The California Central Valley Groundwater-Surface Water Simulation Model

Groundwater Process

CWEMF C2VSim Workshop
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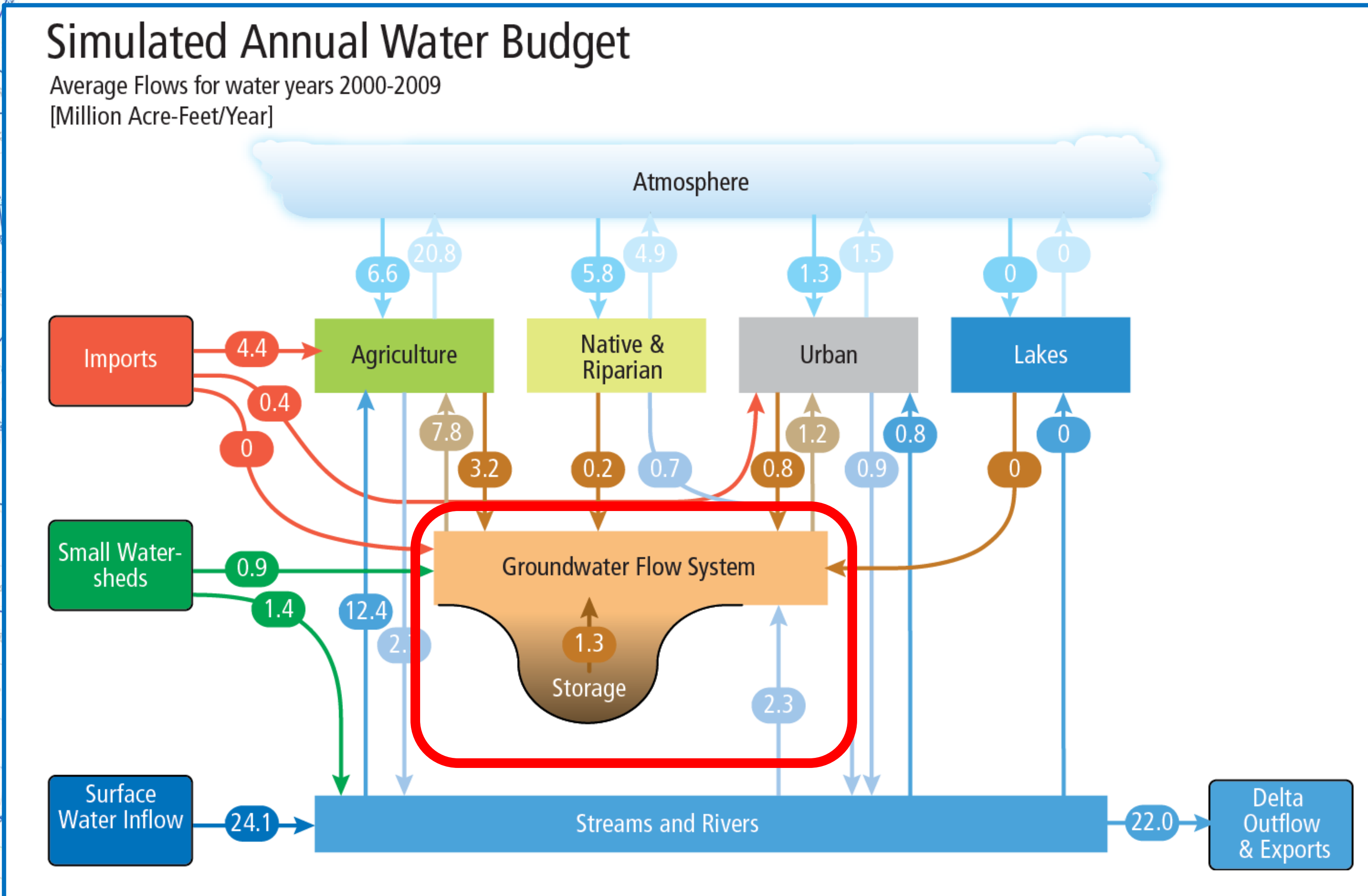
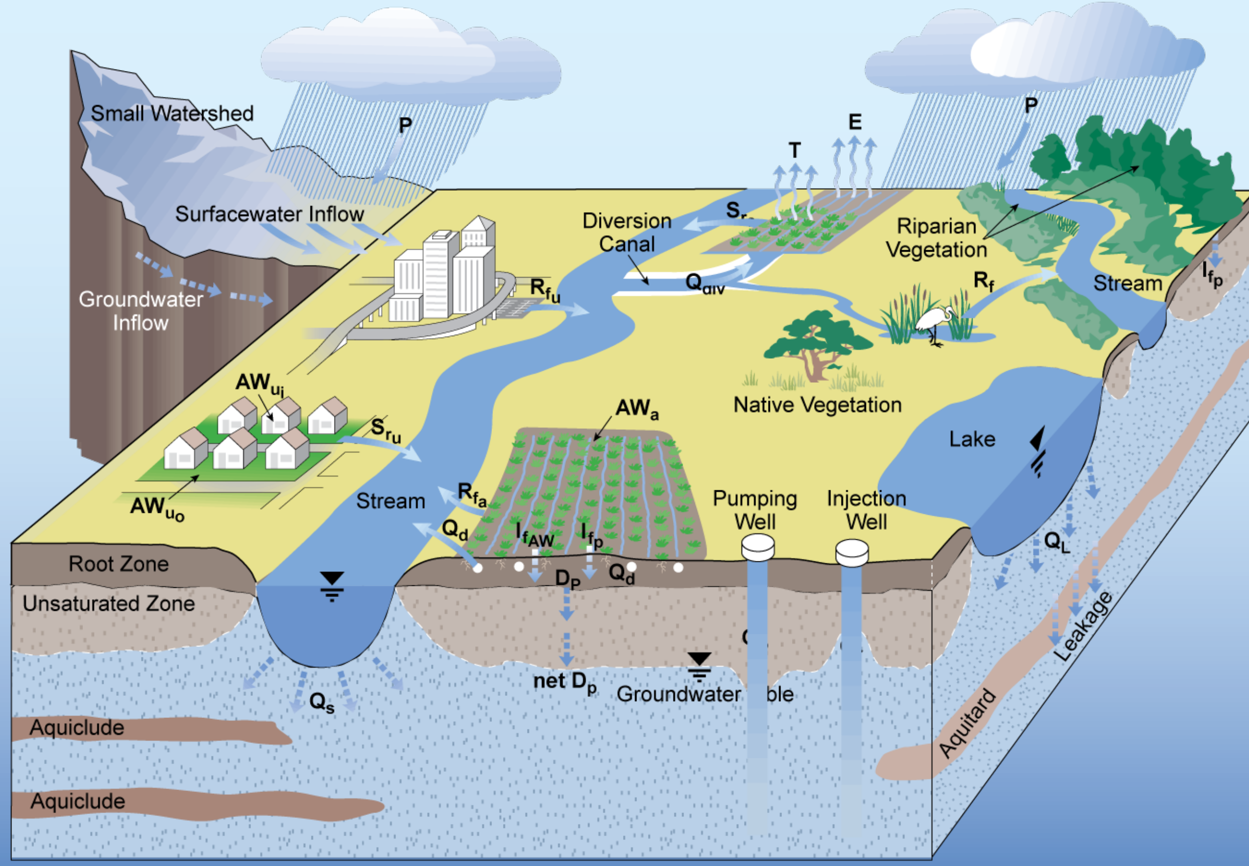
Outline

- IWFM Groundwater Process
  - Groundwater Budget
  - Z-Budget
- C2VSim Results

IWFM Groundwater Process

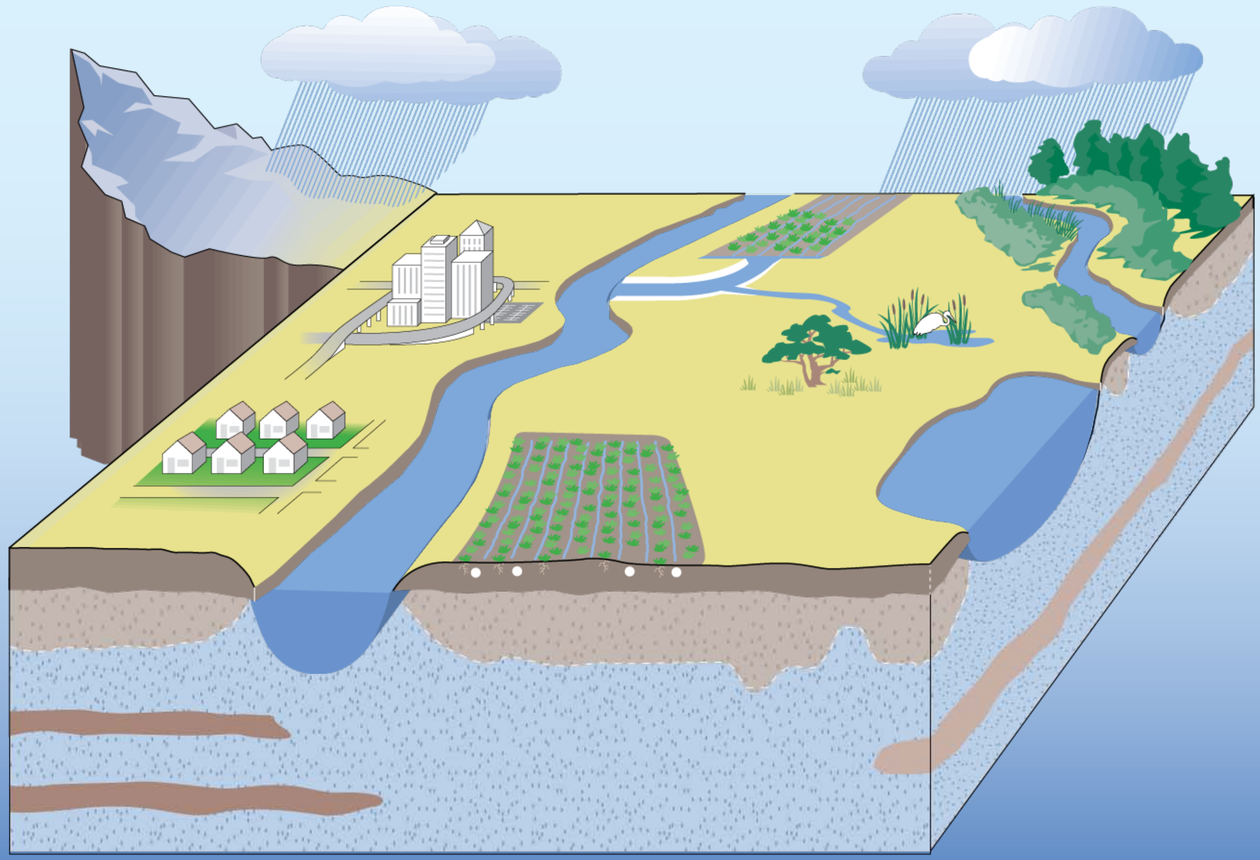


IWFM



Small Watershed
P
Surfacewater Inflow
Groundwater Inflow
Diversion Canal
S_r
T
E
P
Riparian Vegetation
R_{fu}
Q_{div}
R_f
Stream
I_{fp}
Native Vegetation
AW_{ui}
S_{ru}
AW_a
Lake
AW_{uo}
Stream
R_{fa}
Q_d
I_{fAW}
I_{fp}
Pumping Well
Injection Well
Q_L
Root Zone
D_P
Q_d
Unsaturated Zone
Leakage
net D_p
Groundwater ble
Q_s
Aquiclude
Aquitard
Aquiclude

IWFM Groundwater Process



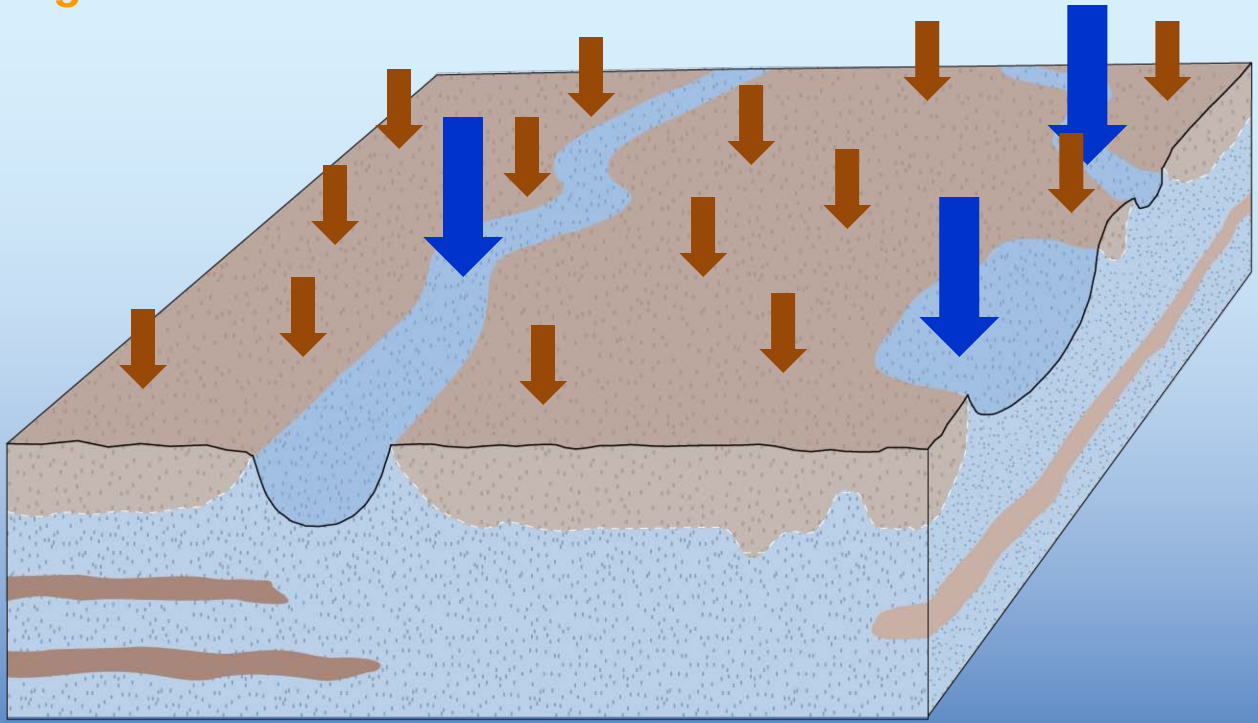
IWFM Groundwater Process

Inflows:

Deep Percolation

Surface Water

Storage



IWFM Groundwater Process

Inflows:
- Deep Percolation
- Surface Water
- Storage

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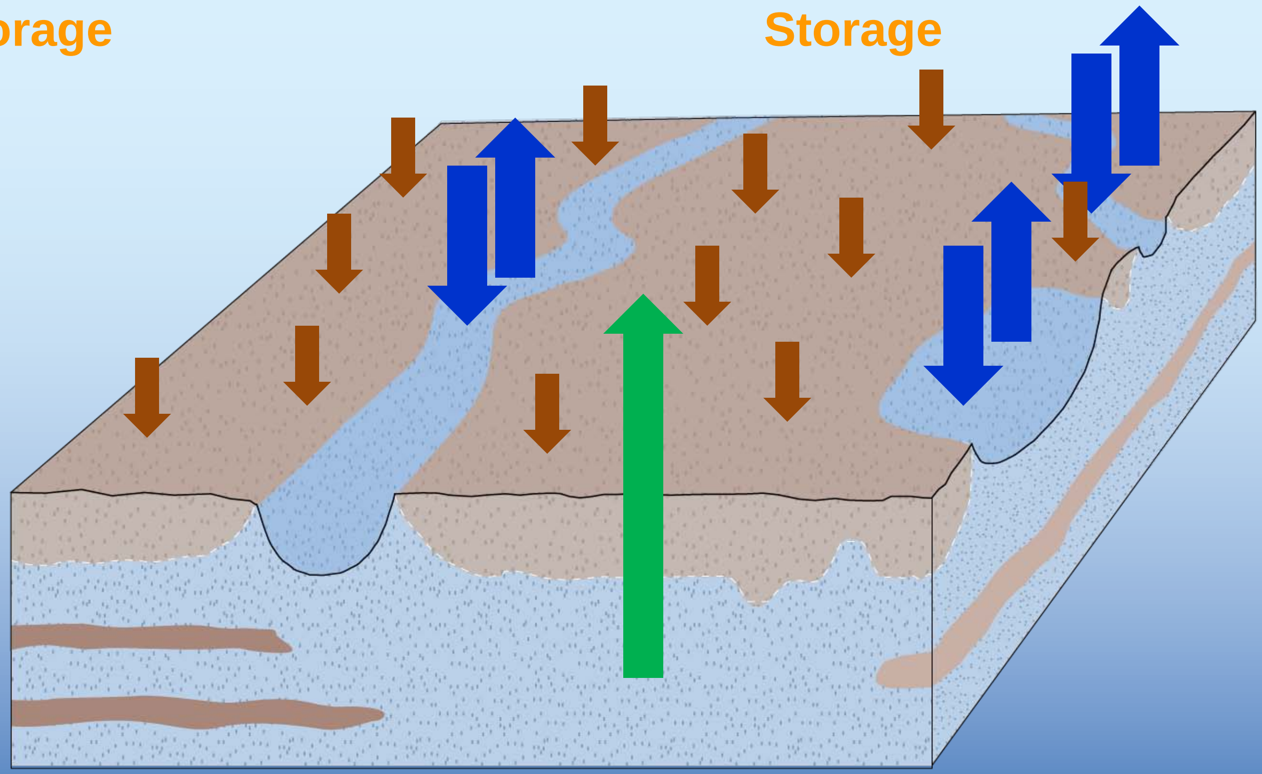
Outflows:
- Pumping
- Surface Water
- Storage

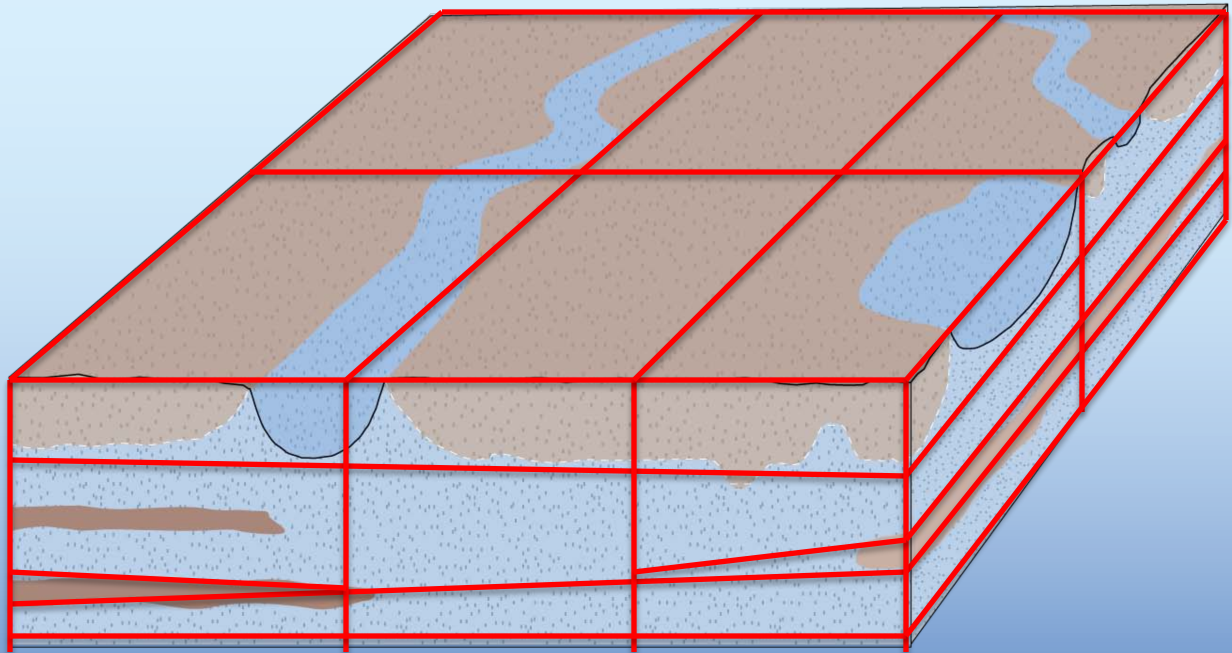


IWFM Groundwater Process

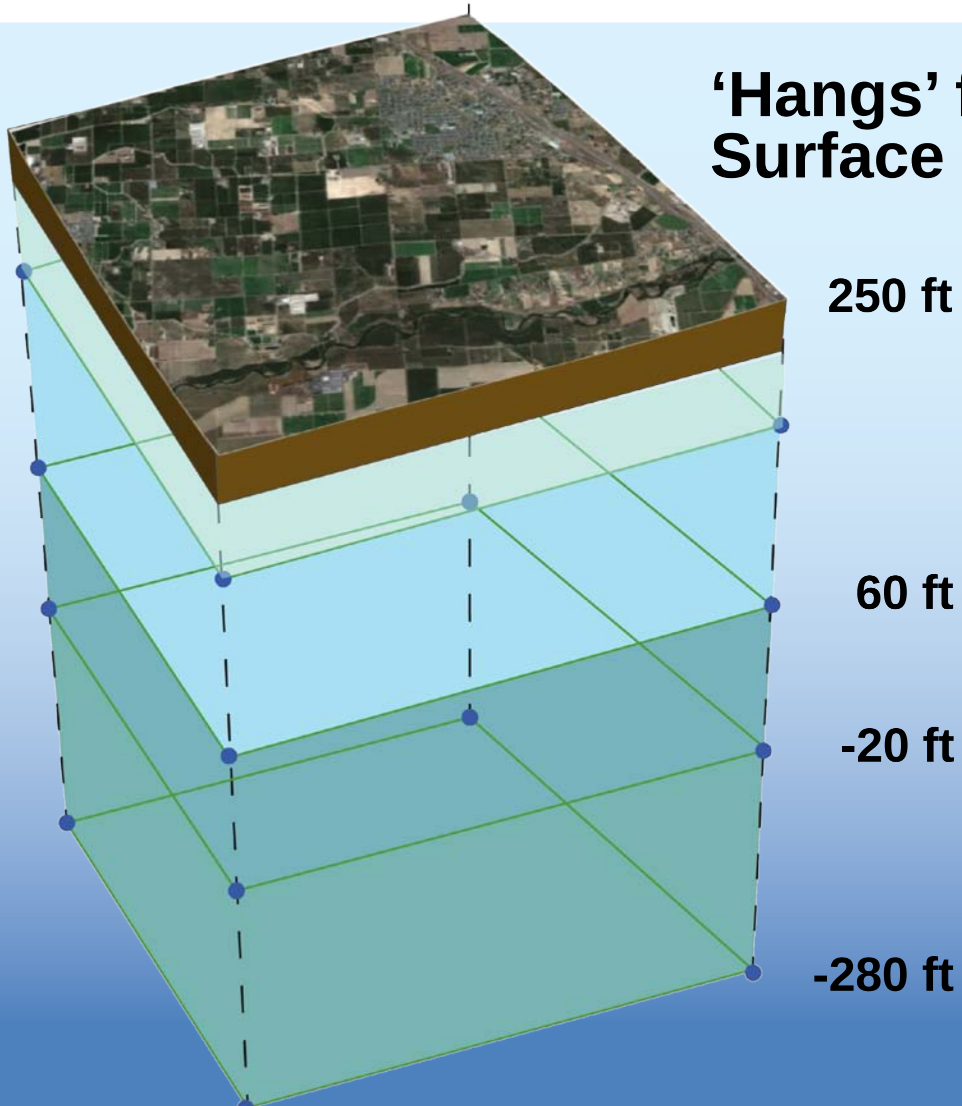
- Simulate a combination of confined, unconfined, and leaky aquifer layers separated by aquitards or aquicludes
- Simulate changing aquifer conditions and subsidence
- Employ a quasi 3-D approach
- Use the Galerkin finite element method for the numerical solution of the governing equation

IWFM Groundwater Process

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



Stratigraphy



Groundwater Flow Equation

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

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------------------------------------------------------------------------------------------------------------------------
  3.281     1.          1.          1.          1.         1.        1.          1.          1.         1.           1.
C-----------------------------------------------------------------------------------------------------------------------
C   VALUE               DESCRIPTION
C-----------------------------------------------------------------------------------------------------------------------
    1mon                / TUNITKH
    1mon                / TUNITV
    1mon                / TUNITL
C*******************************************************************************
```

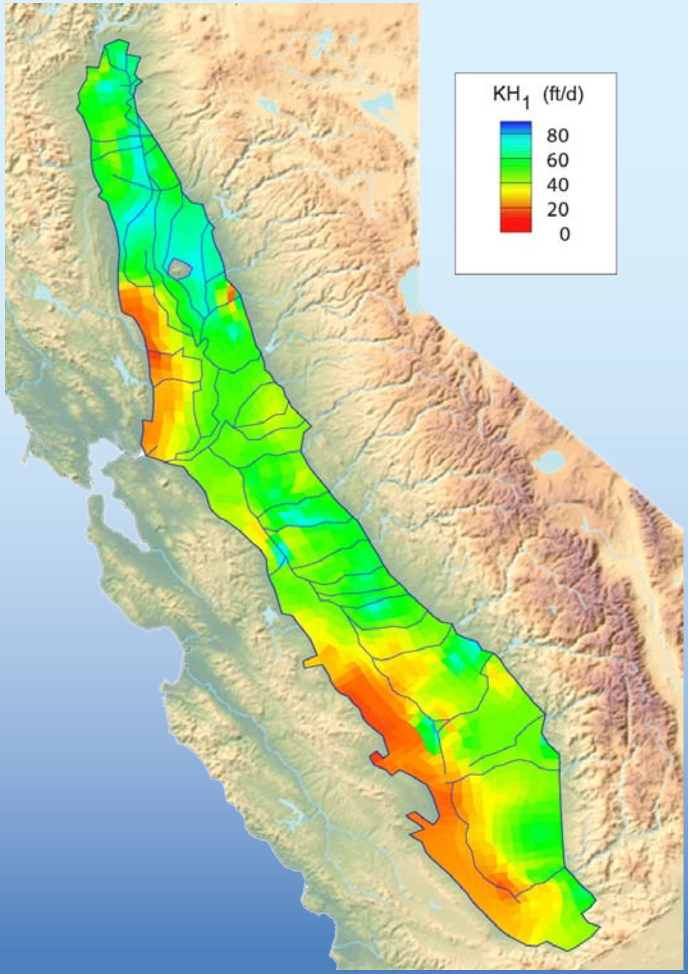
Groundwater Parameters

```
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
C
```

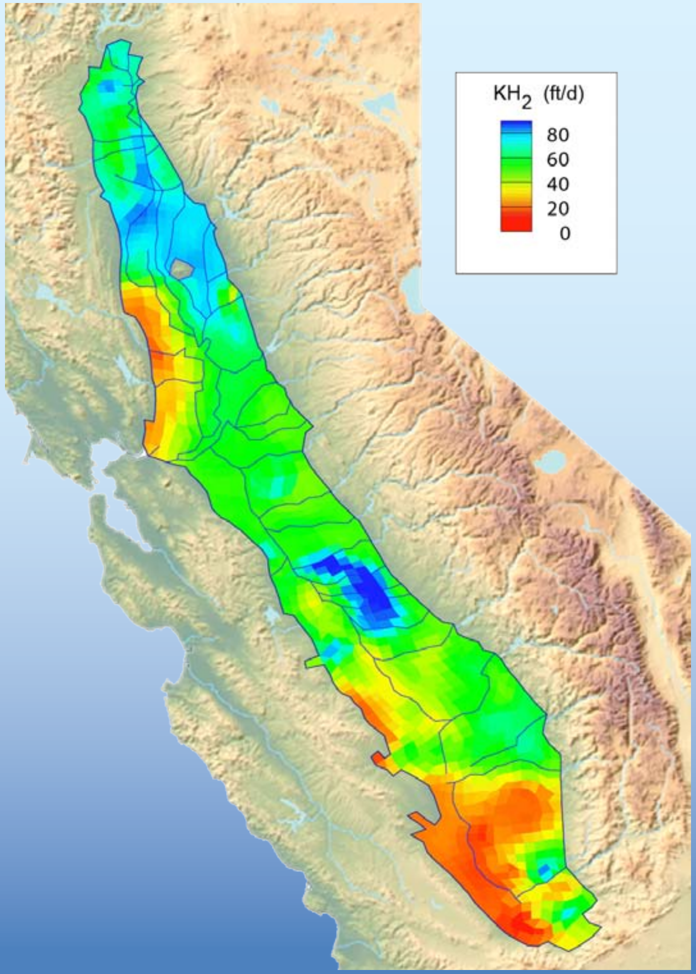
ID	Hydr. cond. PKH	Spec. Stor. PS	Spec. Yld. PN	Aquitard Vert. K PV	Aquifer Vert. K PL	Elastic Stg. Coef. SCE	Inelastic Stg. Coef. SCI	Interbed Thickness DC	Min. Intrbd Thickness DCMIN	Precompc Hyd. Head HC
1	1819.54	2.000E-05	0.1509	2.000E-01	1.821	4.500E-06	1.010E-06	13.0	2.0	605.7
	1978.15	1.930E-05	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

Hydraulic Conductivity

Layer 1

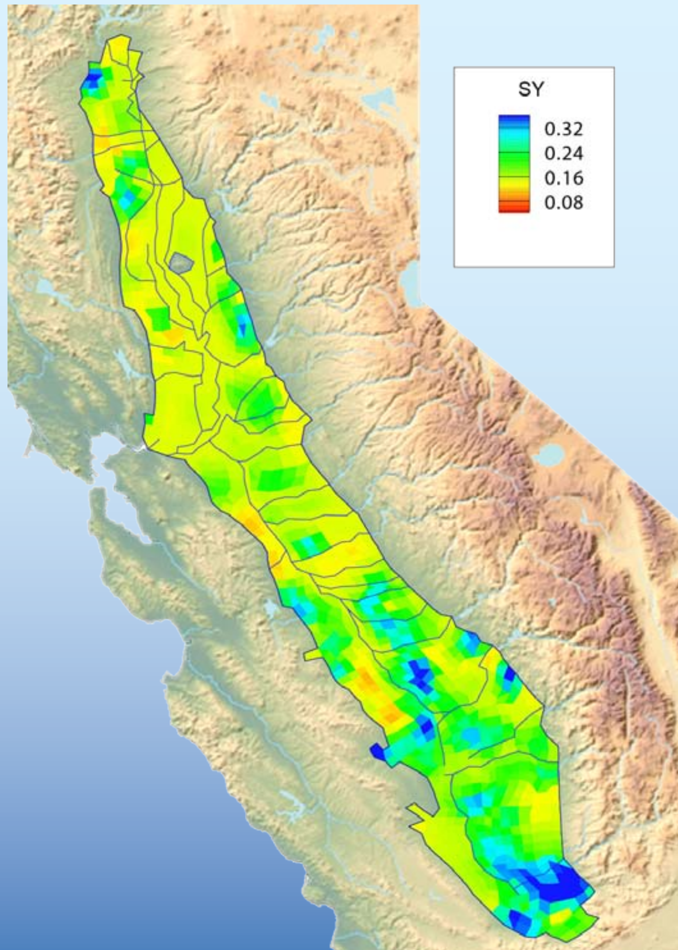


Layer 2

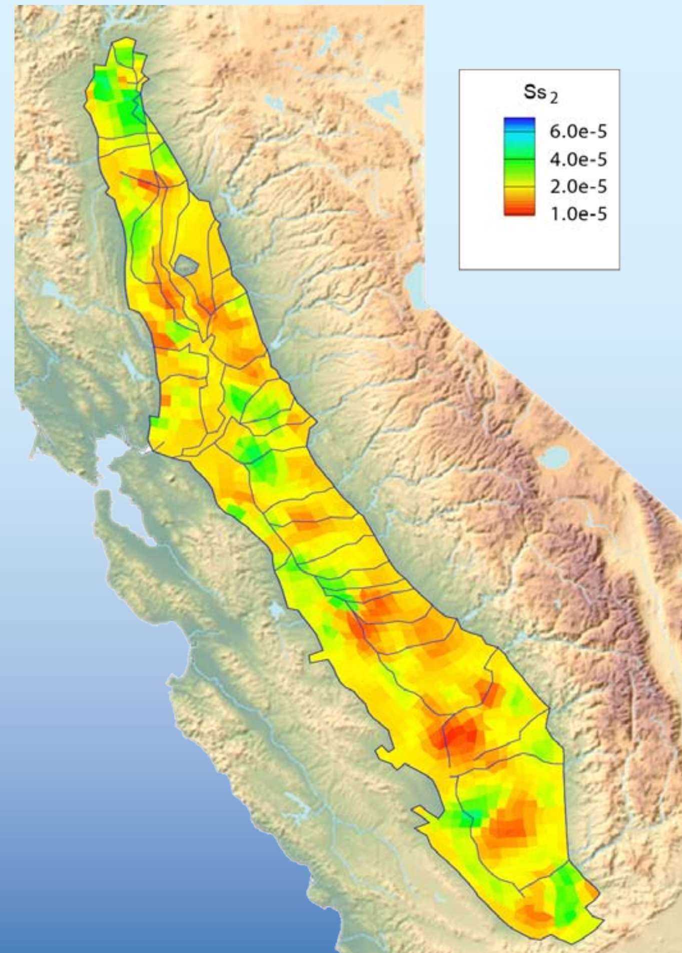


Storage Parameters

Layer 1



Layer 2



Faults

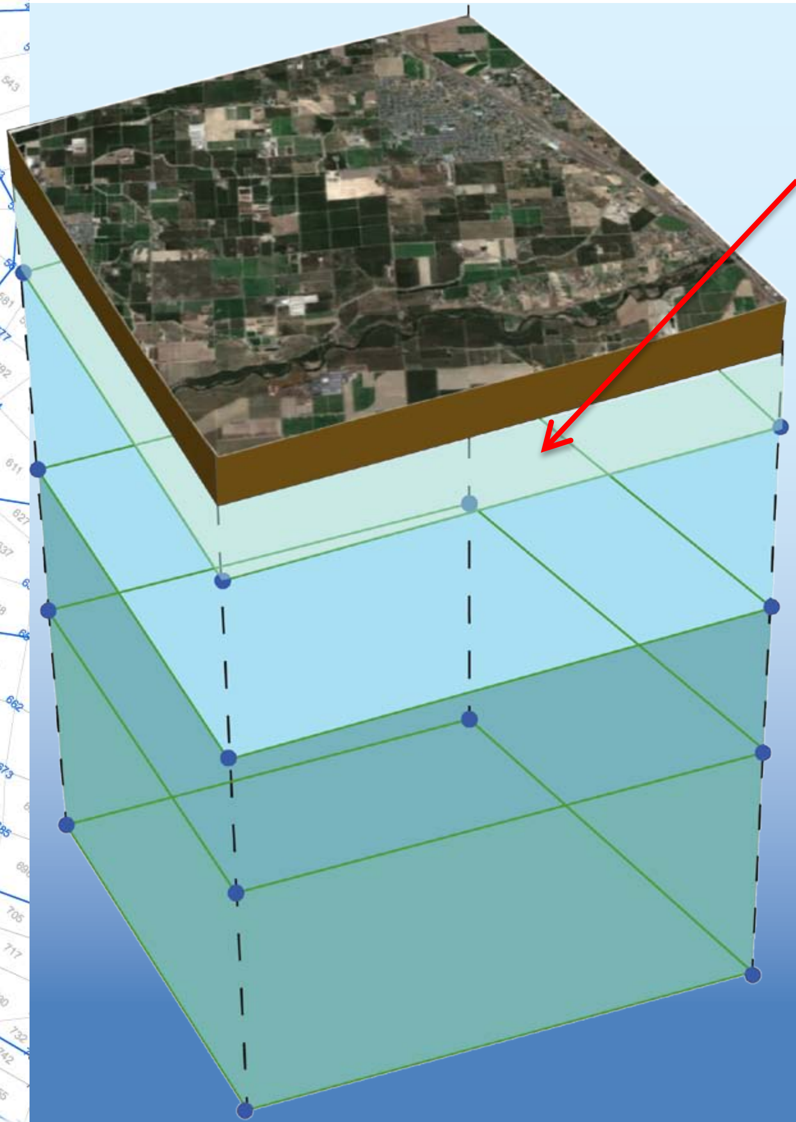
- Battle Creek Fault
- **Red Bluff Arch**
- Plainfield Ridge Anticline
- Pittsburgh – Kirby Hills – Vaca Fault
- Vernalis Fault
- Graveley Ford Faults
- Visalia Fault
- Pond-Poso Creek Fault
- **Edison Fault**
- **White Wolf Fault**

Flow Barrier Parameters

```
C*******************************************************************************
C                     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-------------------------------------------------------------------------------
     7                          /NEBK
     1.0                        /FACT
    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                           LAYER 1  LAYER 2  LAYER 3
C     IC          IEBK         BK       BK       BK
C-------------------------------------------------------------------------------
       1            55    1.0308900 1.0250100 1.0326100
       2            56    1.0308900 1.0250100 1.0326100
       3            57    1.0308900 1.0250100 1.0326100
       4            58    1.0308900 1.0250100 1.0326100
       5          1383    .02979000 .02995000 .03003000
       6          1384    .02979000 .02995000 .03003000
       7          1385    .02979000 .02995000 .03003000
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]
C-----------------------------------------------------------------------------------------------------------
C                           LAYER 1                                     LAYER 2
C              Thickness        Porosity         Kv         Thickness        Porosity         Kv
C    IE            PD             PN             PL             PD             PN             PL
C-----------------------------------------------------------------------------------------------------------
      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
```

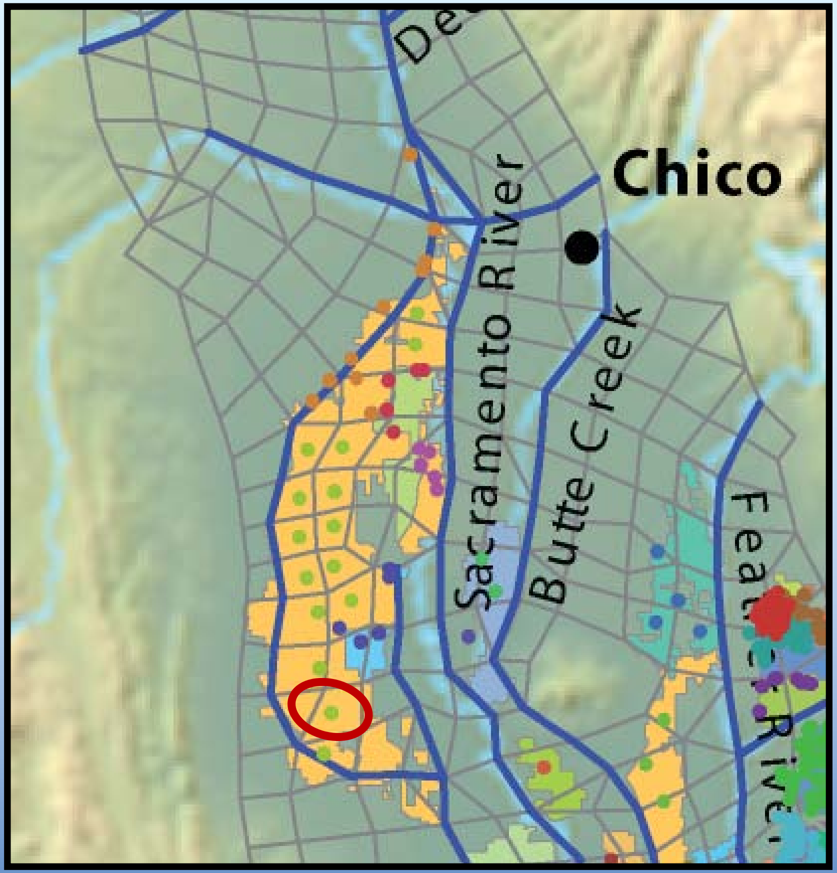
Groundwater Boundary Conditions

- 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

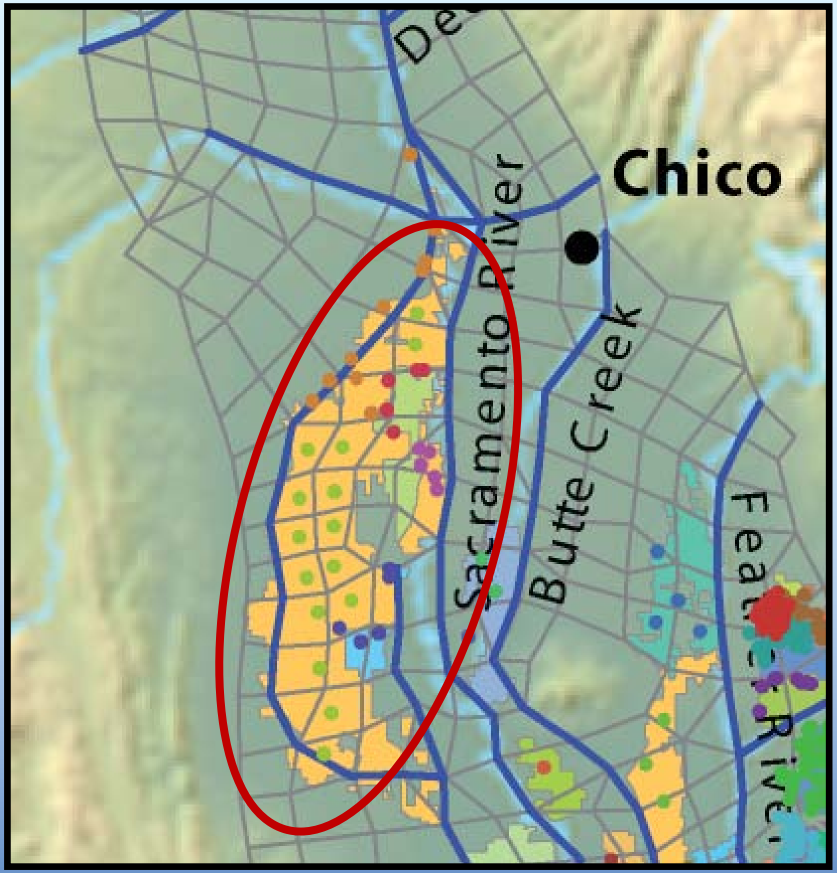
Urban Groundwater Pumping

```
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*******************************************************************************
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-------------------------------------------------------------------------------------------------------------
C ID   ICOLSK ICFIRIGSK  FRACSK  FRACSKL                IRGSK ICADJSK ICSKMAX FSKMAX
C                                  (1)     (2)      (3)
C-------------------------------------------------------------------------------------------------------------
1        1       1       0.0000  0.677   0.323   0.000   -1       1       1       1
2        1       1       0.0057  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
```

Pumping Rates

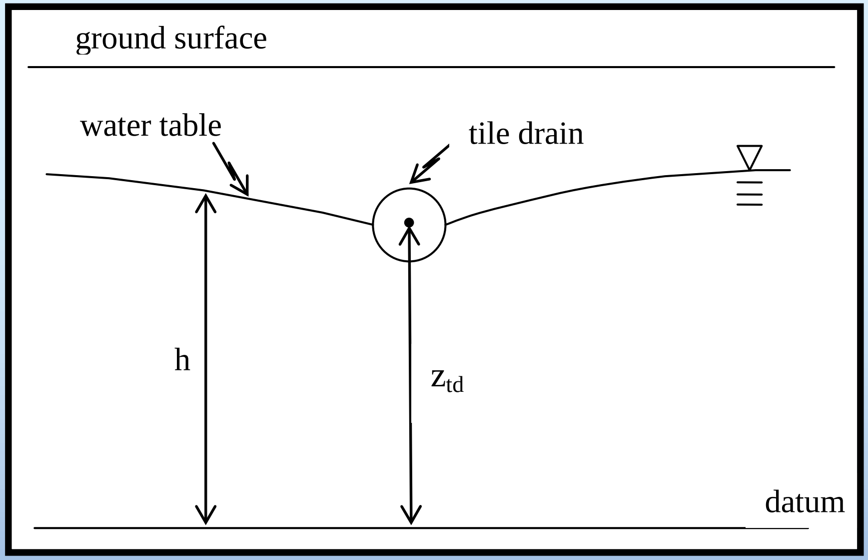
```
C*******************************************************************************
C                          Pumping Data Specifications
C
C   NCOLPUMP; Number of pumping sets (or pathnames if DSS files are used)
C   FACTPUMP; Conversion factor for pumping data - It is used to convert only the spatial component of the unit;
C   NSPPUMP ; Number of time steps to update pumping data * Enter any number if time-tracking option is on
C   NFQPUMP ; Repetition frequency of the pumping data: Enter 0 if full time series data is supplied, any number if time-tracking option is on
C   DSSFL   ; The name of the DSS file for data input (maximum 50 characters); * Leave blank if DSS file is not used for data input
C
C-------------------------------------------------------------------------------
C         VALUE                                       DESCRIPTION
C-------------------------------------------------------------------------------
          42                  / NCOLPUMP
          43560000.0          / FACTPUMP (TAF/mon --> ft^3/mon)
          1                   / NSPPUMP
          0                   / NFQPUMP
                              / DSSFL
C-------------------------------------------------------------------------------
C                              Pumping Data
C                          (READ FROM THIS FILE)
C
C   List the pumping data below if it will not be read from a DSS file (i.e. DSSFL is left blank above).
C
C   For pumping enter negative values, for recharge enter positive values.
C
C   ITPU ;    Time
C   APUMP;    Pumping rate; [L^3/T]
C
C-------------------------------------------------------------------------------
C ITPU     APUMP(1)  APUMP(2)  APUMP(3) ...
C-------------------------------------------------------------------------------
C Column            1       2       3       4       5       6       7       8       9       10      11      12      13      14      15      16      17      18
C Land Use          Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag      Ag
C SR                1       2       3       4       5       6       7       8       9       10      11      12      13      14      15      16      17      18
10/31/1921_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  -4.3422 -1.3802 0.0000  0.0000  -0.8038
11/30/1921_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  -10.6602   -17.3340   -0.3847 0.0000
12/31/1921_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
01/31/1922_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
02/28/1922_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
03/31/1922_24:00    0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  -2.8081 0.0000  0.0000  0.0000  0.0000
```

Tile Drains

- Tile drains are simulated as general head boundary conditions:

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

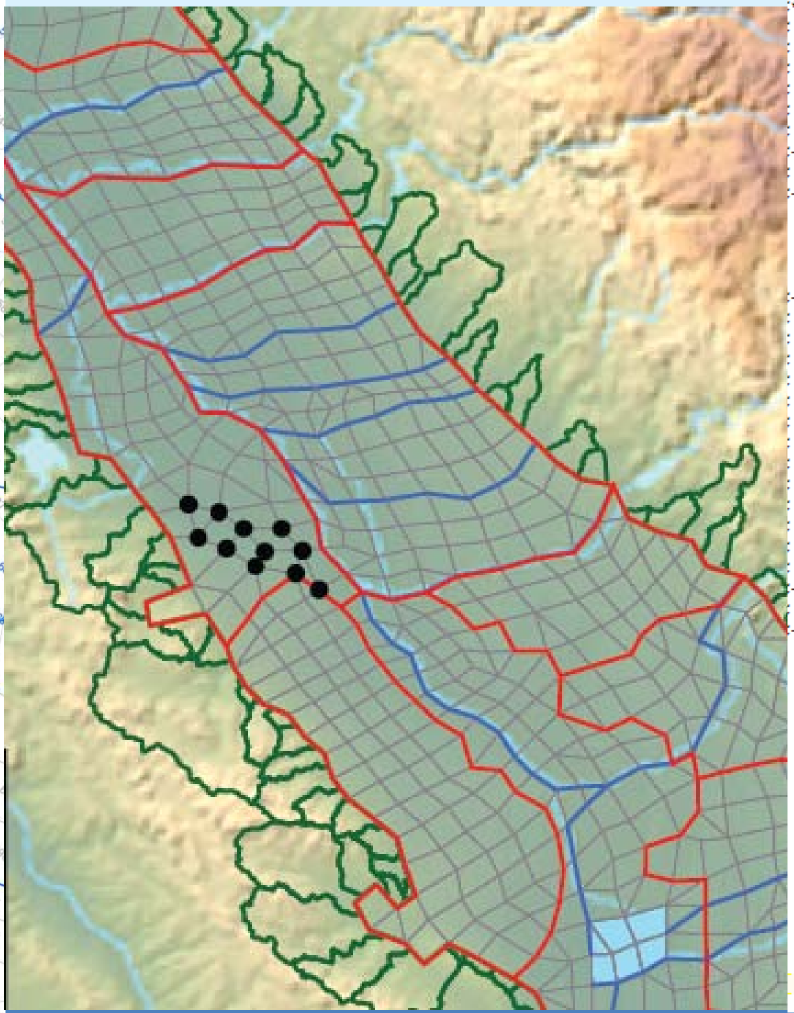
Q_{td} = **tile drain flow, $[L^3/T]$**
C_{td} = **conductance, $[L^2/T]$**
z_{td} = **tile drain elevation, [L]**
h = **groundwater head, [L]**



- 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

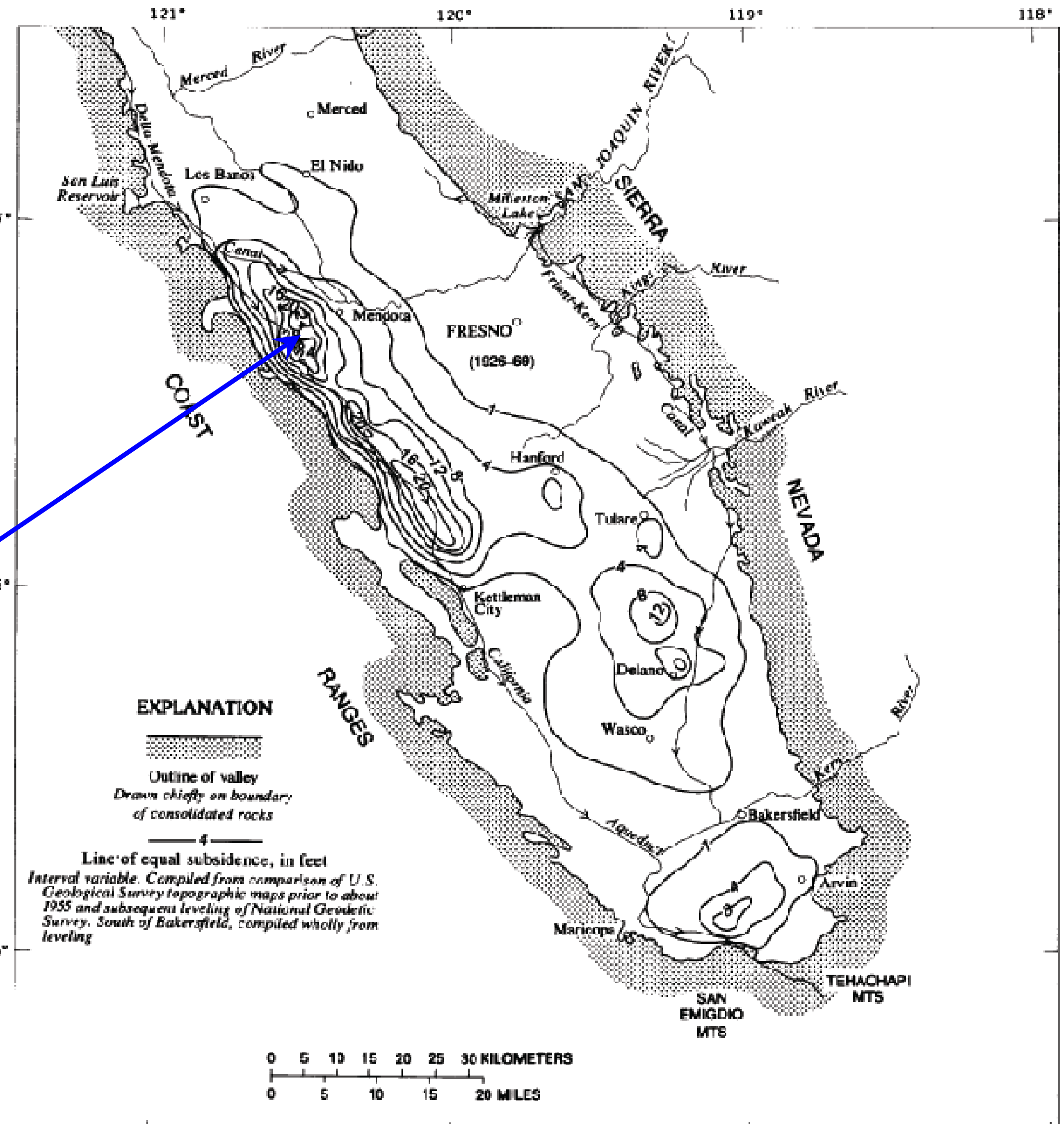
   NTD     ;  Number of groundwater nodes with tile drains
   FACTH   ;  Conversion factor for tile drain elevations
   FACTCDC;   Conversion factor for tile drain conductances
   TUNIT   ;  Time unit of conductance.  This should be one of the units recognized by HEC-DSS
--------------------------------------------------------------------------------
       VALUE                       DESCRIPTION
--------------------------------------------------------------------------------
       11                           /NTD
       1.0                          /FACTH
       60.0                         /FACTCDC  (convert ft^2/sec to ft^2/min)
       1min                         /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 exampl
        Case 2: For drainage into the node, list the node number as a positive value. For exam
   ELEVDR ; Elevation of the drain; [L]
   CDCDR  ; Hydraulic conductance of the interface between the aquifer and the drain; [L^2/T]
   ISTRMDR; Stream node into which drain flows into (input 0 (zero) if the drain flows out of

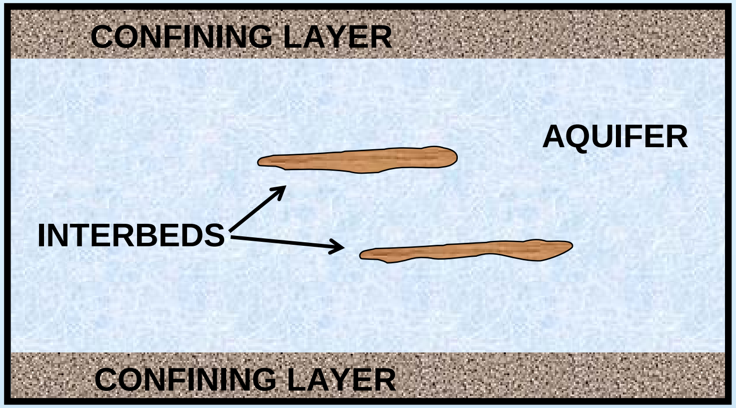
--------------------------------------------------------------------------------
 NODEDR     ELEVDR        CDCDR      ISTRMDR
--------------------------------------------------------------------------------
 -794      110.70      0.1000       114
 -815      181.70      0.1000       114
 -816      115.70      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



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

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)

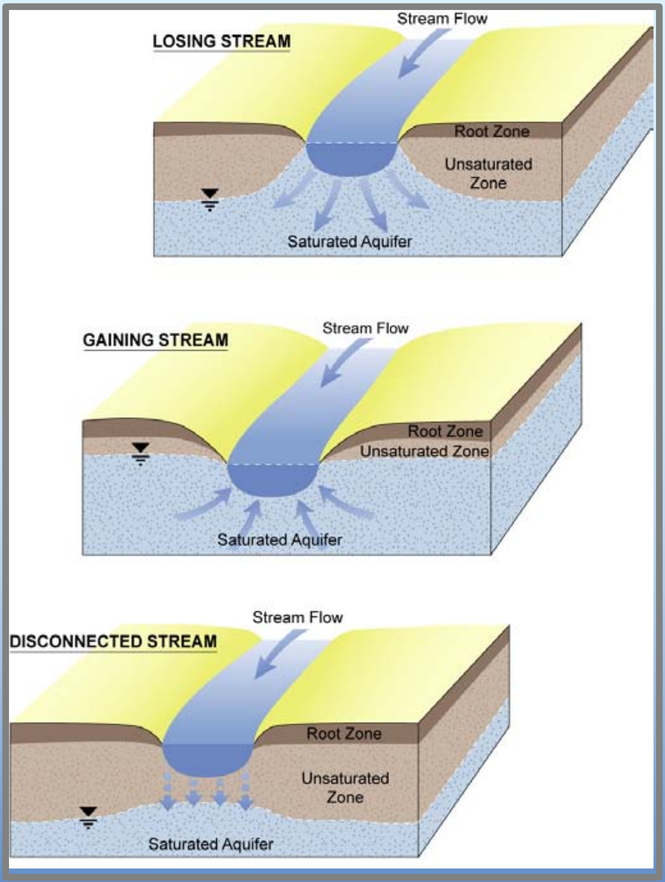
Δb = change interbed thickness, (L)

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             *Note* The above land subsidence parameters are only for interbed layers (i.e. clay layers)
C
C--------------------------------------------------------------------------------
C                          Layer  1
C                          Layer  2
C                             .
C                             .
C
C             Hydr.        Spec.             Spec.    Aquitard     Aquifer      Elastic      Inelastic     Interbed      Min. Intrbd  Precompc
C             cond.        Stor.             Yld.     Vert. K      Vert. K     Stg. Coef.   Stg. Coef.    Thickness     Thickness   Hyd. Head
C     ID      PKH          PS                PN       PV           PL            SCE          SCI           DC           DCMIN        HC
C------------------------------------------------------------------------------------------------------------------------------------------------
       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                    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-------------------------------------------------------------------------------
   0.0                          / FACT
C-----------------------------------------------
C    Initial interbed thickness at Layer 1
C    DC
C-----------------------------------------------
* FACT = 0.0 so use values in Parameter Data Fil
```

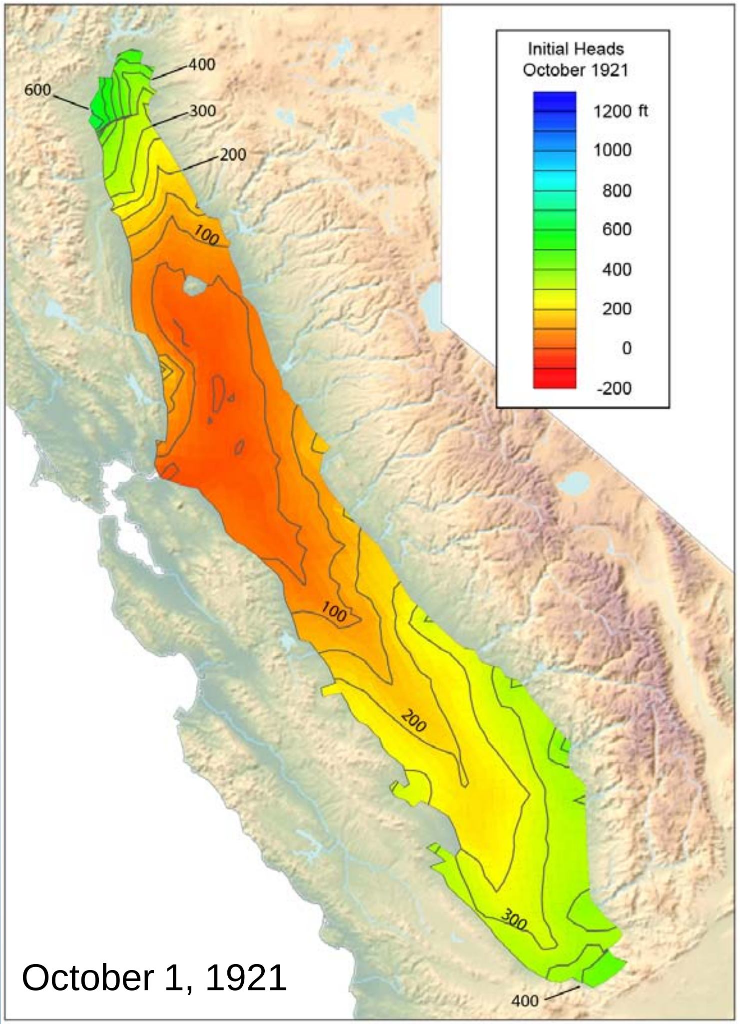
```
C*******************************************************************************
C              Initial Preconsolidation Head Values for Land Subsidence
C
C   The following lists the preconsolidation head for each groundwater node
C   (in sequential order) to overwrite the values specified in parameter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

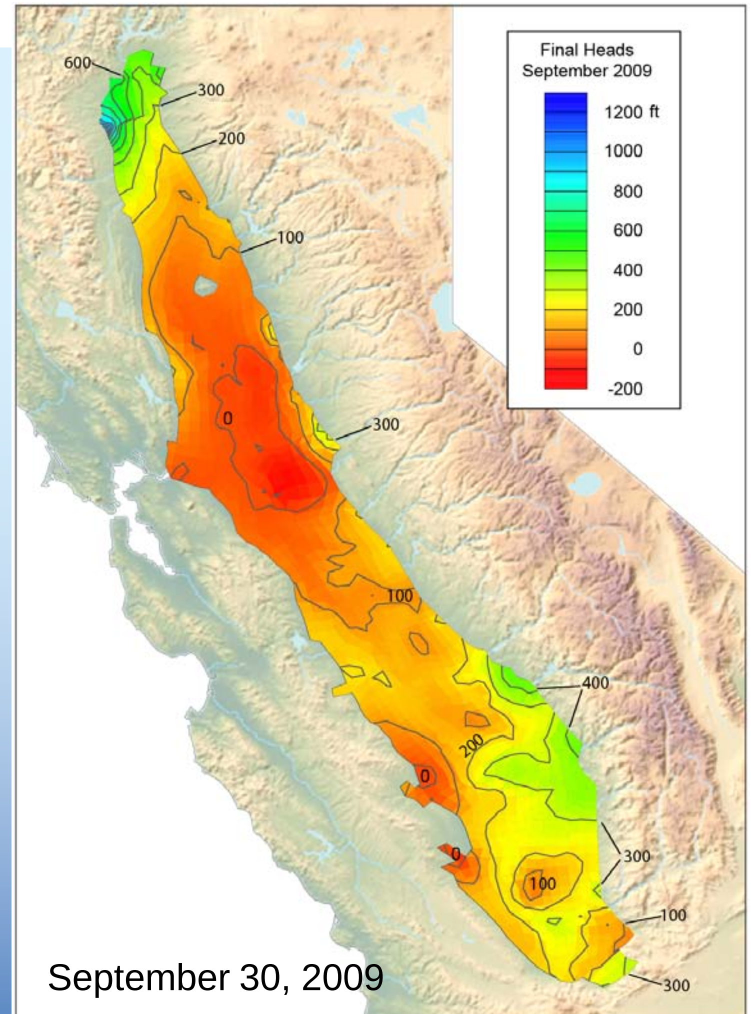
IWFM Groundwater Output

- 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

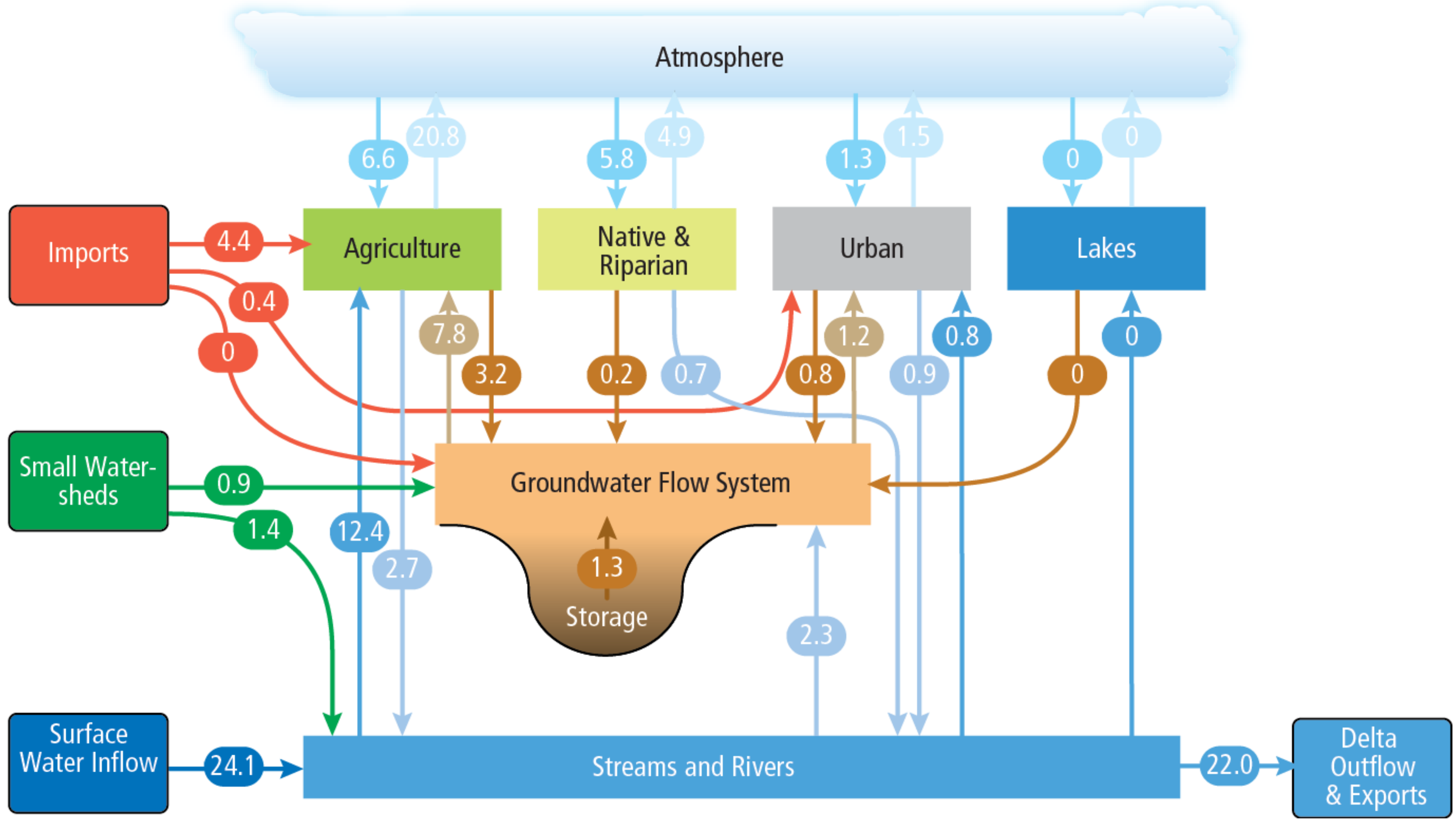
Produced from IWFM's TecPlot® output files





Simulated Annual Water Budget

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



Groundwater Heads

```
*                                   ****************************************
*                                   *    GROUNDWATER HEAD AT ALL NODES     *
*                                   *            (UNIT=FEET)               *
*                                   ****************************************
*                         NODE
```

* TIME	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
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```

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-------------------------------------------------------------------------------
     1387                        / NOUTH
     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, ie. 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)
C
C-------------------------------------------------------------------------------
C       IOUTHL         X           Y            IOUTH
C-------------------------------------------------------------------------------
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            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
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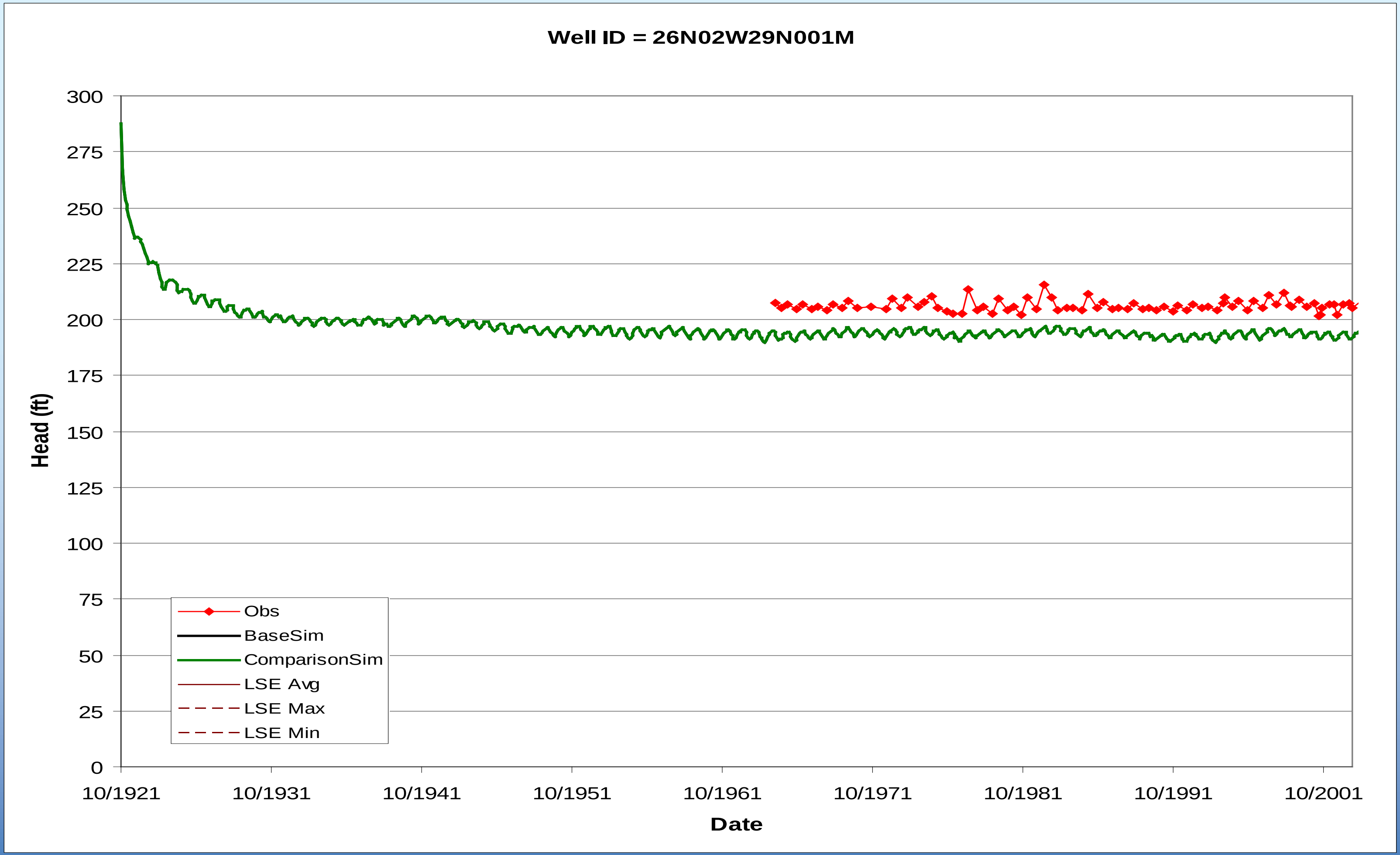
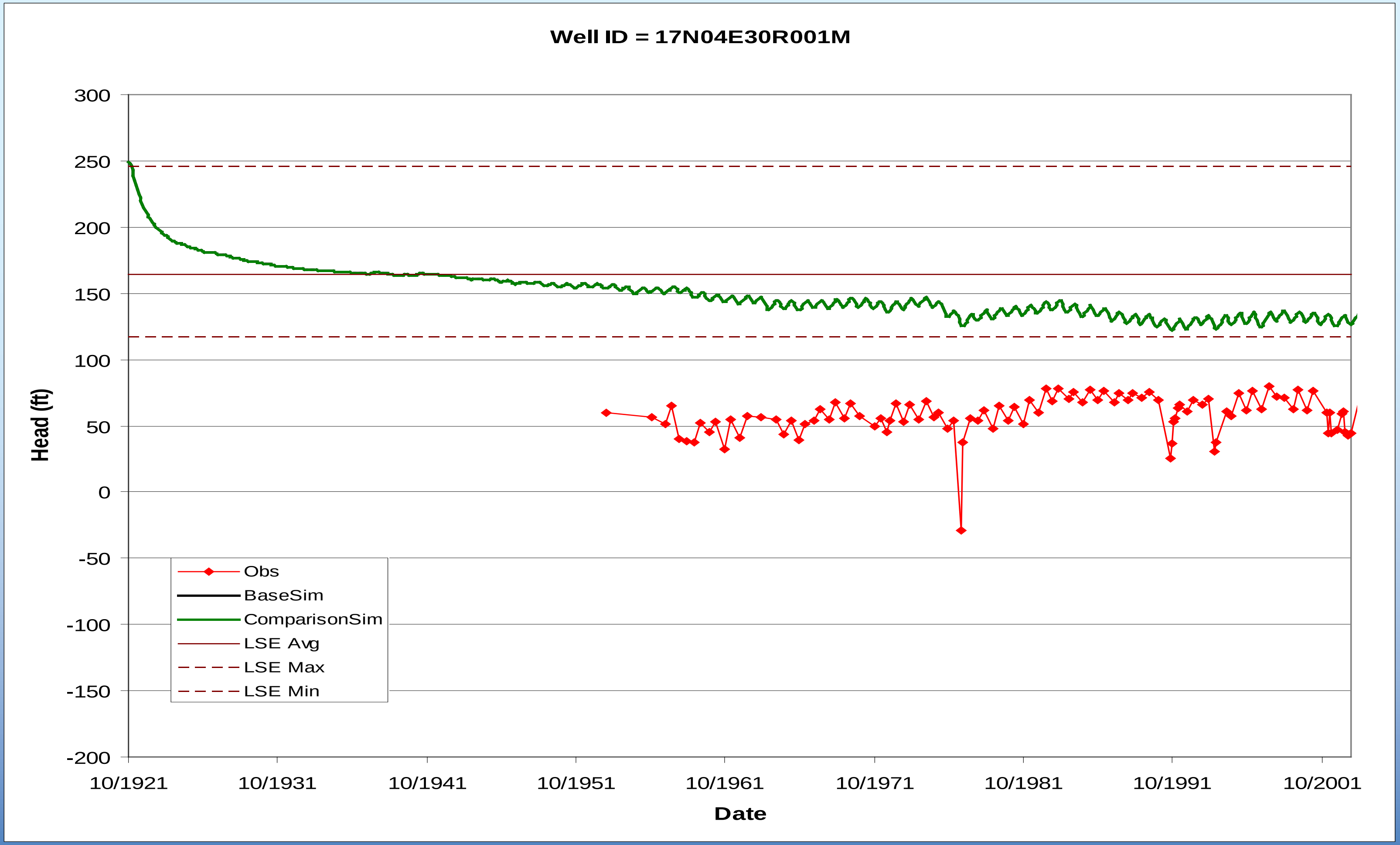
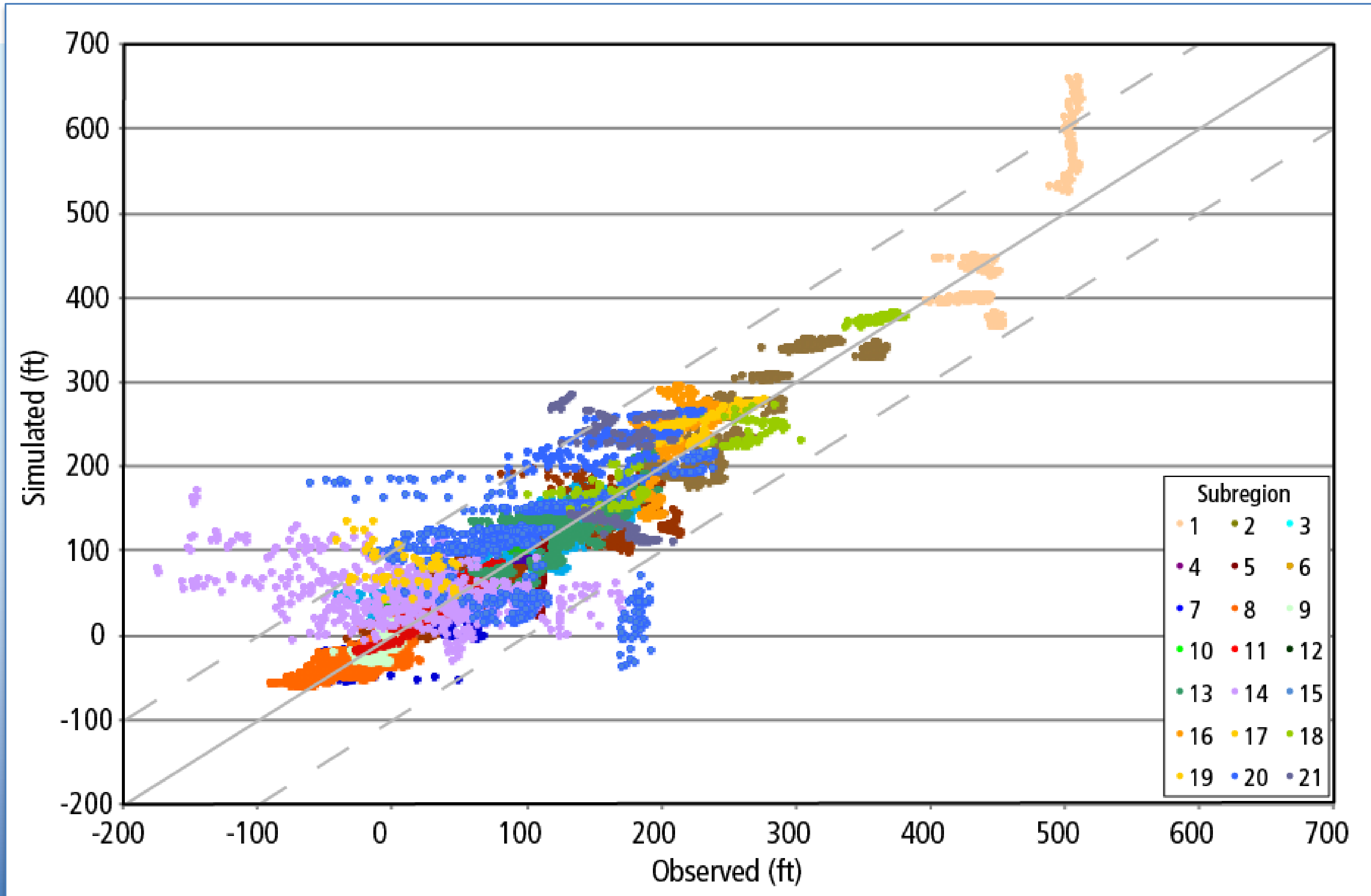
Groundwater Hydrographs



Groundwater Hydrographs



Groundwater Heads



Groundwater Budget

Column	Flow	08/31/2004	Process
Deep Percolation	IN	221,215	RZ
Beginning Storage (+)		2,912,112,878	
Ending Storage (-)		2,910,935,231	
Net Deep Percolation (+)	IN	354,874	UZ
Gain from Stream (+)	+/-	-107,640	SW
Recharge (+)	IN	218,671	LS
Gain from Lake (+)	+/-	-1,939	SW
Boundary Inflow (+)	IN	90,456	SWS
Subsidence (+)		32,908	
Subsurface Irrigation (+)	IN	0	LS
Tile Drain Outflow (-)	OUT	1,060	SW
Pumping (-)	OUT	1,763,915	LS
Net Subsurface Inflow (+)	+/-	0	GW
Discrepancy (=)		0.60	
Cumulative Subsidence		10,492,618	

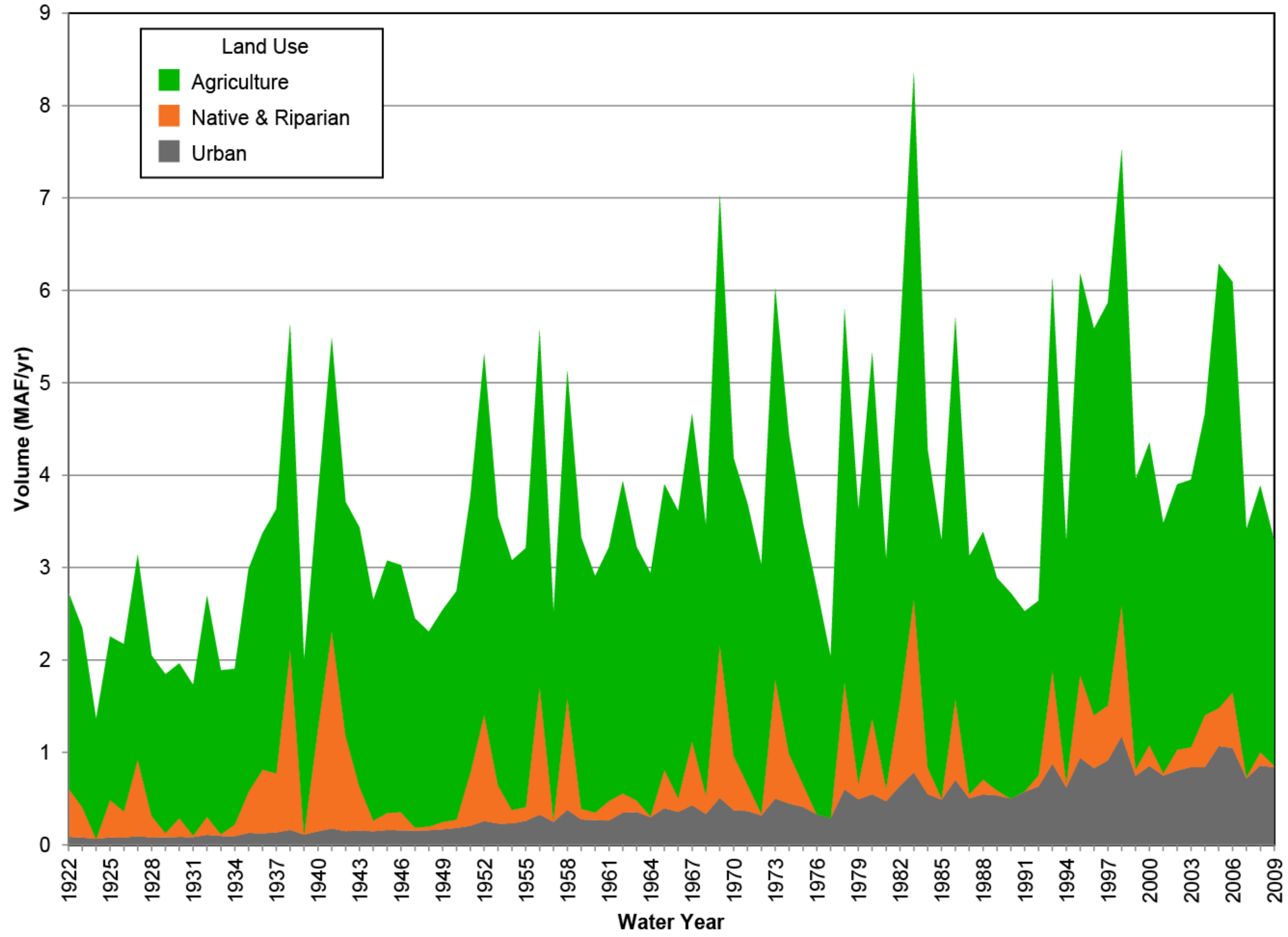
Z-Budget

Column	Flow	IN	OUT	Process
GW Storage		1,032,516	93,444	
Streams	+/-	170,660	240,835	SW
Tile Drains	OUT	0	1,515	SW
Subsidence		84,392	791	
Net Deep Percolation	IN	265,135	0	LS
Small Watershed Baseflow	IN	90,386	0	SWS
Small Watershed Percolation	IN	70	0	SWS
Diversion Recoverable Loss	IN	197,964	0	SW
Bypass Recoverable Loss	IN	29,637	0	SW
Lakes	+/-	5,140	7,524	SW
Pumping by Element	OUT	0	1,366,092	LS
Pumping by Well	OUT	0	165,699	LS
Overall Zone Error		-0.42		

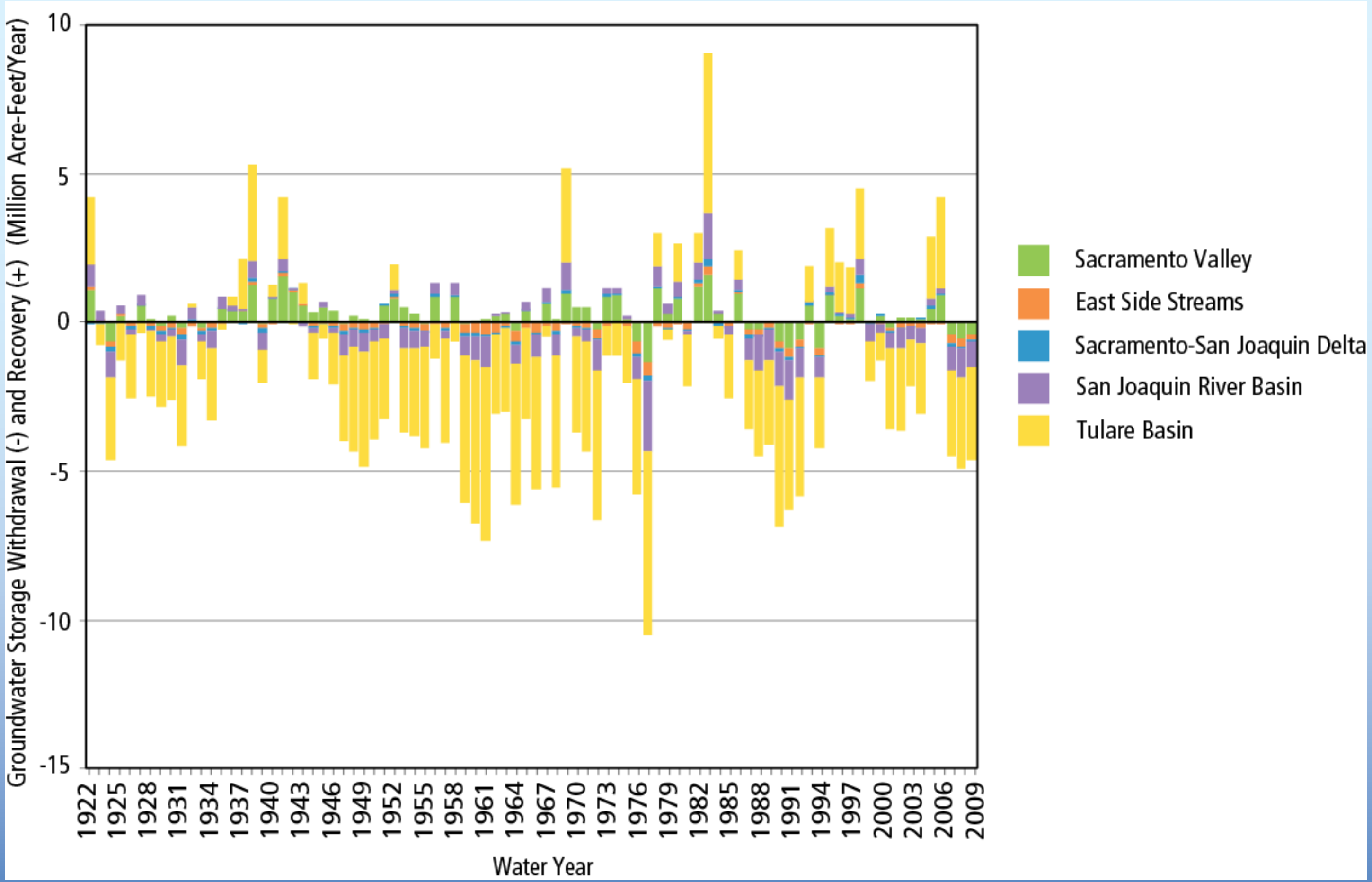
Z-Budget

Column	Flow	IN	OUT	Process
GW Storage		169,453	37,852	
Streams	+/-	94,764	138,619	SW
Tile Drains	OUT	0	0	SW
Subsidence		706	220	
Net Deep Percolation	IN	74,426	0	LS
Small Watershed Baseflow	IN	68,330	0	SWS
Small Watershed Percolation	IN	70	0	SWS
Diversion Recoverable Loss	IN	58,427	0	SW
Bypass Recoverable Loss	IN	0	0	SW
Lakes	+/-	0	0	SW
Pumping by Element	OUT	0	247,307	LS
Pumping by Well	OUT	0	41,451	LS
Zones 1 and 2	+/-	2,448	830	
Zones 1 and 3	+/-	395	2,738	
Overall Zone Error		0.00		

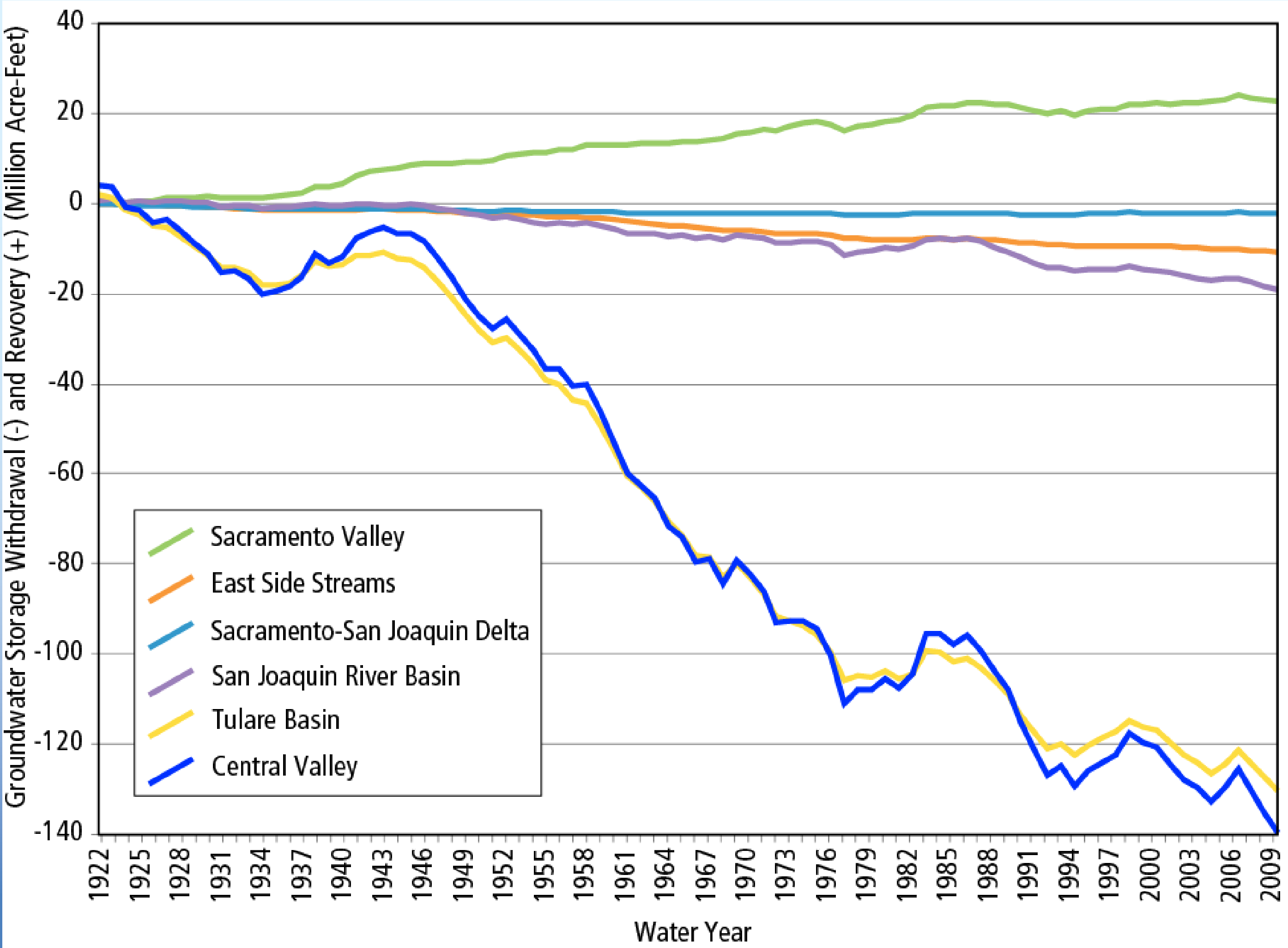
Deep Percolation



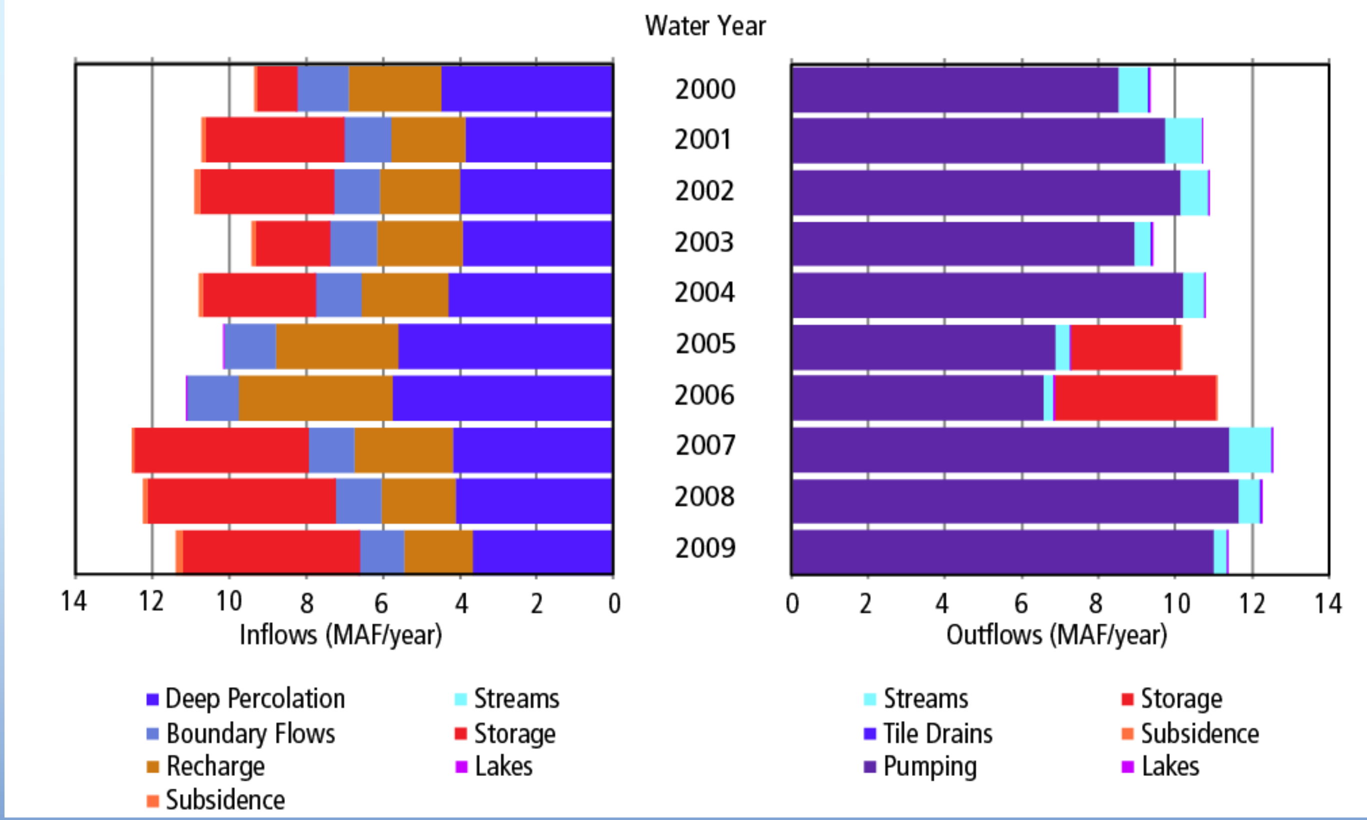
Groundwater Depletion



Groundwater Depletion



Water Balance



Head Difference, 1922-1965

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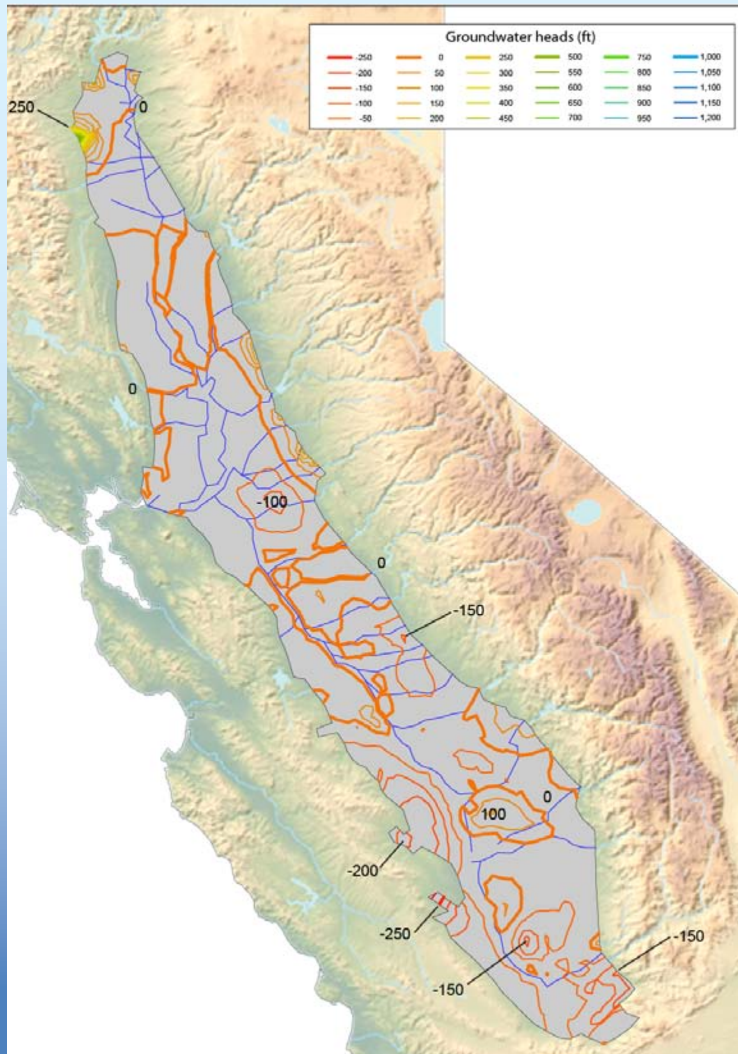
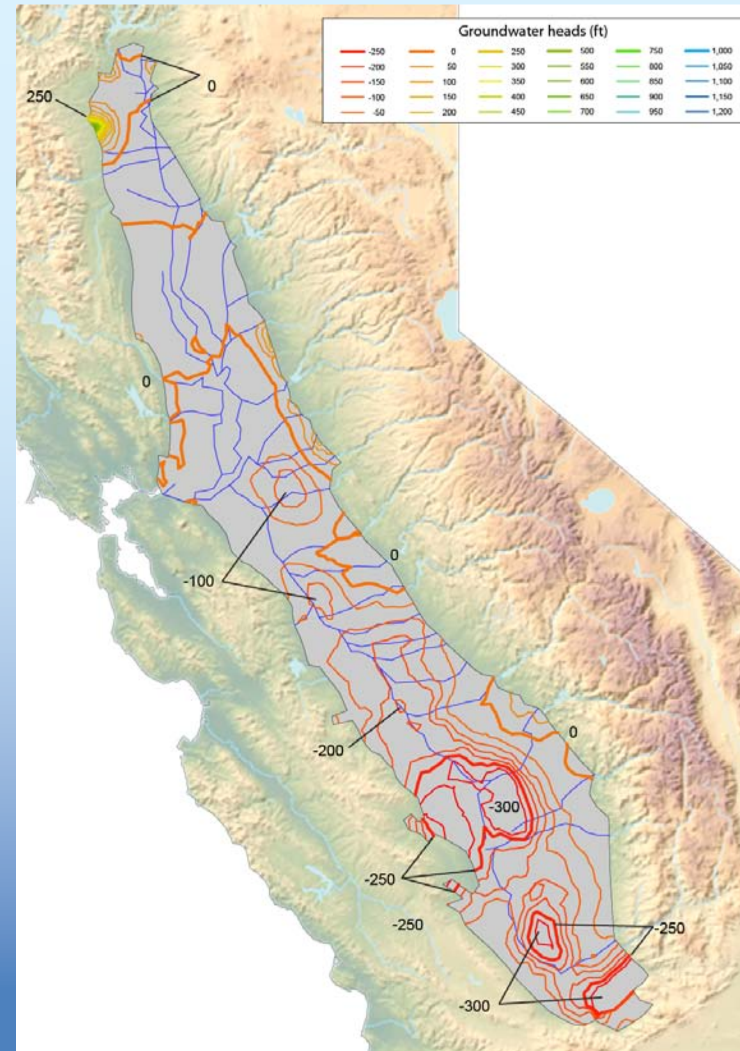
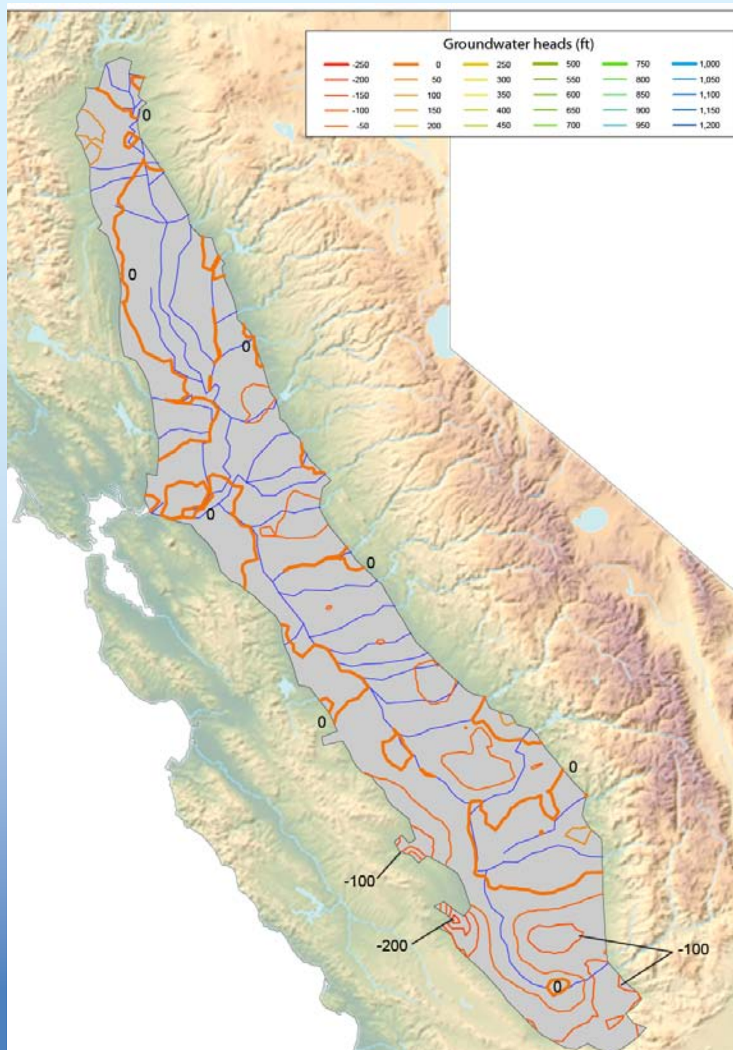


Layer 2



Head Difference, 1965-2009

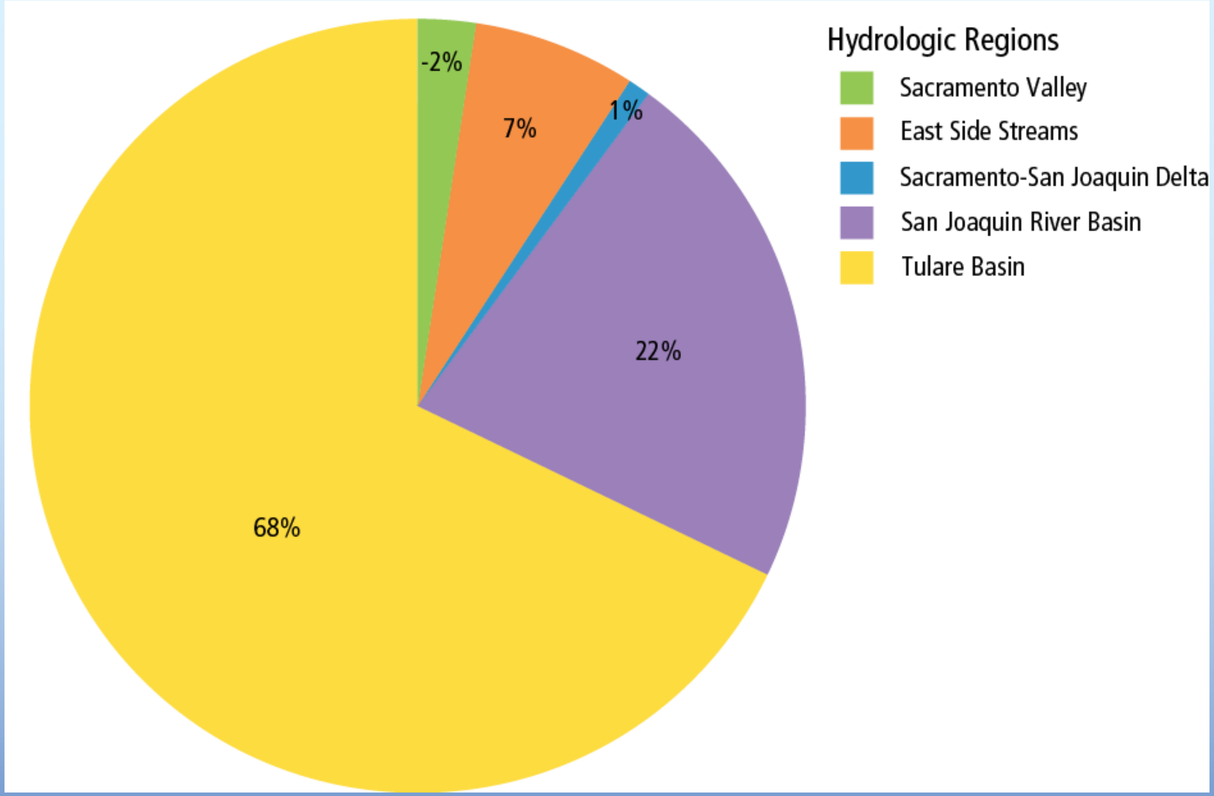
Layer 1



Layer 2

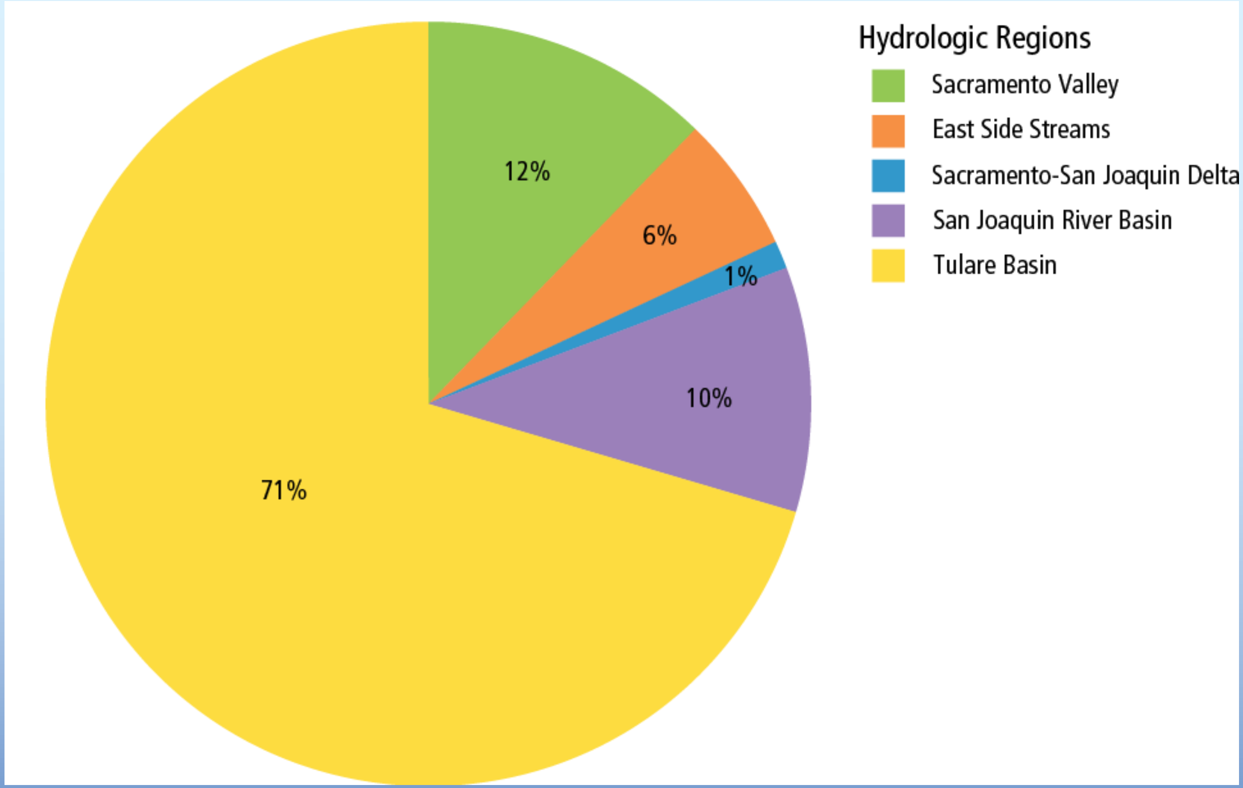
Groundwater Depletion

1922-2009



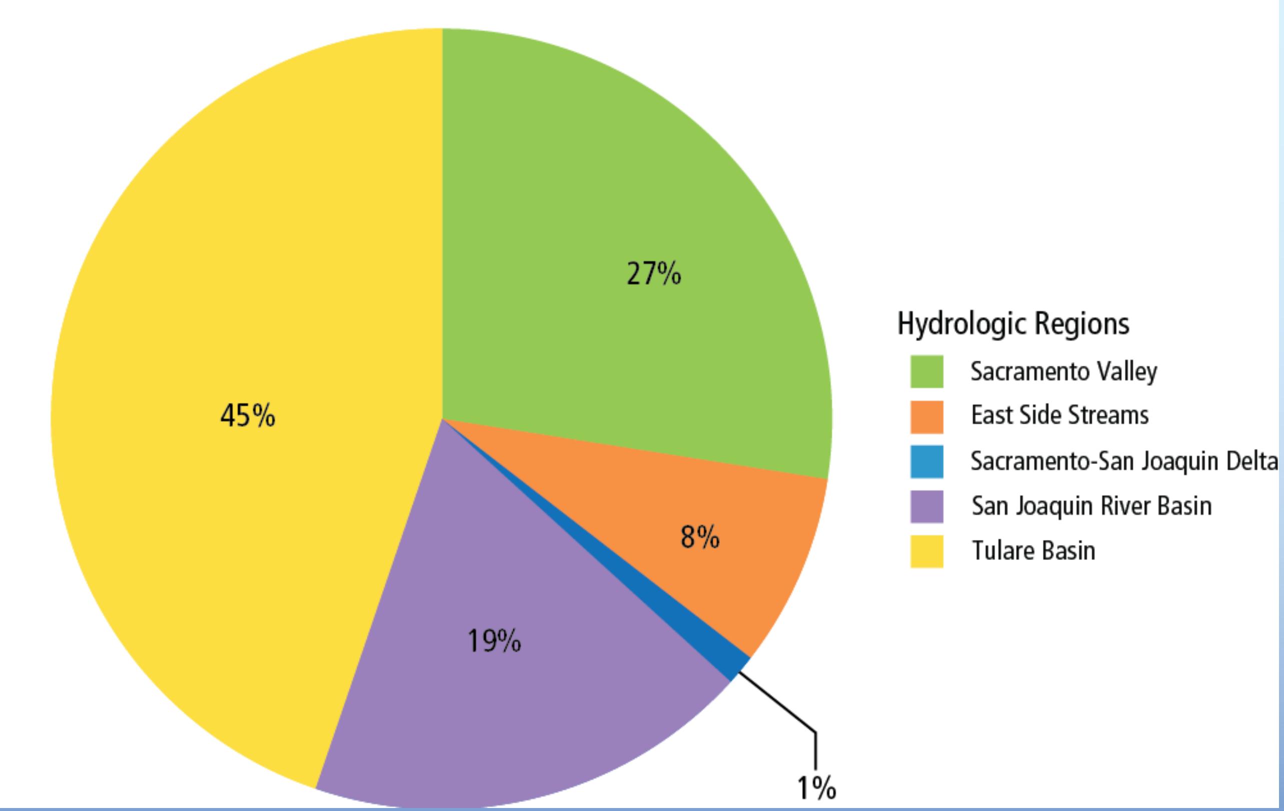
Groundwater Depletion

2000-2009

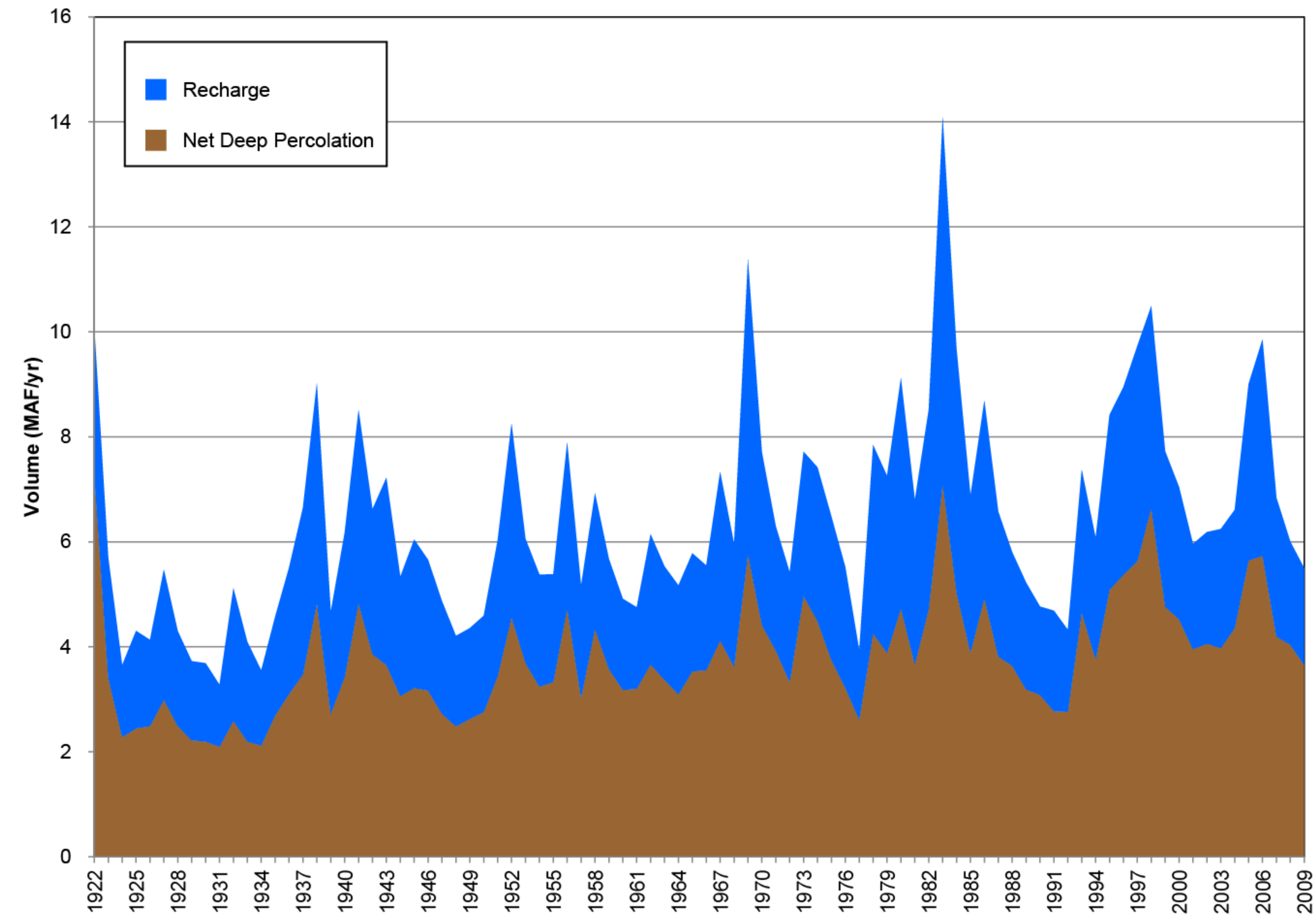


Groundwater Pumping

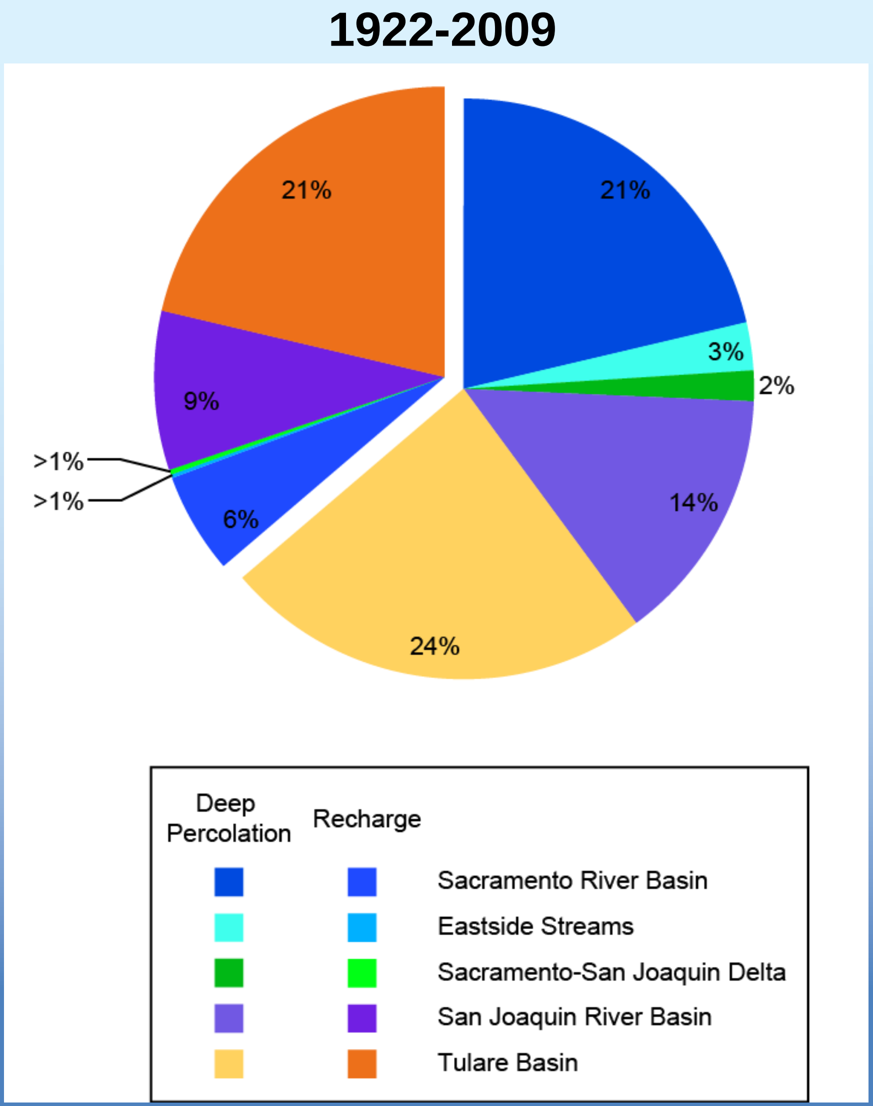
2000-2009



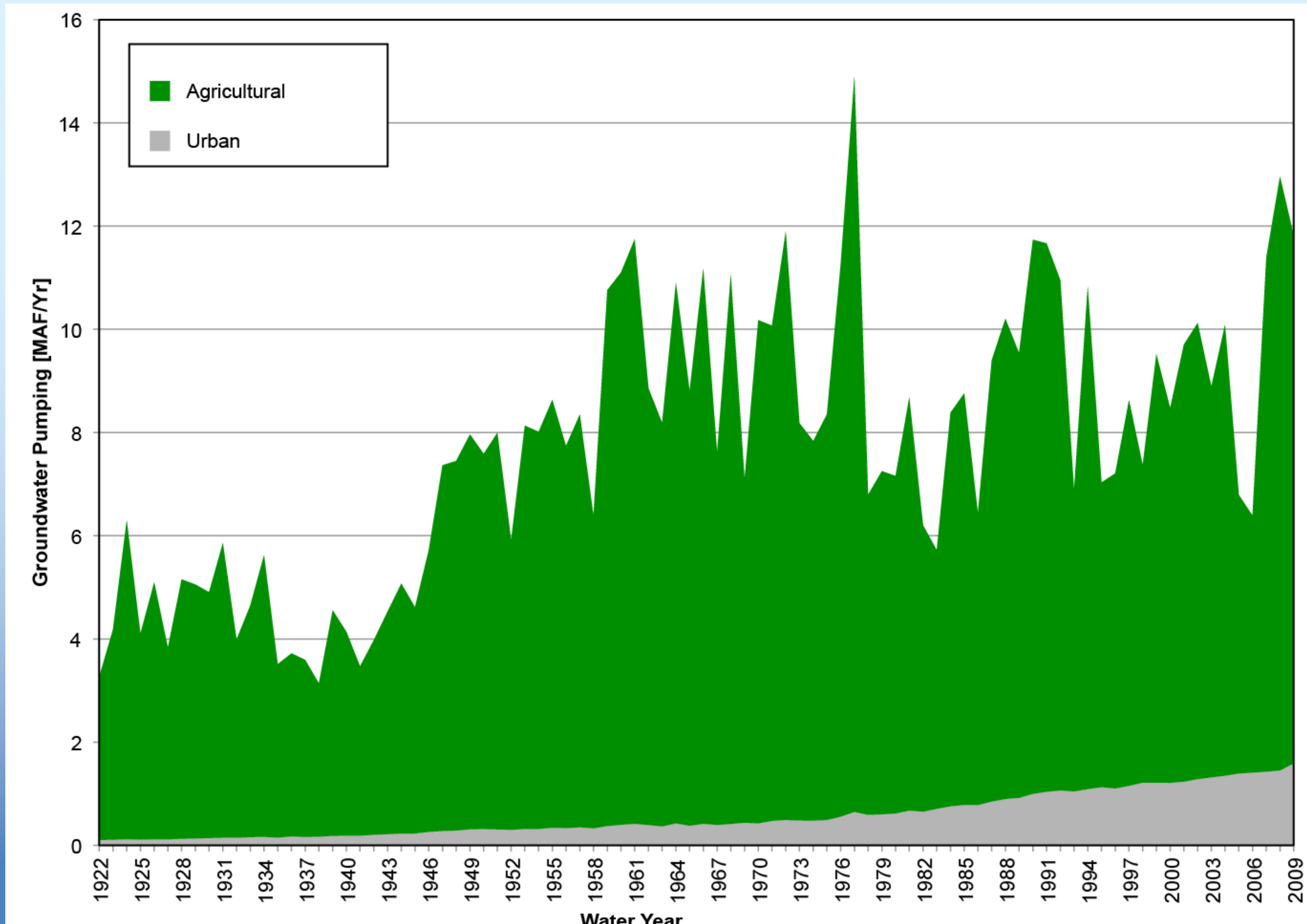
Recharge and Deep Percolation

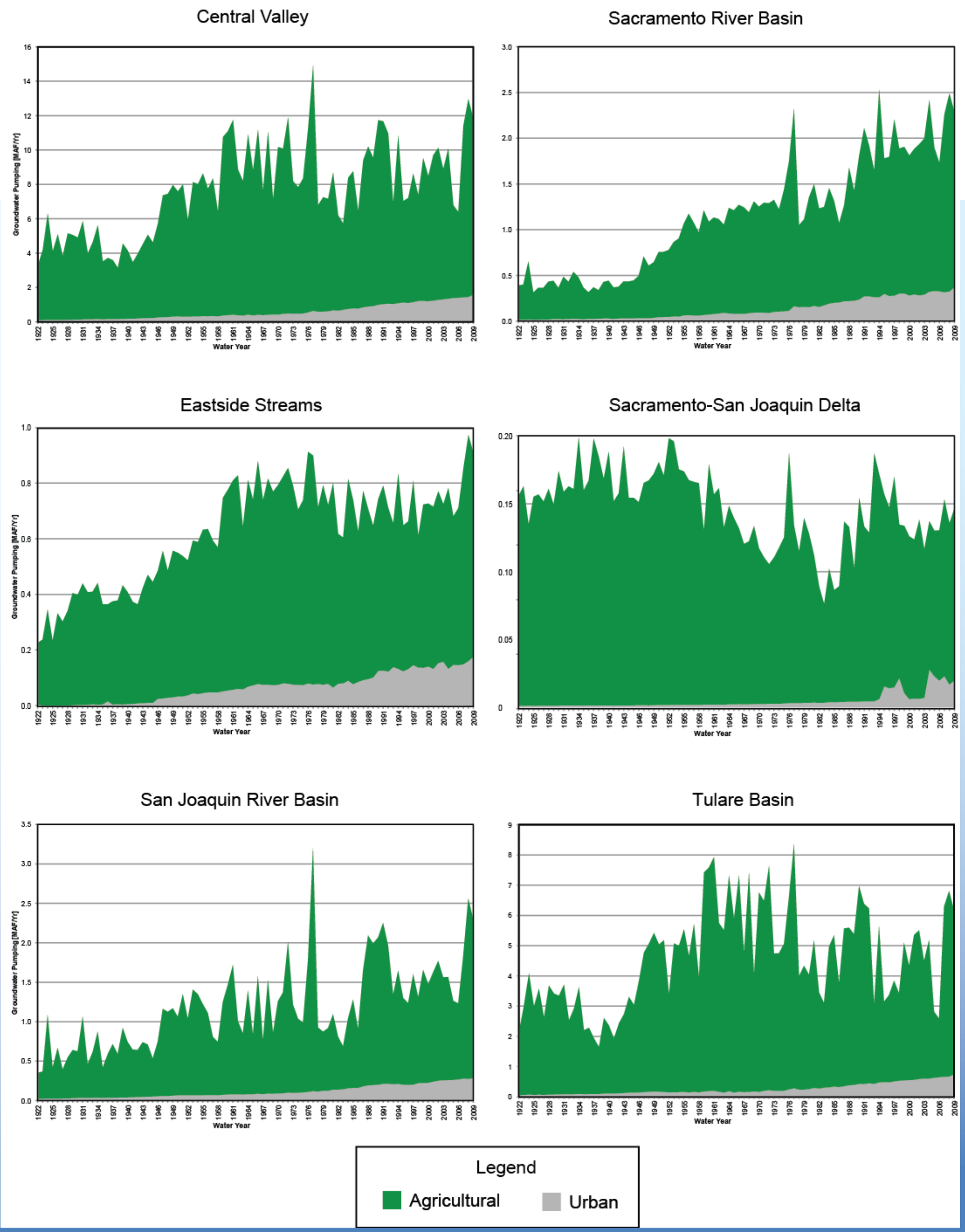


Recharge and Deep Percolation



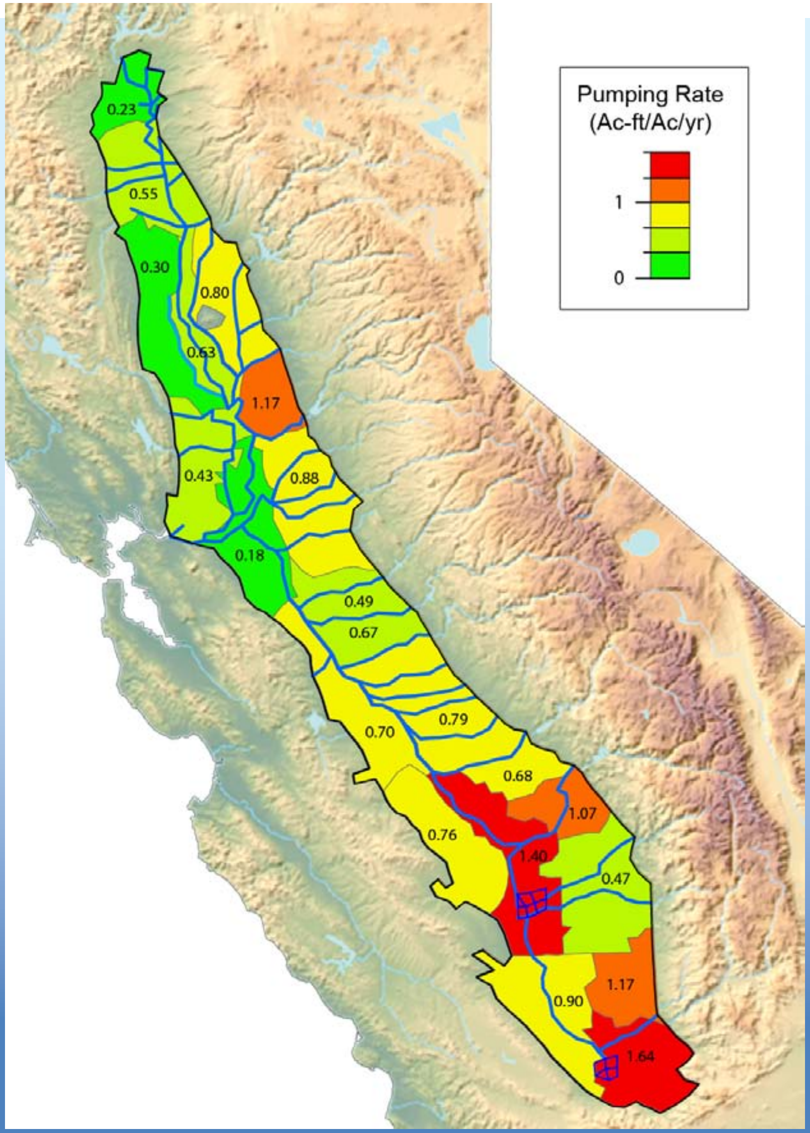
Groundwater Pumping




Central Valley
Sacramento River Basin
Eastside Streams
Sacramento-San Joaquin Delta
San Joaquin River Basin
Tulare Basin
Groundwater Pumping [MAF/Yr]
Water Year
Legend
Agricultural
Urban

Groundwater Pumping

2000-2009



End