The Hunt for PFAS: Modeling the Shenanigans of Groundwater-Surface Water Interactions

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Session: C6. Evaluating Surface Water/Groundwater Interactions: Innovative Monitoring Approaches and Modeling Applications

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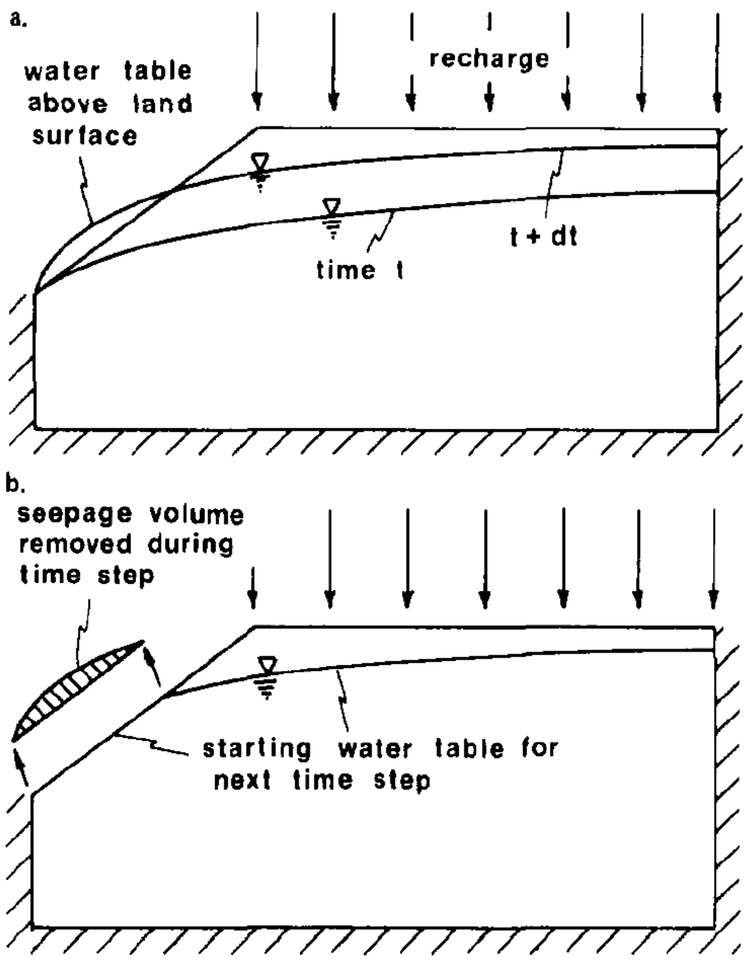
Groundwater/Surface Water Interactions

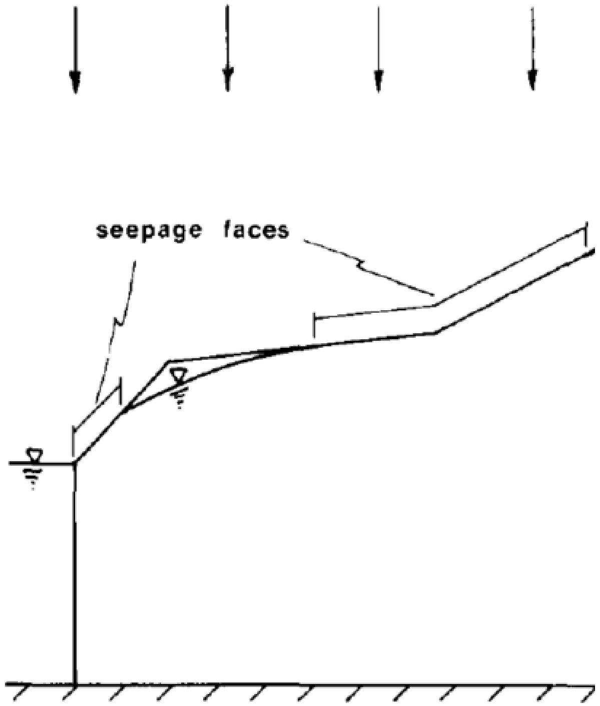
- Are simple in concept but are very complex in natural systems
- In the early 1980's interactions were approximated as a uncoupled transient process O'Loughlin (1981).
  - Water levels would be computed above the land surface between time steps and the water above the land surface was interpreted as the "seepage volume" or groundwater to surface water flow for that period
  - The assumption was, if dt was sufficiently small, this was a reasonable approach
- It was a start but it didn't work very well



Potter and Gburek, 1987

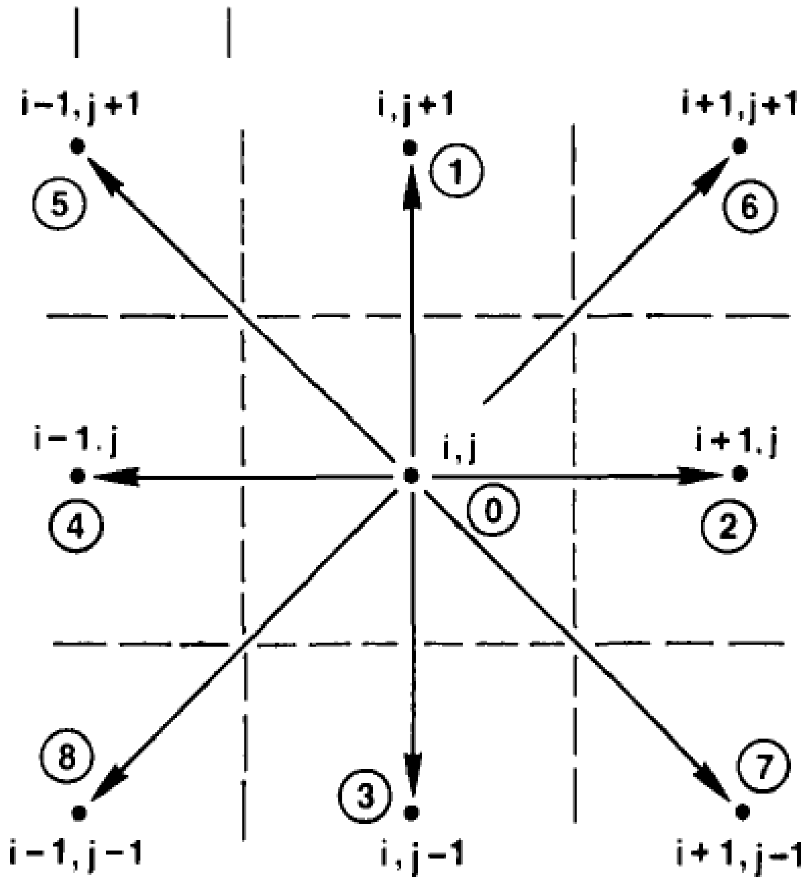
Groundwater/Surface Water Interactions

- We developed a generalized coupled approach in 1987 and incorporated it into PLASM.
- It addressed the limitations that came before.
  - It could solve SS problems
  - Mass conservative
  - Converged to tight convergences
- The basic approach was similar to a "Drain Cell" which came later.
- The element missed was surface translation and re-infiltration



ig. 4. Watershed cross section with two

Potter and Gburek, 1987

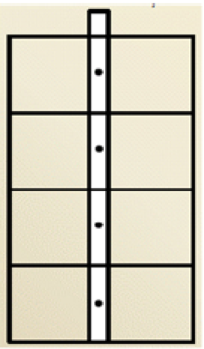


. Schematic for overland flow routing scheme.

Connected Linear Networks (CLN) Generalized BC that promotes creativity . . .

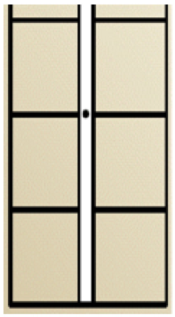
- Allow water & contaminants to move independently while also interacting with the surrounding porous media
- Wells / Drains / Streams / Conduits / . . . .
- MODFLOW-USG simulates flow and transport in groundwater, CLN, and the exchanges between groundwater and CLNs

Well
(Multiple CLN Cells)



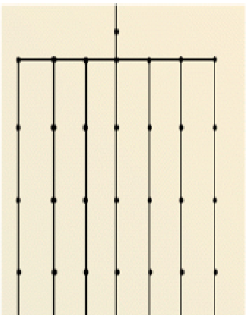
Good for small diameter wells

Well
(1 CLN Cell) for multiple GWF cells

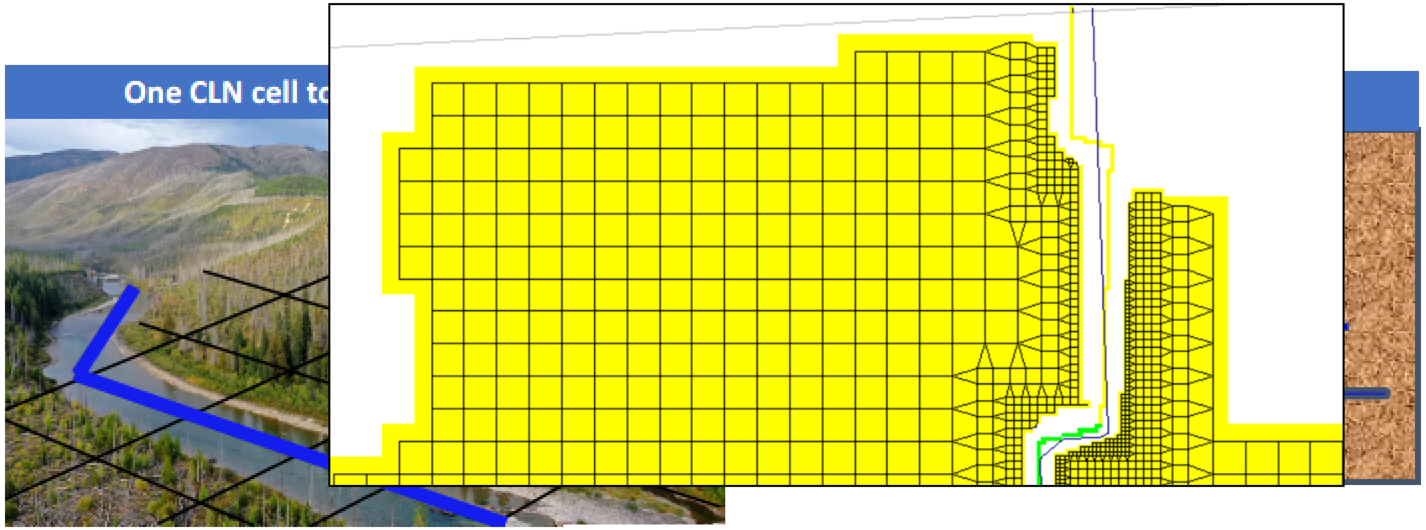


Good for large diameter wells where well is in equilibrium

Tile Drains
(Multiple CLN Cells)



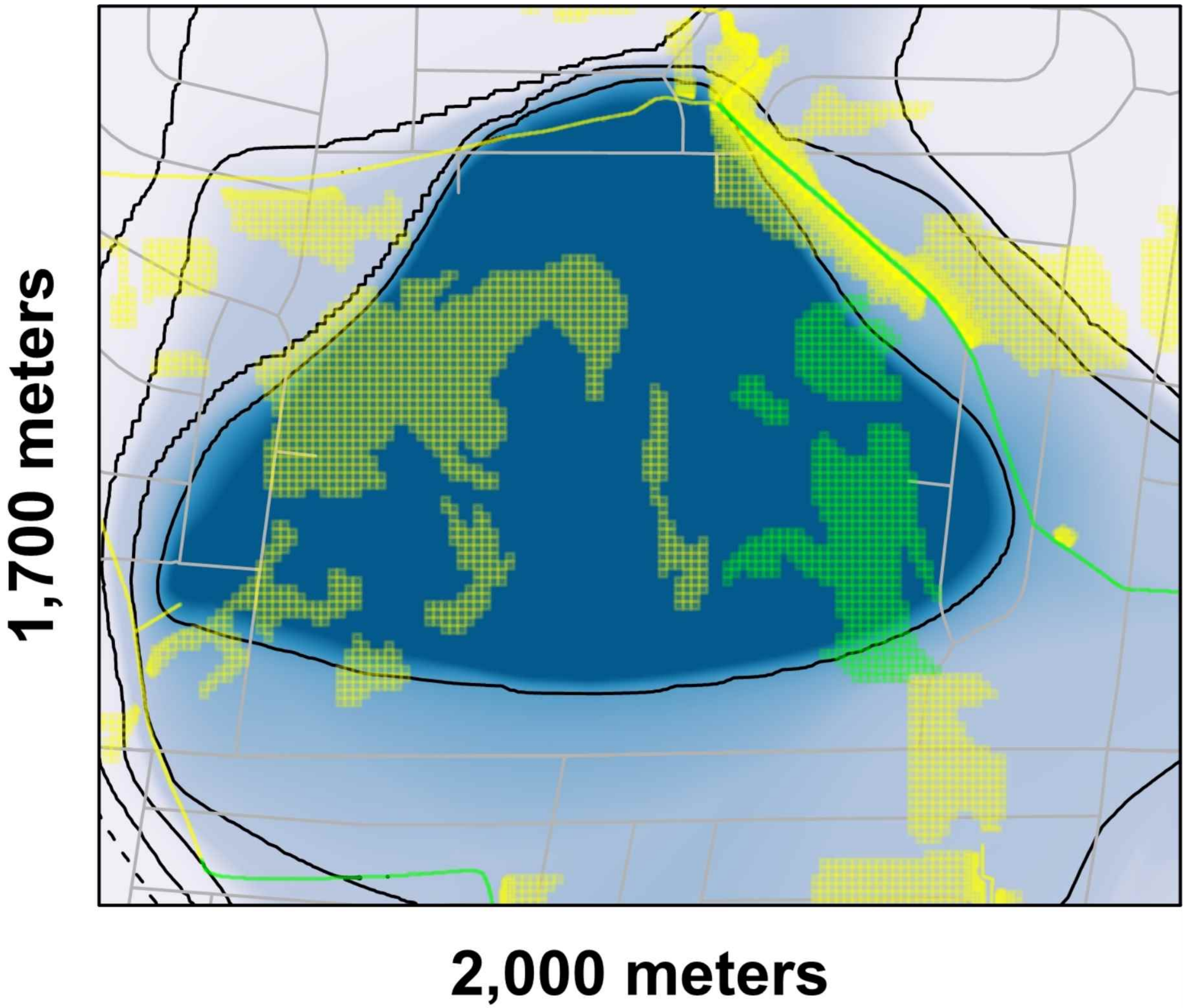
Good for connecting multiple adits to one drain/pumping location



Example CLN

Example Application - CSM

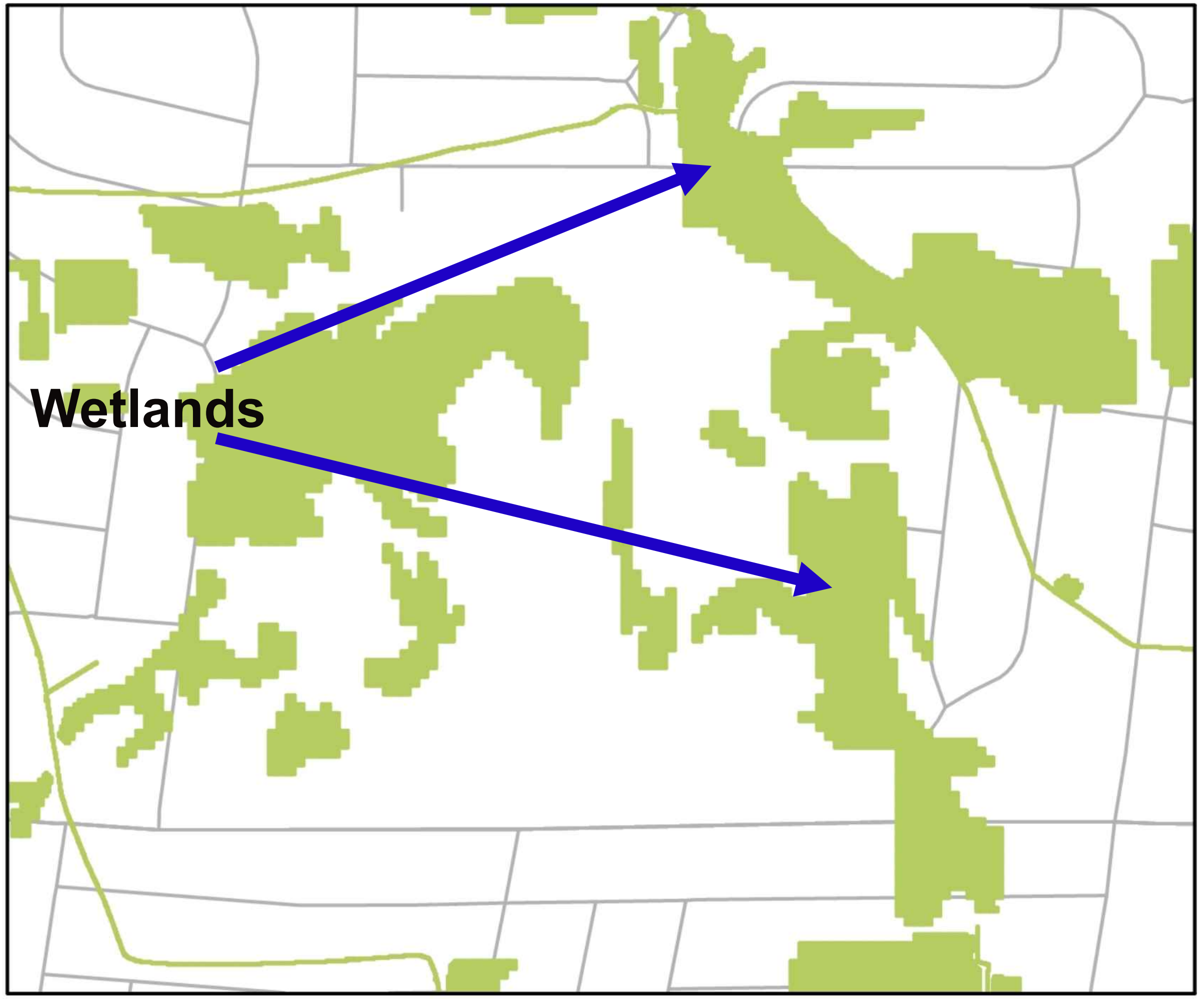
- Large PFAS plume in North America
- Mature Plume
- The area depicted is the center of mass covering approximately 2 km^2
- Shallow water table
- Aquifer is unconsolidated alluvial sediments



Example Application - SW-GW interactions are important

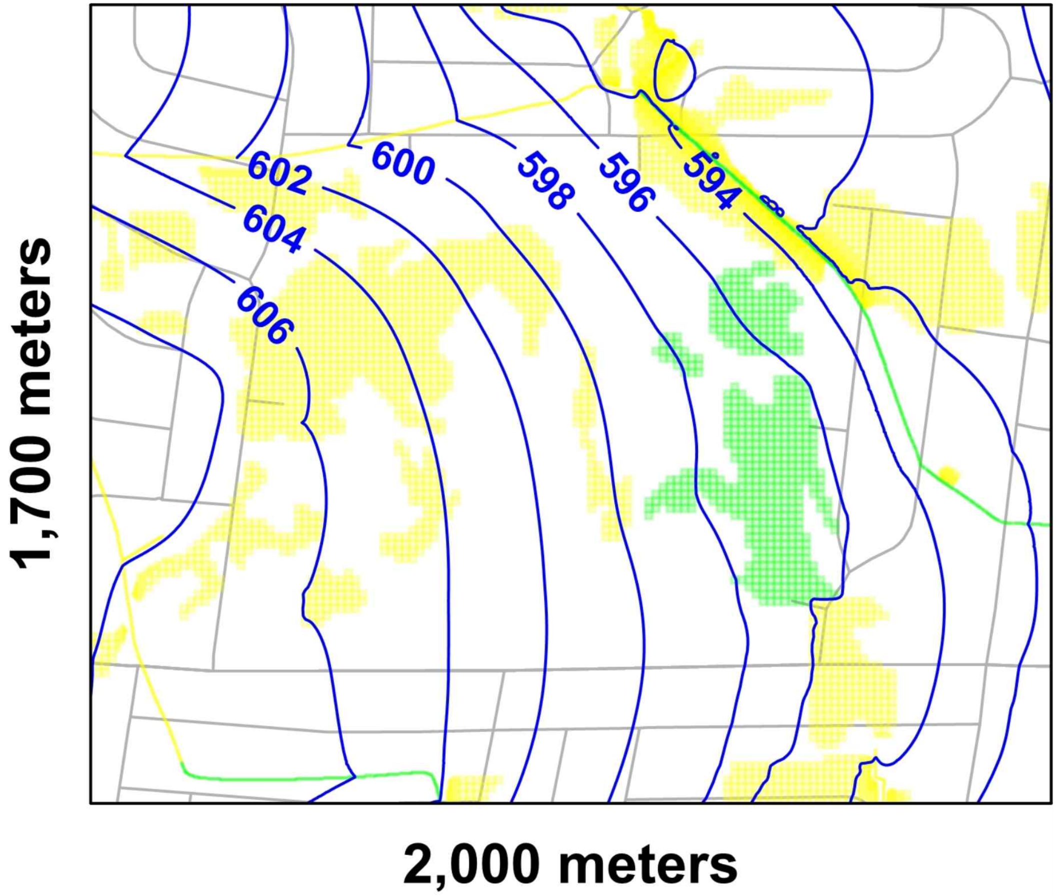
- Interconnected wetlands and streams throughout the plume area
- Shallow water table
- The initial approach incorporated Drain Cells

1,700 meters

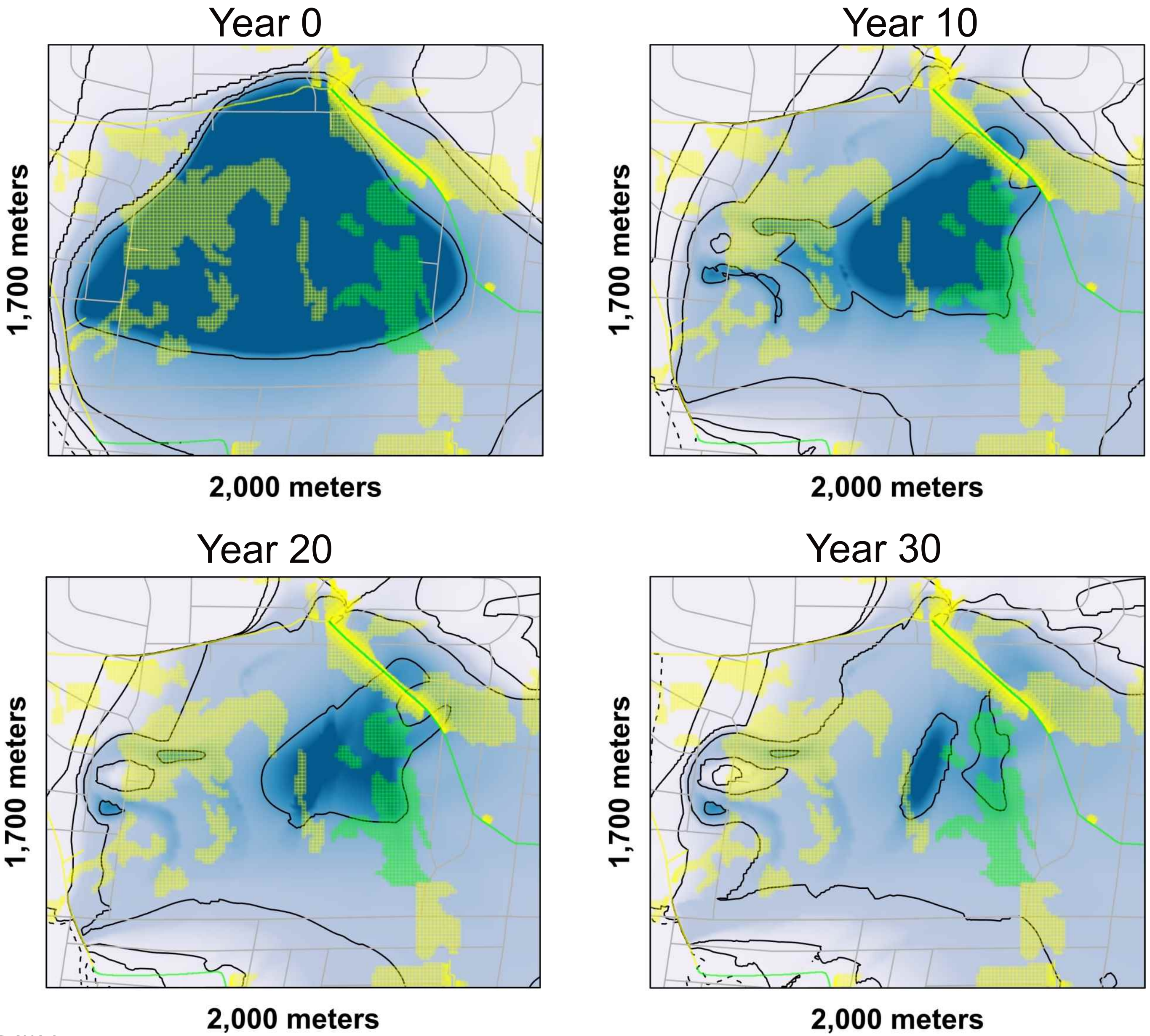


2,000 meters

Flow Calibration with Drains and River Cells



Groundwater Plumes over Time with drains and river cells

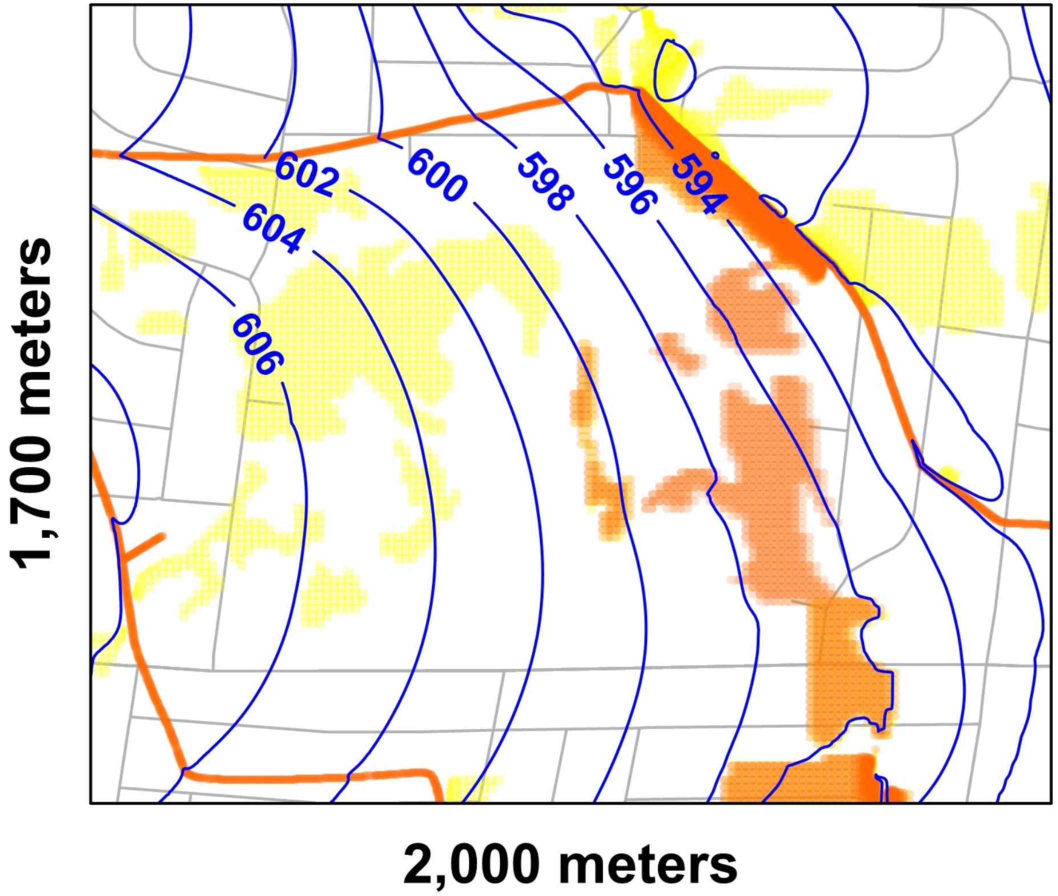


Does this Make Sense?

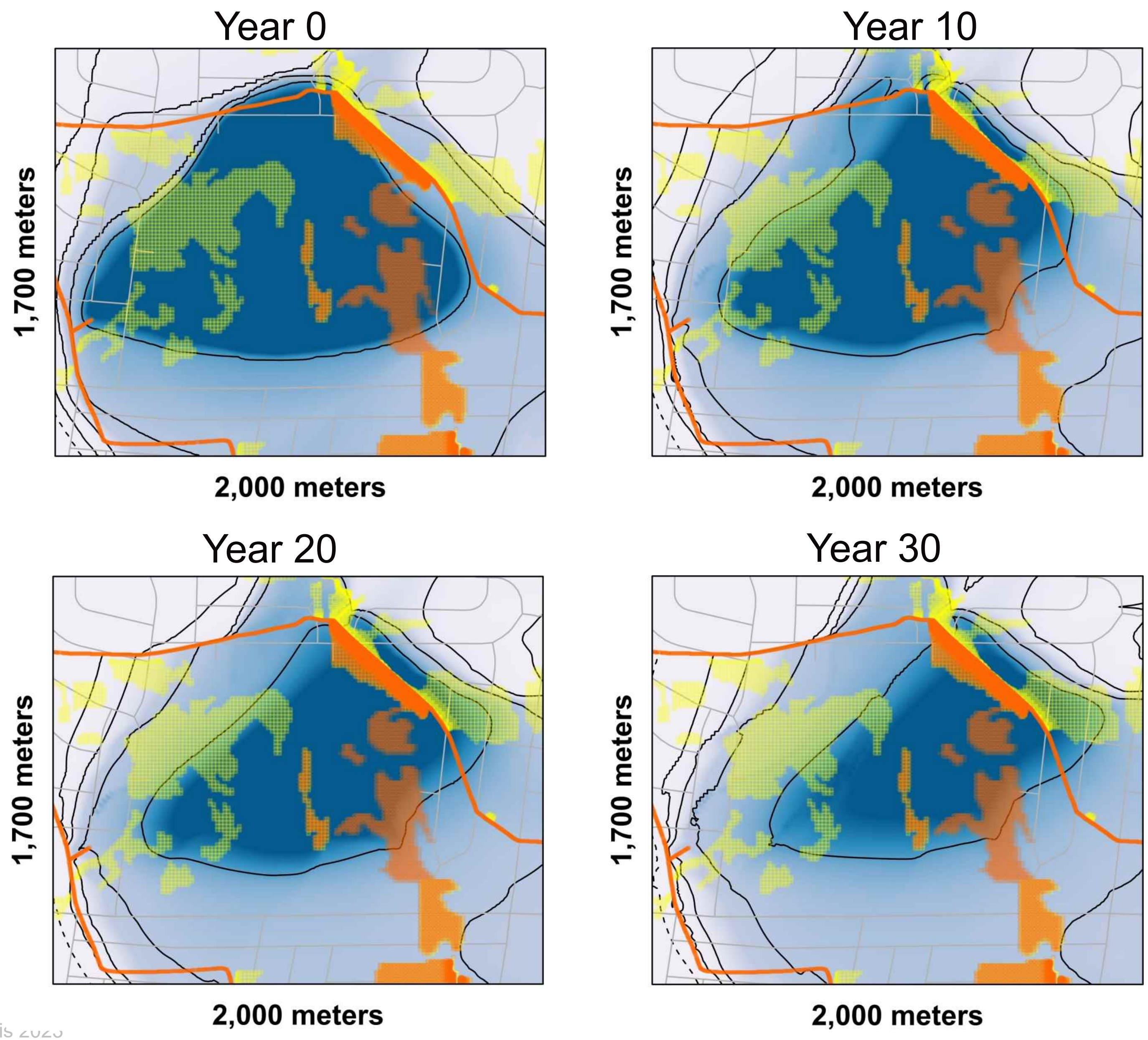
Does this make sense?
Could we expect this plume attenuate?

1. The sources in the model were wrong?
   - Leaching from the vadose zone?
2. Precursors/unidentified sources?
   - C8s were being generated through transformations?
3. Is the modeling flawed?
   - GW Velocity too high – wrong K’s
   - Excess recharge diluting concentrations?
   - Sorption/retardation mischaracterized?
   - Was Diffusion feeding the plume?
4. Are the boundary conditions wrong . . . . .

Flow Calibration with CLNs



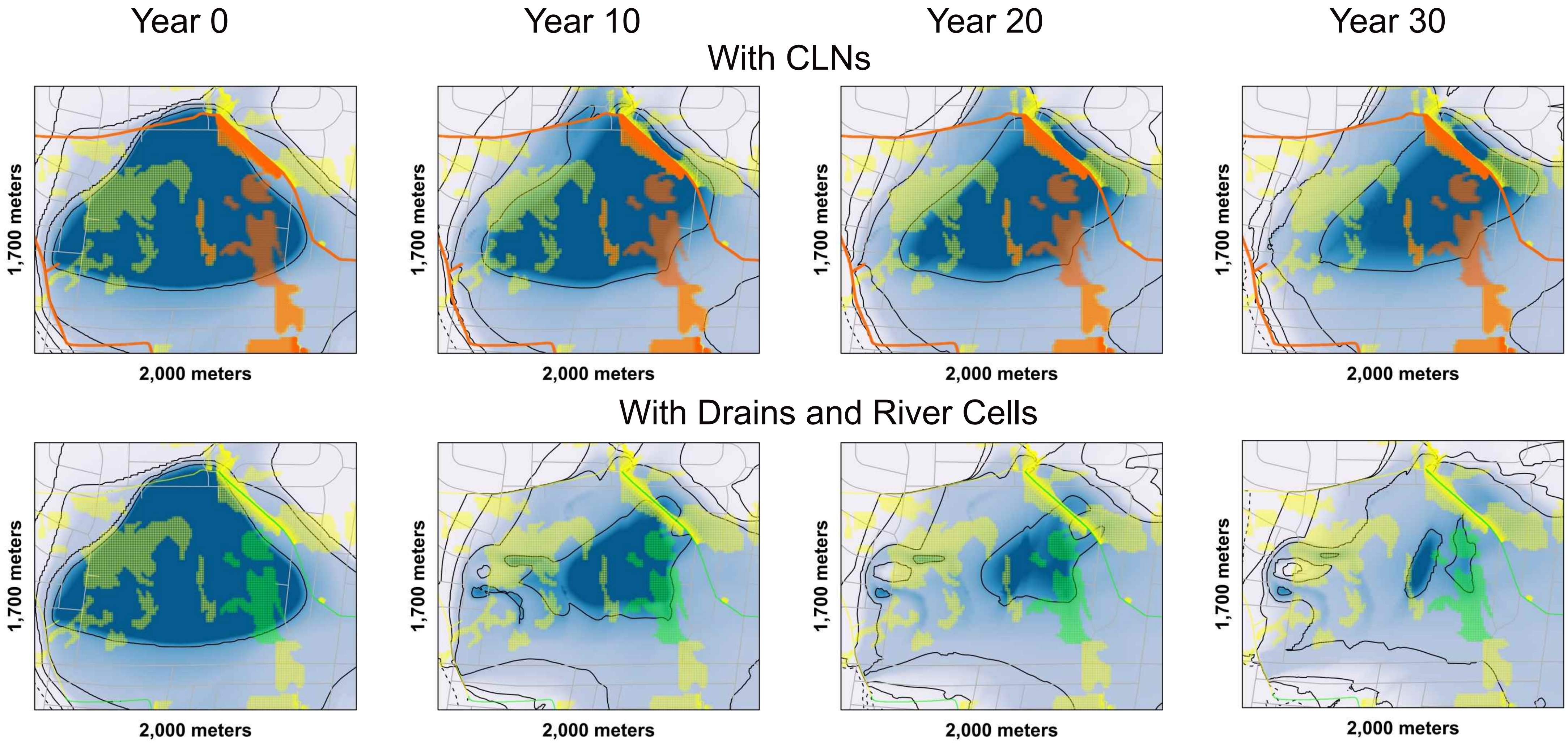
Groundwater Plumes over Time - CLNs



This simulation aligned with the conceptual site model

ARCADIS

Groundwater Plumes over Time



Water Balance

With Drains and River Cells

Boundary Condition	Simulated Inflows (cmd)	Simulated Outflows (cmd)
Constant Head	1.57	3,912.62
Wells	0.00	51.01
Drains	0.00	23,985.18
River	7,003.88	3,066.07
Recharge	24,009.25	0.00
Total	31,014.69	31,014.87

With CLNs

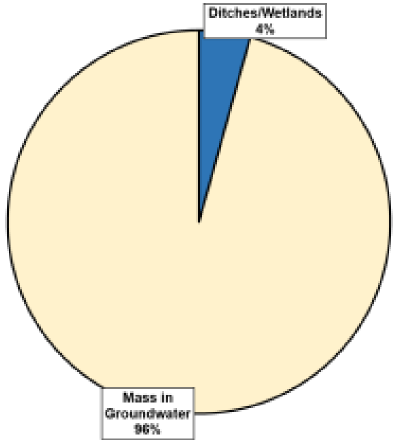
Boundary Condition	Simulated Inflows (cmd)	Simulated Outflows (cmd)
Constant Head	1.57	4,376.56
Wells	0.00	51.01
Drains	0.00	19,095.43
River	2,007.90	2,728.75
Recharge	24,009.25	0.00
Total	26,018.71	26,251.75

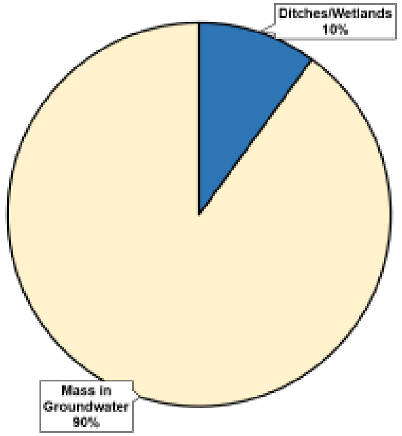
The drains were acting as wells – removing 5,000 m3/day of GW and mass

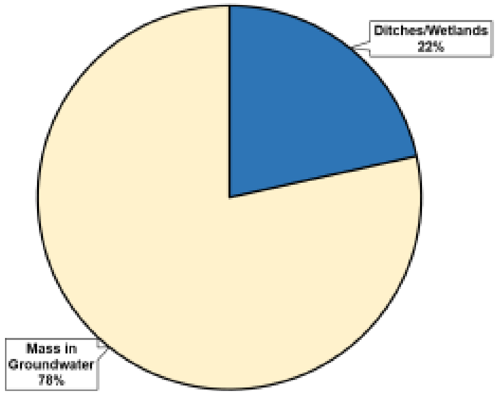
Groundwater Mass Removed

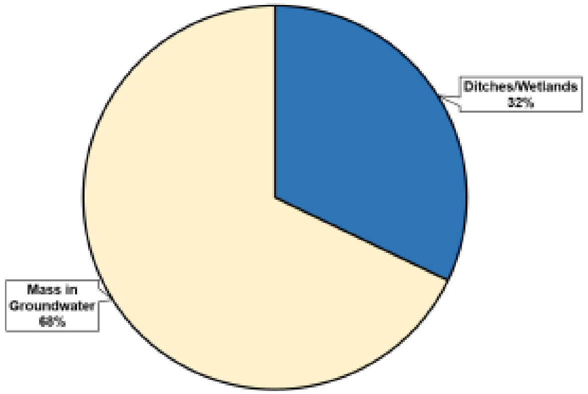
Year 5 | Year 10 | Year 20 | Year 30

With CLNs

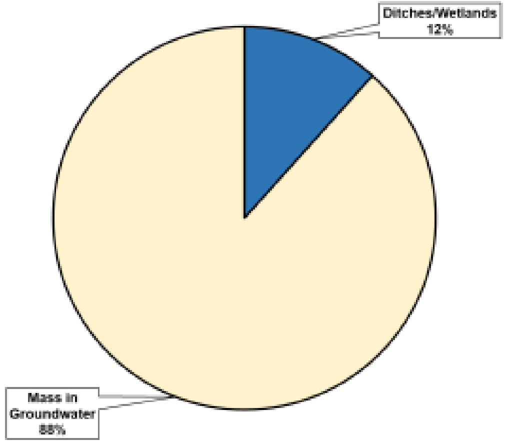


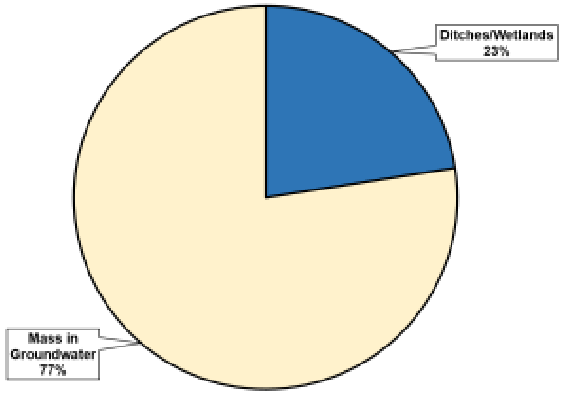


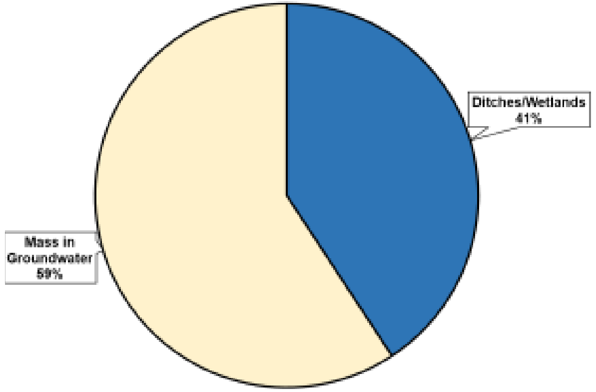


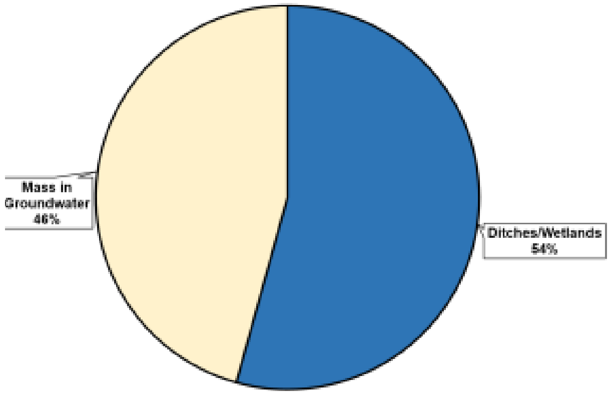


With Drains and River Cells









Conclusions

- Given the low ng/L targets for PFAS – we should carefully consider how we incorporate boundary conditions
- Existing models should be critically reviewed – remedies may need to be re-assessed
- We may have inadvertently made a lot mistakes in the past
- CLNs provide a more realistic representation of groundwater/surface water interactions

Thank you

About Arcadis

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€4 Billion
in revenues in 2022