What Does It All Mean? Recognizing the Uncertainty in the Data We Collect

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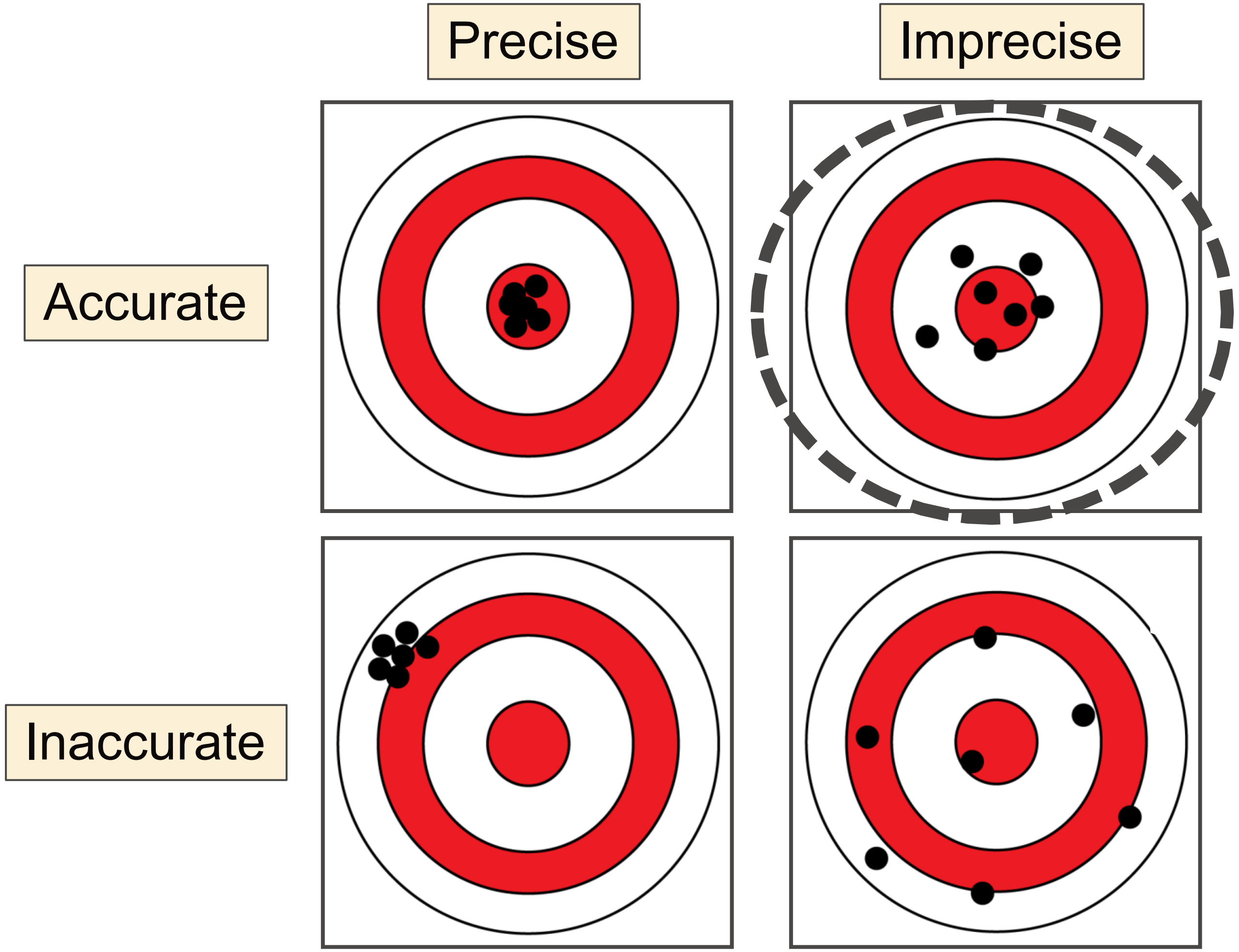
Arcadis logo

Precision vs. Accuracy

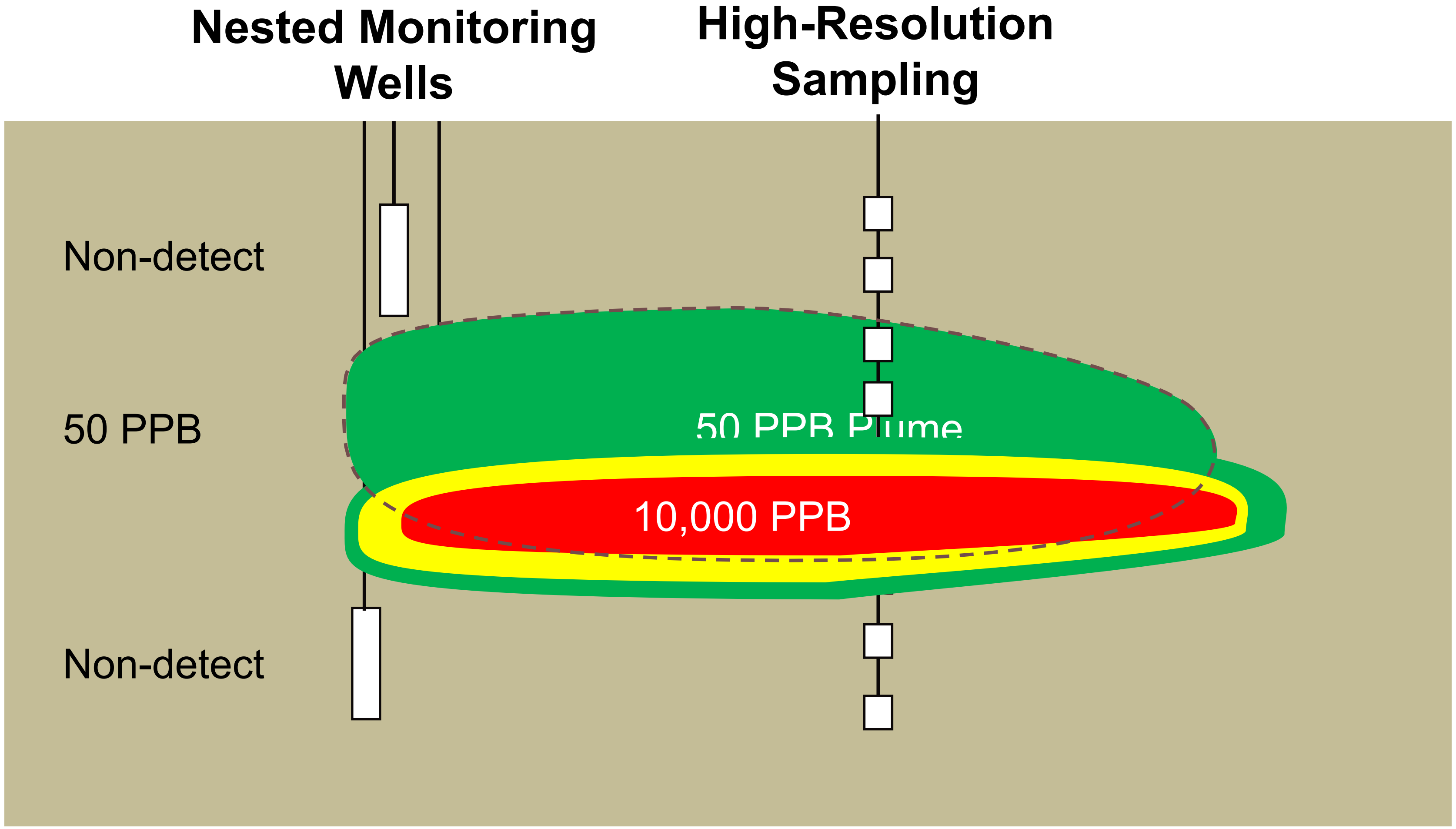


Accuracy refers to how close a measurement is to the actual or correct data value

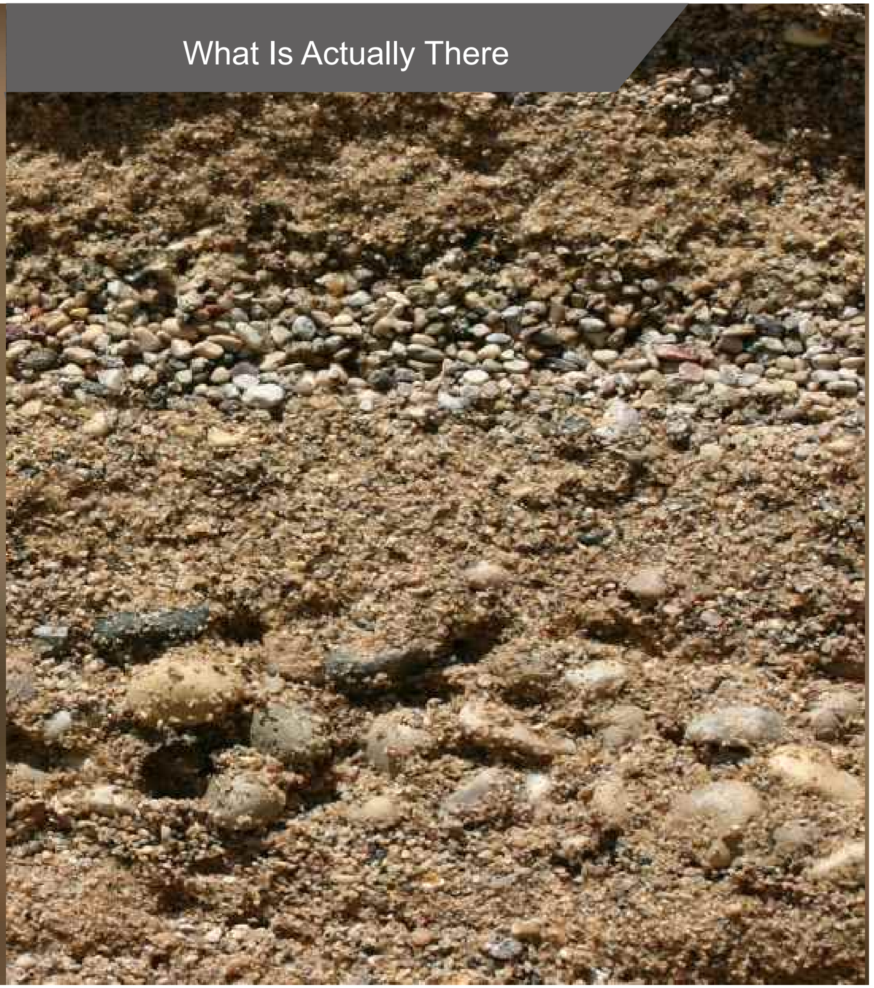
Precision describes how close repeated measurements of data values are to one another

Adapted from *http://www.antarcticglaciers.org/glacial-geology/dating-glacial-sediments-2/precision-and-accuracy-glacial-geology/*

Precision vs. Accuracy



Characterization doesn’t always accurately reflect reality…



. . . or the pathways underlying contaminant movement

http://www.amusingplanet.com/2016/02/the-stunning-beauty-of-braided-rivers.html
Photo credit: Andre Ermolaev/500px

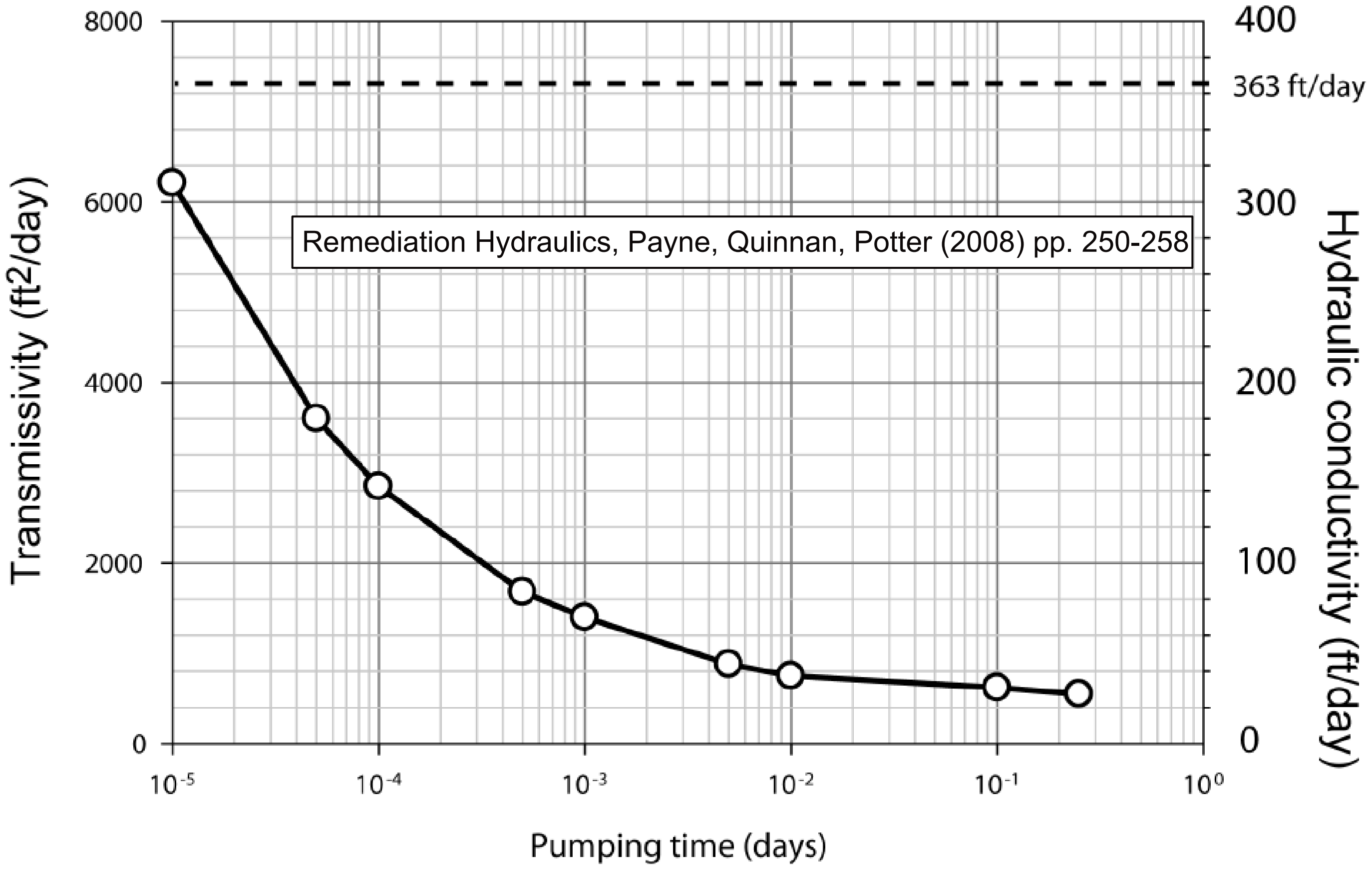
Aquifer Properties

Hydraulic Conductivity

Aquifer Tests

Does aquifer testing underpredict or overpredict hydraulic conductivity?

Underpredicts



What are the implications?

The Good . . . .Water Supply

An underprediction in hydraulic conductivity means we have more water than our testing would indicate.

A properly designed and managed well field should have sufficient supply to meet demands

The Bad . . . .Groundwater Remediation

An underprediction of hydraulic conductivity means we underpredict the amount of groundwater flow through our aquifers.

- Contaminants move faster
- More pumping to achieve capture
- Some technologies may not be effective
- We will underpredict mass flux

Observations and Recommendations

- Expect hydraulic conductivity estimates to be biased low and plan accordingly . . . but they could be high or even correct.
- Aquifer hydraulics alone won't tell us where contaminants are moving…
- *"No environmental system (natural and/or socioeconomic) can be perfectly characterized, especially when many of its key characteristics are inferred and imperfectly sampled. Handling the lack of detailed understanding of groundwater systems is one of the key challenges to their effective management."*

(*Integrated Groundwater Management: Concepts, Approaches and Challenges.* 2016. Jackman et al., editors)

Changes in Water Levels

Impacts on Concentrations

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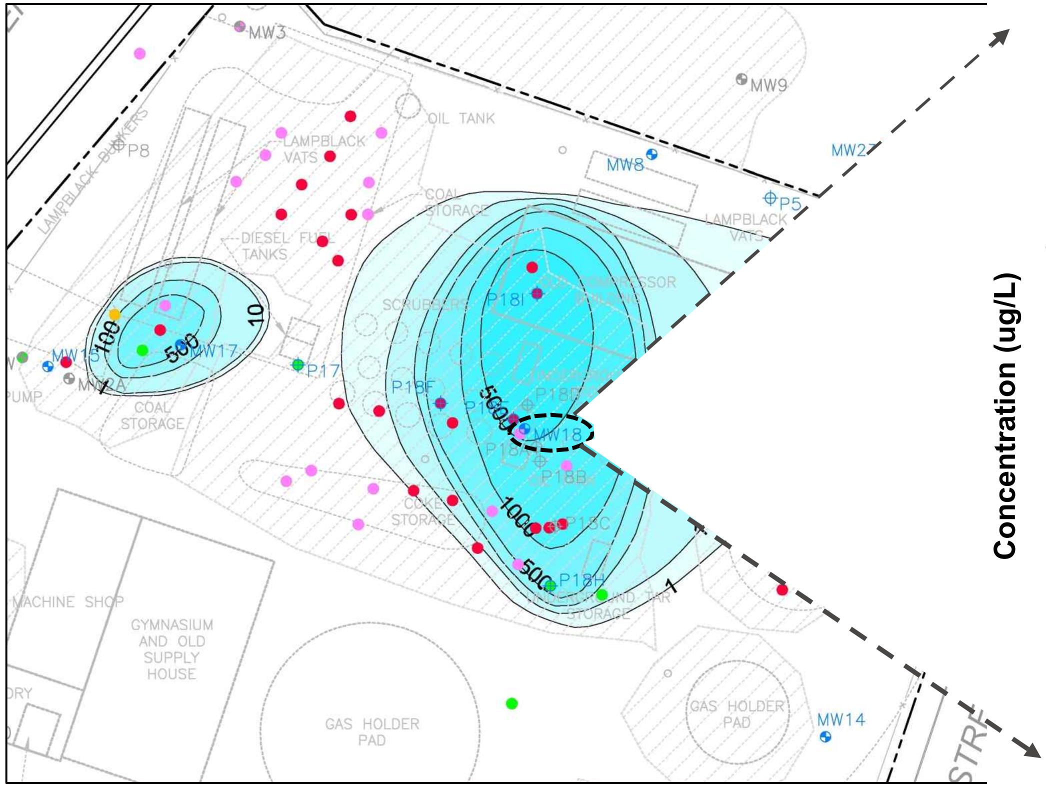
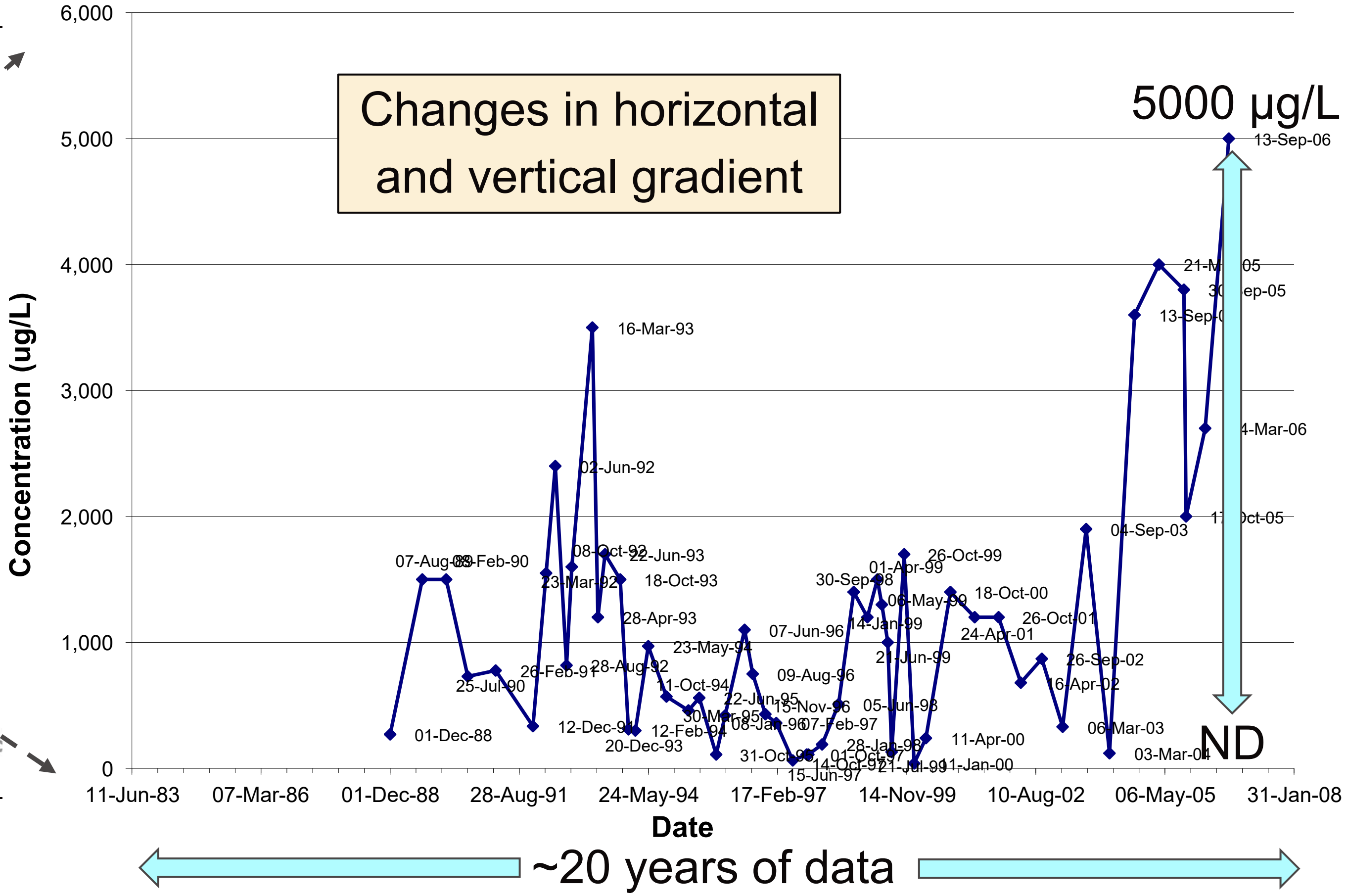
Consider an Old NAPL Pool and BTEX Plume





After 100-years of weathering, a monitoring well beneath an engineered cover in the center of the NAPL would be expected to have less variability in concentrations over time.

Vertical Water Level Changes and Concentrations

Contaminant concentrations at a well cluster

Location	Depth	Fall	Spring	Summer
MW-1	WT	6.9	8.5	7.4
MW-2	-35	1825	**2.2**	2550
MW-3	-45	1000	780	1100

A seasonal change in water levels, causes a change in flow pathways, which changes concentrations in a well.

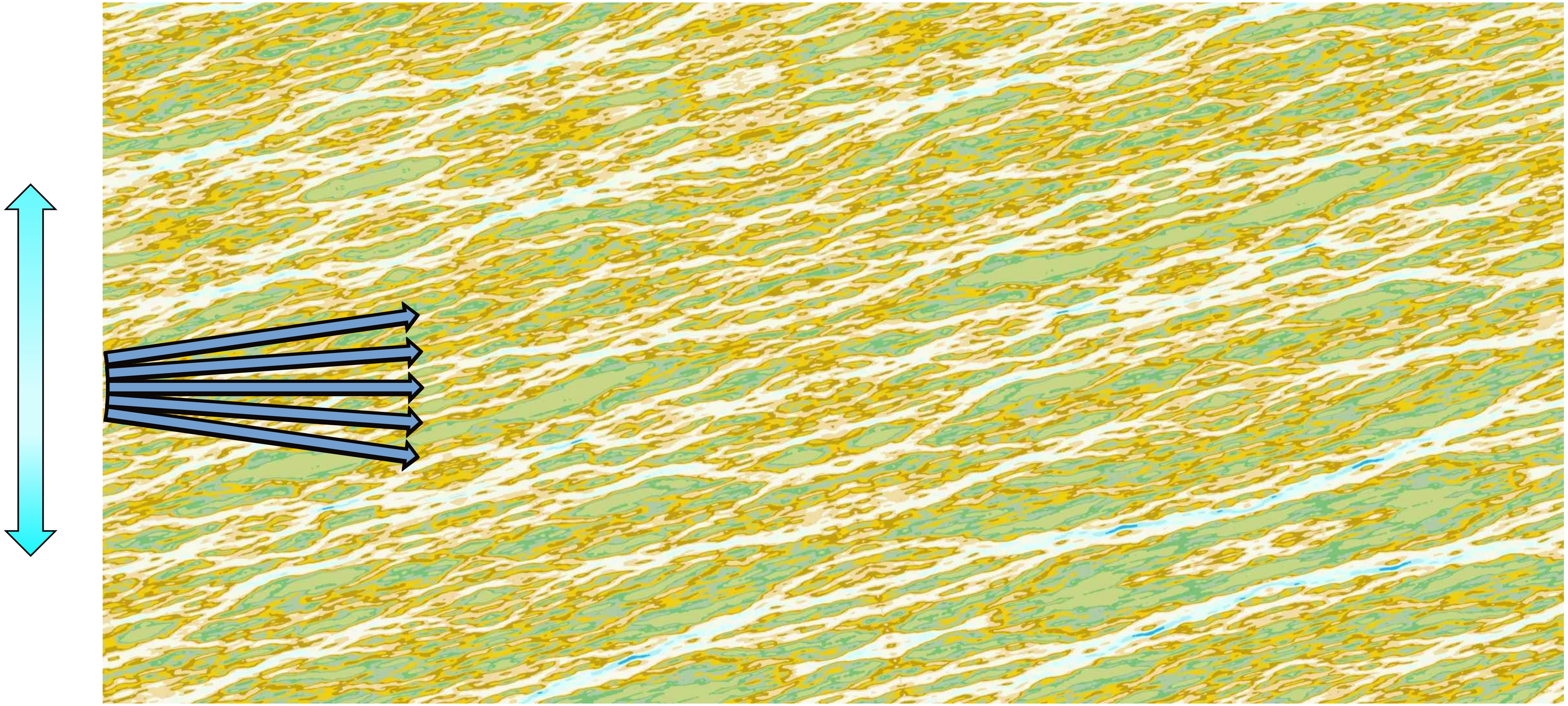
Groundwater flow directions remain unchanged

Spring water levels increased by 2 feet in each interval

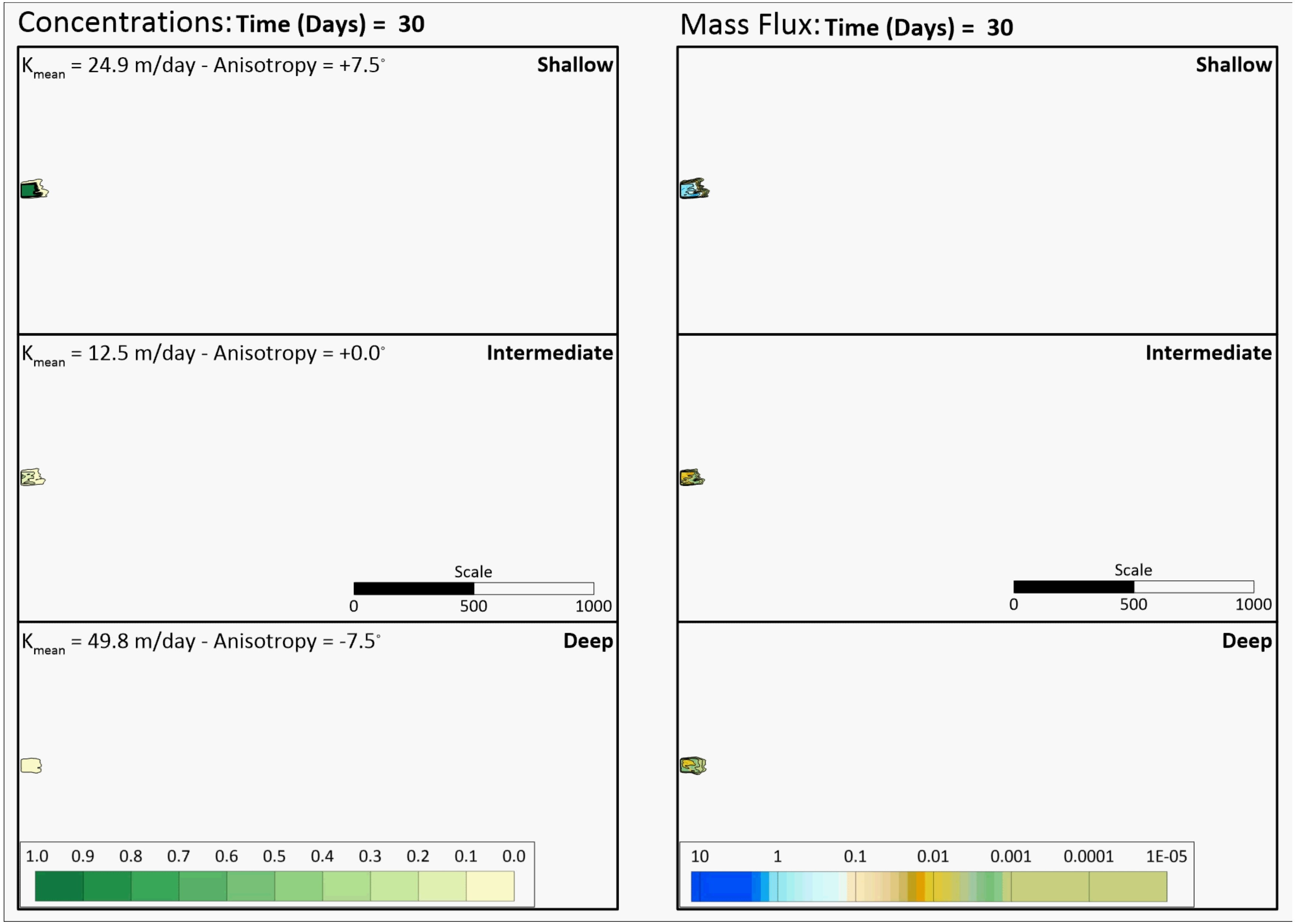
Evaluation of the Effect of Water-Level Changes

15 degrees of annual variation in the horizontal groundwater flow direction

1 inch of
vertical change
In water levels



Concentrations   Mass Flux



Water Level Changes in a *Real Aquifer*

Natural Fluctuations in Water Levels Can Cause

- Changes in flow direction
- Groundwater flux to pulse
- Plumes to spread
- Groundwater concentrations to vary
- A single plume to appear as multiple plumes

Engineered Fluctuations in Water Levels Can Be Applied to Enhance

- Distribution of reagents
- Recovery of contaminant mass

Observations and Recommendations

- Ambient water levels always vary due to natural phenomena (storm, seasonal, and climatic)
- Transient conditions constantly change groundwater flow and transport
- Changing groundwater pathways store and release contaminants from aquifers

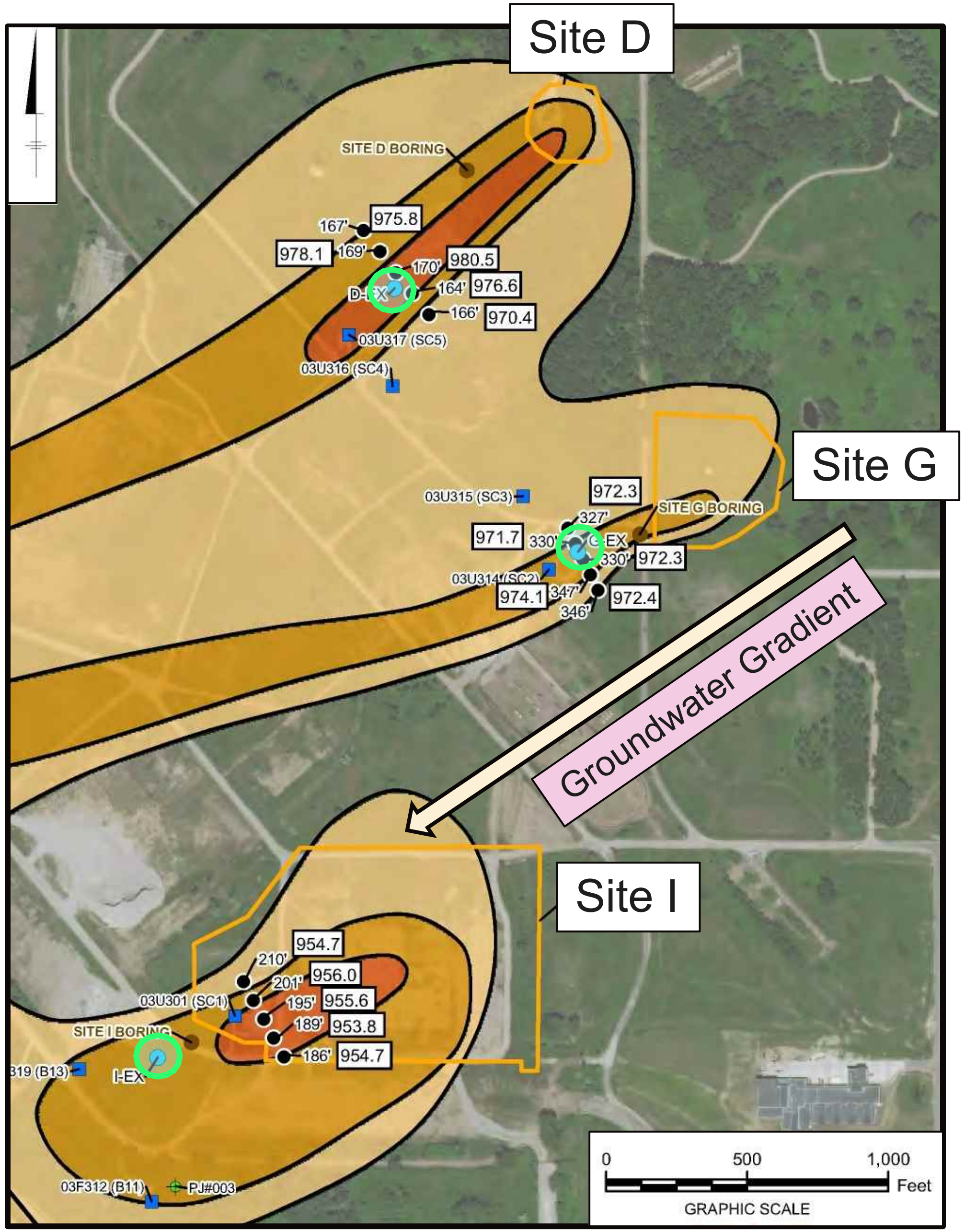
Observations and Recommendations

"EPA recognizes that a plume boundary is more realistically defined by a zone rather than a line. Fluctuations within this zone are likely to occur due to a number of factors (e.g., analytical, seasonal, spatial, etc.) which may or may not be indicative of a trend in plume migration. Therefore, site characterization activities and performance monitoring should focus on collection of data of sufficient quality to enable decisions to be made with a high level of confidence." – USEPA, 1999

Final OSWER Directive "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites" (OSWER Directive Number 9200.4-17P)

Mass Flux

Impacts on Concentrations



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Mass Flux Transects – *How much uncertainty can there be in our assessment?*

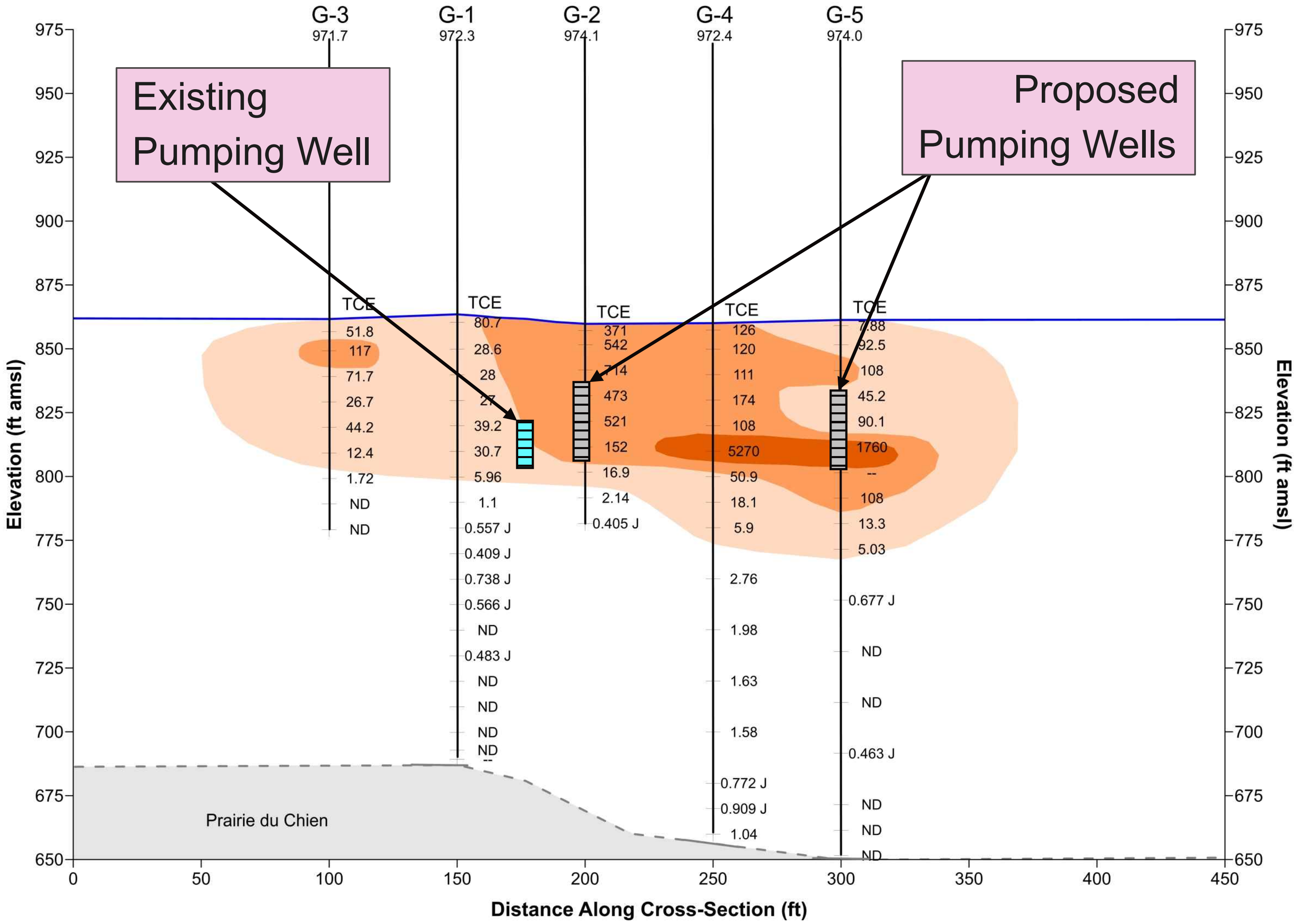
Observation: Operating extraction wells (in a sand and gravel aquifer) were not capable of achieving containment & after 30 years of operation, downgradient plume persisted.

Assumption: The system needed to be optimized; wells needed to be relocated and/or pump more water

Flux-Informed Remediation Decision Making **2010**

by Suthan Suthersan, Craig Divine, Joseph Quinnan, and Eric Nichols

Transect – Site G, TCE

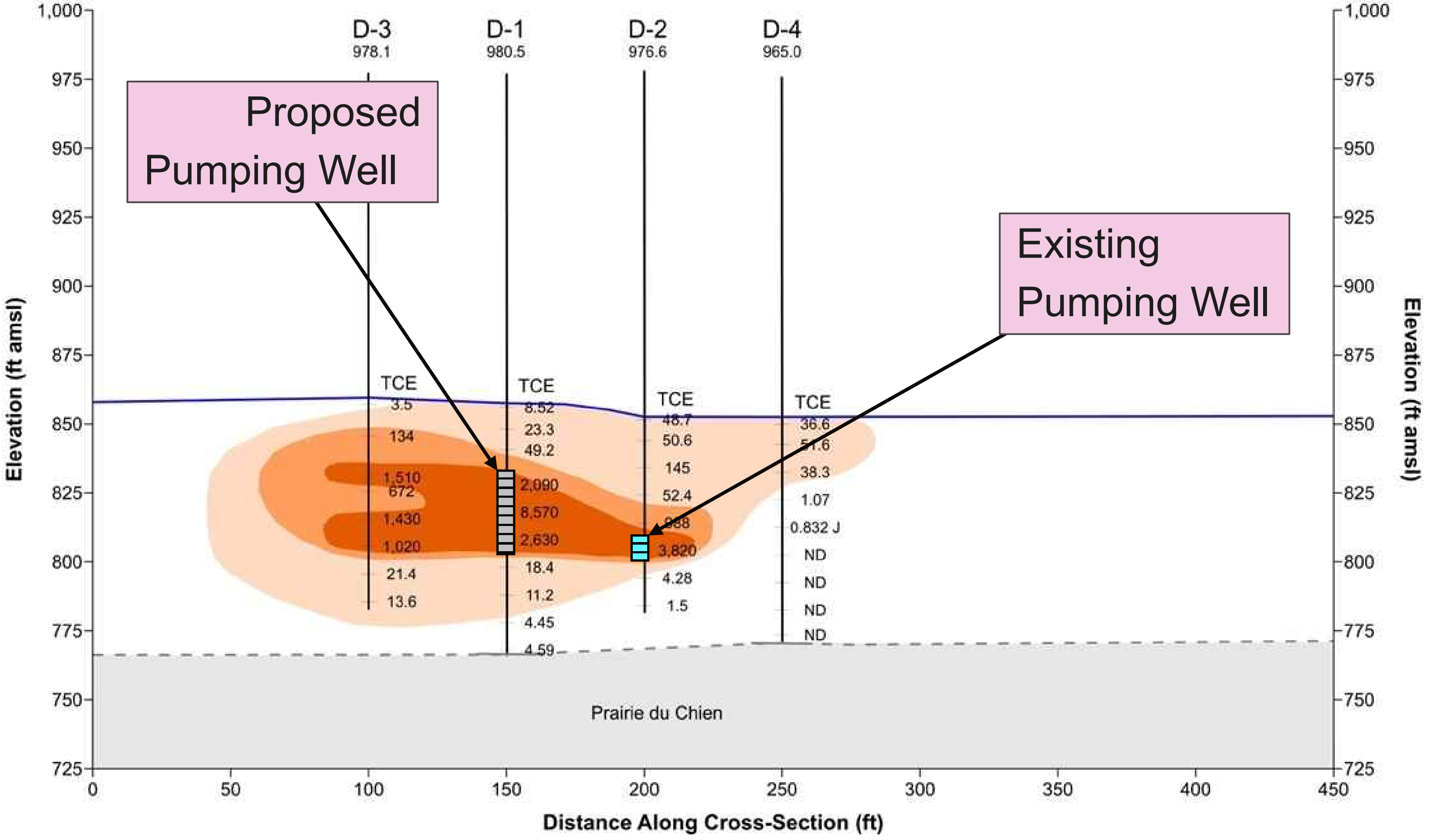


Did the investigation find the mass flux?

Can we identify optimized locations for new extraction wells?

What is the uncertainty of the information?

Transect – Site D, TCE



Did the investigation find the mass flux?

Can we identify optimized locations for new extraction wells?

What is the uncertainty of the information?

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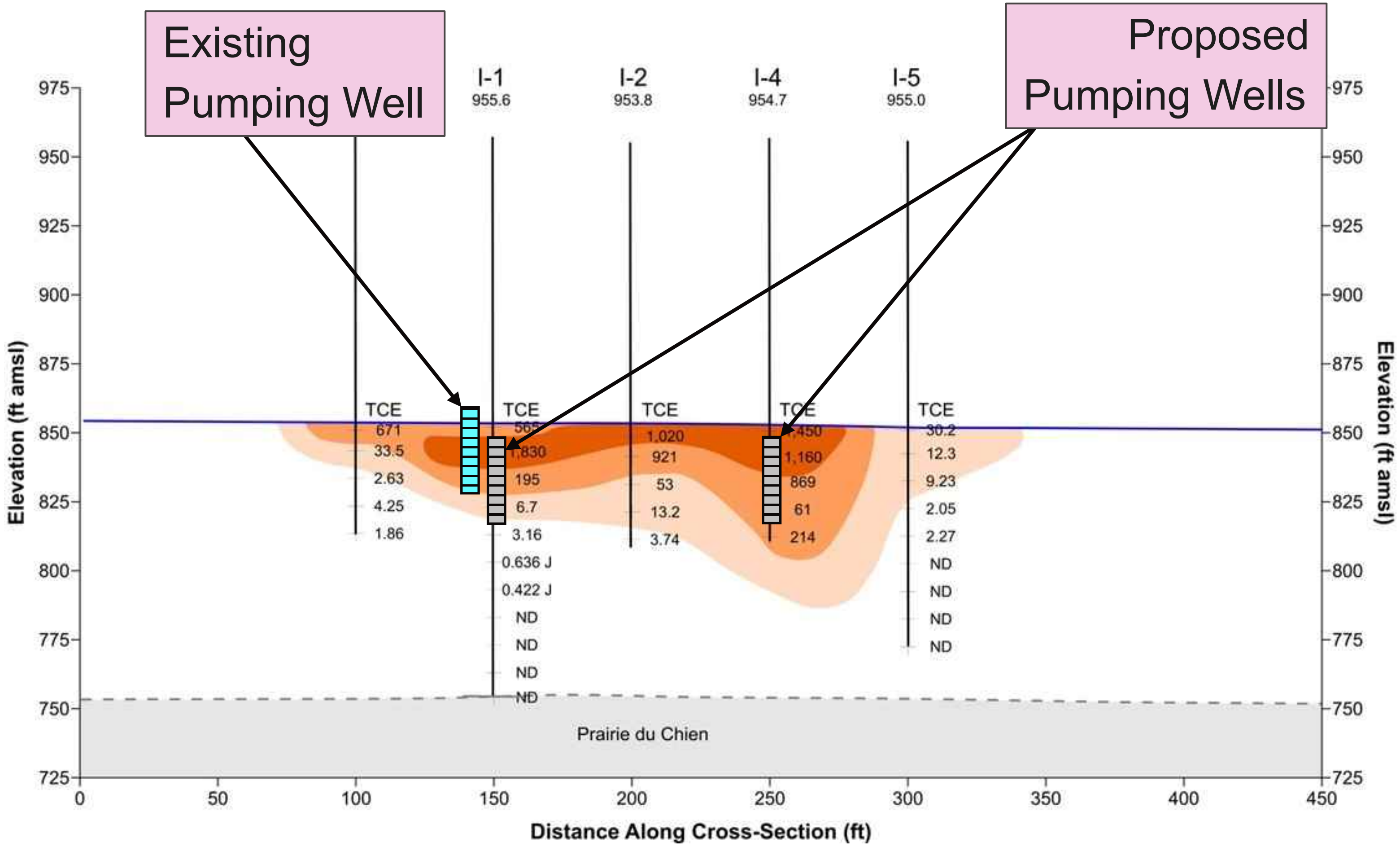
Transect – Site I, TCE



Did the investigation find the mass flux?

Can we identify optimized locations for new extraction wells?

What is the uncertainty of the information?

Mass Flux Summary

A comparison of the TCE mass flux at SC-1, SC-2, and SC-5 to Site I, Site G, and Site D can be used to adjust the calculated mass flux from the cross-sections to match Site observations

Site	TCE Mass Flux per Well (lb/yr)		TCE Mass Flux per Transect (lb/yr)	Ratio of TCE Well Mass Flux to Estimated Transect Mass Flux
I	SC-1	186.2	15.8	11.8
G	SC-2	6.6	16.9	0.4
D	SC-5	1,134.0	43.9	25.8

What else?

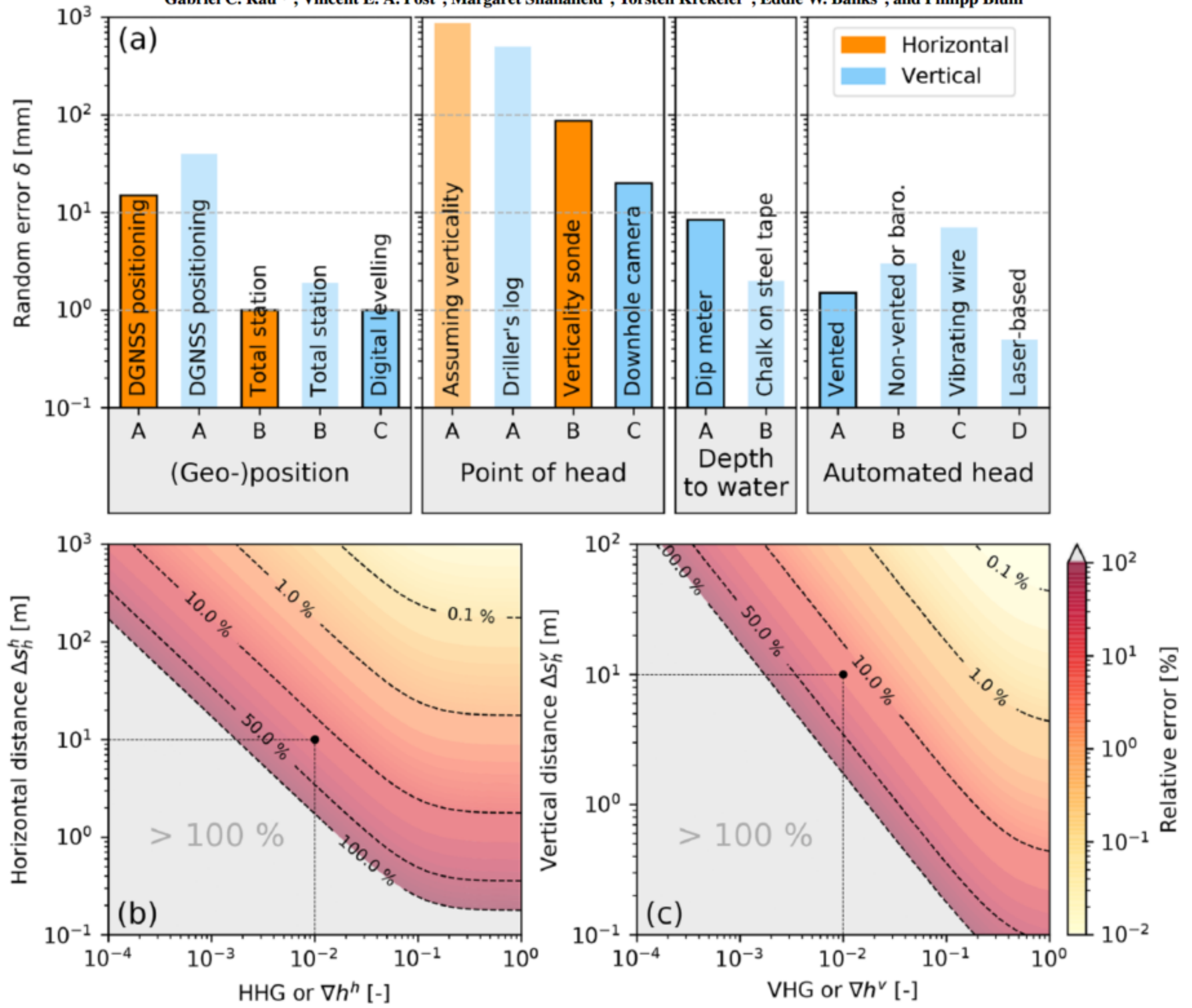
Things we don't always consider, but should…

Water Level Measurement Errors

- WL measurements underpin practically all investigations in hydrogeology (e.g., hydraulic conductivity estimates, hydraulic gradients, mass flux, etc.).
- These errors (1) inhibit reliable estimation of flow directions and (2) significantly increase uncertainty of flow calculations.
- Textbooks contain limited content and studies rarely report on measurement errors.
- With current standard practice (best-case scenario*), horizontal gradients <0.0001 are only resolvable at distances >170 m and it takes extraordinary effort to measure gradients <0.001 over distances < 10 m.

Error in hydraulic head and gradient time-series measurements: a quantitative appraisal **2019**

Gabriel C. Rau[1,2], Vincent E. A. Post[3], Margaret Shanafield[4], Torsten Krekeler[3], Eddie W. Banks[4], and Philipp Blum[1]



*Assumes that systematic errors are absent or that systematic error corrections do not introduce additional error.

Concentration Measurement/Laboratory Errors

For all chemical measurements the uncertainty in an analytical result is a combination of

- Sample heterogeneity: USEPA methods allow for 20–30% variation (soil > water samples)
- Instrument calibration: in general, calibration is checked to be within 25% of true values
- Instrument noise: present in all instruments, limits the sensitivity and precision for all methods, and plays a greater role with sample results close to the detection limit (as high as 33%)
- Laboratory contamination: evaluated by running method blanks, which should not exceed method quantitation level
- Analyte extraction efficiency: varies by method and analyte but recoveries are expected to be within 20–30%
- Chemical/matrix interferences: vary by sample/method but can be 20–30% for inorganic methods and 50–80% for organic methods

The uncertainty all around us…

There are basic questions we always need to ask ourselves and answer.

1. Does the data make sense?
2. Are the conclusions supported by the data?
3. Have you considered alternative interpretations of the data?
4. Have you estimated the variability (uncertainty) in your assessment and the risks associated with the variability (uncertainty)?

The most important tool we have is our brains.

1. Big data analytics and ChatGPT are not substitutes for thoughtful review and dialogue within technical teams.
2. We need to challenge ourselves not to solely rely on technology to derive/filter our interpretations.
3. Sometimes, we need to reach out and rely on professional judgement and experience of others and ourselves because there are too many forks in the road.

Contact Us

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