Green Function and Watershed Modeling

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Presented at
Symposium Honoring Wilfried Brutsaert and Jean-Yves Parlange
Ithaca, New York, May 14 and 15, 2012

Preface

Enabling foundation work by Brutsaert in hydrologic processes for watershed modeling, to just list a few:

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- Summaries and Conclusions

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- **Fond Memories:** **I have had many fond memories with Prof. Brutsaert, which have tremendously impacted my life. To just name a few: Picnics at Stewart Park, Flew two-seated airplane, Visit my hometown, which my family considered an honor, etc.**

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- **Boy and Girl Friends:** Whenever I felt low about my girlfriend, Prof. Brutsaert's wisecracks and comforting advice were always a source of help in easing my emotions.

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- **Area of Specialty versus English:** **I was told many times: What expertise you learn from your PhD program will affect your career for only the first five years. However, how good your English is will affect you for your lifetime. Unfortunately, I must confess that I have failed my advisor in this regard. I am still very poor in my spoken English.**

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- **Serve the Society:** I was reminded in many occasions: return what you have learned, researched, and created to society. I consider myself doing pretty well in this regard. I have foregone opportunities to make millions of dollars, making my computer codes available to almost anyone at no charge.

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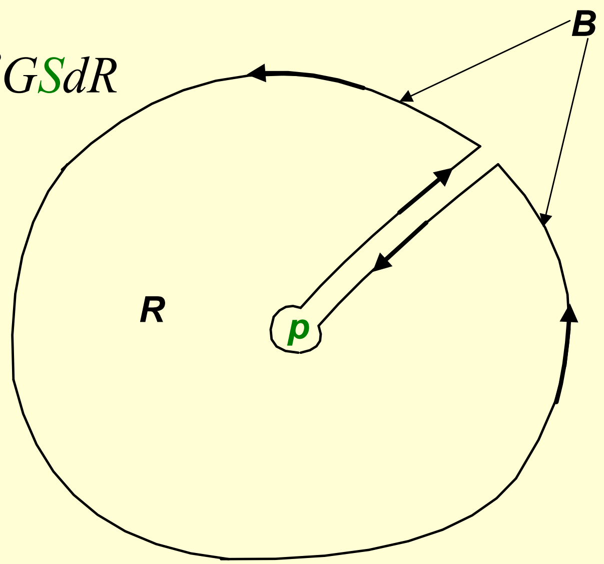
$$-\alpha\Phi_p = \int_{B_n}\left(\Phi\frac{\partial G}{\partial n} - G\frac{\partial \Phi}{\partial n}\right)dB + \int_{B_d}\left(\Phi\frac{\partial G}{\partial n} - G\frac{\partial \Phi}{\partial n}\right)dB - \int_R GSdR$$



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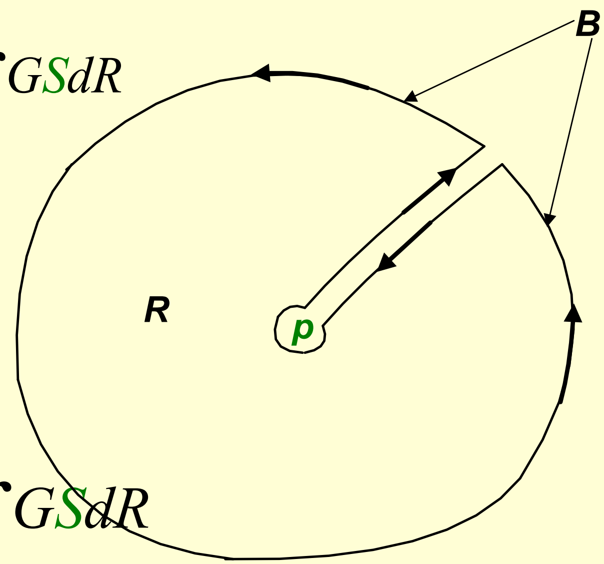

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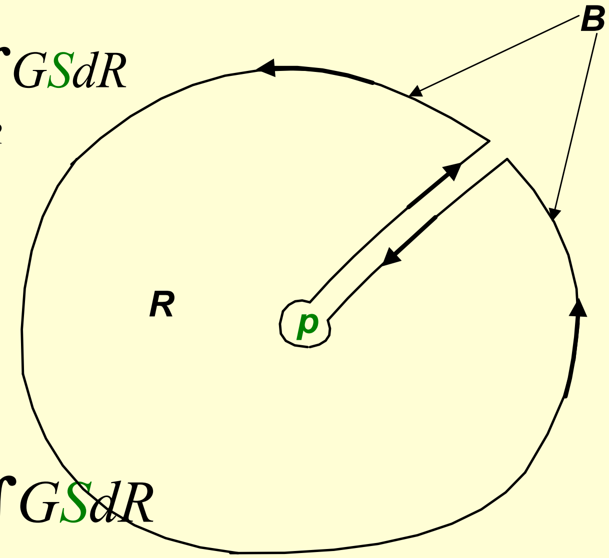

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- **Homogeneous Green Functions reduce the PDEs+BCs to simple integration of known functions (Brutsaert, 1975; Yeh, 1981)**
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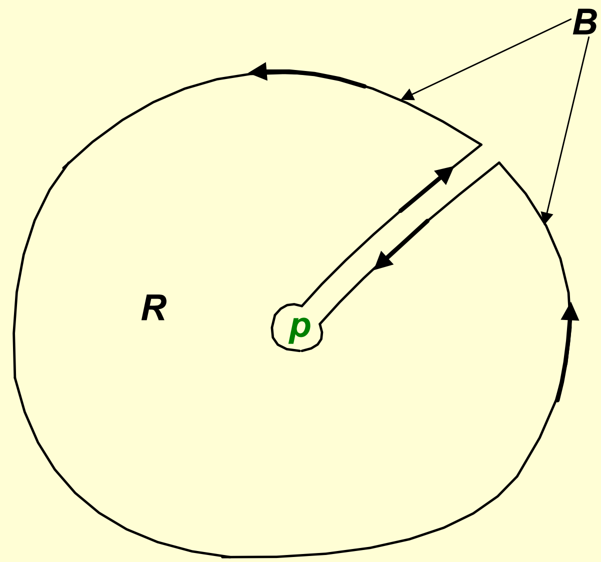

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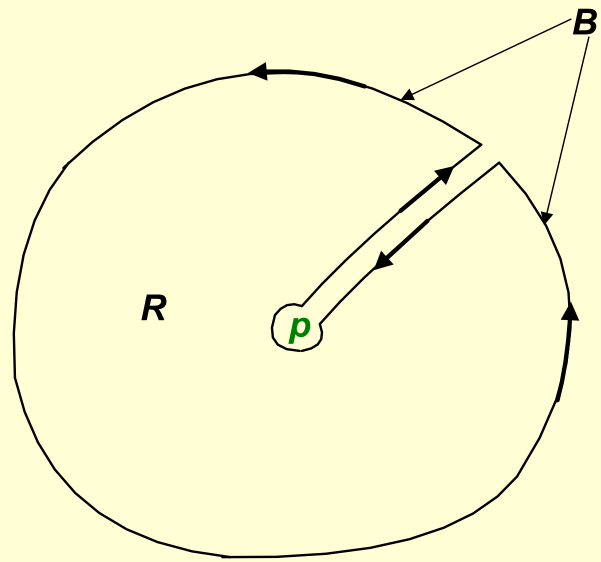

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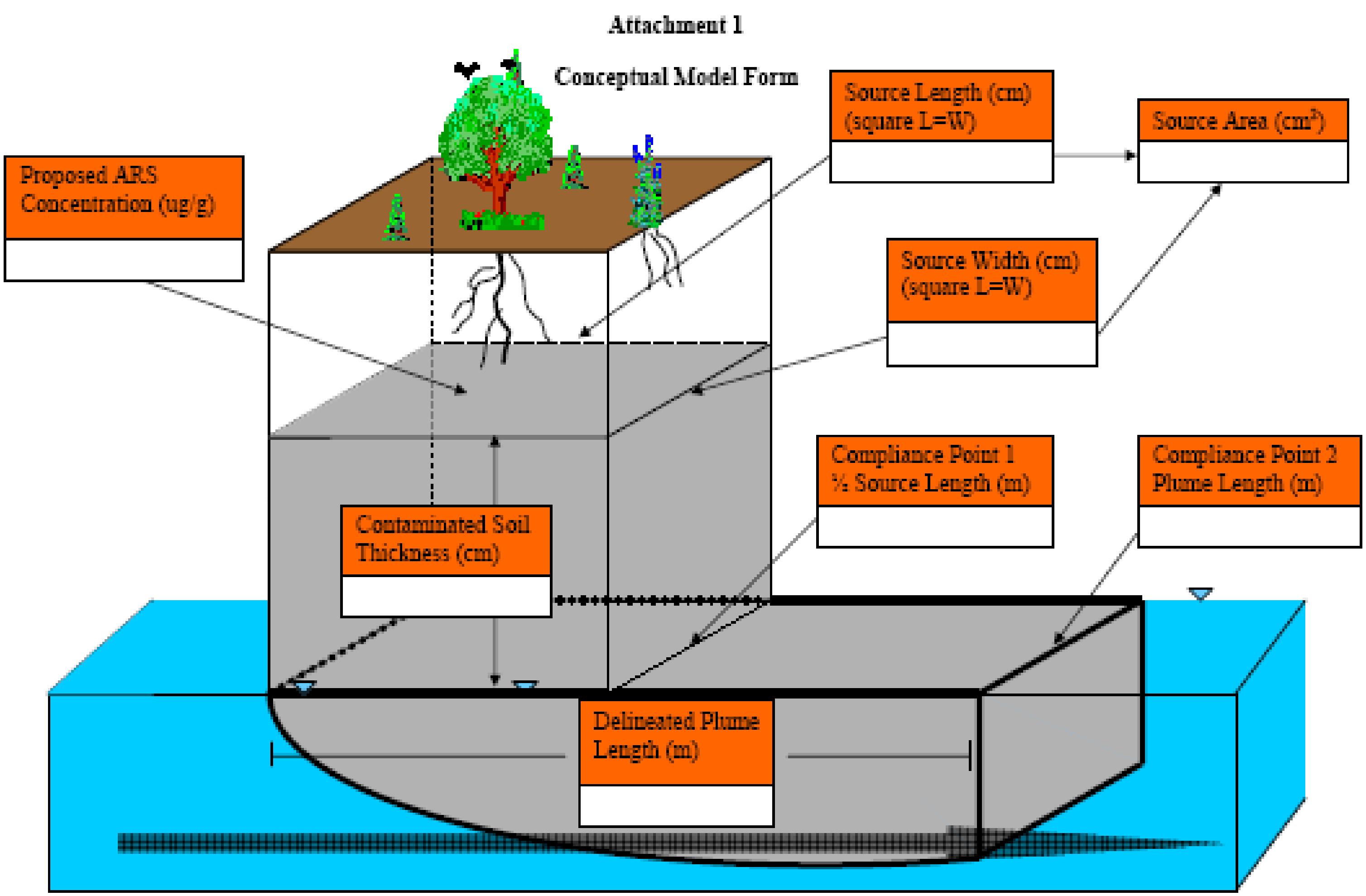
- **A Footnote: Do I have any regret not to market this model? Yes, a little bit, but no, in large, because if I did, I would not have gone on developing a generic reactive chemical transport model named HYDROGEOCHEM that has incubated many similar models.**

How AT123D has been used for regulation



Watershed Modeling: Multi-media and multi-processes

- **Multimedia (Multi-system Components):**

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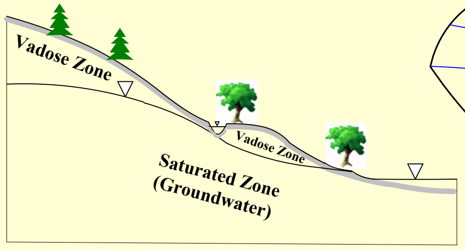

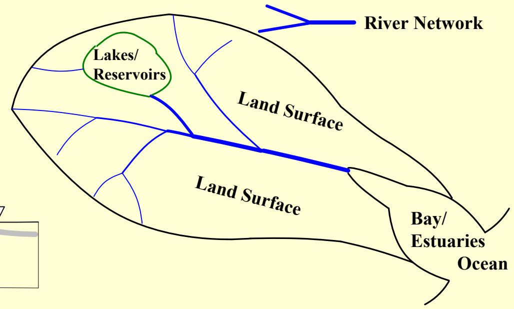

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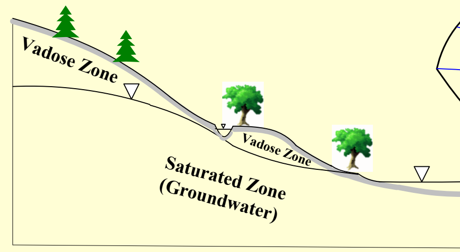

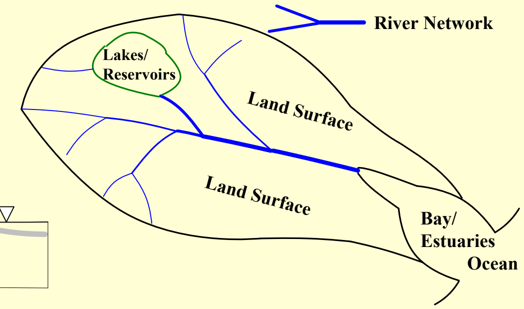

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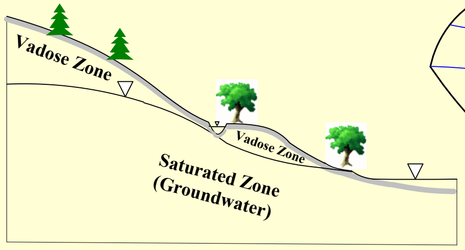

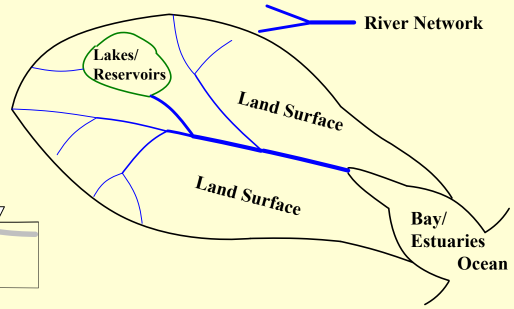

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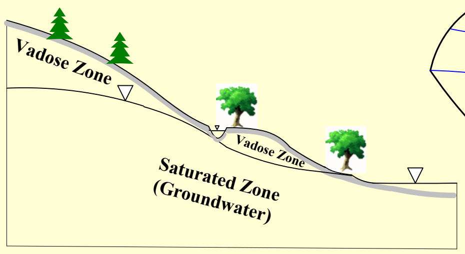

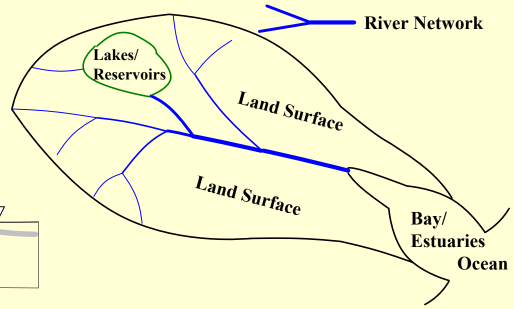

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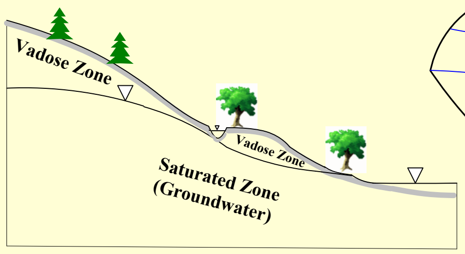

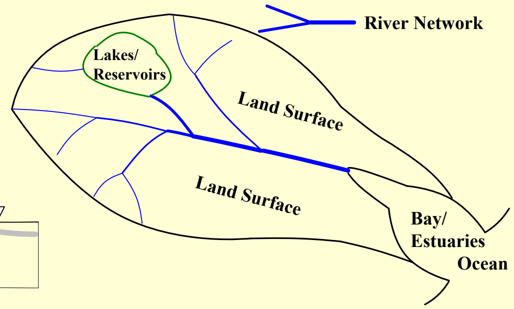

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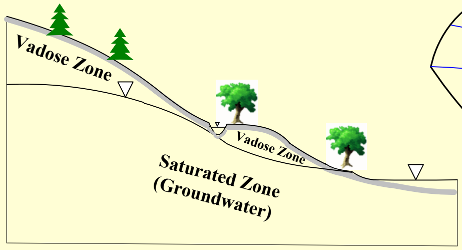

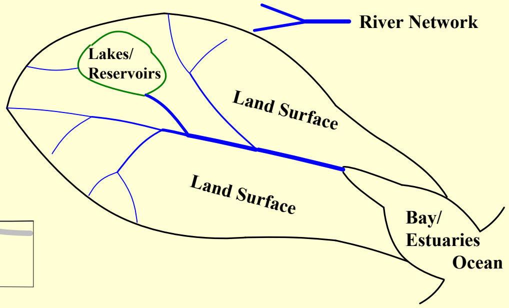

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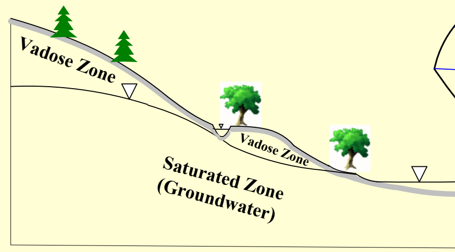

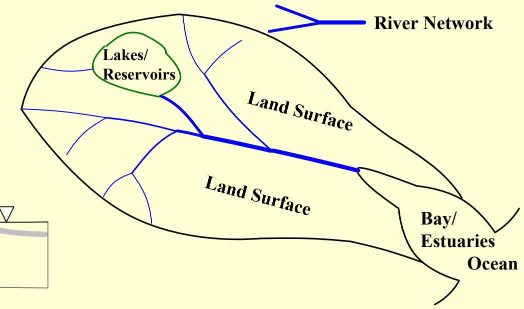

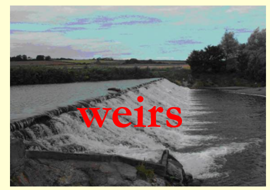

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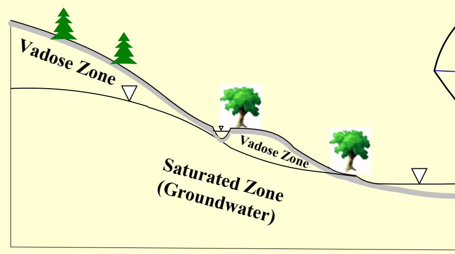

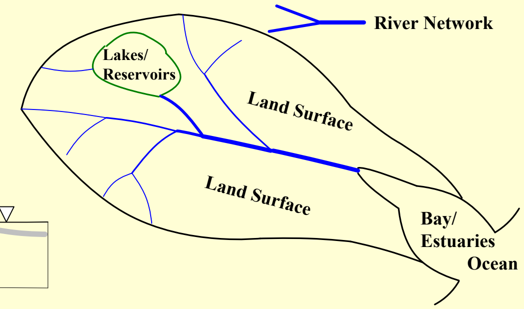

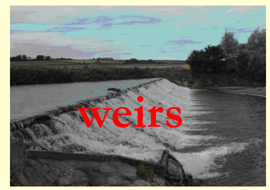

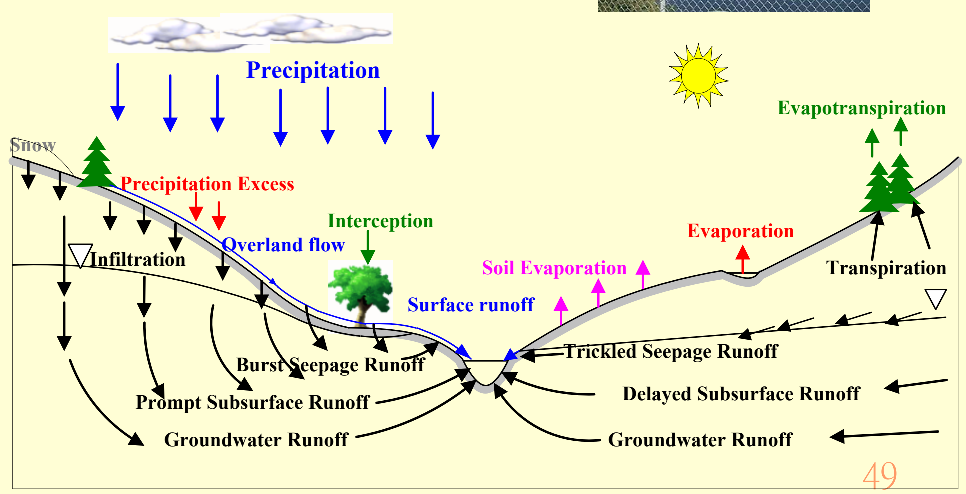

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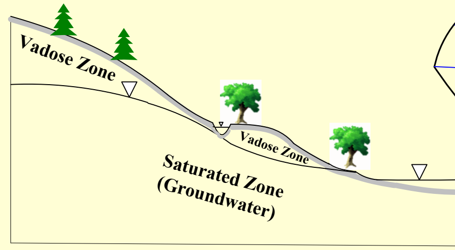
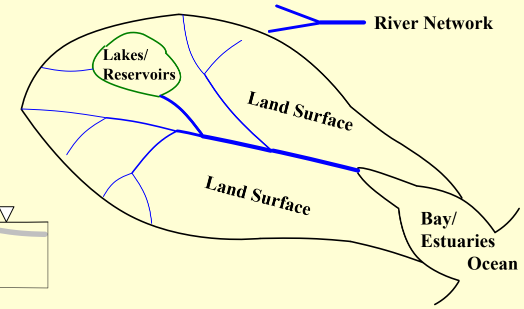
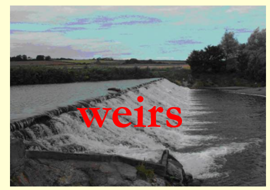
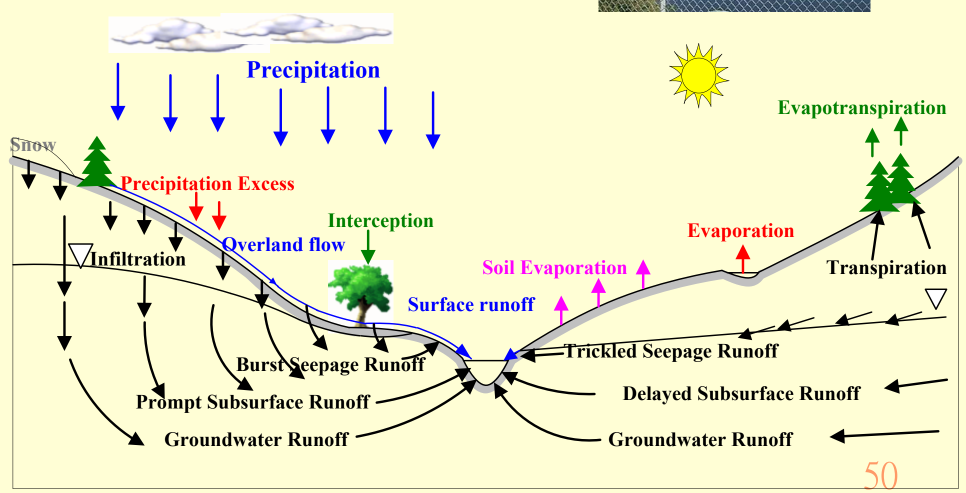


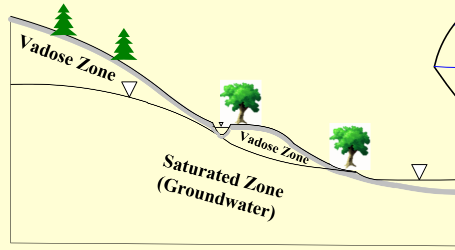


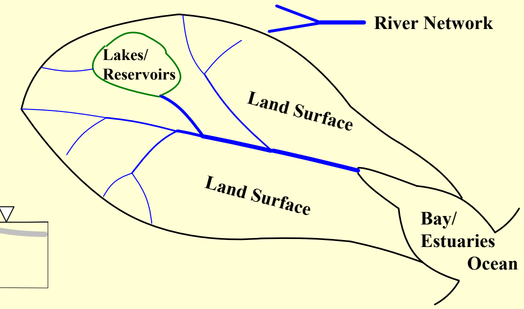


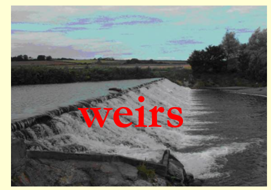


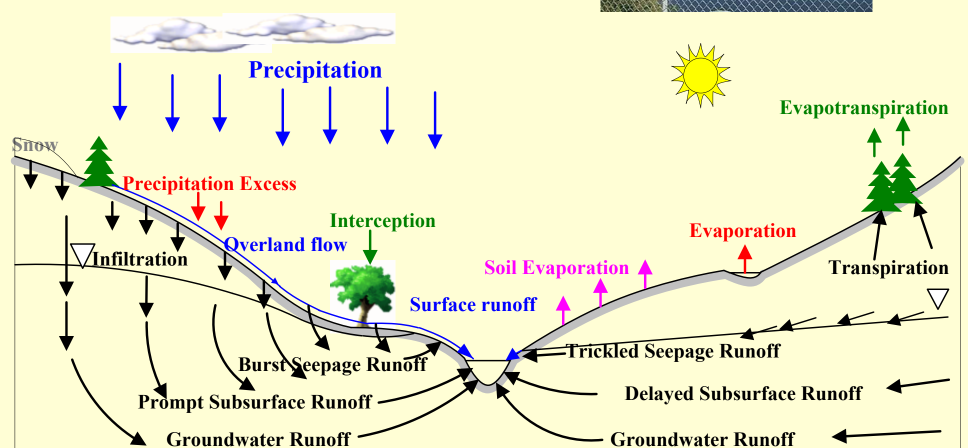
Watershed Modeling: Multi-media and multi-processes

- **Multimedia (Multi-system Components):**
  - Dentric Streams-Rivers-Canal-Open Channel,
  - Land Surface (bare soil, trees, vegetations, and plants)
  - Subsurface Media (Vadose and Saturated Zones), and
  - Ponds (Small Shallow), Lakes-Reservoirs (Small Shallow)
  - Control Structures (weirs, gates, culverts, pumps, levees, and storage ponds)
- **Multi-processes (Hydrologic Cycles)**
  - Evaporation, Evapotranspiration, Infiltration, and Recharges;
  - Flow and Storage Dynamics in Each Medium; and









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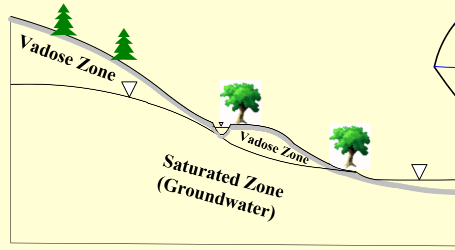
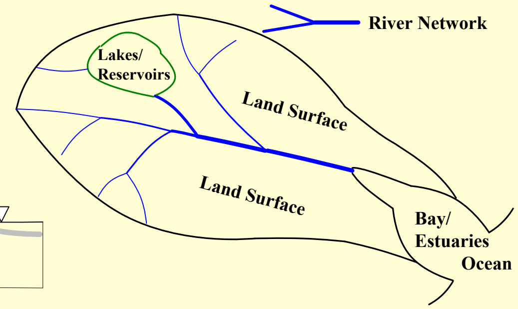
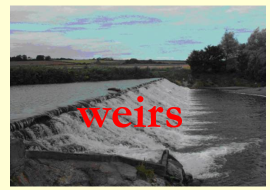
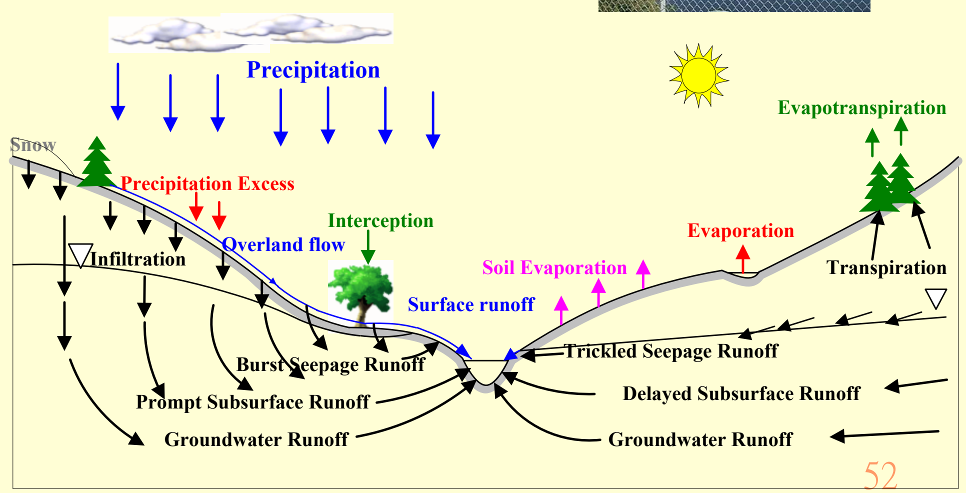
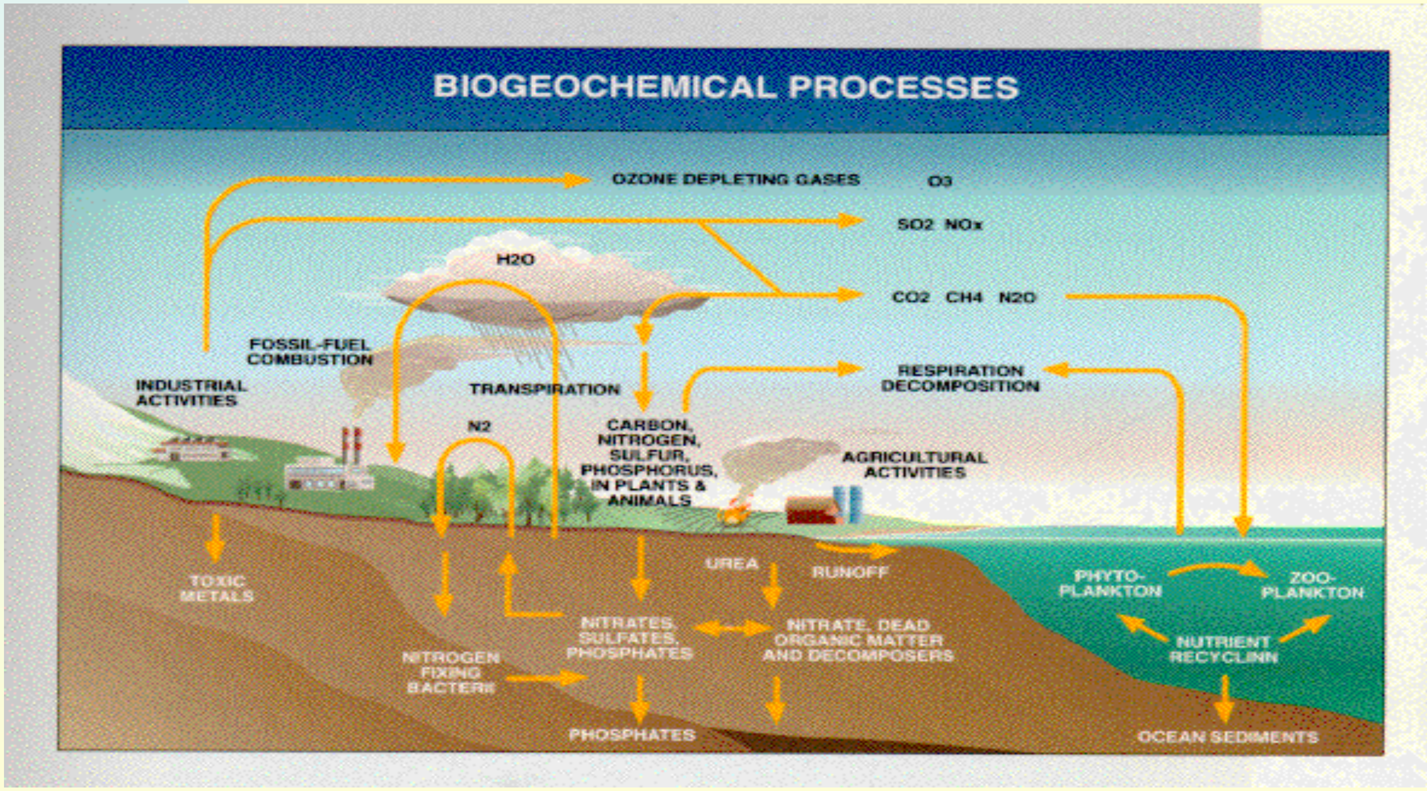








- **Multi-processes: Biogeochemical Cycles**



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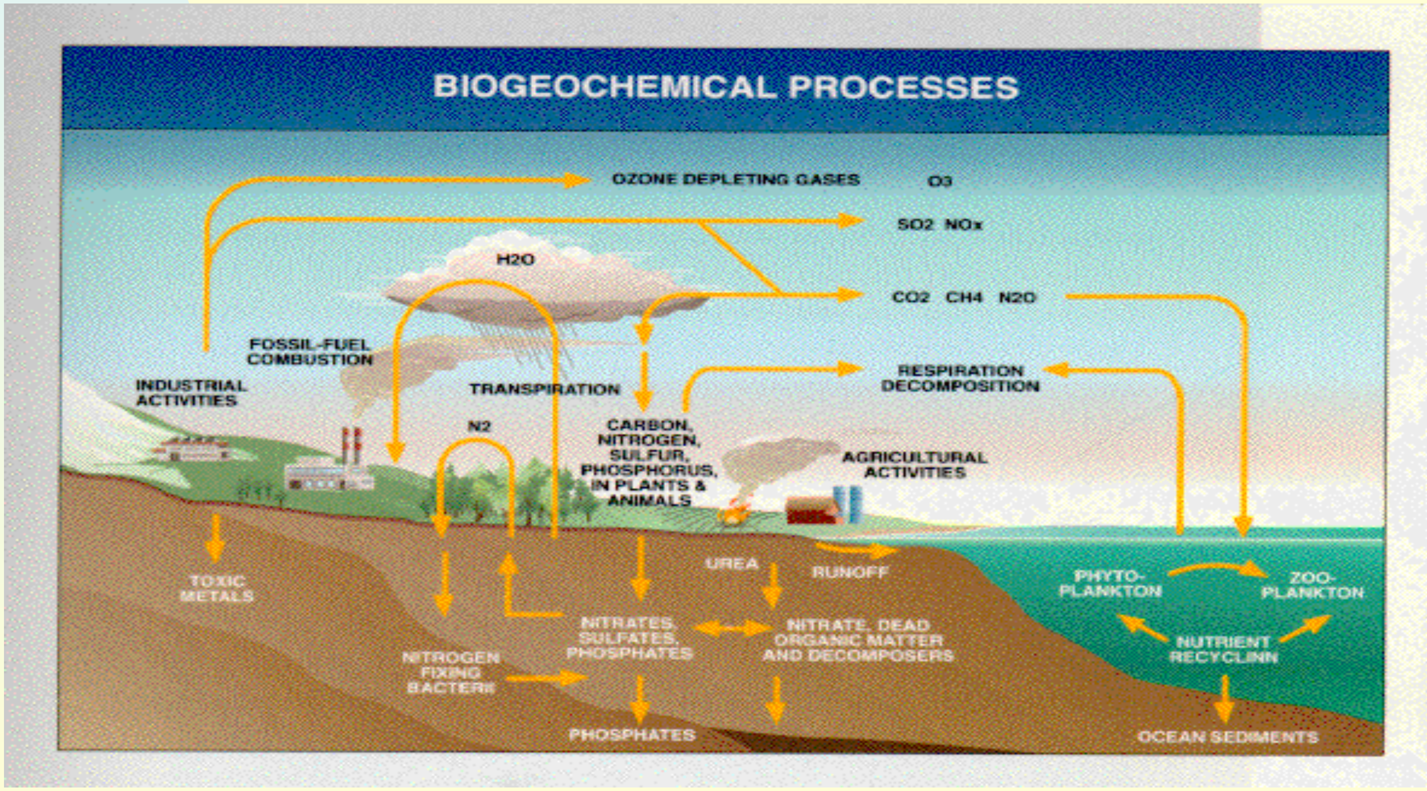

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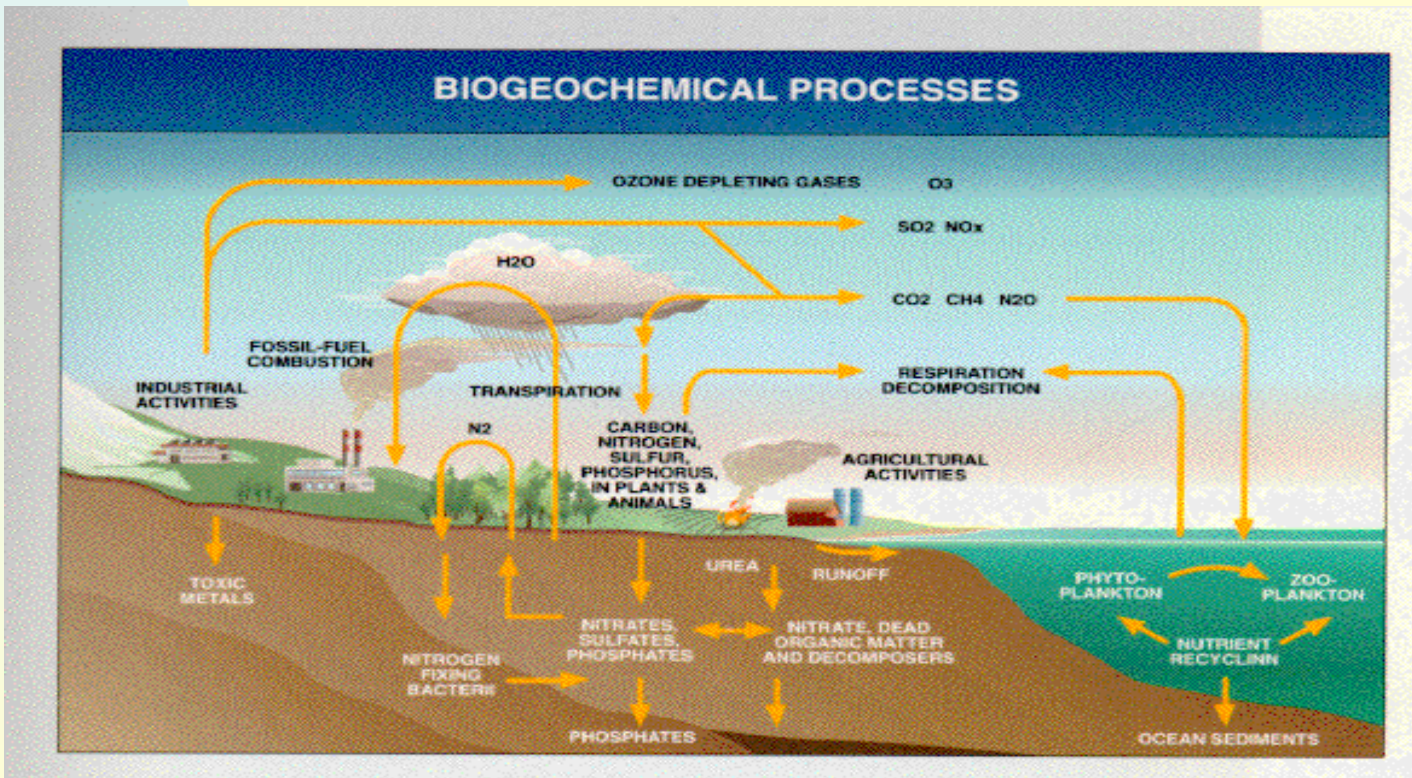

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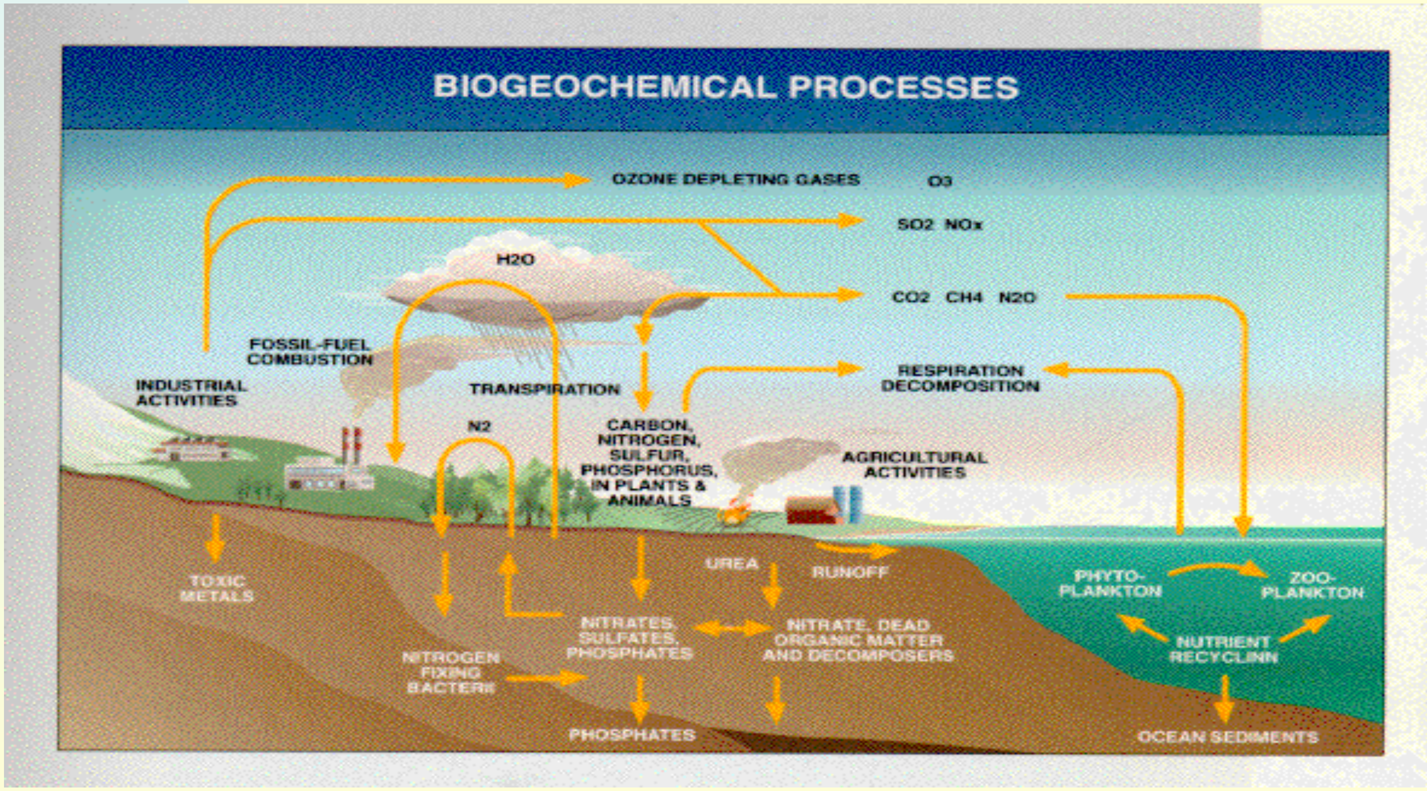
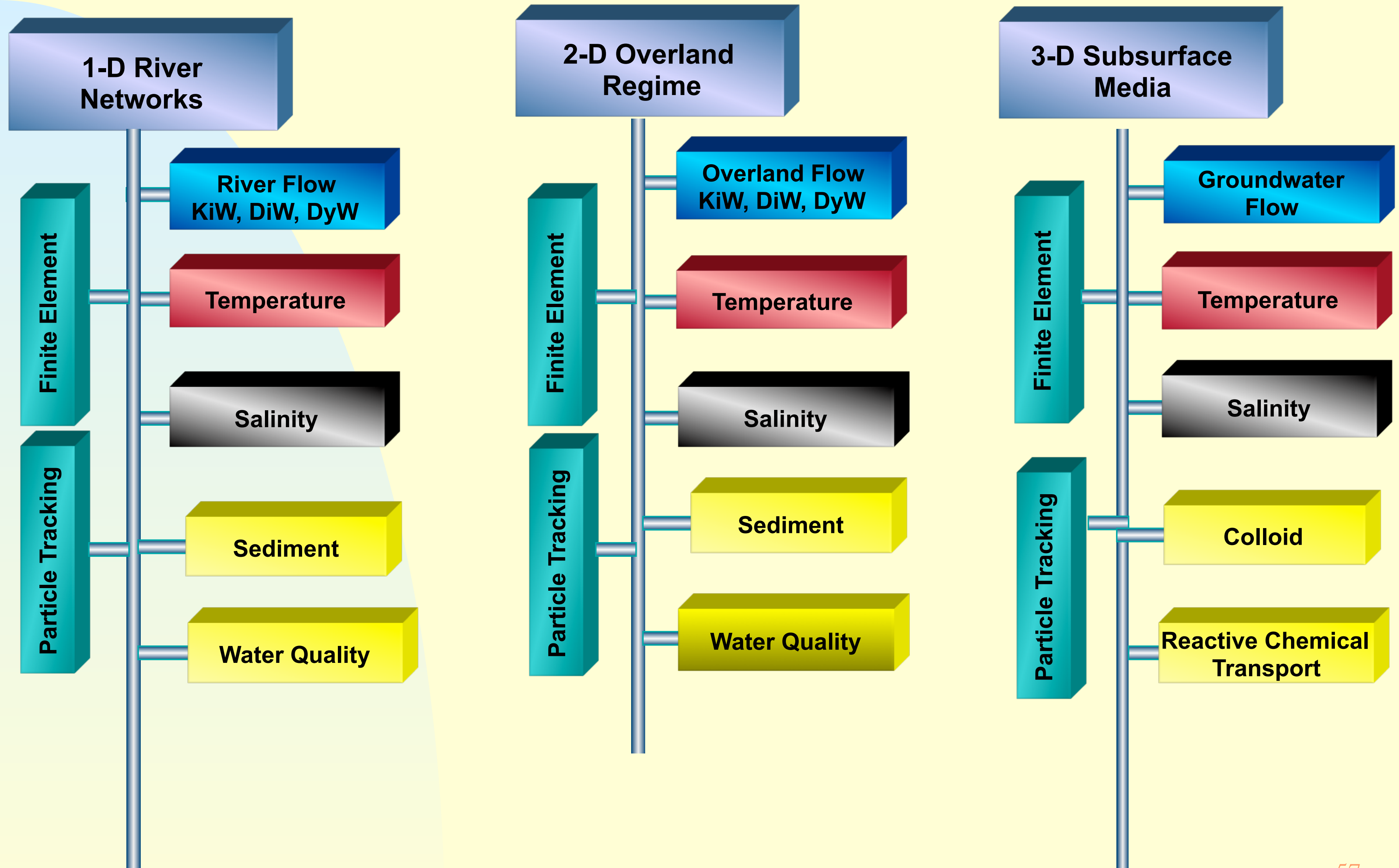


Watershed Modeling: A Numerical Model-WASH123D



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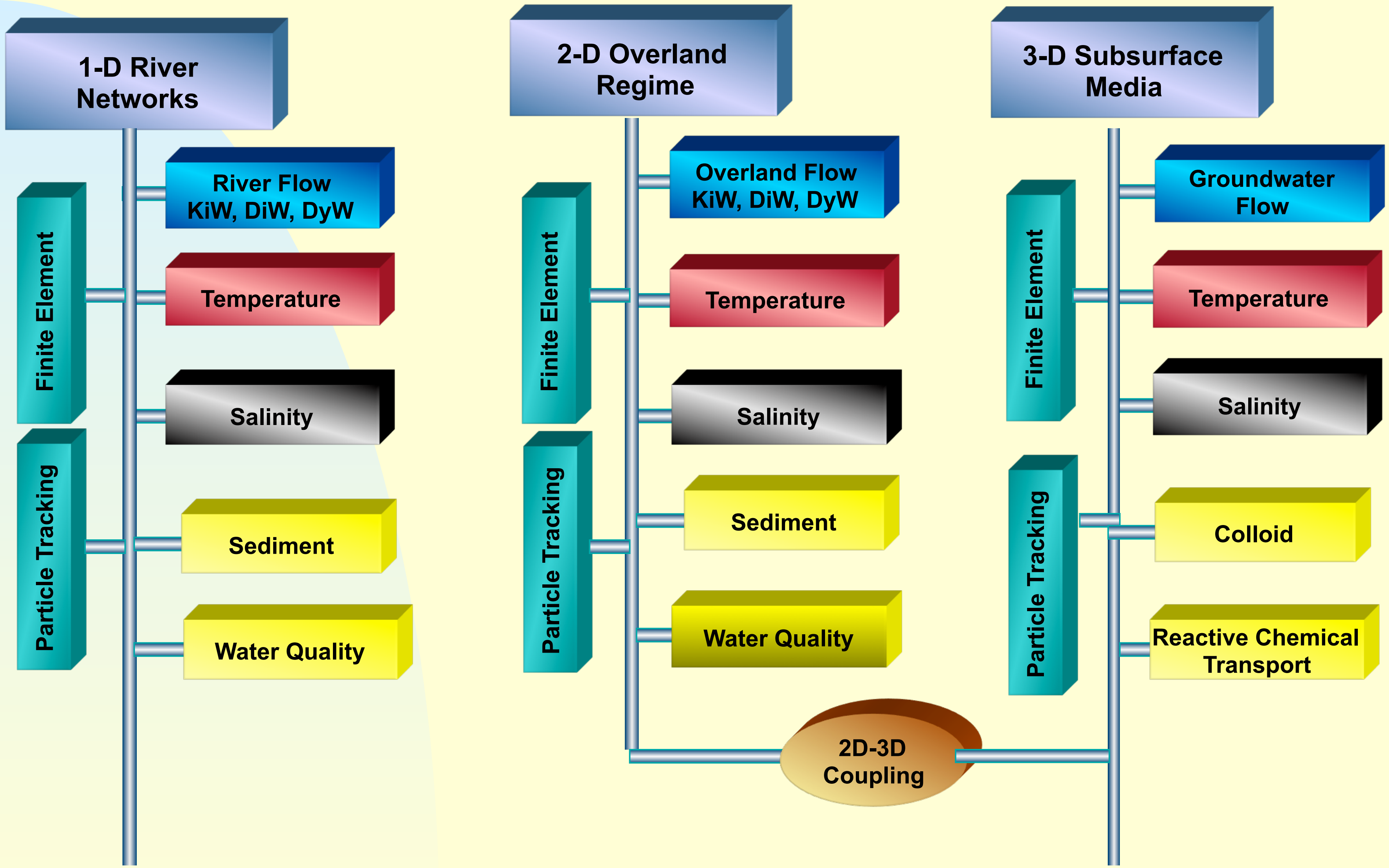

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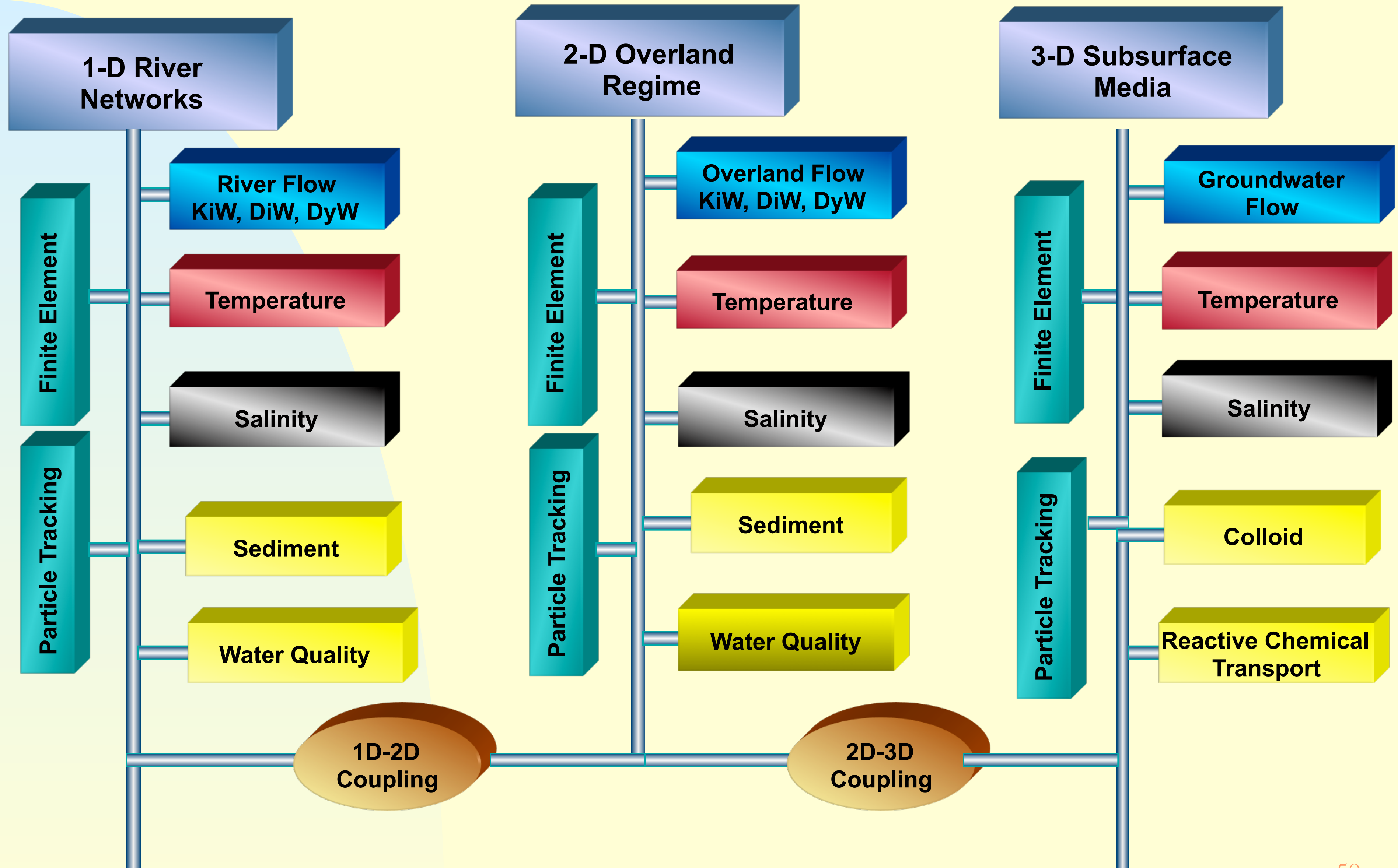

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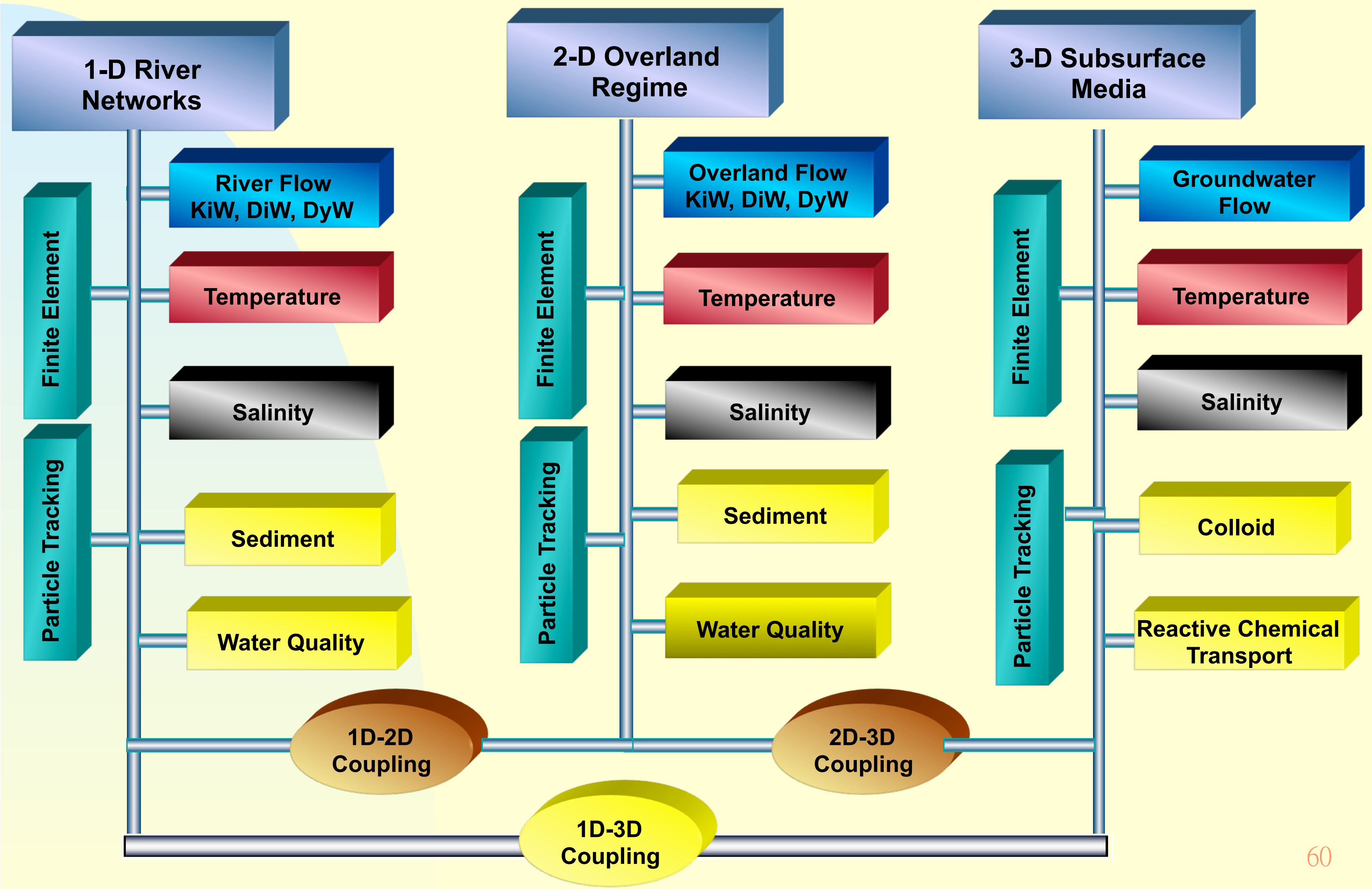

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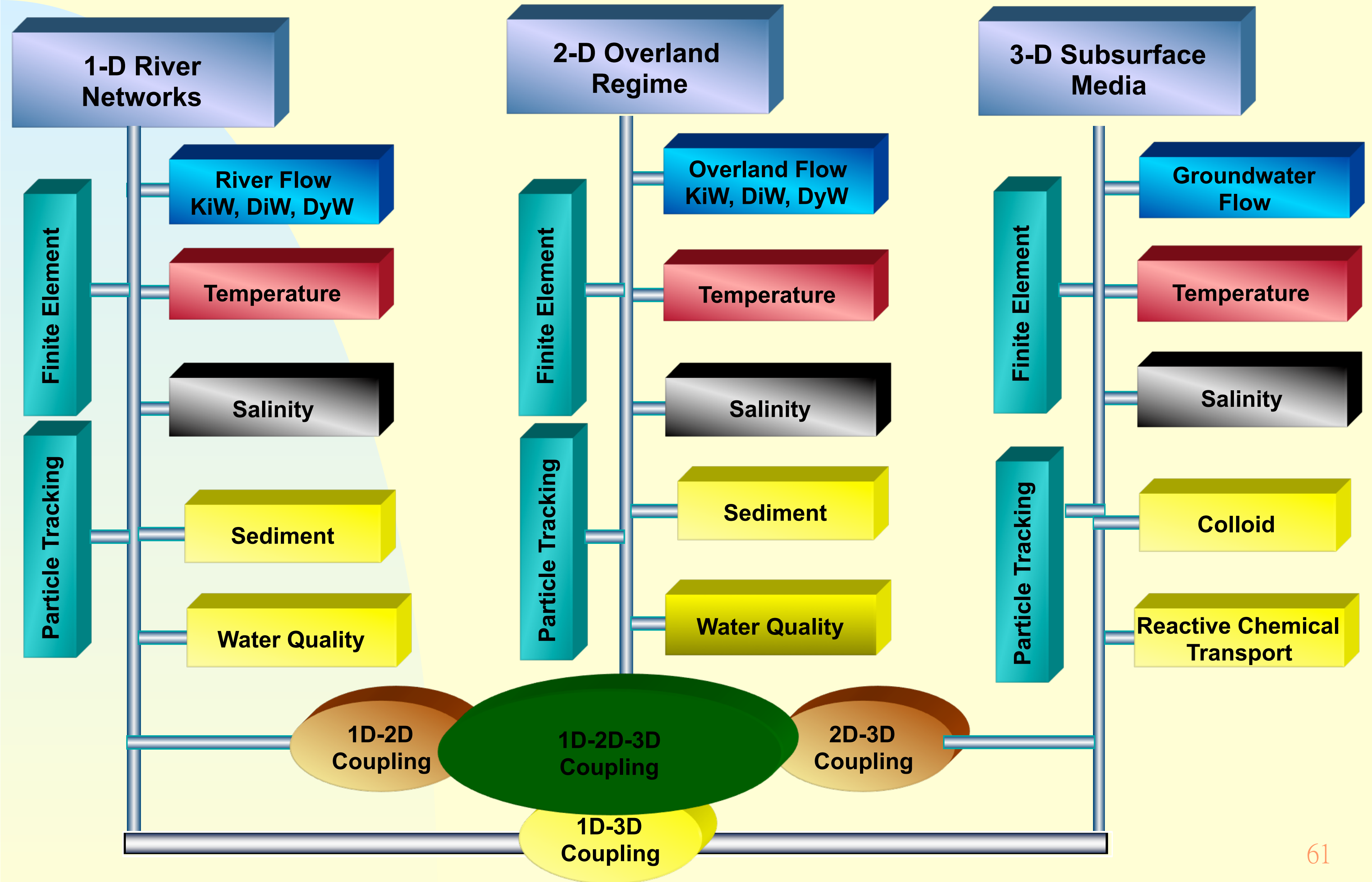

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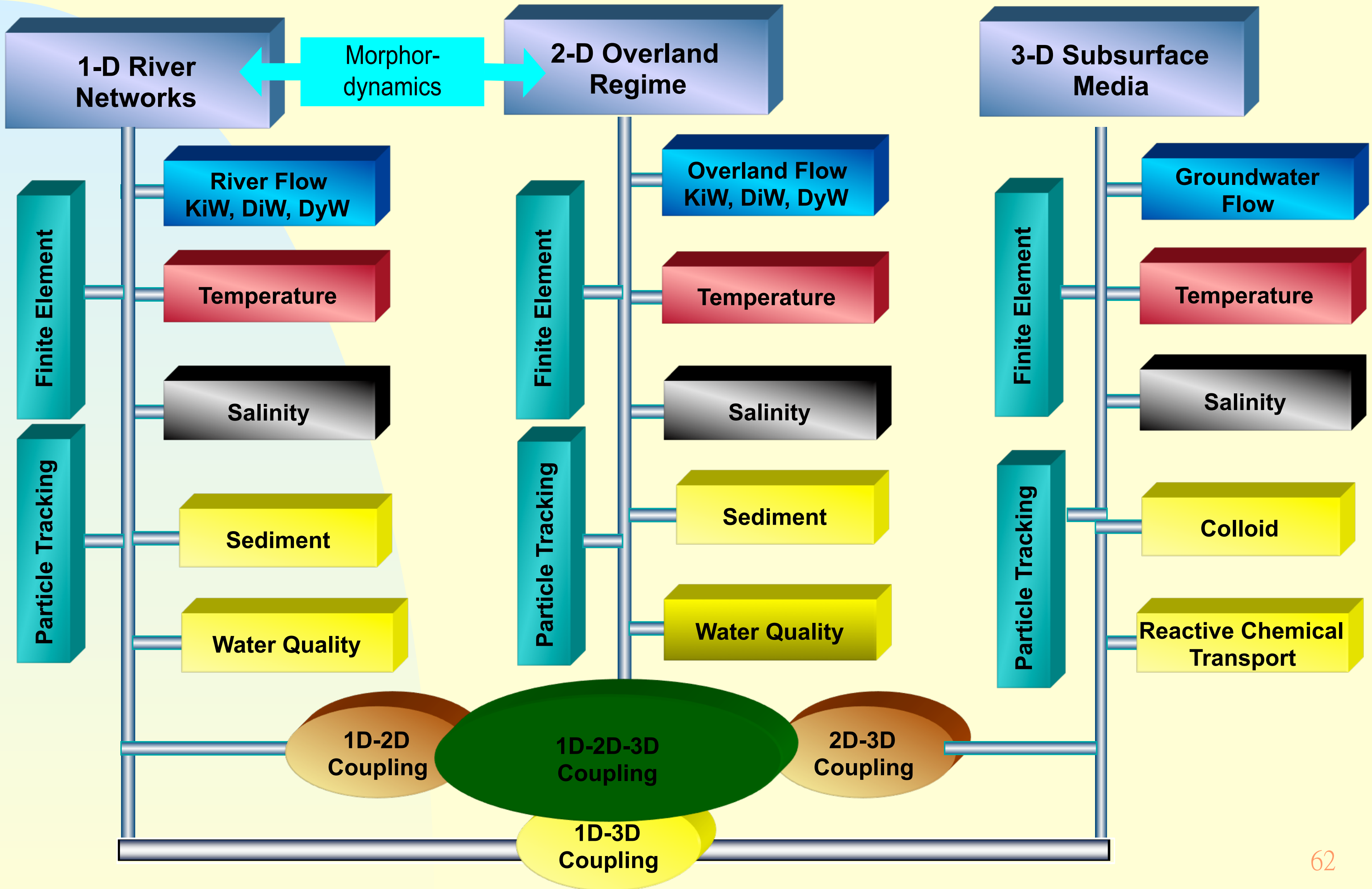

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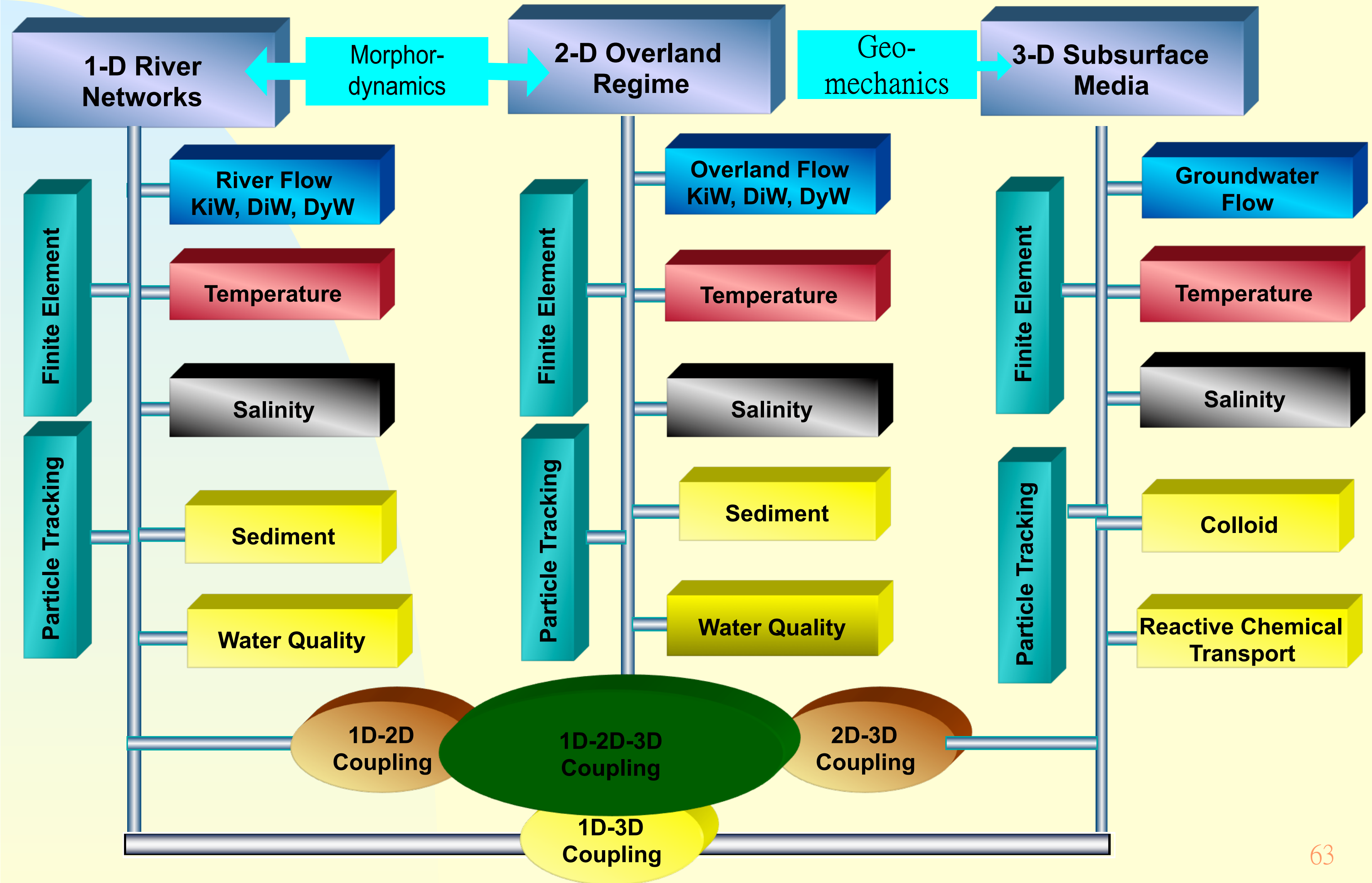

Watershed Modeling: Three Key Issues

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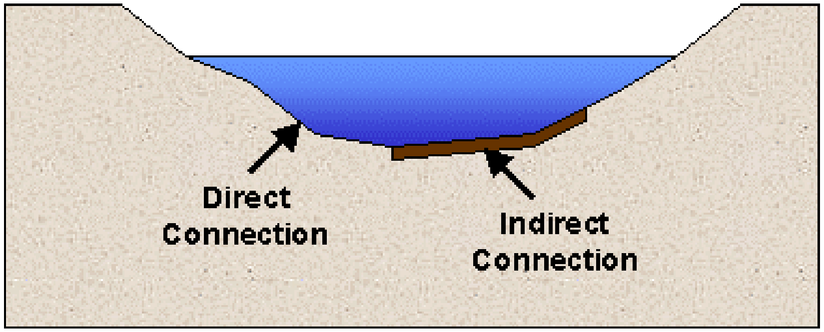
- ✓ **Physical Consideration**
  - **Direct Connection**
  - **Indirect Connection**



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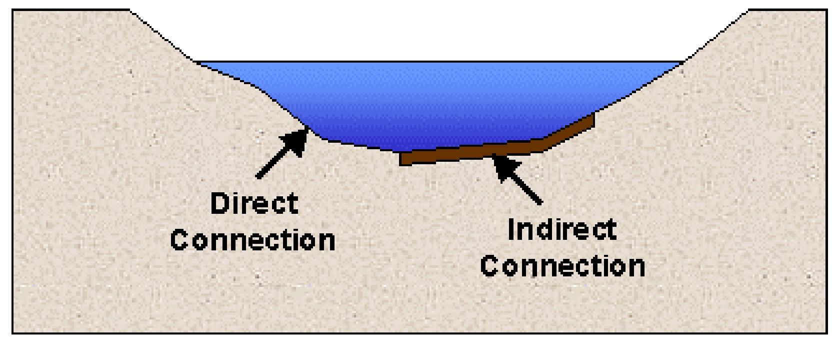

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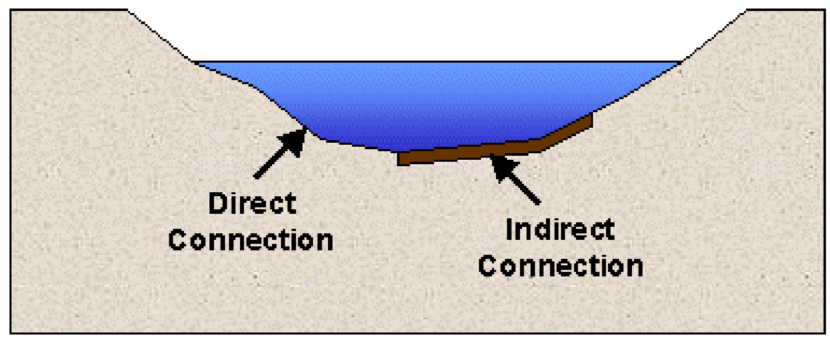
- ✓ **Mathematical Representation**
  - **Continuity of State Variables**

$$Q^S = Q^G \quad \textbf{and} \quad p^S = p^G$$



  - **Linkage Term for Fluxes**

$$Q^S = Q^G \quad \textbf{and} \quad Q^S \ (or\ Q^G) = K\left(p^G - p^S\right)$$

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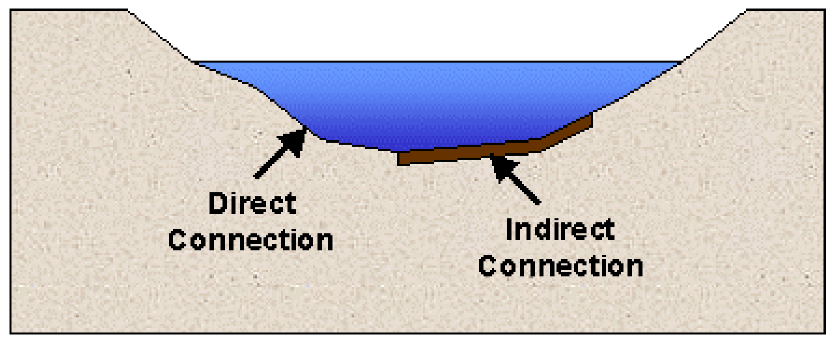


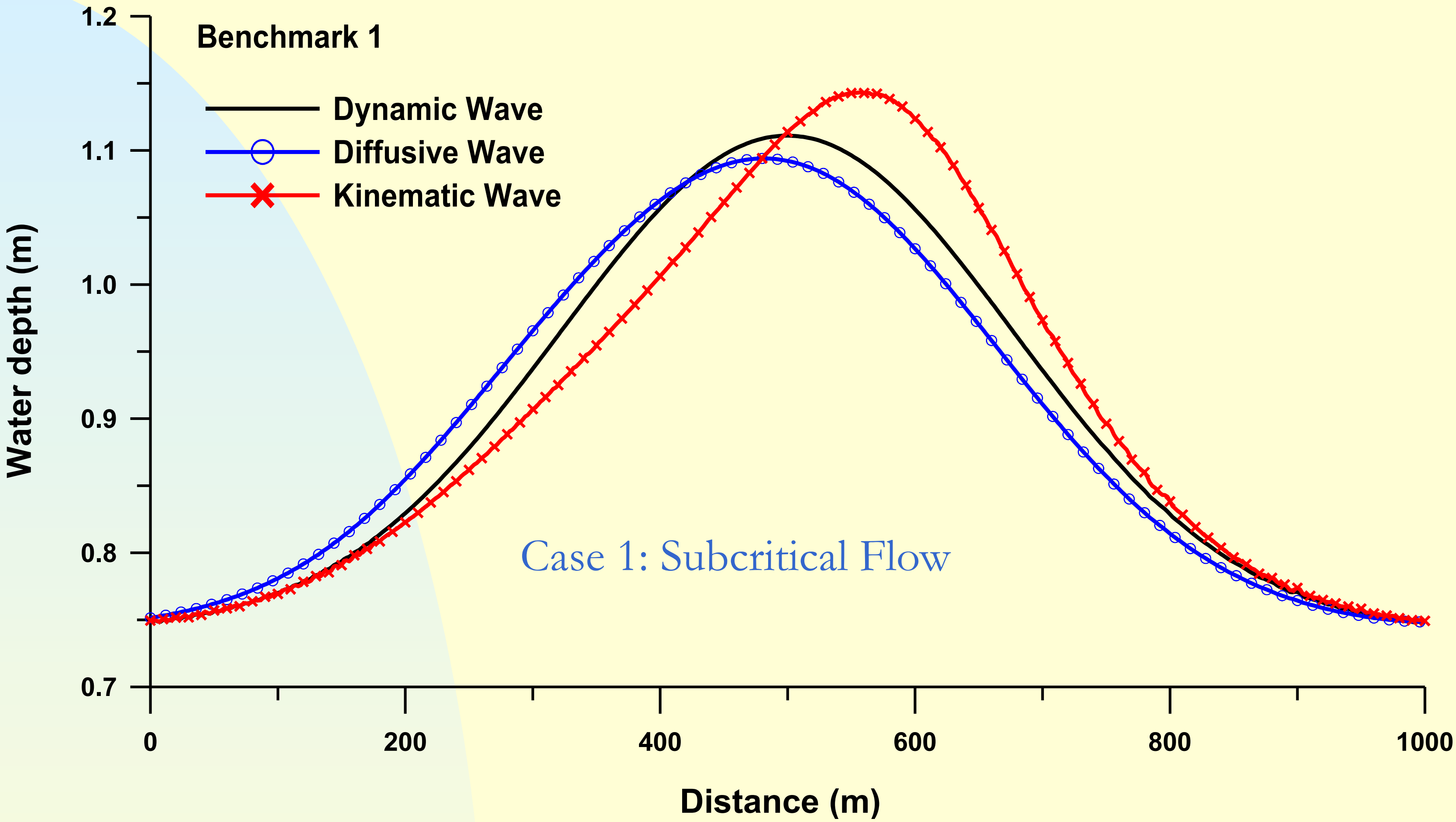
3. Partial versus Complete System Components

Problem Description

One dimensional channel flow benchmark problems (MacDonnell et al., 1997) that are slightly modified

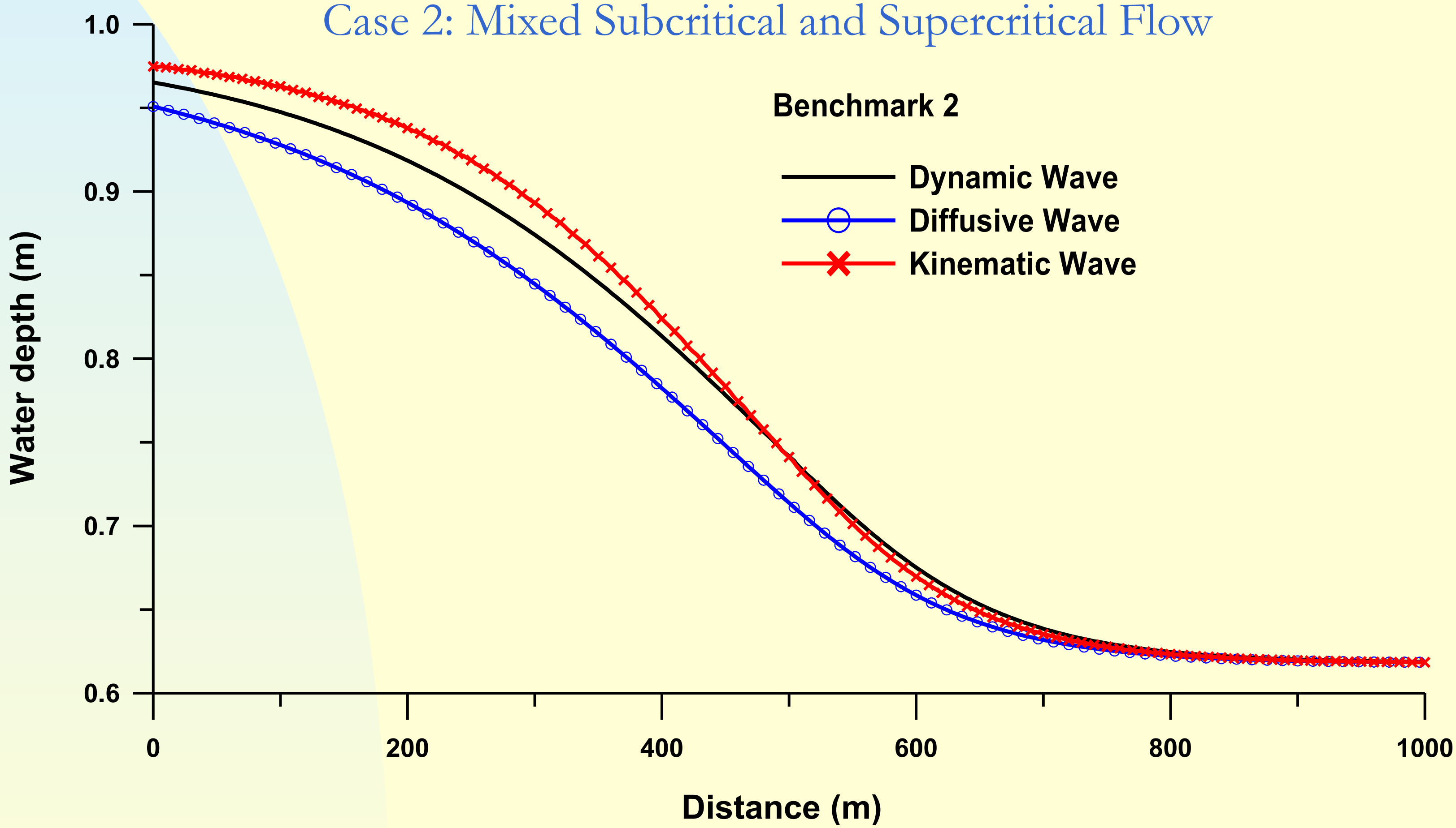
Case No	Channel	Flow Conditions	Manning's n	Upstream BC	Downstream BC
1	Rectangular, B = 20 m, L = 100 m	Subcritical, approaches critical near ends	0.03	Q = 20 m^3/s	h = 0.748409 m
2	Rectangular, B = 20 m, L = 100 m	Subcritcal at inflow, supercritical at outflow, critical section halfway	0.02	Q = 20 m^3/s	Not required
3	Trapezoidal, B = 10 m, S (H:V) = 2:1, L = 500 m	Subcritical oscillartory depth profiles	0.03	Q = 20 m^3/s	h = 1.125 m
4	Trapezoidal, B = 10 m, S (H:V) = 1:1, L = 1000 m	Subcritical at inflow, hydraulic jump at 600 m distance, subcritical at outlfow	0.03	Q = 20 m^3/s	h = 1.349963 m
B = Bottom Width, S = Side Slope, H = Horizontal, V = Vertical, L = Channel Length					

Comparison of Dynamic, Diffusive, and Kinematic Wave Simulations



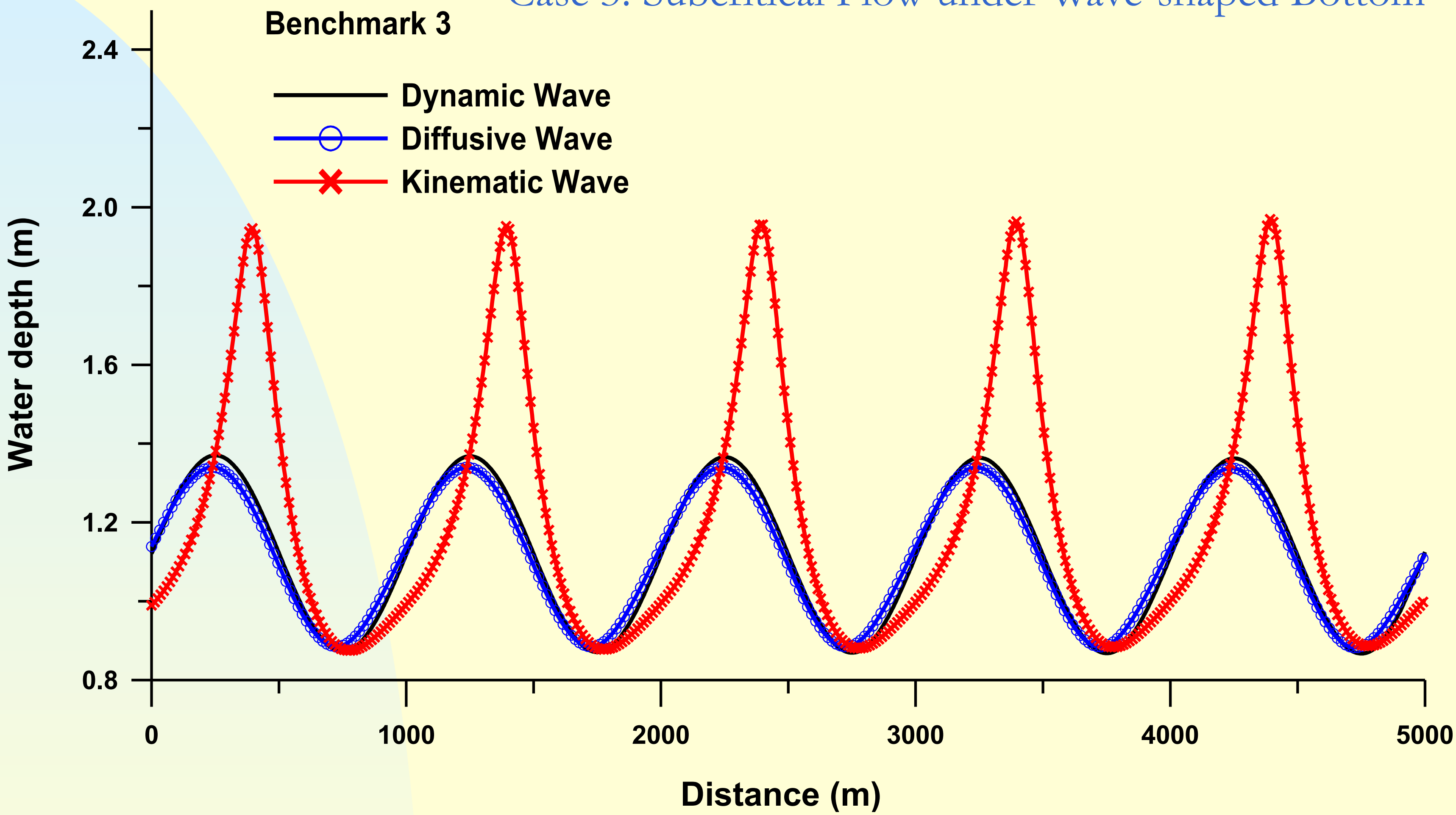
Comparison of Dynamic, Diffusive, and Kinematic Wave Simulations

Case 2: Mixed Subcritical and Supercritical Flow



Comparison of Dynamic, Diffusive, and Kinematic Wave Simulations

Case 3: Subcritical Flow under Wave-shaped Bottom



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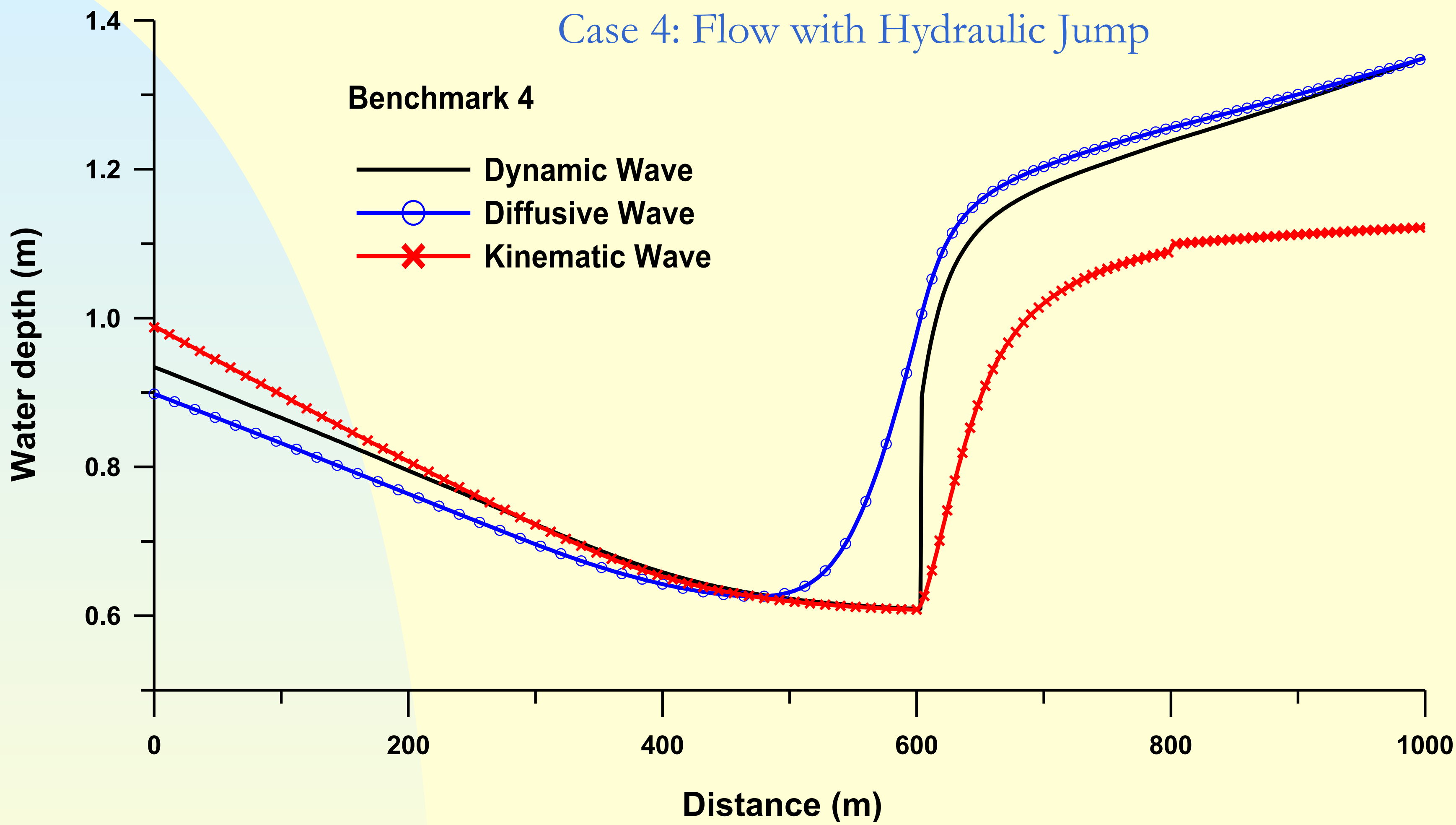
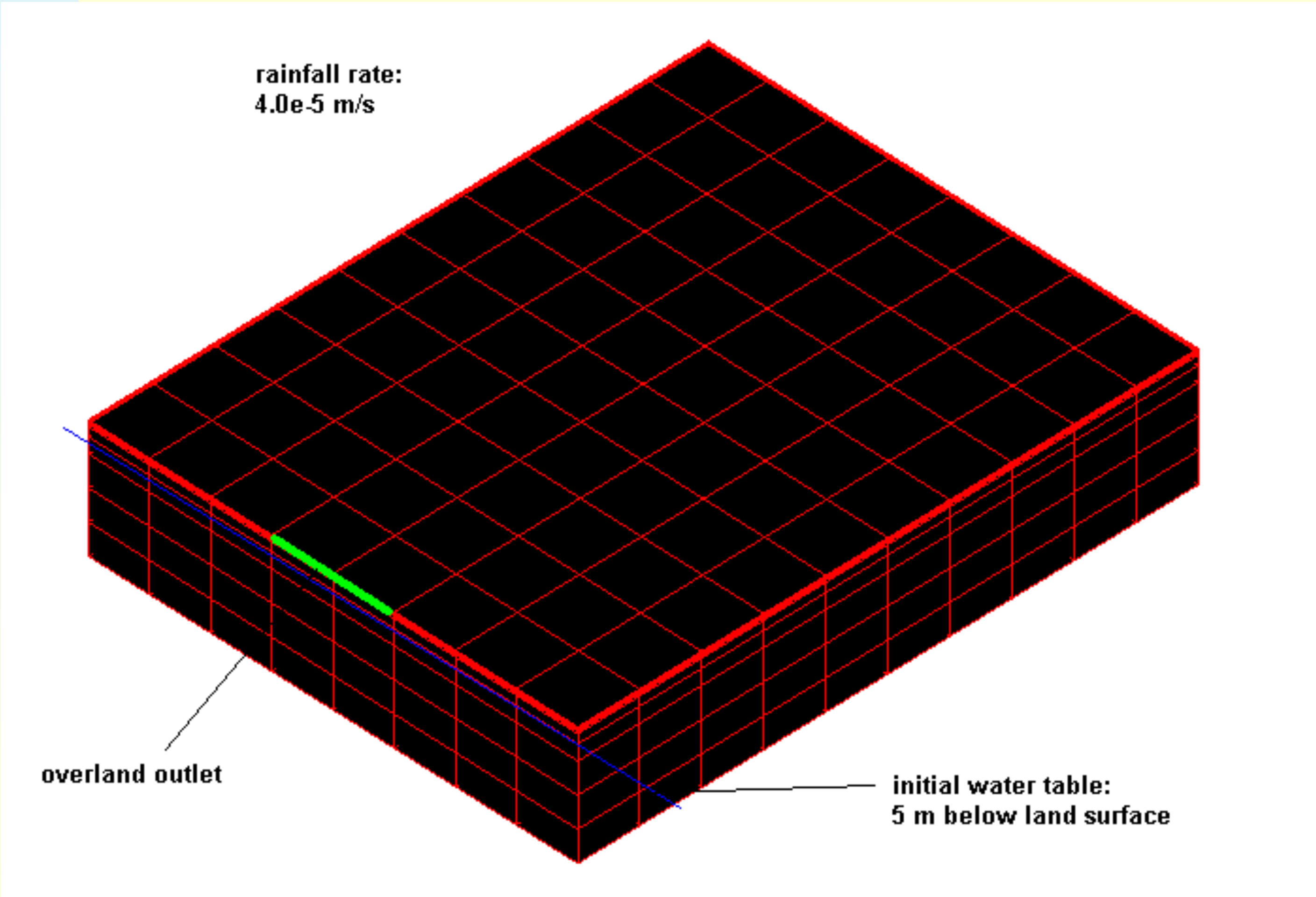


Example No. 2: Overland flow over a porous medium: Physics-based Versus *Ad hoc* Coupling

- This example is designed to simulate rainfall-runoff over an infiltrating surface to demonstrate the inappropriate use of linkage term when there is no physical discontinuity at the interface.



Comparison of Continuity versus Linkage Approaches

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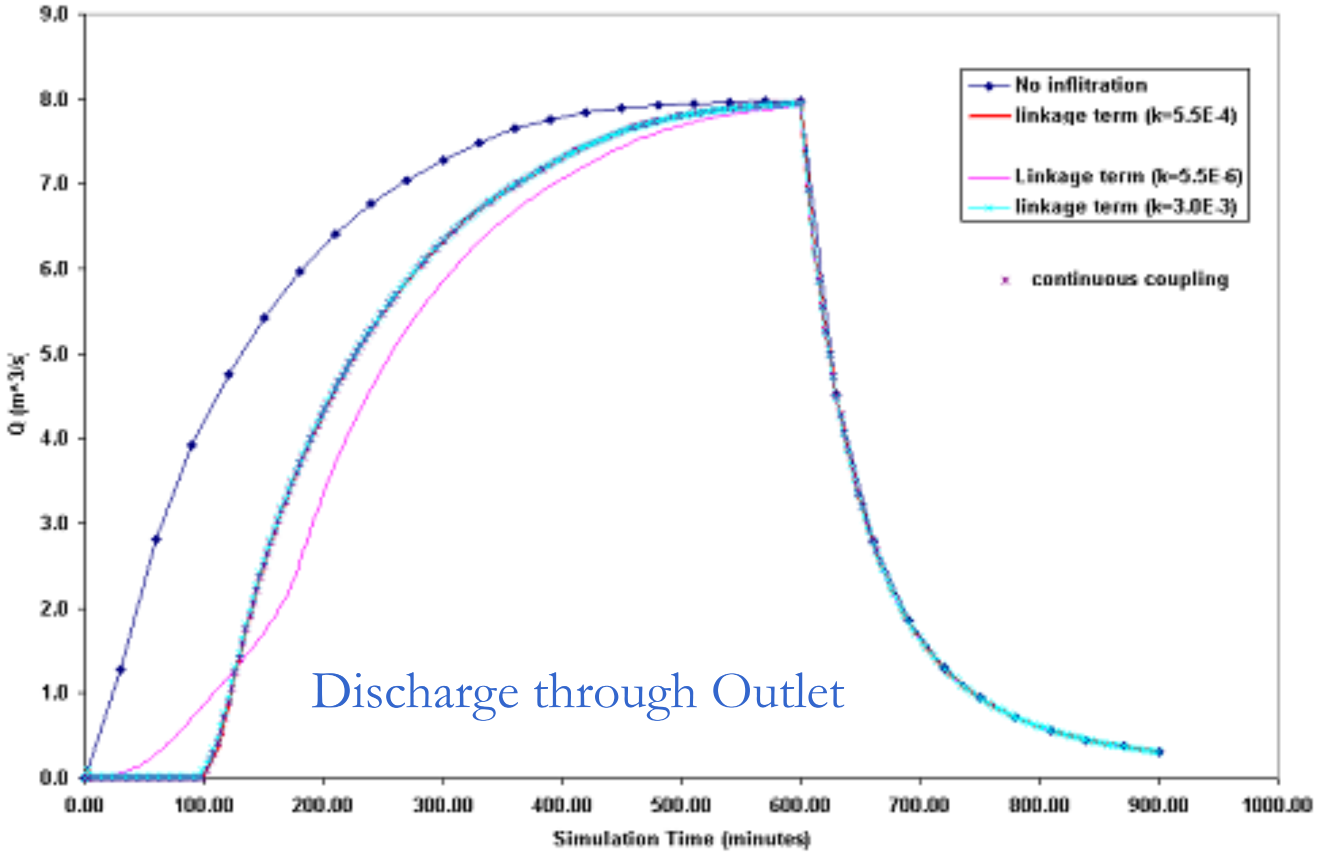

The linkage coefficient k is simply a calibration parameter, it has no physical meaning.

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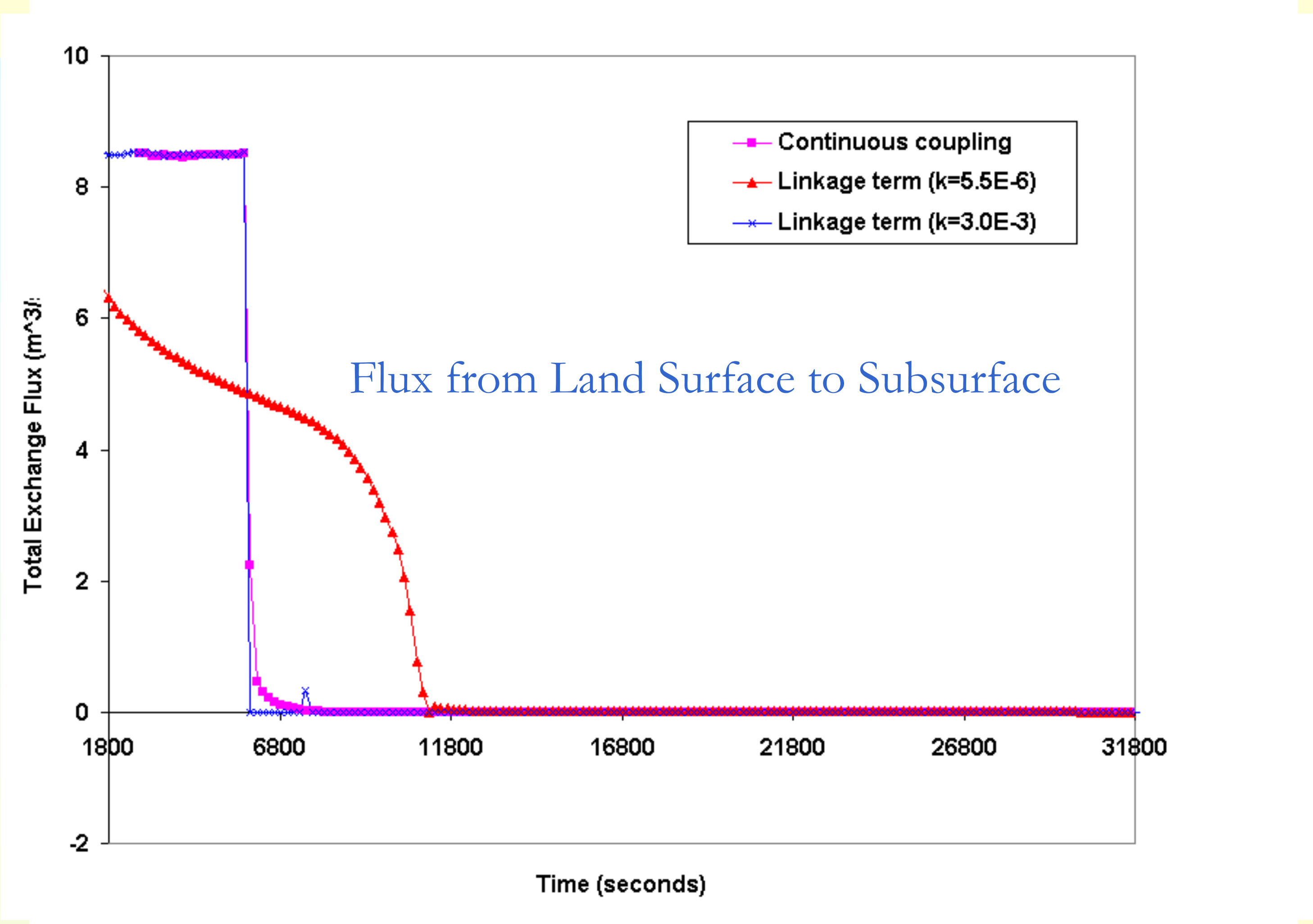

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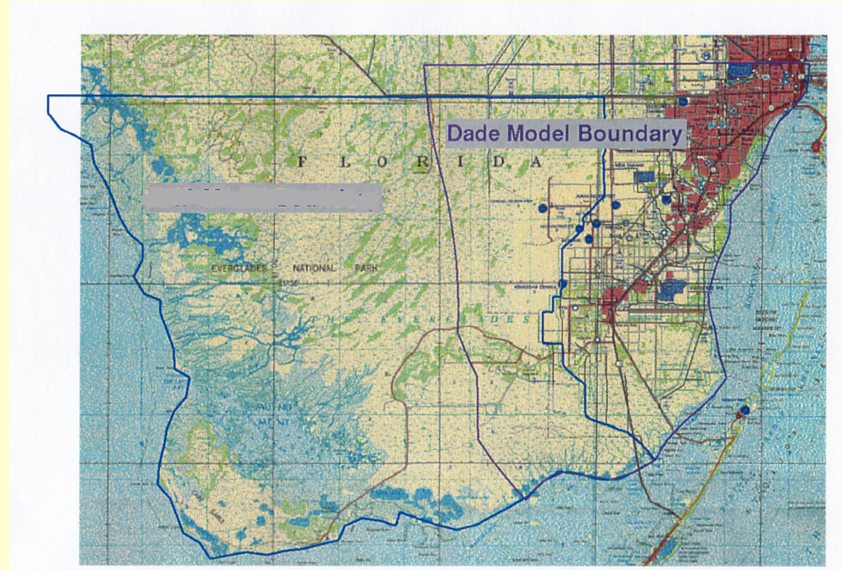
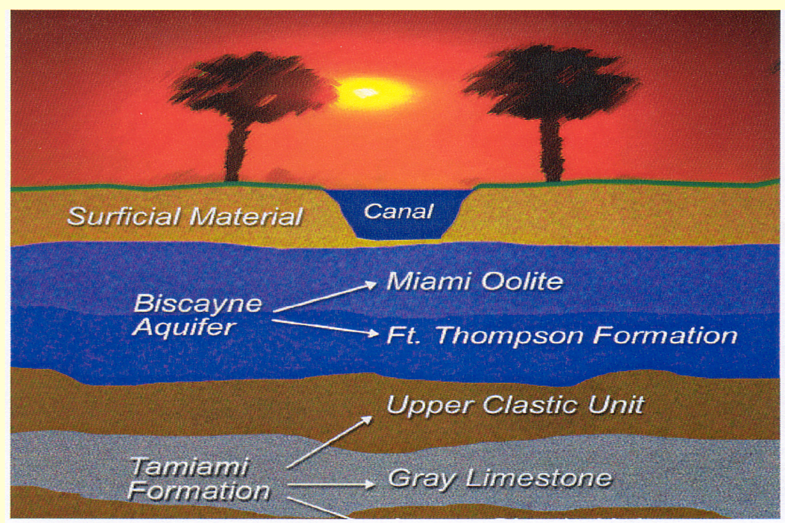
Example No. 3: South Dade County Watershed: Partial versus Complete System Components



South Florida Project Boundaries for Dade Model



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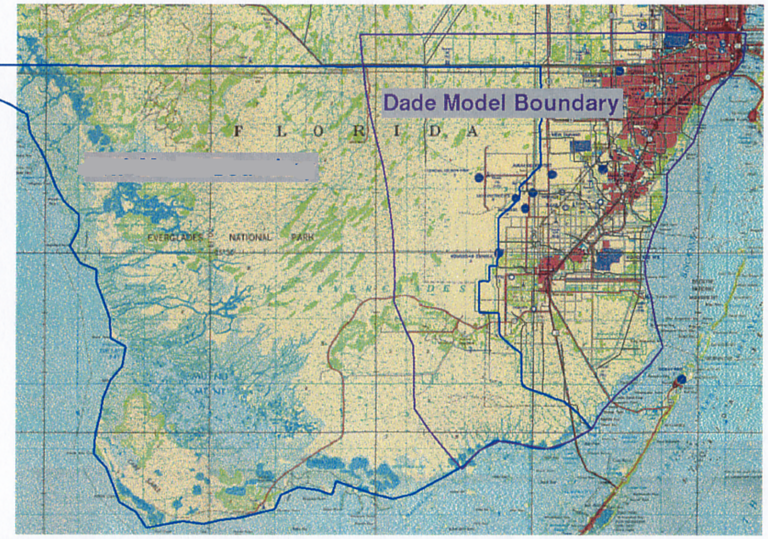
- **Dade model is a large scale regional problem, 30 mi by 40 mi.**



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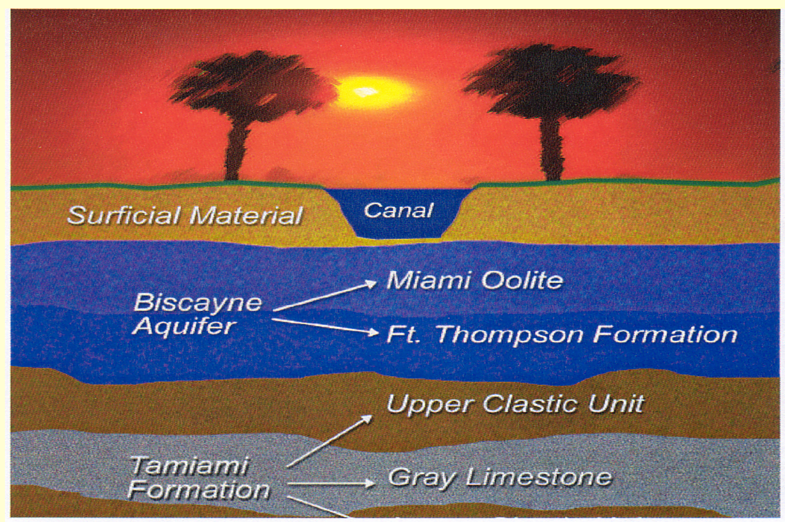

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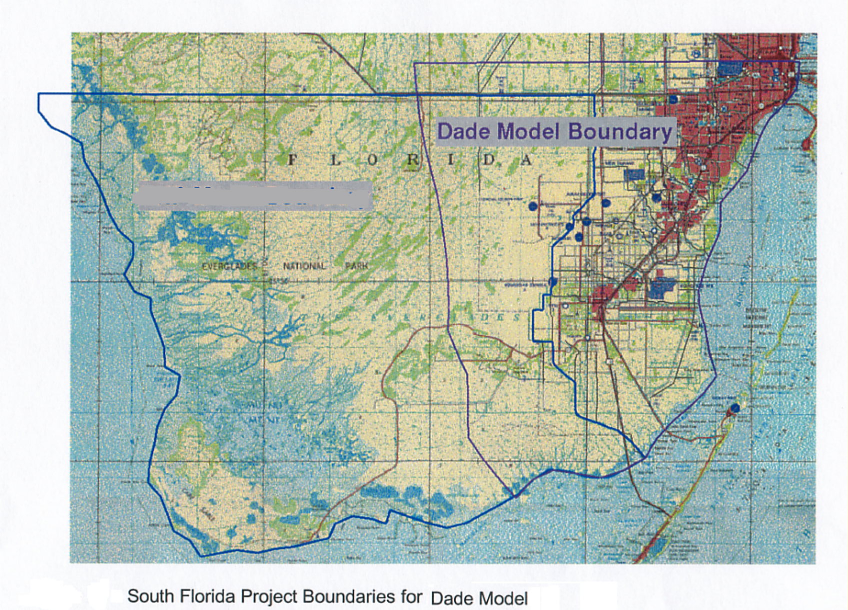

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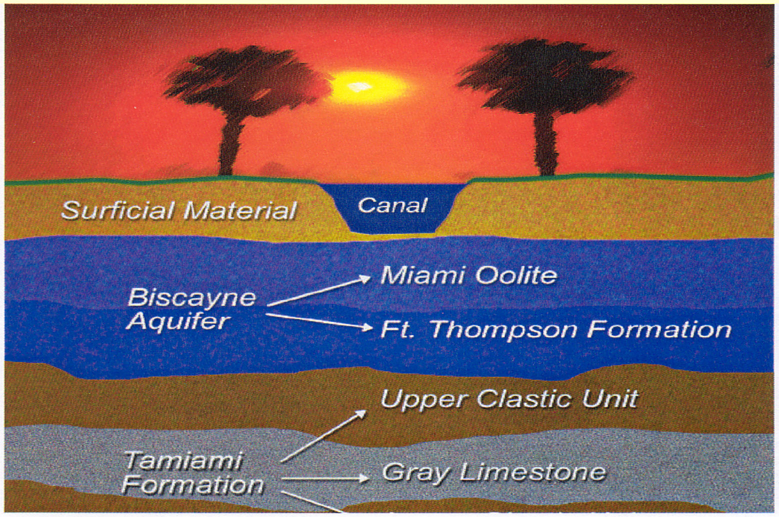

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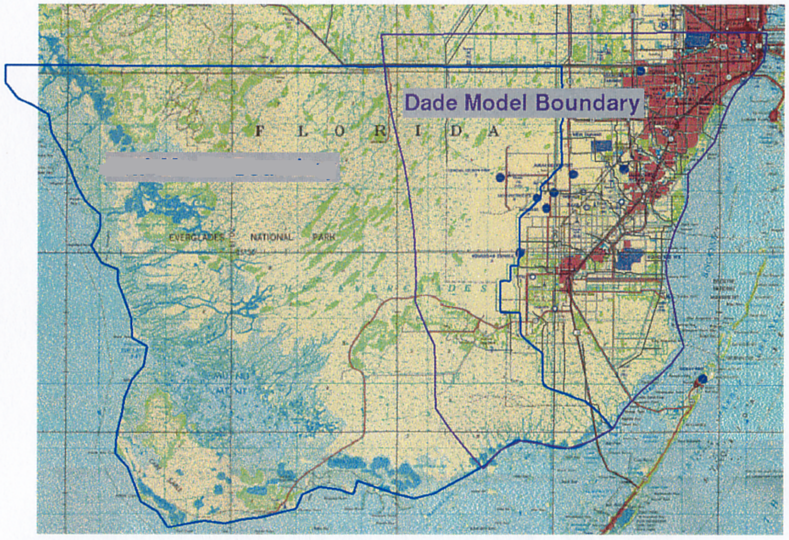

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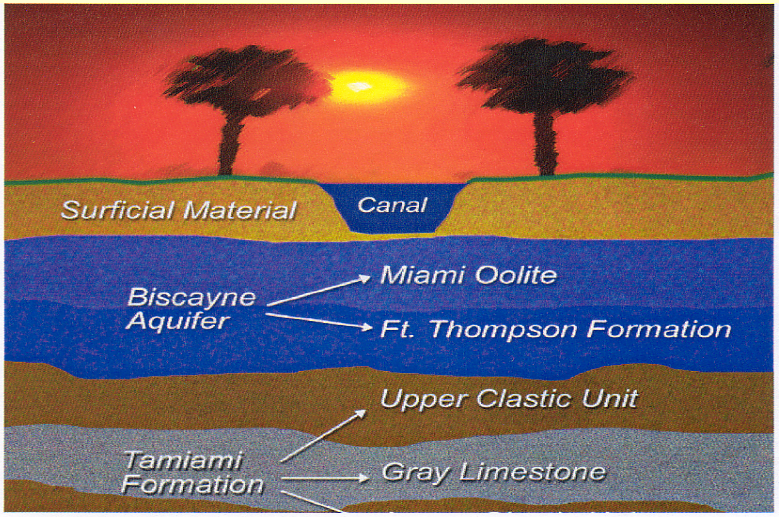

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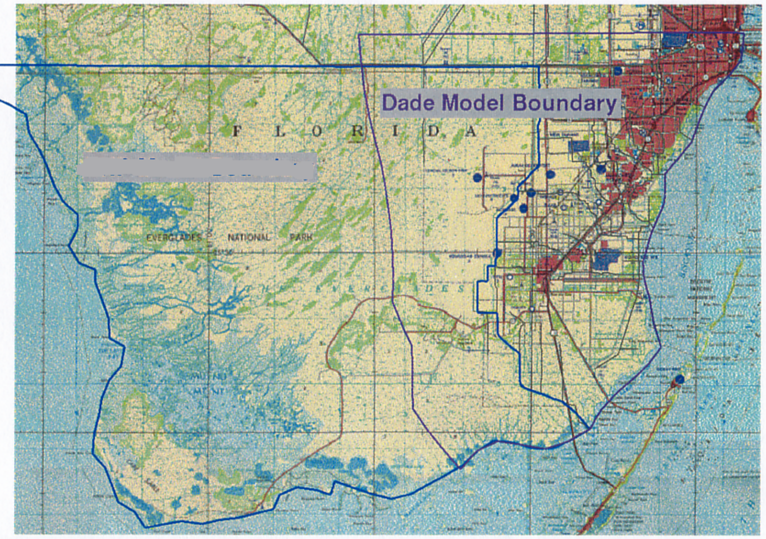
- **Complex hydraulic structure operations**
- **Strong interaction of overland flow, groundwater flow, and canal flow in south Florida**



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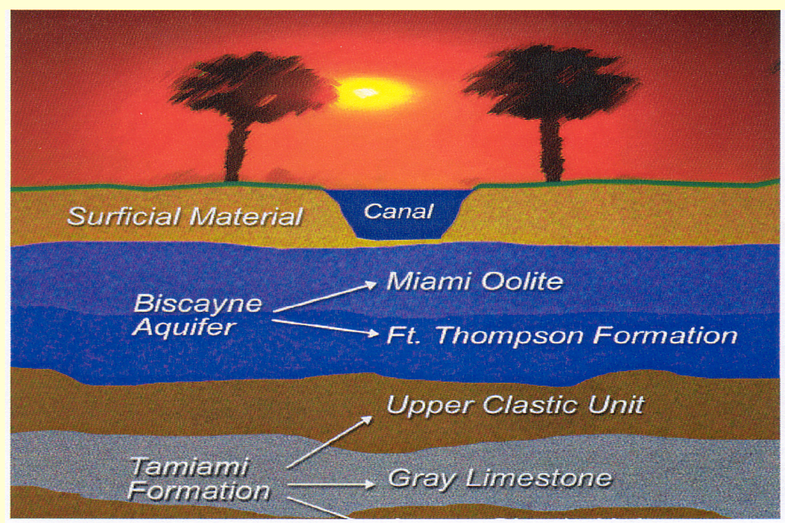
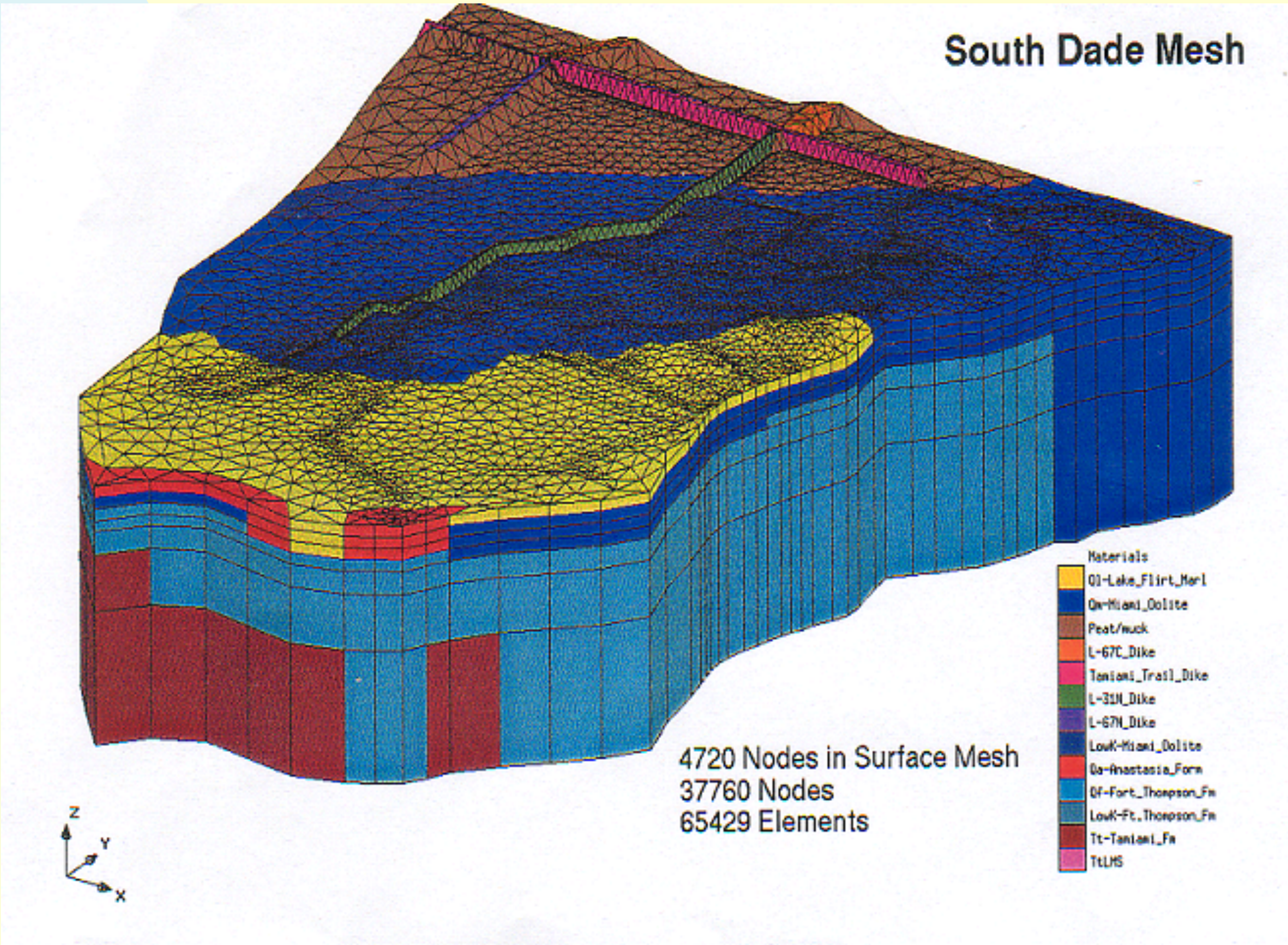
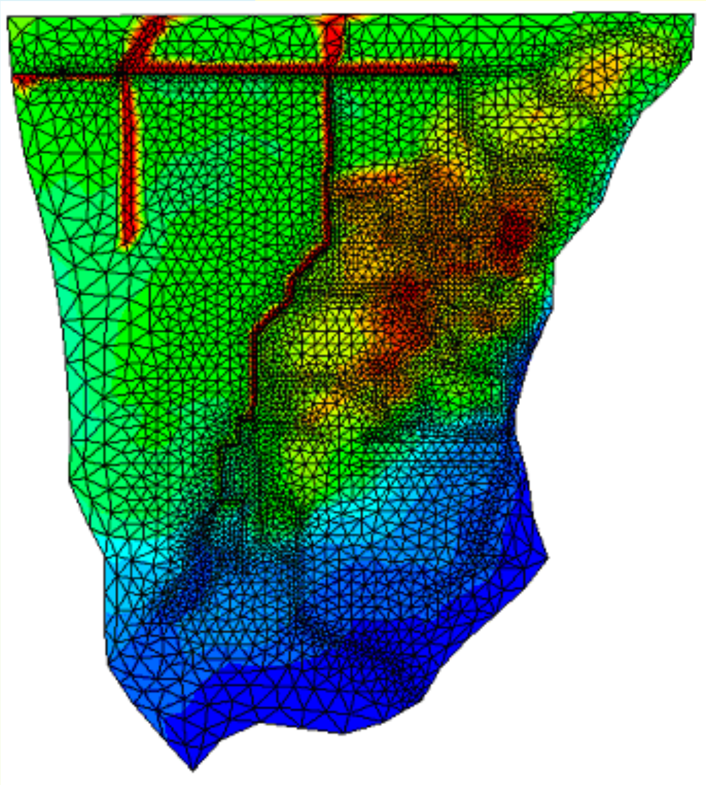


- There are 7 layers in vertical direction: **37,760 nodes, 65,429 elements.**
- Levees are incorporated as part of subsurface media.
- Real Time Simulated: 22 days

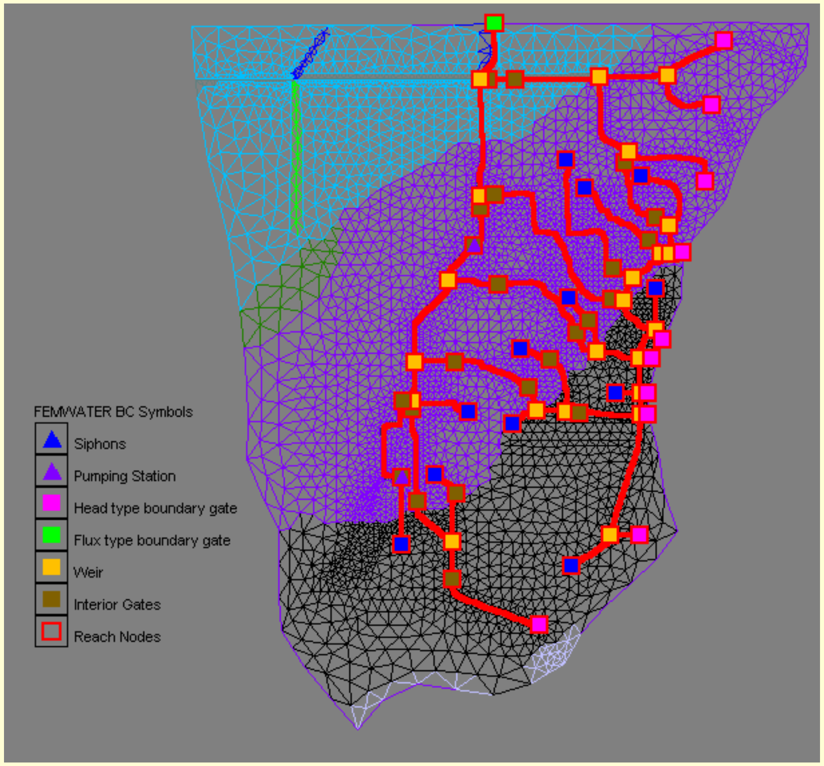


Finite element discretization for 2D overland flow and canal networks

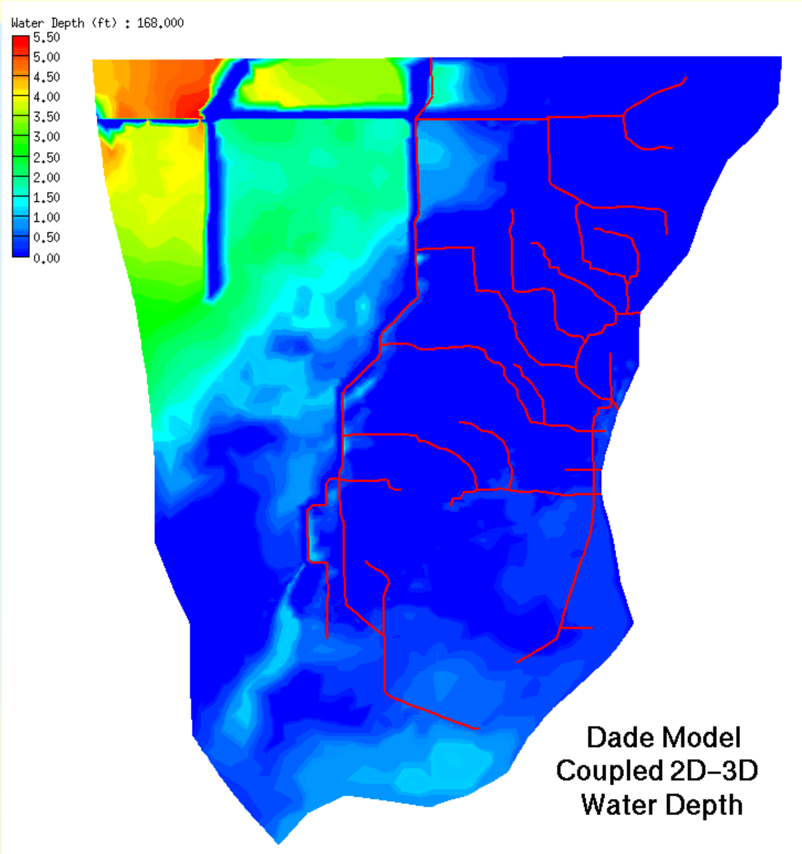
- **2D Overland Mesh:**
  4,720 Surface Nodes

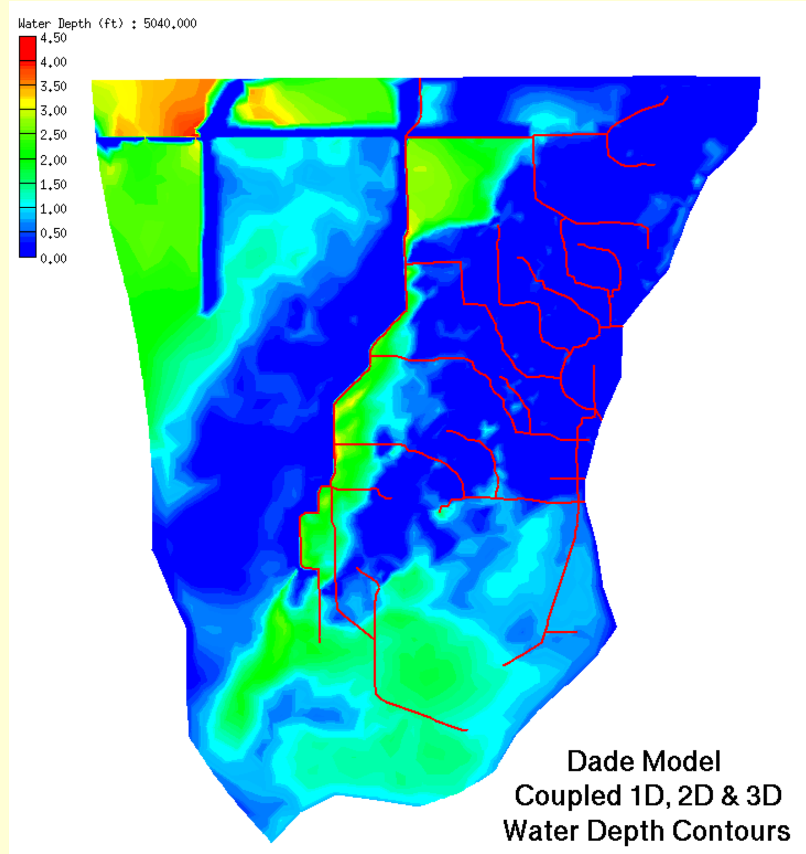


- **Canal Network with Structures**



Comparison of 2D-3D interaction and 1D-2D-3D interaction





There is a significant difference between 2D-3D and 1D-2D-3D simulations. It is thus important to consider interactions among all system components.

Summaries and Conclusions

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- Green Function, especially the homogeneous Green Function, is perhaps one of the most versatile means to obtain analytical models.
- In watershed modeling, three very important issues must be considered. Whenever possible,
  1. complete physics is preferred,
  2. physics-based coupling must be employed to avoid artifact calibration of non-physics parameters, and
  3. Complete system components are preferred.