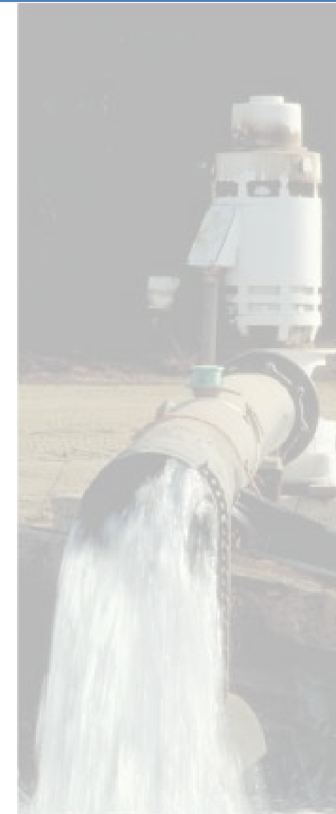
The California Central Valley Groundwater-Surface Water Simulation Model



C2VSim Overview

CWEMF C2VSim Workshop
January 23, 2013

Charles Brush

Modeling Support Branch, Bay-Delta Office

California Department of Water Resources, Sacramento, CA

Outline

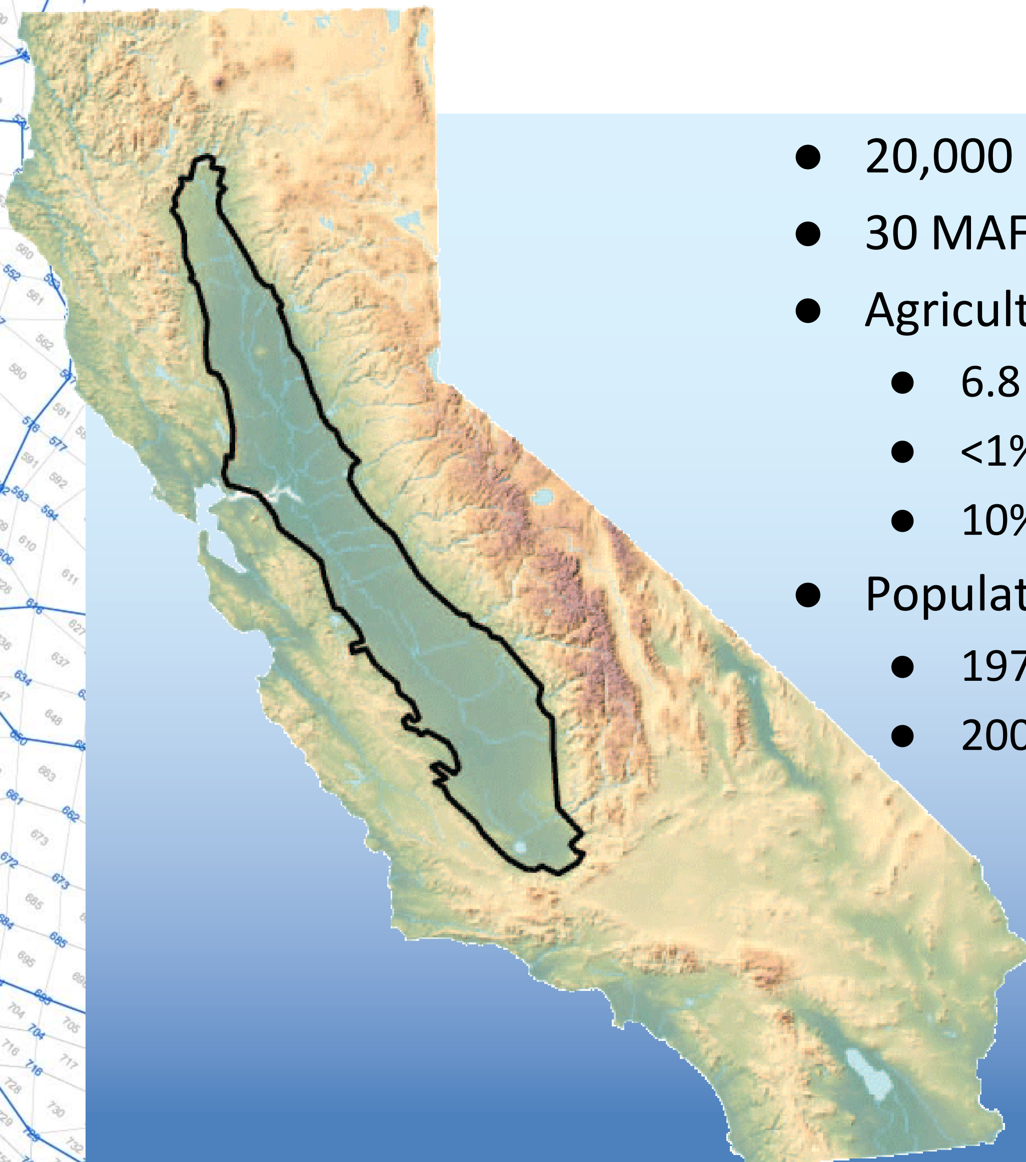
Background and Development History

C2VSim Framework

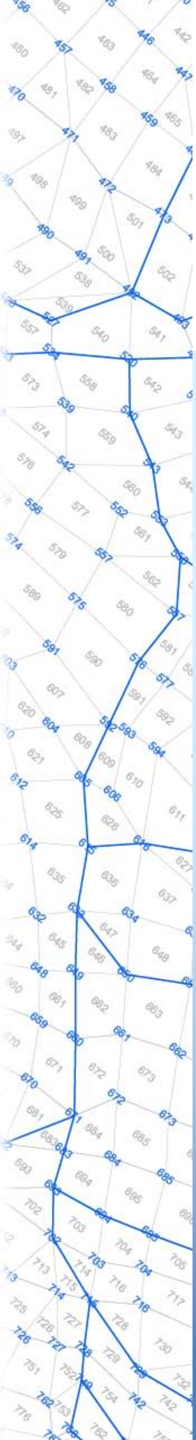
Coarse-Grid and Fine-Grid Versions

Future Directions

California’s Central Valley



- 20,000 sq. mi. (55,000 sq. km.)
- 30 MAF/yr Surface Water Inflow
- Agricultural Production
  - 6.8 million acres (27,500 sq. km)
  - <1% of US farm land
  - 10% of US crops value in 2002
- Population Growth
  - 1970: 2.9 million
  - 2005: 6.4 million
- Groundwater Pumping
  - ~9 MAF in 2002
  - 10-18% if US pumping
  - Not measured or regulated



C2VSim Development

Derived from the CVGSM model

- WY 1922-1980 Boyle & JM Montgomery (1990)
- WY 1981-1998 CH_2M Hill for CVPIA PEIS

Steady modification

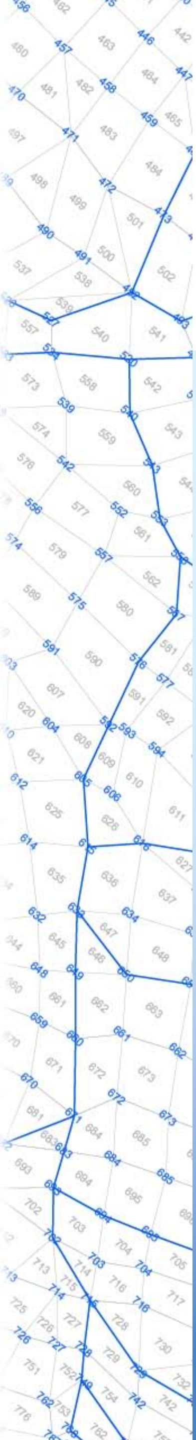
- DWR IWFM/C2VSim development began in 2000
- IWFM process and solver improvements
- C2VSim data sets reviewed and refined
- C2VSim input data extended through WY 2009

Calibration

- PEST parameter estimation program
- Three phases: Regional, Local, Nodal
- Calibration Period: WY 1973-2003 in phases 1 & 2, 1922-2004 in phase 3

Release

- C2VSim 3.02-CG released December 2012
- C2VSim 3.02-FG expected summer 2013



C2VSim Applications

- CalSim 3 groundwater component
- Integrated Regional Water Management Plans
- Stream-groundwater flows
- Climate change assessments
- Groundwater storage investigations
- Planning studies
- Ecosystem enhancement scenarios
- Infrastructure improvements
- Impacts of operations on Delta flows

C2VSim Versions

C2VSim CG 3.02 (R367): Release Version

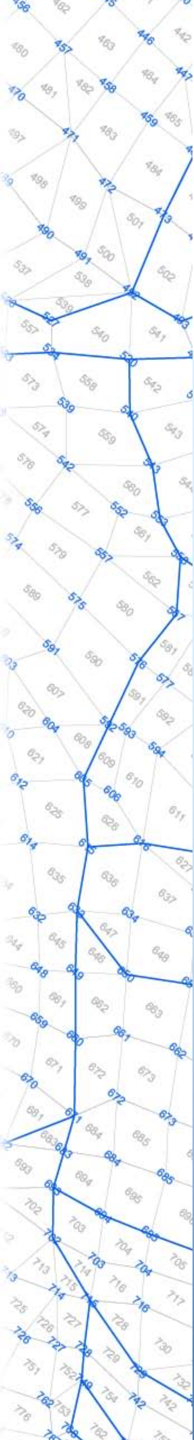
- Current version, released December 2012
- Water Years 1922-2009, monthly time step
- IWFM version 3.02

C2VSim FG 3.02 (R356): Draft Version

- Based on C2VSim 3.02 CG of Jan 2012
- Refine rivers, inflows, land use
- Upgrade to match CG version before release
- Expected release in Summer 2013

Planned Improvements

- C2VSim 3.02 CG/FG: Extend to WY 2011 or 2012
- C2VSim 4.0 FG: Element-level land use, crop and diversion data



C2VSim Coarse Grid

"C2VSim CG-3.02"

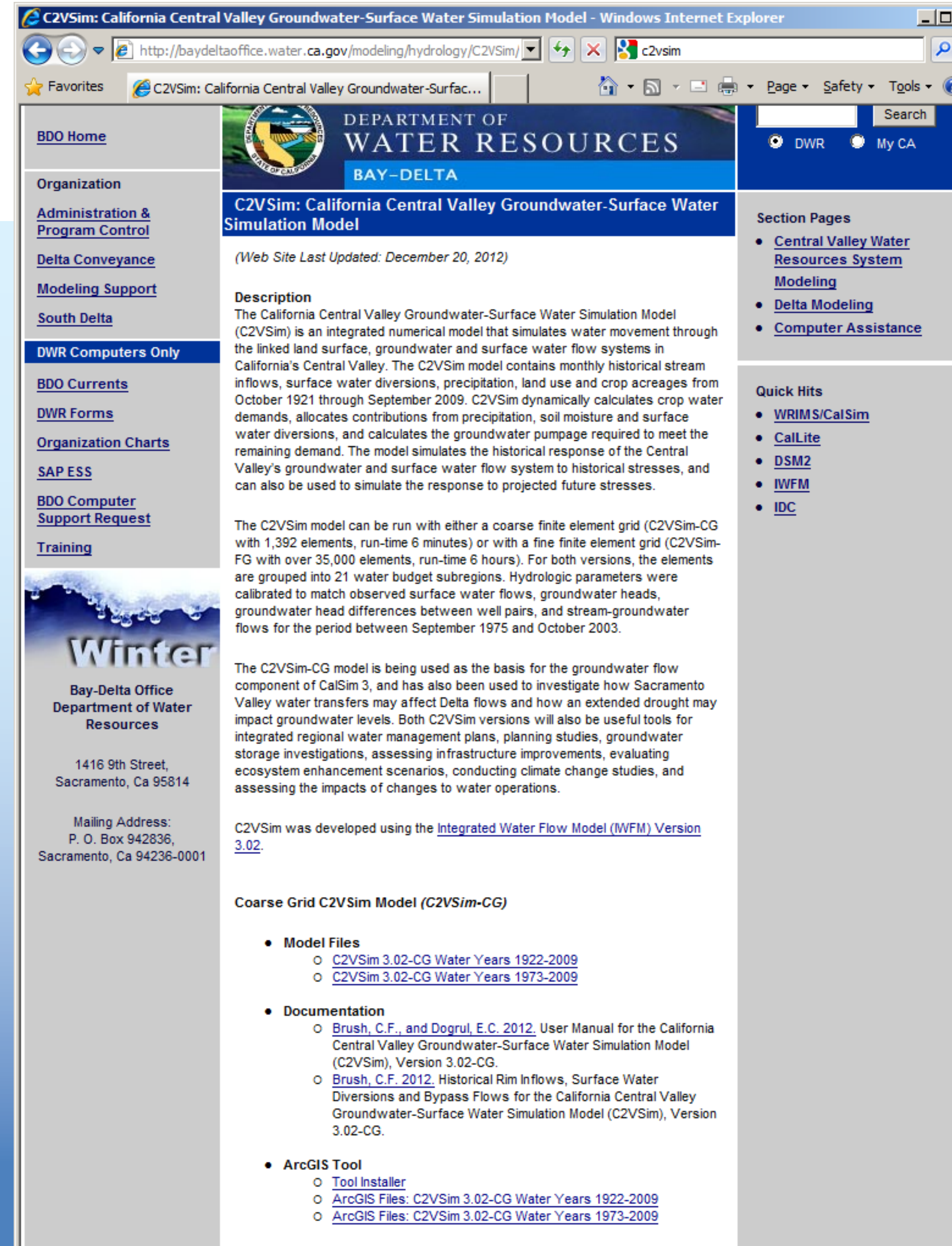
DWR Web Site

- Model files
- Documetation
- C2VSim ArcGIS GUI
- IWFM Application
- IWFM Tools

Support

- **Training**: IWFM and C2VSim workshops will be offered through CWEMF
- **Technical support**: Email and telephone

A Google search for "C2VSim" brings up this page



C2VSim: California Central Valley Groundwater-Surface Water Simulation Model - Windows Internet Explorer

http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/

BDO Home

Organization

Administration & Program Control

Delta Conveyance

Modeling Support

South Delta

DWR Computers Only

BDO Currents

DWR Forms

Organization Charts

SAP ESS

BDO Computer Support Request

Training

Winter

Bay-Delta Office
Department of Water Resources

1416 9th Street,
Sacramento, Ca 95814

Mailing Address:
P. O. Box 942836,
Sacramento, Ca 94236-0001

DEPARTMENT OF WATER RESOURCES
BAY-DELTA

C2VSim: California Central Valley Groundwater-Surface Water Simulation Model

(Web Site Last Updated: December 20, 2012)

Description

The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) is an integrated numerical model that simulates water movement through the linked land surface, groundwater and surface water flow systems in California's Central Valley. The C2VSim model contains monthly historical stream inflows, surface water diversions, precipitation, land use and crop acreages from October 1921 through September 2009. C2VSim dynamically calculates crop water demands, allocates contributions from precipitation, soil moisture and surface water diversions, and calculates the groundwater pumpage required to meet the remaining demand. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses, and can also be used to simulate the response to projected future stresses.

The C2VSim model can be run with either a coarse finite element grid (C2VSim-CG with 1,392 elements, run-time 6 minutes) or with a fine finite element grid (C2VSim-FG with over 35,000 elements, run-time 6 hours). For both versions, the elements are grouped into 21 water budget subregions. Hydrologic parameters were calibrated to match observed surface water flows, groundwater heads, groundwater head differences between well pairs, and stream-groundwater flows for the period between September 1975 and October 2003.

The C2VSim-CG model is being used as the basis for the groundwater flow component of CalSim 3, and has also been used to investigate how Sacramento Valley water transfers may affect Delta flows and how an extended drought may impact groundwater levels. Both C2VSim versions will also be useful tools for integrated regional water management plans, planning studies, groundwater storage investigations, assessing infrastructure improvements, evaluating ecosystem enhancement scenarios, conducting climate change studies, and assessing the impacts of changes to water operations.

C2VSim was developed using the Integrated Water Flow Model (IWFM) Version 3.02.

Coarse Grid C2VSim Model *(C2VSim-CG)*

- **Model Files**
  - C2VSim 3.02-CG Water Years 1922-2009
  - C2VSim 3.02-CG Water Years 1973-2009
- **Documentation**
  - Brush, C.F., and Dogrul, E.C. 2012. User Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG.
  - Brush, C.F. 2012. Historical Rim Inflows, Surface Water Diversions and Bypass Flows for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG.
- **ArcGIS Tool**
  - Tool Installer
  - ArcGIS Files: C2VSim 3.02-CG Water Years 1922-2009
  - ArcGIS Files: C2VSim 3.02-CG Water Years 1973-2009

Section Pages

- Central Valley Water Resources System Modeling
- Delta Modeling
- Computer Assistance

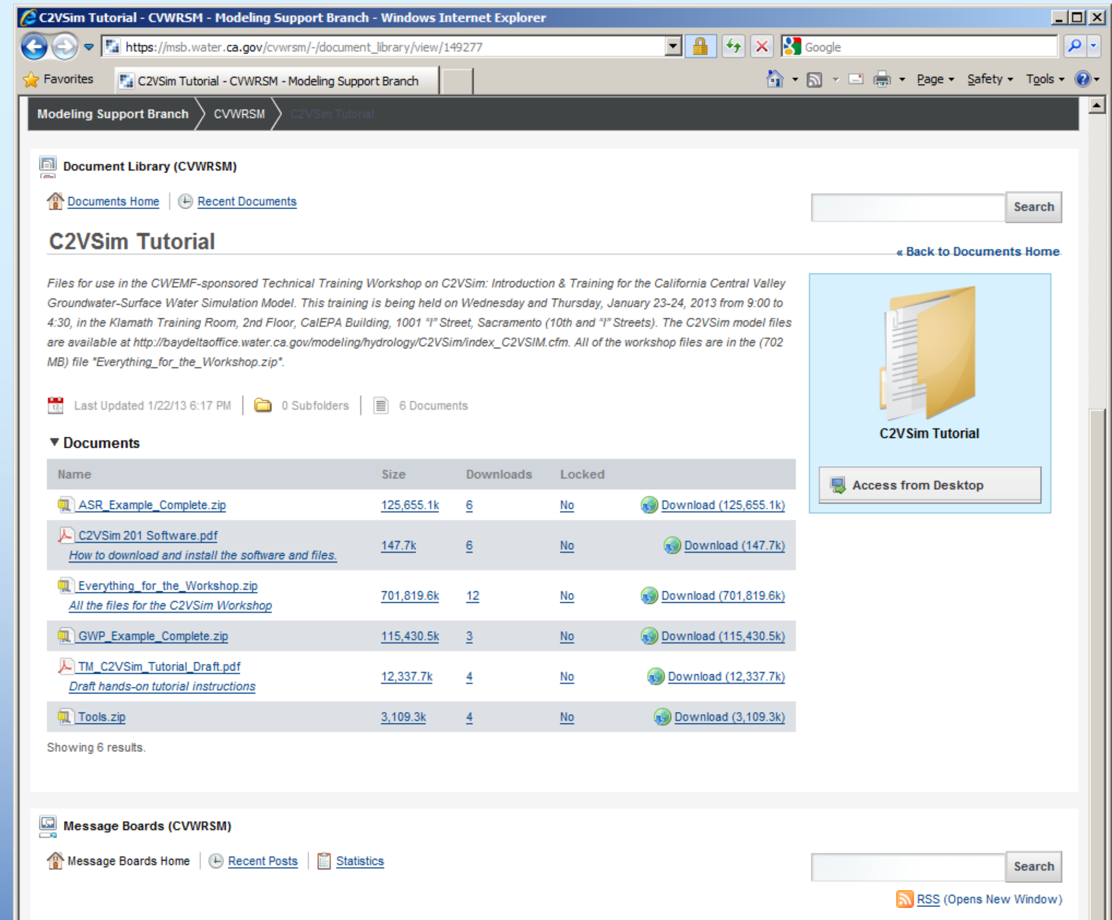
Quick Hits

- WRIMS/CalSim
- CalLite
- DSM2
- IWFM
- IDC

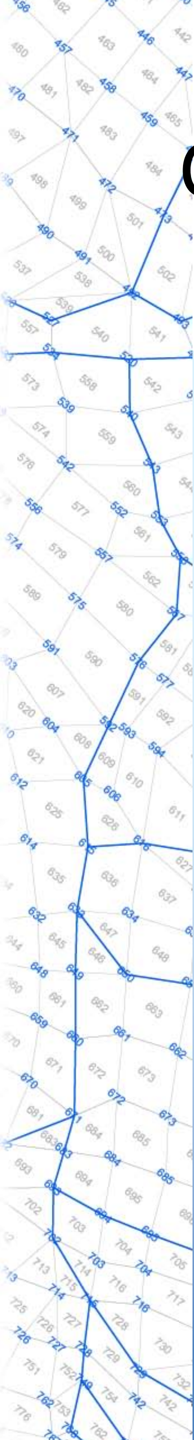
C2VSim Portal

Interactive Web Site

- Tutorial Files
- Project Files
- Collaboration
- Message Board
- User/Password for additional access



https://msb.water.ca.gov/c2vsim/-/document_library/view/140143



C2VSim Coarse-Grid

"C2VSim CG-3.02"

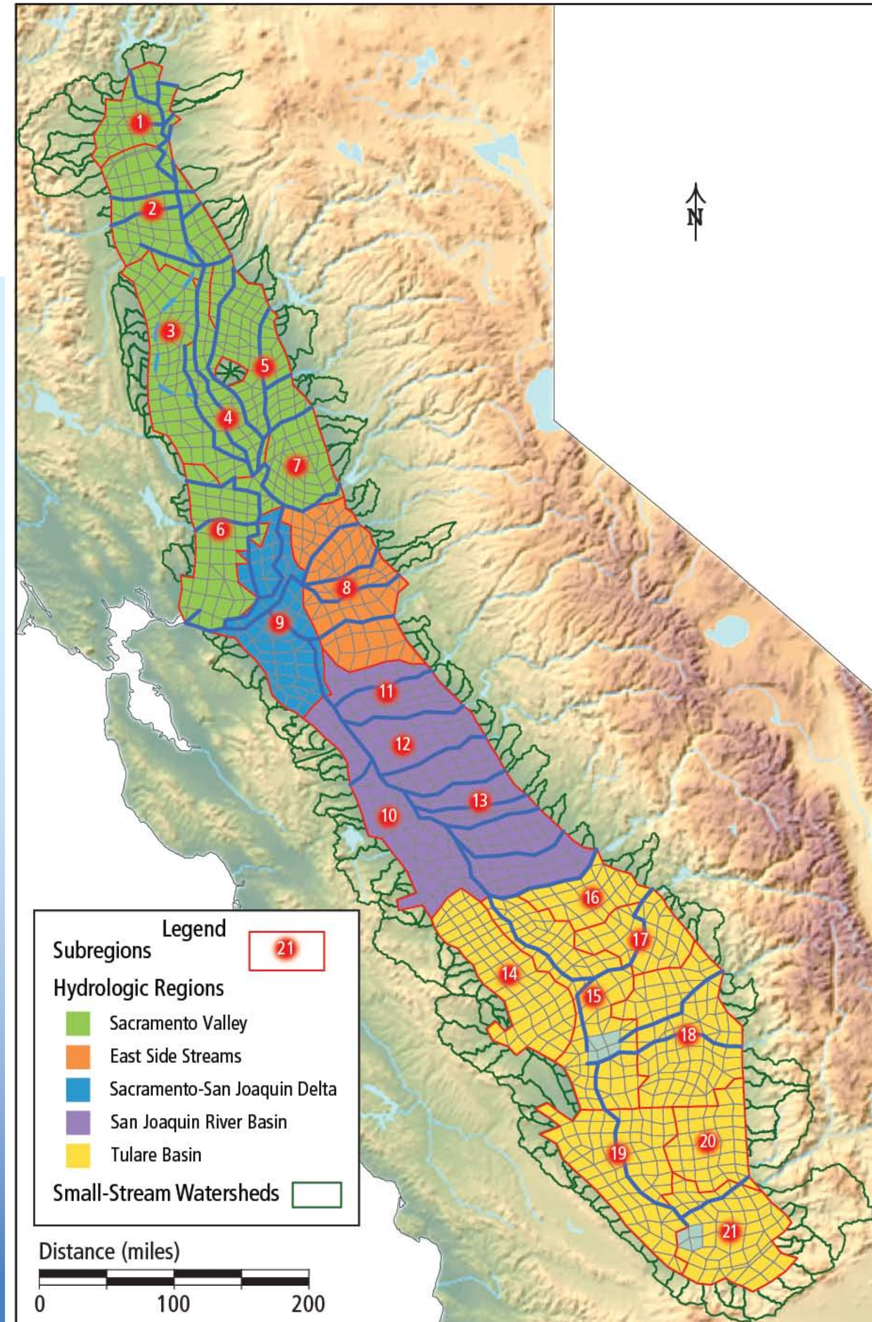
Finite Element Grid
- 3 Layers or 9 Layers
- 1393 Nodes & 1392 Elements

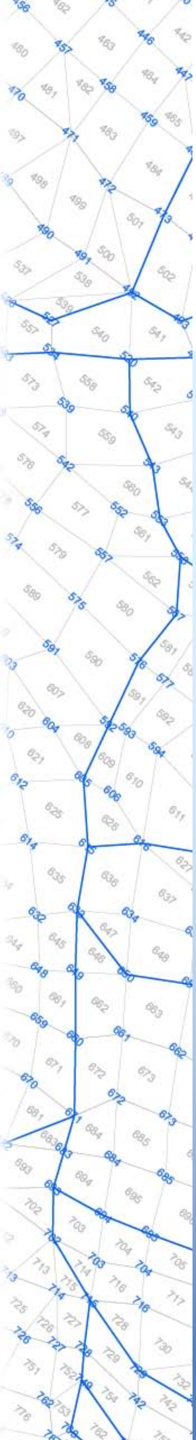
Surface Water System
- 75 River Reaches, 2 Lakes
- 243 Surface Water Diversions
- 38 Inflows, 11 Bypasses
- 210 Small-Stream Watersheds

Land Use Process
- 21 Subregions (DSAs)
- 4 Land Use Types

Simulation periods
- 10/1921-9/2009 (88 yrs)
- runs in 3-6 min

IWFM version 3.02



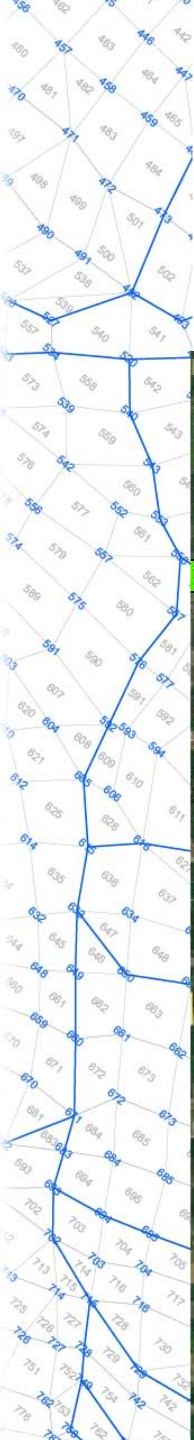


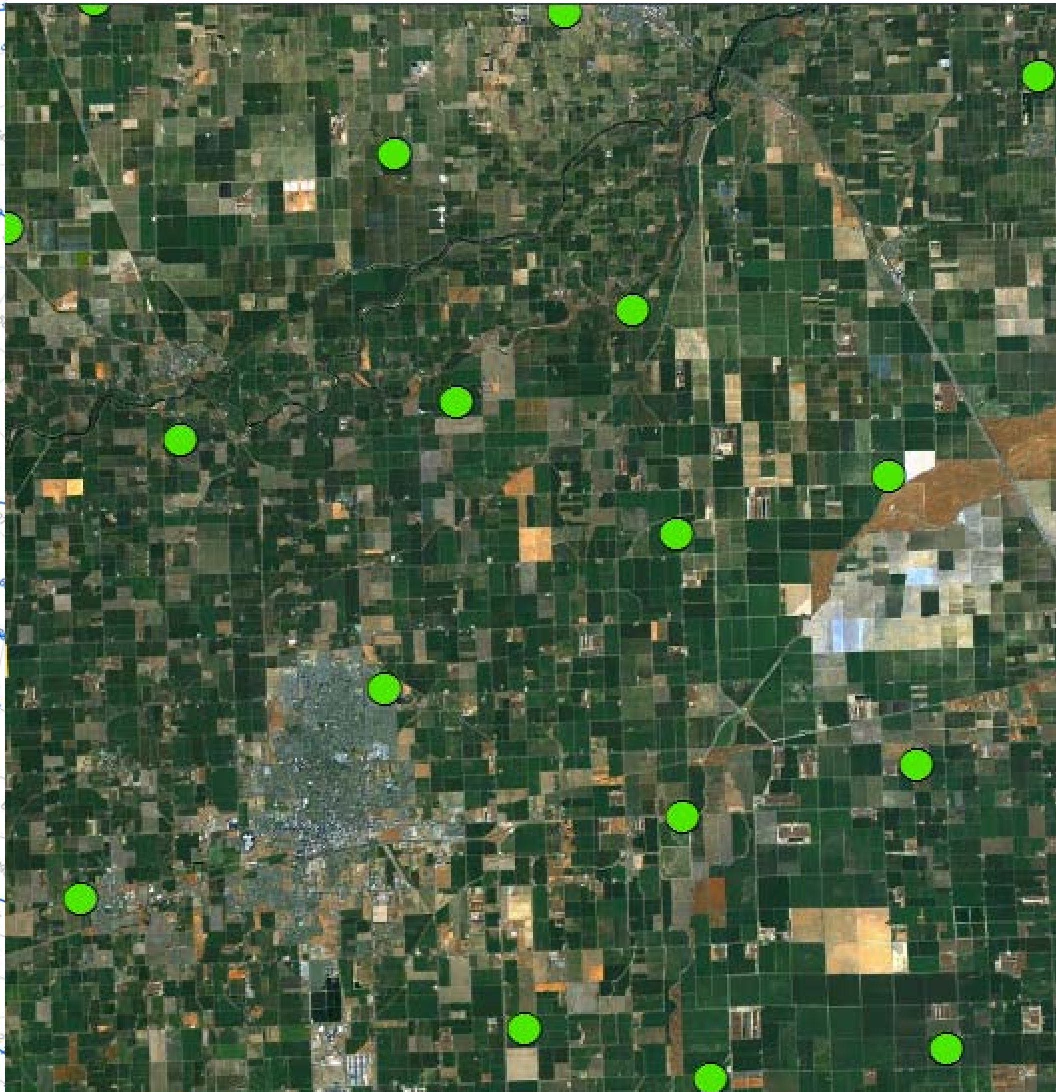
C2VSim Framework

Pre-processor

- Nodal coordinates
- Nodes form elements
- Vertical aquifer stratigraphy
- Lakes
- River nodes
- River reaches & flow network
- Element properties
- Pumping wells
- Assign elements to subregions

Nodes





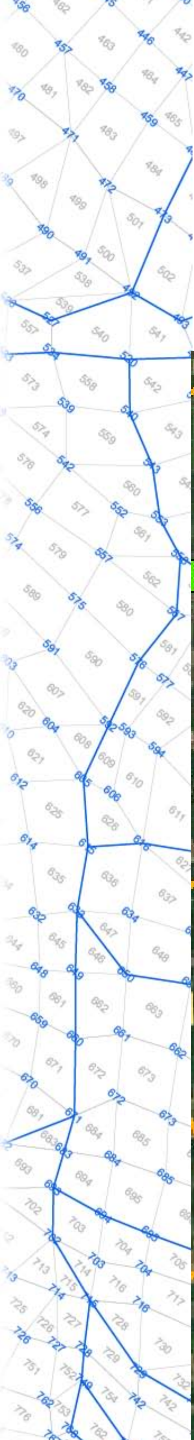
X-Y Grid

- UTM 10N
- X = Easting
- Y = Northing

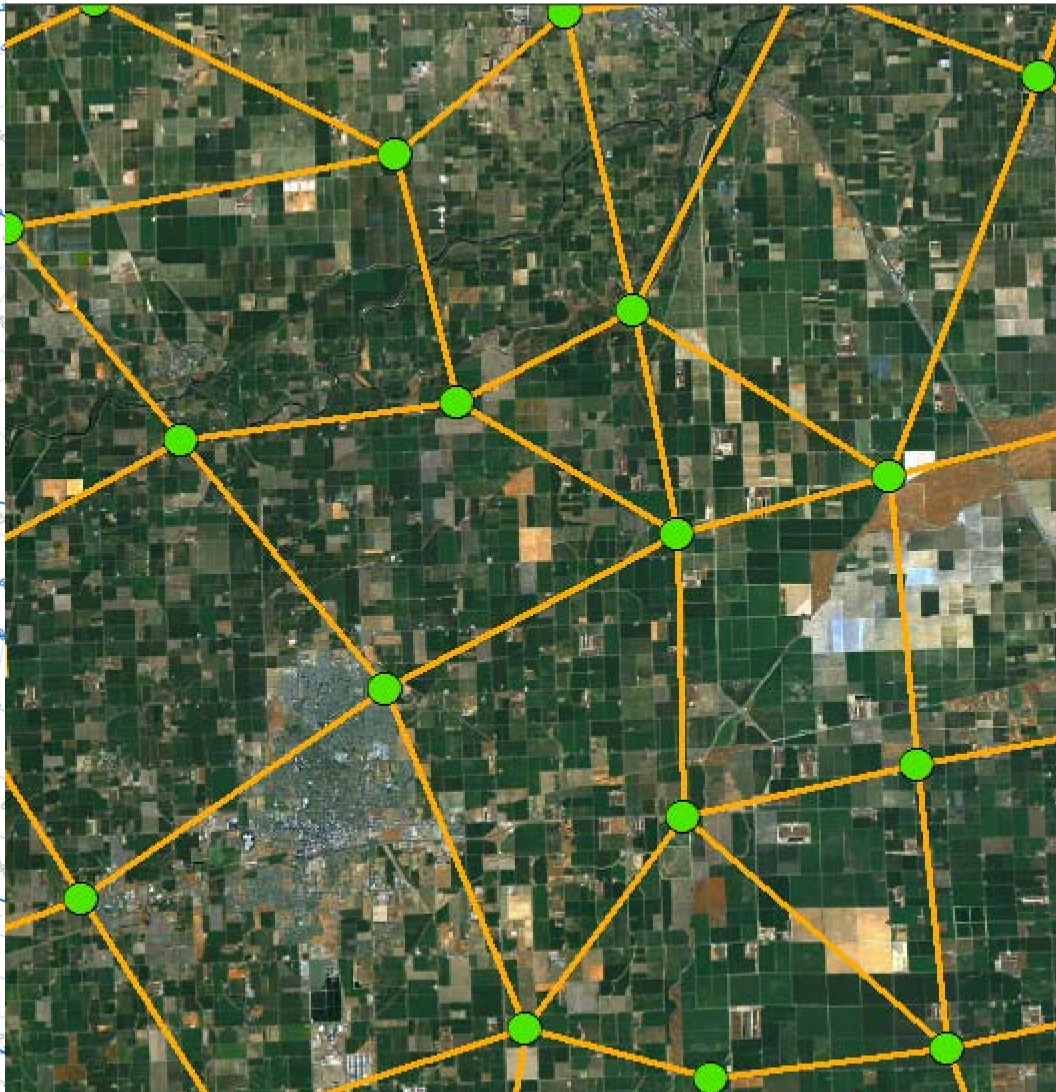
Convert to FT

- FACT = 3.2808

```
C**************************************************************
C                    Groundwater Node Specifications
C
C   ND;     Number of groundwater nodes
C   FACT;   Conversion factor for nodal coordinates
C--------------------------------------------------------------
C   VALUE                              DESCRIPTION
C--------------------------------------------------------------
  1393                                       /ND
  3.2808                                     /FACT
C--------------------------------------------------------------
C**************************************************************
C                      Groundwater Node Locations
C   The following lists the node number and x & y coordinate of
C
C   ID;    Groundwater node number
C   X,Y;   Coordinates of groundwater node location; [L]
C
C--------------------------------------------------------------
C   Node      ----------Coordinates----------
C    ID              X                  Y
C--------------------------------------------------------------
      1         551396.4          4496226
      2         555618.8          4497861
      3         561555.5          4500441
      4         568374.3          4498058
      5         553186.9          4492706
      6         558611.6          4492797
      7         566864.0          4493337
      8         548989.2          4487360
      9         553710.4          4488293
     10         559339.9          4488690
     11         566095.7          4489966
     12         576267.3          4488069
     13         539084.8          4481476
```



Elements



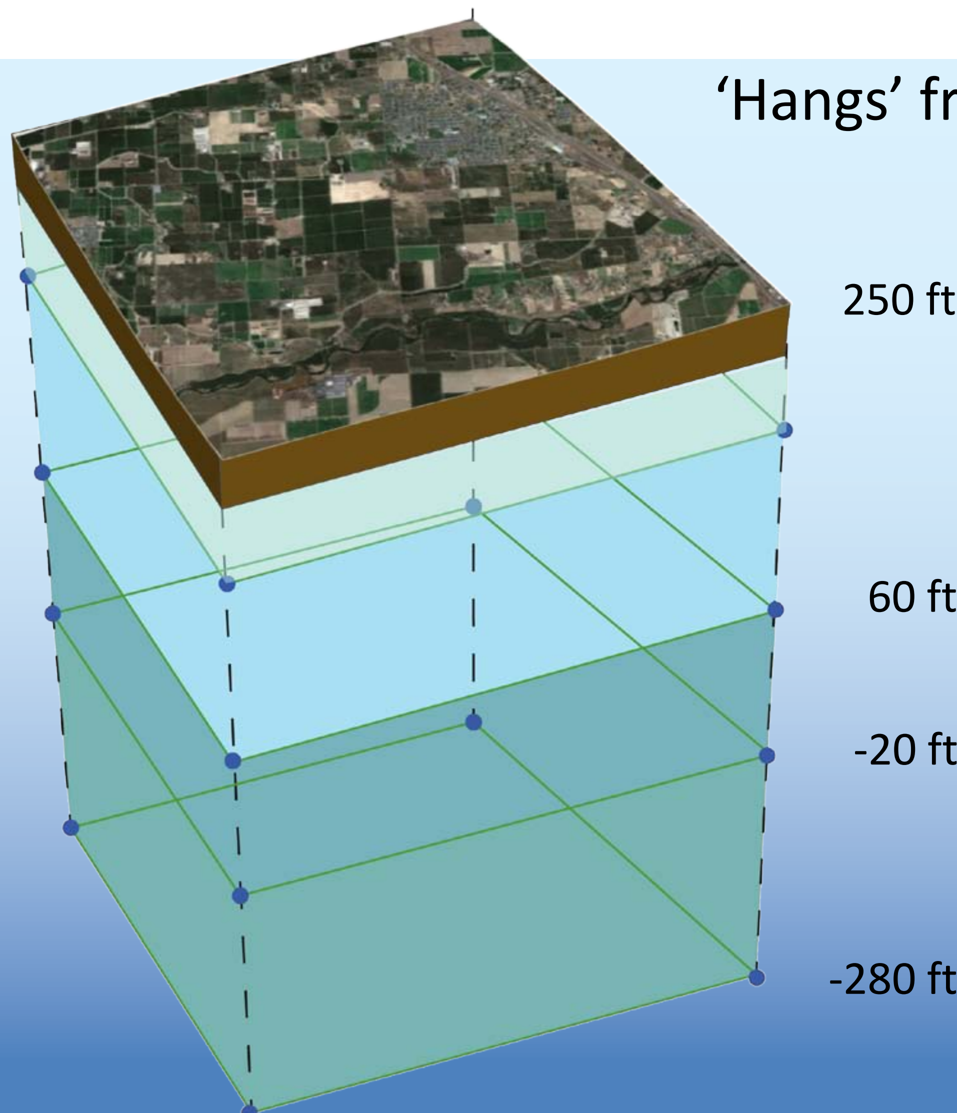
Finite Element Mesh
- 4 nodes = quadrilateral
- 3 nodes = triangle

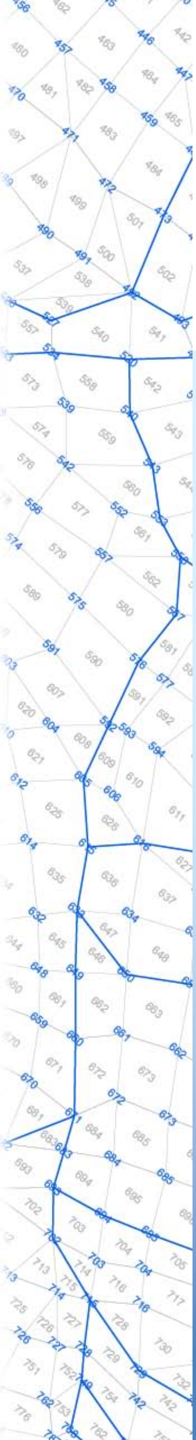
1392 elements

```
C*************************************************************
C                 Element Configuration Data
C
C   NE;    Number of elements within the model domain
C-------------------------------------------------------------
C   VALUE                          DESCRIPTION
C-------------------------------------------------------------
    1392                           /NE
C-------------------------------------------------------------
C*************************************************************
C
C   The data listed below represents all elements and correspo
C   within the model domain.
C
C   IE;      Element number
C   IDE;     Nodes corresponding to each element
C            *Note* IDE(4) is zero for all triangular elements
C
C-------------------------------------------------------------
C   Element      ------------Corresponding Nodes--------------
C   IE           IDE(1)       IDE(2)       IDE(3)       IDE(4)
C-------------------------------------------------------------
       1            1            8            9            5
       2            1            5            6            2
       3            2            6            7            3
       4            3            7            4            0
       5            5            9           10            6
       6            6           10           11            7
       7            8           14           15            9
       8            9           15           16           10
       9           10           16           17           11
      10           11           17           18           12
      11           13           19           20           14
      12           14           20           21           15
      13           15           21           22            0
```

Stratigraphy

‘Hangs’ from Ground Surface





Stratigraphy

At each node:

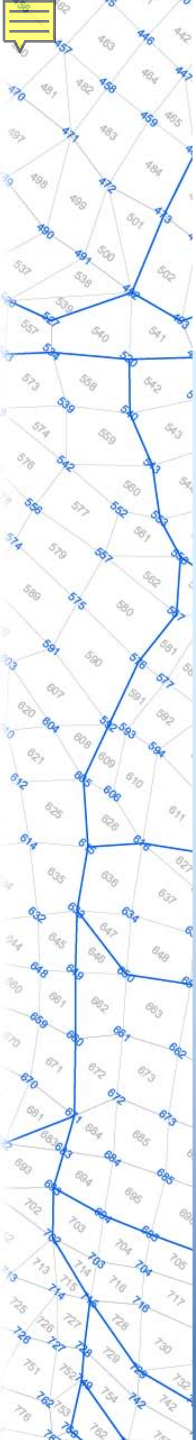
Land Surface Elevation

For each layer

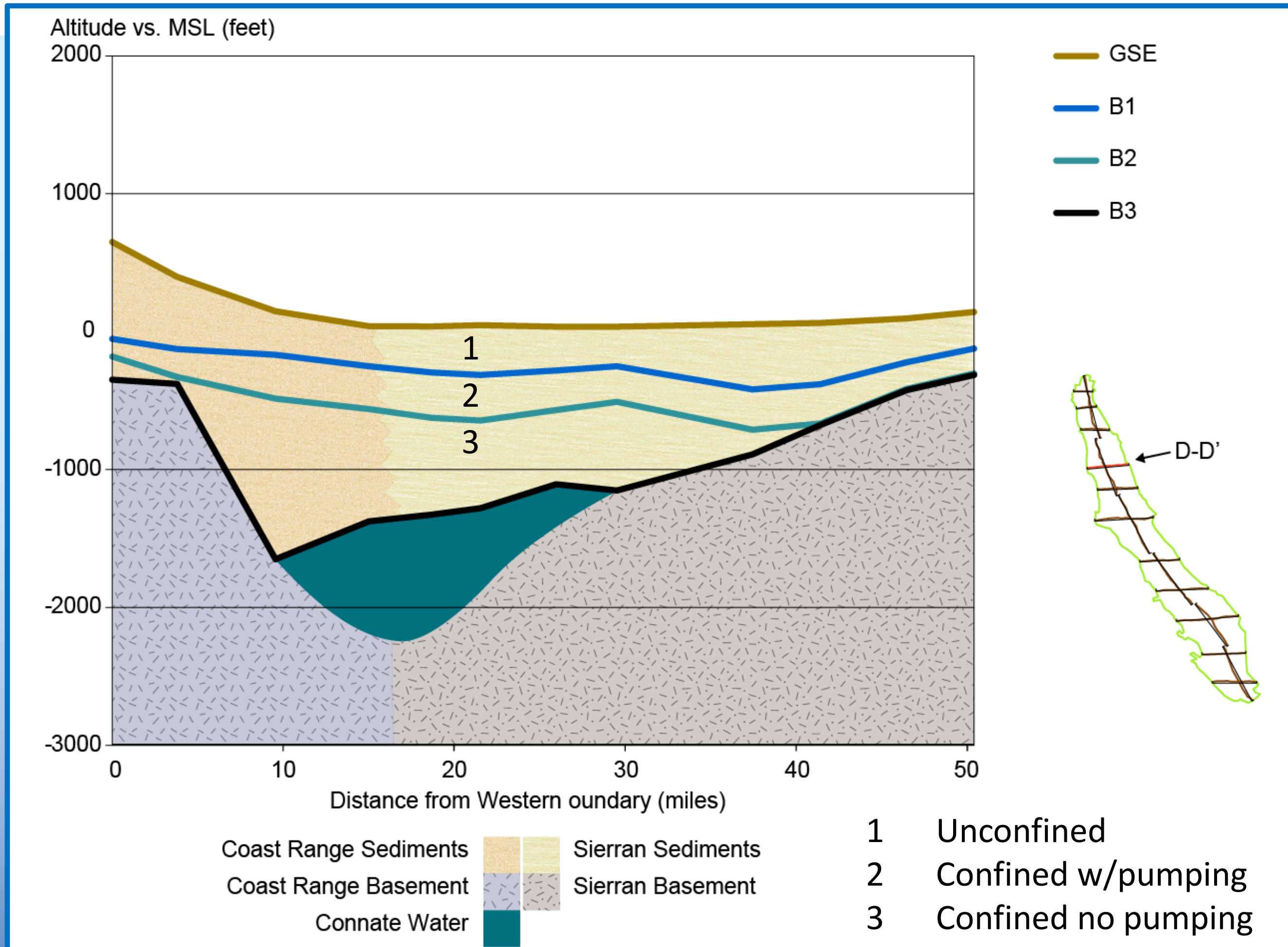
- Aquiclude thickness
- Aquifer thickness

```
C*******************************************************************************
C                   Stratigraphy Specification Data
C
C   NL;     Number of layers to be modeled
C   FACT;   Conversion factor for stratigraphic data
C-------------------------------------------------------------------------------
C   VALUE                            DESCRIPTION
C-------------------------------------------------------------------------------
     3                                /NL
     1                                /FACT
C-------------------------------------------------------------------------------
C---------------------------------------------------------------------
C    Node  Elevation     --Layer #1--     --Layer #2--    --Layer #3--
C     ID     ELV          W(1)    W(2)     W(3)   W(4)     W(5)    W(6)
C---------------------------------------------------------------------
```

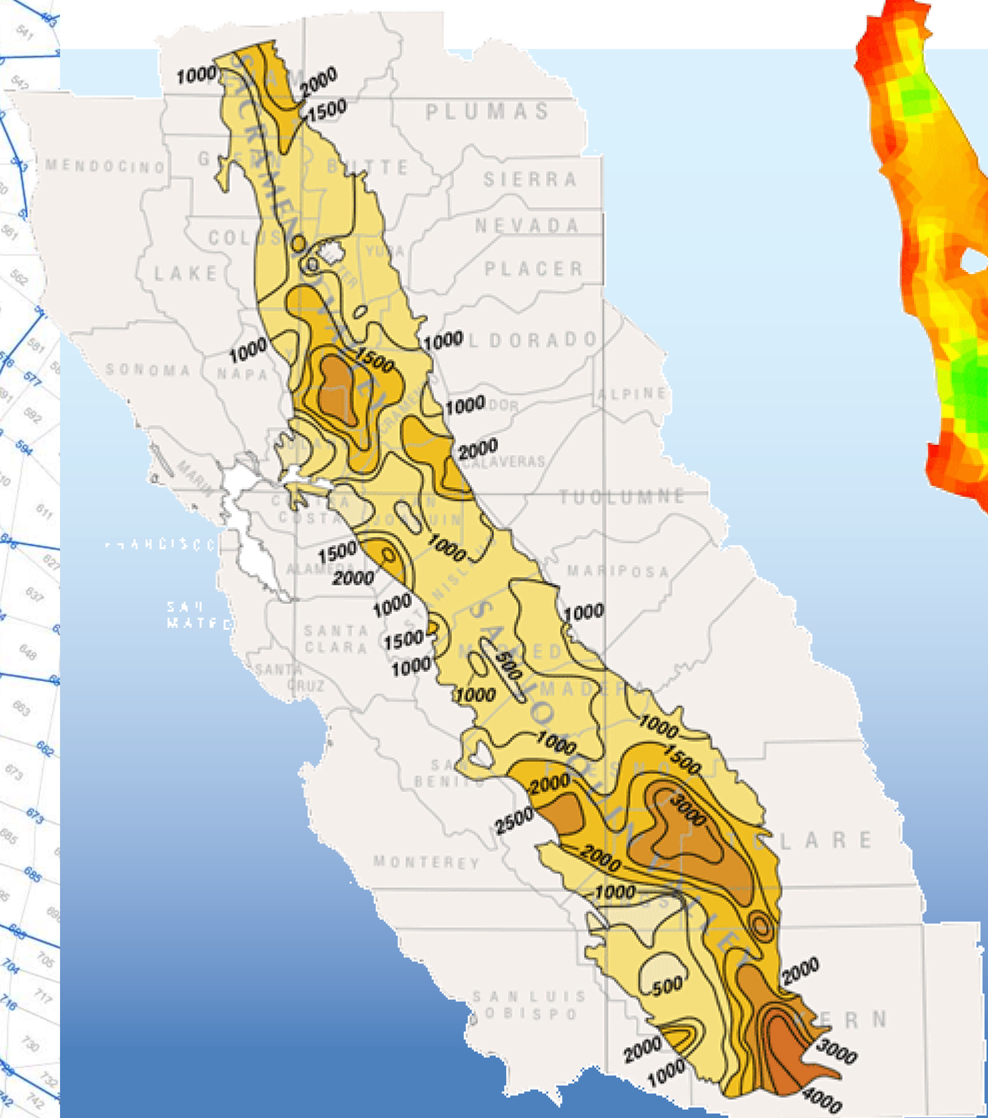
Node ID	Elevation ELV	Layer #1 W(1)	Layer #1 W(2)	Layer #2 W(3)	Layer #2 W(4)	Layer #3 W(5)	Layer #3 W(6)
1	733	0	243	0	100	0	100
2	695	0	245	0	100	0	100
3	705	0	235	0	100	0	100
4	732	0	282	0	100	0	100
5	463	0	89	0	133	0	134
6	590	0	186	0	134	0	133
7	705	0	334	0	133	0	134
8	613	0	213	0	100	0	100
9	455	0	133	0	133	0	133
10	554	0	296	0	178	0	179
11	460	0	168	0	143	0	144
12	800	0	326	0	134	0	134
13	1056	0	606	0	100	0	100
14	795	0	345	0	100	0	100
15	418	0	144	0	163	0	164
16	496	0	317	0	235	0	236
17	499	0	340	0	248	0	249
18	777	0	474	0	167	0	166
19	885	0	305	0	100	0	130
20	818	0	314	0	133	0	134
21	599	0	326	0	198	0	198
22	403	0	420	0	413	0	413
23	457	0	401	0	319	0	318
24	635	0	411	0	186	0	185
25	631	0	122	0	133	0	133
26	622	0	257	0	164	0	165
27	669	0	536	0	317	0	318
28	580	0	808	0	654	0	653
29	372	0	341	0	333	0	334
30	594	0	424	0	213	0	213
31	613	0	20	0	120	0	133
32	735	0	226	0	133	0	133
33	726	0	313	0	140	0	139
34	521	0	246	0	215	0	216
35	436	0	346	0	351	0	351
36	408	0	706	0	697	0	698

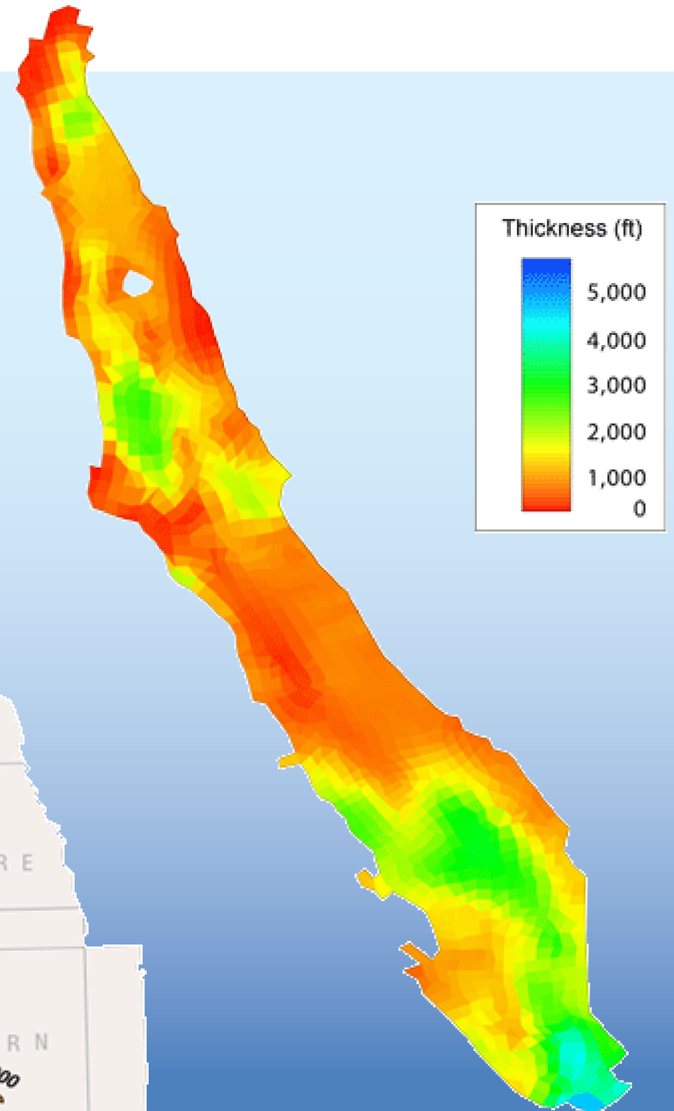


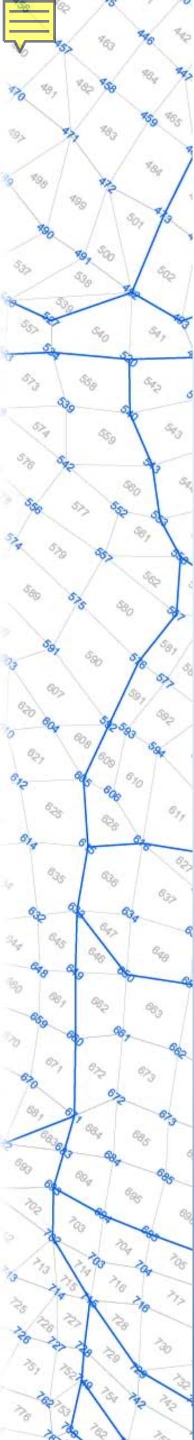
C2VSim Aquifer Cross Section

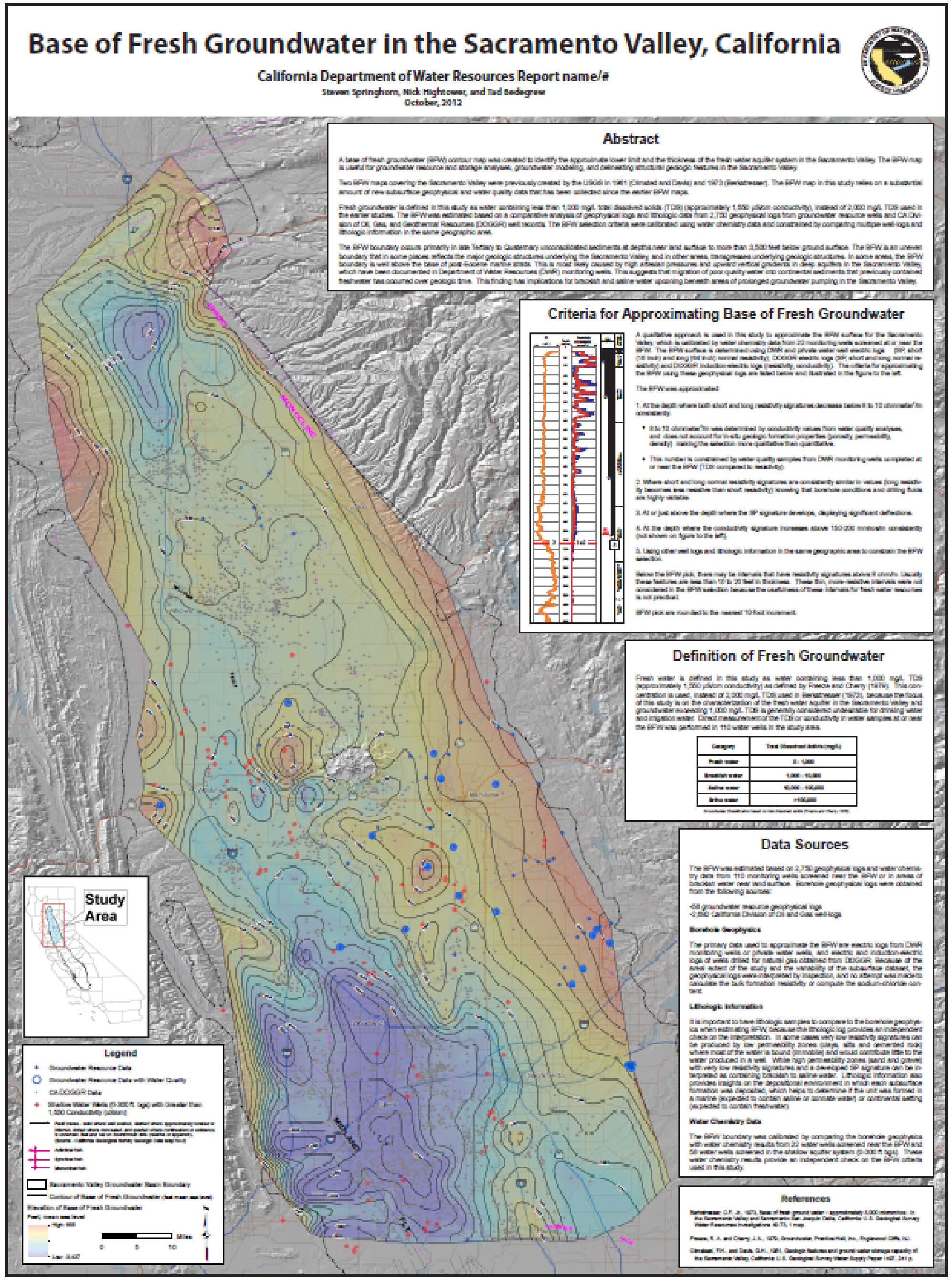


C2VSim Aquifer Thicknesses





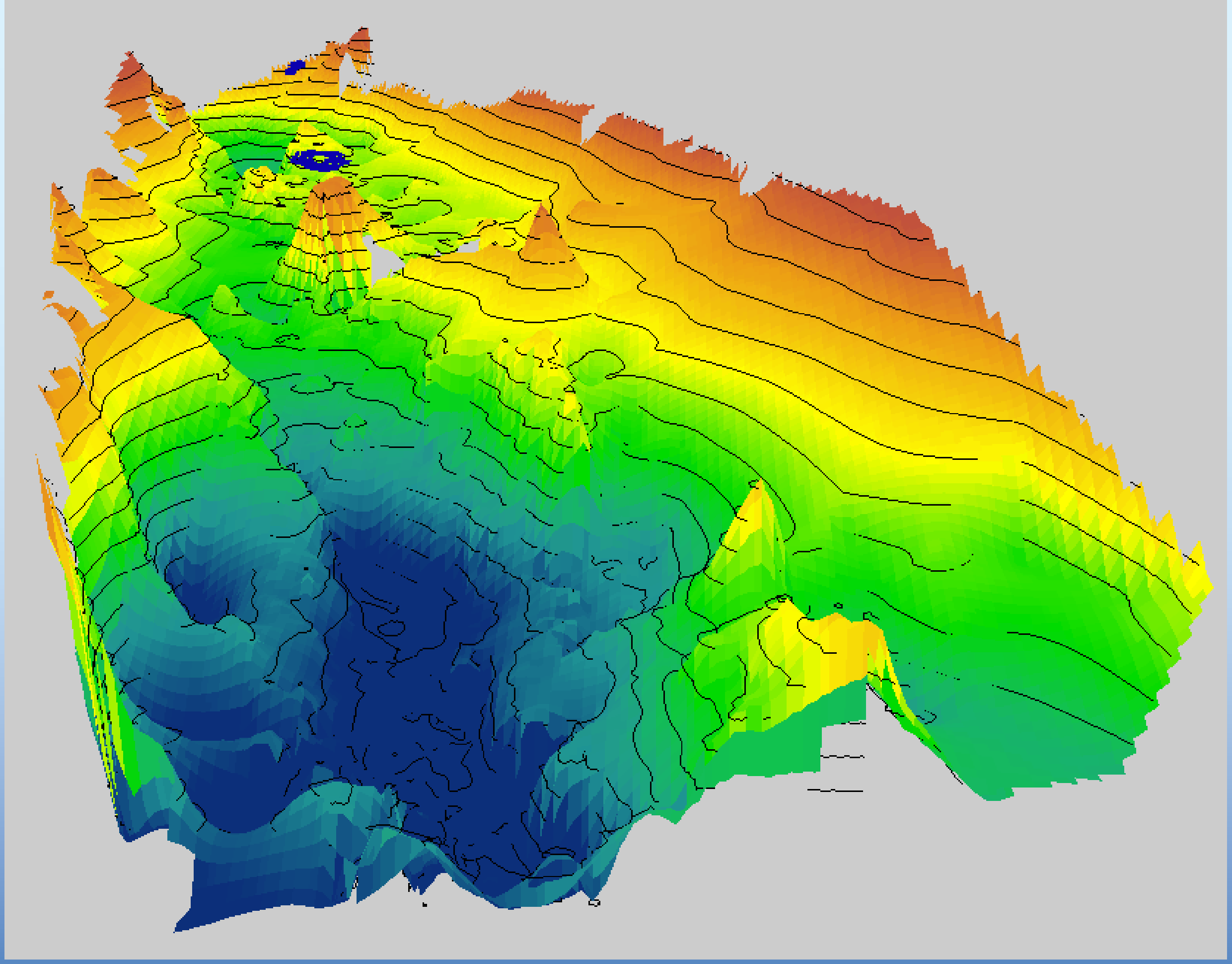


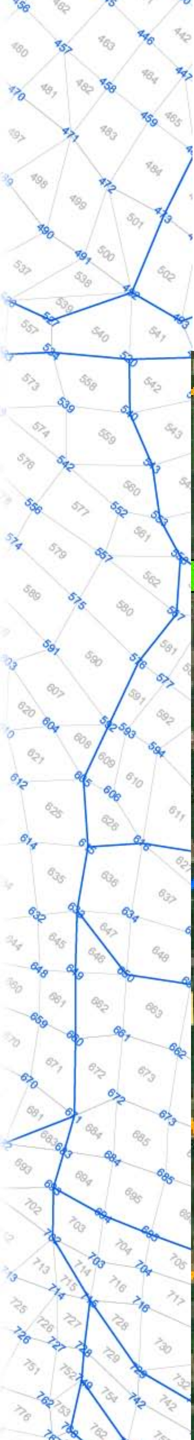


Base of Fresh Groundwater in the Sacramento Valley, California
California Department of Water Resources Report name/#
Steven Springhorn, Nick Hightower, and Tad Bedegrew
October, 2012
Abstract
Criteria for Approximating Base of Fresh Groundwater
Definition of Fresh Groundwater
Data Sources
References
Study Area
Legend

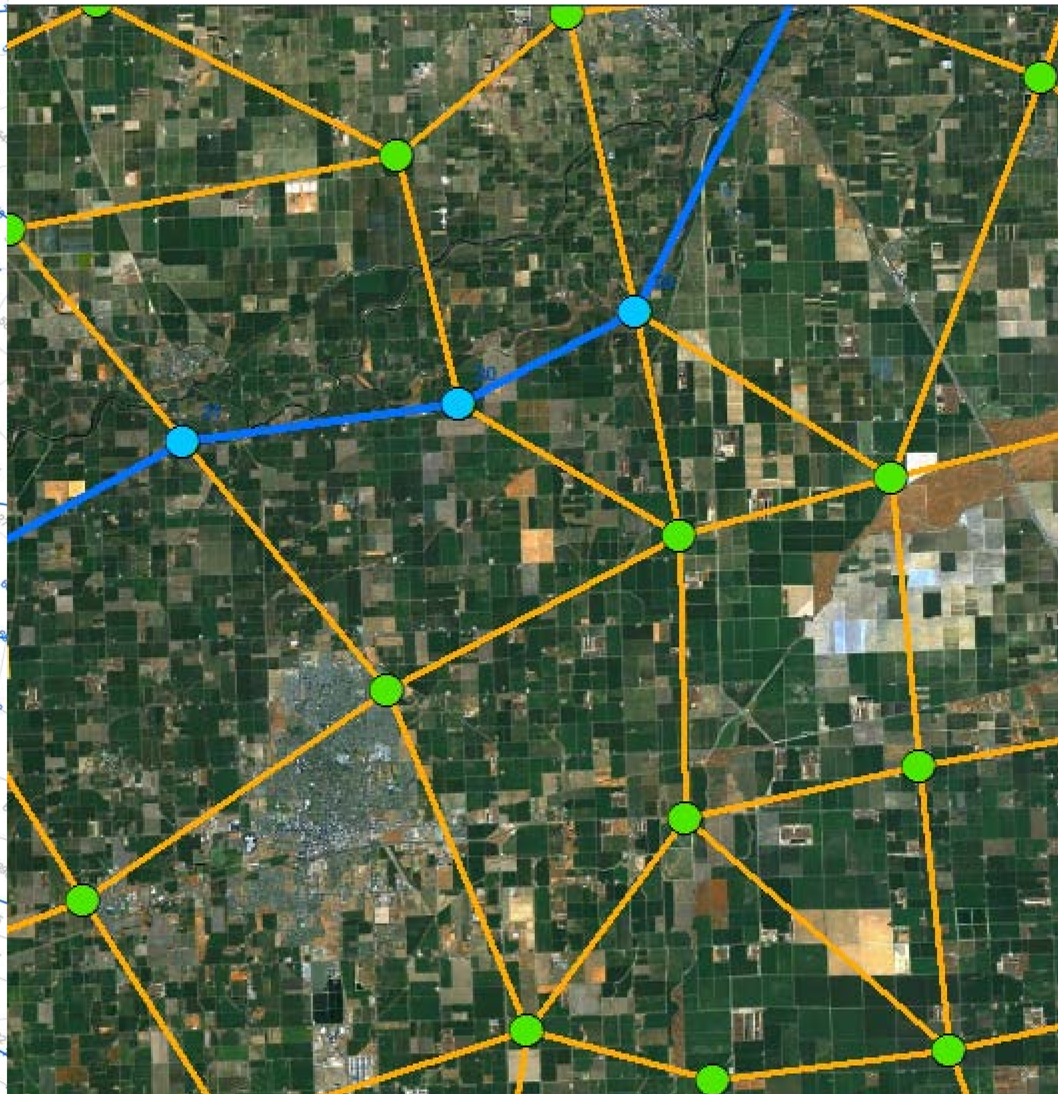
Base of Fresh Water

Three dimensional view (looking north) of the base of fresh water surface



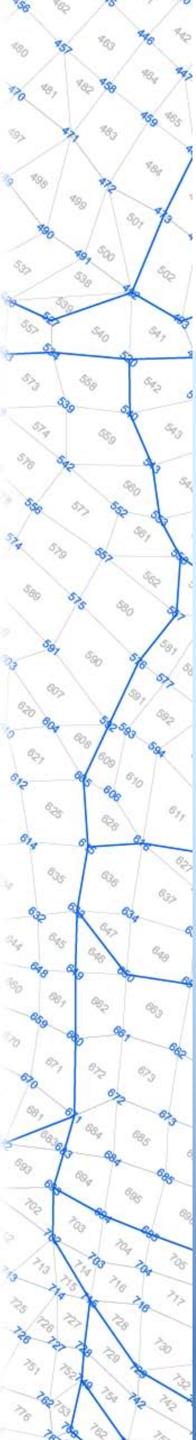


River Nodes and Reaches



Listed by Reach
Nodes linked to mesh

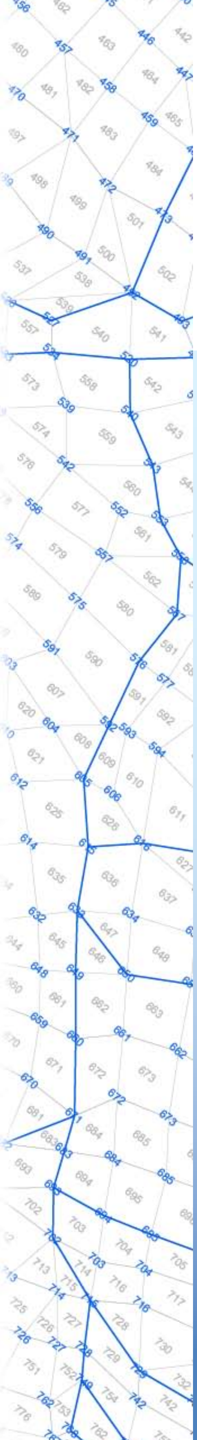
```
C*************************************************************
C                           Stream Reach Specifications
C
C    NRH;    Number of stream reaches modeled
C    NR;     Number of stream nodes modeled
C    NRTB;   Number of data points in stream rating tables
C
C-------------------------------------------------------------
C    VALUE                            DESCRIPTION
C-------------------------------------------------------------
       75                              / NRH
      449                              / NR
       5                               / NRTB
C-------------------------------------------------------------

C-----------------------------------------------
C      REACH  1   -  KERN RIVER
C    Reach  Upstream  Downstream  Outflow
C             Node        Node       Node
C    ID       IBUR        IBDR       IDWN
C-----------------------------------------------
      1         1           9        434
C-----------------------------------------------
C    Stream   Groundwater   Subregion
C    node        node        number
C    IRV         IGW          IRGST
C-----------------------------------------------
      1         1304          21
      2         1315          21
      3         1317          21
      4         1326          21
      5         1325          21
      6         1333          21
      7         1332          21
      8         1331          21
      9         1342          21
C-----------------------------------------------
C      REACH 2   -   KINGS RIVER
C    Reach  Upstream  Downstream  Outflow
C             Node        Node       Node
C    ID       IBUR        IBDR       IDWN
C-----------------------------------------------
      2        23          32         33
C-----------------------------------------------
C    Stream   Groundwater   Subregion
```



River Nodes and Reaches

Rating table for each node
at the end of the file

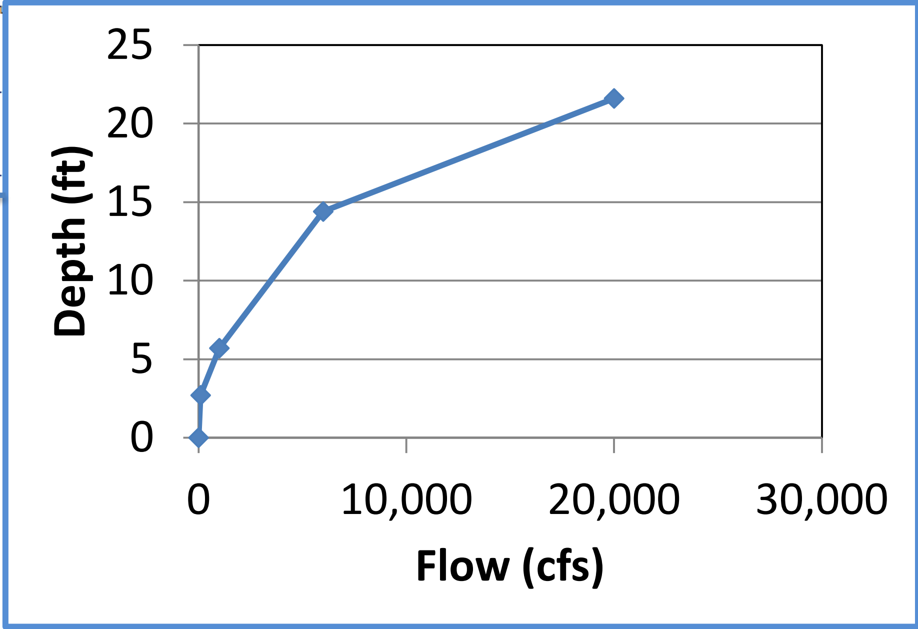
```
C-------------------------------------------------------------------------------
C   VALUE                           DESCRIPTION
C-------------------------------------------------------------------------------
     1.0                             / FACTLT
     60.0                            / FACTQ    (cfs --> cu.ft./min; since "second" is not recognized
     1min                            / TUNIT
C-------------------------------------------------------------------------------
C   The following lists a stream rating table for each of the stream nodes
C   *Note* In order to define a specified stream depth, enter all HRTB values
C             as equal to the specified depth value
C
C   ID;    Stream node number
C   BOTR;  Stream bottom elevation relative to a common datum [L]
C   HRTB;  Stream depth [L]
C   QRTB;  Flow rate at stream depth HRTB [L^3/T]
C
C-------------------------------------------------------------
C   Stream    Bottom   Stream      Flow
C   node     elevation  depth      rate
C   ID         BOTR     HRTB       QRTB
C-------------------------------------------------------------
     1         420.0      0.0        0.00
                          2.7      100.00
                          5.7     1000.75
                         14.4     6000.00
                         21.6    20000.00
     2         400.0      0.0        0.00
                          2.7      100.00
                          5.7     1000.75
                         14.4     6000.00
                         21.6    20000.00
     3         378.3      0.0        0.00
                          2.7      100.00
                          5.7     1000.75
                         14.4     6000.00
                         21.6    20000.00
     4         354.0      0.0        0.00
                          2.7      100.00
                          5.7     1000.75
                         14.4     6000.00
                         21.6    20000.00
     5         328.7      0.0        0.00
                          2.7      100.00
                          5.7     1000.75
                         14.4     6000.00
```

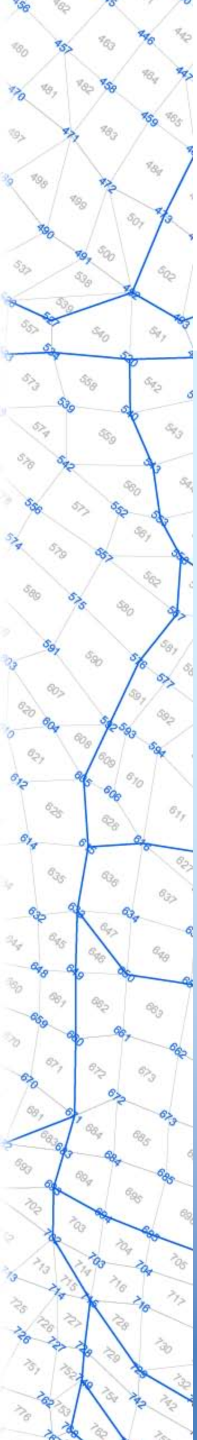


River Nodes and Reaches

Rating table for each node at the end of the file

```
C--------------------------------------------------------------------------------
C   VALUE                           DESCRIPTION
C--------------------------------------------------------------------------------
     1.0                            / FACTLT
     60.0                           / FACTQ     (cfs --> cu.ft./min; since "second" is not recognized
     1min                           / TUNIT
C--------------------------------------------------------------------------------
C   The following lists a stream rating table for each of the stream nodes
C   *Note* In order to define a specified stream depth, enter all HRTB values
C             as equal to the specified depth value
C
C   ID;    Stream node number
C   BOTR;  Stream bottom elevation relative to a com
C   HRTB;  Stream depth [L]
C   QRTB;  Flow rate at stream depth HRTB [L^3/T]
C
C-----------------------------------------------------
C   Stream     Bottom    Stream       Flow
C   node     elevation   depth        rate
C   ID          BOTR      HRTB        QRTB
C-----------------------------------------------------
     1         420.0       0.0        0.00
                           2.7      100.00
                           5.7     1000.75
                          14.4     6000.00
                          21.6    20000.00
     2         400.0       0.0        0.00
                           2.7      100.00
                           5.7     1000.75
                          14.4     6000.00
                          21.6    20000.00
     3         378.3       0.0        0.00
                           2.7      100.00
                           5.7     1000.75
                          14.4     6000.00
                          21.6    20000.00
     4         354.0       0.0        0.00
                           2.7      100.00
                           5.7     1000.75
                          14.4     6000.00
                          21.6    20000.00
     5         328.7       0.0        0.00
                           2.7      100.00
                           5.7     1000.75
                          14.4     6000.00
```



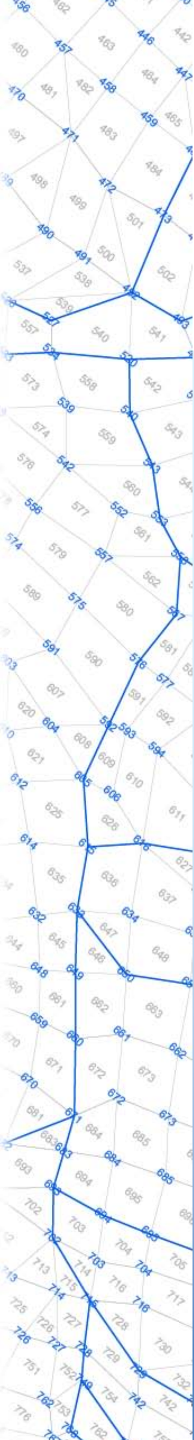


Lakes

Groups of Elements

Outflow = River Node #

```
C*******************************************************************************
C                  Lake Configuration Data
C
C   NLAKE  ; Number of lakes that are being modeled
C   NTELAKE; Total number of lake elements
C
C-------------------------------------------------------------------------------
C   VALUE                          DESCRIPTION
C-------------------------------------------------------------------------------
     2                             / NLAKE
     10                            / NTELAKE
C-------------------------------------------------------------------------------
C

C   ID    ;  Sequential number for the lakes
C   INLAKE;  Next downstream lake number
C              0 : if flow from lake leaves the modeled area
C            -nd : if flow from lake goes to stream node nd
C             nd : if flow from lake goes to the downstream lake, nd
C   NELAKE;  Number of lake elements where lake lies
C   IELAKE;  Element in which the lake is located
C-------------------------------------------------------------------------
C   Lake No.    Next Lake  Elem per Lake   Element
C     ID         INLAKE       NELAKE        IELAKE
C-------------------------------------------------------------------------
C    Buena Vista Lake
     1          -434          4             1352
                                            1353
                                            1363
                                            1364
C    Tulare Lake
     2           -42          6             1109
                                            1110
                                            1111
                                            1136
                                            1137
                                            1138
```



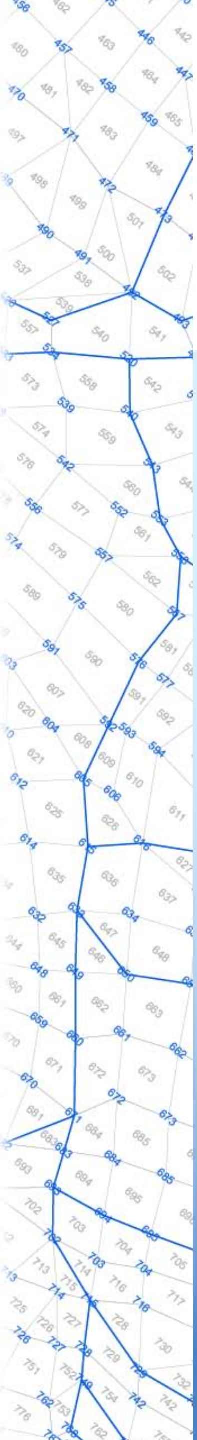
Element Characteristics

- Precipitation data column
- River node receiving drainage
- Subregion
- Soil type

  A = 1 B = 2

  C = 3 D = 4

```
C
C  The following lists the hydrologic characteristics of each element:
C
C  IE;     Element number
C  IRNE;    Rainfall station assigned to the element IE
C          (enter zero for all elementsif no land processes other than
C           streams and lakes are modeled)
C  FRNE;    Factor to convert rainfall at the assigned rainfall station to
C          rainfall at the element IE
C  ISTE;    Stream node to which surface water from element IE drains to
C          (enter zero if the surface flow from element IE leaves the model area)
C  IRGE;    Subregion number to which element IE belongs to
C  ISGE;    Element sub-group number to which element IE belongs to
C  ISOILE;  Hydrologic soil property of the element (ie. A=1, B=2, C=3, D=4)
C          (Reference for A-D soil types: USDA, 1985)
C
C-------------------------------------------------------------------------------------------
C   Element   Rain      Rain     Drain    Sub-     Sub-     Soil
C   number    station   factor   node     region   group    type
C   IE        IRNE      FRNE     ISTE     IRGE     ISGE     ISOILE
C-------------------------------------------------------------------------------------------
    1         1         1        207      1        1        3.100
    2         2         1        206      1        1        3.000
    3         3         1        206      1        1        3.000
    4         4         1        206      1        1        3.000
    5         5         1        207      1        1        3.850
    6         6         1        207      1        1        3.150
    7         7         1        208      1        1        3.150
    8         8         1        208      1        1        4.000
    9         9         1        208      1        1        4.000
    10        10        1        213      1        1        2.200
    11        11        1        209      1        1        3.000
    12        12        1        209      1        1        3.100
    13        13        1        209      1        1        3.000
    14        14        1        209      1        1        3.900
    15        15        1        210      1        1        3.850
    16        16        1        214      1        1        2.200
    17        17        1        216      1        1        3.000
    18        18        1        216      1        1        3.000
    19        19        1        216      1        1        3.200
    20        20        1        216      1        1        2.900
```



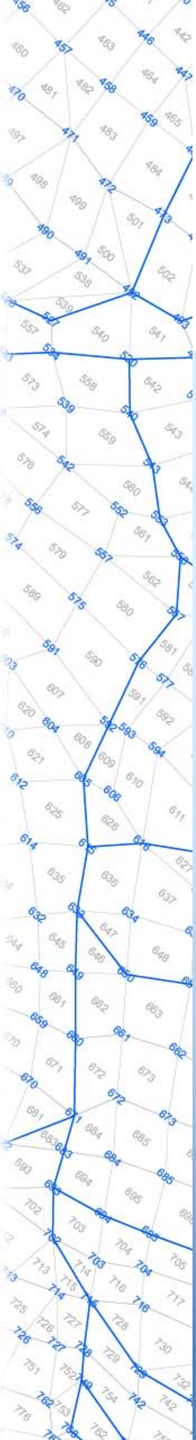
Pumping Wells

X-Y Location
- UTM 10N
- X = Easting
- Y = Northing

Convert to FT
- FACT = 3.2808

Well Properties
- RWELL = 1
- Screen Top
- Screen Bottom

```
*******************************************************************************
          List of modeled wells and their corresponding parameters

   NWELL ; Number of wells modeled
   FACTCX; Conversion factor for well coordinates
   FACTRW; Conversion factor for well diameter
   FACTLT; Conversion factor for perforation depths

------------------------------------------------------------------------------
        VALUE                                          DESCRIPTION
------------------------------------------------------------------------------
    133                    / NWELL
    3.2808                 / FACTCX
    1.0                    / FACTRW
    1.0                    / FACTLT
-------------------------------------------------------------------------------
*******************************************************************************

   ID;          Well identification number
   XWELL,YWELL; X-Y coordinates for each well; (L)
   RWELL;       Well diameter; (L)
   PERFT,PERFB; Elevations of the top and bottom perforations; (L)

-------------------------------------------------------------------------------
     ID     XWELL     YWELL   RWELL PERFTOP PERFBOT
-------------------------------------------------------------------------------
      1  559446 4477519   1         200       0       / Anderson
      2  560944 4470571   1         200       0       / Cottonwood
      3  551369 4492833   1         450     400       / Redding A (Downtown)
      4  555410 4490970   1         450     400       / Redding B (Enterprise)
      5  570071 4419834   1         200       0       / Corning
      6  584397 4399421   1          50    -100       / Hamilton City
      7  576717 4430310   1          50    -100       / Los Molinos
      8  568798 4399798   1         150       0       / Orland
      9  564962 4447605   1         200       0       / Red Bluff
     10  574748 4430889   1          50    -100       / Tehama
     11  581466 4318921   1          50    -100       / Arbuckle
     12  573445 4334080   1           0    -200       / Williams
     13  569277 4375051   1          50    -150       / Willows
     14  585470 4340806   1           0    -200       / Colusa
     15  610713 4363090   1         -50    -150       / Biggs
     16  599583 4398071   1          50    -150       / Chico
     17  612513 4357721   1           0    -100       / Gridley
     18  615500 4348007   1           0    -100       / Live Oak
     19  621676 4333692   1         -50    -200       / Marysville
     20  625136 4328130   1         -50    -200       / Olivehurst
     21  607655 4335030   1         -50    -200       / Sutter
     22  636457 4318838   1         -50    -150       / Wheatland
     23  619438 4333059   1         -50    -200       / Yuba City
     24  609719 4266809   1        -100    -300       / Davis
     25  602713 4255729   1        -100    -300       / Dixon
     26  585403 4282871   1          50     -50       / Esparto
```



Calibrated Parameters

Aquifer nodes
- Conductivity
- Storage
- Subsidence

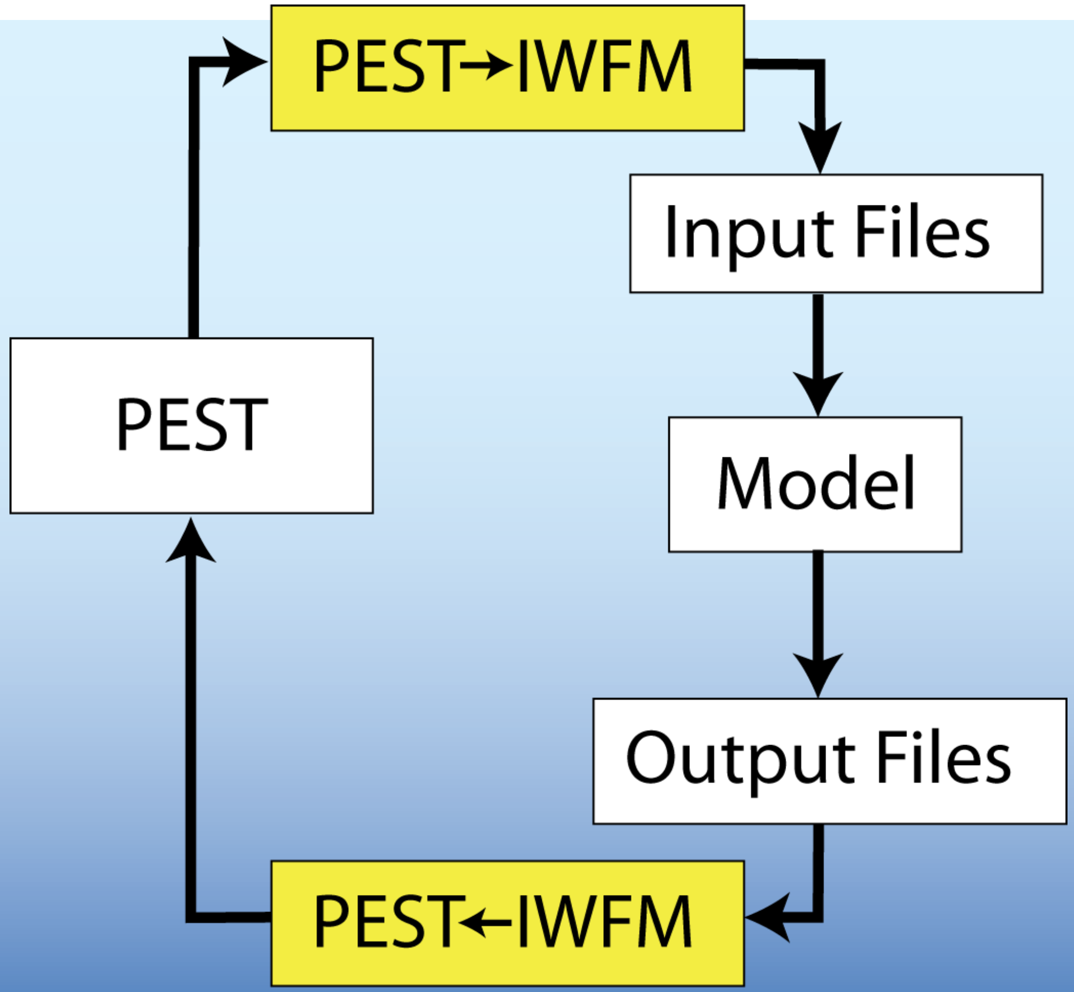
River nodes
- Conductance

Unsaturated Zone
- Porosity
- Conductivity

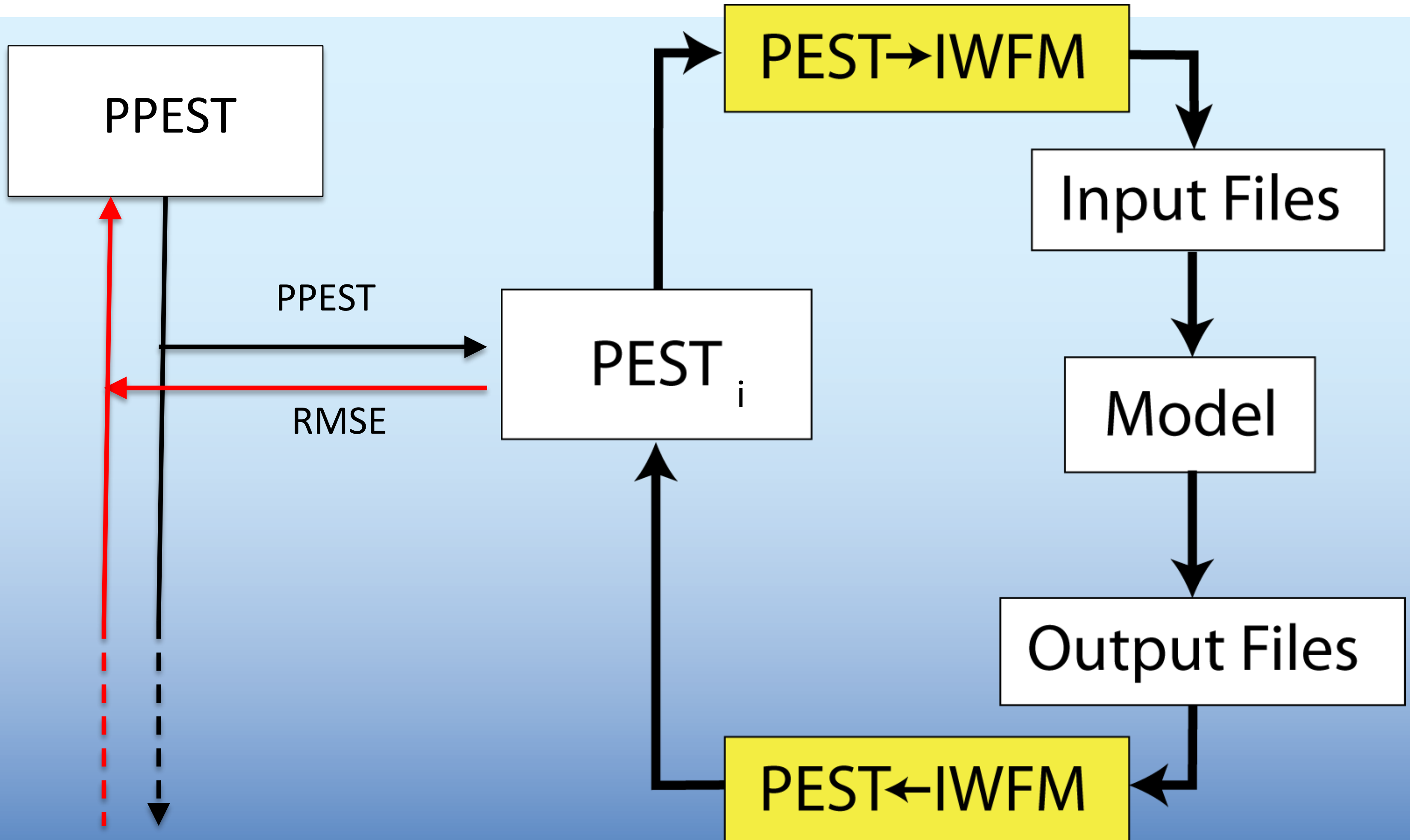
Soil properties
- Field capacity
- Porosity
- Recharge factor
- Curve Numbers

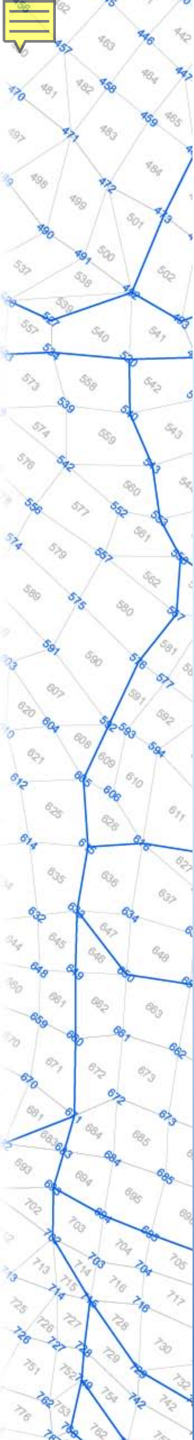
Small Watersheds
- Field capacity
- Porosity
- Conductivity
- Discharge threshold
- Recession coefficients

Calibration with PEST



Calibration with PPEST

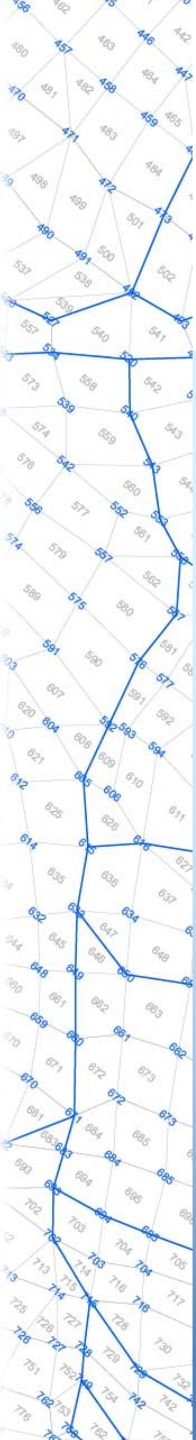




C2VSim Calibration

- Calibrate parameter values at each model node and layer
- Using computers at the USDOE National Energy Research Scientific Computing Center (NERSC)
  - Carver
    - IBM iDataPlex
    - 3,200 CPU cores, 34 Tflop/s
- Comparison:

	PPs	Compter	Run Time
R300	137	15 PCs	1 week
R326	394	15 PCs	3 weeks
R346	1393	15 PCs	16 weeks
R346	1393	NERSC	2 weeks



Calibration Observations

Groundwater Heads

- 56,947 observations at 1,145 wells

Vertical Head Difference

- 3,017 observations at 121 well pairs

Surface Water Flow

- 5,636 observations at 21 locations

Stream-Groundwater Flows

- Average annual rates on 24 reaches

Parameter Sensitivity

Parameters

Observations

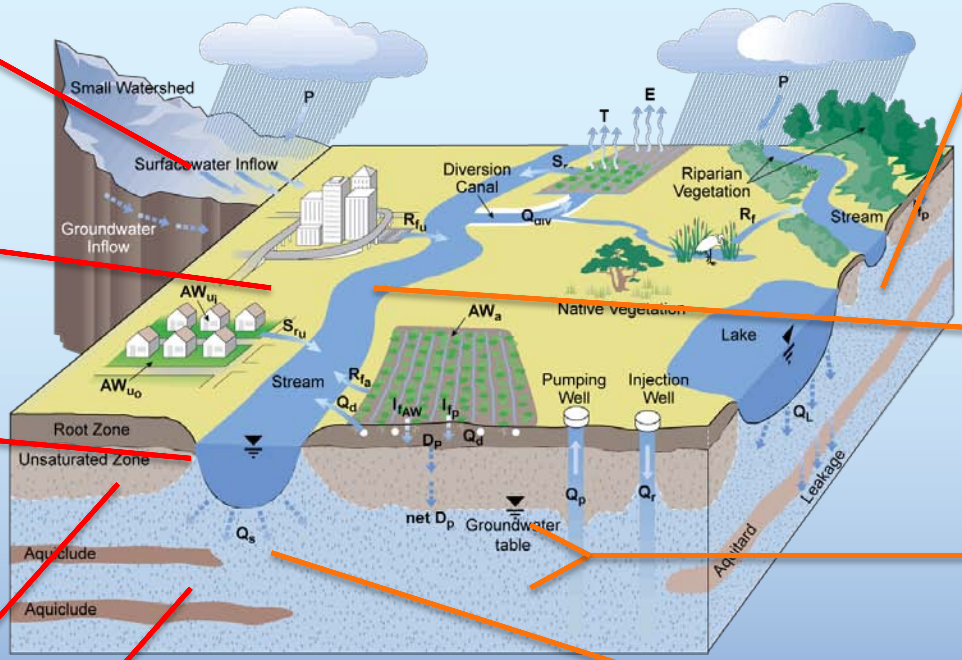
Ungaged Watersheds

Land Surface

Streambed

Unsaturated Zone

Saturated Zone



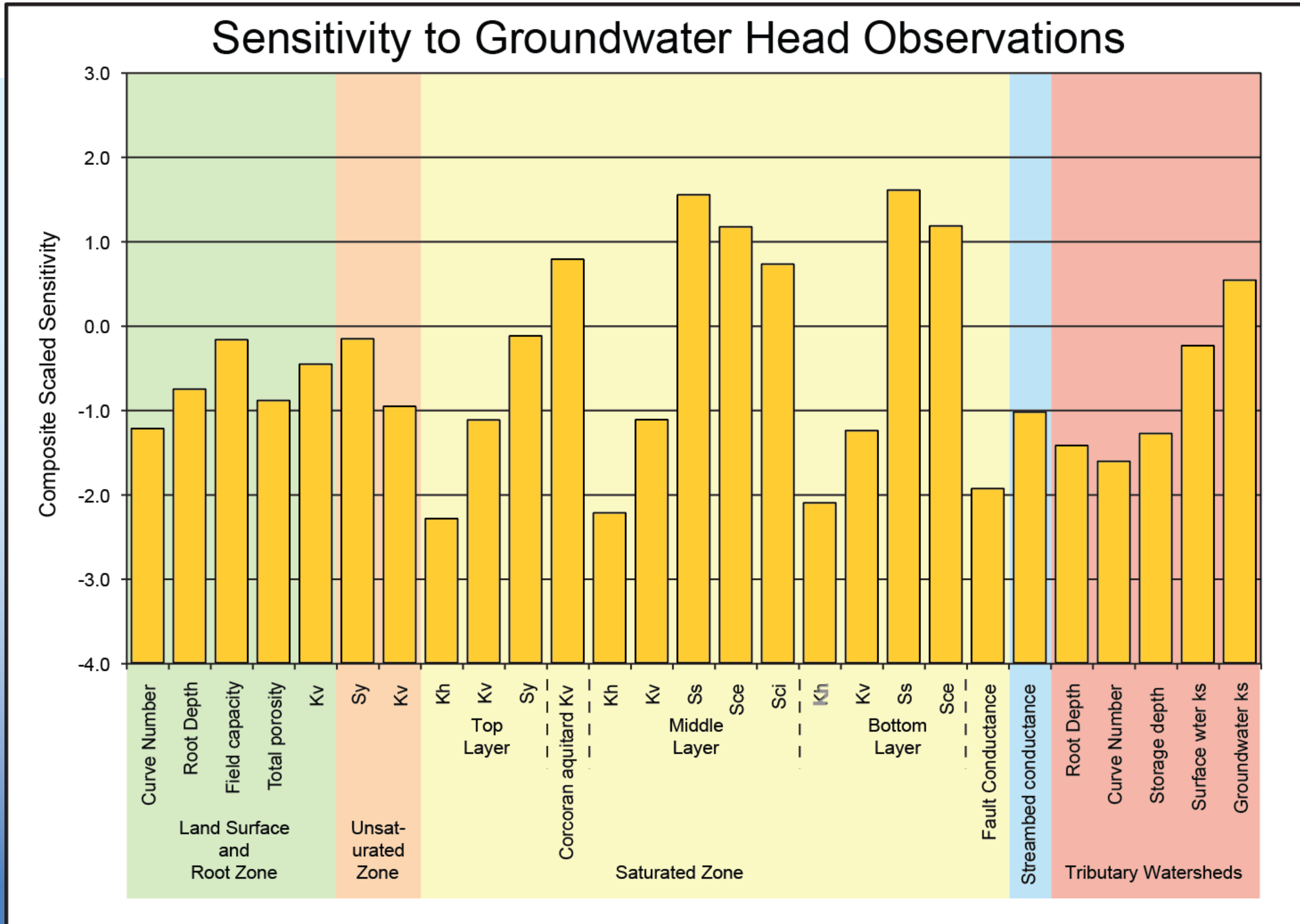
Groundwater Head

River Flow

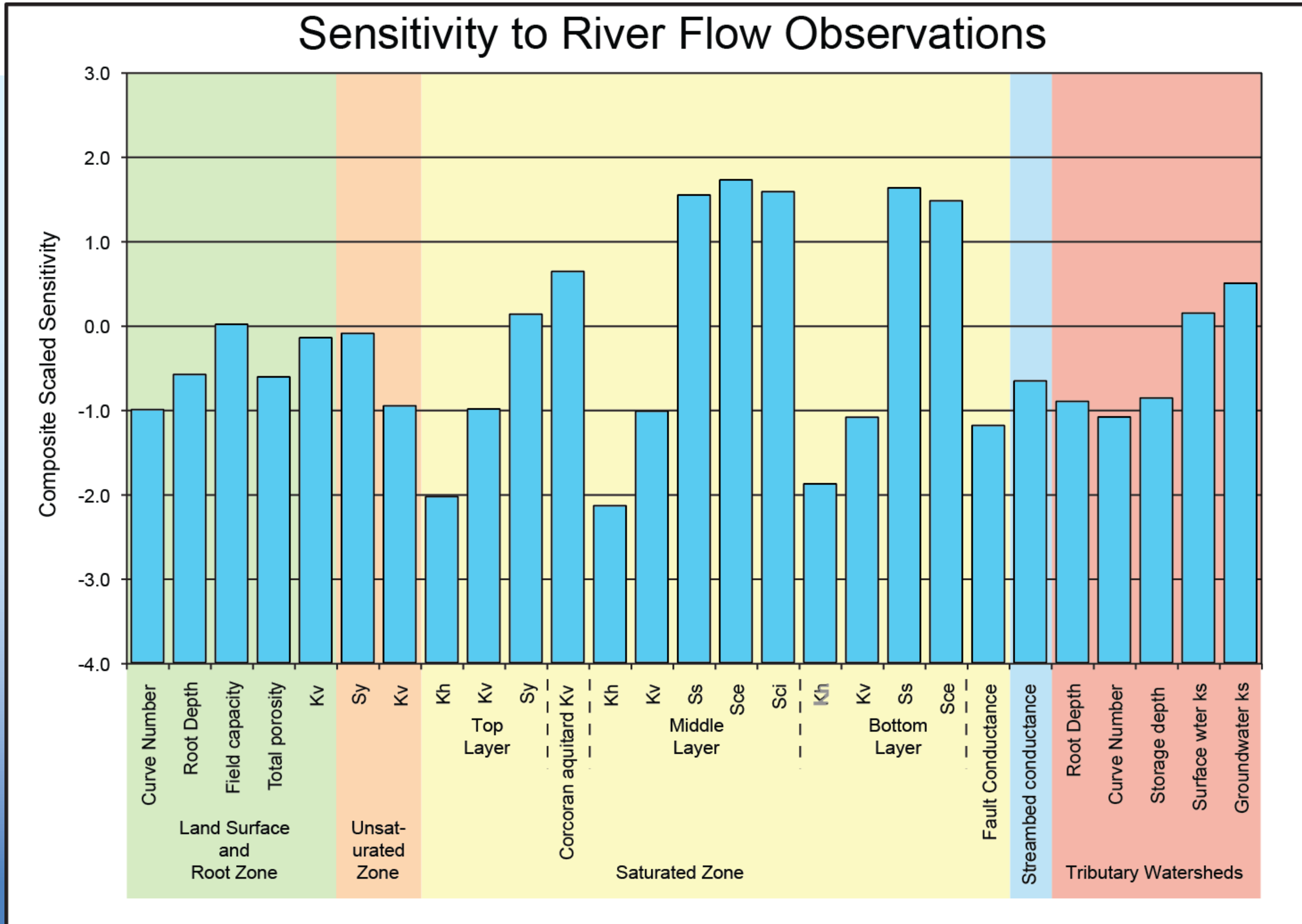
Groundwater Gradient

Stream-Groundwater Flow

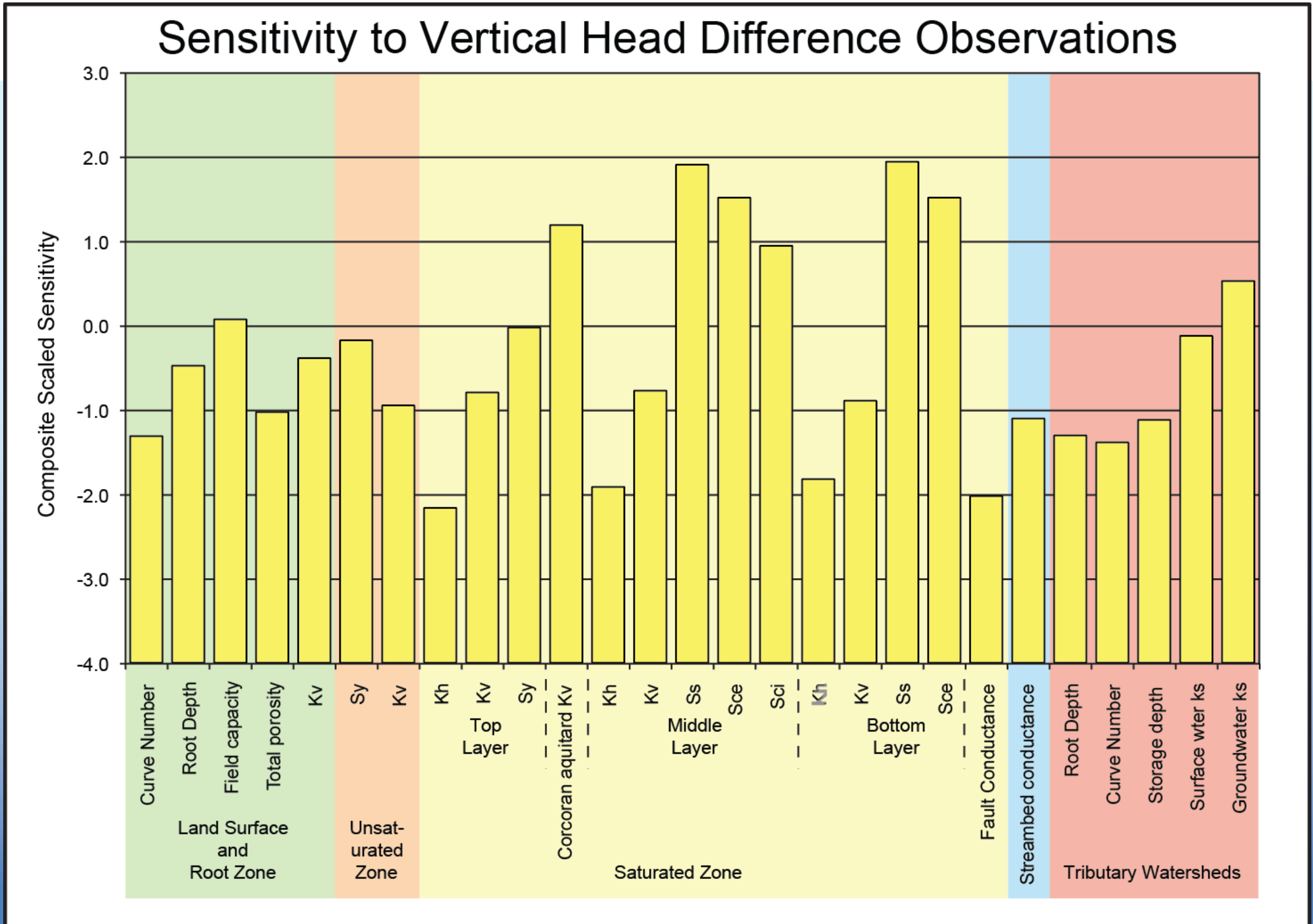
Parameter Sensitivity



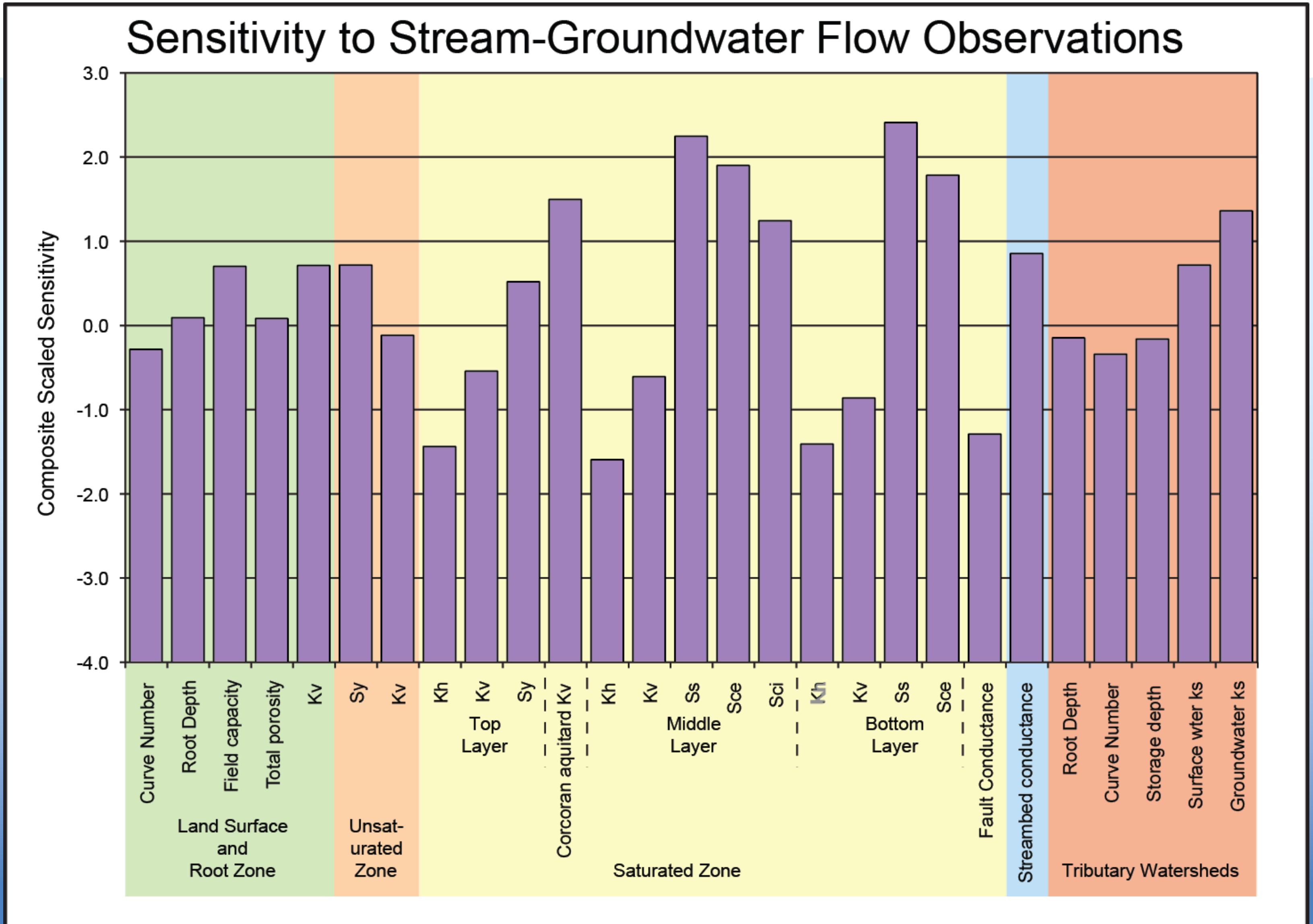
Parameter Sensitivity



Parameter Sensitivity

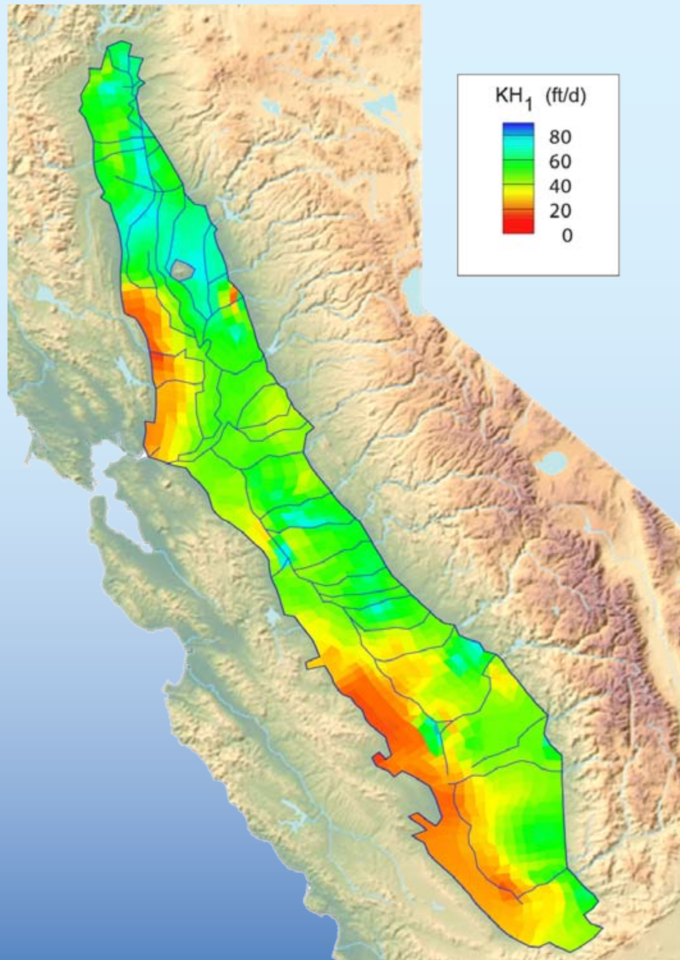


Parameter Sensitivity

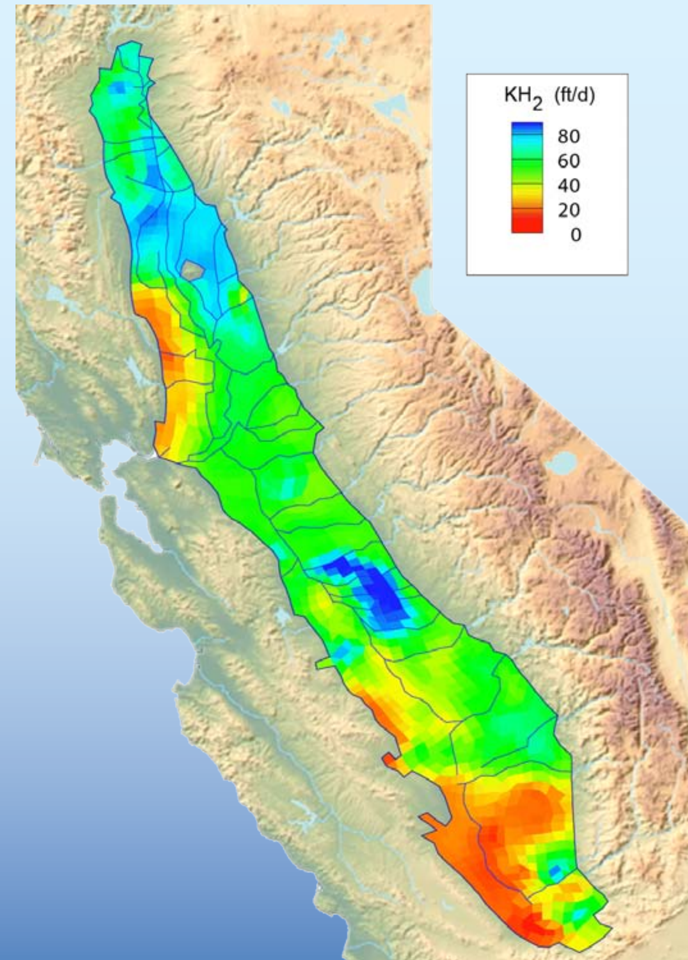


Hydraulic Conductivity

Layer 1

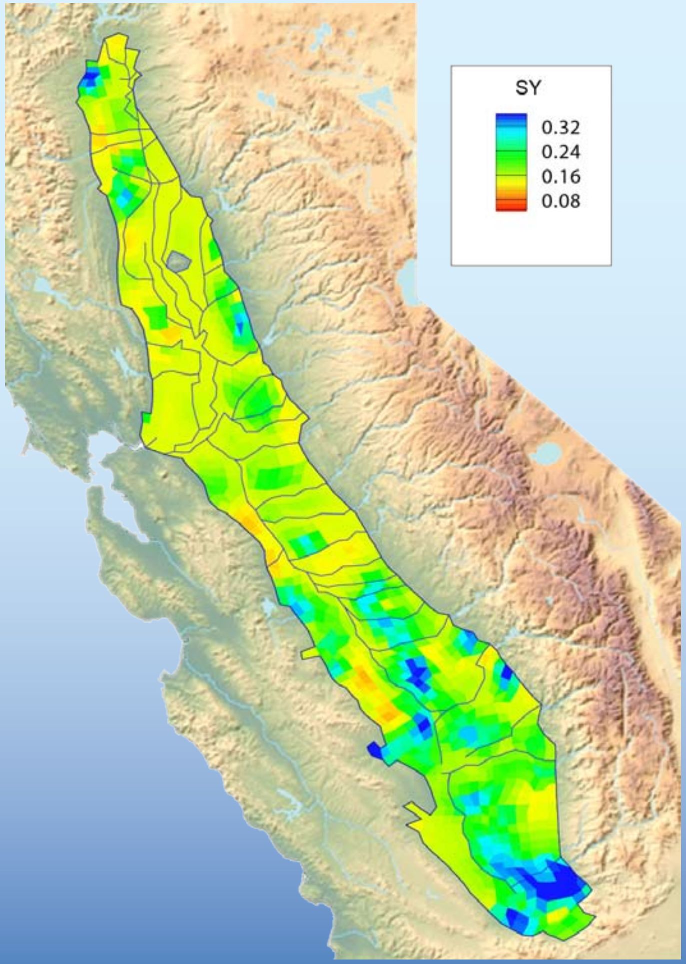


Layer 2

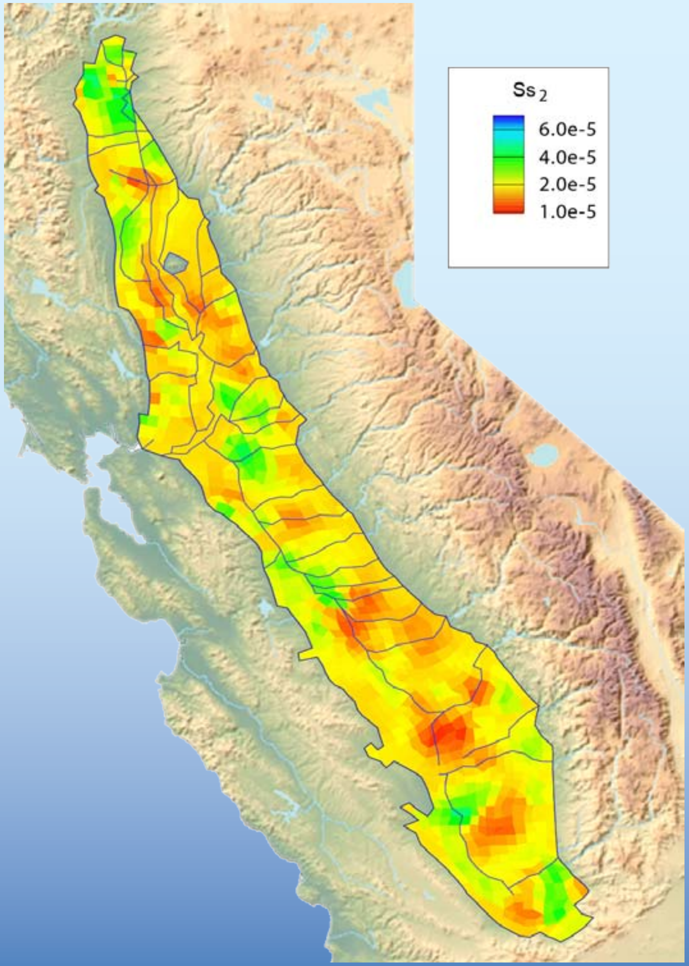


Storage Parameters

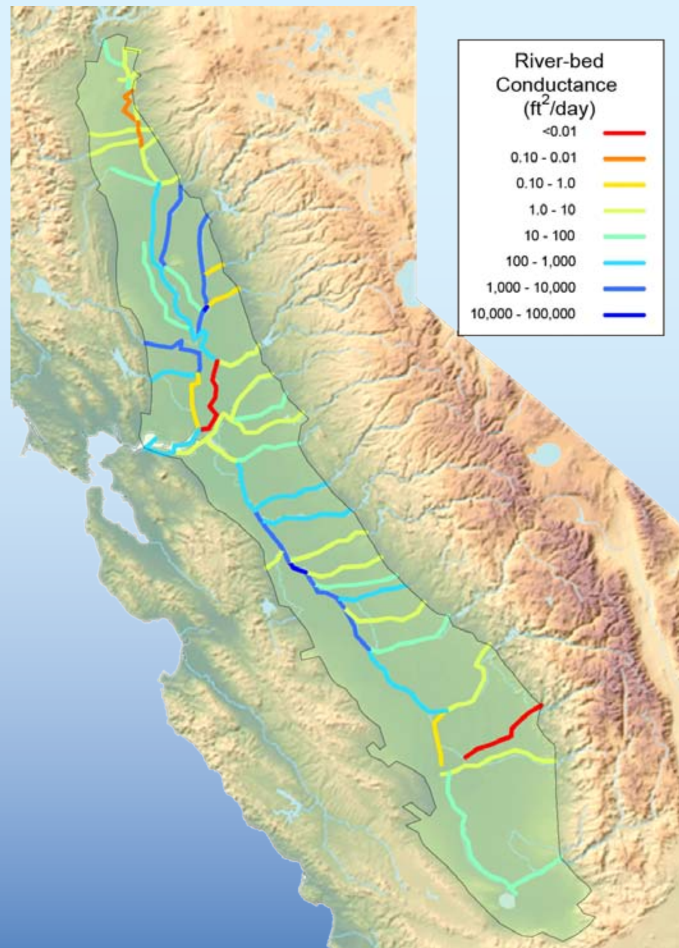
Layer 1



Layer 2



River-Bed Conductance



Model Performance

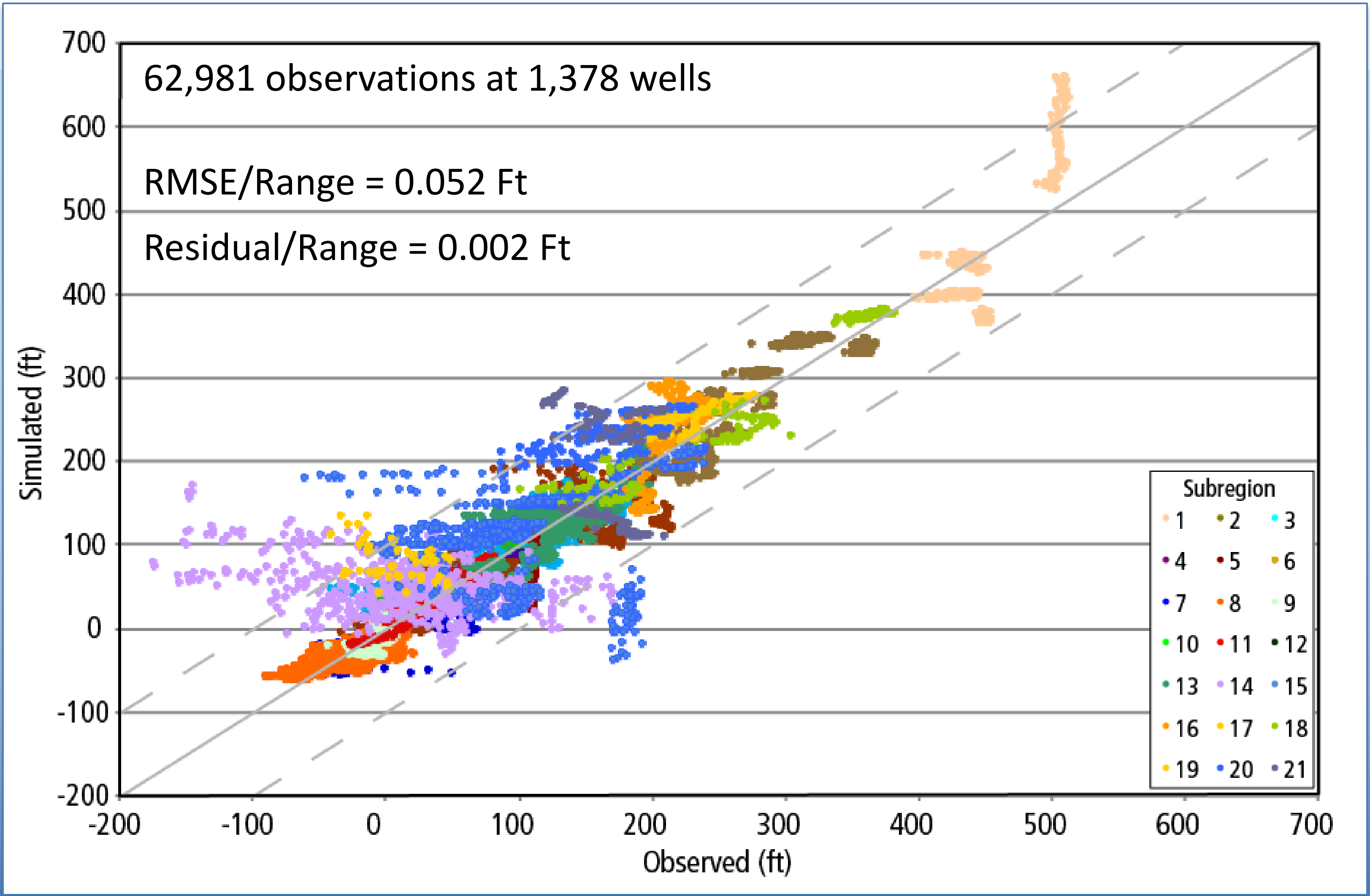
Observation Type	No. Observation Sites	No. Observations	Range
Groundwater heads	1,378	62,981	1,252
Vert. Groundwater Head Difference	163	3,017	698
River Flows	22	5,636	6,561,453
River-Groundwater Flows	33	33	38,117
Subsidence	24	3,700	6.2
TOTAL	1,620	75,367	

Observation Type	Root Mean Squared Error	Residual	RMSE / Range	Residual / Range
Groundwater heads	65.4	2.14	0.052	0.002
Vert. Groundwater Head Difference	96.2	-13.3	0.138	-0.019
River Flows	145,591	-13,720	0.022	-0.002
River-Groundwater Flows	8,875	3,620	0.233	0.095
Subsidence	17.4	-11.5	2.81	-1.86

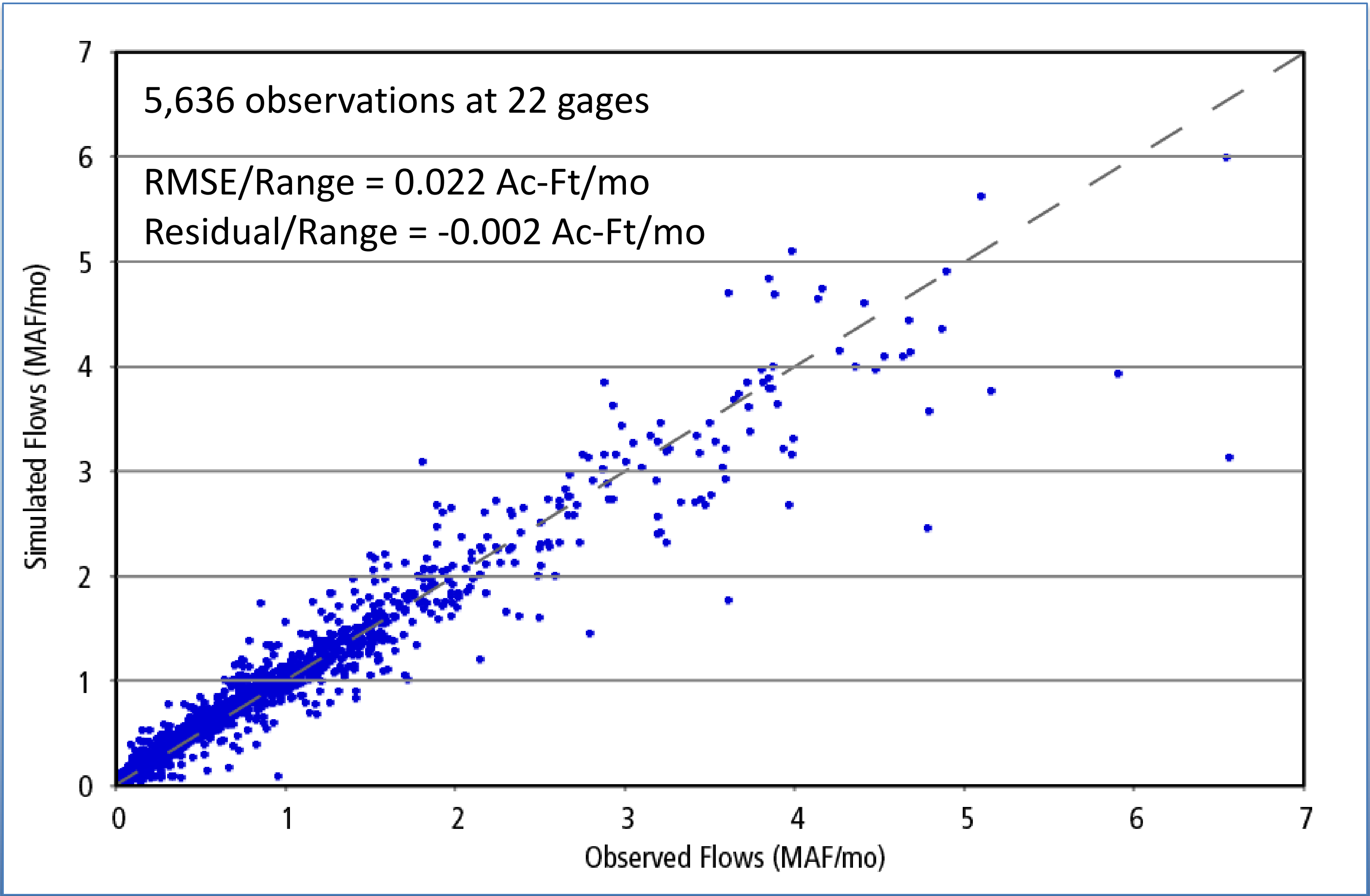
Units: Heads and subsidence in feet, flows in acre-feet

Head and flow observations from October 1975 to September 2003, Subsidence observations from September 1957 to May 2004

Groundwater Heads

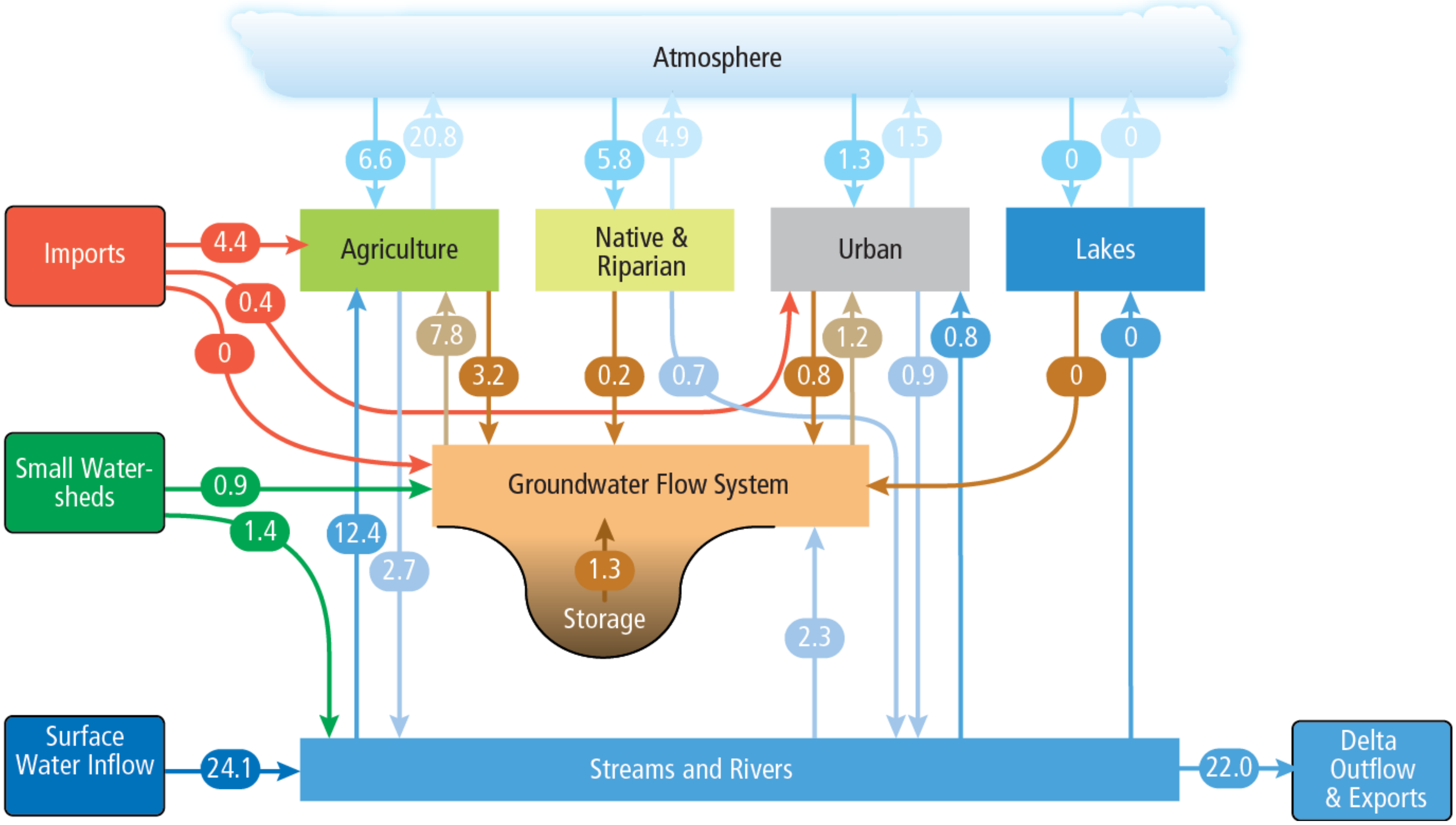


Surface Water Flows



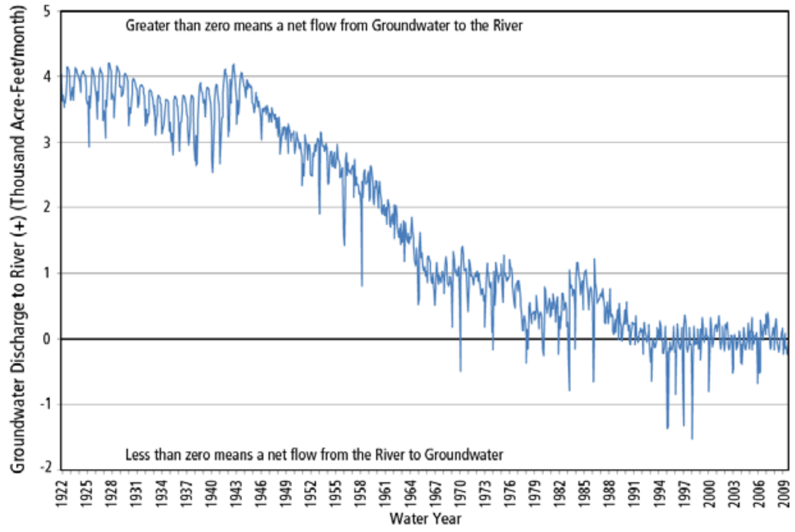
Simulated Annual Water Budget

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

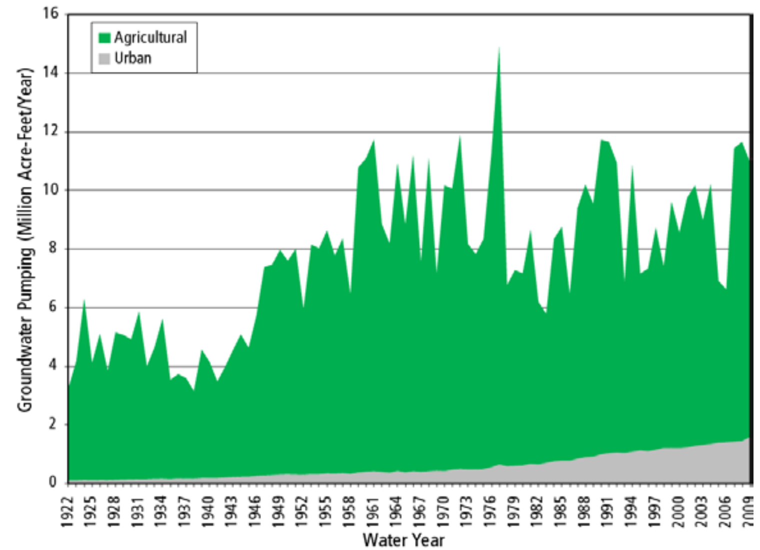


River-Groundwater Flows

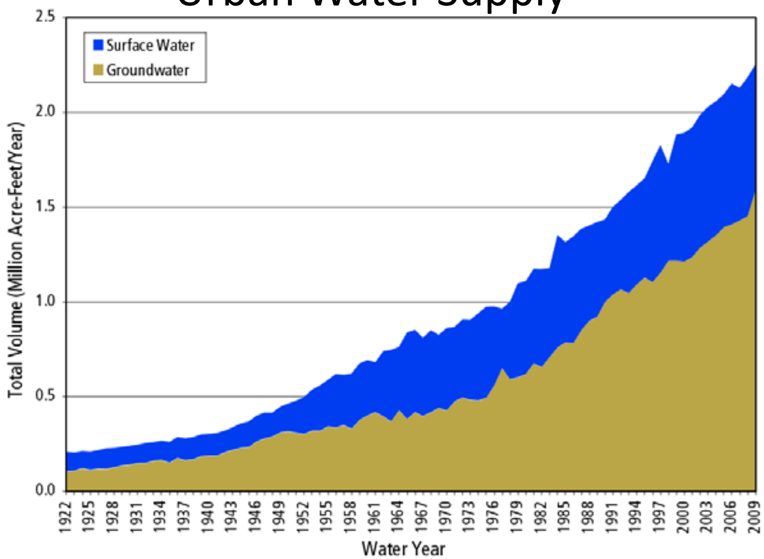
Sacramento River reach near Chico



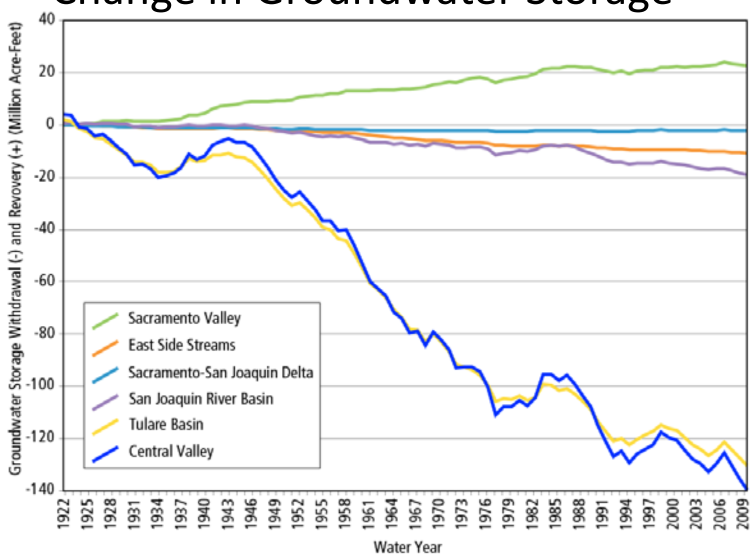
Groundwater Pumping

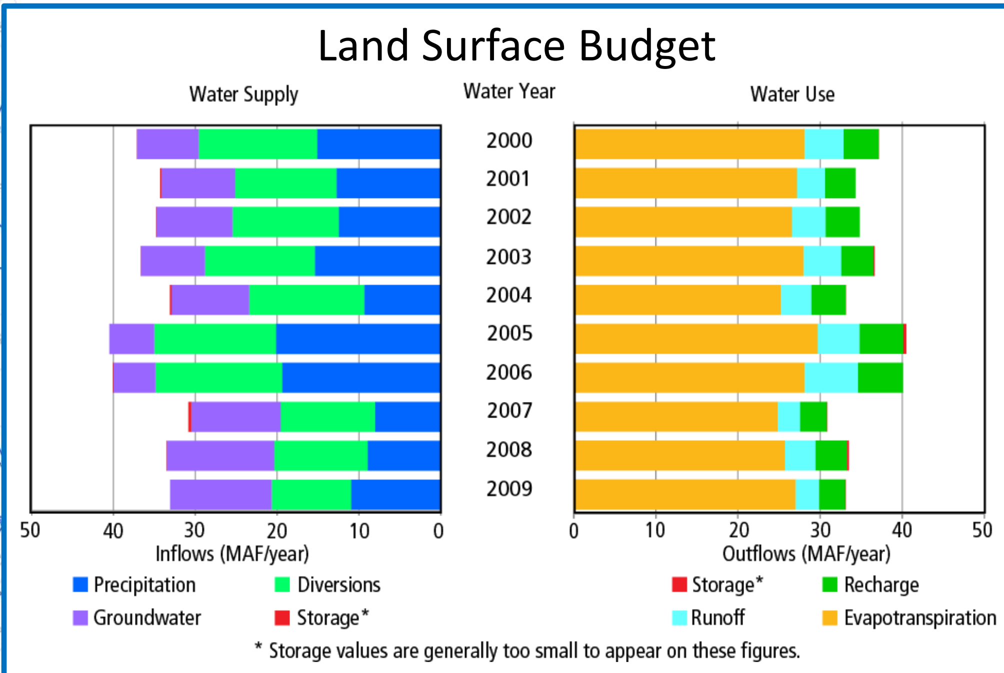


Urban Water Supply



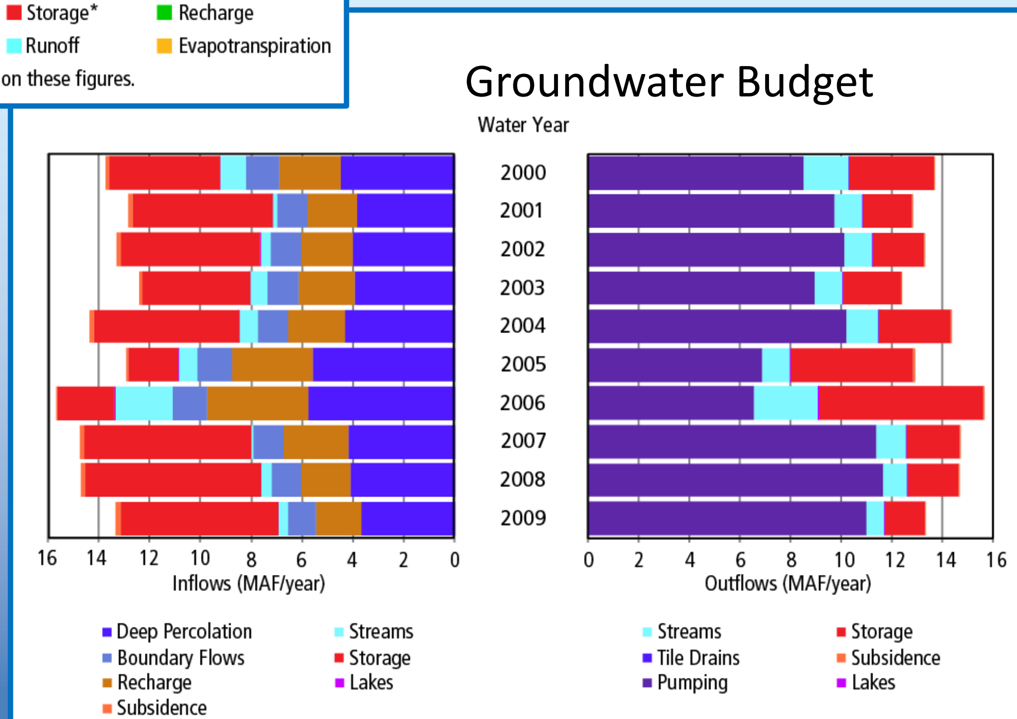
Change in Groundwater Storage





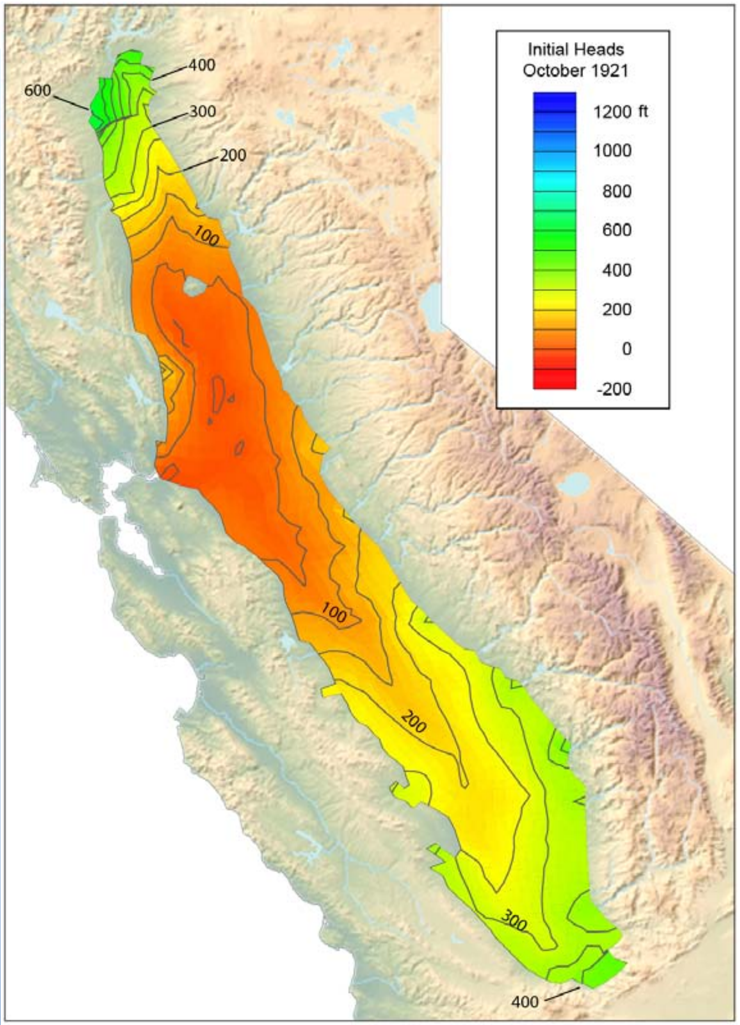
Process-level output tables have a complete water balance, and can be used to produce budget figures

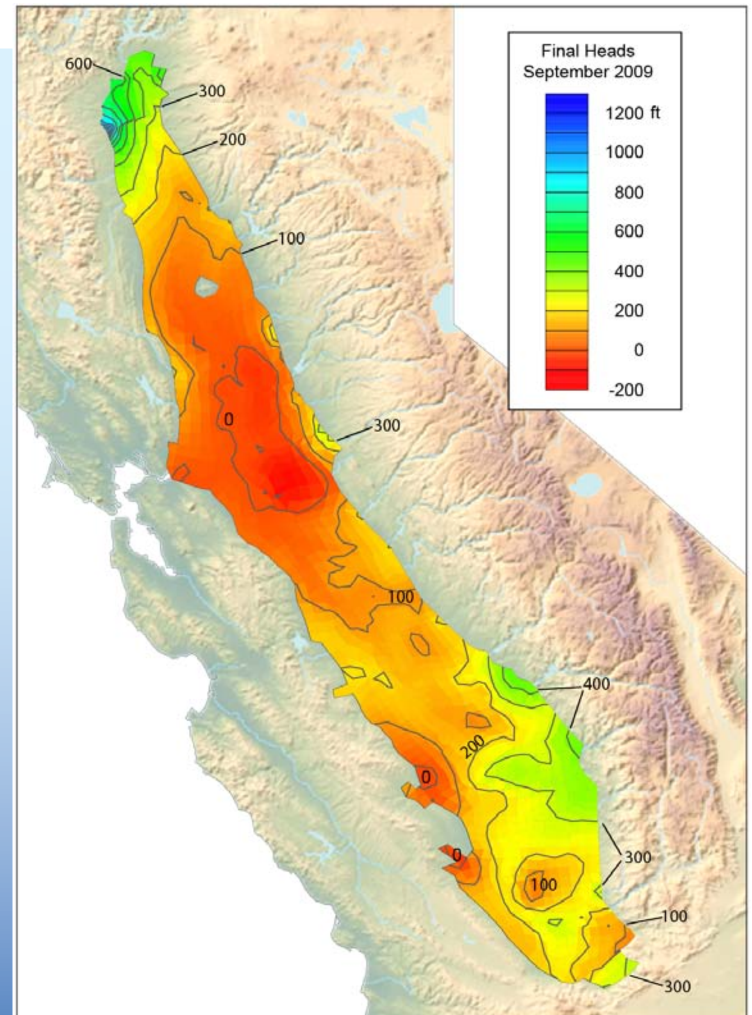
Groundwater budgets can also be produced for ‘zones’ of one to many elements



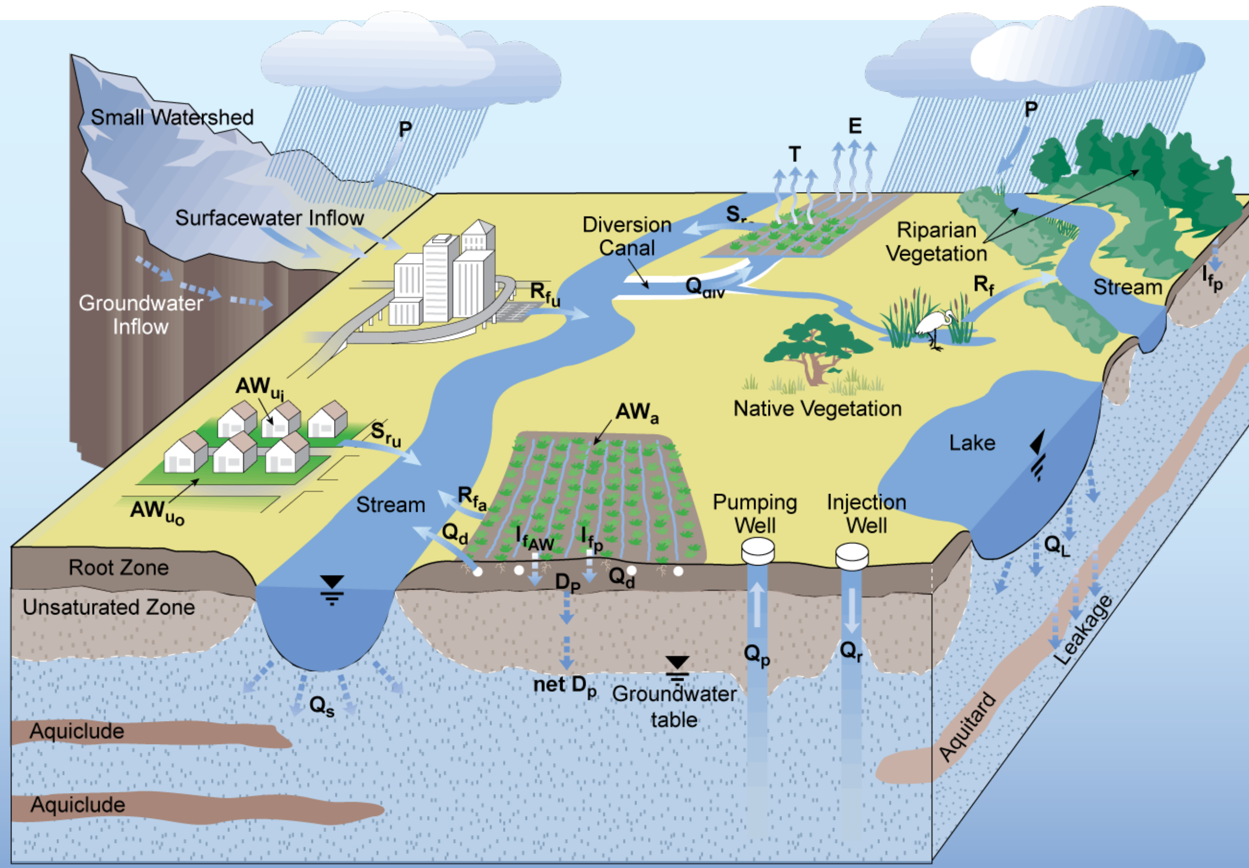
Water Table Altitude

Produced from IWFM's TecPlot® output files

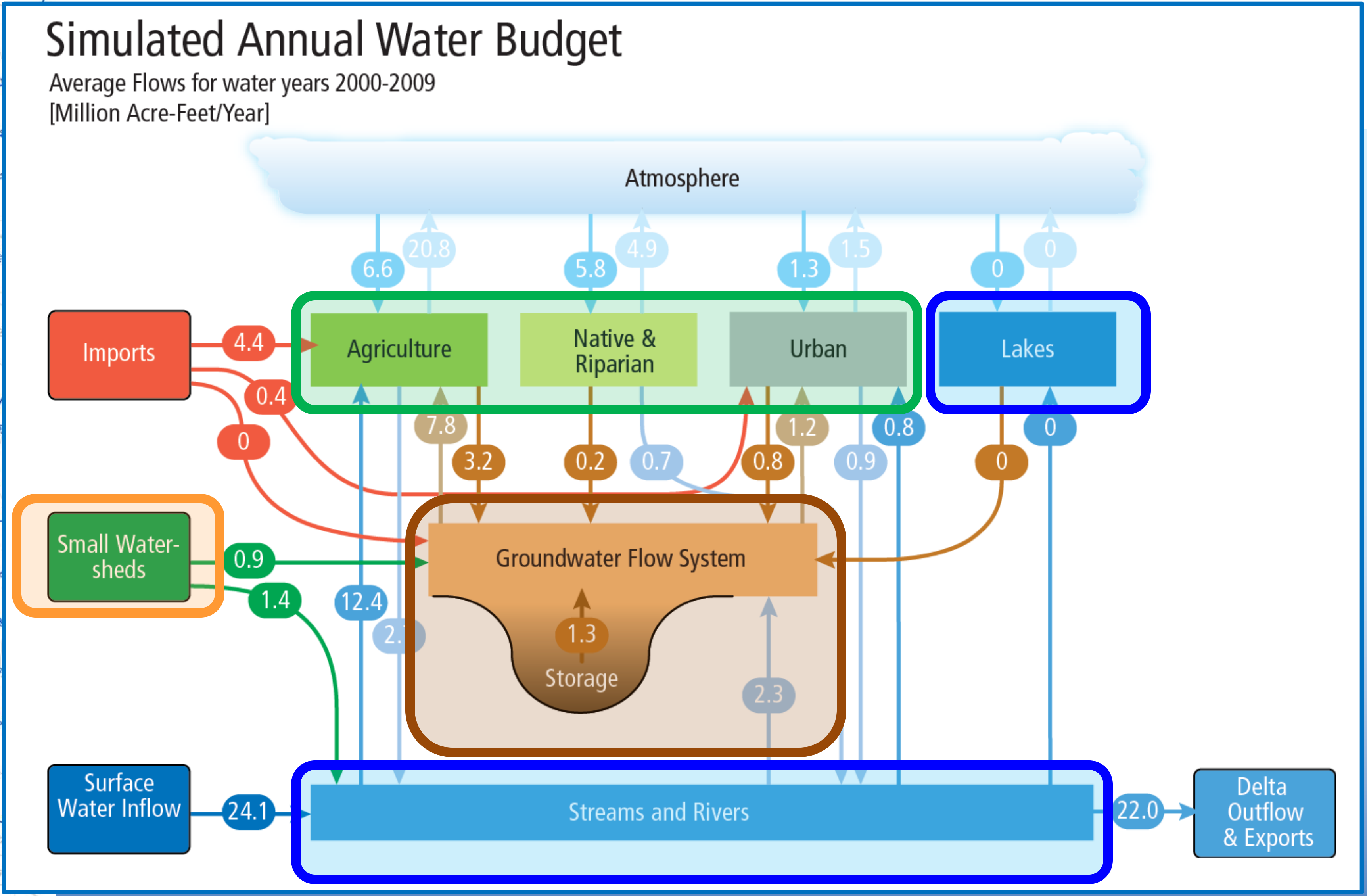




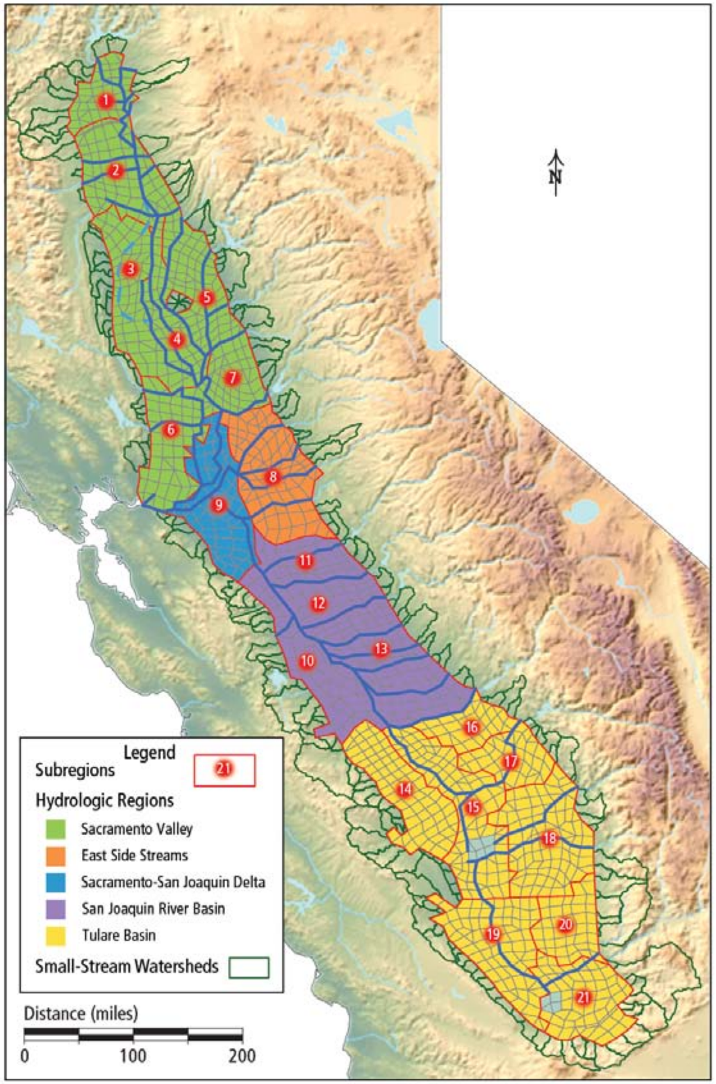
IWFM


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

IWFM Water Balance Diagram



C2VSim Model



- Land Surface Processes
  - Land and Water Use Budget
  - Root Zone Budget

- Groundwater Process
  - Groundwater Budget
  - Z-Budget Budget

- Surface Water Processes
  - Stream Reach Budget
  - Lake Budget

- Small-Streams Watershed Process
  - Small Watershed Budget

END