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Managing Water in the West

Integrated Surface/Subsurface Flow and Transport Model for Multi-Scale Hydrologic Systems

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Topics

- Motivation
- Next Generation Codes
- HydroGeoSphere
- Current Applications
- Conclusions

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Motivation

A diverse group of problems exists that requires quantification of entire hydrologic cycle by integrated simulation of water flow and contaminant migration in surface and subsurface regimes

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Motivation

Problem Examples:

- Increased demand on limited resources for potable water and other purposes has driven development of innovative management practices …
  - ✓Water recycling
  - ✓Drainage water reuse for salt-tolerant crops
  - ✓Conjunctive use of surface and subsurface water resources
  - ✓Artificial recharge of subsurface aquifers during wet periods

Motivation

Problem Examples:

- Complex cycle of irrigation; evapotranspiration; infiltration; discharge to lakes, rivers and streams needs to be quantified to resolve water supply and demand issues

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Motivation

Problem Examples:

- Concerns over drying and restoration of wetlands or the effects of subsurface withdrawals on surface water bodies require fully-coupled analysis of various flow regimes

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Motivation

Problem Examples:

- Ecosystems of lakes, rivers, and bays depend on minimum flows as do hydropower generation, recreational use and downstream water districts, states and countries for their water needs

Solution of these problem examples requires an understanding of surface/subsurface water interactions and overall seasonal hydrologic cycle behavior

Motivation

- Sequential Time-Lag Approach

  Unless a reasonable time step is chosen, may produce erroneous hydrographs

- Sequential Iterative Approach

  If good convergence achieved, yields acceptable results

- Fully-coupled Approach

  Most robust, efficient and reliable

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Next Generation Codes

First Generation Codes:

- InHM

  (VanderKwaak, Univ. of Waterloo, PhD Thesis, 1999)

- MODHMS

  (Panday & Huyakorn, Adv. Water Resour., 2004)

HydroGeoSphere

HydroGeoSphere = FRAC3DVS + MODHMS Surface Module

(2004)

(Therrien and Sudicky, Jour. Cont. Hydro., 1996)

(Panday and Huyakorn, Adv. Water Resour., 2004)

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HydroGeoSphere: Team

- Sudicky et al. (University of Waterloo)
- Therrien et al. (Laval University)
- Huyakorn et al. (HydroGeoLogic, Inc.)
- Matanga et al. (Reclamation)

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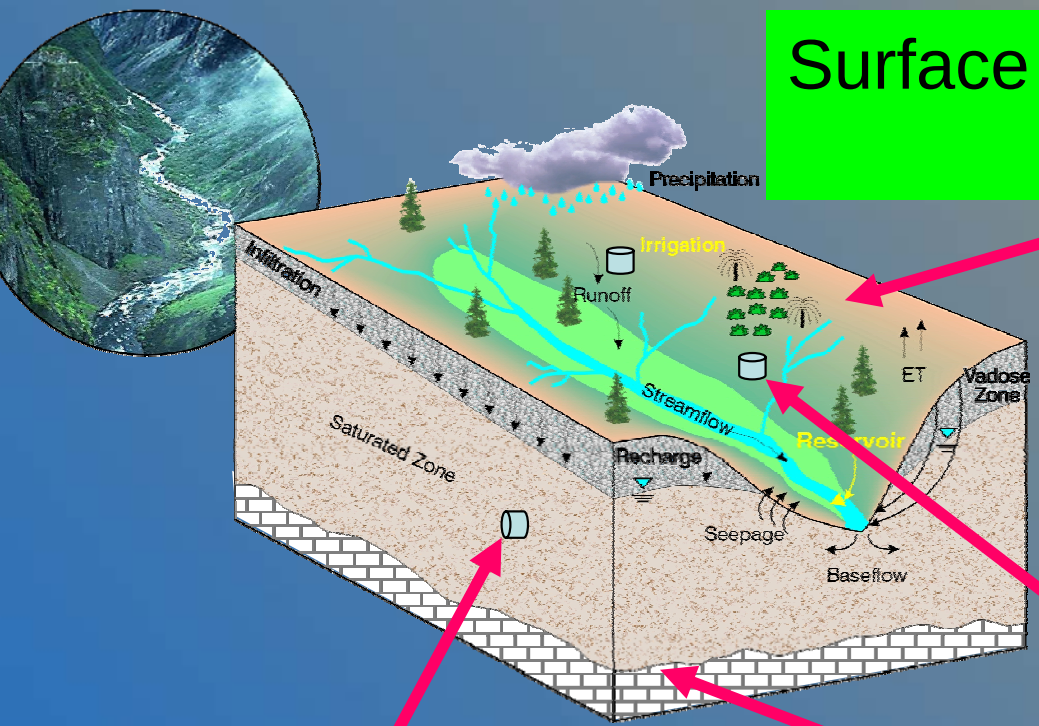
HydroGeoSphere: Conceptualization



Surface Water: 2-D areal
or 2-D areal into 1-D channel

Subsurface Water:
3-D variably saturated

Well: 1-D

Tile drain: 1-D

Macro-pores: 1-D, 2-D or 3-D

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HydroGeoSphere: Flow Equations

Surface

$$-\overline{\overline{\nabla}} \cdot d_o \mathbf{q}_o - d_o \Gamma_{surf} \pm Q_o = \frac{\partial \phi_o h_o}{\partial t}$$

Γ_{surf}

Subsurface

$$-\nabla \cdot (\omega_m \mathbf{q}) + \Gamma_{surf} + \Gamma_{tile} + \Gamma_{well} + \sum \Gamma_{pores} \pm Q = \omega_m \frac{\partial}{\partial t}(\theta_s S_w)$$

Γ_{tile}

Γ_{well}

Γ_{pores}

Tile

$$-\overline{\nabla} \cdot (A \mathbf{q}_t) + Q_t \delta(l - l') - A \Gamma_{tile} = \frac{\partial A}{\partial t}$$

Macro-pores

Well

$$-\overline{\nabla} \cdot (\pi r_s^2 \mathbf{q}_w) \pm Q_w \delta(l - l') - P_{well} \Gamma_{well} = \pi \frac{\partial}{\partial t}\left[\left(\frac{r_c^2}{L_s} + r_s^2 S_{ww}\right)\psi_w\right]$$

$$\Gamma_{ex} = \beta_{ex}(h - h_{ex})$$

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HydroGeoSphere: Transport Equations

Surface

$$-\overline{\overline{\nabla}}\left[\mathbf{q_o}C_o - \mathbf{D_o}\phi_o h_o \overline{\nabla} C_o\right] + \left[\phi_o h_o R_o \lambda C_o\right]_{par} - d_o \Omega_{surf} = \frac{\partial \phi_o h_o R_o C_o}{\partial t} + \phi_o h_o R_o \lambda C_o$$

Porous medium

$$-\nabla \cdot \omega_m \left[\mathbf{q}C - \theta_s S_w \mathbf{D} \nabla C\right] + \left[\omega_m \theta_s S_w R \lambda C\right]_{par} \pm Q_c + \Omega_{surf} + \Omega_{tile} + \Omega_{well} + \sum \Omega_{pores} = \omega_m \left[\frac{\partial(\theta_s S_w R C)}{\partial t} + \theta_s S_w R \lambda C\right]$$

Ω_{surf}

Ω_{tile}

Ω_{well}

Ω_{pores}

Macro-pores

Tile

$$-\overline{\nabla} \cdot A\left(\mathbf{q}_t C_t - S_{wt} D_t \overline{\nabla} C_t\right) + A\left[\lambda C_t\right]_{par} -$$

$$AQ_t\left(C_t - C_{t_{Inj}}\right)\delta(l - l') - A\Omega_{tile} = \frac{\partial (AC_t)}{\partial t}$$

Well

$$-\overline{\nabla} \cdot \pi r_s^2 \left(\mathbf{q}_w C_w - S_{ww} D_w \overline{\nabla} C_w\right) + \pi r_s^2 \left[\lambda C_w\right]_{par} - Q_w\left(C_w - C_{w_{Inj}}\right)\delta(l - l') - \pi r_s^2 \Omega_{well} = \pi r_s^2 \frac{\partial C_t}{\partial t}$$

$$\Omega_{ex} = \alpha_{ex}(C - C_{ex})$$

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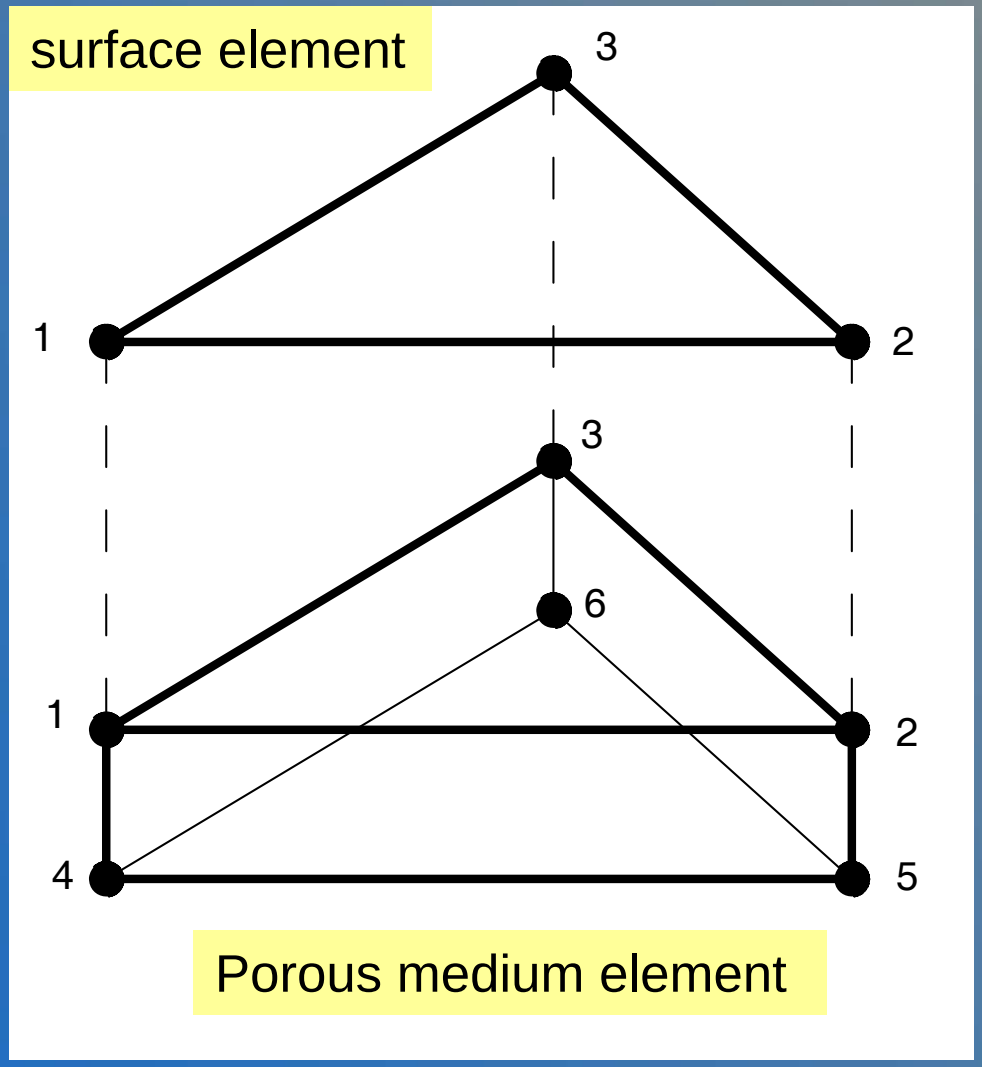
HydroGeoSphere: Discretization



	p_1	s_1	p_2	s_2	p_3	s_3	p_4	p_5	p_6
p_1	●	●	●		●		●		
s_1	●	●		●		●			
p_2	●		●	●	●			●	
s_2		●	●	●		●			
p_3	●		●		●	●			●
s_3		●		●	●	●			
p_4	●						●	●	●
p_5			●				●	●	●
p_6					●		●	●	●

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Current Applications

- Sacramento River basin:

  Evaluate interaction of surface and subsurface water regimes
- Klamath River Basin – Long Lake Valley:

  Feasibility study of off-stream reservoir
- Sub-timing/sub-gridding Testing:
  - ✓ Red Rock Ranch (small scale), San Joaquin valley:

    Evaluate capability of drainage-water reuse system to control drainage water and salinity
  - ✓ Westside of San Joaquin Valley:

    Evaluate flow and transport processes in coupled wetlands and subsurface system

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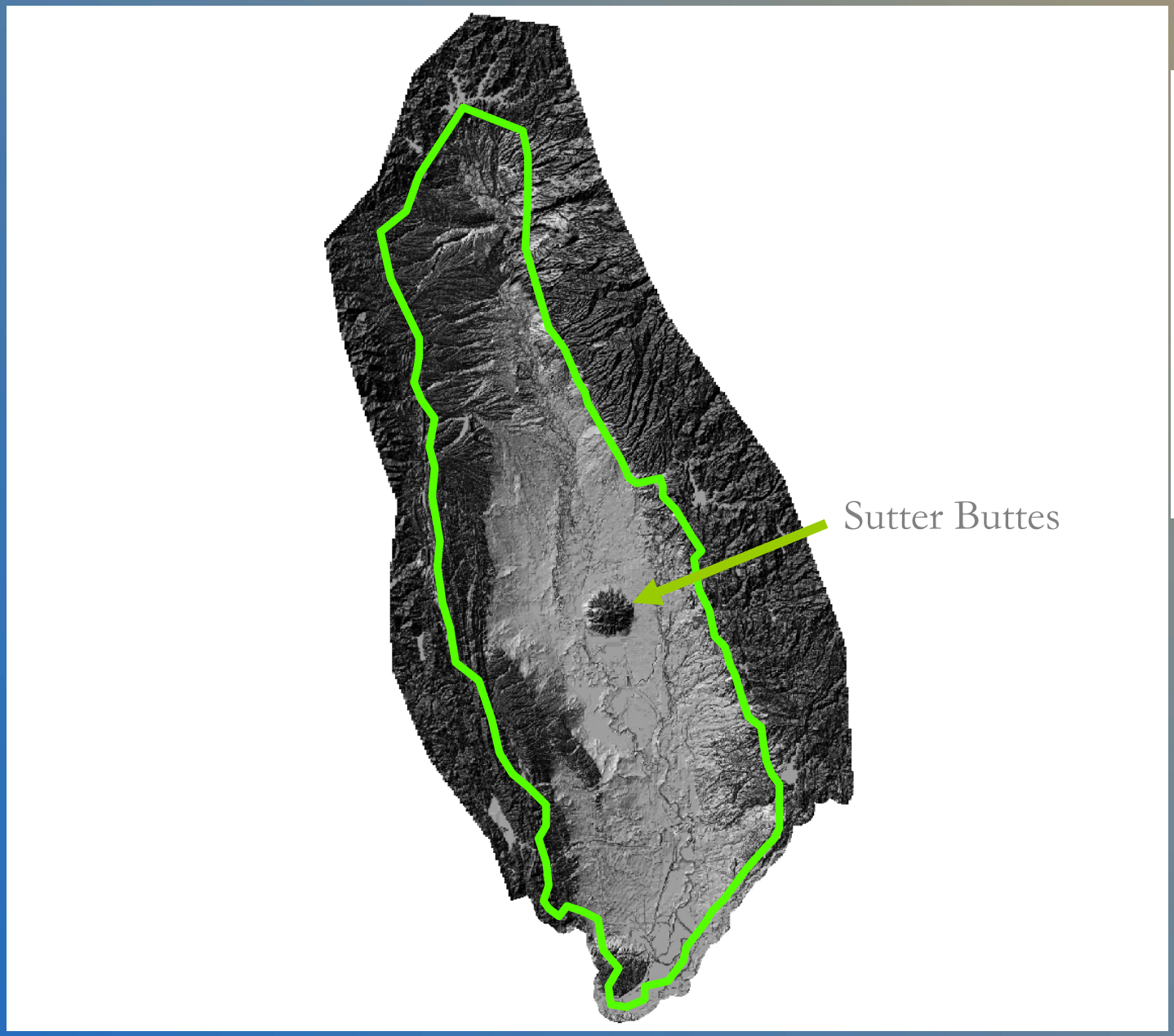
Application: Model Boundary



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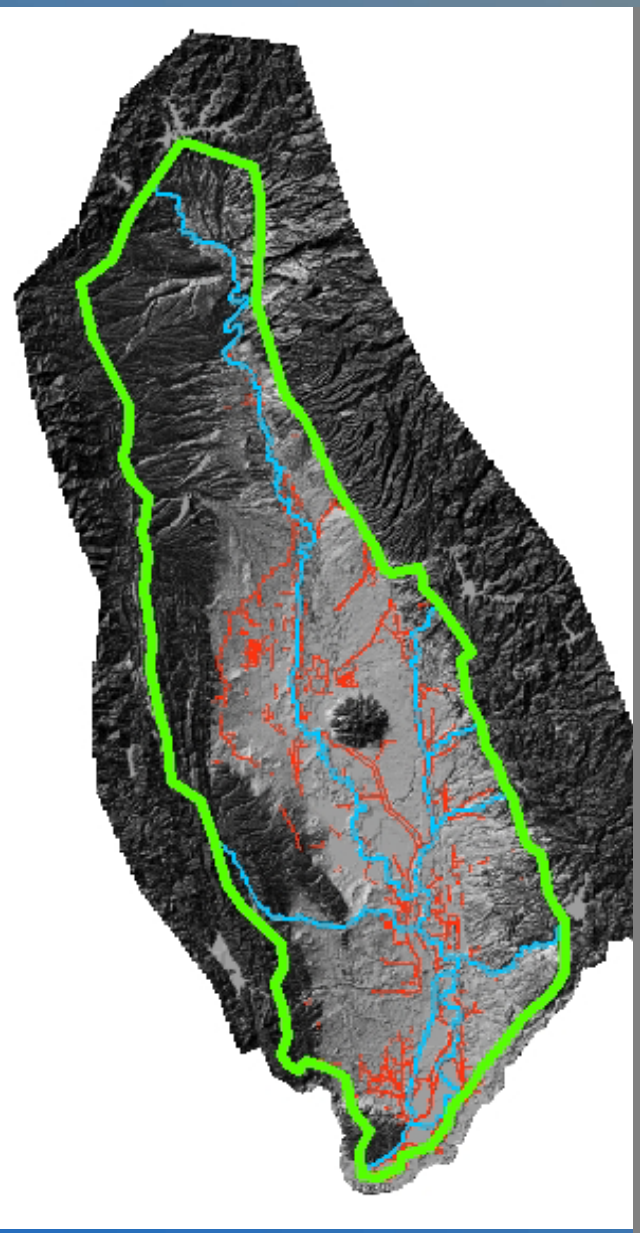
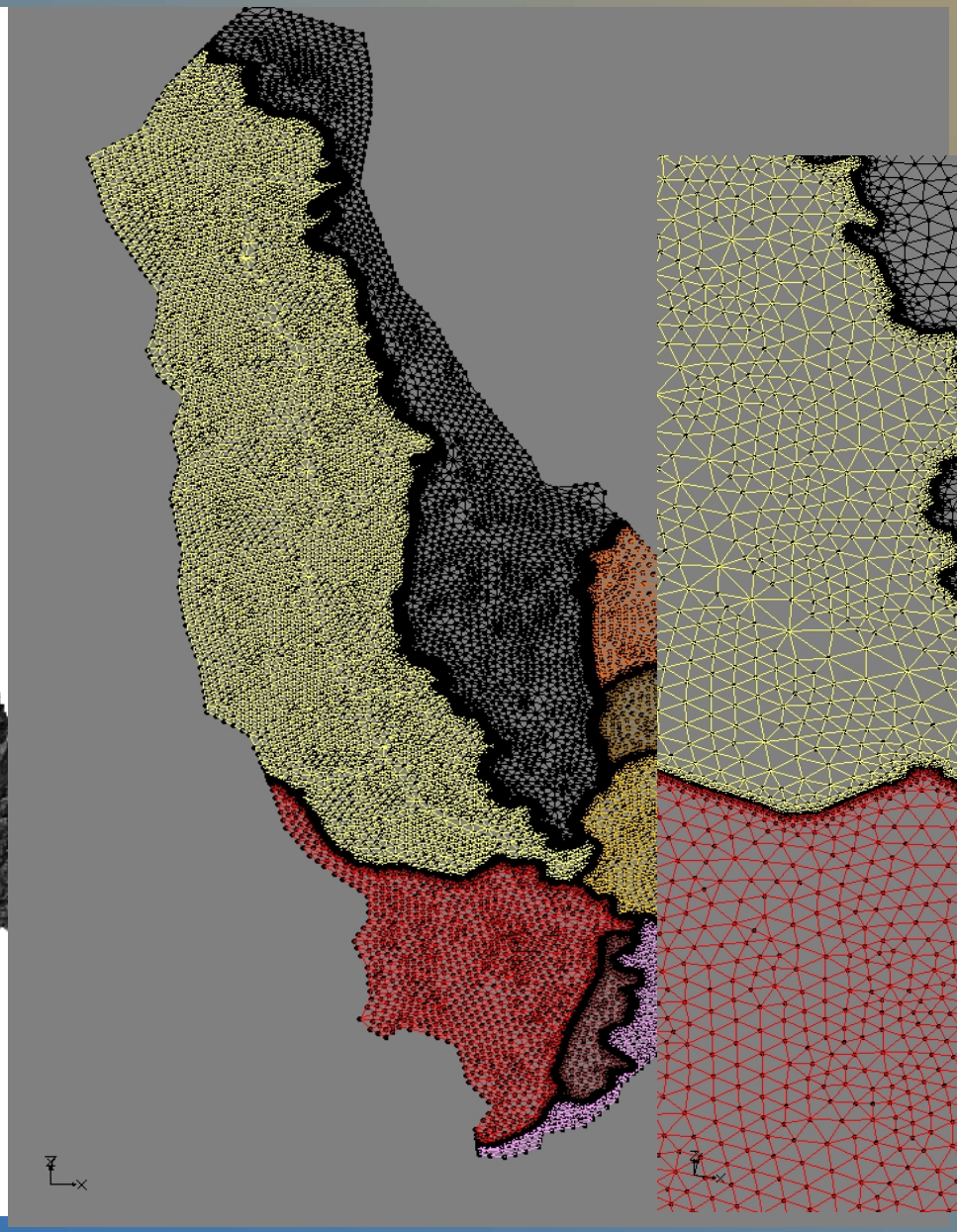
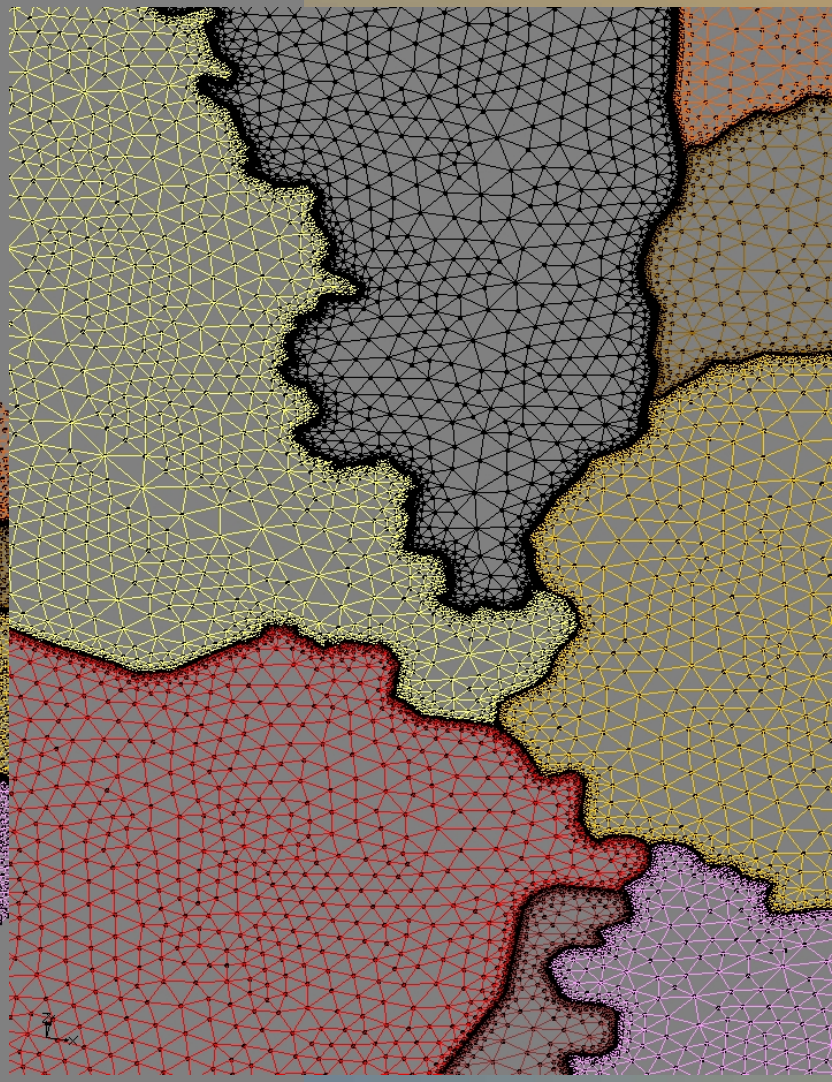
Application: Hydrology & Levees







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Application: Input Data – Geology

- Conceptual model of USGS Groundwater Atlas
- Top layer = alluvial material 10 m thick
- Thickness of underlying continental deposits spatially varied according to Atlas
- Plans to refine our geological conceptual model as new data become available…
- In particular, this will be in collaboration with USGS CV-RASA project.

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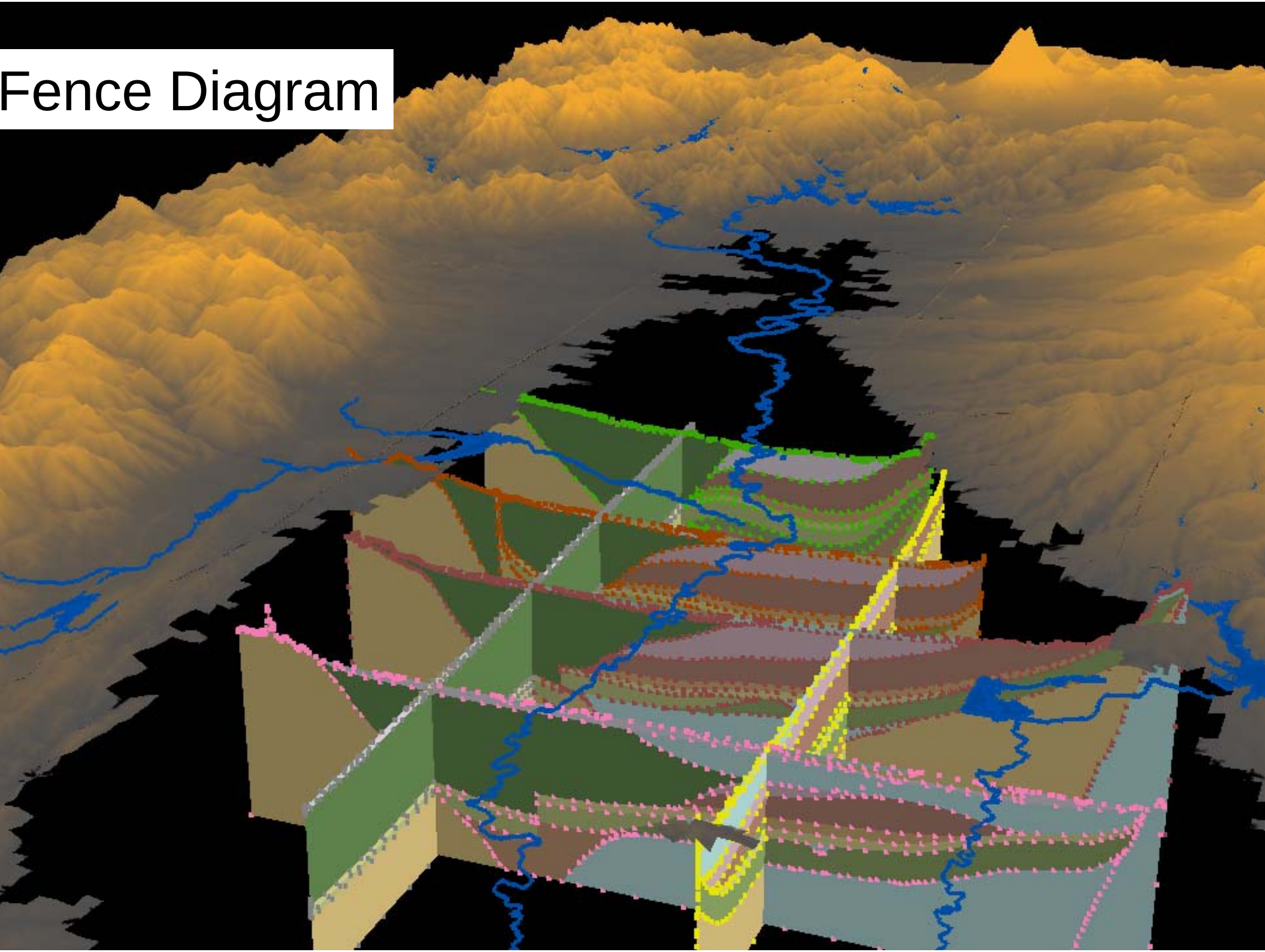
Fence Diagram



Application: Input Data – Soils

- USDA STATSGO database used to define soil types on basis of sand, silt, and clay content
- 8 different soil types identified in Valley

  ↳ silt, loam, clay, sandy loam, sandy clay loam, silty loam, silty clay loam, silty clay
- Unsaturated flow parameters (van Genuchten) defined for each soil type according to USDA Rosetta class average values

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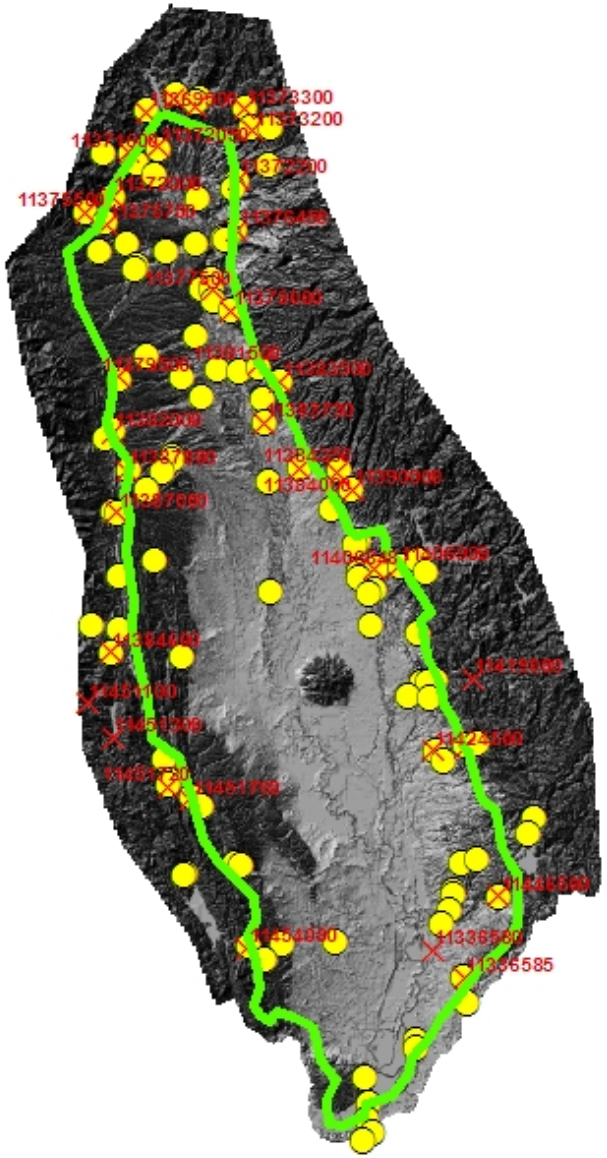
Application: Input Data – Stream Inflows



- Data from USGS National Water Information Service (http://nwis.waterdata.usgs.gov/ca/nwis)
- Gage stations with annual avg Q $\geq$ 20 cfs
- 36 inflow points on model boundary
- Monthly avg Q used

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Application: Input Data – Precipitation

- Parameter-elevation Regressions on Independent Slopes Model (PRISM)
- PRISM combines point measurements of rainfall with digital elevation models (DEMs)
- Creates map of annual and monthly avg values
- PRISM accounts for spatial variations due to
  - ✓ elevation
  - ✓ terrain orientation
  - ✓ terrain steepness
  - ✓ moisture regime
  - ✓ coastal proximity
  - ✓ inversion layer

Application: Input Data – Evapotranspiration (ET)

- California Irrigation Management Information System (CIMIS)
- Network of over 120 automated weather stations throughout California
- Reference ET measured based on highly transpiring grass reference crop
- Crop coefficients convert to actual ET
- Currently using reference ET values
- Future work: use crop maps to get crop coefficients

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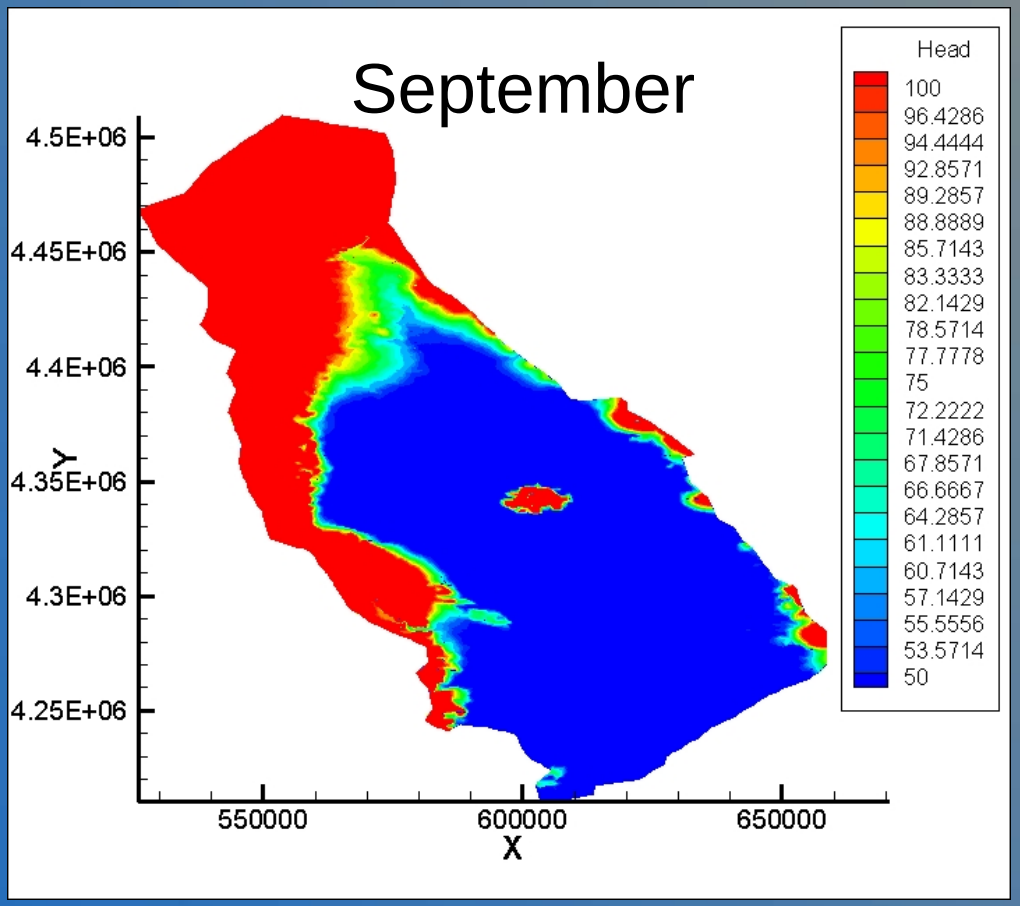
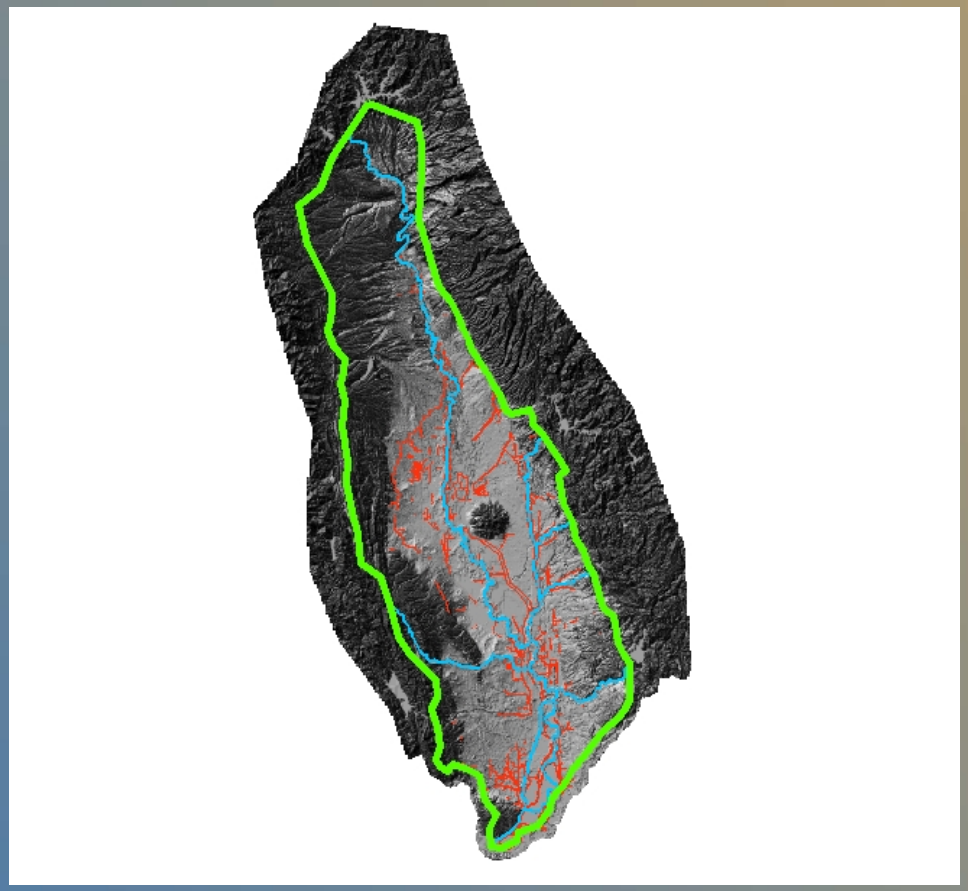
Result: Top Subsurface Head





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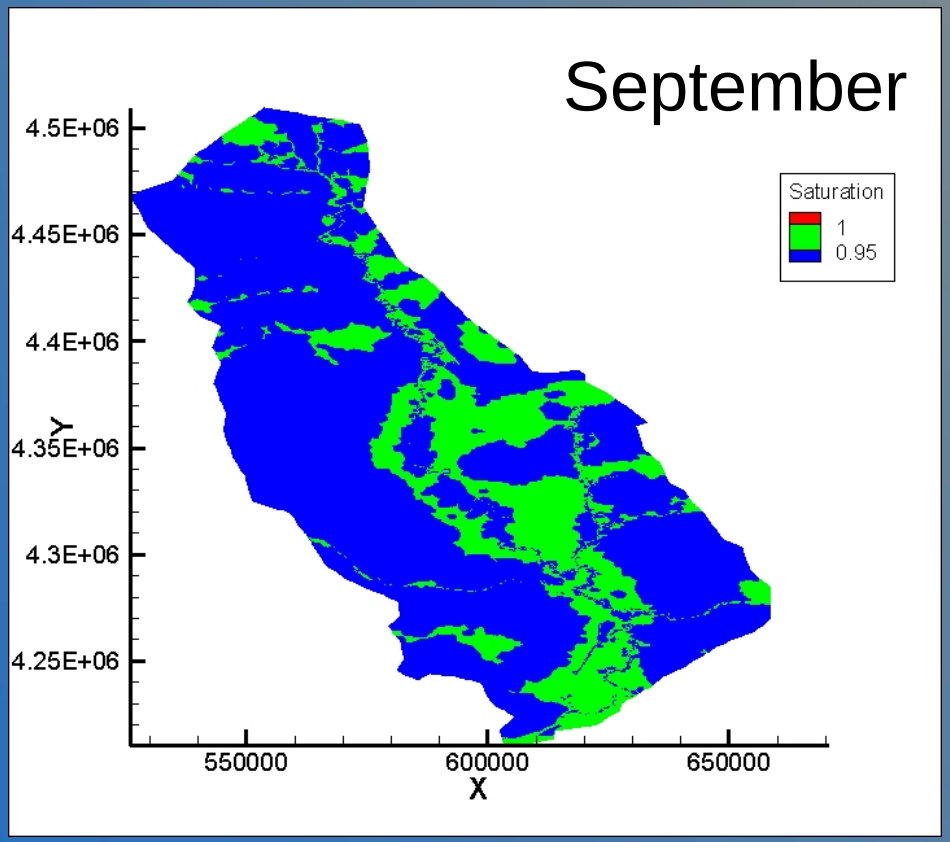
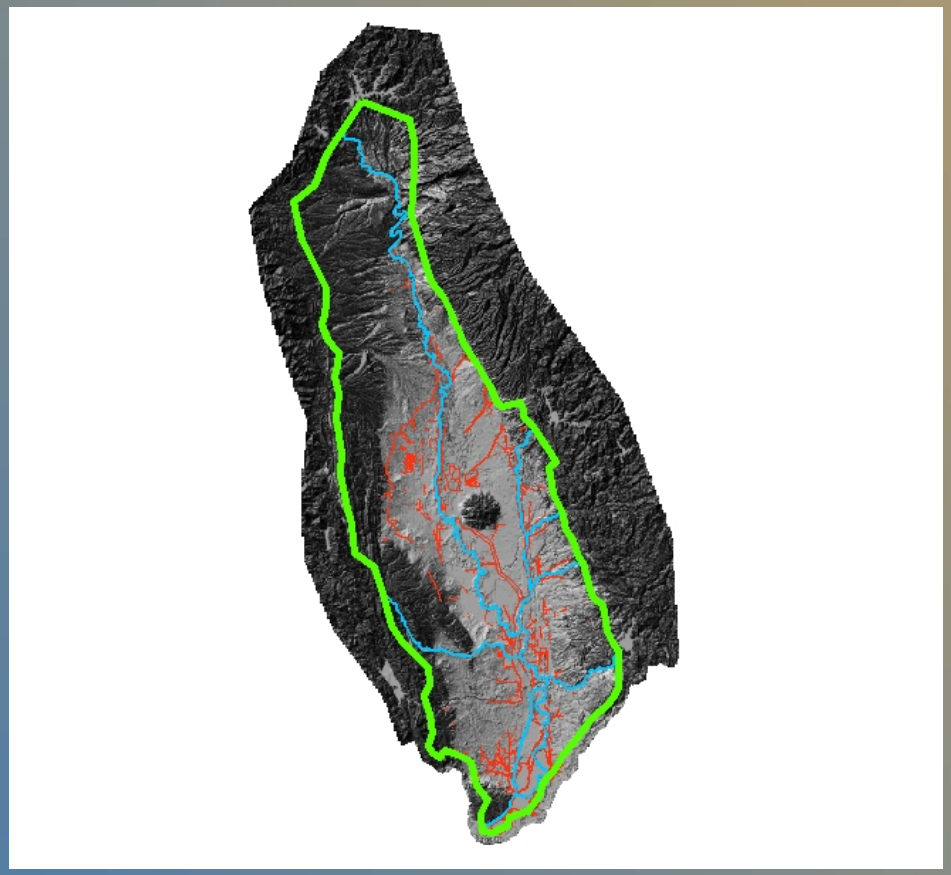
Result: Top Subsurface Saturation





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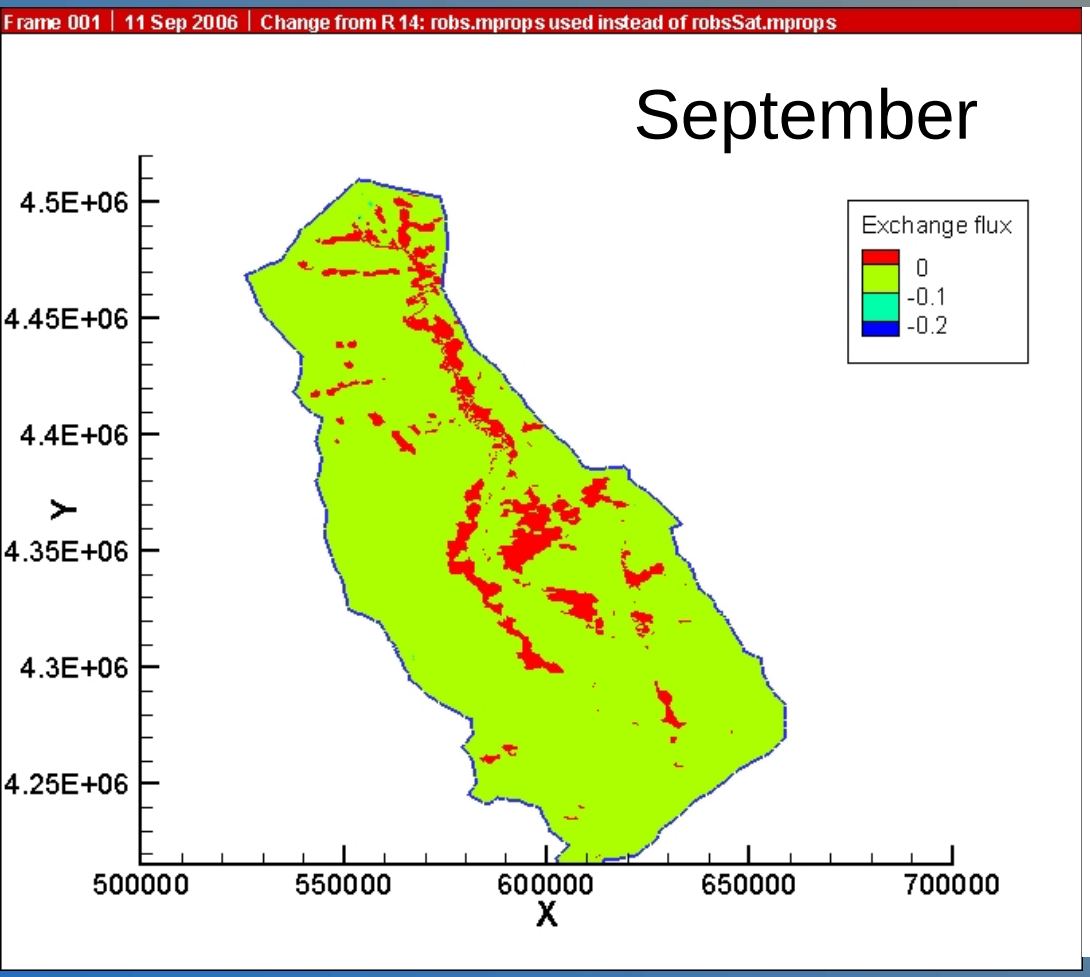
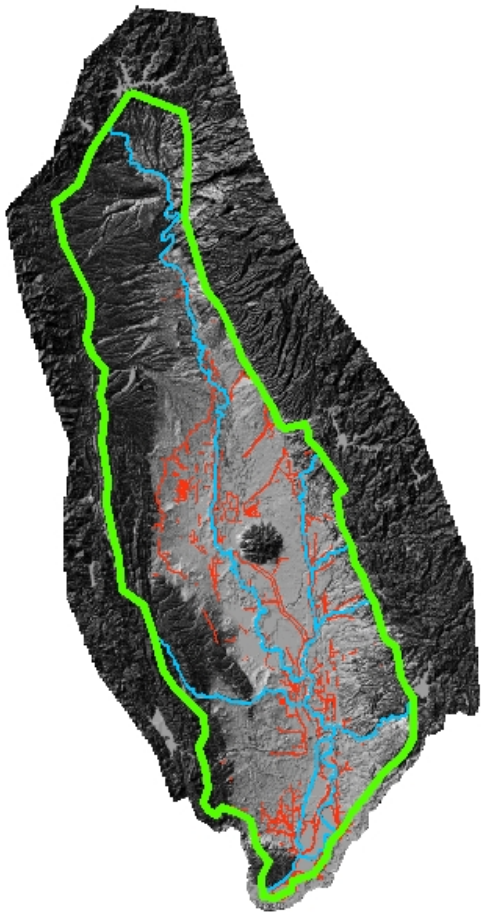
Result: Fluid Exchange Flux





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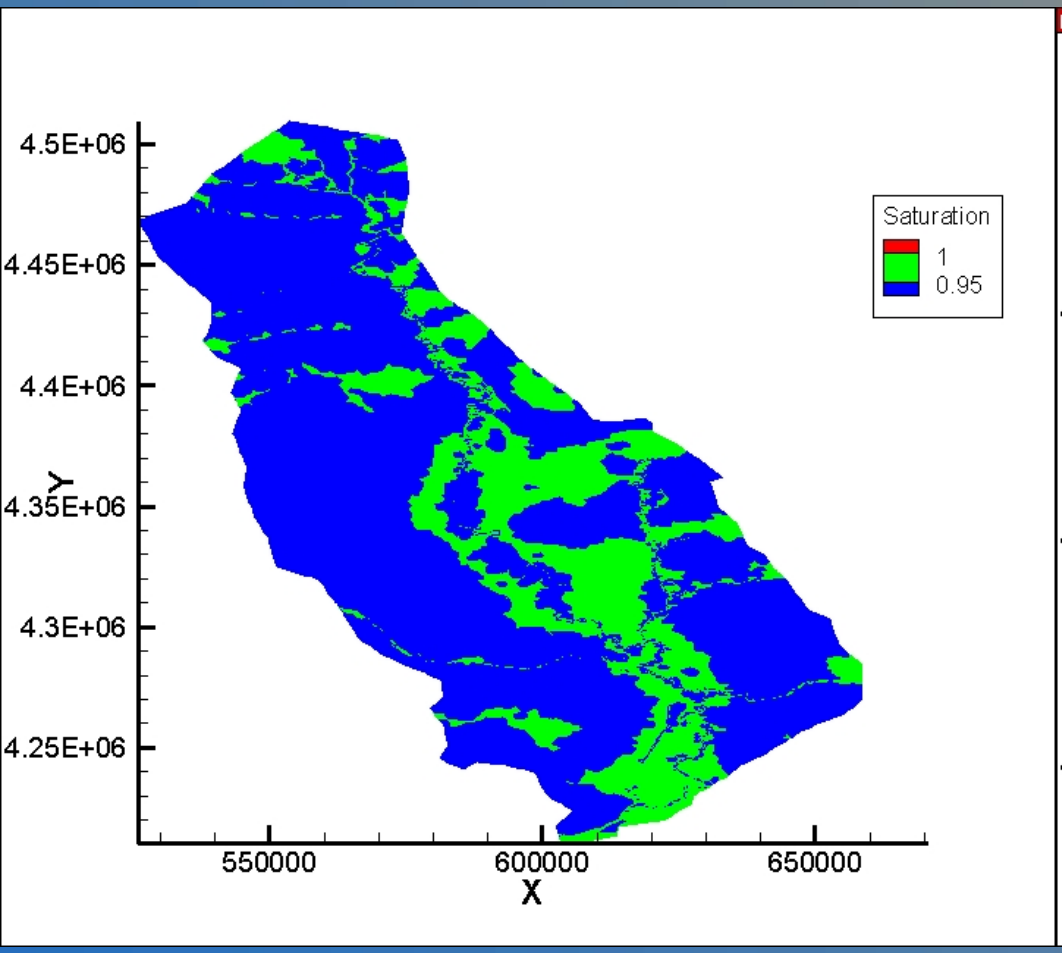
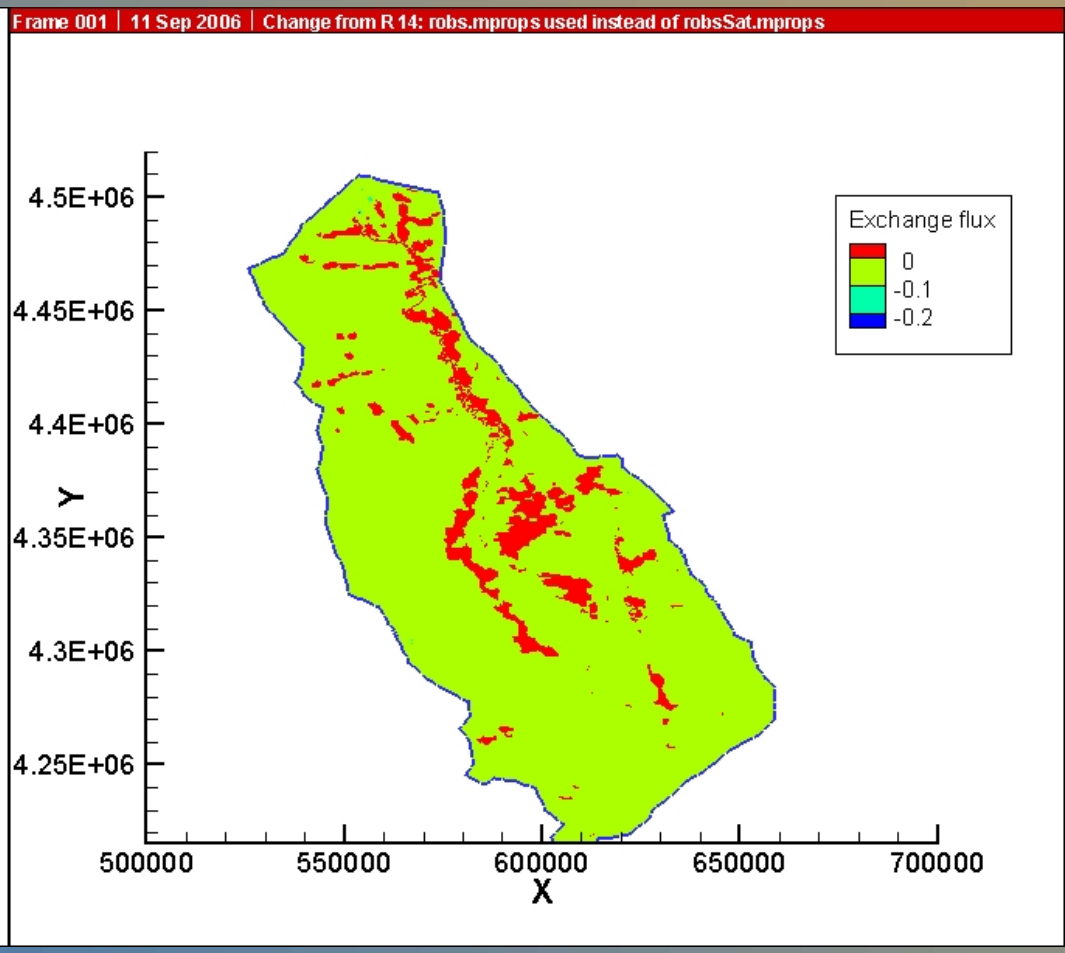
Result: Saturation versus Flux





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Conclusions

- With respect to water quality and ecosystem analysis, need to take steps towards a more integrated approach to assessing these concerns
- This can be achieved by enhancing HydroGeoSphere by incorporating additional hydrologic and water quality processes

Conclusions

- HydroGeoSphere is HydroGeoSphere currently can handle 3-D flow, mass and heat (temperature) transport in subsurface regime and 2-D flow and mass transport in surface regime
- suitable for this endeavor as it already contains components of flow and transport of conservative and reactive chemical species

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Conclusion

- Proposed enhancements include incorporation of modules related to simulation of:
  - ✓Temperature and snowmelt
  - ✓Dissolved oxygen (DO)
  - ✓Nutrients
  - ✓Erosion/sedimentation

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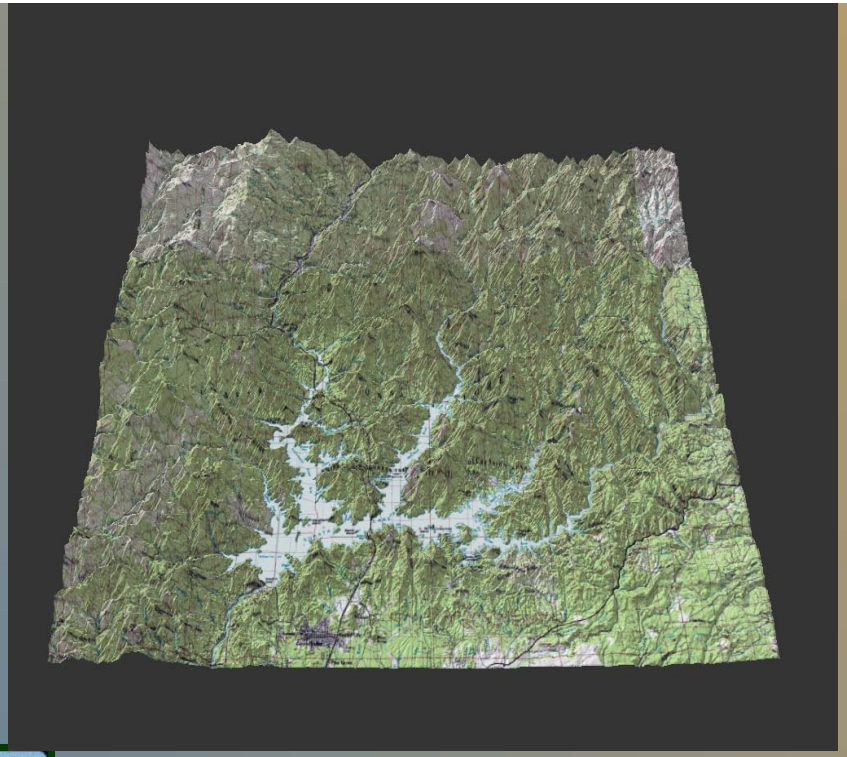
Thank



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