Integrated **W**ater **F**low **M**odel (IWFM)

CWEMF Peer Review Workshop
on
Integrated Groundwater/Surface Water Models

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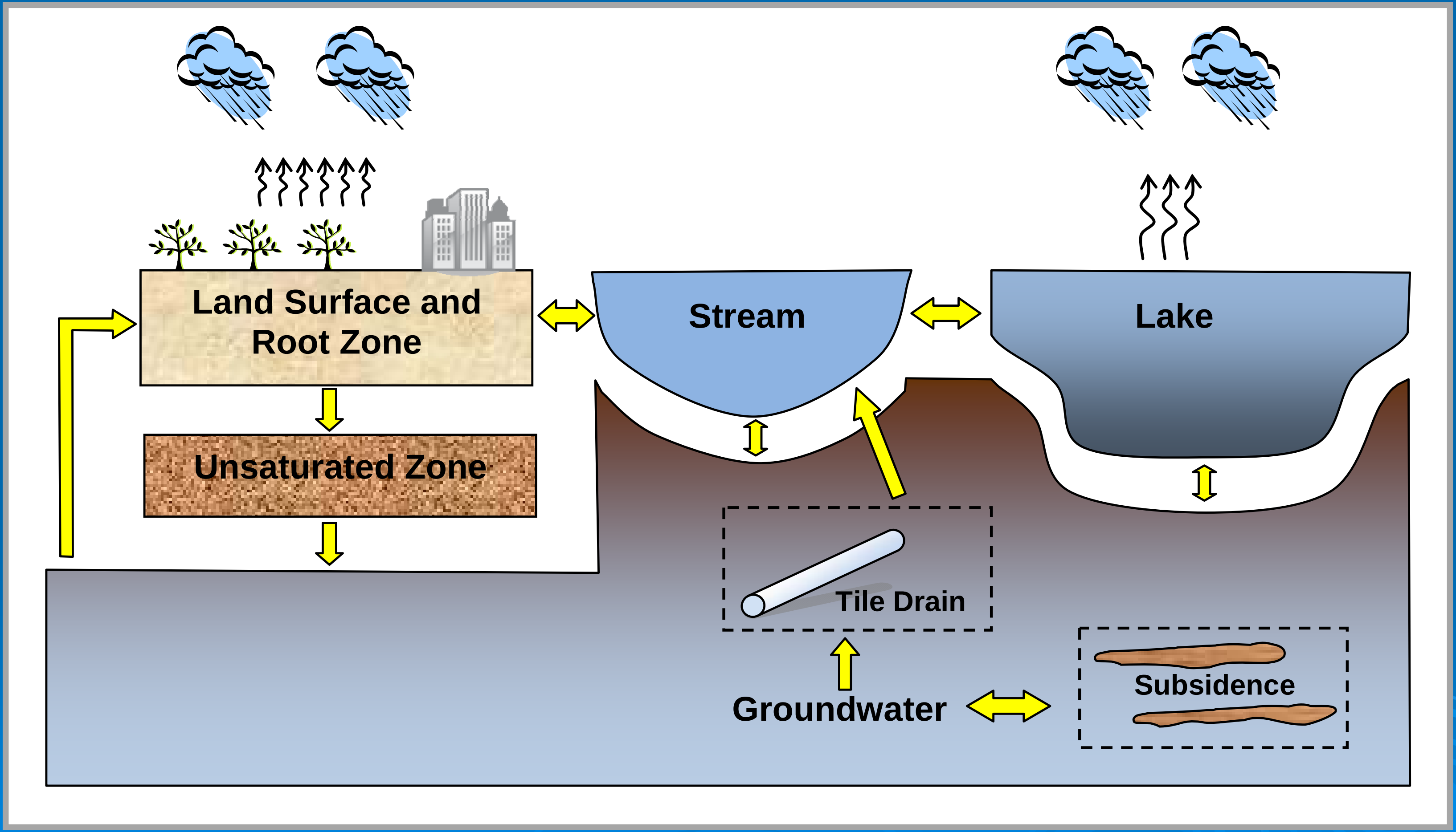
Outline

- Introduction
- Overview of IWFM
- Applications
- On-going developments and future plans

Introduction

- What is an Integrated Groundwater – Surface Water model ?
- Why was IWFM developed ?
- DWR’s guiding principles for model development
- Historical timeline for IWFM development
- Documents released to the CWEMF Peer Reviewers
- Summary

What is an Integrated Groundwater – Surface Water model



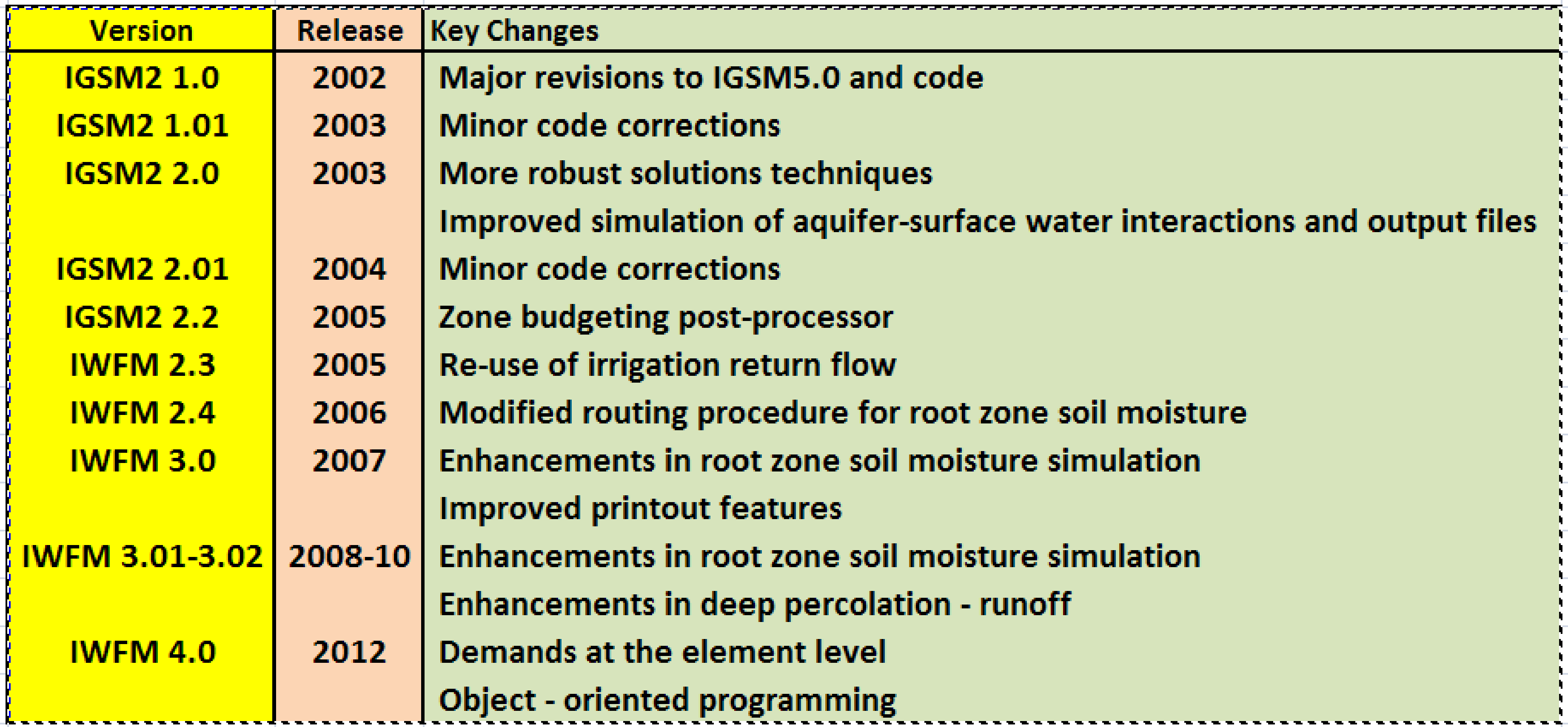
Why was IWFM Developed

- To improve accounting of ground water and the surface-ground water interaction in the CVP-SWP system model CalSim3
- As a stand-alone to better understand the historical evolution of water resources in the Central Valley (C2VSIM)
- To study the impacts of climate change on long term ground water conditions and of meeting future demands with constrained supplies
- Tool to address the complexities of planning for and implementing Integrated Regional Water Management Plans and others

Guiding Principles for Model Development

- Meets DWR needs
- Non-proprietary models (to the extent possible)
- Technically qualified staff in development, enhancement, application, and technical support
- Transparency in development and stakeholders input
- Public availability (free) through GNU license
- Practicality in applications

Historical Timeline for IWFM Development



Version	Release	Key Changes
IGSM2 1.0	2002	Major revisions to IGSM5.0 and code
IGSM2 1.01	2003	Minor code corrections
IGSM2 2.0	2003	More robust solutions techniques
		Improved simulation of aquifer-surface water interactions and output files
IGSM2 2.01	2004	Minor code corrections
IGSM2 2.2	2005	Zone budgeting post-processor
IWFM 2.3	2005	Re-use of irrigation return flow
IWFM 2.4	2006	Modified routing procedure for root zone soil moisture
IWFM 3.0	2007	Enhancements in root zone soil moisture simulation
		Improved printout features
IWFM 3.01-3.02	2008-10	Enhancements in root zone soil moisture simulation
		Enhancements in deep percolation - runoff
IWFM 4.0	2012	Demands at the element level
		Object - oriented programming

Documents Released to Peer Reviewers

Model Documentation

1. IWFM v3.02 Theoretical Documentation **(print, digital)**
2. IWFM v3.02 User’s Manual **(print, digital)**
3. Source code **(digital)**
4. Verification Problems for IWFM **(print, digital)**
5. IWFM-MODFLOW FMP Comparison Documents **(print, digital)**
6. Accuracy control and performance enhancement of linear solvers for the Integrated Water Flow Model (Dixon et. al, 2010) **(print, digital)**
7. Flow computation and mass balance in Galerkin finite-element groundwater models (Dogrul and Kadir, J. Hydraulic Engineering, 2006) **(print, digital)**
8. Error control of iterative linear solvers for integrated groundwater models (Dixon et. al, Ground Water, 2011) **(print, digital)**

Documents Released to Peer Reviewers (cont)

Field Applications

1. Butte County IWFM model documents **(digital)**
2. Walla Walla Basin, Oregon model documentation **(digital)**
3. Drought resilience of the California Central Valley surface-ground-water-conveyance system (Miller et. al, JAWRA, 2009) **(print, digital)**
4. IDC application by WRIME to Treasure Valley in Idaho **(digital)**
5. WESTSIM **(digital)**

Note: The C2VSIM documentation was released in May 2012 for internal review prior to public release. It is available to the Peer Reviewers

Summary

- Sound theoretical basis
- Extensively tested
- Well documented
- Available for free to the public (posted on website)
- Technical support
- Numerous applications at regional scales
- Peer reviewed
- Linked to system (reservoir allocation) model CalSim 3.0

Integrated Water Flow Model (IWFM): Overview

- An open-source, regional-scale integrated hydrologic model that simulates groundwater flow, surface flows, and surface-groundwater interactions
- A tool that allows the user to represent agricultural and urban water management practices, and their effects on the water system
- A planning and analysis tool as it computes agricultural and urban water demands based on climatic, soil, land-use and agronomic parameters, and tries to meet this demand with pumping and stream diversions
- Written in FORTRAN

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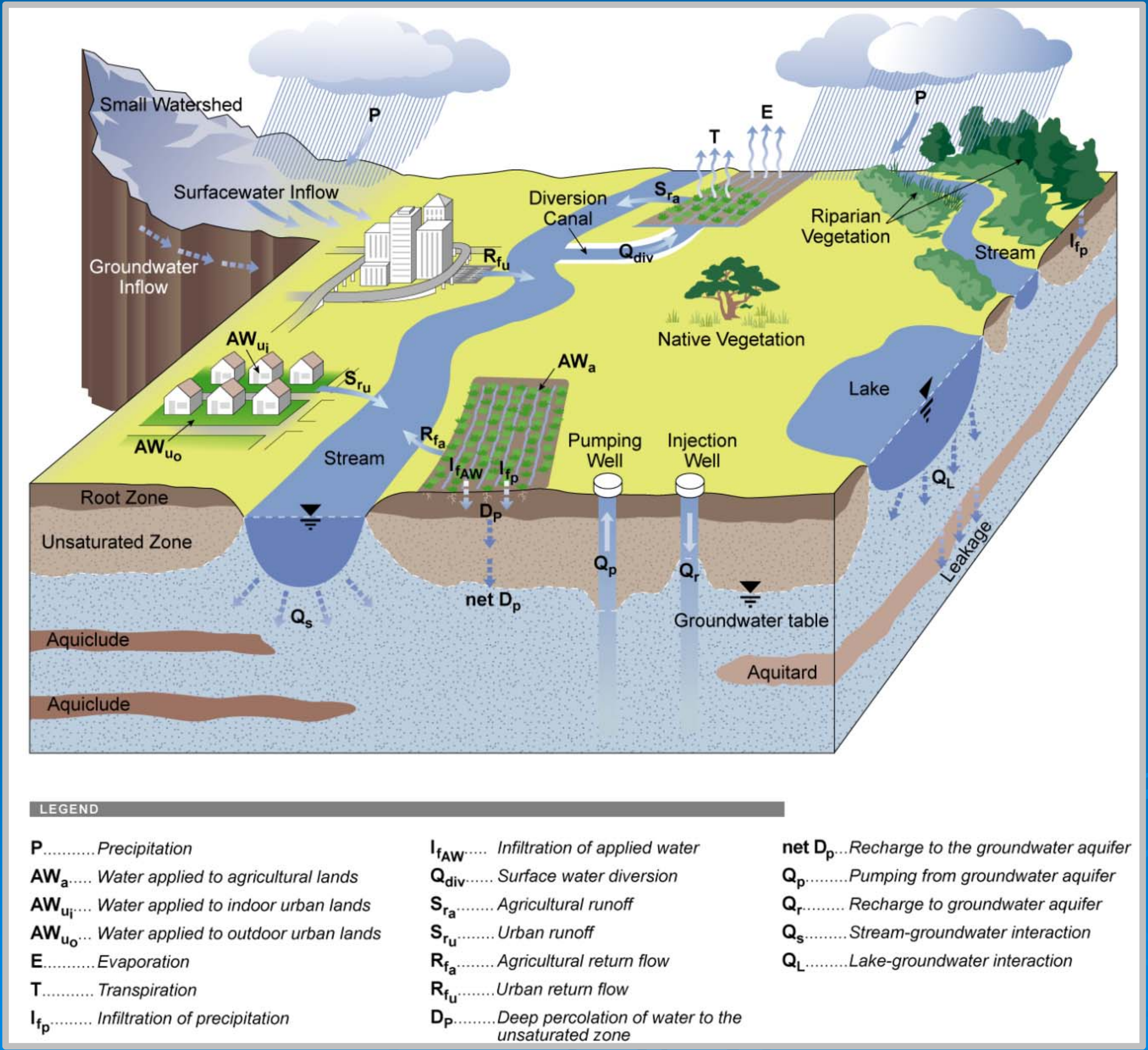
IWFM: Overview

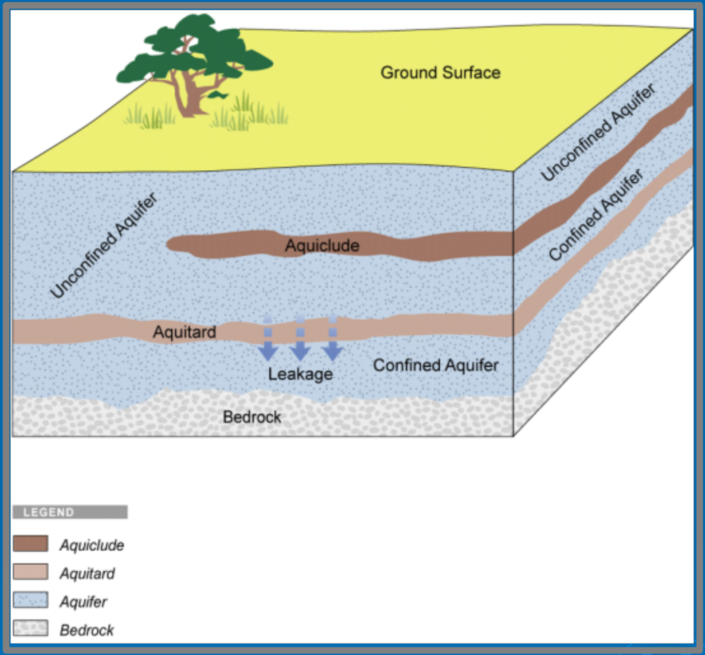


LEGEND

P	Precipitation
AW_a	Water applied to agricultural lands
AW_{u_i}	Water applied to indoor urban lands
AW_{u_o}	Water applied to outdoor urban lands
E	Evaporation
T	Transpiration
I_{f_p}	Infiltration of precipitation
I_{fAW}	Infiltration of applied water
Q_{div}	Surface water diversion
S_{r_a}	Agricultural runoff
S_{r_u}	Urban runoff
R_{f_a}	Agricultural return flow
R_{f_u}	Urban return flow
D_P	Deep percolation of water to the unsaturated zone
net D_p	Recharge to the groundwater aquifer
Q_p	Pumping from groundwater aquifer
Q_r	Recharge to groundwater aquifer
Q_s	Stream-groundwater interaction
Q_L	Lake-groundwater interaction

Groundwater Flow

- Flow simulation for a combination of confined, unconfined, and leaky aquifer layers separated by aquitards or aquicludes
- Simulation of changing aquifer conditions and subsidence
- Quasi 3-dimensional approach
- Use of Galerkin finite element method for the numerical solution of the governing equation



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);

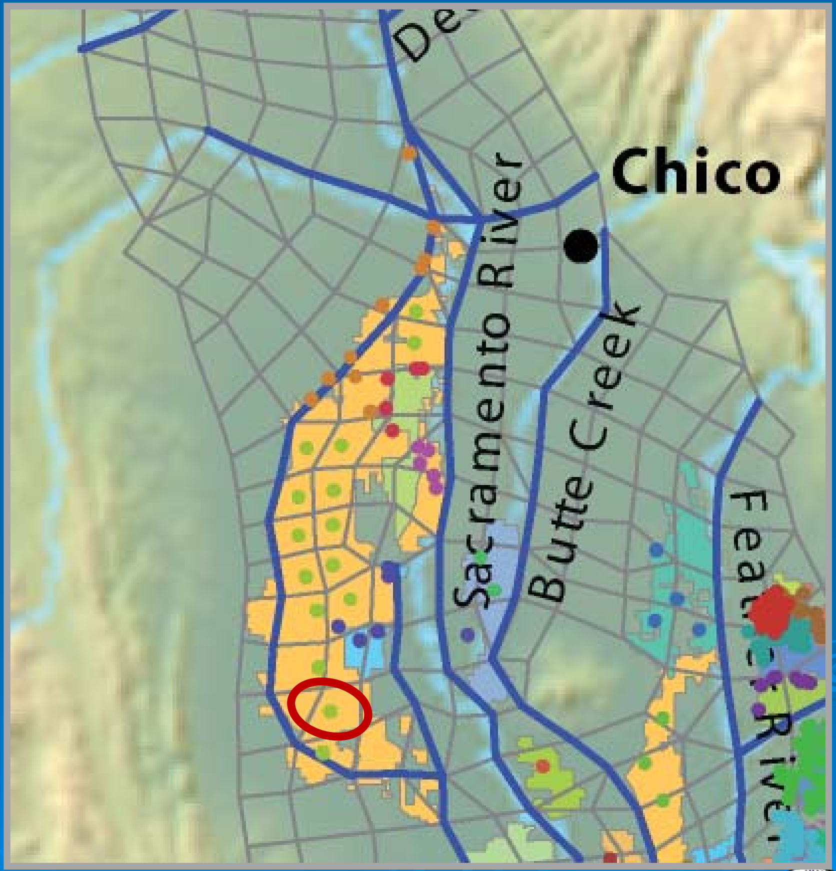
Q = Source/sink term, (L/T).

Boundary Conditions for Groundwater

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

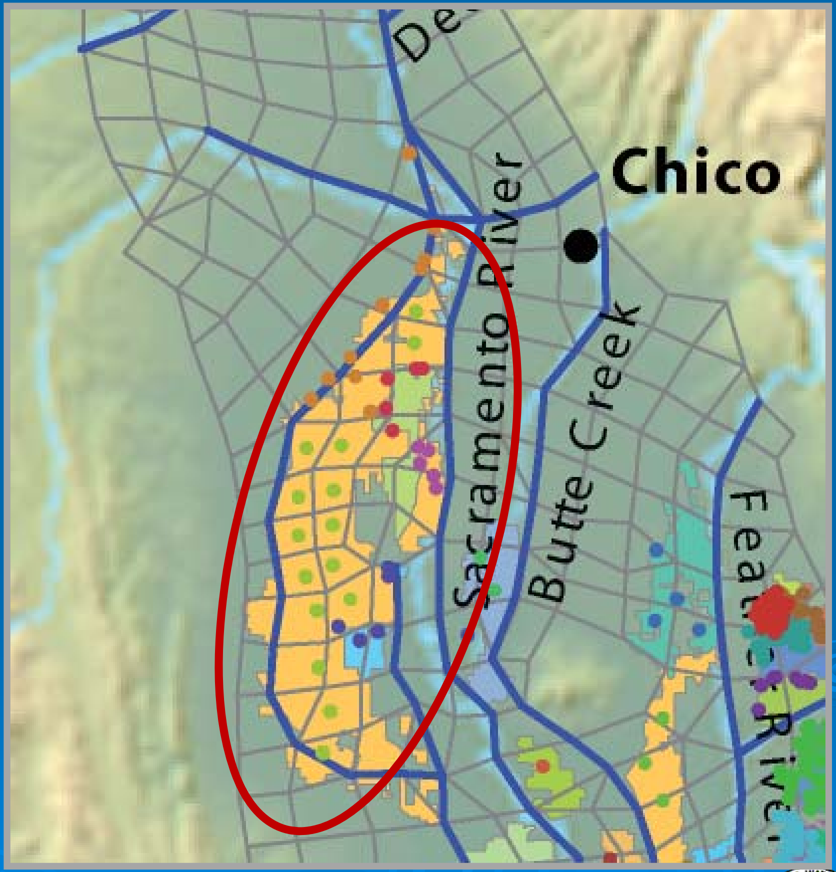
Pumping

- 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



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

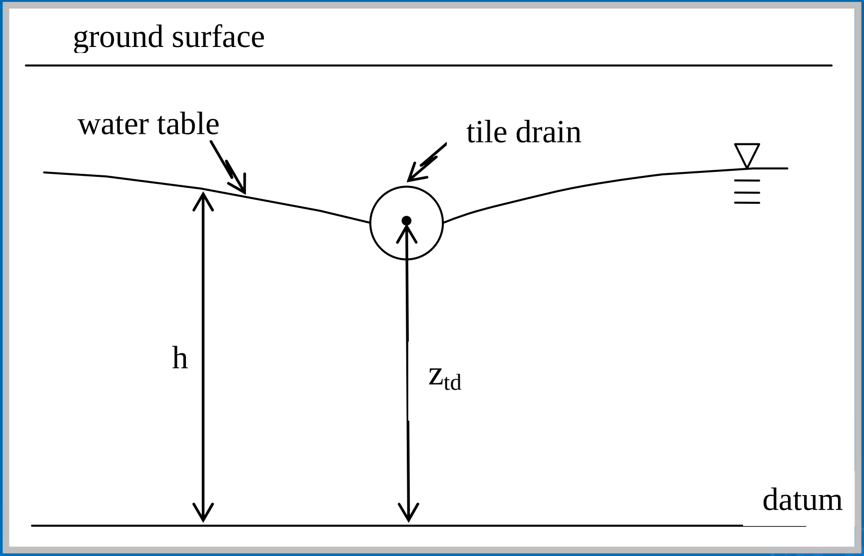


Tile Drains

- Tile drains are simulated as general head boundary conditions:

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

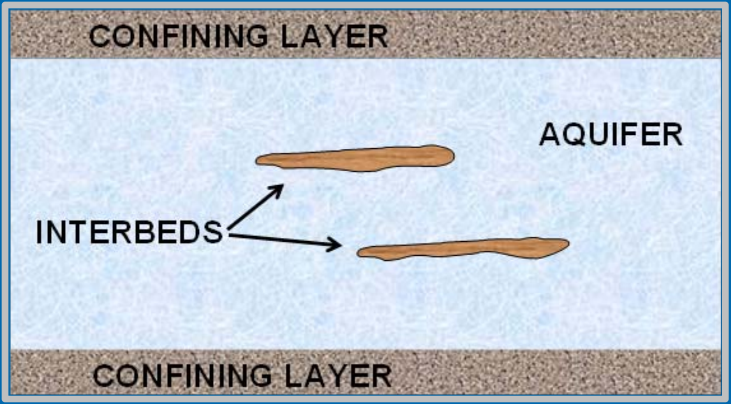
Q_{td} = tile drain flow, $[L^3/T]$
C_{td} = conductance, $[L^2/T]$
z_{td} = tile drain elevation, $[L]$
h = groundwater head, $[L]$



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

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)

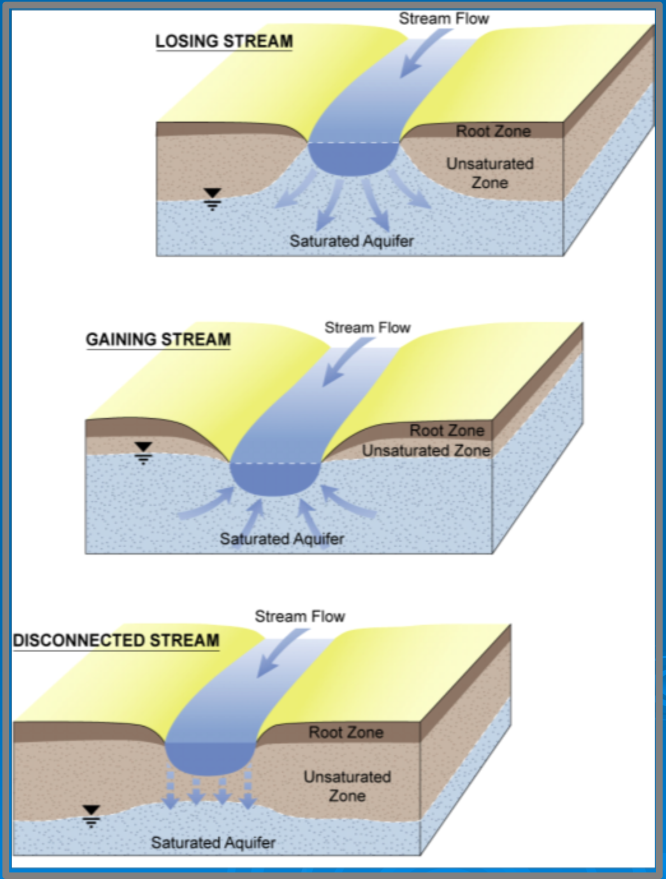
h_c = pre-consolidation head, (L)

Δh = change in groundwater head, (L)

Δb = change interbed thickness, (L)

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



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Stream Flow

- Assumption of zero storage at a stream node

$$\mathbf{Q_s - Q_{sin} + Q_{sout} = 0}$$

Q_s = stream flow, (L^3/T)

Q_{sin} = inflows into stream (flow from upstream nodes, return flow, rainfall runoff, tributary inflows, tile drain, lake outflow, bypass, user specified flows), (L^3/T)

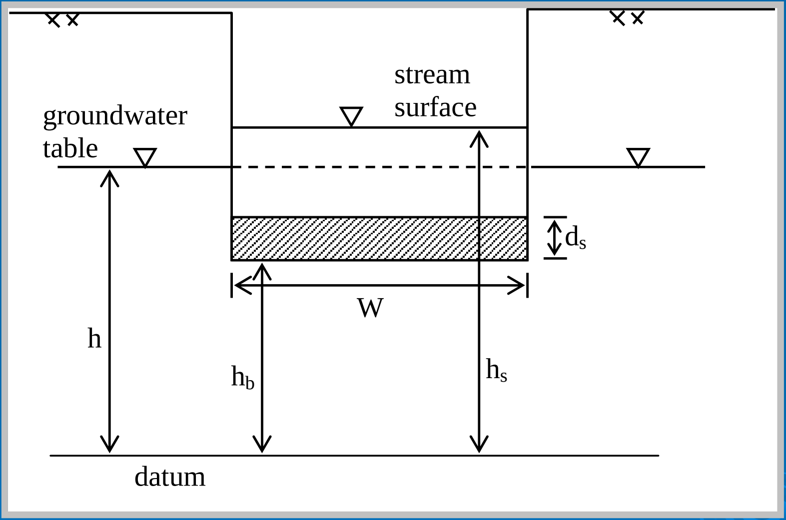
Q_{sout} = outflows from stream (diversions, bypass flows, stream-aquifer interaction), (L^3/T)

- Assumption requires simulation time step to be large enough for stream flow to travel from upstream to downstream in a single time step

Stream-Groundwater Interaction

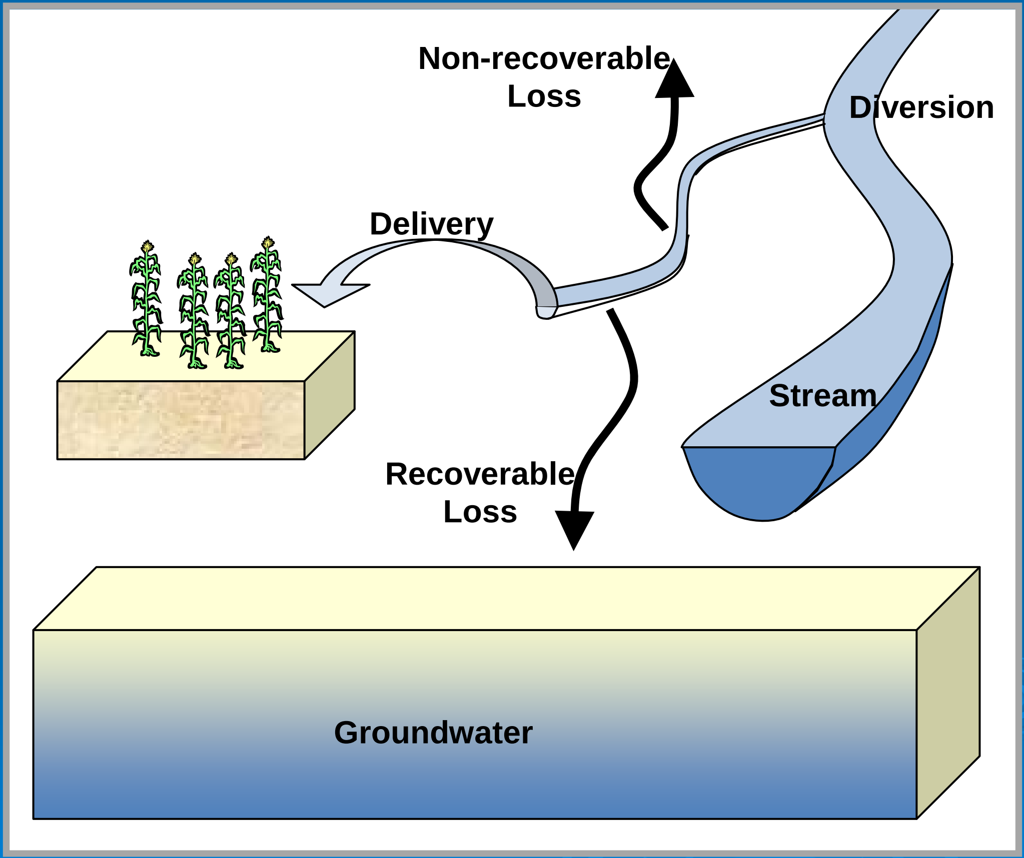
$$Q_{sint} = C_s\left[\max\left(h_s, h_b\right) - \max\left(h, h_b\right)\right] \quad ; \quad C_s = \frac{K_s}{d_s}LW$$

Q_{sint} = stream-aquifer interaction, (L^3/T)
h = groundwater head, (L)
h_s = stream surface elevation, (L)
h_b = stream bottom elevation, (L)
K_s = stream bed hydraulic conductivity, (L/T)
d_s = stream bed thickness, (L)
L = length of stream segment, (L)
W = channel width, (L)



Stream Diversions

- Used to meet agricultural and urban water demands
- User-specified fractions of diversion become recoverable (recharge to groundwater) and non-recoverable (evaporation) losses
- May be used to simulate spreading basins (100% recoverable and non-recoverable losses)



Lakes and Lake-Aquifer Interaction

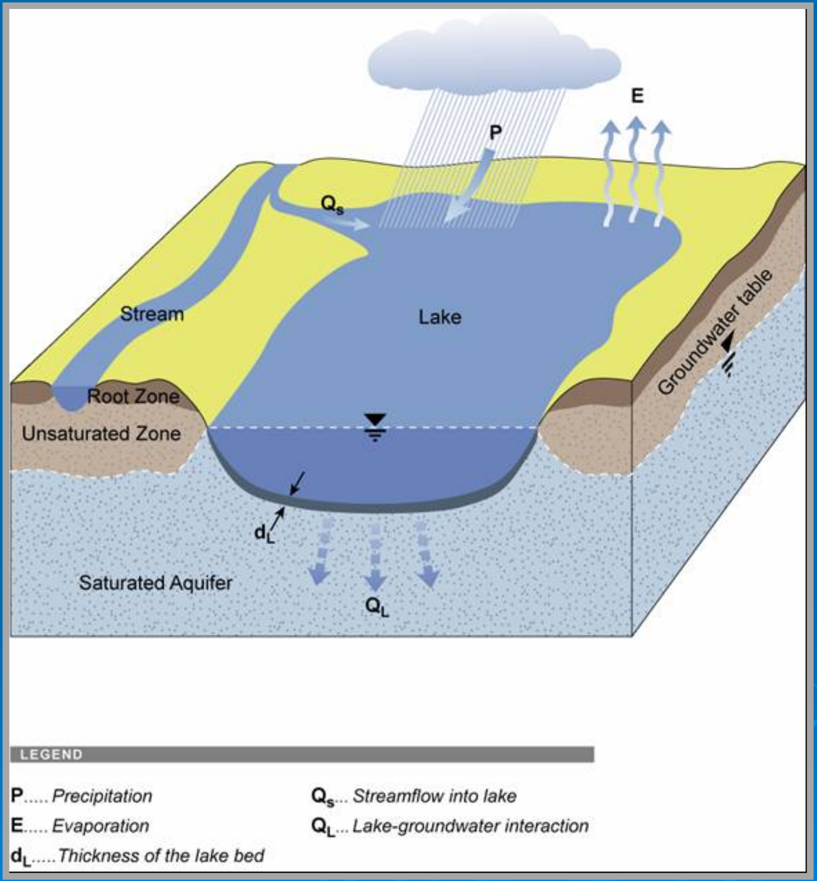
- One or more elements can be specified as lake elements
- Lakes are fully coupled with groundwater
- Lake storage is a function of precipitation, evaporation, inflows, lake-aquifer interaction and lake outflow

$$\frac{\Delta S_{lk}}{\Delta t} - Q_{lkin} + Q_{lkout} = 0$$

ΔS_{lk} = change in lake storage, (L^3)

Q_{lkin} = lake inflow (precipitation, inflows from streams and upstream lakes), (L^3/T)

Q_{lkout} = lake outflow (evaporation, lake spill, lake-aquifer interaction), (L^3/T)



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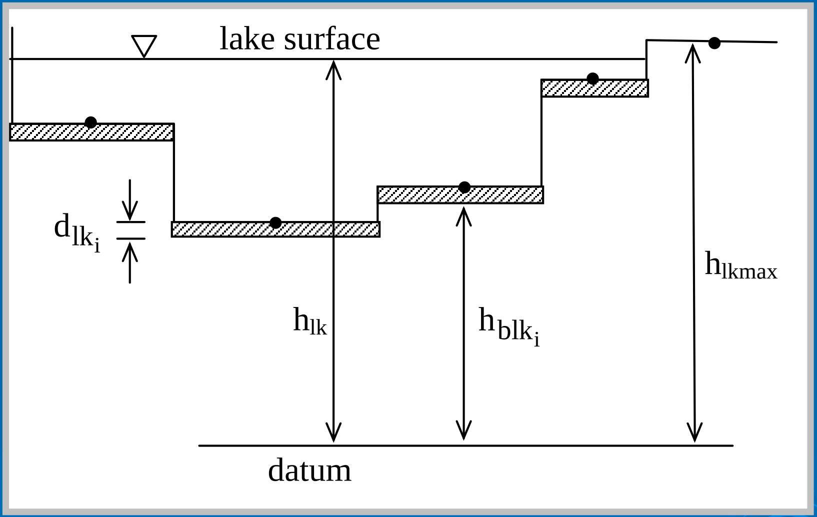
Lake-Groundwater Interaction

$$\mathbf{Q_{lkint} = C_{lk}\left[\max\left(h_{lk},h_{blk}\right) - \max\left(h,h_{blk}\right)\right] \;;\quad C_{lk} = \frac{K_{lk}}{d_{lk}} A_{lk}}$$

Q_{lkint} = lake-aquifer interaction, (L^3/T)
h = groundwater head, (L)
h_{lk} = lake surface elevation, (L)
h_{blk} = lake bottom elevation, (L)
K_{lk} = lake bed hydraulic conductivity, (L/T)
d_{lk} = lake bed thickness, (L)
A_{lk} = area of lake, (L)



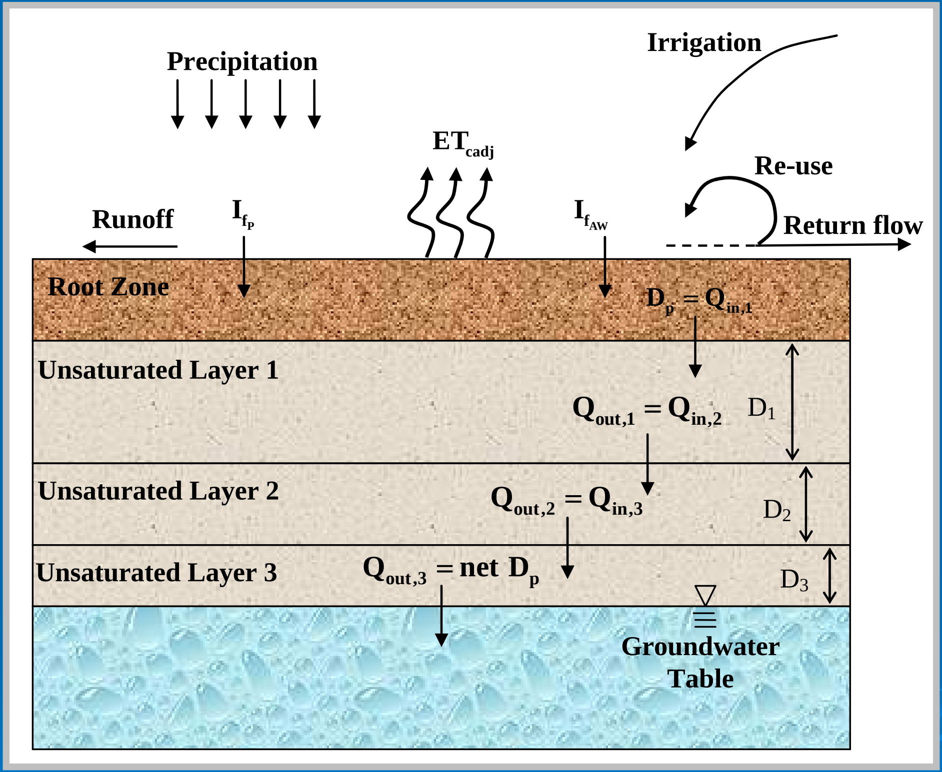
- Lake outflow is computed when lake surface elevation exceeds maximum lake elevation
- Lake outflow can be directed to a stream node or a downstream lake

Land Surface and Root Zone Processes

- Land surface and root zone component makes IWFM a powerful tool as it routes the water through the root zone as well as calculates the water demands
- Calculation of water demands based on land-use, climate, soil and agronomic properties allows estimation of historical or future stresses (pumping and diversions) in a basin
- Simulated as one-dimensional vertical flow

Land Surface and Root Zone Processes

- Precipitation and irrigation less direct runoff and return flow is the inflow into root zone
- Deep percolation from root zone is the inflow into unsaturated zone
- Net deep percolation from unsaturated zone is the recharge to groundwater
- 4 land-use types considered: agricultural, urban, native vegetation, riparian vegetation



- Unsaturated zone layer thicknesses are time-dependent; conservation equations in unsaturated zone layers are solved iteratively

Land Surface and Root Zone Processes

- Governing conservation equation for the root zone:

$$\theta_r^{t+1} = \theta_r^{t} + \left[\left(P - S_r\right) + \left(A_W - R_f\right) - ET_{cadj} - D_p\right]\Delta t$$

where θ_r = soil moisture, (L);

P = precipitation, (L/T);

S_r = surface runoff from precipitation, (L/T);

A_W = applied water, (L/T);

R_f = return flow of applied water, (L/T);

ET_{cadj} = adjusted evapotranspiration, (L/T);

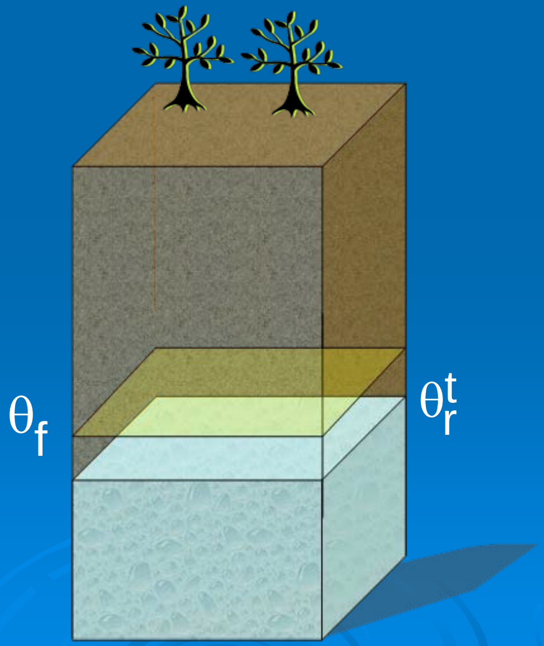
D_p = deep percolation, (L/T);

Δt = time step length, (T);

t = time step counter (dimensionless).

Land Surface and Root Zone Processes

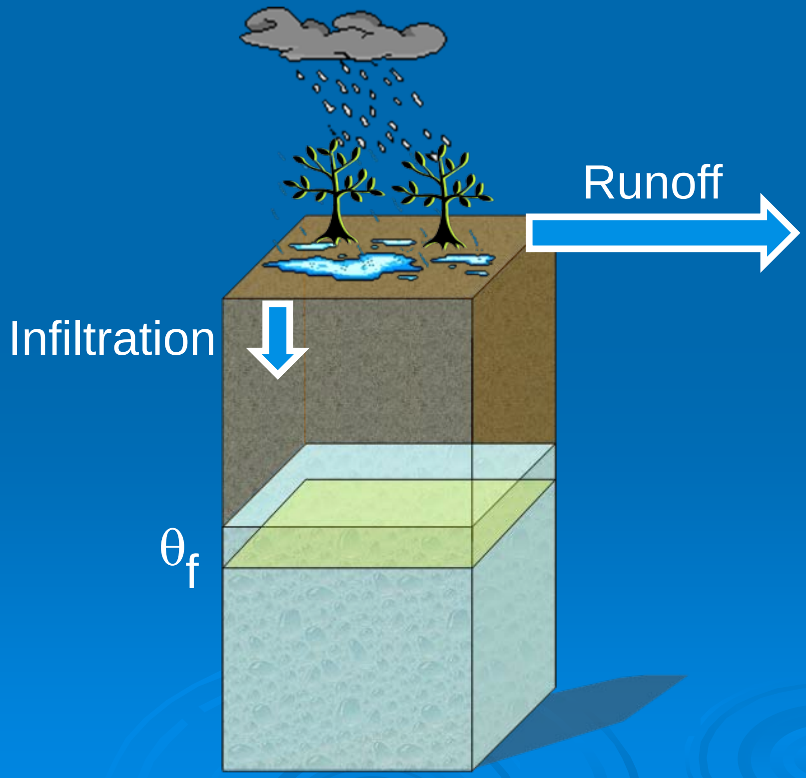
Initial condition



Land Surface and Root Zone Processes

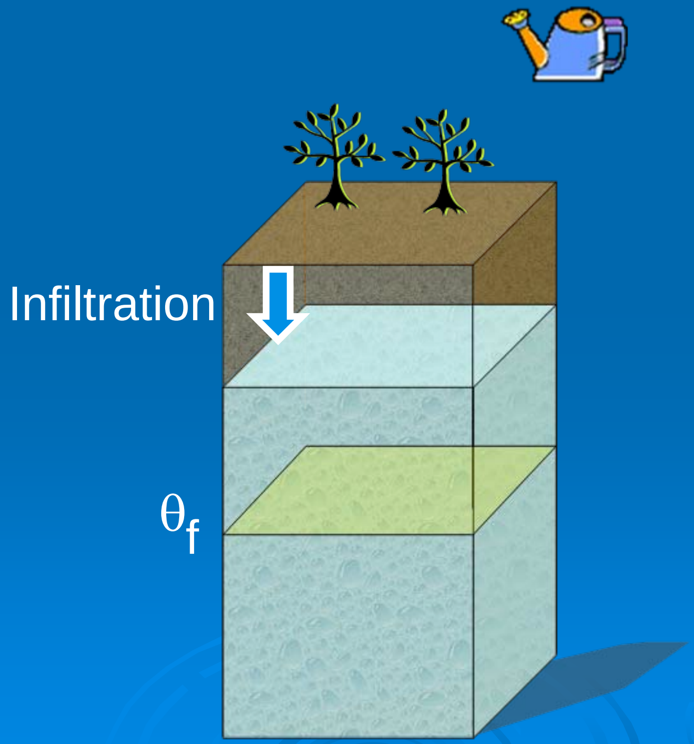
Step 1: Compute rainfall runoff and infiltration of precipitation

- Modified SCS Curve Number method (retention parameter, S, decreases as moisture goes above half of field capacity)



Land Surface and Root Zone Processes

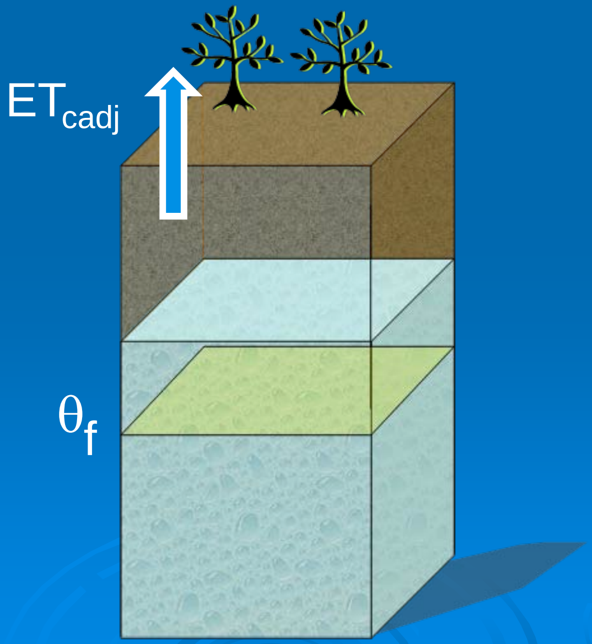
Step 2: Apply irrigation and initially assume all infiltrates



Land Surface and Root Zone Processes

Step 3: Compute evapotranspiration (FAO Paper 56, 1998)

- Same as potential ET when moisture is at or above half of field capacity
- Decreases linearly when moisture is below half of field capacity

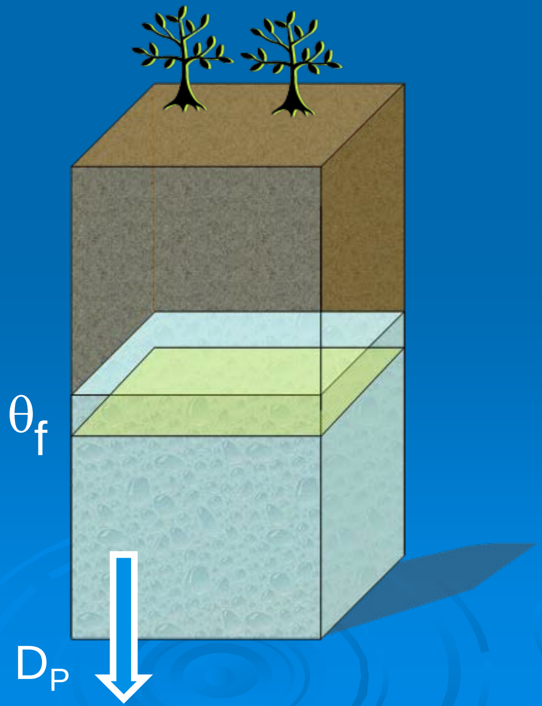


Land Surface and Root Zone Processes

Step 4: Compute deep percolation if moisture is above field capacity

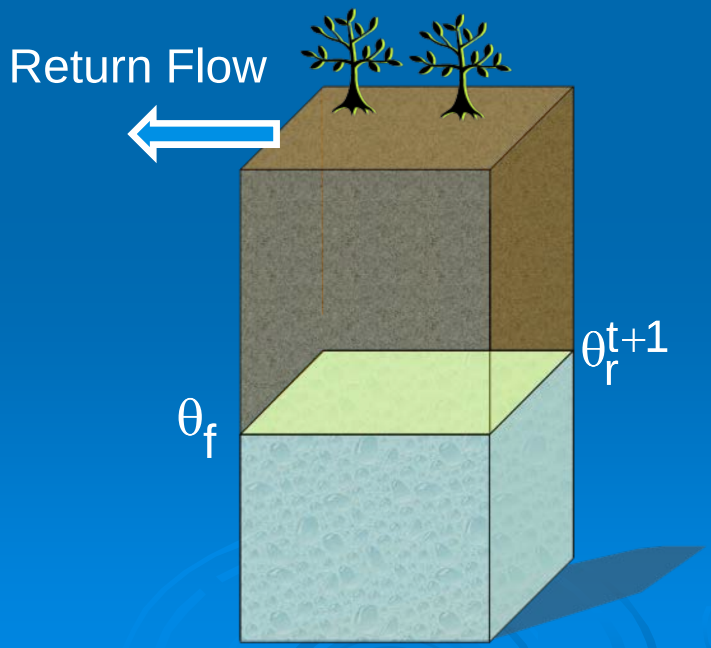
Expressed using one of the methods below specified by user

- A fraction of moisture that is above field capacity
- Physically-based method using hydraulic conductivity; $D_P = K_S \left(\frac{\theta_r}{\eta_T} \right)^4$

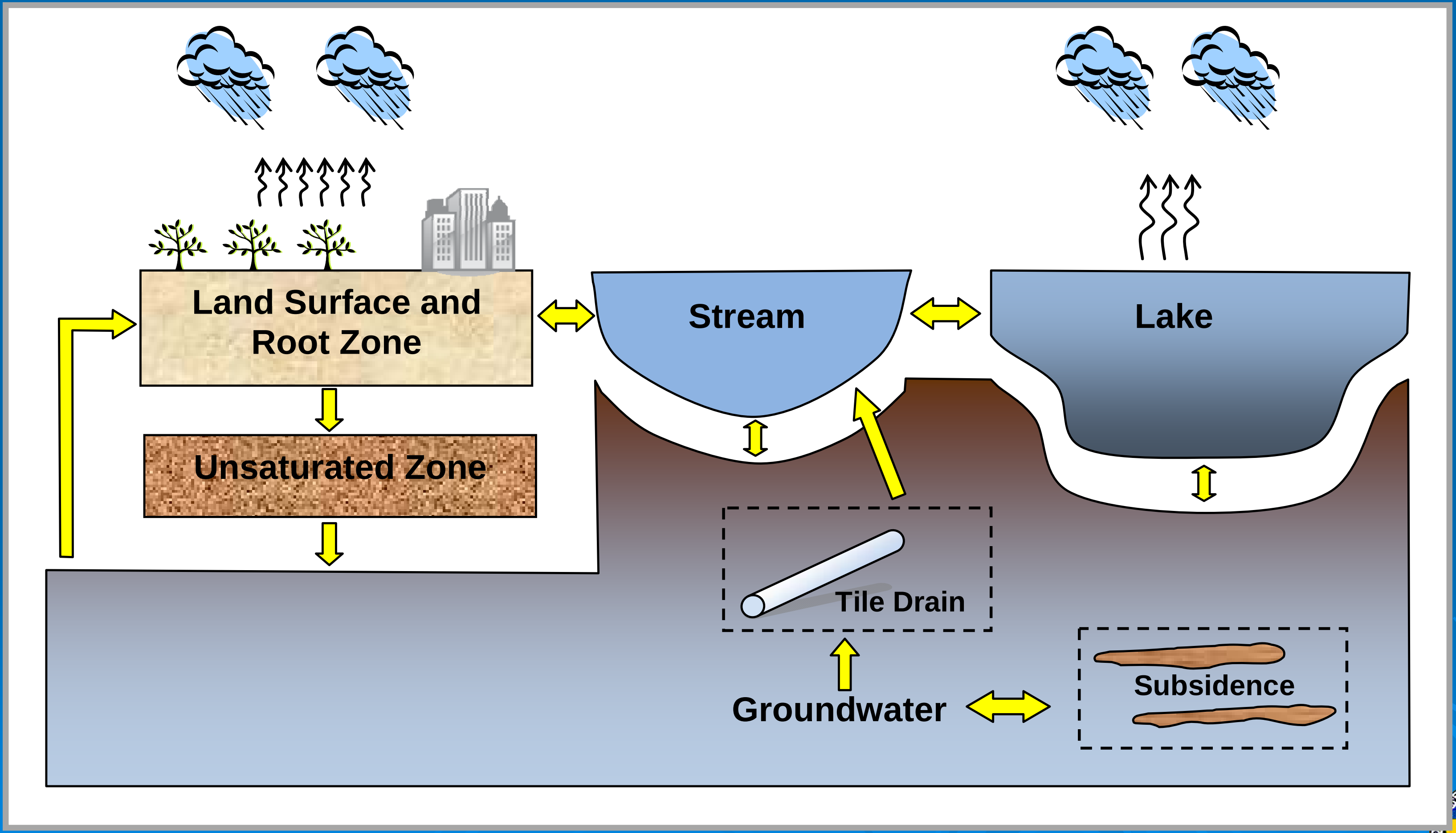


Land Surface and Root Zone Processes

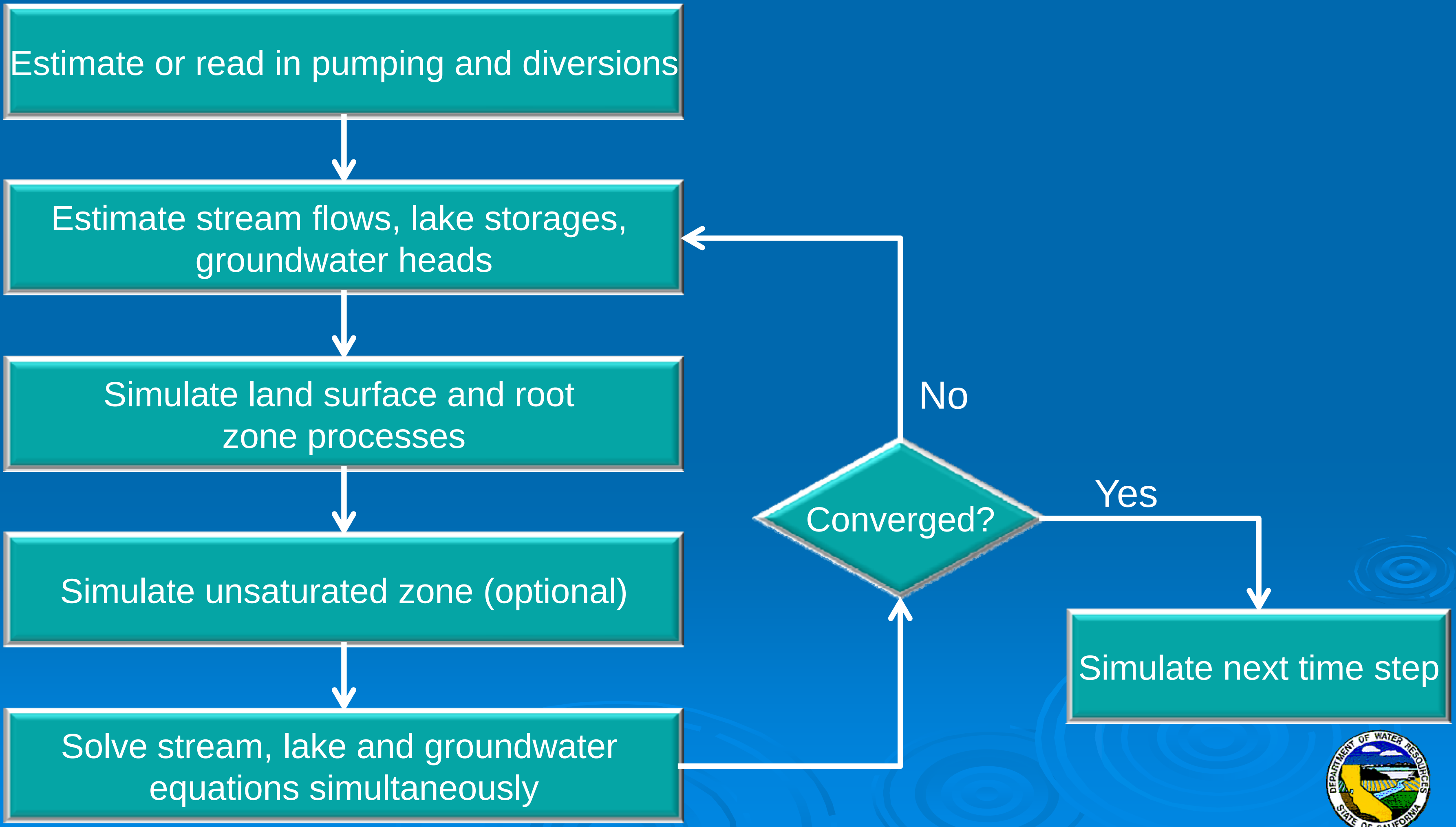
Step 5: Compute return flow and update infiltration of applied water



IWFM Component Interactions



Simulation Scheme



Estimate or read in pumping and diversions

Estimate stream flows, lake storages, groundwater heads

Simulate land surface and root zone processes

Simulate unsaturated zone (optional)

Solve stream, lake and groundwater equations simultaneously

Converged?

No

Yes

Simulate next time step

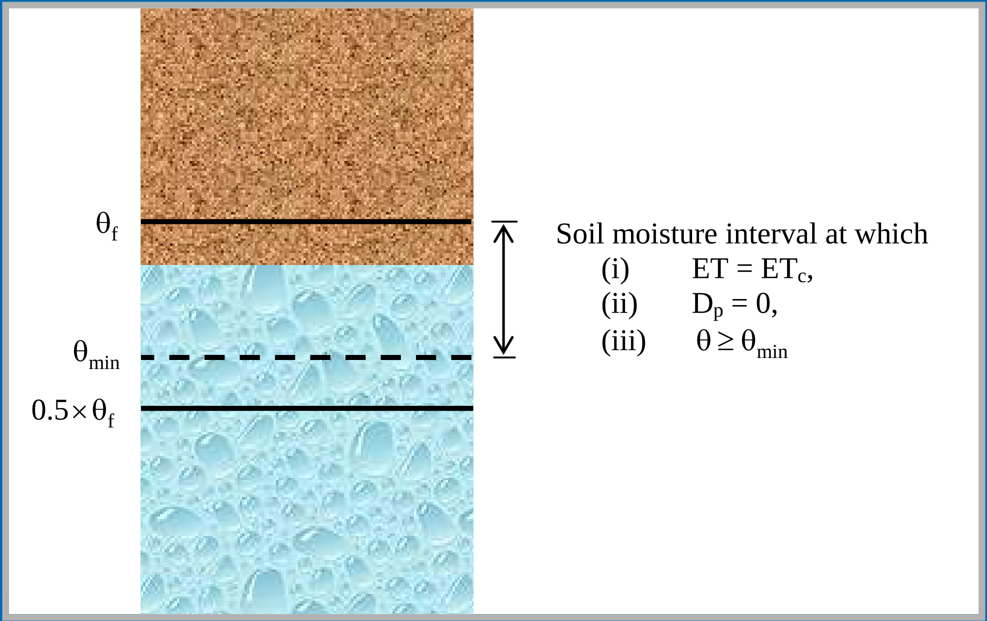
A Need for Demand Computation

$$\theta_r^{t+1} = \theta_r^t + \left[\left(P - S_r\right) + \left(A_W - R_f\right) - ET_{cadj} - D_p\right]\Delta t$$

- Routing of water through a developed basin requires the knowledge of applied water
- In California, groundwater pumping is generally neither measured nor regulated; i.e. total historical applied water is unknown
- Most major surface diversions are measured in California’s Central Valley but their spatial allocation may be unknown
- For planning studies applied water is an unknown and has to be computed dynamically
- To address the uncertainties in historical and future water supplies and where these supplies were/will be used, a demand-supply balance is needed

Agricultural Demand Computation

- Agricultural demand is the required amount of applied water in order to maintain optimum agricultural conditions



Soil moisture interval at which
(i) $ET = ET_c$,
(ii) $D_p = 0$,
(iii) $\theta \geq \theta_{min}$

- At optimum agricultural conditions
  1) ET rates are at their potential levels for proper crop growth
  2) soil moisture loss as deep percolation and return flow is minimized
  3) minimum soil moisture requirement for each crop is met at all times

Agricultural Demand Computation

- Use governing conservation equation to express the applied water that will satisfy the optimum agricultural conditions:

$$\theta_{min} = \theta_r^t + \left[\left(P - S_r\right) + CU_{AW} - ET_c\right]\Delta t$$

$$\Rightarrow \quad CU_{AW} = \frac{\theta_{min} - \theta_r^t}{\Delta t} - \left(P - S_r\right) + ET_c \quad \geq \quad 0$$

$$D_{ag} = \frac{CU_{AW}}{I_E}$$

where

CU_{AW} = potential consumptive use of applied water assuming 100% irrigation efficiency, (L/T)

I_E = irrigation efficiency, (dimensionless)

D_{ag} = agricultural water demand, (L/T)

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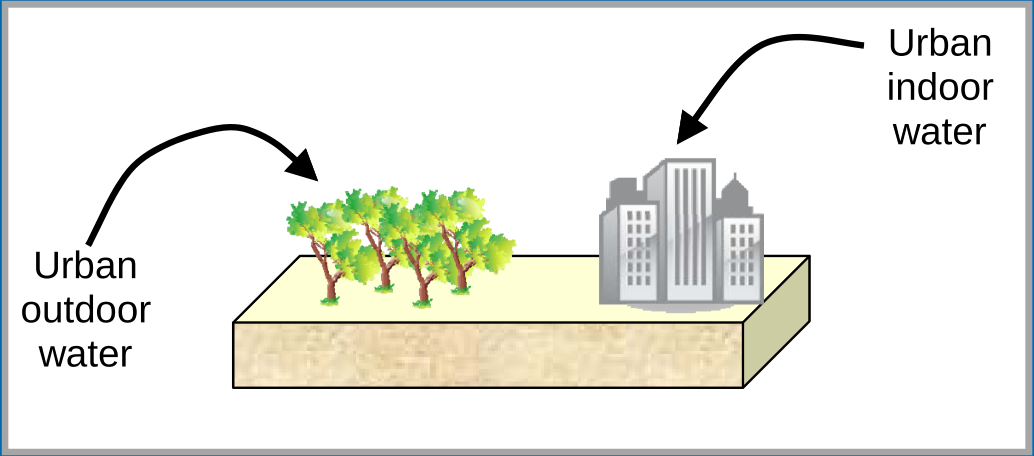
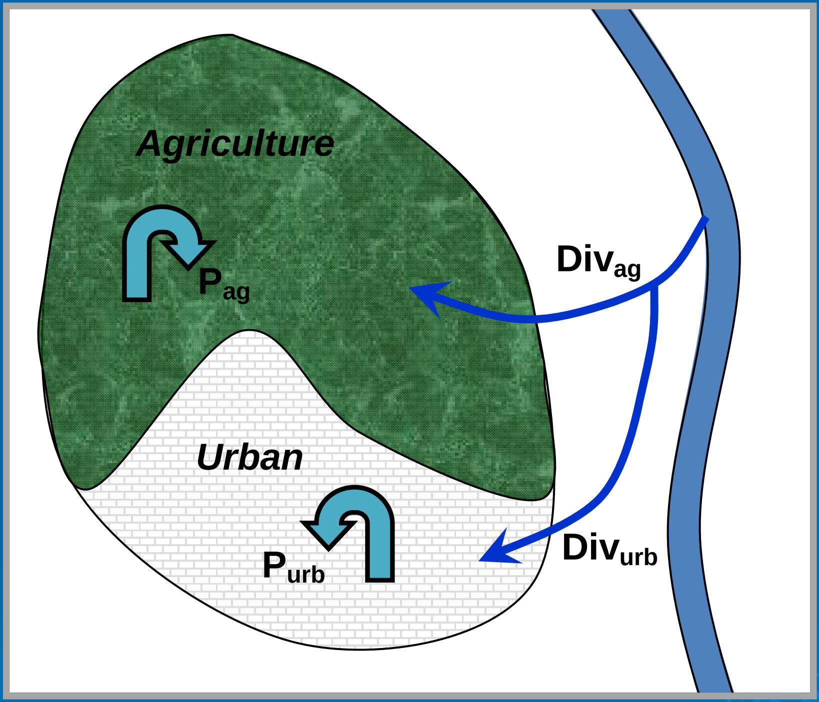
Urban Water Demand and Moisture Routing

- Urban water demands are user-specified time-series input data
- Outdoor urban applied water and precipitation are routed through the root zone using the governing conservation equation
- Urban indoor applied water and precipitation over non-pervious urban areas become entirely return flow and surface runoff



Automated Supply Adjustment

- Automatic adjustment of diversions and pumping to meet agricultural and urban water demands
- Diversion or pumping adjustment can be turned on or off during simulation period (represents evolution of water supply facilities over time)
- All supplies have equal priorities; handling of complex water rights is deferred to systems models like CalSim



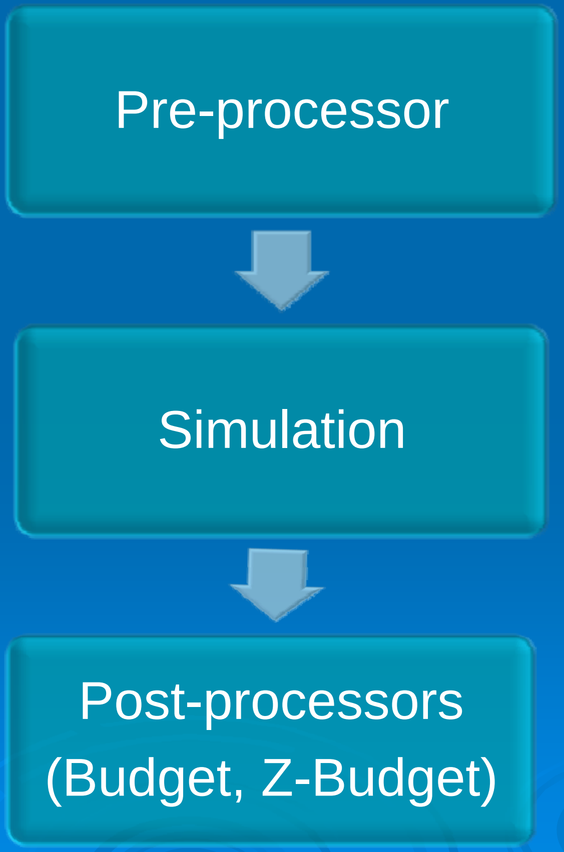
- Useful in estimating historical pumping in Central Valley, and future diversions and pumping
- No supply adjustment for native and riparian vegetation

Balance between Supply and Demand

- IWFM can route water supplies (diversions and pumping) as specified or automatically adjust supplies to meet demands (increase/decrease in diversions and/or pumping)
- When supplies are adjusted, they may still be less than demand if there is not enough water in the system
- When supply is less than demand deep percolation, return flows, moisture content and ET diminish; when larger than demand deep percolation, return flow and moisture content increase

User Interface

- IWFM consists of a pre-processor, a simulation and a post-processor executables



Pre-processor

Simulation

Post-processors

(Budget, Z-Budget)

User Interface

- Input files are tabular and contain comment fields
- Time-tracking simulations aware of actual date and time; input and output time-series data with date and time stamp
- Optional time-series data input from and output to HEC-DSS database
- Detailed budget tables for each simulated component
- Budget-To-Excel tool to import budget tables into Excel
- TecPlot ready output for 2-D and 3-D animations of groundwater heads and subsidence
- Mesh generator embedded in ArcGIS (state-of-the-art mesh generator-GIS linkage; paper accepted in June 2012 for publication in Geosciences & Computers)

Documentation and User Support

- Theoretical documentation, user’s manual, reports, technical memorandums, previous presentations and posters, user’s group presentations, and published articles in peer reviewed journals are available at the IWFM web site (google “IWFM”)
- Technical support by DWR staff

Integrated Water Flow Model
IWFM v3.02
revision 36

Theoretical Documentation

Integrated Hydrological Models Development Unit
Modeling Support Branch
Bay-Delta Office
October, 2011

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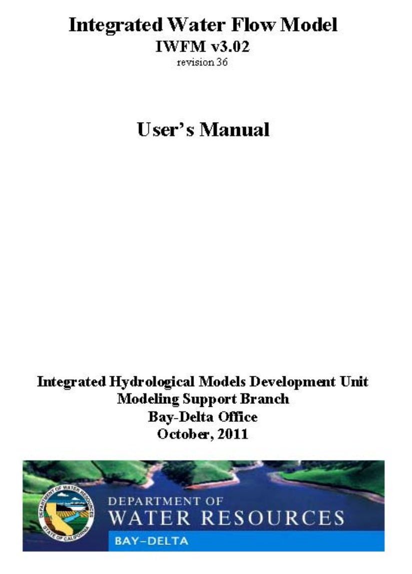

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revision 36

User’s Manual

Integrated Hydrological Models Development Unit
Modeling Support Branch
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October, 2011

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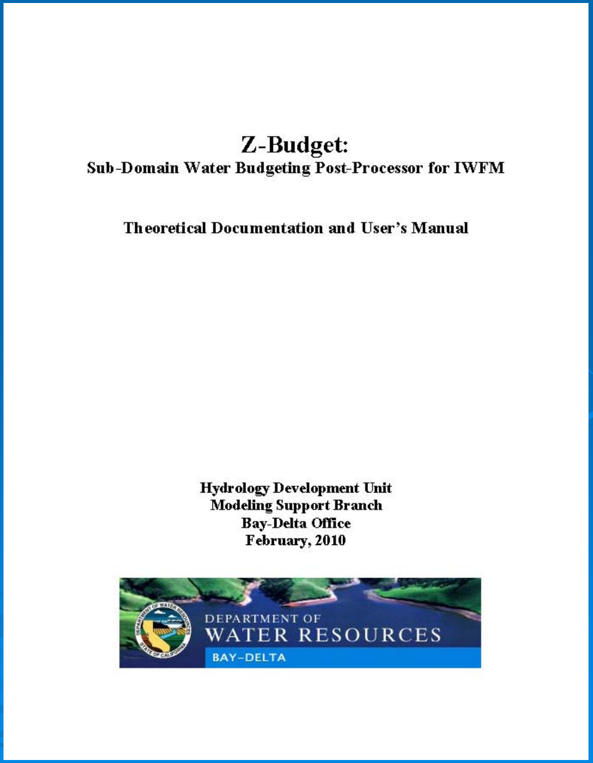

Z-Budget:
Sub-Domain Water Budgeting Post-Processor for IWFM

Theoretical Documentation and User’s Manual

Hydrology Development Unit
Modeling Support Branch
Bay-Delta Office
February, 2010

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WATER RESOURCES
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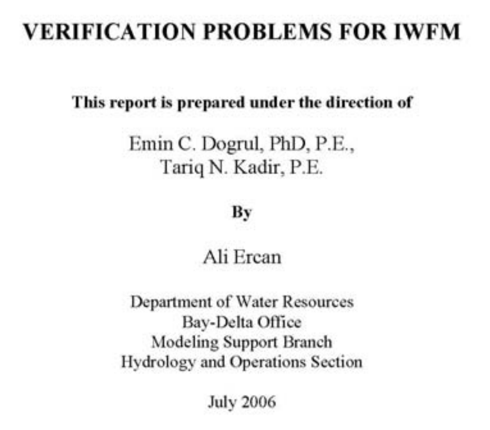
Validation and Verification

- Total of 11 verification runs; report available at IWFM web site (Ercan, 2006)



VERIFICATION PROBLEMS FOR IWFM

This report is prepared under the direction of

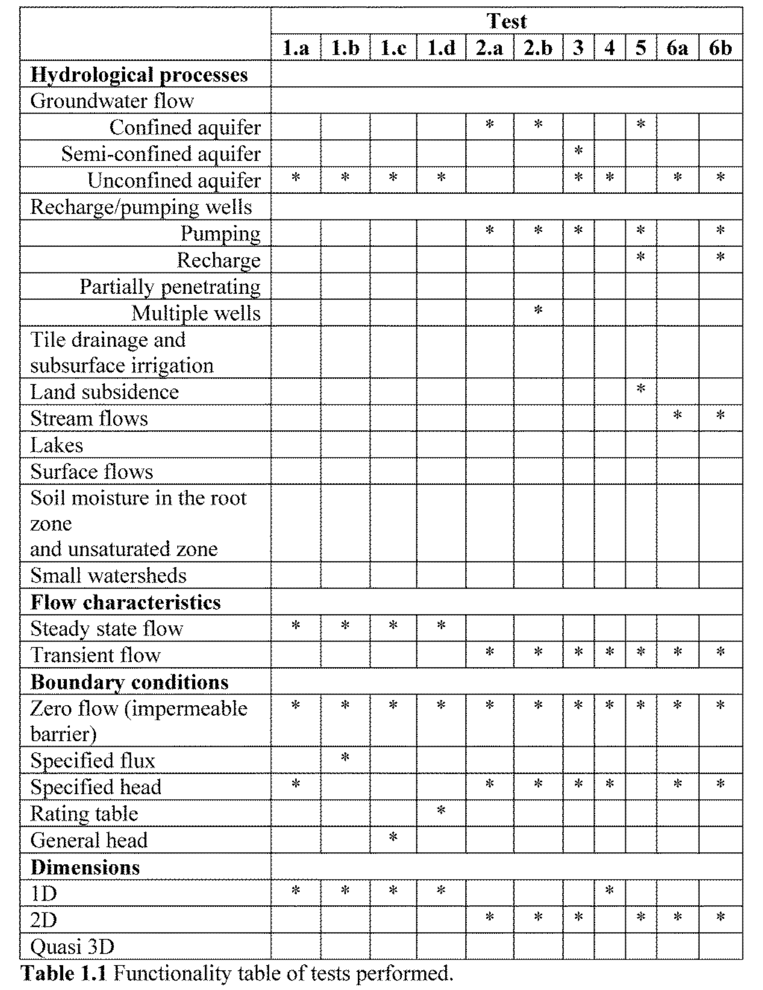
Emin C. Dogrul, PhD, P.E.,
Tariq N. Kadir, P.E.

By

Ali Ercan

Department of Water Resources
Bay-Delta Office
Modeling Support Branch
Hydrology and Operations Section

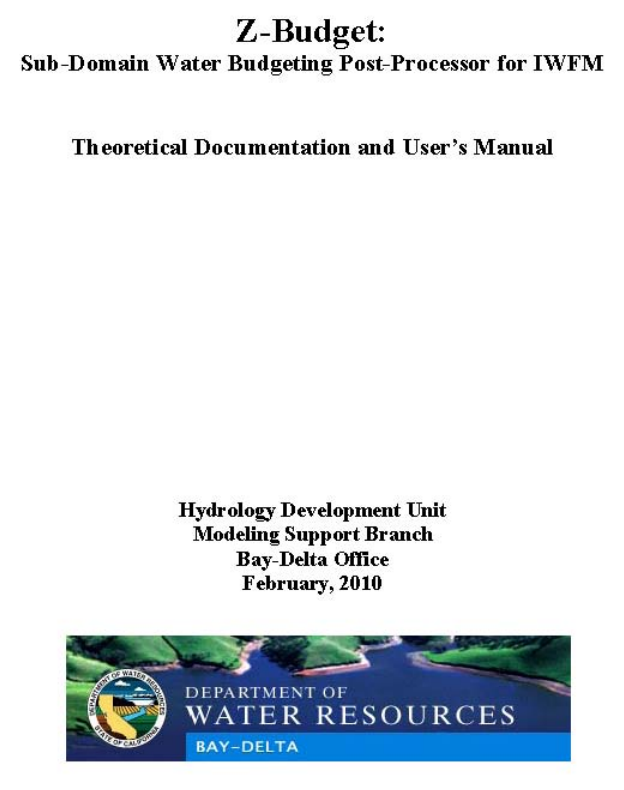
July 2006



	Test										
	1.a	**1.b**	**1.c**	**1.d**	**2.a**	**2.b**	**3**	**4**	**5**	**6a**	**6b**
Hydrological processes											
Groundwater flow											
Confined aquifer					*	*			*		
Semi-confined aquifer							*				
Unconfined aquifer	*	*	*	*			*	*		*	*
Recharge/pumping wells											
Pumping					*	*	*		*		*
Recharge									*		*
Partially penetrating											
Multiple wells						*					
Tile drainage and subsurface irrigation											
Land subsidence									*		
Stream flows										*	*
Lakes											
Surface flows											
Soil moisture in the root zone and unsaturated zone											
Small watersheds											
Flow characteristics											
Steady state flow	*	*	*	*							
Transient flow					*	*	*	*	*	*	*
Boundary conditions											
Zero flow (impermeable barrier)	*	*	*	*	*	*	*	*	*	*	*
Specified flux		*									
Specified head	*				*	*	*	*		*	*
Rating table				*							
General head			*								
Dimensions											
1D	*	*	*	*				*			
2D					*	*	*		*	*	*
Quasi 3D											

Table 1.1 Functionality table of tests performed.

Validation of Z-Budget Post-processor



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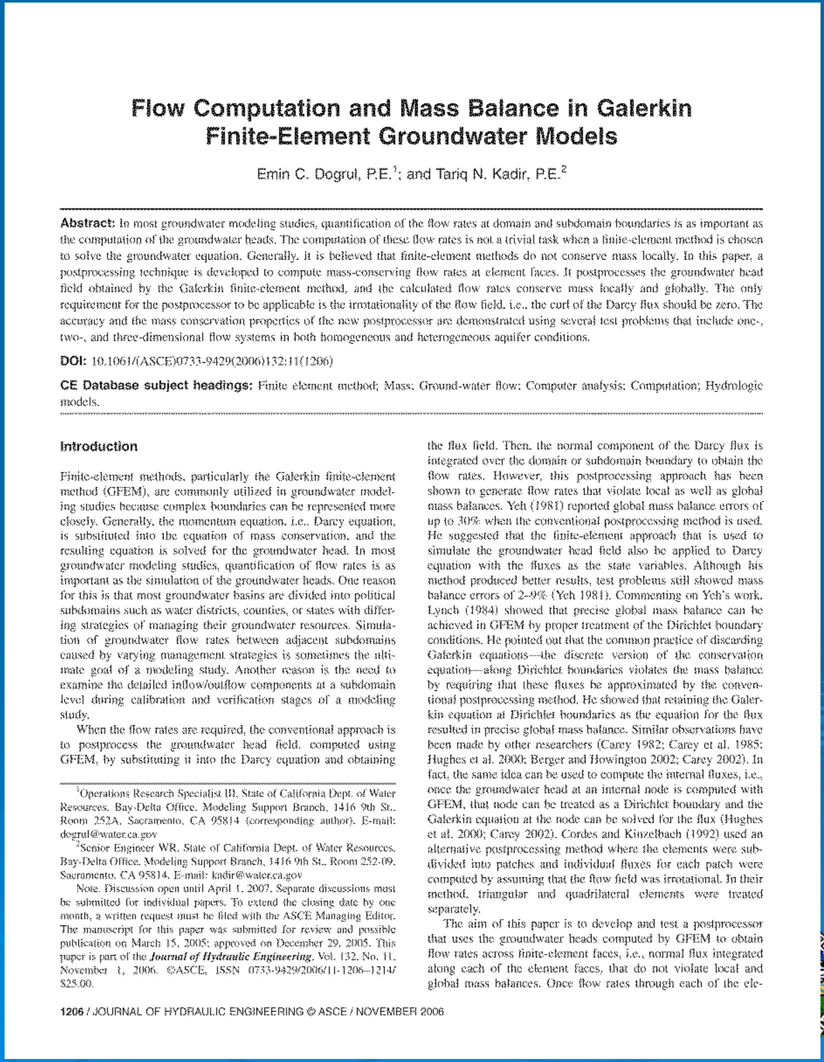

Flow Computation and Mass Balance in Galerkin Finite-Element Groundwater Models

Emin C. Dogrul, P.E.[1]; and Tariq N. Kadir, P.E.[2]

Abstract: In most groundwater modeling studies, quantification of the flow rates at domain and subdomain boundaries is as important as the computation of the groundwater heads. The computation of these flow rates is not a trivial task when a finite-element method is chosen to solve the groundwater equation. Generally, it is believed that finite-element methods do not conserve mass locally. In this paper, a postprocessing technique is developed to compute mass-conserving flow rates at element faces. It postprocesses the groundwater head field obtained by the Galerkin finite-element method, and the calculated flow rates conserve mass locally and globally. The only requirement for the postprocessor to be applicable is the irrotationality of the flow field, i.e., the curl of the Darcy flux should be zero. The accuracy and the mass conservation properties of the new postprocessor are demonstrated using several test problems that include one-, two-, and three-dimensional flow systems in both homogeneous and heterogeneous aquifer conditions.

DOI: 10.1061/(ASCE)0733-9429(2006)132:11(1206)

CE Database subject headings: Finite element method; Mass; Ground-water flow; Computer analysis; Computation; Hydrologic models.

Introduction

Finite-element methods, particularly the Galerkin finite-element method (GFEM), are commonly utilized in groundwater modeling studies because complex boundaries can be represented more closely. Generally, the momentum equation, i.e., Darcy equation, is substituted into the equation of mass conservation, and the resulting equation is solved for the groundwater head. In most groundwater modeling studies, quantification of flow rates is as important as the simulation of the groundwater heads. One reason for this is that most groundwater basins are divided into political subdomains such as water districts, counties, or states with differing strategies of managing their groundwater resources. Simulation of groundwater flow rates between adjacent subdomains caused by varying management strategies is sometimes the ultimate goal of a modeling study. Another reason is the need to examine the detailed inflow/outflow components at a subdomain level during calibration and verification stages of a modeling study.

When the flow rates are required, the conventional approach is to postprocess the groundwater head field, computed using GFEM, by substituting it into the Darcy equation and obtaining the flux field. Then, the normal component of the Darcy flux is integrated over the domain or subdomain boundary to obtain the flow rates. However, this postprocessing approach has been shown to generate flow rates that violate local as well as global mass balances. Yeh (1981) reported global mass balance errors of up to 30% when the conventional postprocessing method is used. He suggested that the finite-element approach that is used to simulate the groundwater head field also be applied to Darcy equation with the fluxes as the state variables. Although his method produced better results, test problems still showed mass balance errors of 2–9% (Yeh 1981). Commenting on Yeh's work, Lynch (1984) showed that precise global mass balance can be achieved in GFEM by proper treatment of the Dirichlet boundary conditions. He pointed out that the common practice of discarding Galerkin equations—the discrete version of the conservation equation—along Dirichlet boundaries violates the mass balance by requiring that these fluxes be approximated by the conventional postprocessing method. He showed that retaining the Galerkin equation at Dirichlet boundaries as the equation for the flux resulted in precise global mass balance. Similar observations have been made by other researchers (Carey 1982; Carey et al. 1985; Hughes et al. 2000; Berger and Howington 2002; Carey 2002). In fact, the same idea can be used to compute the internal fluxes, i.e., once the groundwater head at an internal node is computed with GFEM, that node can be treated as a Dirichlet boundary and the Galerkin equation at the node can be solved for the flux (Hughes et al. 2000; Carey 2002). Cordes and Kinzelbach (1992) used an alternative postprocessing method where the elements were subdivided into patches and individual fluxes for each patch were computed by assuming that the flow field was irrotational. In their method, triangular and quadrilateral elements were treated separately.

The aim of this paper is to develop and test a postprocessor that uses the groundwater heads computed by GFEM to obtain flow rates across finite-element faces, i.e., normal flux integrated along each of the element faces, that do not violate local and global mass balances. Once flow rates through each of the ele-

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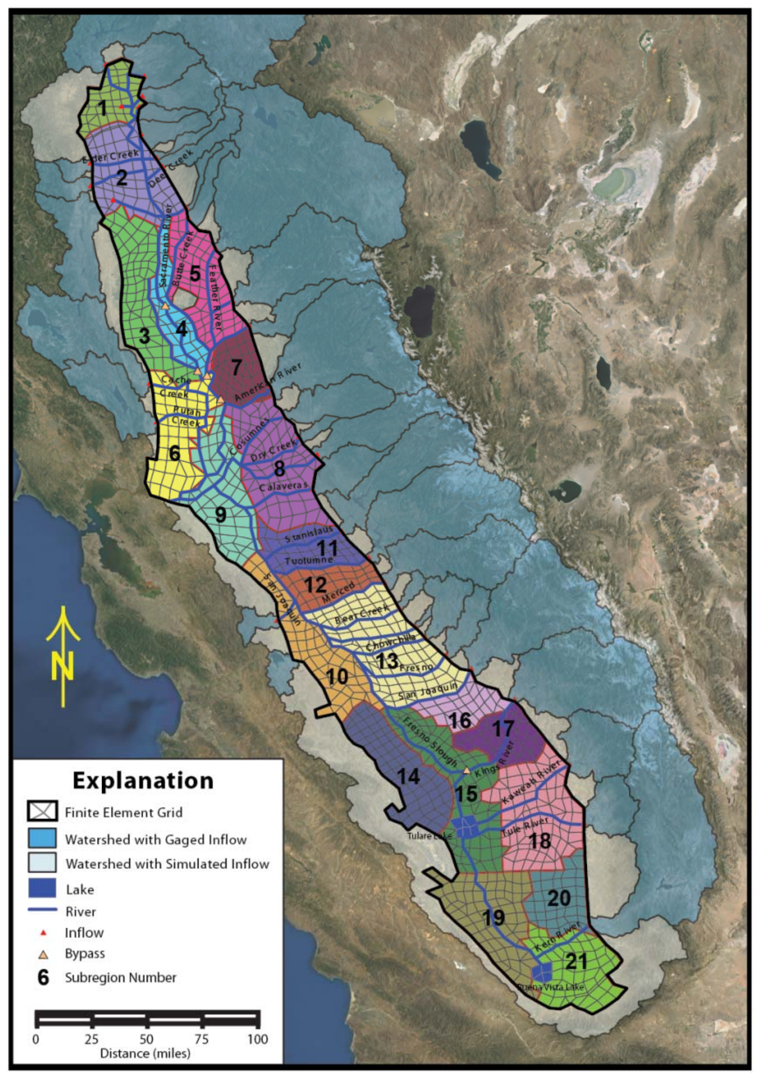
Note. Discussion open until April 1, 2007. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on March 15, 2005; approved on December 29, 2005. This paper is part of the *Journal of Hydraulic Engineering*, Vol. 132, No. 11, November 1, 2006. ©ASCE, ISSN 0733-9429/2006/11-1206–1214/$25.00.

Key Limitations

- Time step and stream routing: Stream flow must travel from upstream to downstream within the length of time step for the zero-storage assumption to be valid
- Time step and rainfall runoff: Curve numbers need to be re-calibrated for different time steps (for California’s Central Valley this is not an issue since time interval of available input data is itself a limitation)
- Spatial scale of demand and supply: Demand and supply computations are performed at subregional level in versions prior to IWFM 4.0
- Vertical distribution of pumping: Static distribution limits capability to simulate changes in the pumping depth during simulation period
- Aquifer and root zone thickness: Aquifer thickness should be large compared to root zone thickness to minimize error in case groundwater table is close to ground surface; likely to occur in native and riparian vegetation areas

Applications: California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)

- **Finite Element Grid**
  - 3 Layers or 9 Layers
  - 1393 Nodes
  - 1392 Elements
- **Surface Water System**
  - 75 River Reaches
  - 2 Lakes
  - 243 Surface Water Diversions
  - 11 Bypasses
  - 210 Small-Stream Watersheds
- **Land Use Process**
  - 21 Subregions (DSAs)
  - 4 Land Use Types
    - Agriculture
    - Urban
    - Native
    - Riparian
- **Simulation periods**
  - 10/1921-9/2009 (88 yrs)



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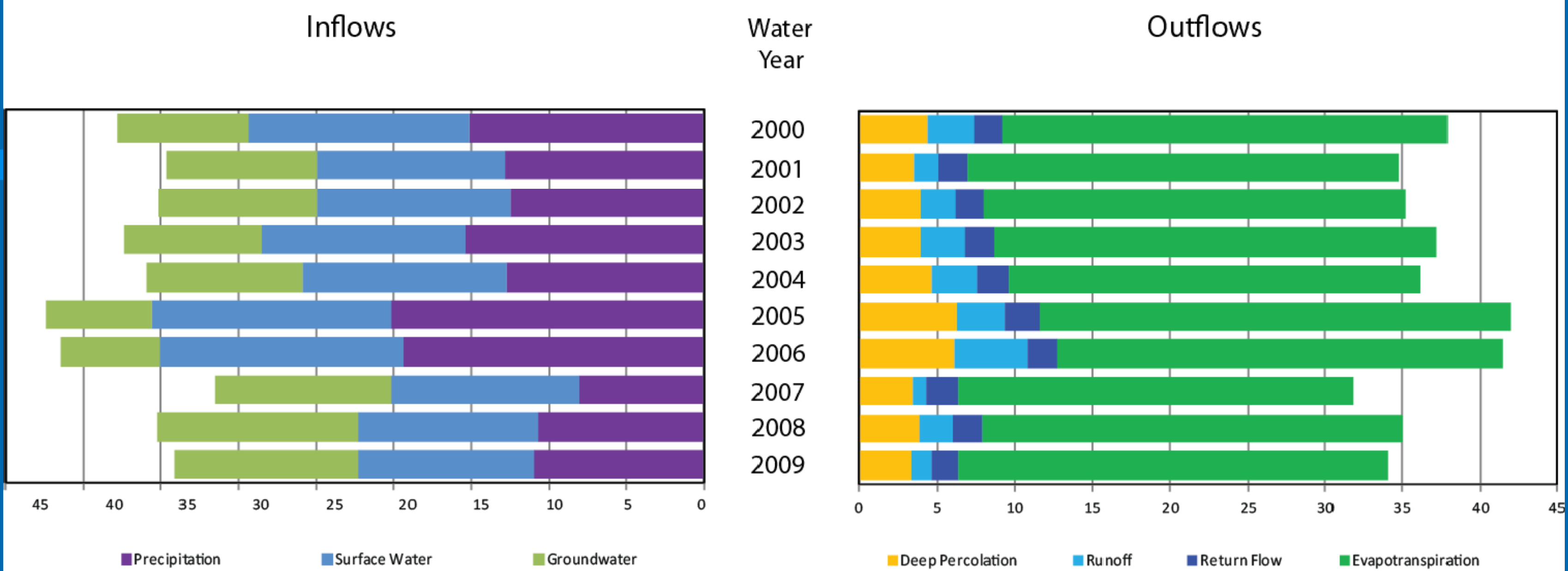
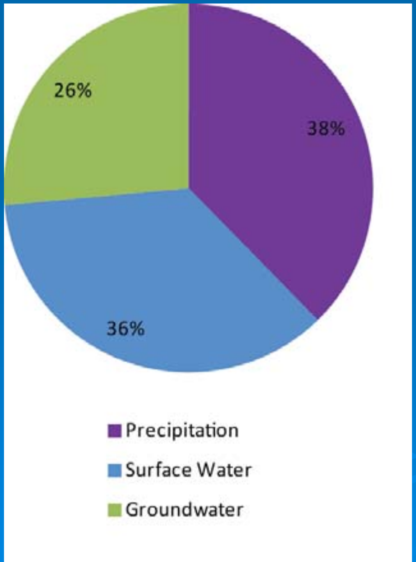
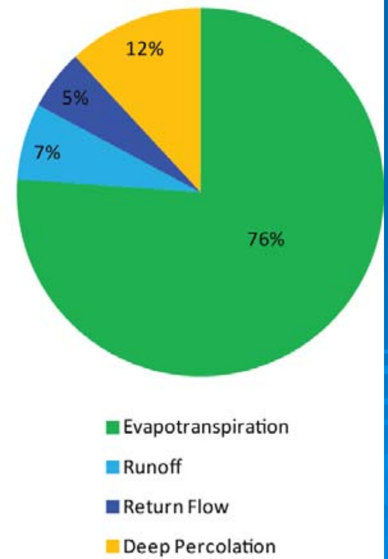
Land Surface Budget



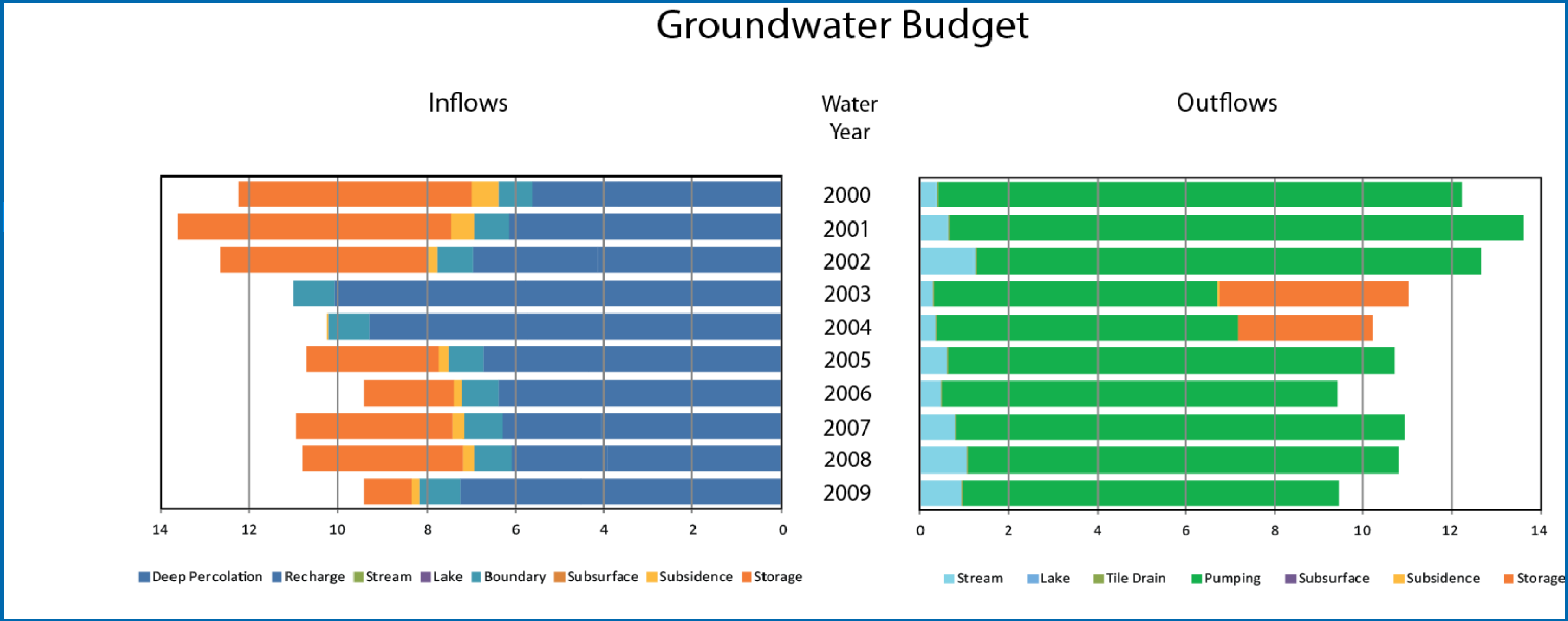


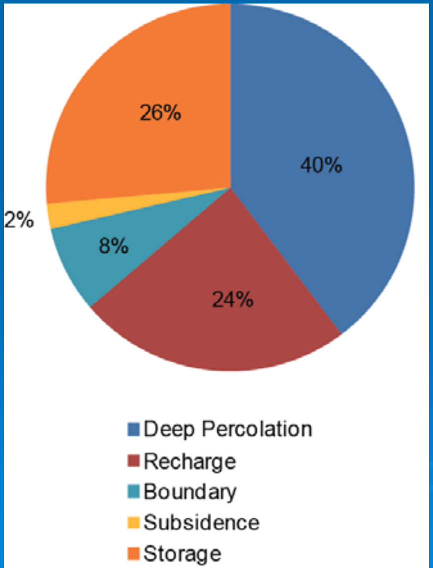
Average



Source: Draft C2VSim Report; June 2012

[Million Acre-Feet per year]





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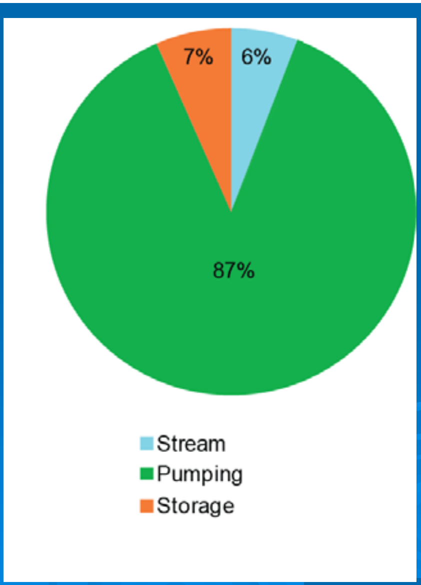
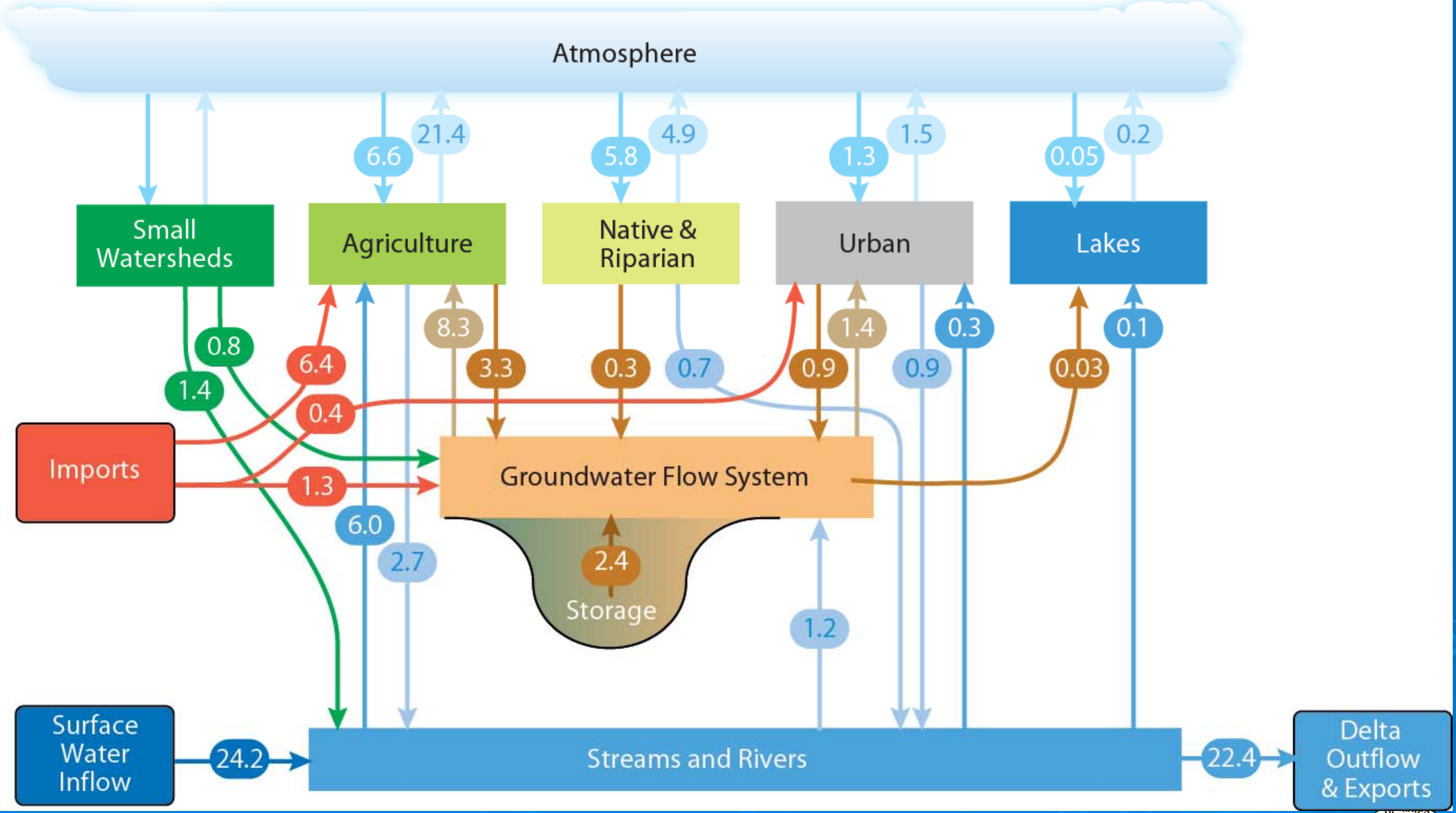


[Million Acre-Feet per year]

Source: Draft C2VSim Report; June 2012

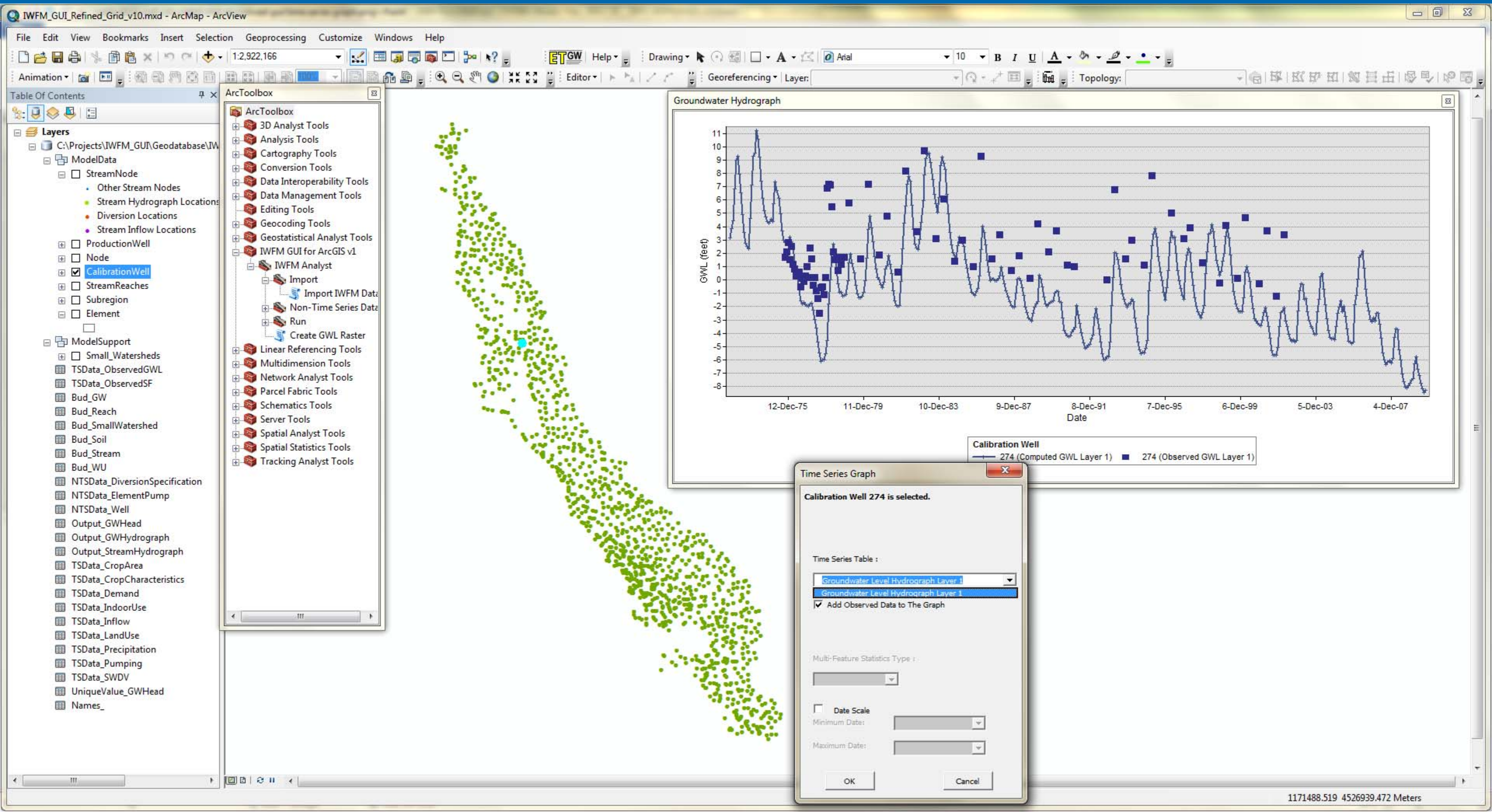
C2VSim Water Budget Components

Average Flows for California's Central Valley for Water Years 2000-2009, in Millions of Acre-Feet per Year



Source: Draft C2VSim Report; June 2012

C2VSim Output GUI



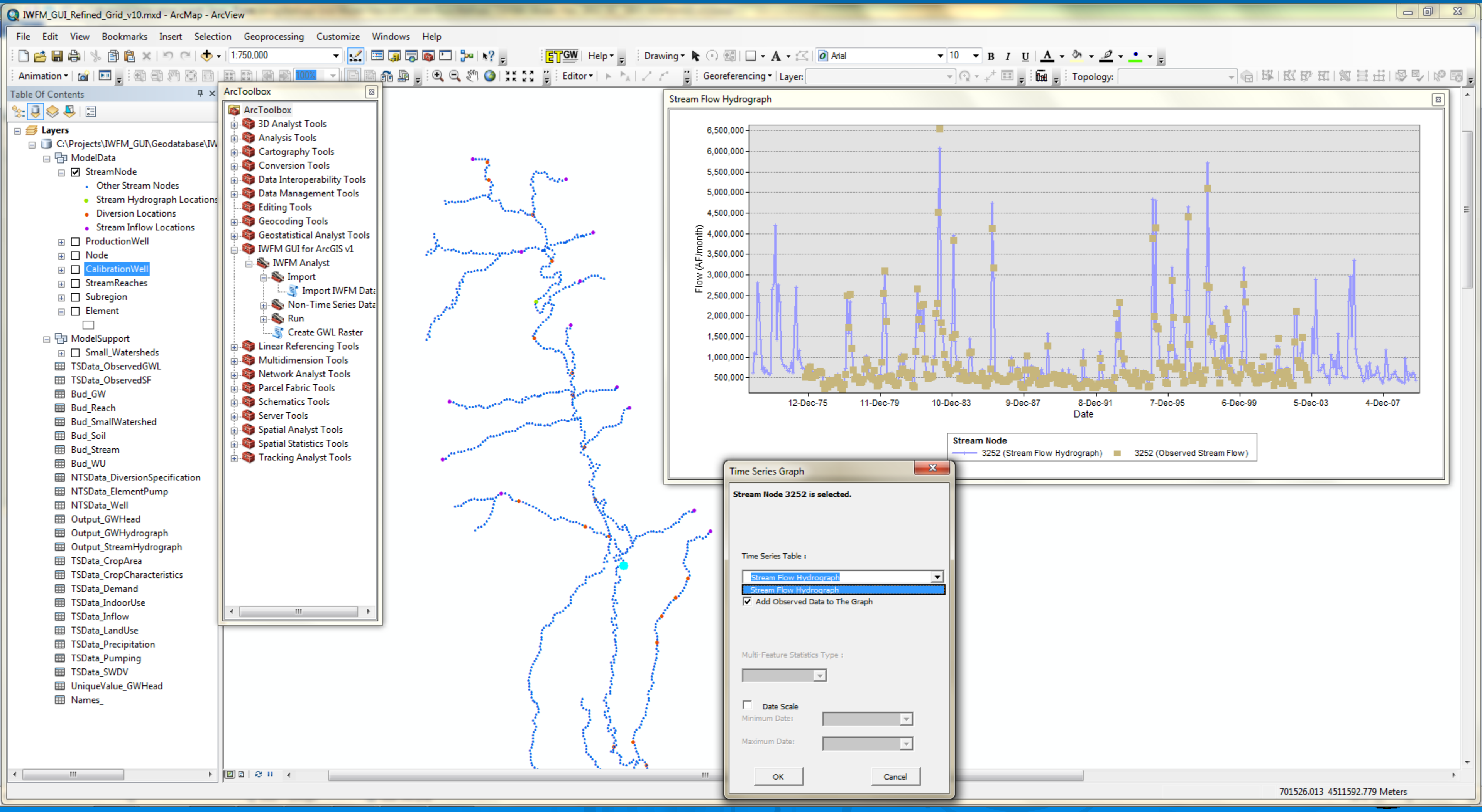
Calibration Well 274 is selected.

Time Series Table : Groundwater Level Hydrograph Layer 1

☑ Add Observed Data to The Graph

☐ Date Scale

C2VSim Output GUI



IWFM_GUI_Refined_Grid_v10.mxd - ArcMap - ArcView

Time Series Graph

Stream Node 3252 is selected.

Time Series Table : Stream Flow Hydrograph

☑ Add Observed Data to The Graph

Multi-Feature Statistics Type :

☐ Date Scale

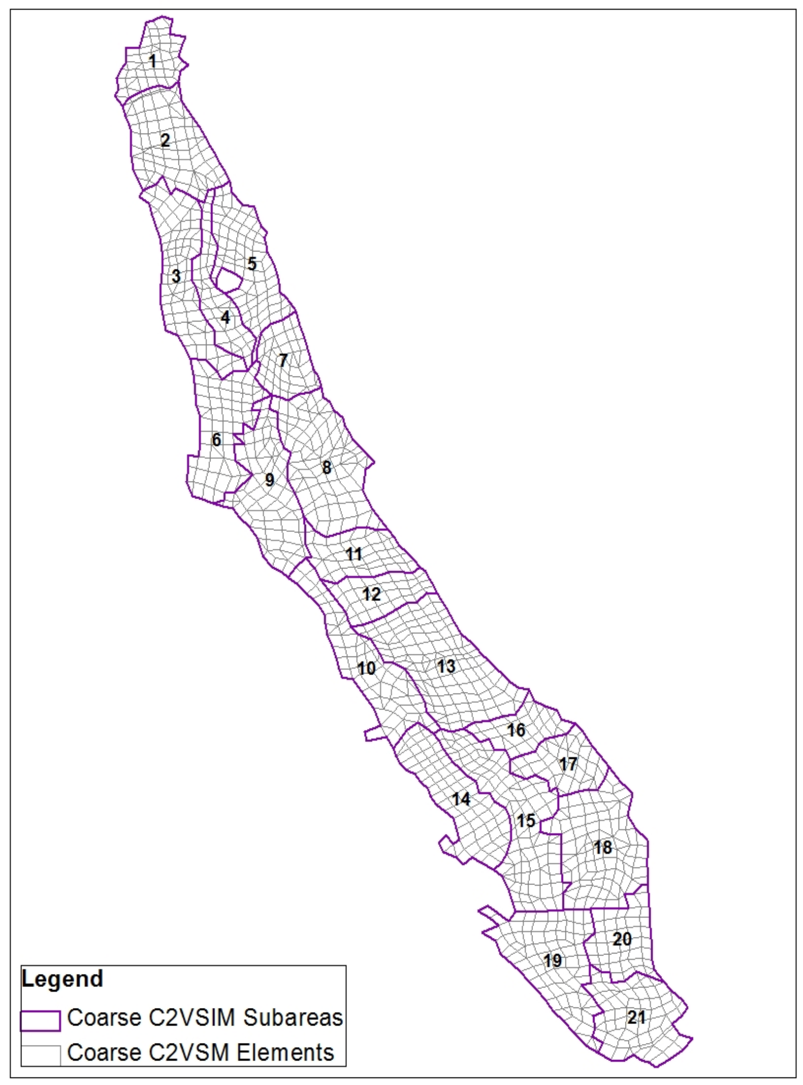
Minimum Date:

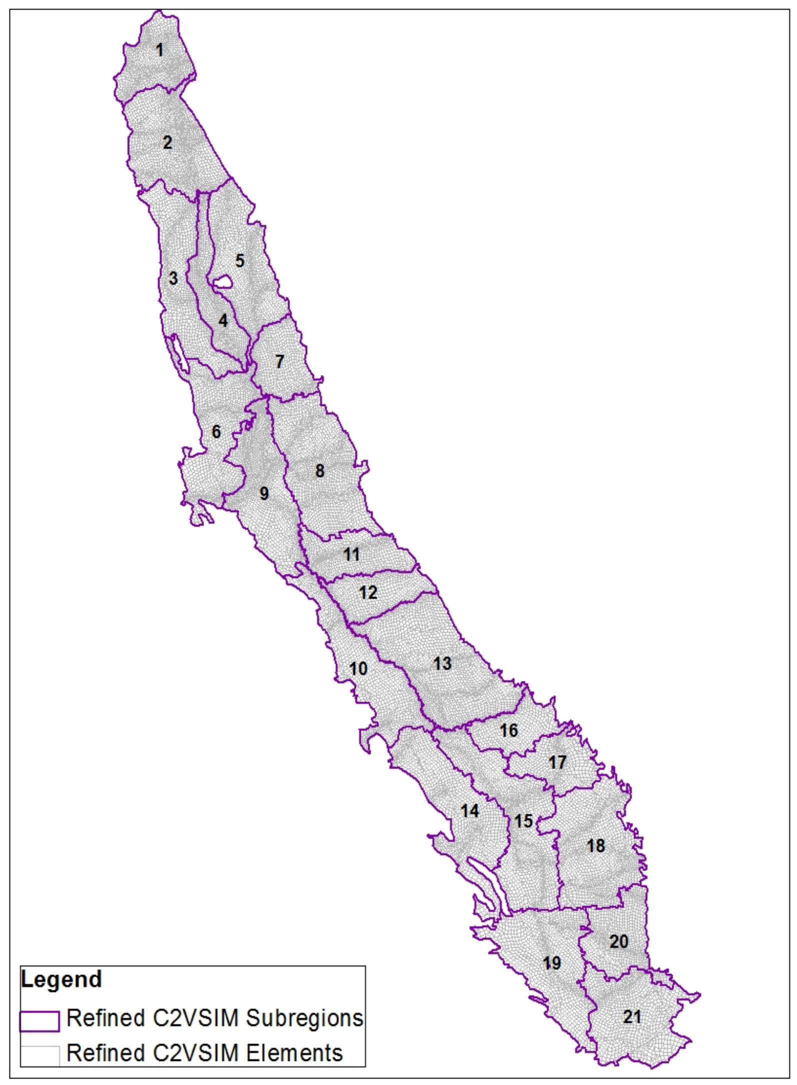
Maximum Date:

OK Cancel

701526.013 4511592.779 Meters

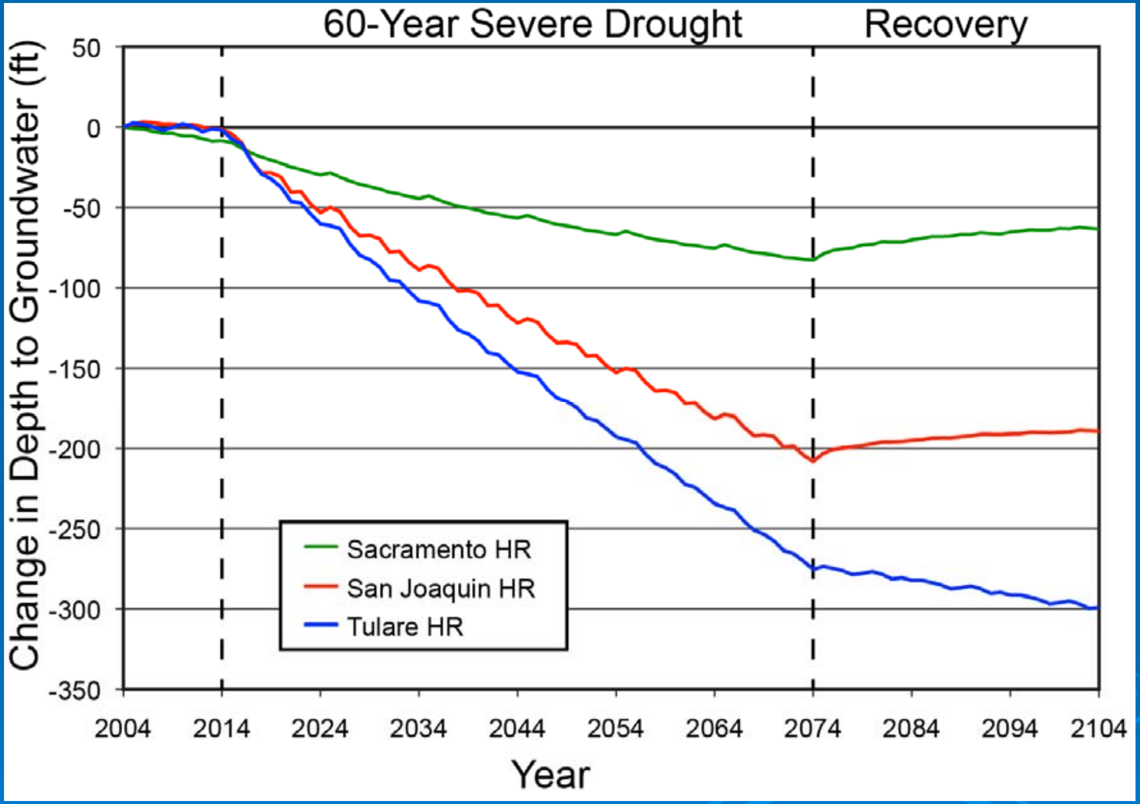
Applications: C2VSim Refined Grid





Applications: Drought Scenarios with C2VSim

- Droughts with intensities ranging from 30% to 70% reduction in stream flows, with durations ranging from 10 years to 60 years
- Land-use constant at 2003 level
- CalSim II was used to generate rim inflows under specified climatic conditions



- The impact of droughts on the groundwater and the groundwater recovery period were examined

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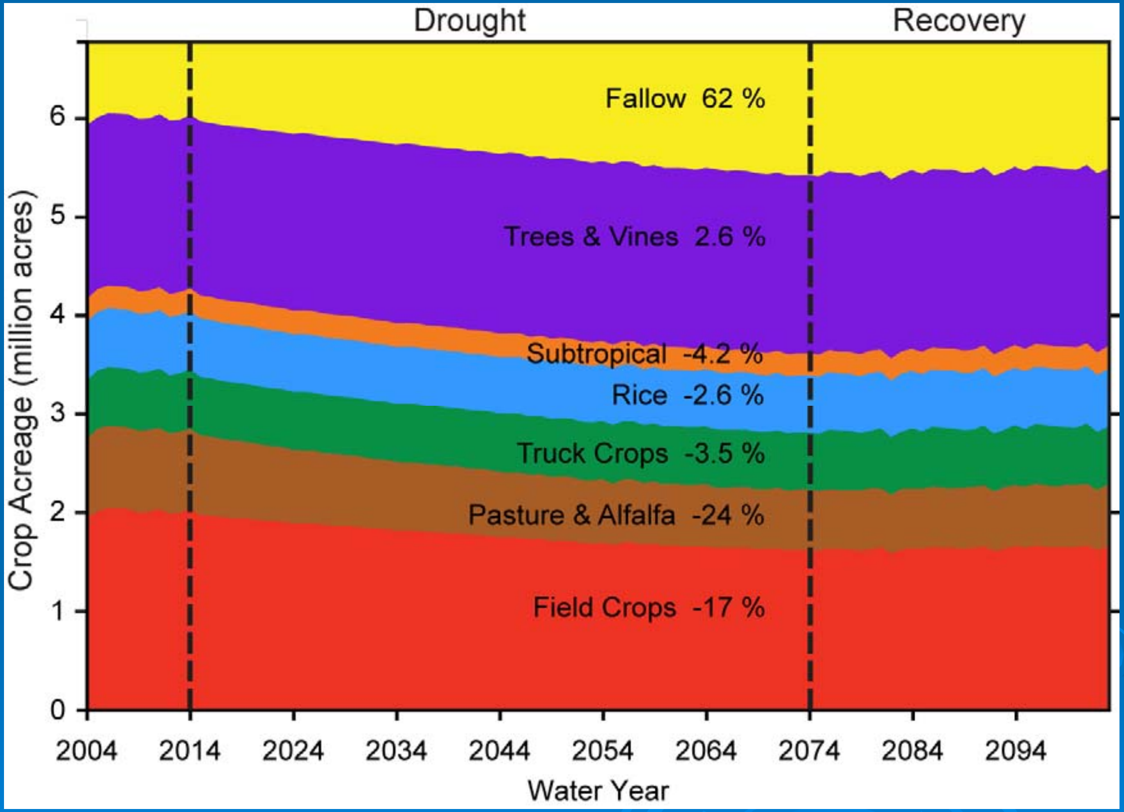
Applications:
Drought Scenarios with C2VSim-CVPM Linkage

- Same drought scenarios as in previous slide
- Cropping pattern modified based on logit functions that are trained using Central Valley Production Model (CVPM)
- The impact of droughts on the cropping patterns, groundwater storage and the groundwater recovery period were examined

Severe drought for 60 years



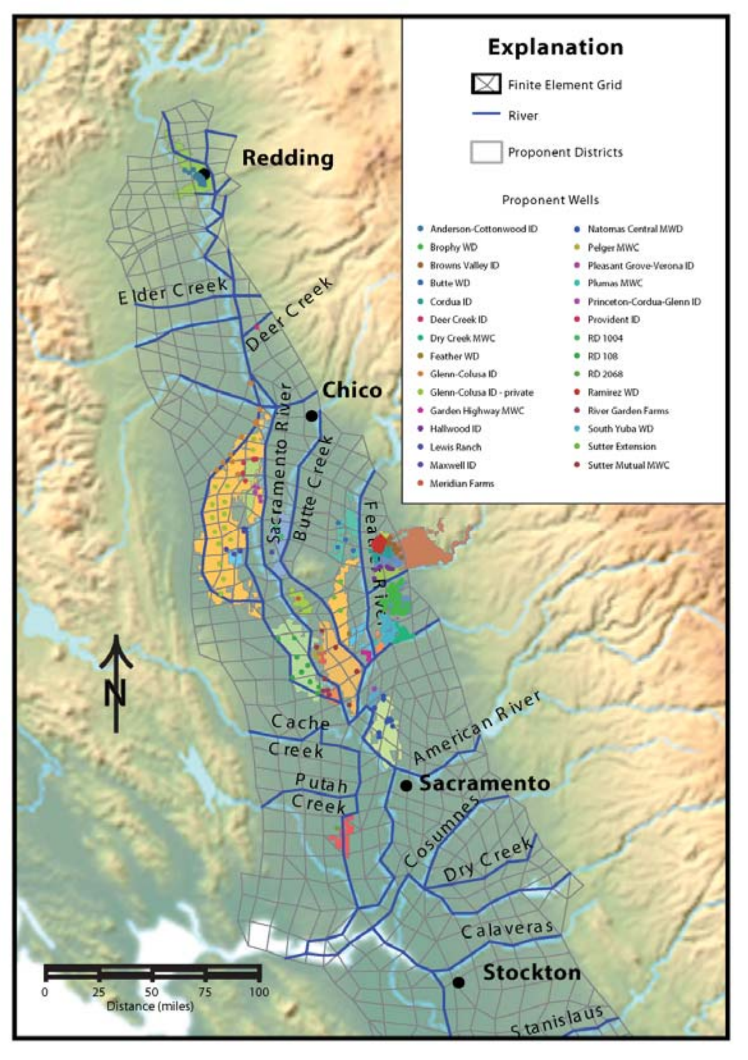
Applications:
Conjunctive Use Analysis with C2VSim

SVWMP Wells

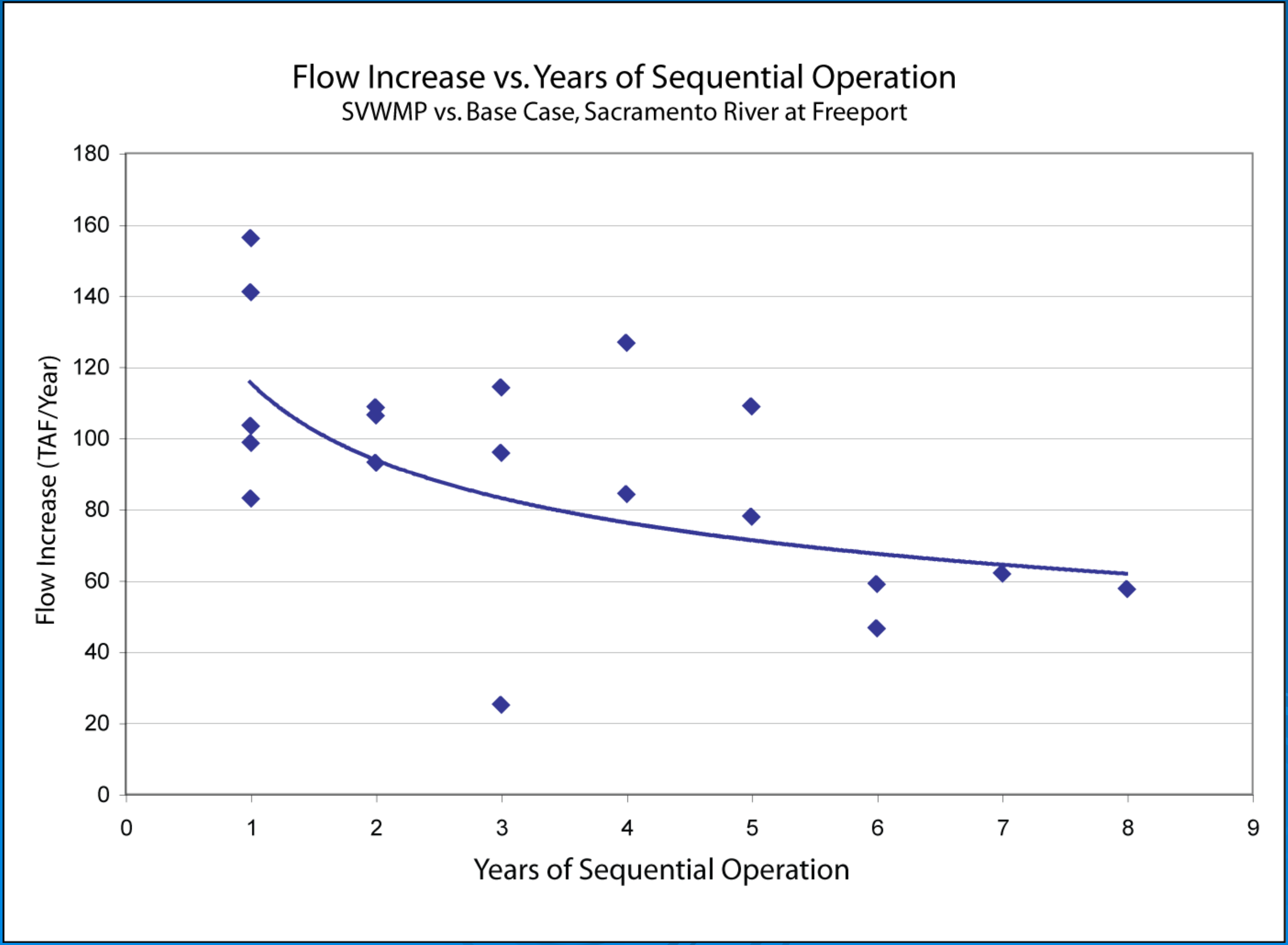
- 29 Districts
- 293 wells
- 187,633 AF/year

Operate non-wet years

1973	1 yr
1976-81	6 yrs
1985	1 yr
1987-94	8 yrs
2000-03	4 yrs



Applications:
Conjunctive Use Analysis with C2VSim



Other Applications

- Linkage of C2VSim to CalSim; i.e. CalSim 3.0
- IWFM application to Butte County (reports available on Butte County web site)
- IWFM application to Walla Walla Basin at Oregon and Washington border
- WESTSIM; application to Western San Joaquin Basin
- MercedSim; application to Merced County
- IWFM application to RD 2068 (Solano County)
- Root zone component of IWFM (i.e. IDC) used around California and in Idaho’s Treasure Valley to predict future demands, in developing recharge rates for Modflow application to Riverside/San Bernandino counties, in developing recharge rates for MicroFEM application to Sacramento Valley

Future and On-going Developments

- IWFM v4.0 (released May 2012): Revamped root zone component, soil moisture routing and demand-supply computations at element level, explicit simulation of rice and refuge pond operations, dynamic computation of demand or use of contractual (i.e. pre-specified) demands
- More stand-alone IWFM components; e.g. groundwater
- Improved simulation of riparian vegetation
- Improved simulation of rainfall runoff and overland flow
- Improved hydraulic routing of stream flows that account for change in storage
- ArcGIS based GUI (currently being developed)
- Simulation of water quality(???)
- Migrate C2VSim to IWFM v4.0

Thank You