.7163	602.79
	537.2719	618.8206	761.1317	711.8996	427.2212	491.9288	676.4216	522.1506	449.2527	488.1658	422.4567	584.68
	536.0289	619.9177	759.9170	713.2655	430.6512	501.7169	675.0725	522.3820	452.4618	470.0252	430.0798	583.99
12/31/1921_24:00	559.7253	626.4941	778.8026	711.9323	405.0872	470.0265	701.0771	538.4067	433.4887	529.7875	395.2382	602.08
	535.1548	614.1116	756.9566	709.7005	431.0799	485.3329	675.7231	520.2724	446.6704	499.9515	419.4728	584.82
	534.1095	613.8619	756.0491	709.9305	433.5108	489.7443	674.3601	519.6385	448.6073	488.2381	423.5106	583.88
01/31/1922_24:00	556.6106	624.8496	774.1004	712.3350	411.3714	472.7992	698.4002	537.1228	433.7074	527.8736	399.6783	601.68
	533.2754	611.9585	752.6939	708.7528	435.5723	483.9579	674.2124	519.5671	446.1423	505.8817	420.3626	584.38
	532.2790	611.3997	751.8309	708.6961	437.5870	485.8677	673.0395	518.7696	447.4122	498.7186	422.6122	583.50
02/28/1922_24:00	554.1231	623.2328	769.5294	712.4848	418.4383	475.3440	695.8086	535.8483	434.1378	526.2594	403.8224	601.16
	532.2208	610.5301	748.5922	708.0016	440.8475	484.6176	672.4648	519.2462	446.3920	508.8789	422.6197	583.77
	531.2147	609.9057	747.7418	707.8610	442.5106	485.4482	671.4091	518.4353	447.3785	504.5079	424.0777	582.94
03/31/1922_24:00	551.8889	621.6561	765.0880	712.4125	424.7935	477.7347	693.2916	534.5697	434.5078	524.8182	407.6567	600.43
	531.0630	609.3017	744.6478	707.1907	445.7142	486.0432	670.6284	518.7887	446.7806	510.2482	425.2959	583.03
	530.1286	608.6762	743.8112	707.0170	447.2520	486.4234	669.6432	518.0329	447.6918	507.5370	426.4157	582.23
04/30/1922_24:00	549.9195	620.1071	760.7607	712.1237	429.2258	480.0141	690.8360	533.2872	434.9209	523.5224	411.1921	599.47
	529.8682	608.0550	740.7817	706.1872	449.2661	487.6893	668.7105	518.1745	447.1793	510.6551	427.9807	582.12
	528.9984	607.4495	739.9663	706.0036	450.9066	487.8920	667.7823	517.4777	448.0799	508.9357	428.9659	581.37
05/31/1922_24:00	547.9643	618.6017	756.5670	711.6744	431.9572	482.2220	688.4498	532.0672	435.2667	522.3907	414.4798	598.34
	528.8885	606.8665	737.1097	705.2023	451.6508	489.4522	666.8618	517.6573	447.6148	510.6111	430.6189	581.13
	528.0466	606.2732	736.3057	704.9891	453.4392	489.5625	665.9549	516.9855	448.5088	509.4415	431.5322	580.42
06/30/1922_24:00	545.6662	617.1232	752.4909	711.0657	432.9822	484.3418	686.1224	530.9061	435.3365	521.4005	417.4911	596.99
	527.4034	605.6060	733.5128	704.0770	452.6426	491.1582	665.0029	517.0142	447.8094	510.2711	433.0724	579.99
	526.6440	605.0309	732.7287	703.8526	454.6567	491.2350	664.1241	516.3812	448.7539	509.4264	433.9639	579.32
07/31/1922_24:00	543.3408	615.6669	748.5270	710.3137	433.4271	486.3390	683.8492	529.8186	435.4430	520.5264	420.3405	595.56
	525.6253	604.3125	730.0035	702.8536	452.9566	492.7704	663.1553	516.3039	447.9290	509.7837	435.3838	578.75
	524.9304	603.7502	729.2379	702.6179	455.0989	492.8354	662.3000	515.7013	448.8987	509.1225	436.2578	578.12
08/31/1922_24:00	541.1210	614.2313	744.6704	709.4332	433.6702	488.2499	681.6249	528.8516	435.6471	519.7732	423.0844	594.12
	524.1634	603.0232	726.5821	701.5489	453.1086	494.3094	661.3279	515.7687	448.1191	509.2521	437.5937	577.48
	523.4696	602.4694	725.8339	701.3021	455.2789	494.3633	660.4922	515.1657	449.0767	508.6816	438.4433	576.87
09/30/1922_24:00	538.9506	612.8141	740.9163	708.4376	433.7330	490.0455	679.4462	527.9494	435.7721	518.9587	425.7423	592.70
	522.1797	601.7238	723.2439	700.1740	452.9294	495.7448	659.5231	515.0478	448.1903	508.6465	439.7224	576.19
	521.5601	601.1779	722.5124	699.9170	455.1433	495.7952	658.7049	514.4796	449.1669	508.1433	440.5427	575.60

Final Condition

Initial condition file for future run

```
C*****
C **** SIMULATION RESULTS AT TIME 1056.00 1MON
C*****
C
C ***** GROUNDWATER HEAD VALUES
C*****
C LAYER 1
C*****
1.000000
491.365959131455      451.363945033210      471.303817944818      467.050134419368      416.708010544385      431.315219799938      456.5040361
434.955684511344      519.562114239272      1122.29761425654      784.367647391422      395.998244775361      398.408290688344      398.9948407
461.715969778429      371.535561698151      373.467483412123      428.679674028319      1410.04782813506      580.167262086595      448.2369179
3475.89137321302      1688.63903658737      742.324600007109      540.927424408226      440.595005409107      383.007743341686      305.6049019
645.032173998446      510.089555394980      433.651205040752      361.969907250033      282.420435040637      316.360836318181      341.5024107
1355.64735969628      636.958530923166      501.541697733061      416.152497558914      323.440659621583      262.667499525198      1572.529808
420.764362735285      1057.09481503464      1206.69102598266      782.939312159887      542.772338149845      401.488661414374      305.7566767
491.524072880294      262.316317052342      257.115944620256      786.386717039034      710.968766735895      613.795880723210      430.0337430
661.014267626904      581.002518198251      497.685868777338      375.501166231293      240.422613650458      173.559276423360      192.3929265
435.291501281061      351.481253843441      228.007159638837      169.163909381197      186.150537031163      195.452299093036      335.8553336
457.777046110878      391.915847683978      316.255673422149      220.309984817844      155.624451278433      164.762899248263      181.4779103
297.256978556029      202.495243001374      121.364413707846      132.902752753766      164.939056397131      96.7159510263238      122.6654264
146.491696909384      425.778706118718      392.930375446187      346.154667331108      321.708466525513      235.480183832405      138.1645742
101.317384879430      117.374492633656      390.289599290055      356.190760498309      329.144126306864      205.933092219586      196.7161547
105.524487887434      119.784332117012      211.775743136390      99.1052505151330      97.6218485879690      111.721384350372      121.9246504
111.863477656228      121.544434250270      137.218823990925      103.522885631192      85.4989292796596      90.4793201514790      107.7961628
111.708748525812      122.300737430726      101.539726666277      92.1684073173525      343.541259273063      284.423080608098      208.1209470
79.4547271273011      81.7511963975400      92.76997223202306      73.2543059161836      77.1713692748748      95.5661786790349      84.35402866
212.322326844353      169.919665908279      140.911565071835      117.274749079808      92.6457077641251      71.1810869477538      72.34169524
80.1913467300388      83.31666010141784      49.3772290001403      49.3772290001403      196.628744190813      171.527324609357      157.8168268
82.3015256737128      65.3367283383457      64.1982961571552      60.0286179757938      55.6743117284675      70.0107391354296      67.88117060
138.46927364948      115.330597549066      95.8663221810843      74.4478590097849      167.328690613240      131.876027663369      106.8740444
53.1030713553204      56.5080156150040      57.9694294477298      50.4471763575842      61.2206479735995      156.659610406203      122.3810146
56.4326309864575      47.7395597355890      35.2000526122886      33.9690242470078      129.270027561179      119.136939640003      85.37619187
49.6755287928313      45.0640962747265      44.3895784347497      54.8330697894150      44.3382995915859      41.3382995915859      34.23778735
90.3890414481167      61.8250962846969      24.1654686237810      39.2786140374030      44.0700919838254      41.2091860789605      173.1584885
30.2940866677907      29.2527202409611      42.0598998769922      185.964934025554      153.645387520759      95.3533083352546      50.96540170
24.8374100970982      196.3756487074210      173.958886407722      102.657916529034      14.6672498615117      14.6672498615117      21.64041767
14.0858448497480      15.8134397932372      38.6653927109746      33.3779058304739      31.2584896854721      229.032631193339      188.7005489
20.4687953351949      12.8140164019800      7.00972660119936      11.4442683968501      22.5494502609079      19.9859151744020      16.26910033
9.95142690411809      0.2593916069438900      15.9118312731268      6.71846823824966      4.19567508703910      8.46277616168383      17.54853641
150.264634937990      82.2216976660683      29.2435264432997      -1.40092760591817      13.7127826354252      3.70763060151766      3.750699257
9.67848397460249      130.088028921932      110.867012374860      66.9770491075709      26.6606810725313      -0.716221032698507      12.43172444
-0.776496108967235      -6.56299500155179      8.24196412169380      6.64934631591855      222.341873425104      65.37090905      65.37090905
-19.7292147831658      -29.1124823863866      -25.5873008928026      -19.1967331791206      57.0053706978379      181.312668704138      77.61419802
5.74559252299520      -44.1319039585183      -54.9935480303229      -58.1397732164932      -24.5301442422346      65.5390569687723      222.2317170
3.45597118718997      5.61671312962470      5.57634943151190      -57.4413450686088      -72.2998903237882      -67.1940803502954      -29.21985834
-70.16873743060993      0.886220502455769      -2.8732636711514      -38.2699965490843      -71.7595099973813      -45.1932688011505      -45.08697528
64.9803153885133      -61.76418202171593      -62.84256863733277      -35.82932663733277      -0.147455075248908      -0.147455075248908      -64.33384526
```

Groundwater Hydrographs

```

C*****
C      Groundwater Hydrograph Print Control Specifications
C
C      The following lists the node and layer numbers for which groundwater
C      hydrograph will be printed
C
C      NOUTH; Total number of hydrographs to be printed (set NOUTH = 0 if no hydrograph data is to be printed)
C      FACT ; Conversion factor for nodal coordinates
C              If FACT = 0.0 the input data is by nodes
C              If FACT > 0.0 the input data is by X-Y coordinates
  
```

```

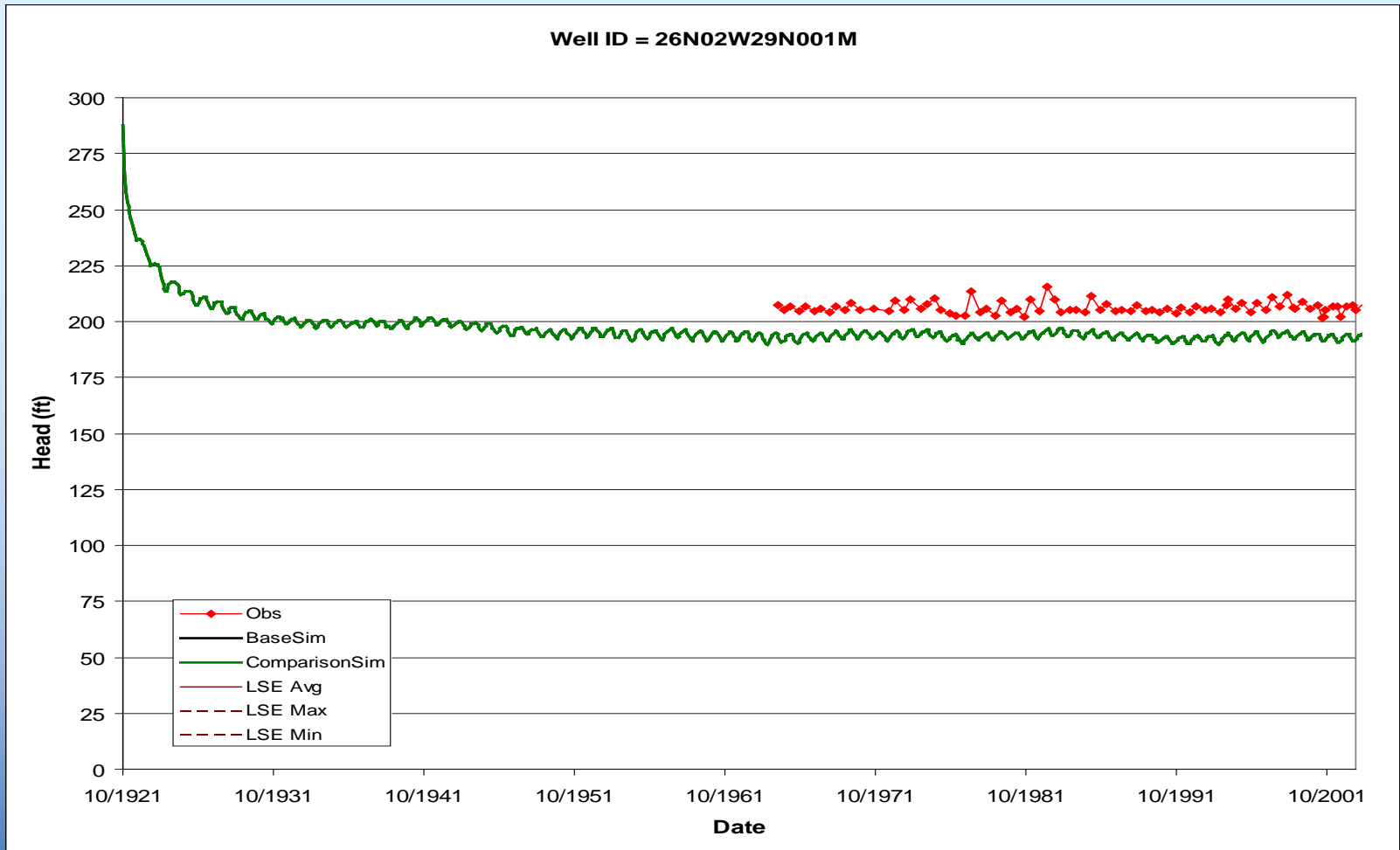
C-----
C      VALUE              DESCRIPTION
C-----
C      1387                / NOUTH
C      3.2808              / FACT
C-----
  
```

```

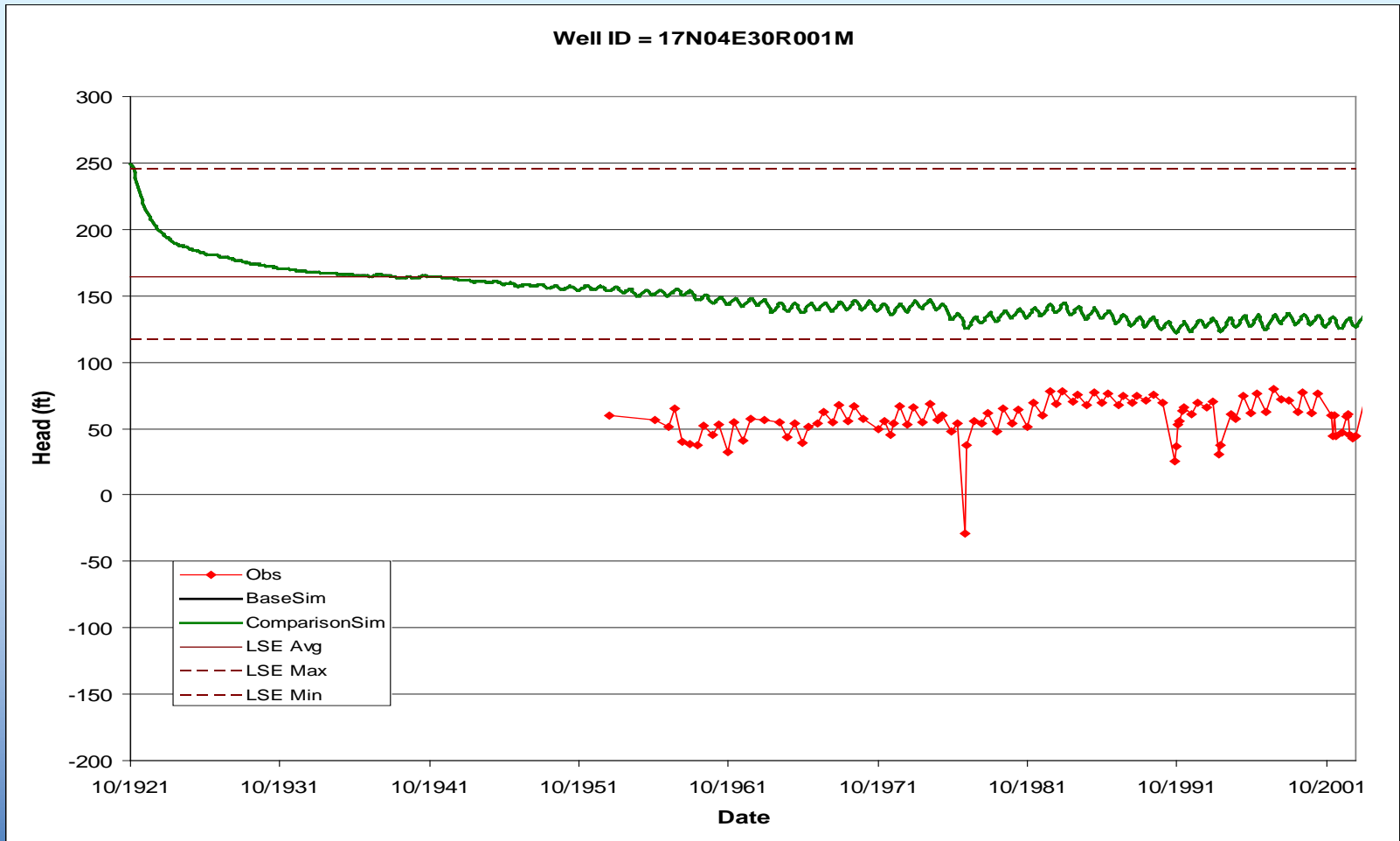
C
C      The following lists the layer number and groundwater node number for
C      each groundwater hydrograph to be printed (skip if no hydrographs are
C      to be printed, i.e. NOUTH = 0)
C
C      IOUTHL; Layer number (IOUTHL = 0 to print average head for all layers)
C      X      ; The x-coordinate of the well location (specify ONLY if FACT > 0.0); [L]
C      Y      ; The y-coordinate of the well location (specify ONLY if FACT > 0.0); [L]
C      IOUTH ; Groundwater node number (specify ONLY if FACT = 0.0)
  
```

IOUTHL	X	Y	IOUTH	
1	616887	4198677	01N03E17E001M	1
1	651178	4198961	01N06E14Q003M	2
1	646419	4200584	01N06E17A001M	3
1	657401	4200943	01N07E09Q003M	4
1	669131	4199945	01N08E15J001M	5
3	681153	4201456	01N09E13D001M	6
1	675756	4199795	01N09E17R002M	7
1	620500	4192071	01S03E03M001M	8
1	627598	4184842	01S04E32H001M	9
1	642092	4184458	01S05E35Q002M	10

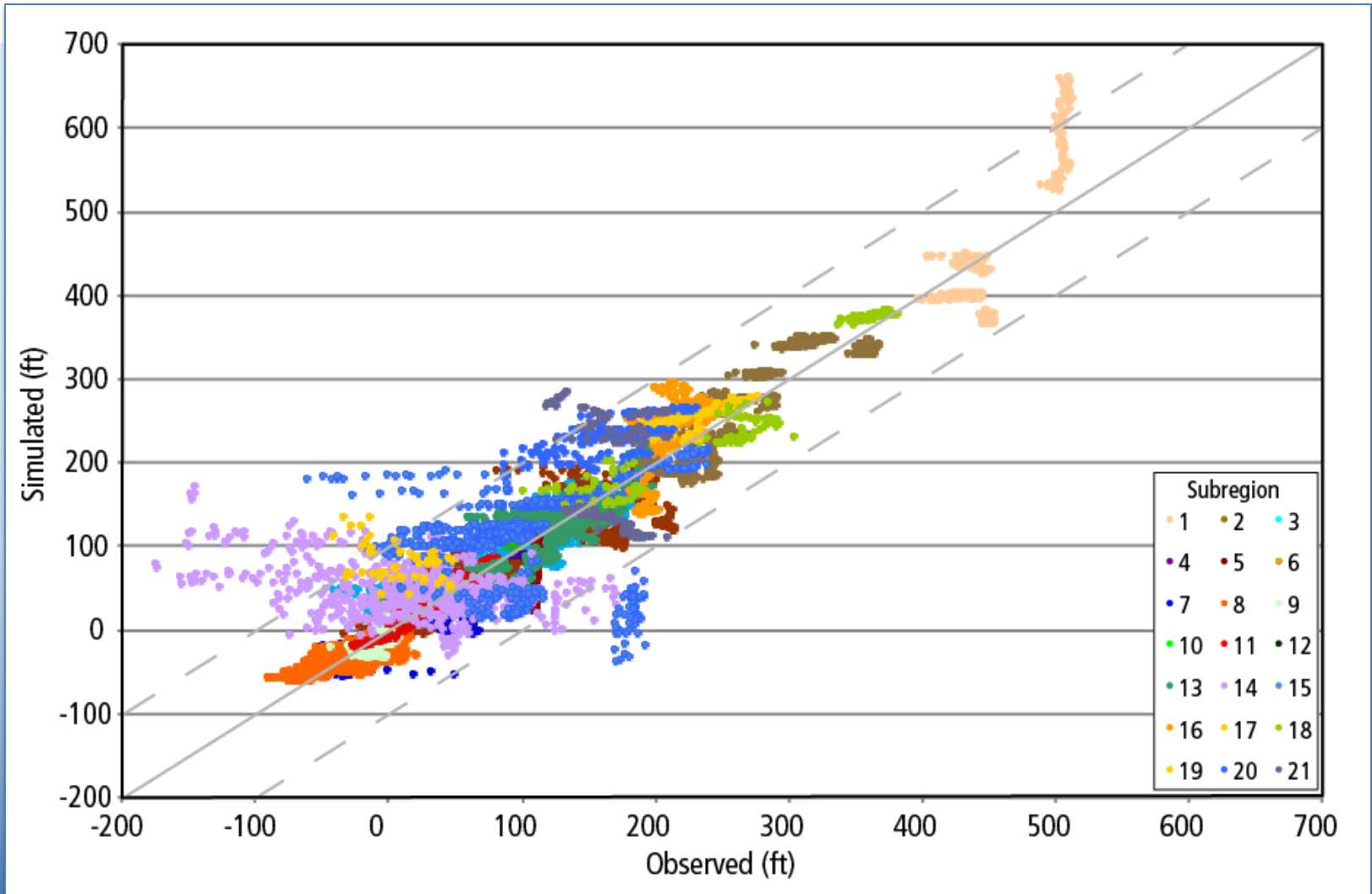
Groundwater Hydrographs



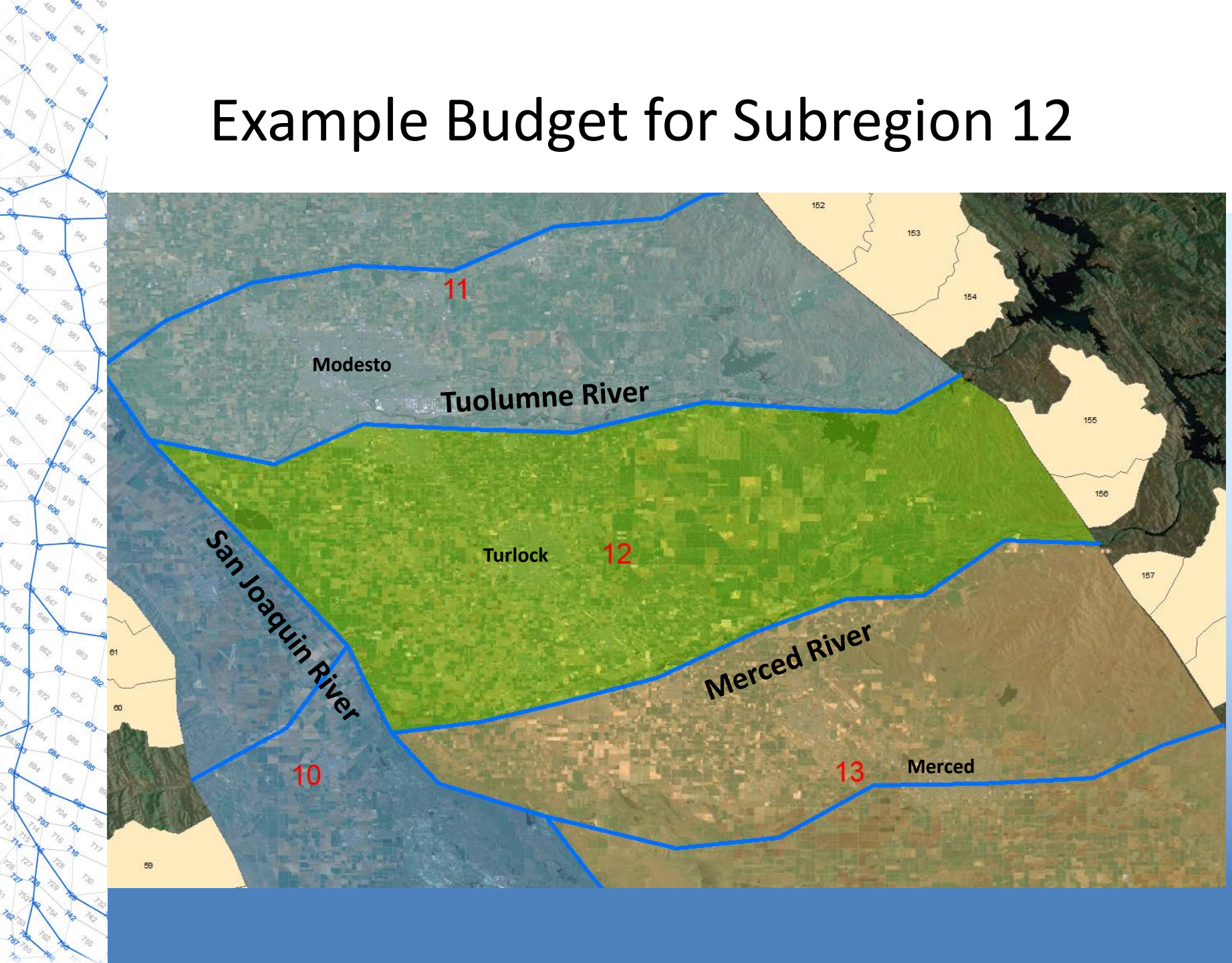
Groundwater Hydrographs



Groundwater Heads



Example Budget for Subregion 12



Groundwater Budget

Subregion 12

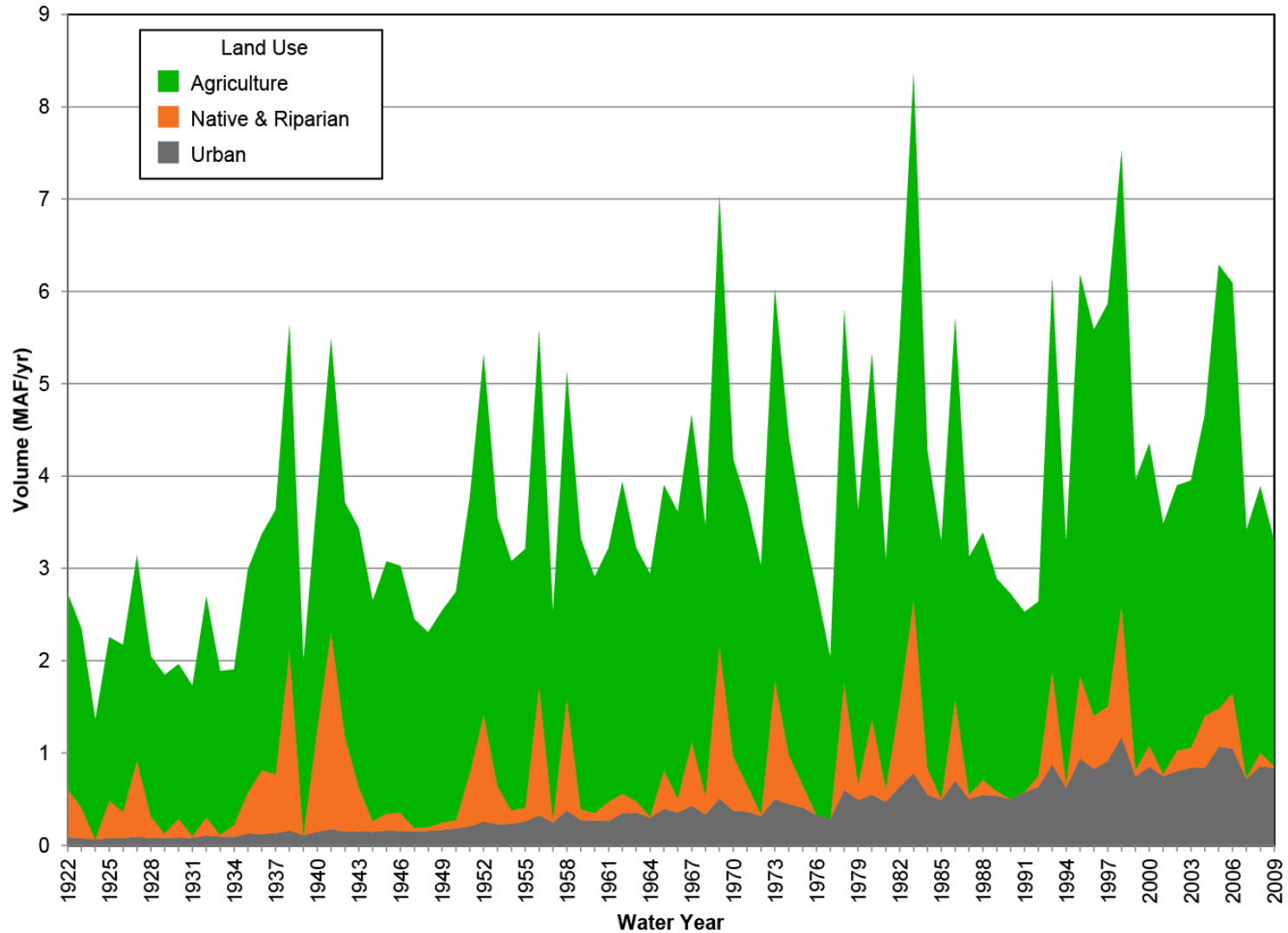
Column	Flow	08/31/2004	Process
Deep Percolation	IN	2,880	RZ
Beginning Storage (+)		42,057,306	
Ending Storage (-)		42,064,339	
Net Deep Percolation (+)	IN	8,203	UZ
Gain from Stream (+)	+/-	-11,243	SW
Recharge (+)	IN	21,179	LS
Gain from Lake (+)	+/-	0	SW
Boundary Inflow (+)	IN	0	SWS
Subsidence (+)		-62	
Subsurface Irrigation (+)	IN	0	LS
Tile Drain Outflow (-)	OUT	0	SW
Pumping (-)	OUT	7,200	LS
Net Subsurface Inflow (+)	+/-	-3,844	GW
Discrepancy (=)		0.00	
Cumulative Subsidence		977	

Z-Budget

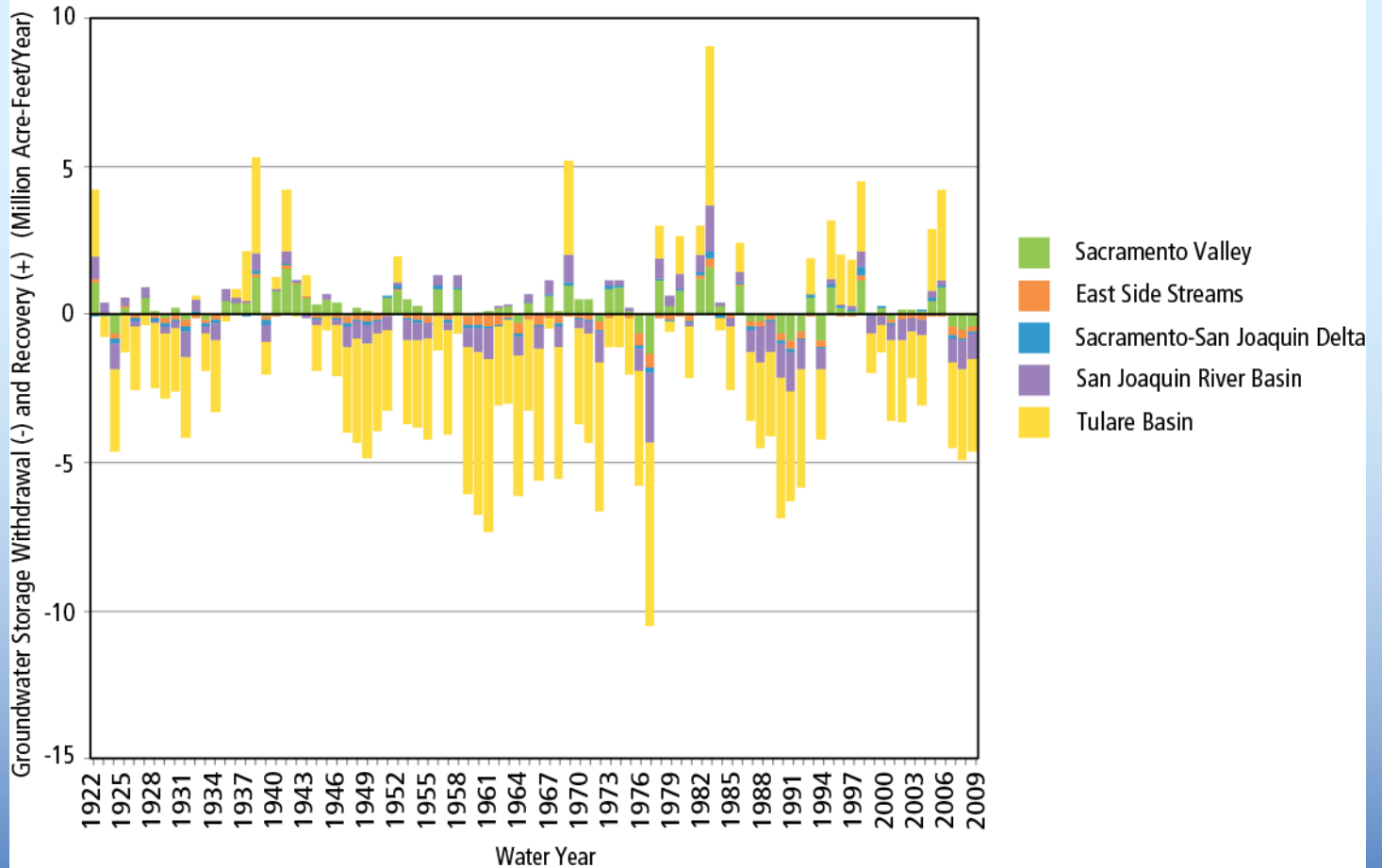
Subregion 12, 8/31/2008

Column	Flow	IN	OUT	Process
GW Storage		8,766	15,838	
Streams	+/-	6,253	17,491	SW
Tile Drains	OUT	0	0	SW
Subsidence		18	80	
Net Deep Percolation	IN	8,203	0	LS
Small Watershed Baseflow	IN	0	0	SWS
Small Watershed Percolation	IN	0	0	SWS
Diversion Recoverable Loss	IN	21,179	0	SW
Bypass Recoverable Loss	IN	0	0	SW
Lakes	+/-	0	0	SW
Pumping by Element	OUT	0	0	LS
Pumping by Well	OUT	0	7,200	LS
Zones 12 and 10	+/-	397	2,248	
Zones 12 and 11	+/-	2,952	2,619	
Zones 12 and 13	+/-	713	3,005	
Overall Zone Error		0.00		

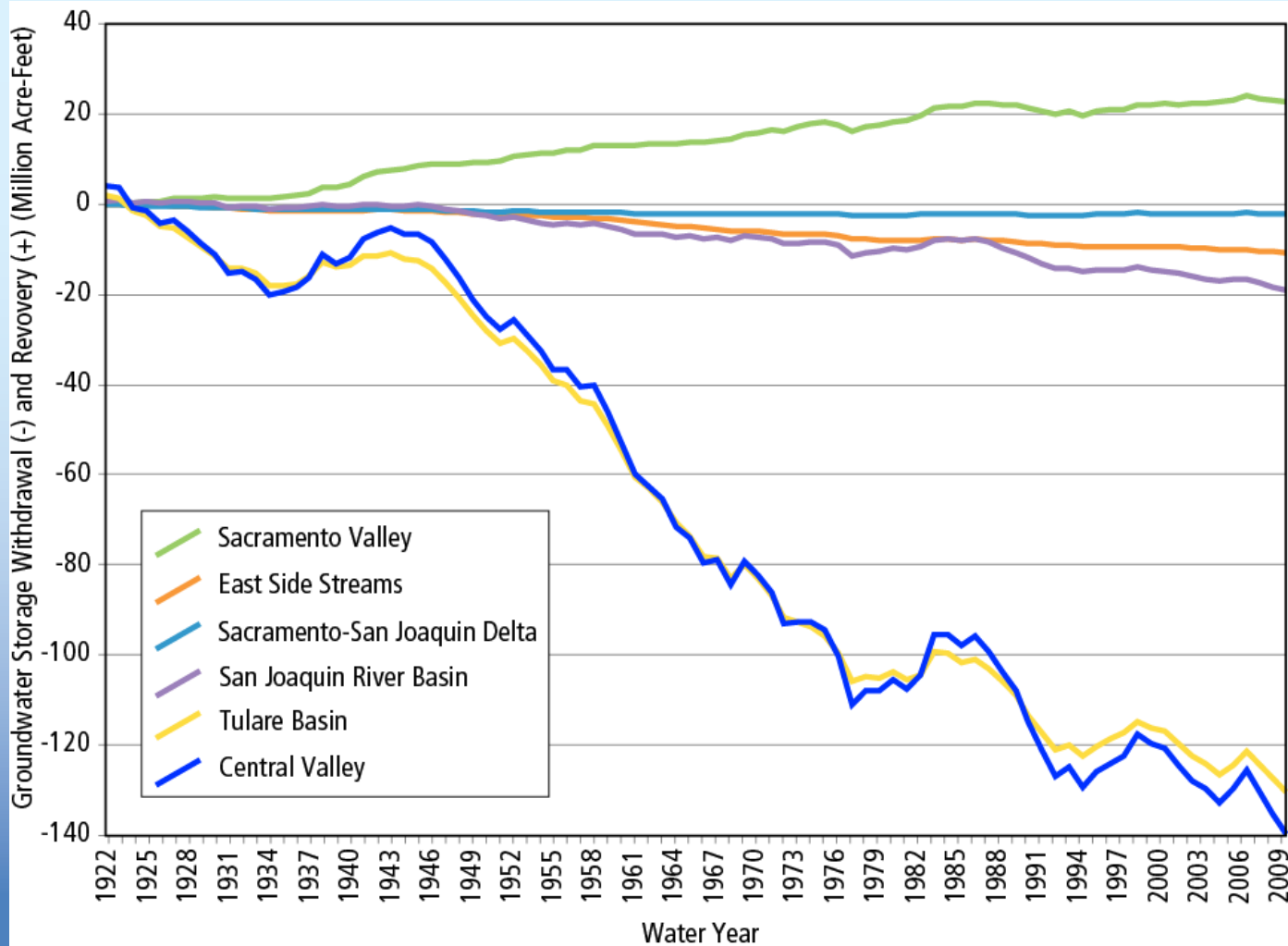
Deep Percolation



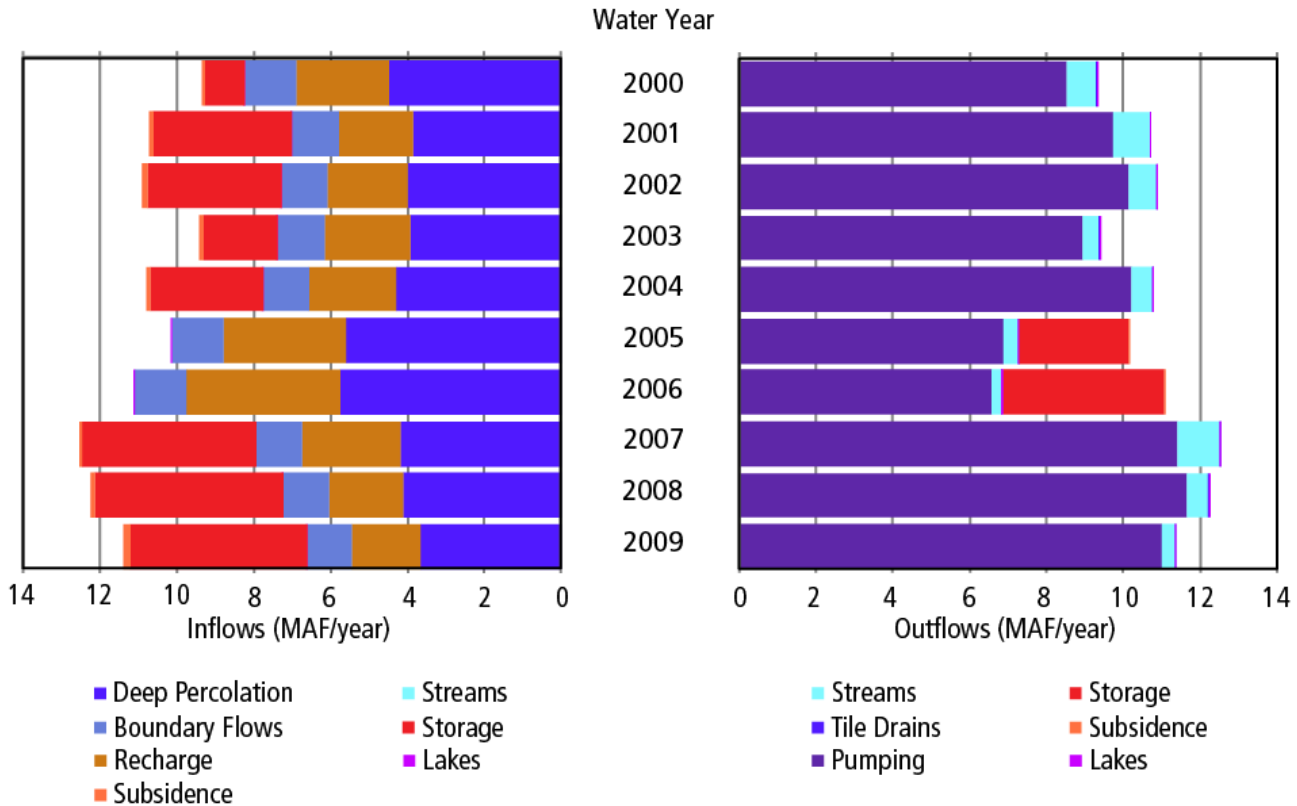
Groundwater Depletion



Groundwater Depletion



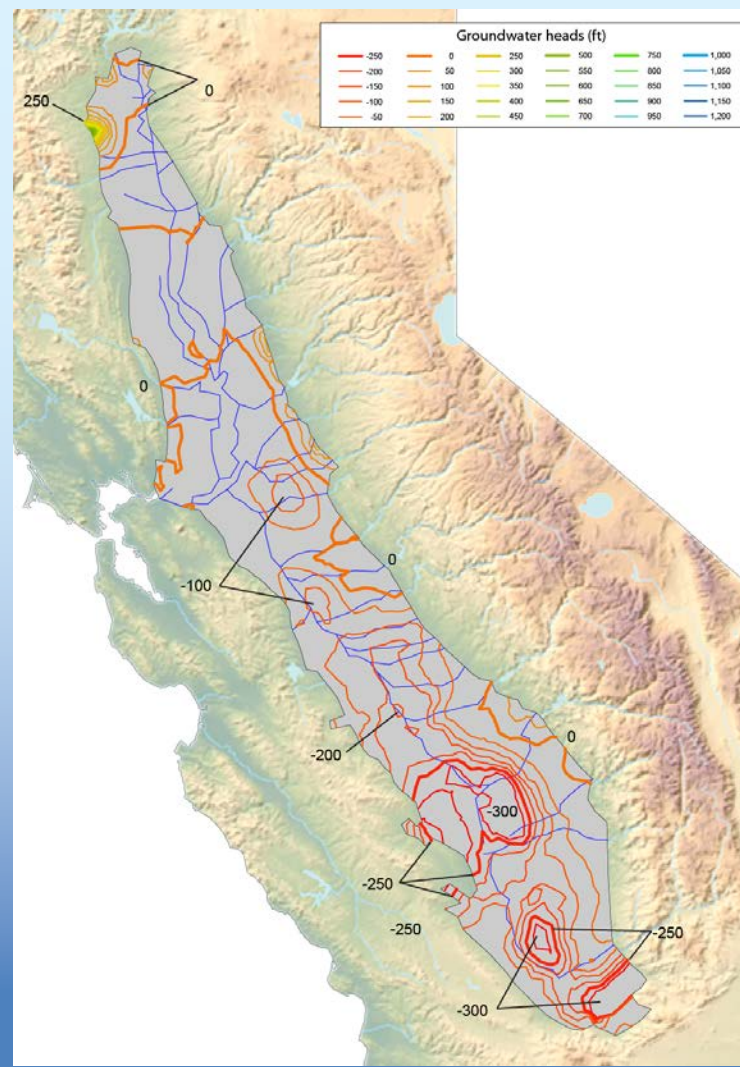
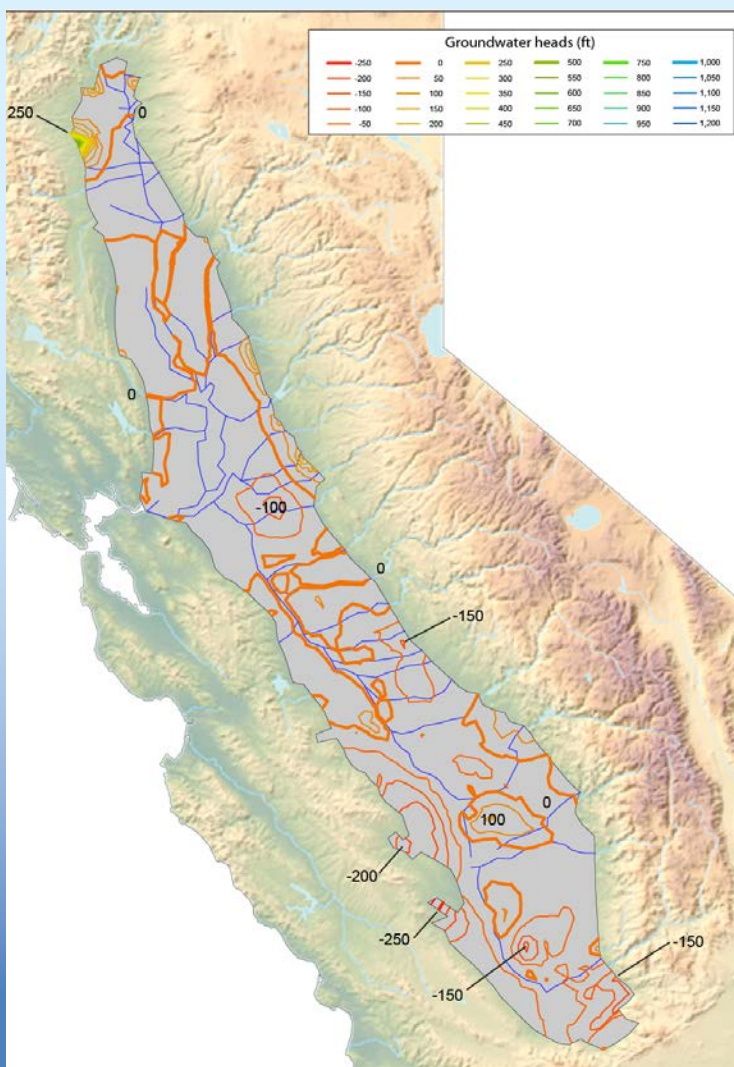
Water Balance



Head Difference, 1922-1965

Layer 1

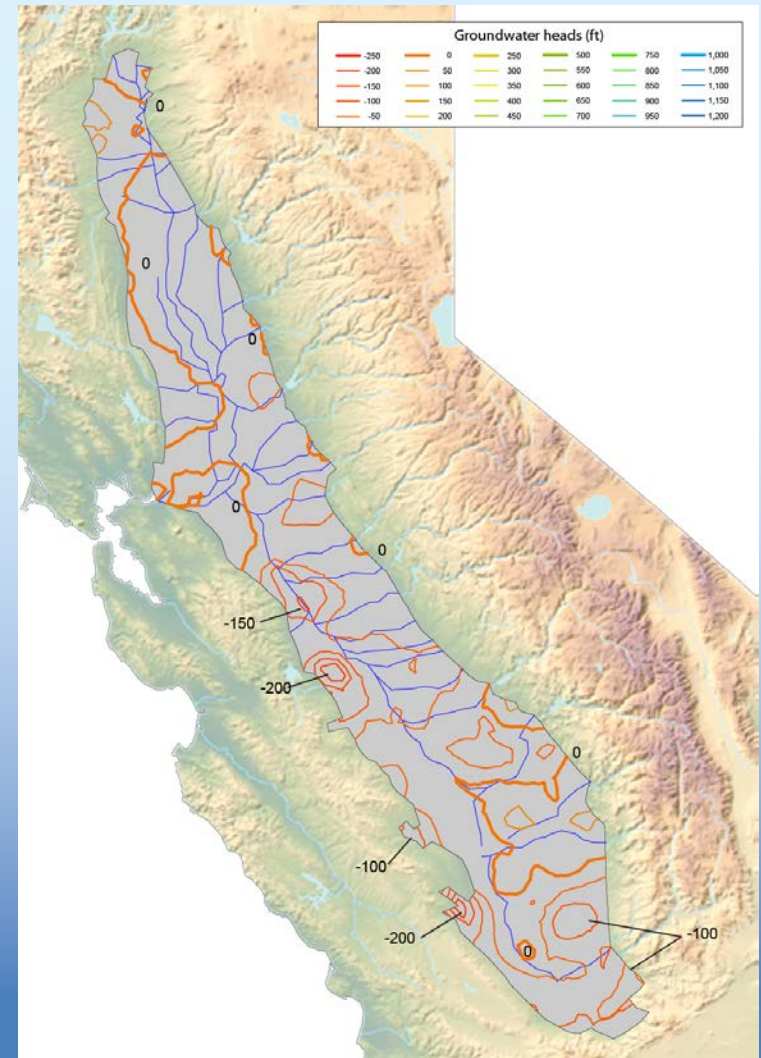
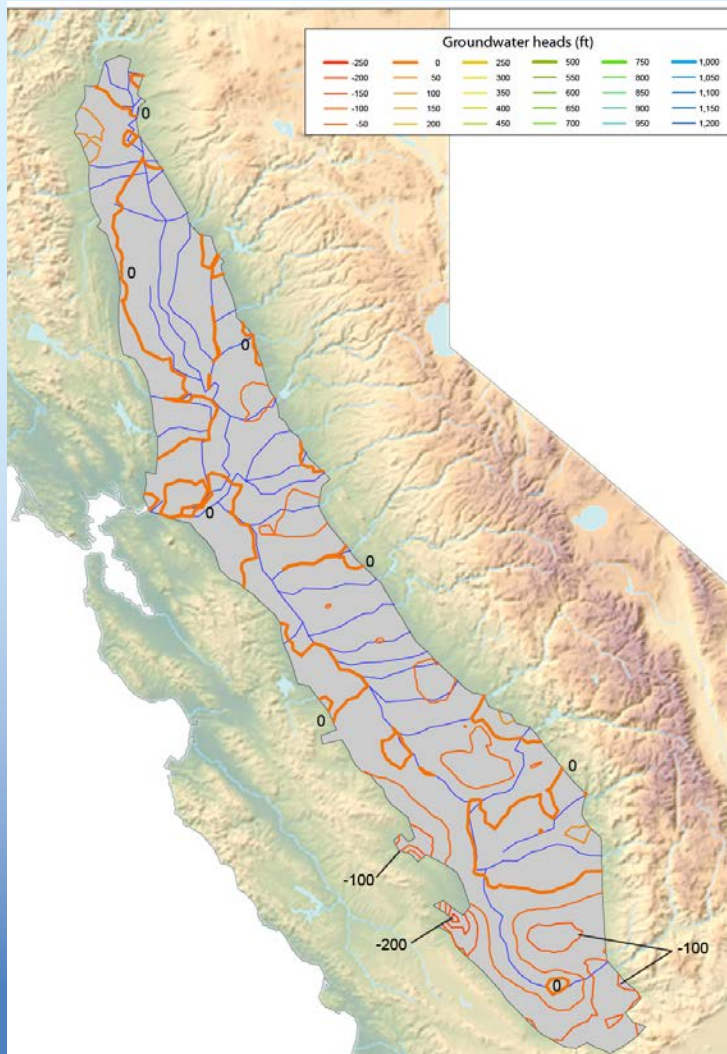
Layer 2



Head Difference, 1965-2009

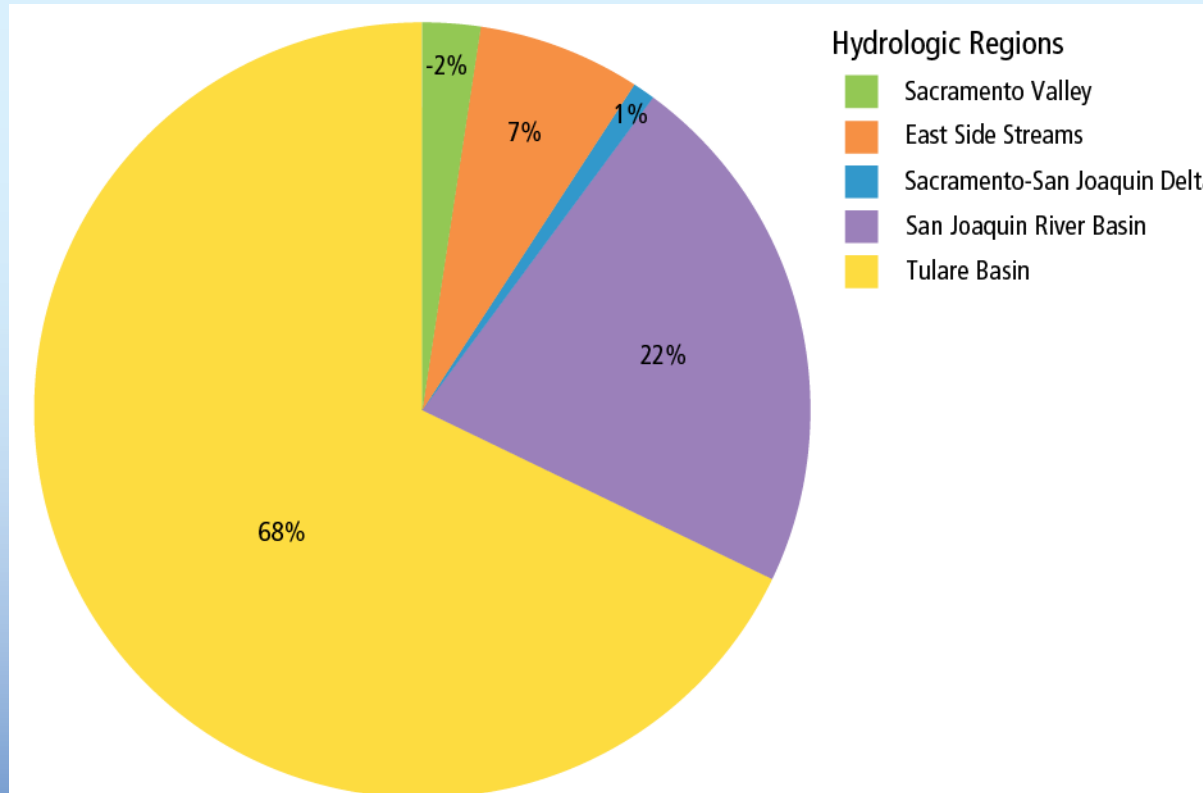
Layer 1

Layer 2



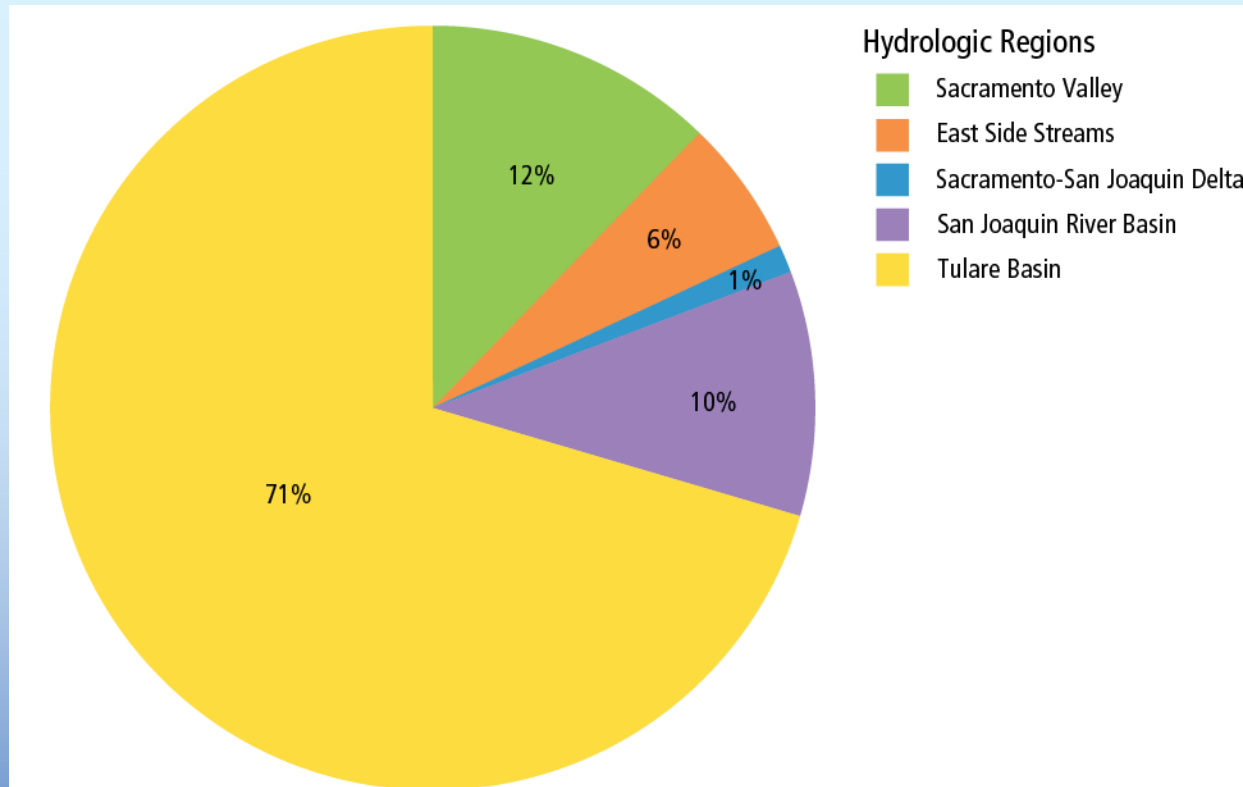
Groundwater Depletion

1922-2009



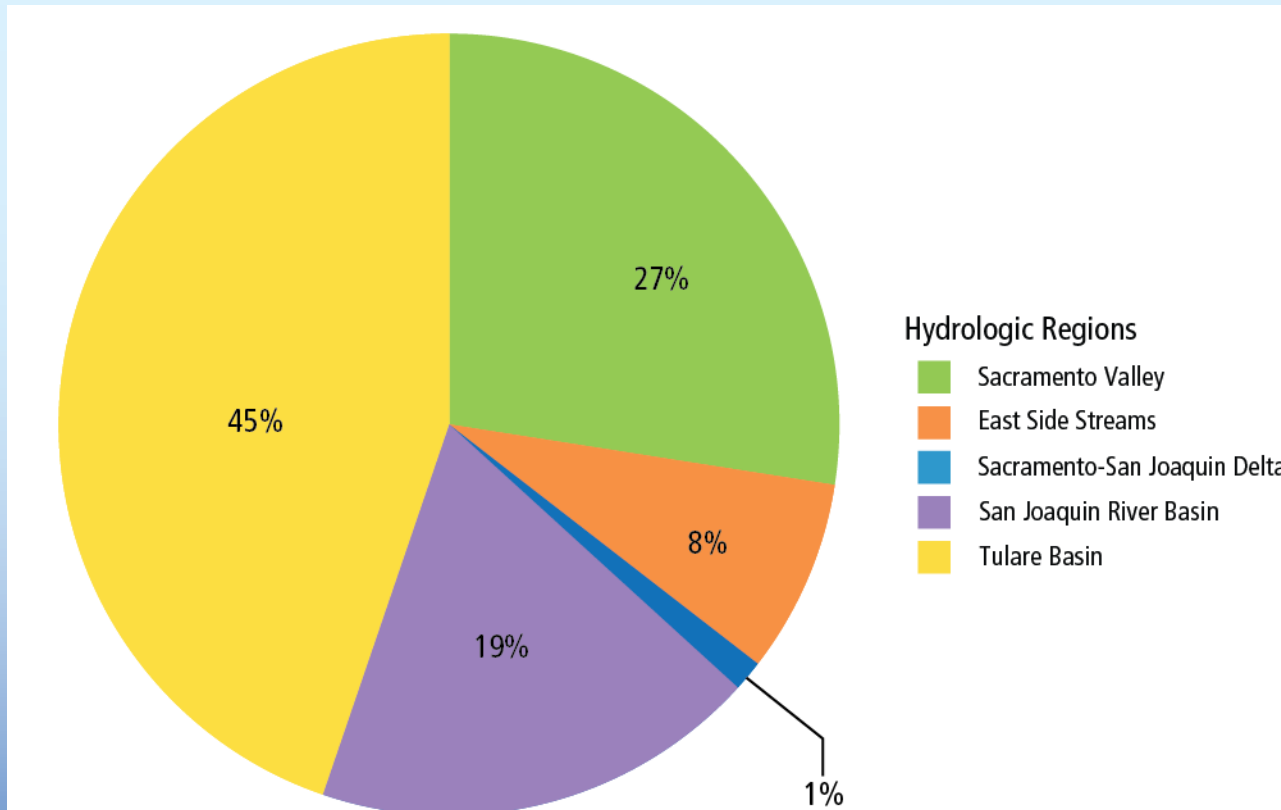
Groundwater Depletion

2000-2009

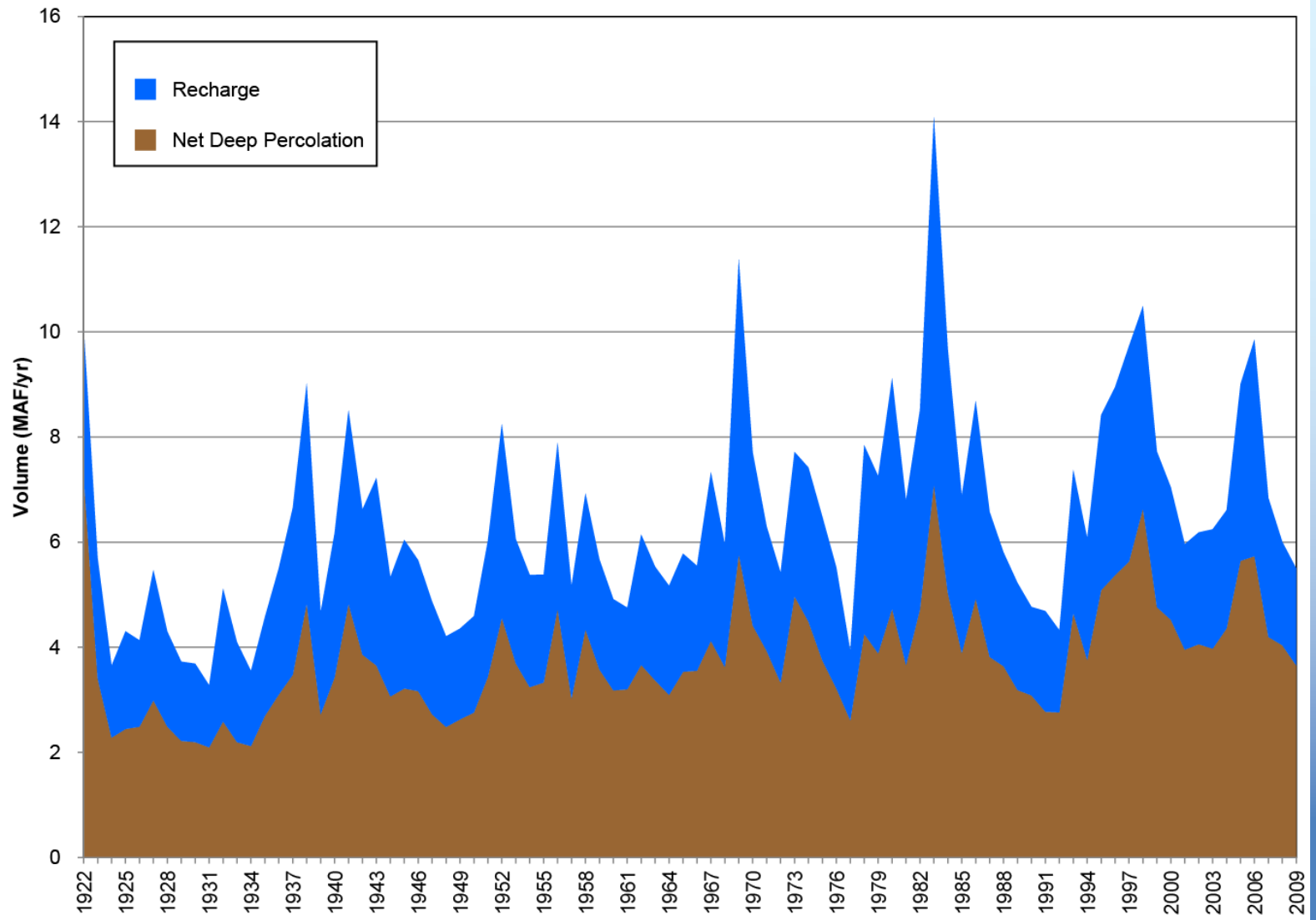


Groundwater Pumping

2000-2009

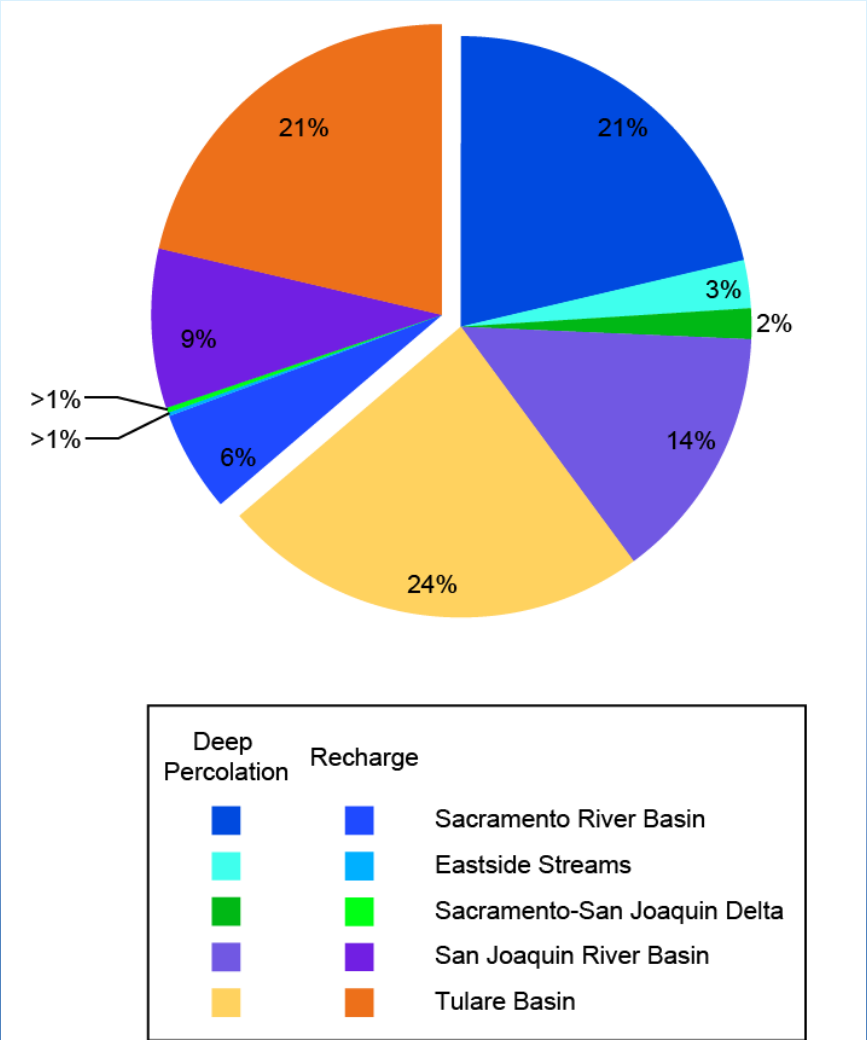


Recharge and Deep Percolation

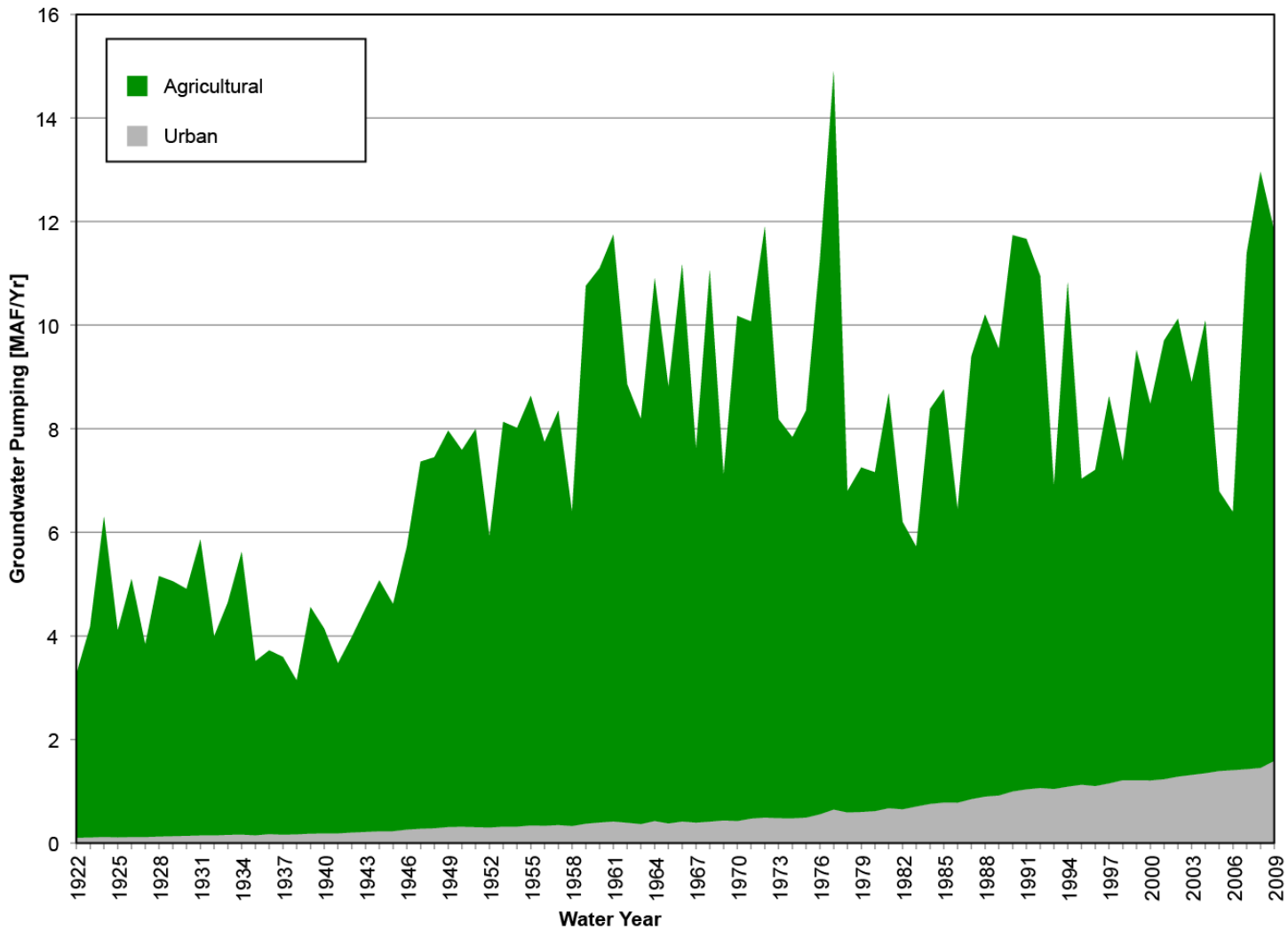


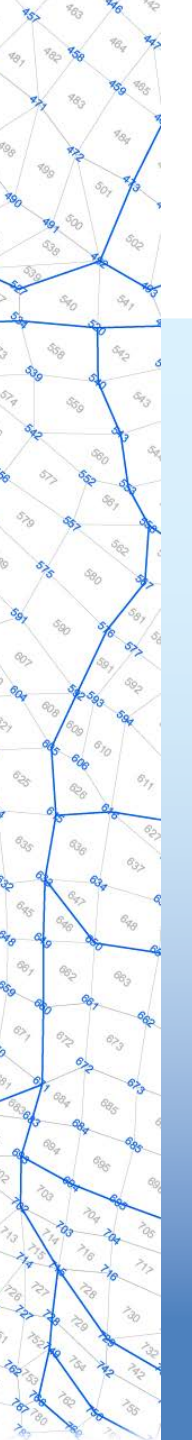
Recharge and Deep Percolation

1922-2009

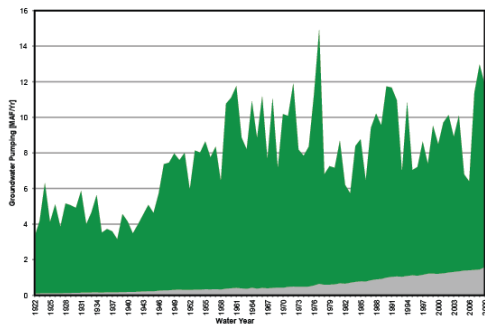


Groundwater Pumping

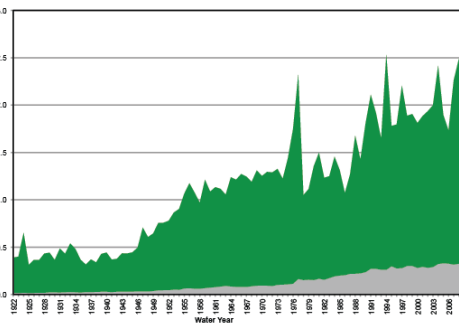




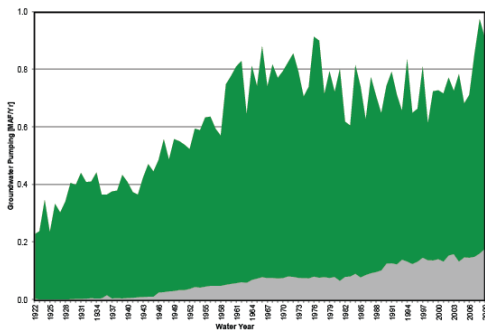
Central Valley



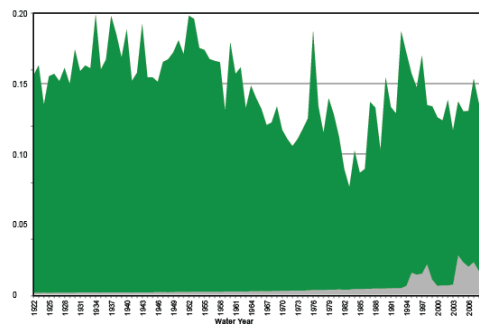
Sacramento River Basin



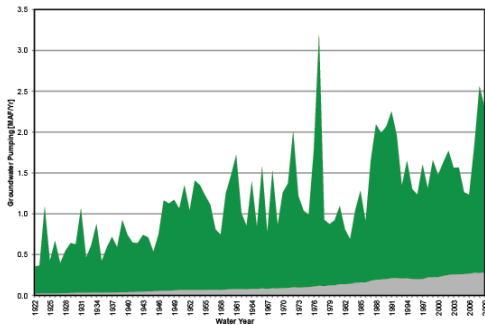
Eastside Streams



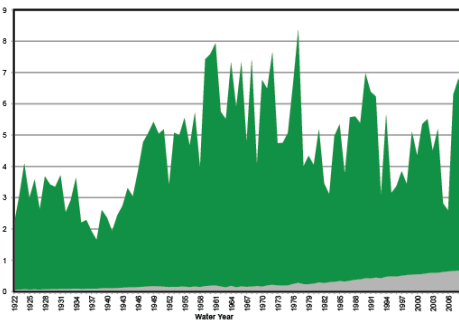
Sacramento-San Joaquin Delta



San Joaquin River Basin



Tulare Basin

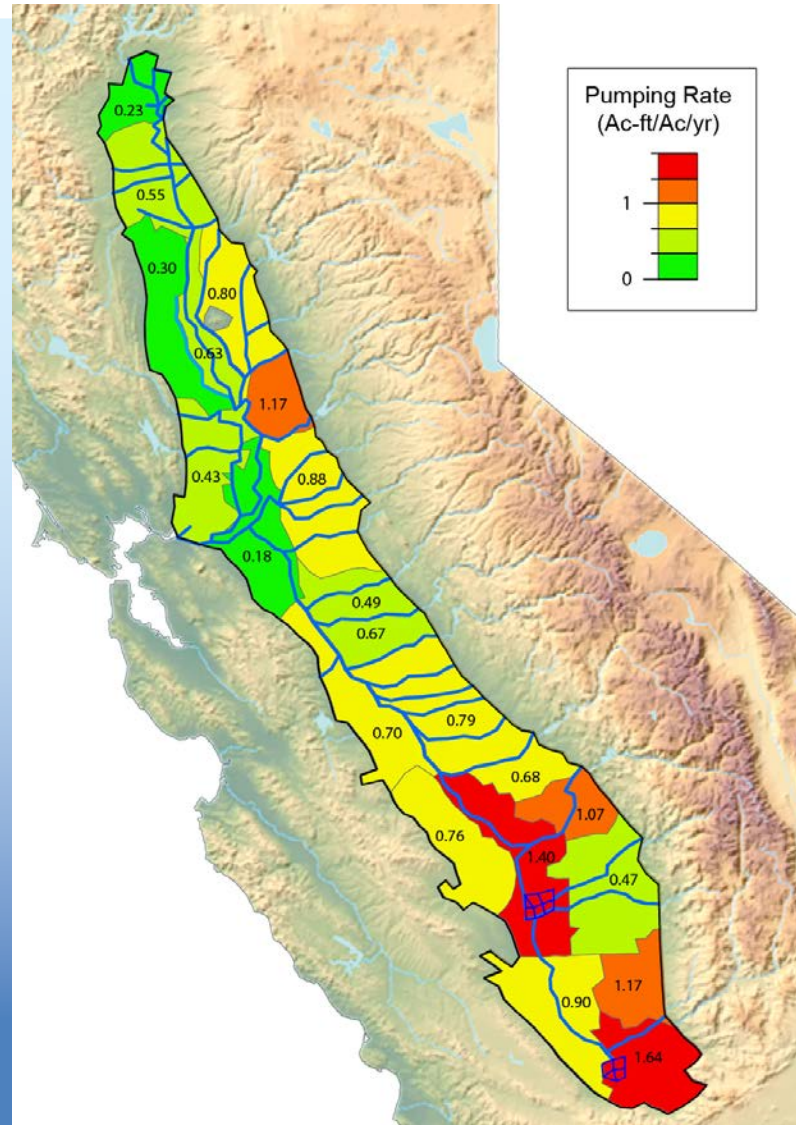


Legend

-
 Agricultural
 Urban

Groundwater Pumping

2000-2009





End