A basin-scale groundwater flow model in the Columbia Plateau (Pacific Northwest, USA); insights for management of fractured aquifer-types

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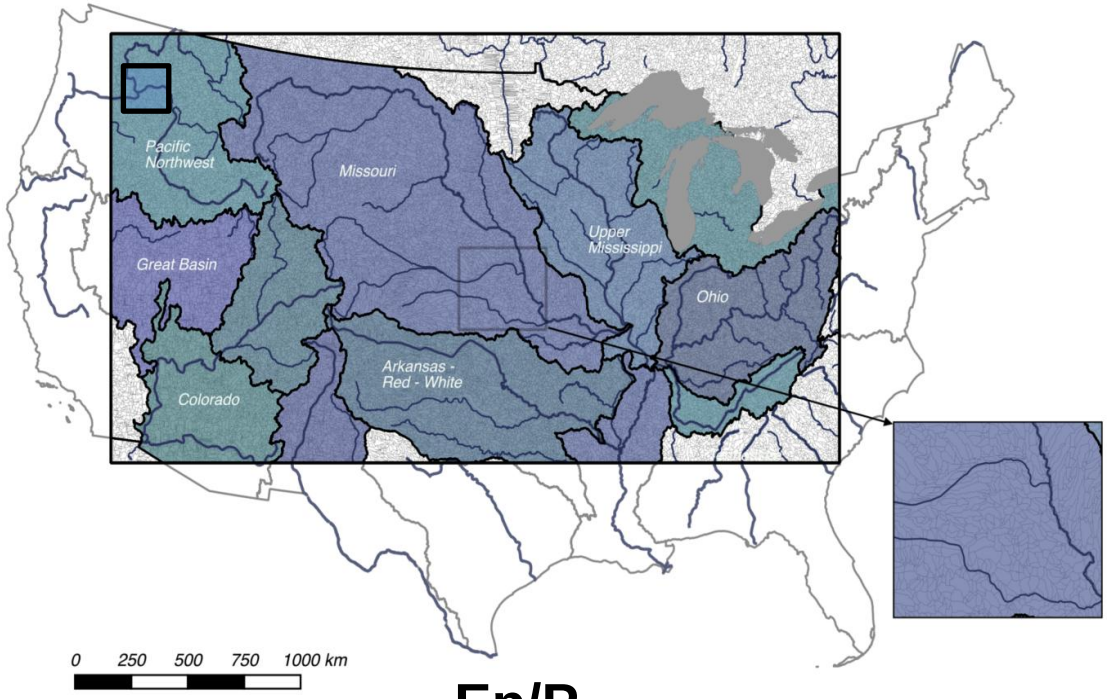
Washington State University

Project background

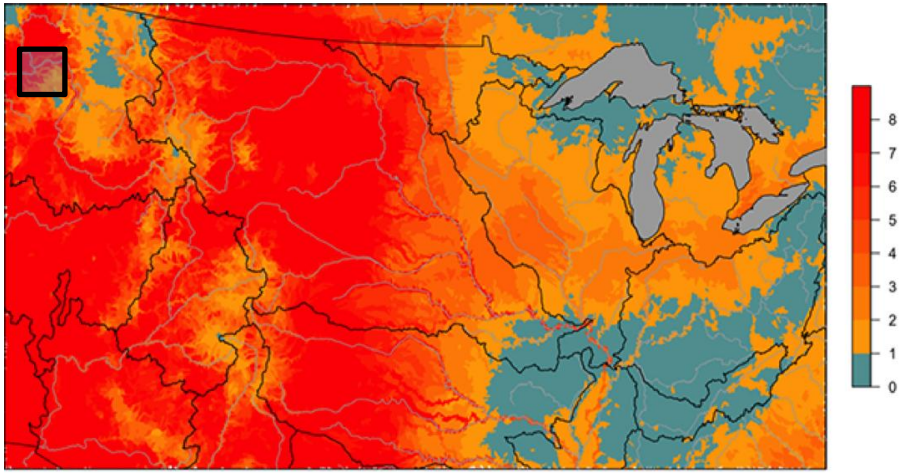


- Palouse (USA)
- Water abstraction worldwide problem in semi-arid and arid areas
- Fractured and vulnerable aquifer to contamination

→ Necessary to protect the groundwater resource

Ep/P

Arid ← → **Wet**

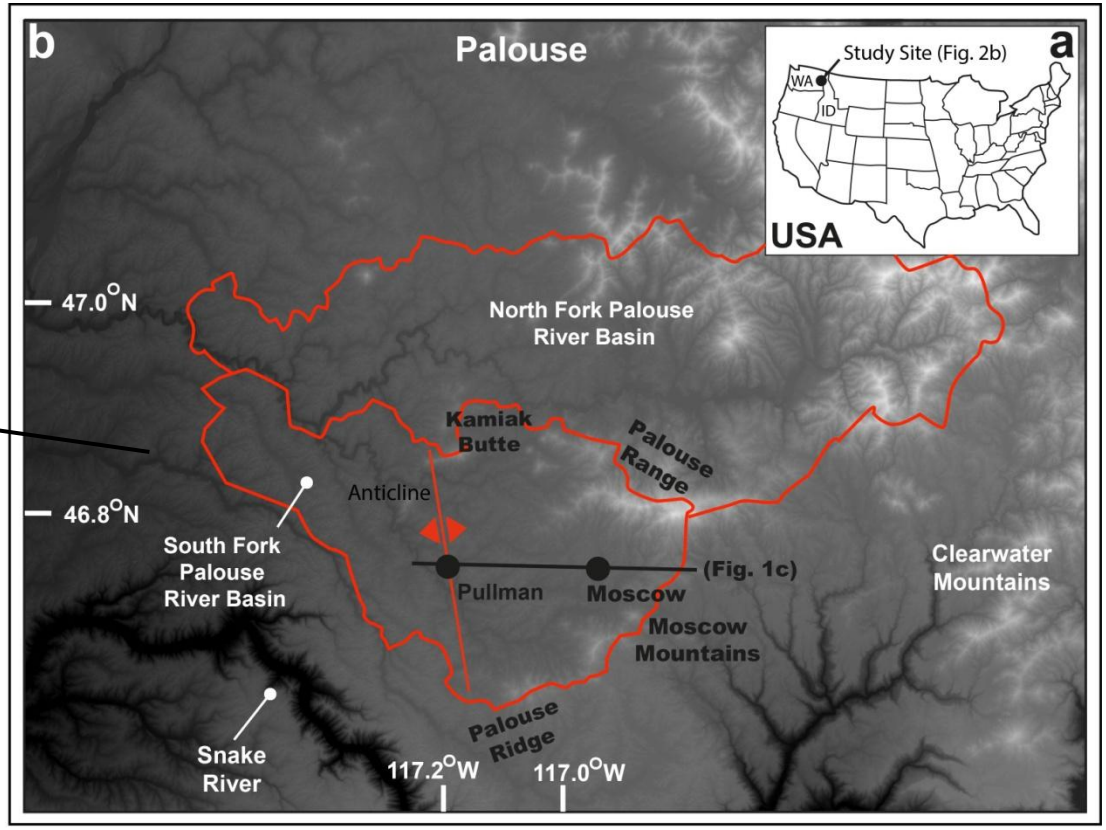


- Aridity index in the United States of America
- Condon and Maxwell 2017 *HESS*

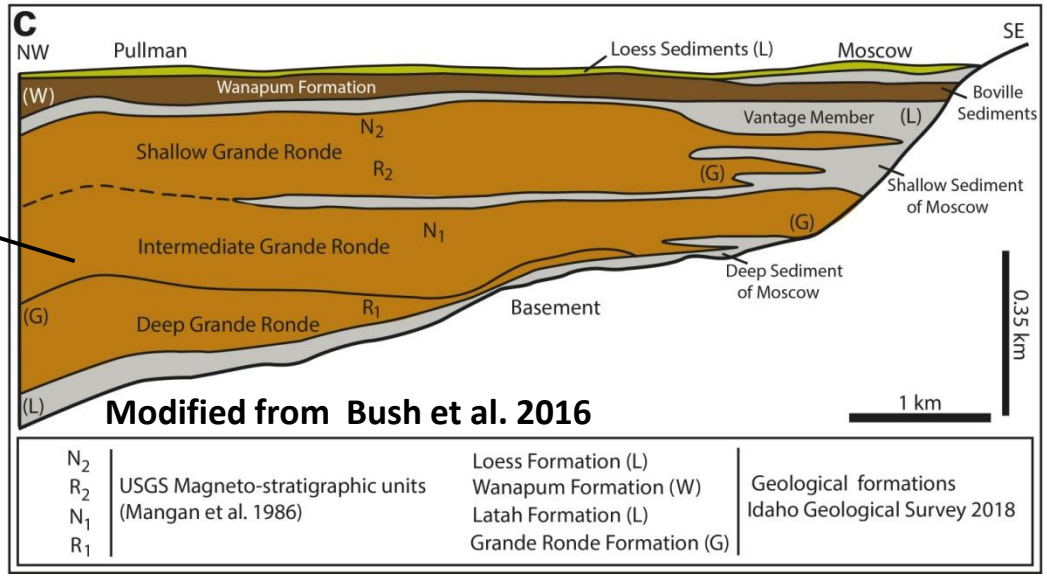
Study Area

Watershed and Polygon Boundary

- **MODFLOW NWT Steady State Flow Model**
- **MODPATH**



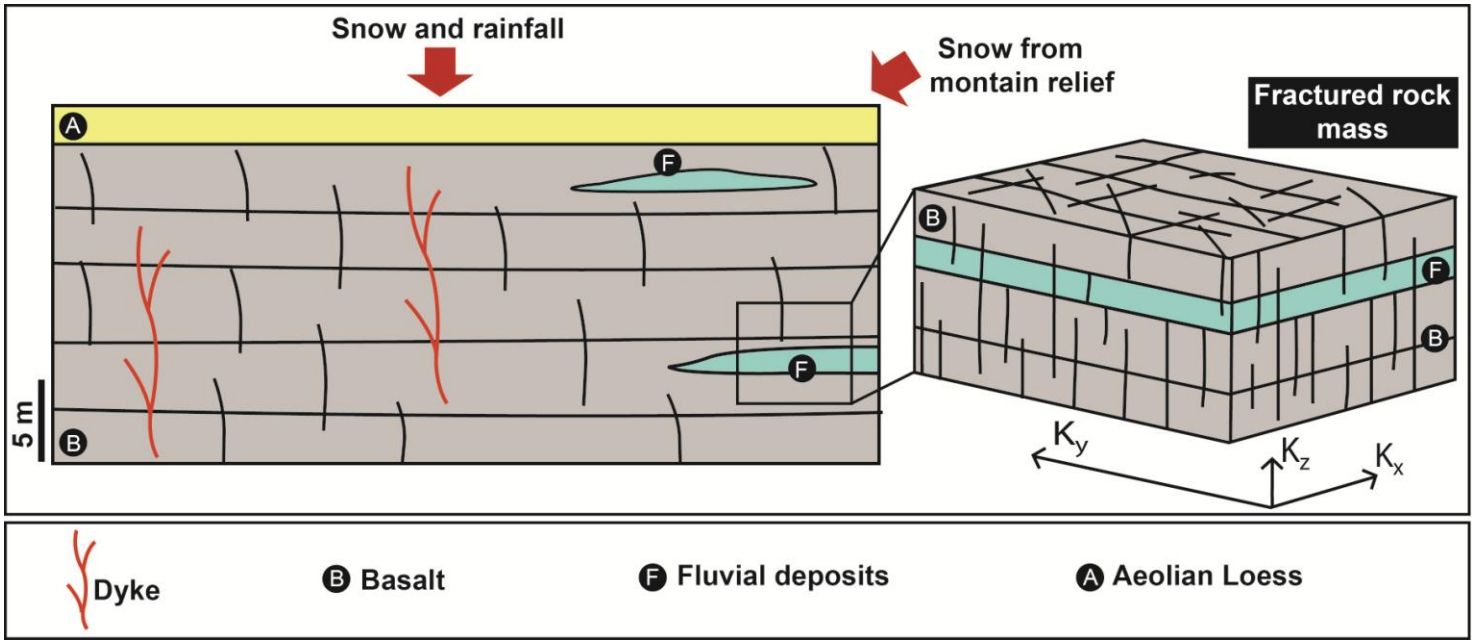
- **Geological Cross Section**
- **Fractured basalts with clay rich fluvial interfingers of Miocene Age**



Research Objectives

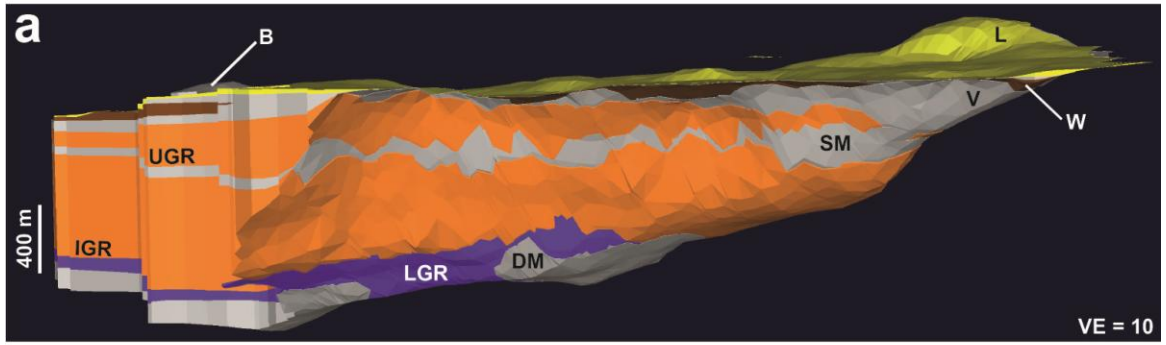
- Back-up → outputs 3D groundwater and particle tracking model → use to spatially constrain contamination risk
- Individuate area exposed to higher contamination risk
- Test the effect of the horizontal flow anisotropy on capture zones

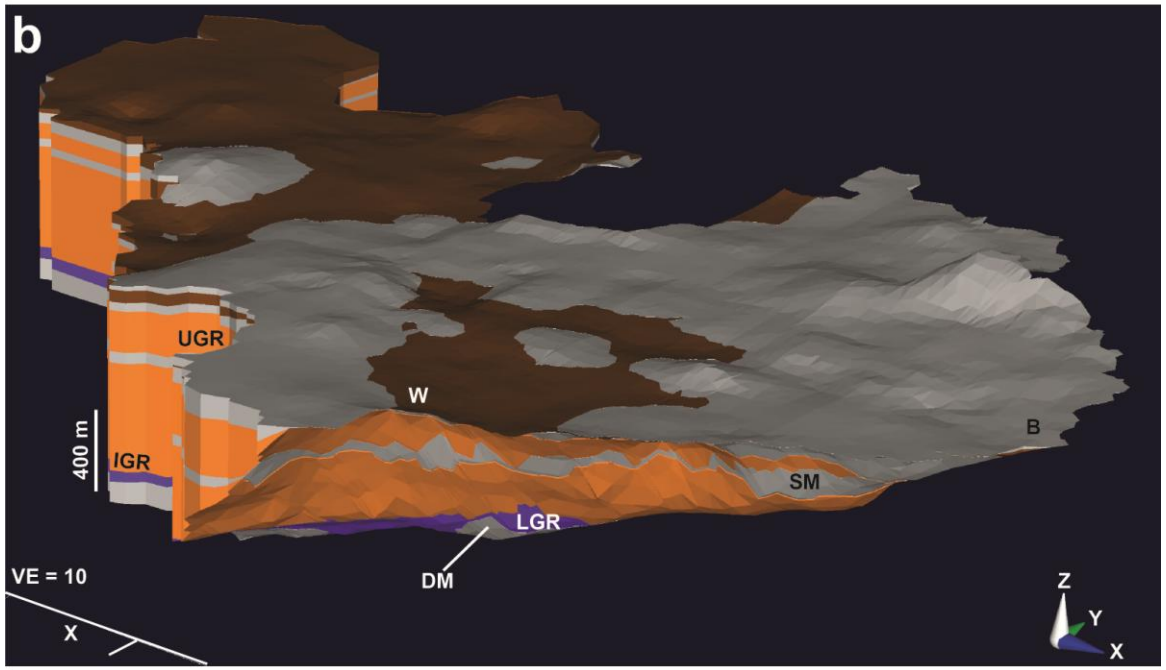
Conceptual Model



Layered aquifer → **Bedding planes vertical flow anisotropy** → **Subvertical joints horizontal flow anisotropy**

3D Groundwater Flow Model → Geology





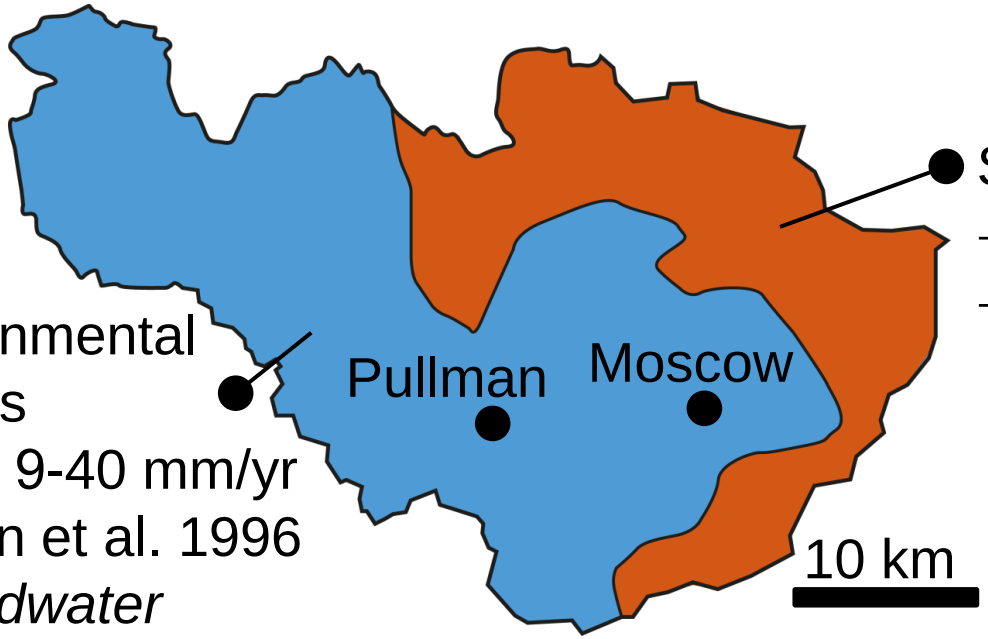
Volcanic deposits	Fluvial deposits	Aeolian deposits
Columbia River Basalt Group	Latah Formation	Loess Formation (L)
Wanapum Basalt Formation (W)	Sediment of Boville Member (B)	VE = Vertical exaggeration
Upper Grande Ronde Basalt Formation (UGR)	Vantage Member (V)	
Inter. Grande Ronde Basalt Formation (IGR)	Shallow Sediment of Moscow (SM)	
Lower Grande Ronde Formation (LGR)	Deep Sediment of Moscow (DM)	

20 Layers → Fluvial deposits finer layering

Laterally discontinous fluvial layers → basalts 80% volume → 0.01 flowing porosity

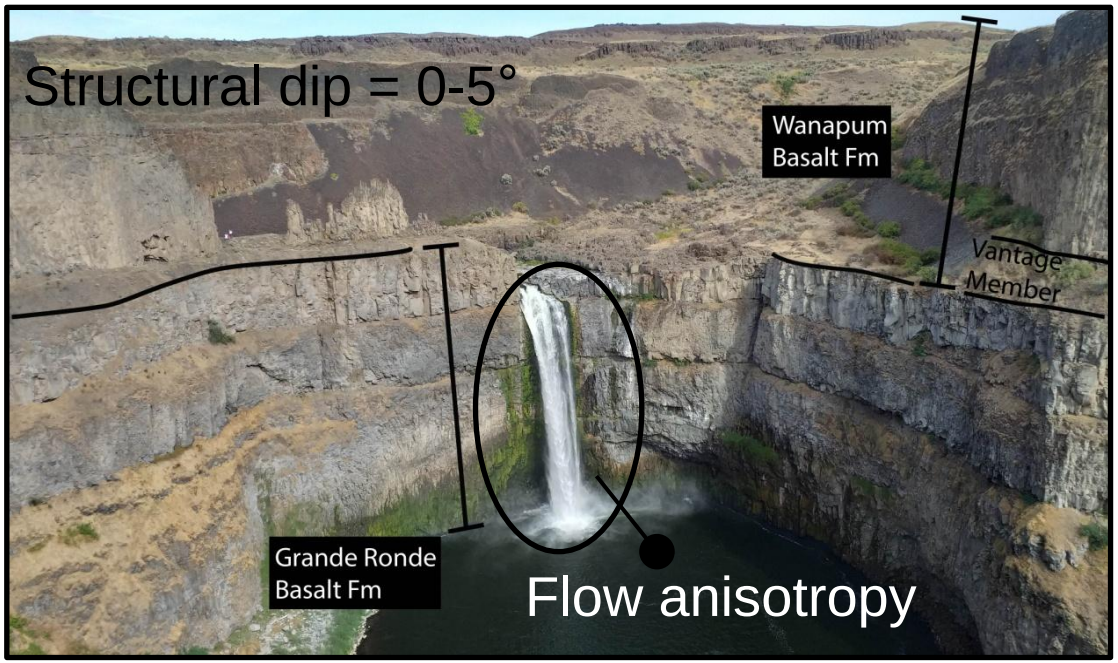
Vertical Exaggeration (VE) 10

Model Calibration and Recharge Constraints



Environmental Tracers
→ R = 9-40 mm/yr
O'Brien et al. 1996
Groundwater

Snow melt, Rocky Mountains
→ high recharge (>40 mm/yr)
→ Isotope study,
Duckett et al. 2019
Hydrology



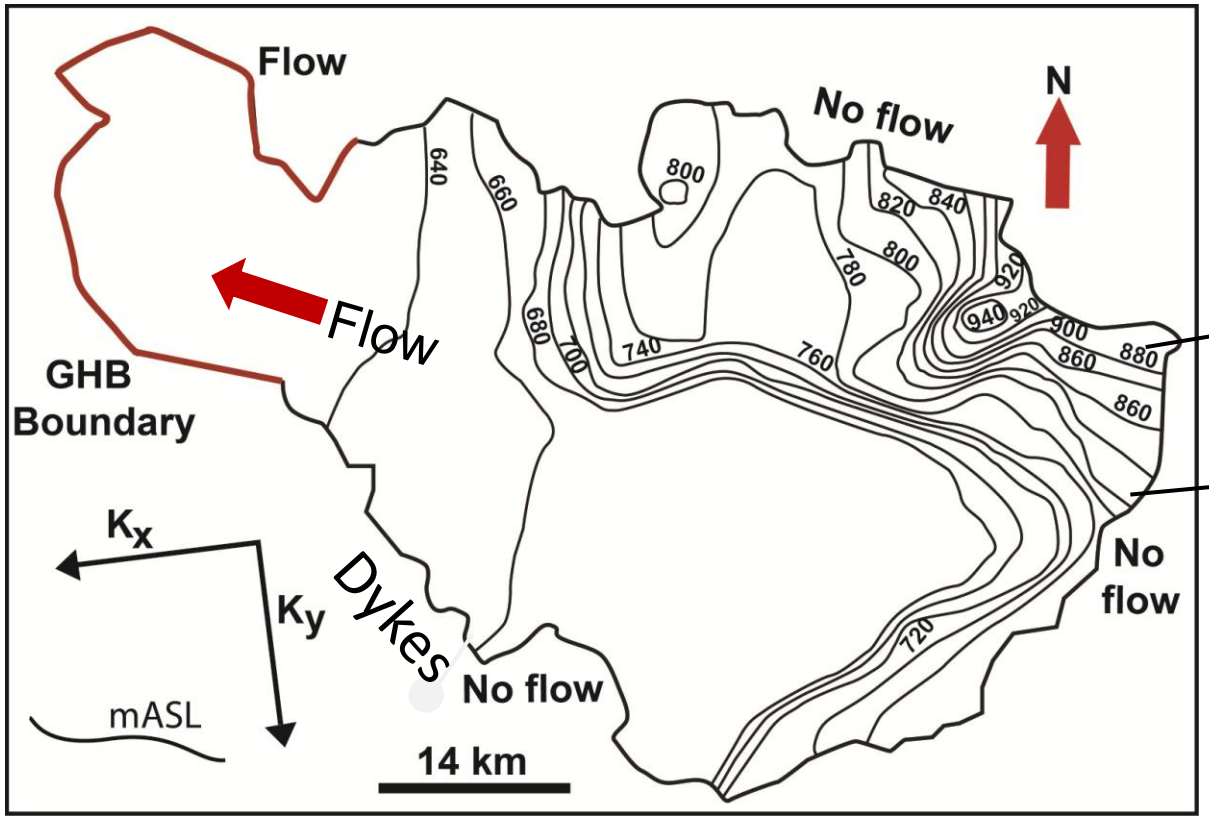
Flow anisotropy

- High anisotropy
  → K_h / K_v = 2000 - 5000

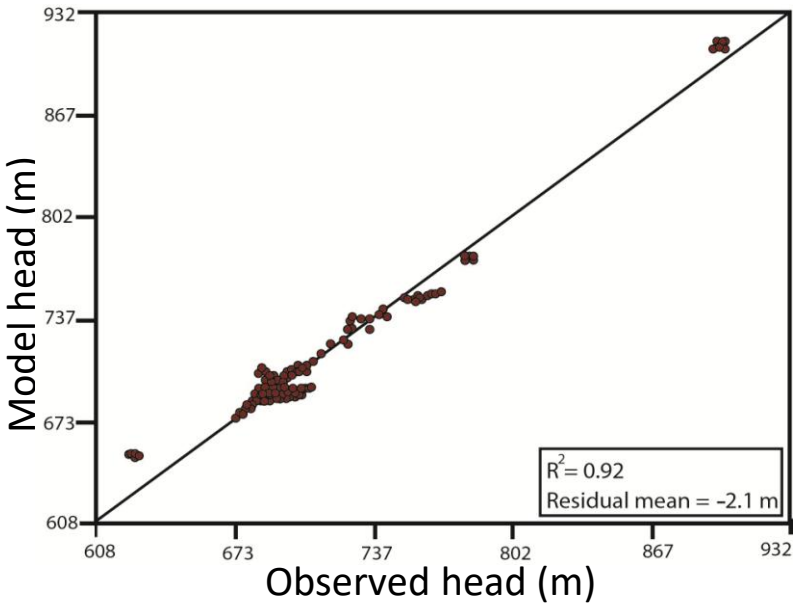
Ely et al. 2011 *USGS report*

- K_h → Calibration
- K_v → Calibation

Steady State Flow Model

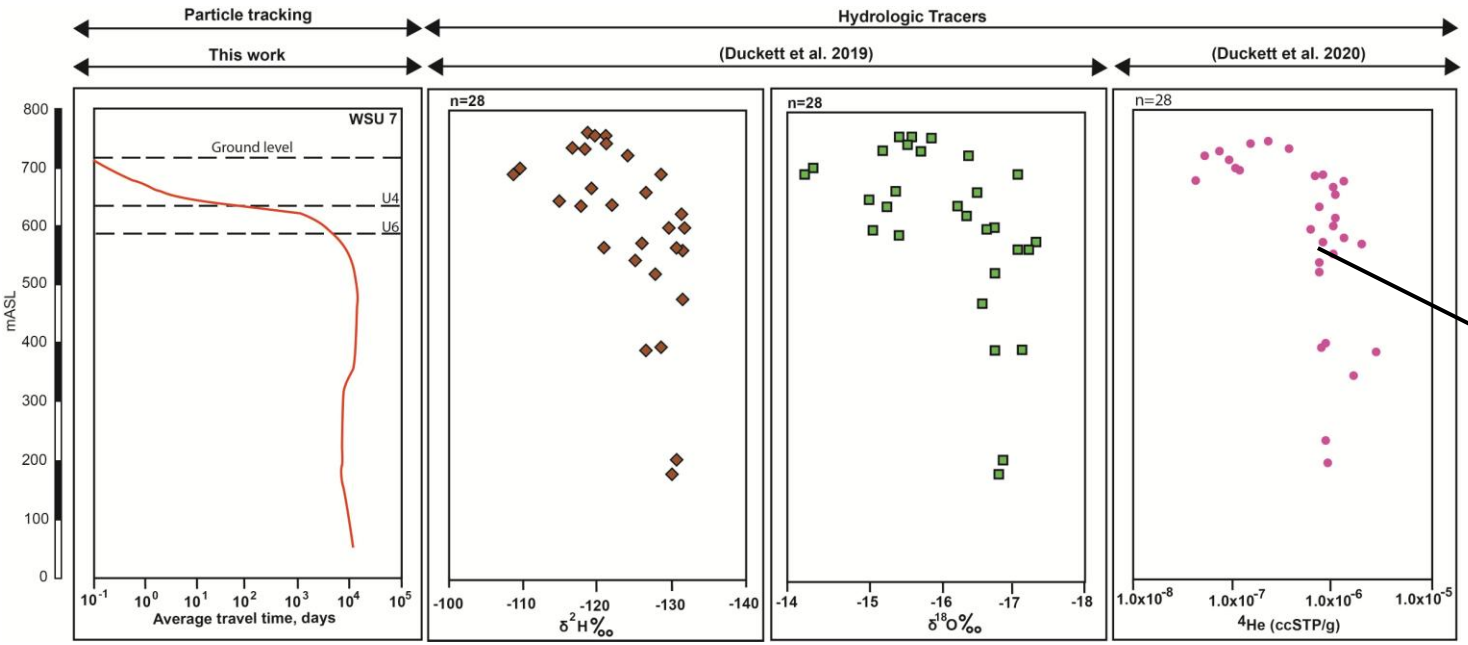


- Igneous-Metamorphic Basement
- Moscow Mountains

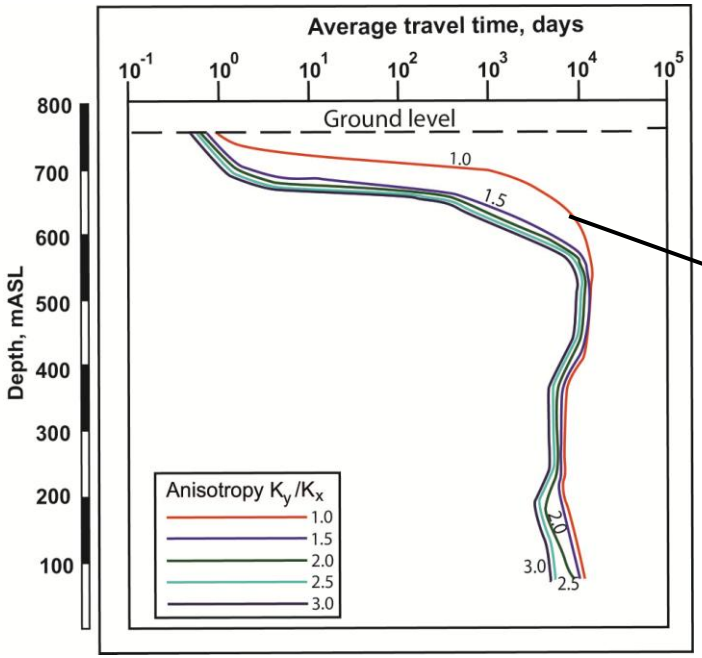


Calibration Steady State Flow Model
PEST Tikhonov Regularization Steady State Flow Model

Backwards Particle Tracking Analysis - MODPATH



Fit Environmental Tracers-Particle Tracking → Back up for model outputs

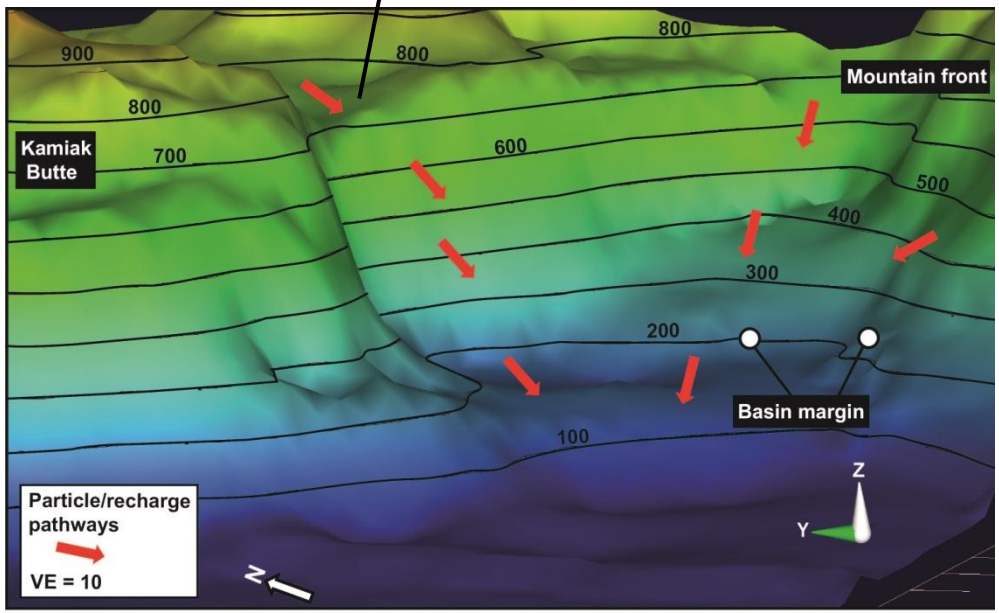


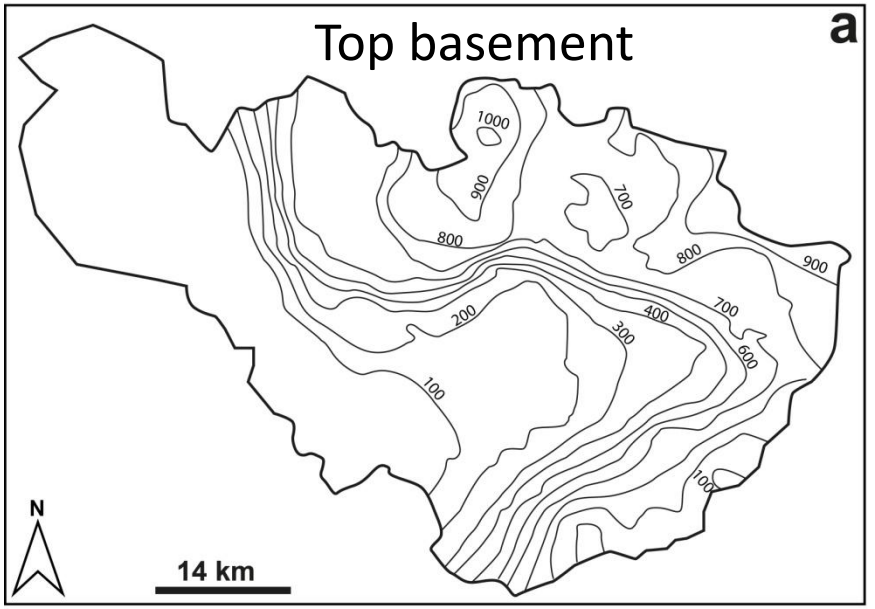
Average particle travel time, abstraction well to recharge boundary

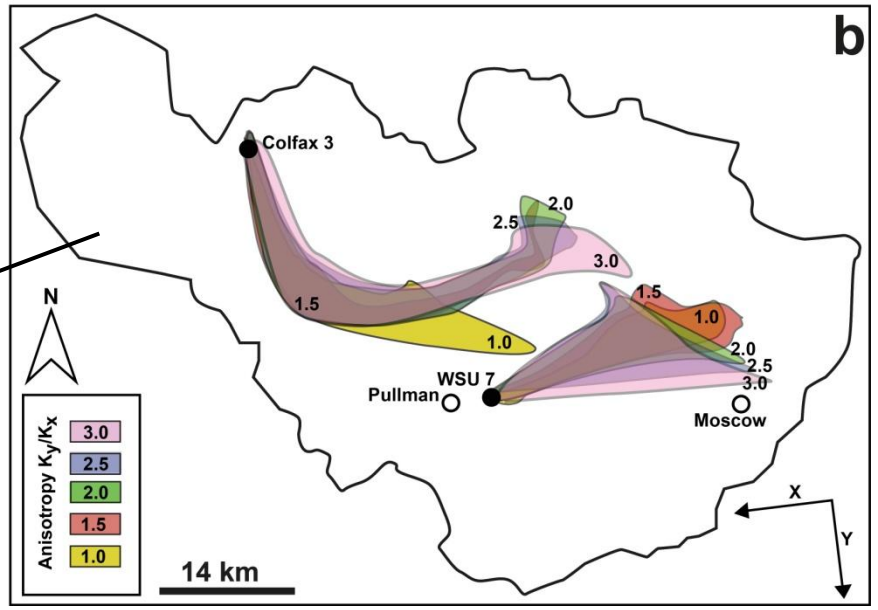
Washington State University Well 7

Backwards Particle Tracking Analysis - MODPATH

Preferential flow pathways
in correspondence
of the basin margins



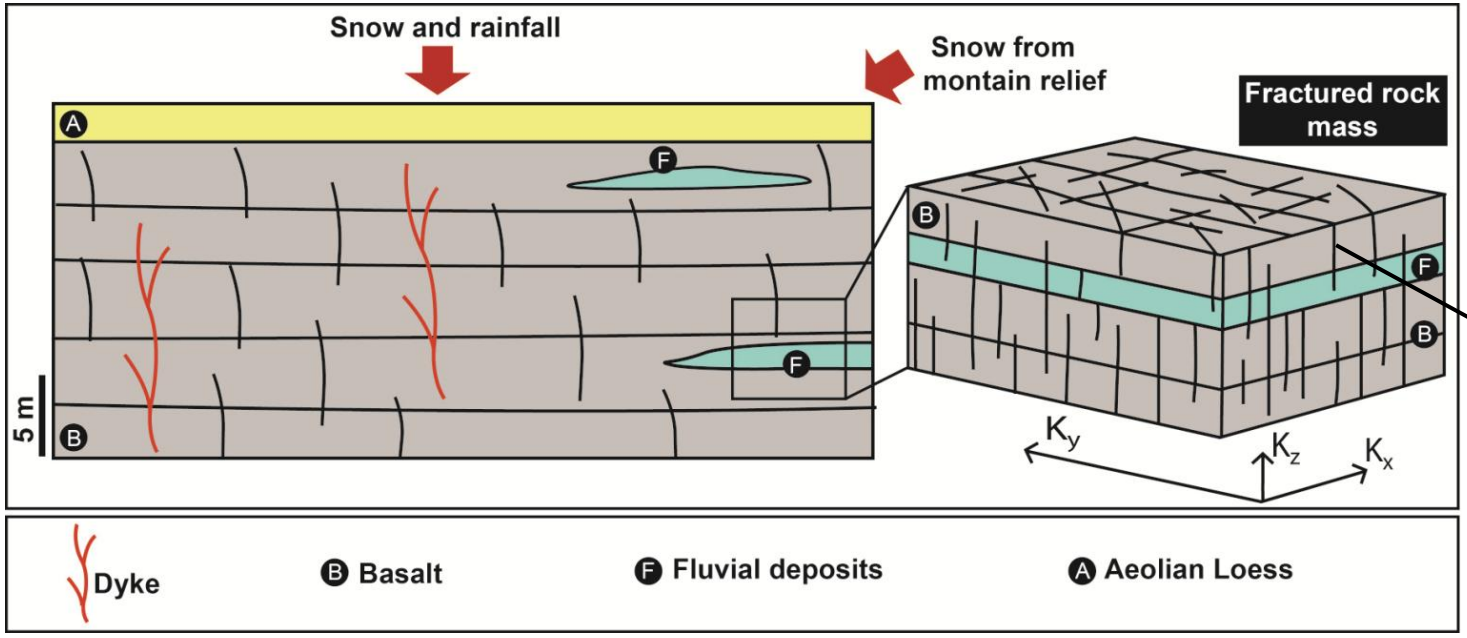




- Capture Zone (vulnerable area around abstraction well) vs horizontal flow anisotropy
- Outer zones, t = 10 years

Conclusions

- Environmental tracers → useful data to back up outputs of groundwater flow and transport models → robust models provide information to better define aquifer vulnerability
- Area of maximum vulnerability for the studied aquifer in the proximity of the basin marngins according to a particle tracking model
- Capture zones around abstraction wells → influenced by horizontal flow anisoropy → significant effect in the proximity of the mountain front



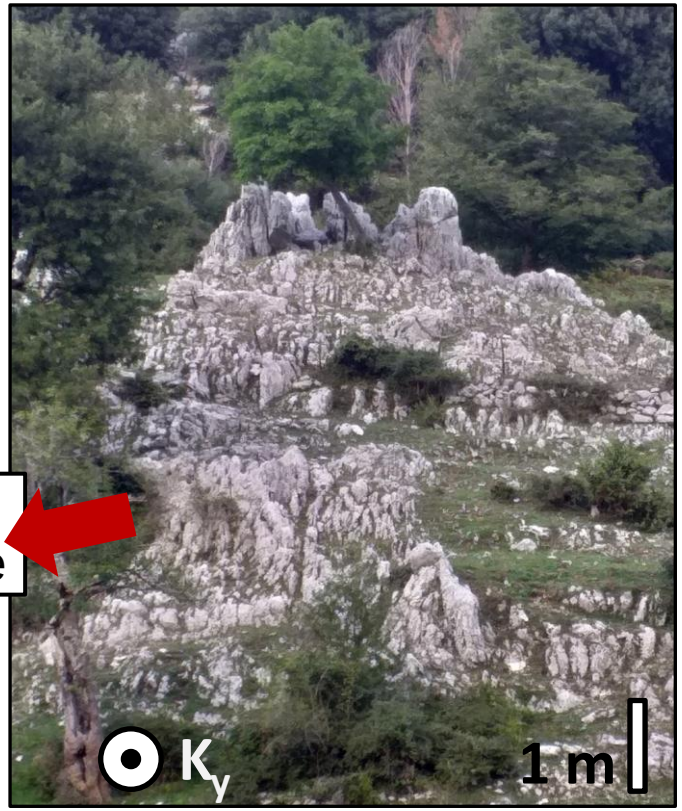
Sub-vertical joints → horizontal flow anisotropy

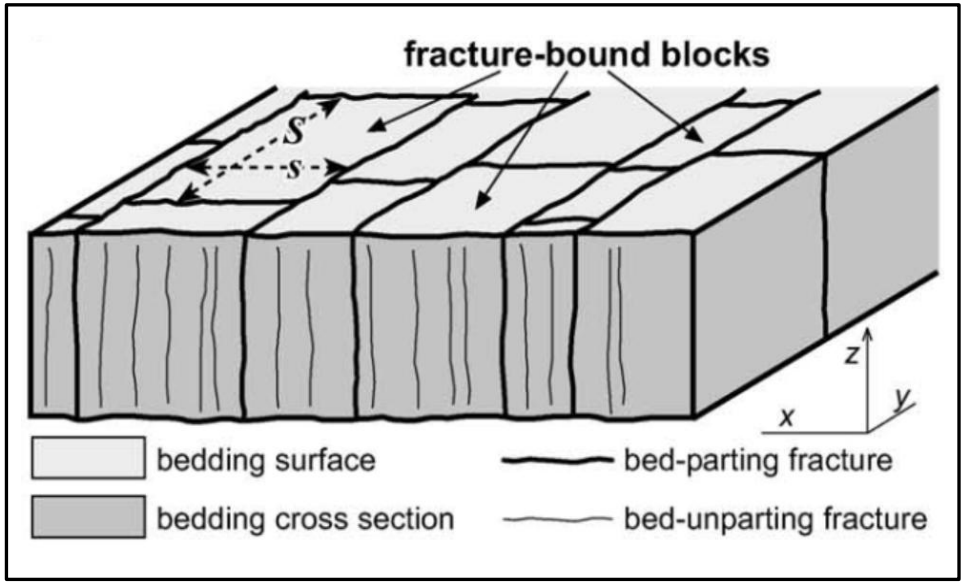
Fractured aquifers (study case)

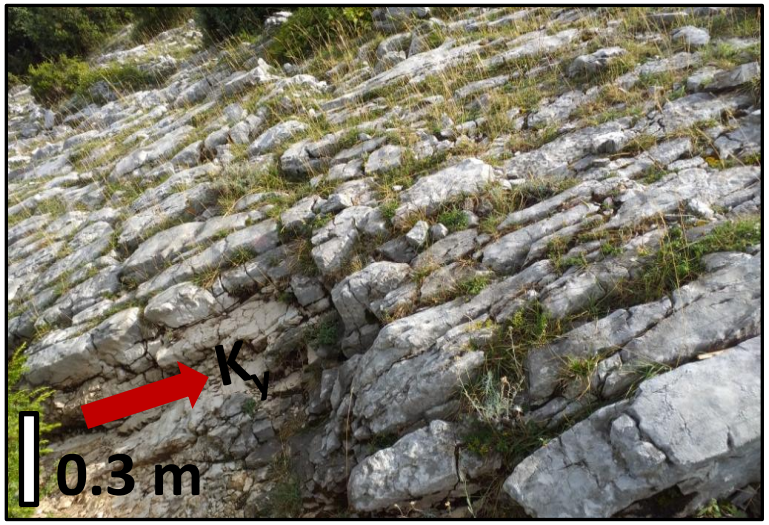
Fractured & karst aquifers

Potential higher effect of horizontal flow anisotropies

Central Apennines, Italy







Mechanical anisotropy in fractured rocks → oriented sub-vertical joints, common in a variety of tectonic settings → impact on capture zones and contaminant plumes

Billi 2005 *J Struct Geol*

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