MODFLOW 6 TRANSPORT

MODFLOW 6 / FLOPY Workshop

Delft, The Netherlands

March 25—27, 2019

U.S. Department of the Interior
U.S. Geological Survey

Transport Model

- New model type in MODFLOW 6 called GWT
- Compatible with unstructured grids and the Newton flow formulation
- Simulates advection, dispersion, sources and sinks, sorption, decay, and any number of immobile domain
- Implicit formulation (no particles)
  - Second-order TVD
  - Optional use of XT3D for dispersion

GWT Packages

Table 1–1. List of packages available for use with the Groundwater Transport Model.

Package Name	**Abbreviation**	**Package Category**
Temporal Discretization	TDIS	Data Input
Spatial Discretization	DIS, DISV, or DISU	Data Input
Initial Conditions	IC	Data Input
Iterative Model Solver	IMS	Data Input
Advection	ADV	Transport/Grid
Dispersion	DSP	Transport/Grid
Storage	STO	Transport/Internal
Decay	DCY	Transport/Internal
Sorbtion	SRB	Transport/Internal
Immobile Domain	IMD	Transport/Internal
Source-Sink Mixing	SSM	Transport/External
Mass Source Loading	SRC	Transport/External
Constant Concentration	CNC	Transport/External
Model Observations	OBS	Output
Output Control	OC	Output

Transport Equation

$$\underbrace{\frac{\partial\left(S_w\theta C\right)}{\partial t}}_{STO} = \underbrace{-\nabla\cdot\left(\mathbf{q}C\right)}_{ADV} \underbrace{+\nabla\cdot\left(S_w\theta\mathbf{D}\nabla C\right)}_{DSP} \underbrace{+q_s'C_s + q_e'C}_{SSM} \underbrace{-\lambda_1\theta S_w C - \gamma_1\theta S_w}_{DCY}$$

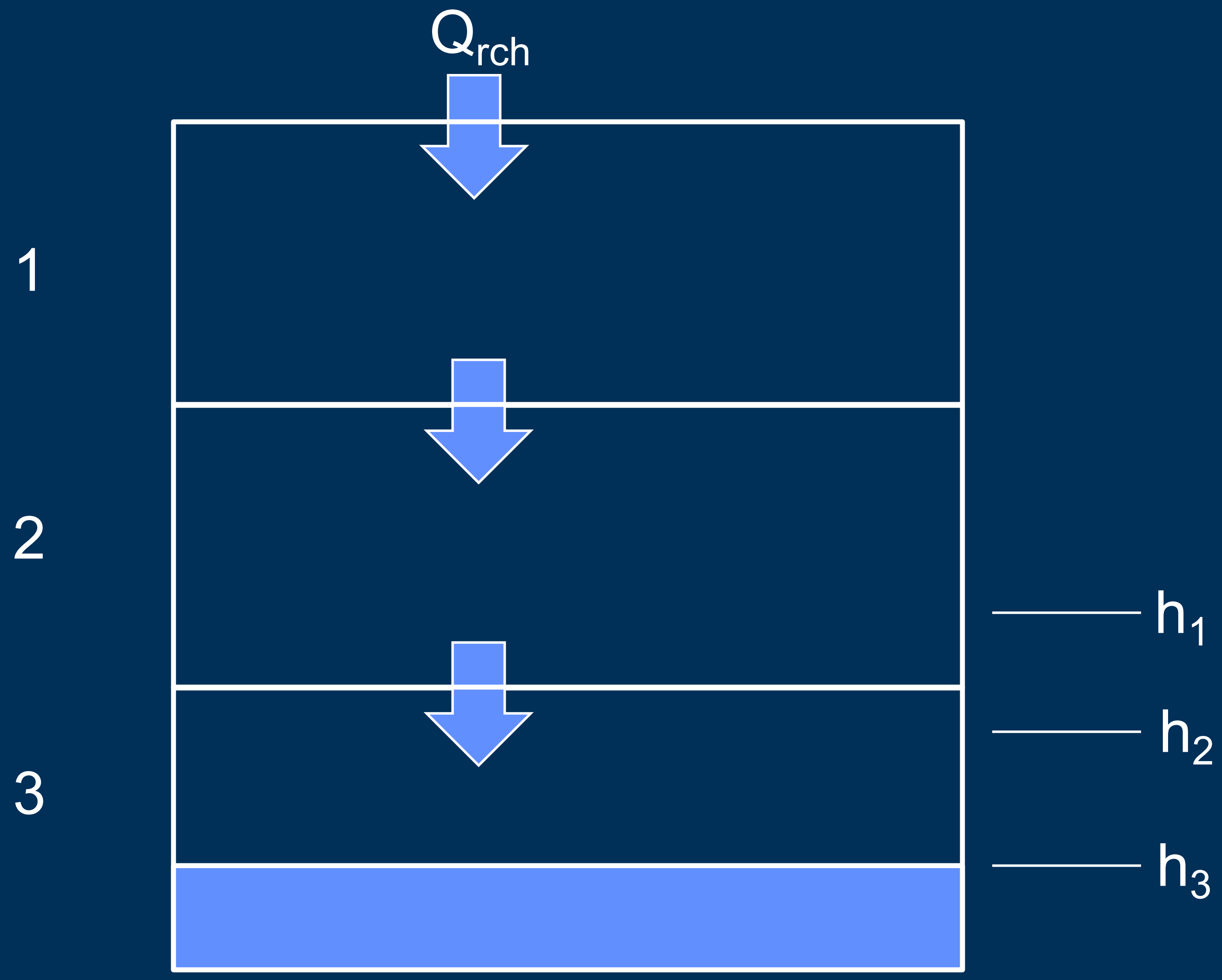
$$\underbrace{-f_m\rho_b\frac{\partial\left(S_w\overline{C}\right)}{\partial t} - \lambda_2\rho_b\overline{C} - \gamma_2\rho_b}_{SRB} \underbrace{-\zeta\left(C - C_{im}\right)}_{IMD} \underbrace{+M_s}_{SRC}.$$

USGS

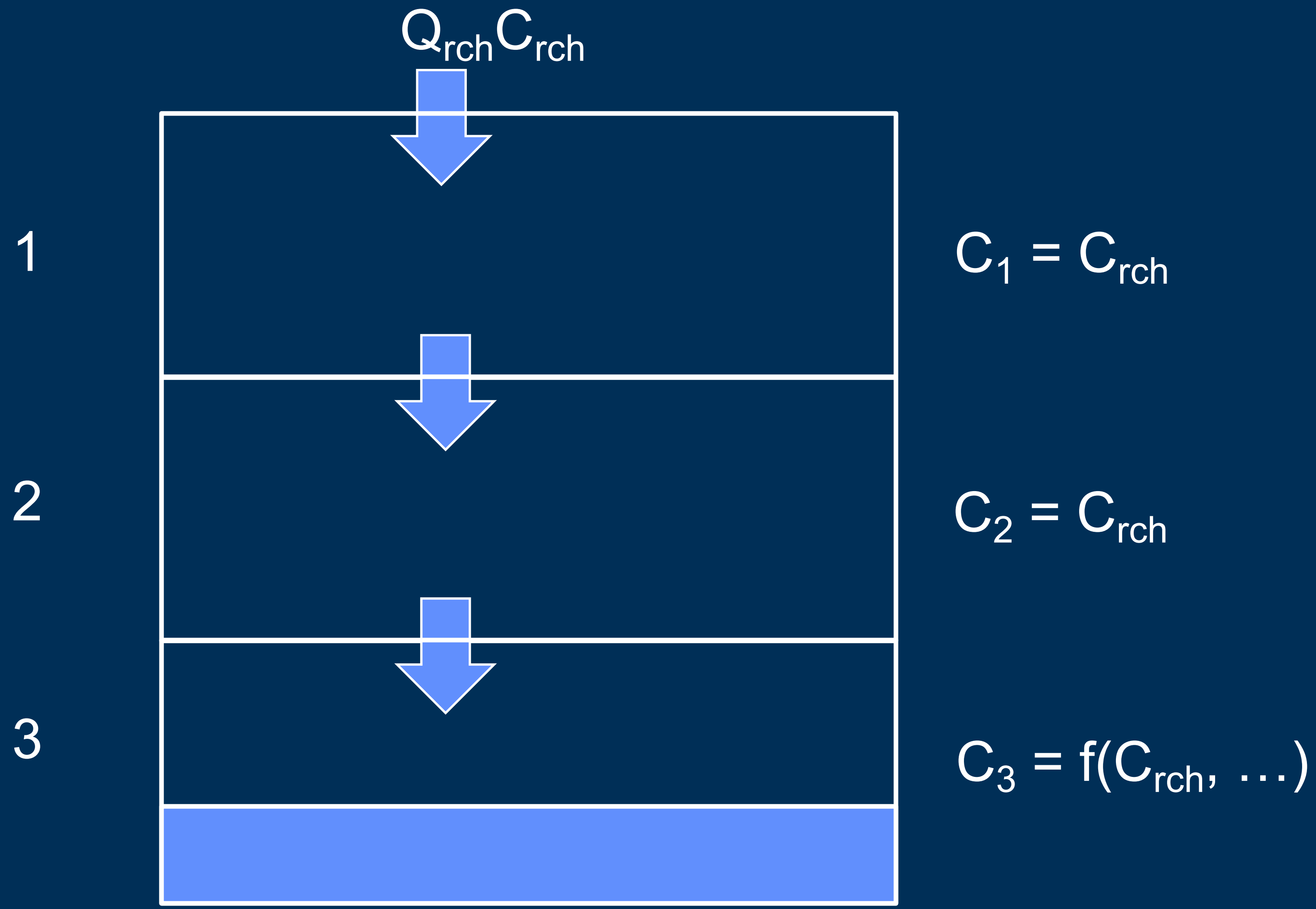
Limitations

- Flow and transport grids must be identical
- Time step lengths are specified by the user in the TDIS package
- No particle methods
- Version 1:
  - No transport across different model grids
  - Cannot run independently (must run with GWF6 in a simulation)
  - Single species, but can specify multiple models

Newton Formulation for Dry Cells

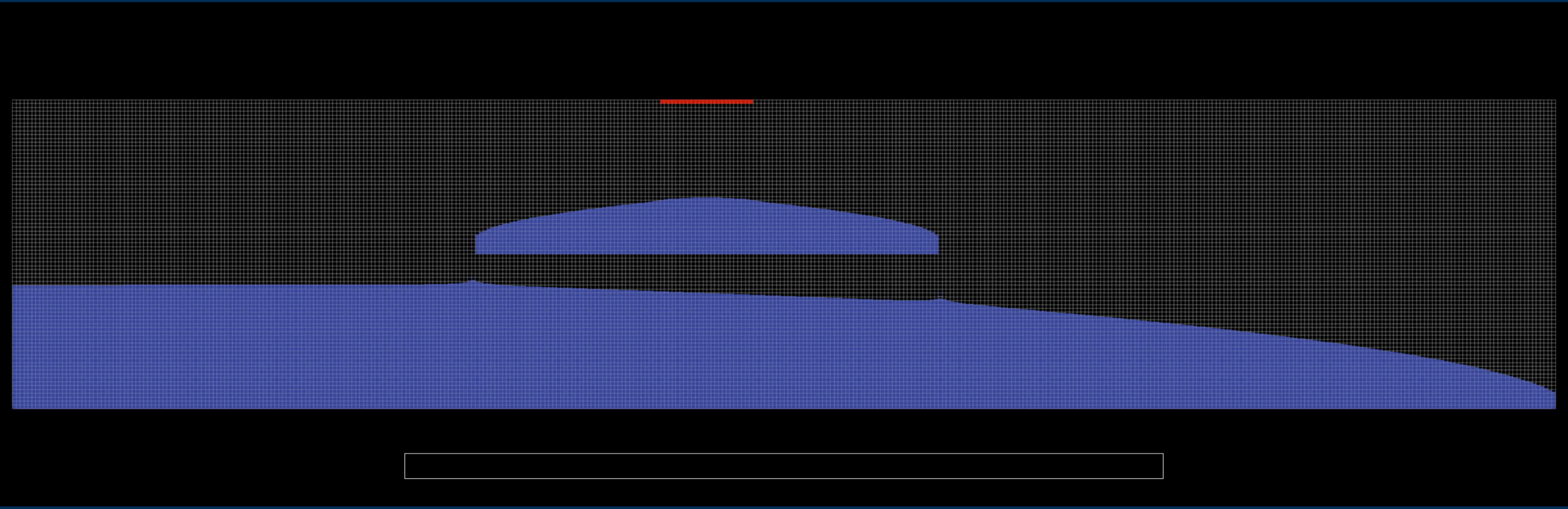


Transport Formulation for Dry Cells



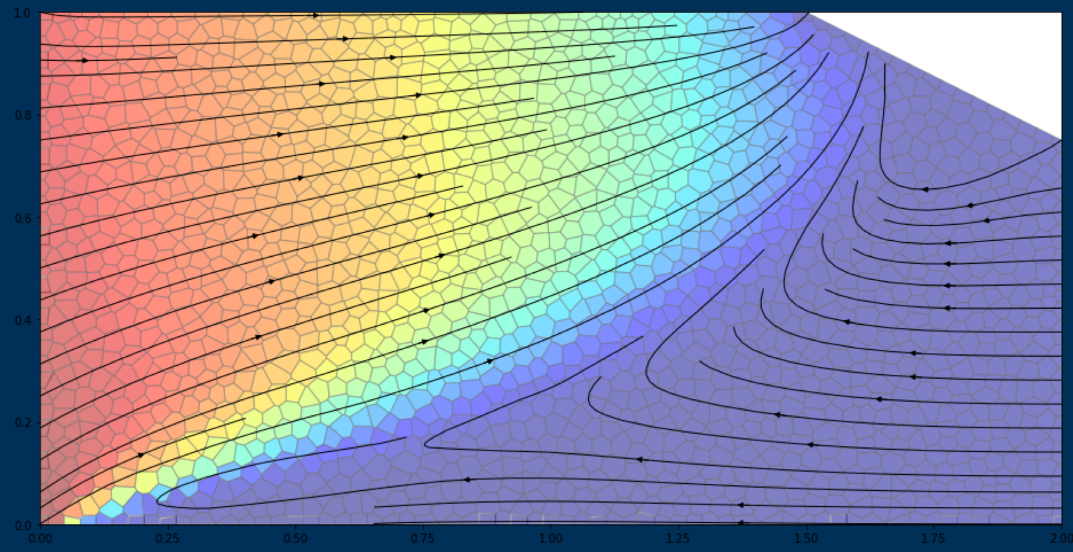
Keating Example

- Transport through dry cells



SEAWAT Capabilities

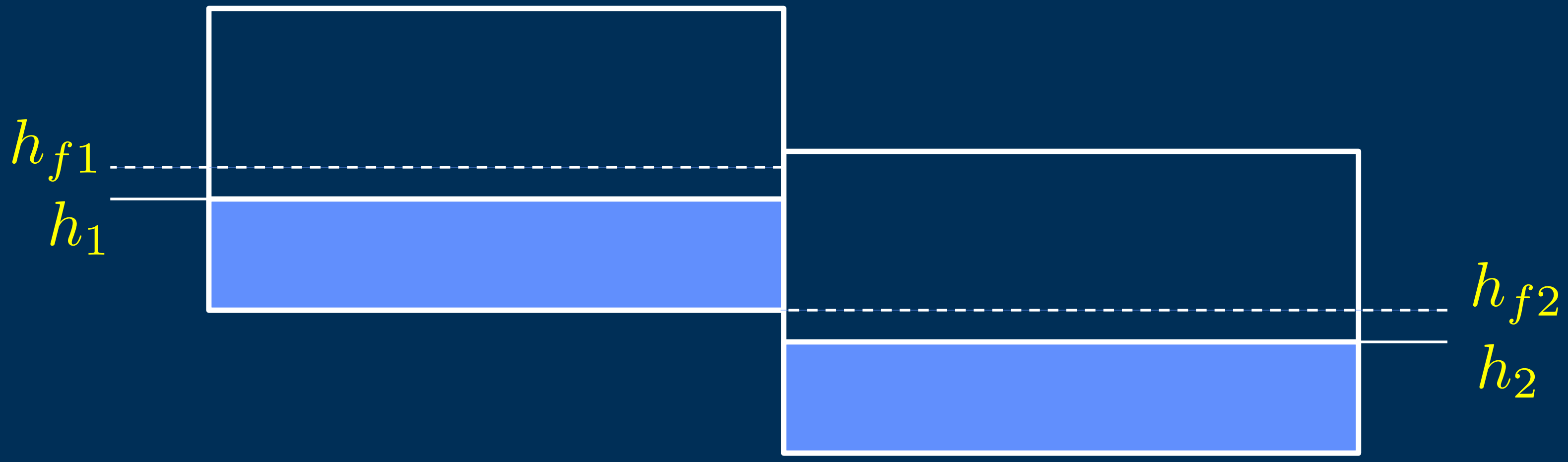
- Simulated concentrations can be used to calculate densities used by the GWF Buoyancy Package
- Flow and transport can be solved in a single matrix
- Compatible with unstructured grids and the Newton flow formulation



SEAWAT Freshwater Head Formulation

SEAWAT uses a freshwater head formulation

$$q = -K_f \left[\nabla h_f + \left(\frac{\rho}{\rho_0} - 1 \right) \nabla z \right]$$

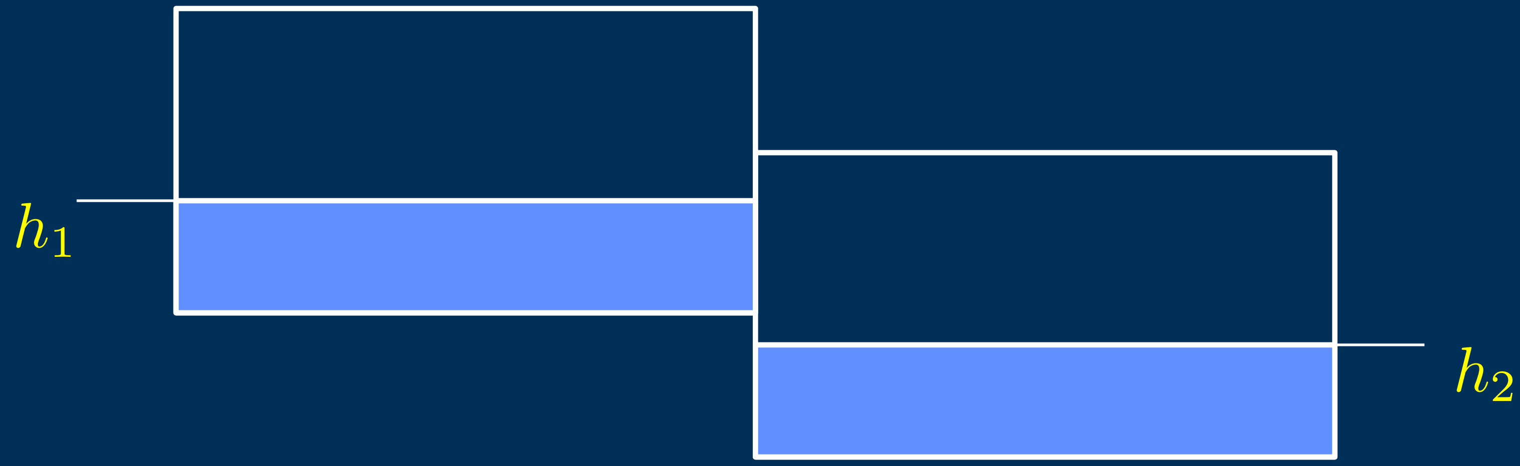


Problem: freshwater head is
not the water table

Alternative Hydraulic Head Formulation

What about a hydraulic head formulation?

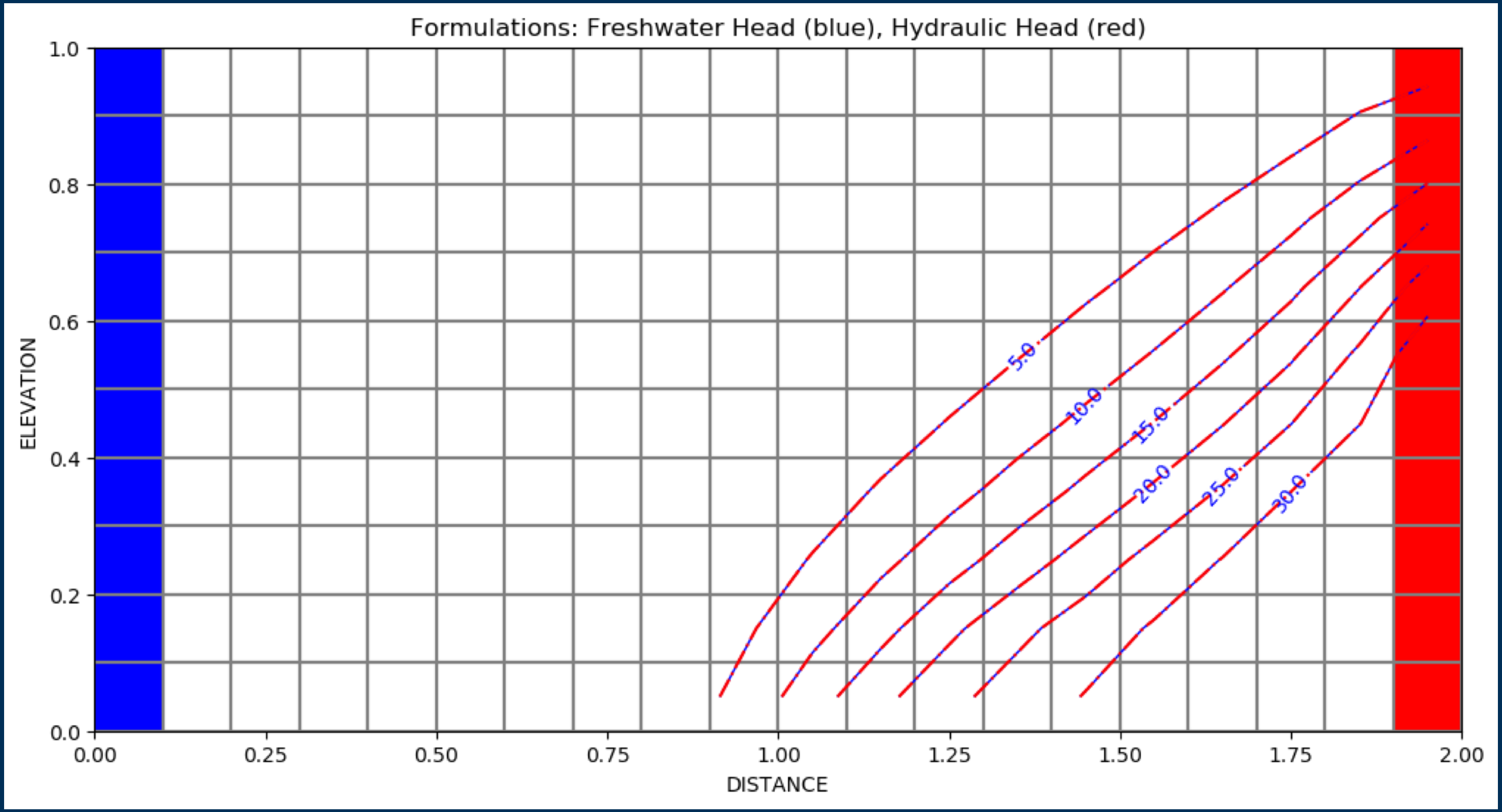
$$q = -K_f\left[\frac{\rho}{\rho_0}\nabla h + h\nabla\frac{\rho}{\rho_0} - z\nabla\frac{\rho}{\rho_0}\right]$$



Head is the dependent variable and the water table

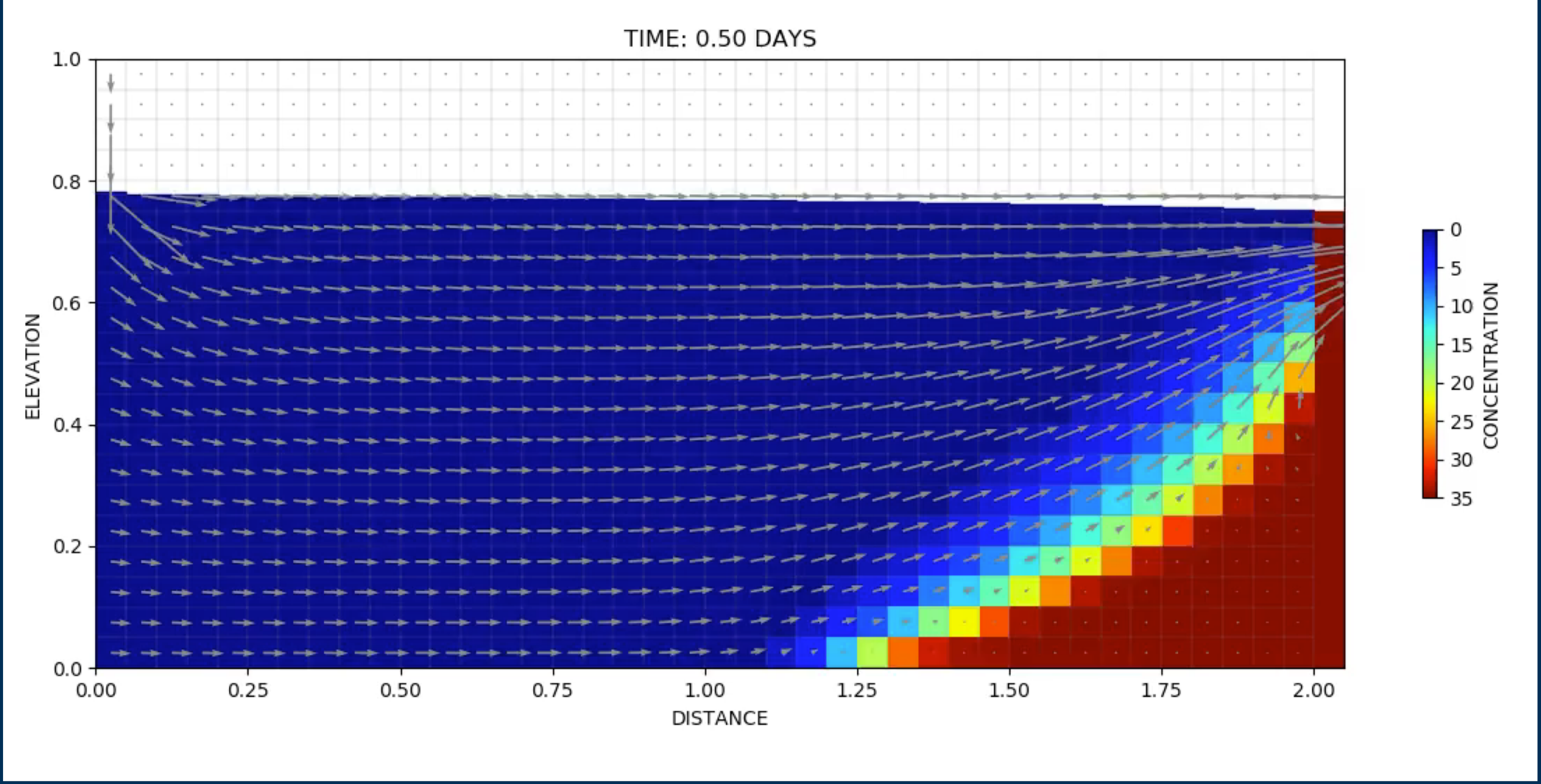
USGS

Comparison for Henry Problem



USGS

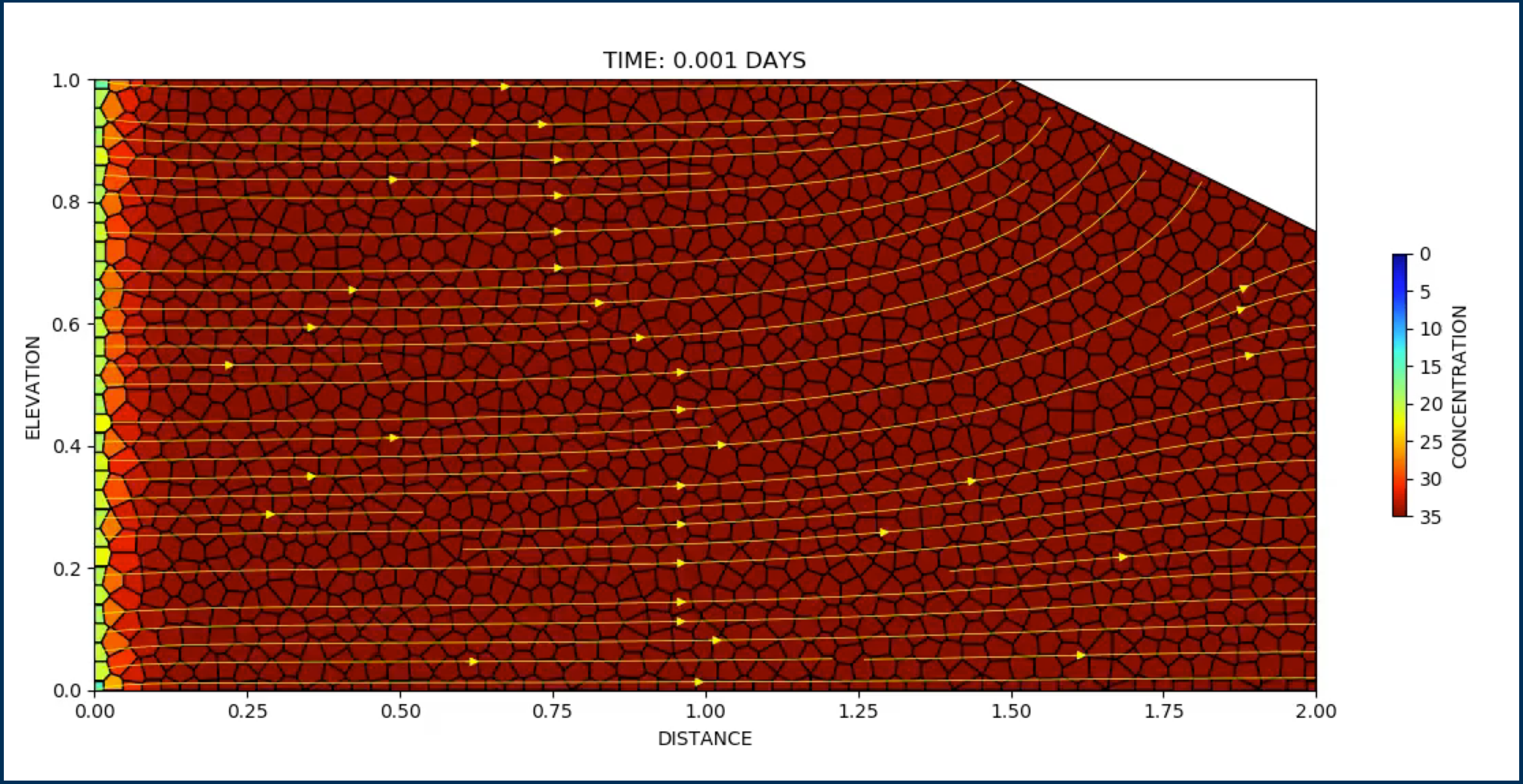
MODFLOW 6 Animation



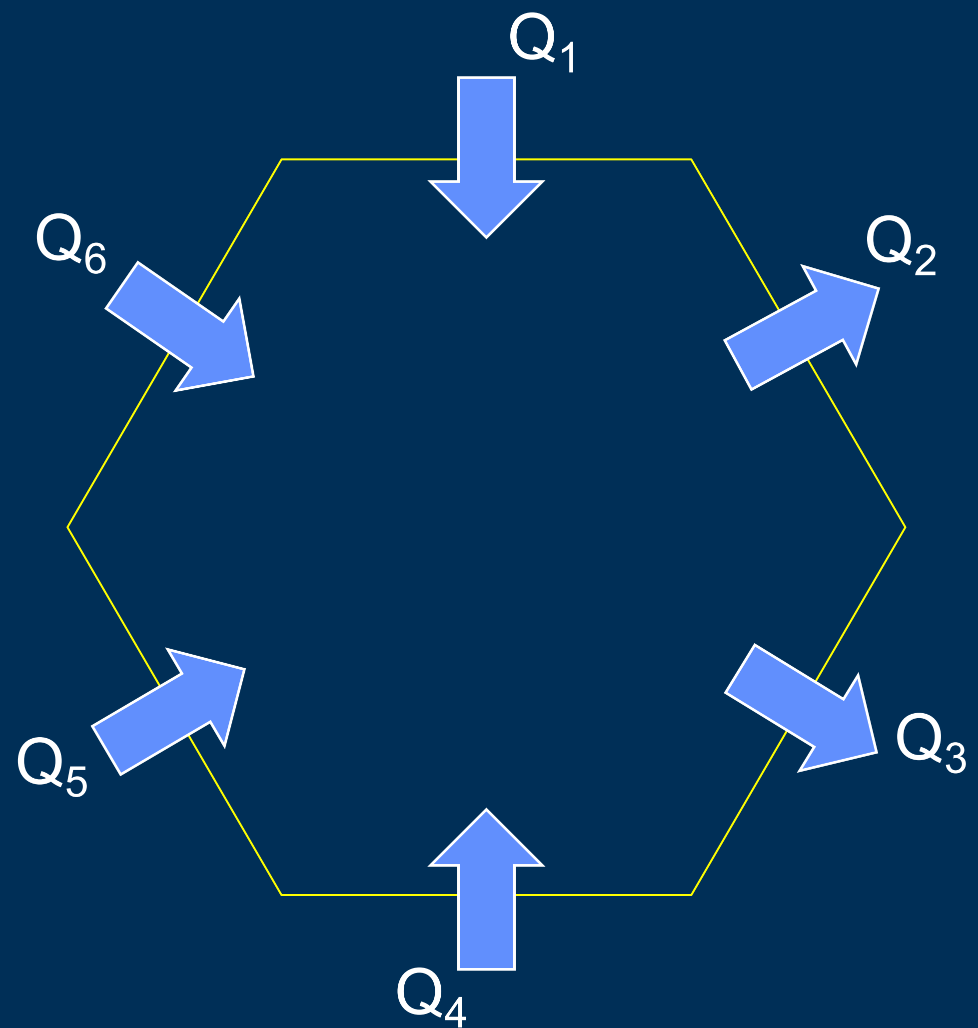
USGS

Ongoing Work

- **Unstructured cross sections**

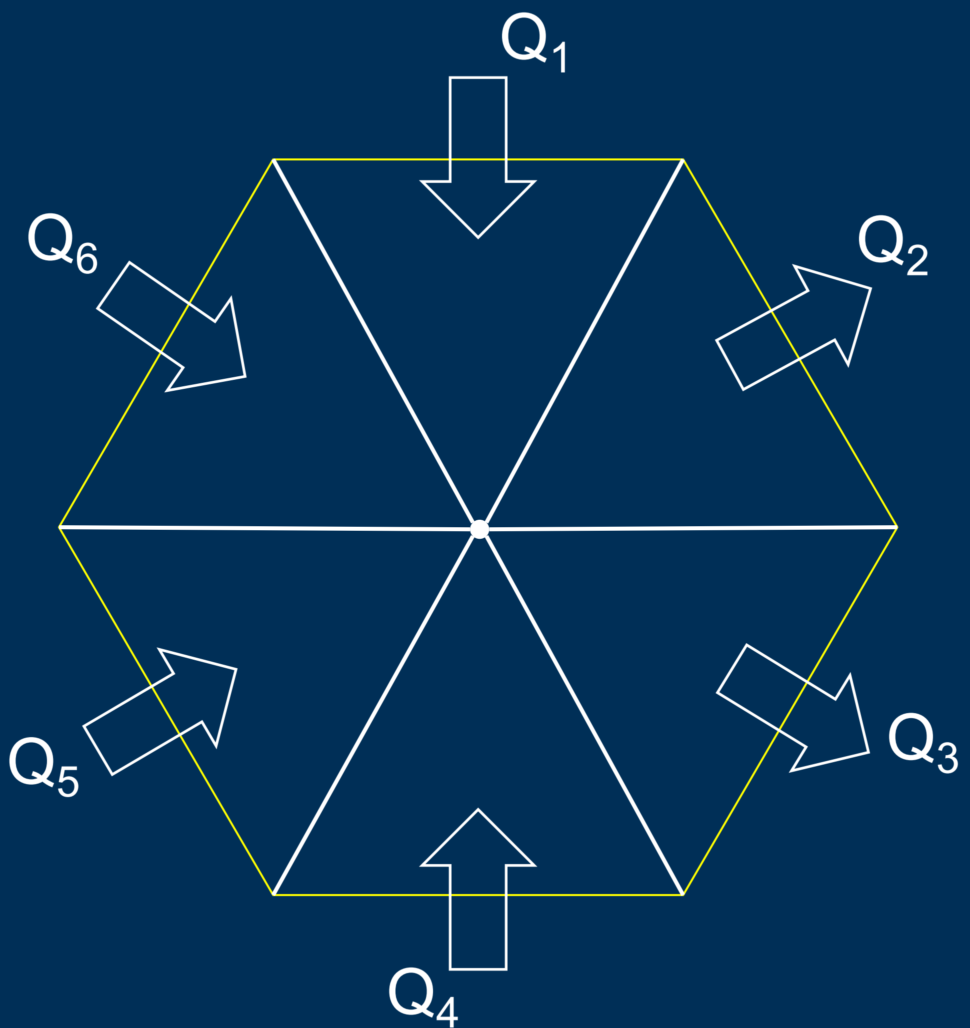


Ongoing Work: unstructured grid particle tracking



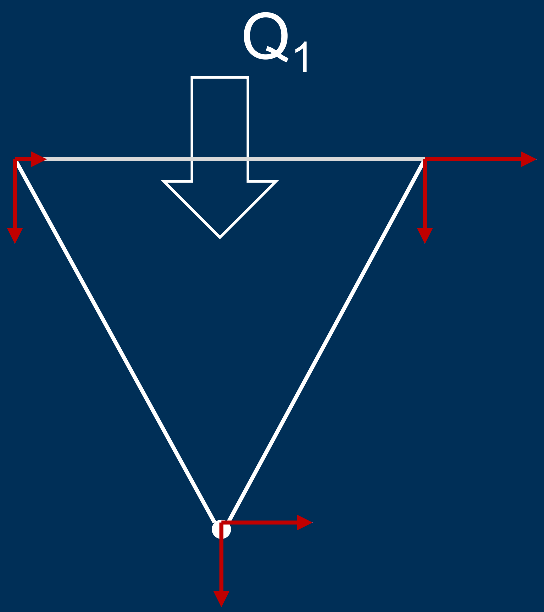
USGS

Unstructured Grid Particle Tracking



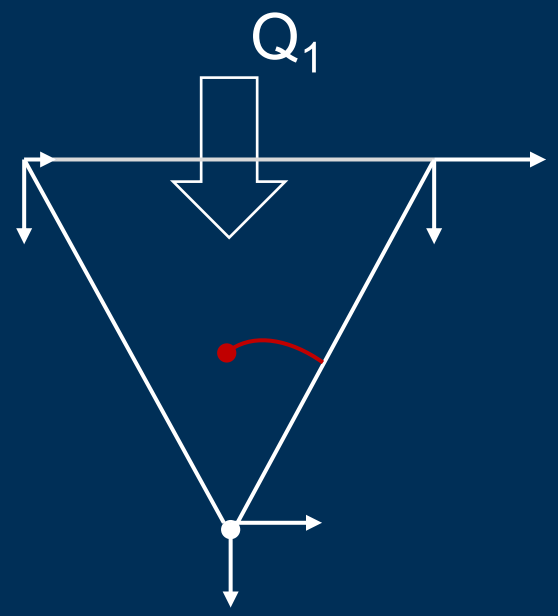
USGS

Calculate Corner Velocities



USGS

Solve Exit Point Semi-Analytically



USGS

Ongoing Work

- **Particle Tracking**