Factoring Uncertainty into Restoration Modeling of In-Situ Leach Uranium Mines

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Postmining restoration is one of the greatest concerns for uranium in-situ leach (ISL) mining operations. The ISL-affected aquifer needs to be returned to conditions specified in the mining permit (either premining or other specified conditions). When uranium ISL operations are completed, postmining restoration is usually achieved by injecting reducing agents into the mined zone. The objective of this process is to restore the aquifer to premining conditions by reducing the solubility of uranium and other metals in the ground water.

Reactive transport modeling is a potentially useful method for simulating the effectiveness of proposed restoration techniques. While reactive transport models can be useful, they are a simplification of reality that introduces uncertainty through the model conceptualization, parameterization, and calibration processes. For this reason, quantifying the uncertainty in simulated temporal and spatial hydrogeochemistry is important for postremedial risk evaluation of metal concentrations and mobility. Quantifying the range of uncertainty in key predictions (such as uranium concentrations at a specific location) can be achieved using forward Monte Carlo or other inverse modeling techniques (trial-and-error parameter sensitivity, calibration constrained Monte Carlo). These techniques provide simulated values of metal concentrations at specified locations that can be presented as nonlinear uncertainty limits or probability density functions. Decisionmakers can use these results to better evaluate environmental risk as future metal concentrations with a limited range of possibilities, based on a scientific evaluation of uncertainty.

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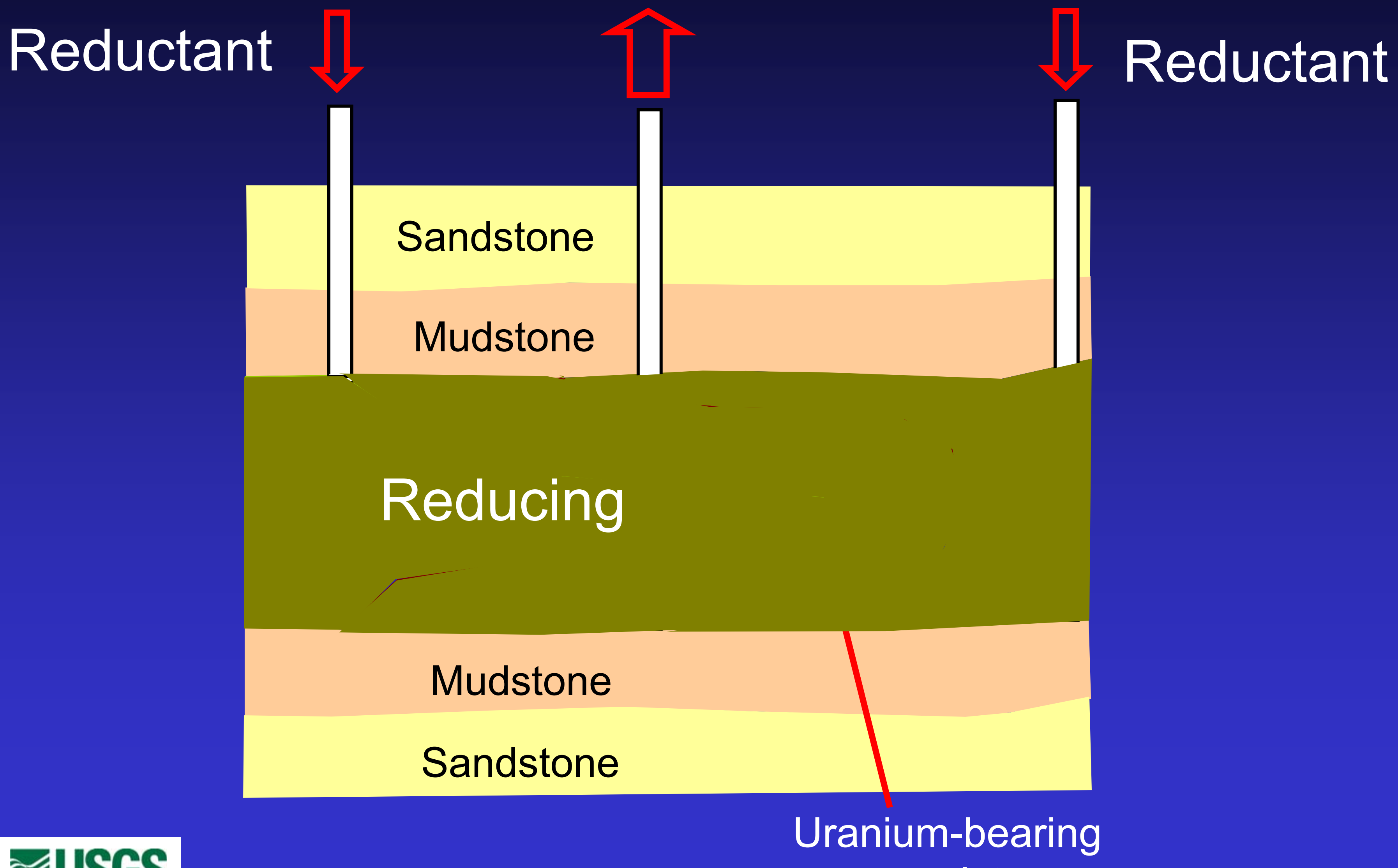
U.S. Geological Survey

In-situ leach operation



Restoration

- Goal – get back to premining conditions and (or) conditions specified in the mine permit
- Lot of current research on possible methods and procedures

Why attempt to model uranium ISL restoration?

- Better understanding of the processes
- Evaluate pros/cons of various restoration methods
- Optimize efficiency of a selected method
- May be part of the permit
- Provide predictions of future ground-water flow and quality

Reactive transport modeling

- Ground-water flow first
- Multispecies advection and dispersion
- Couple with multispecies reactions

2006 Darcy Lecture by Eileen Poeter

All models are wrong

How do we know which are useful?

Reality → Model

Constant balance of complexity versus simplicity (adds uncertainty)

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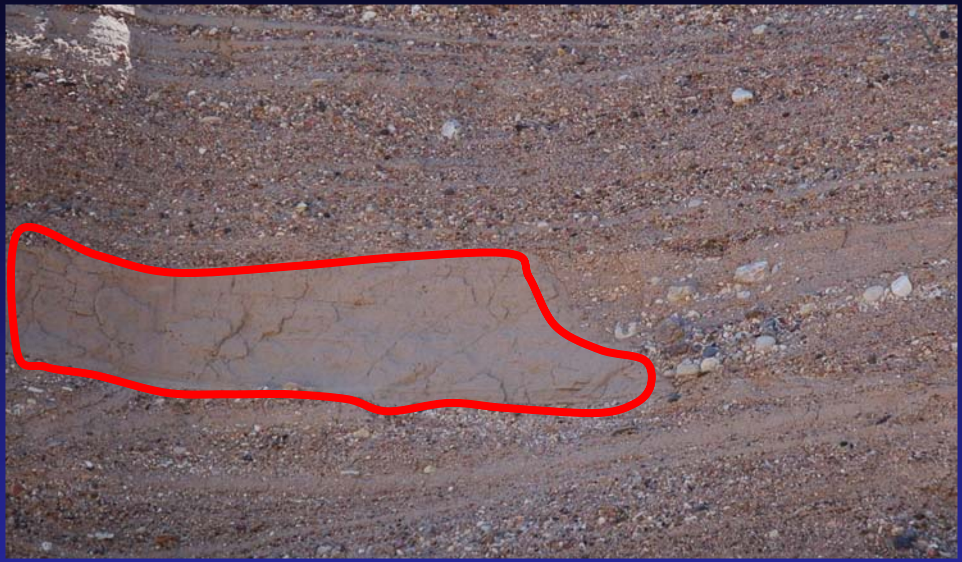
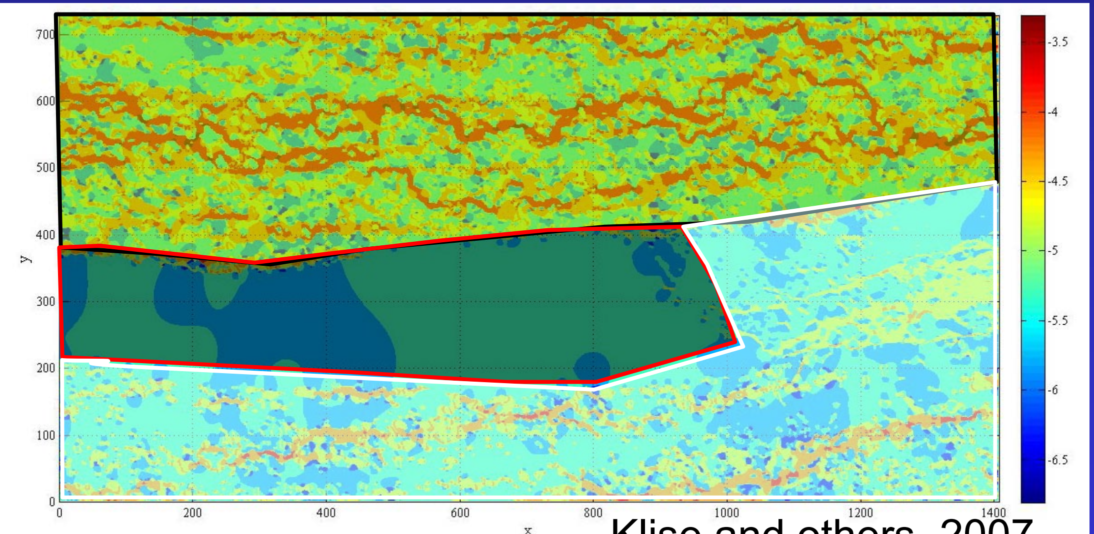
Should we simplify or not?



Outcrop photo

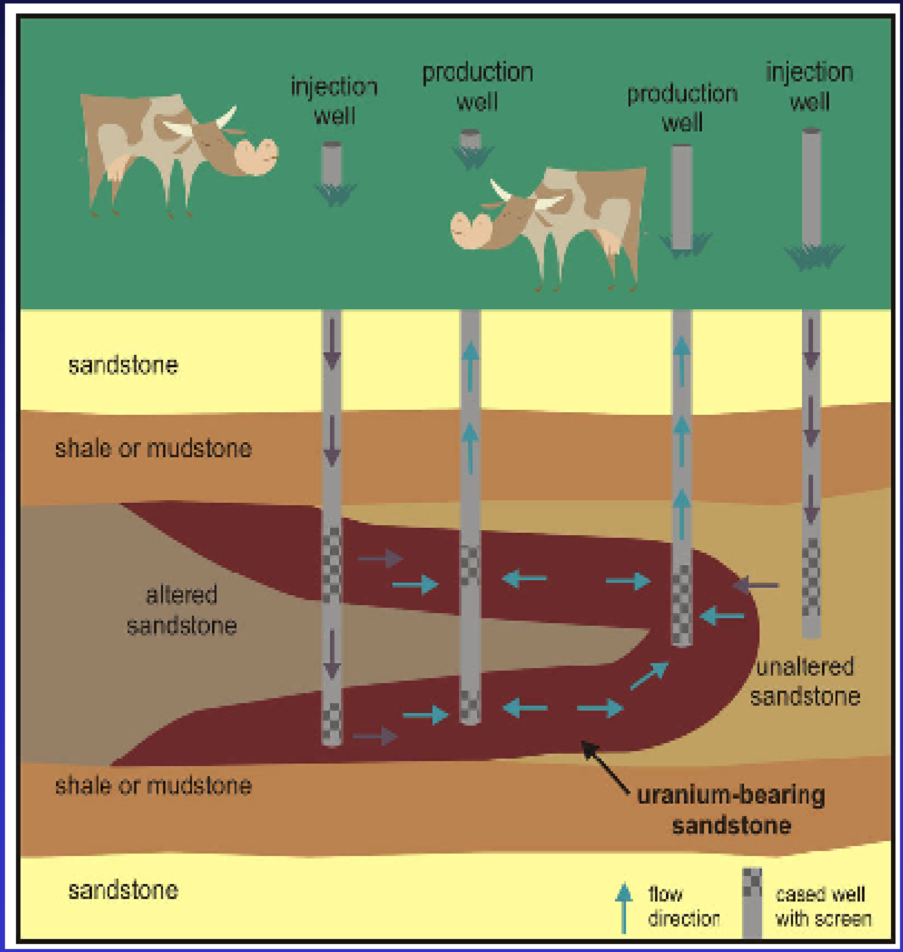


Klise and others, 2007

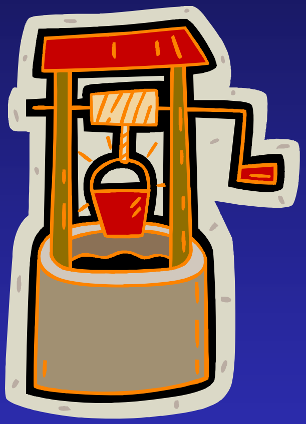
Ground-water velocity field

Images courtesy of Gary Weissmann
Univ. of New Mexico

Would you believe this?



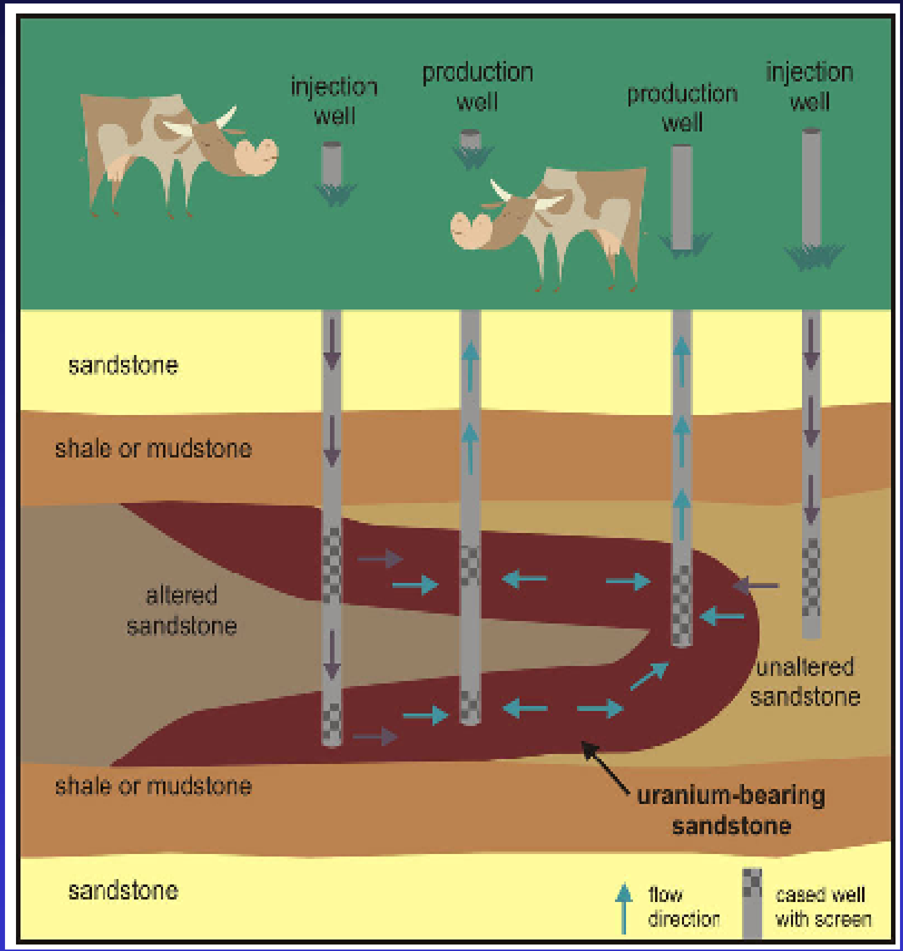
Compliance point



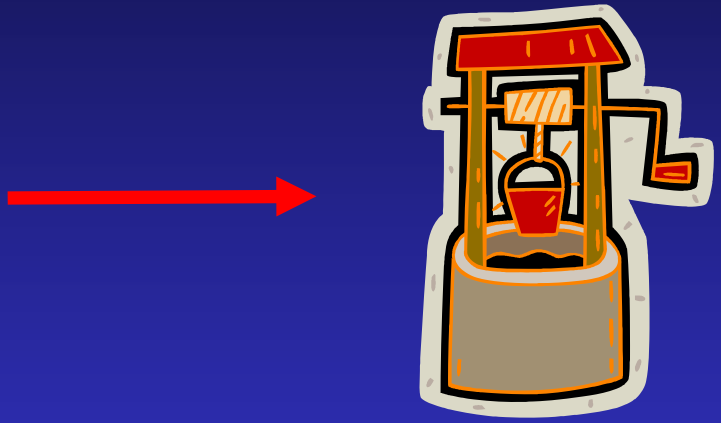
30 years

Uranium = 30 ppb

Or more likely to believe this?



Compliance point



30 years

80 percent probability that uranium will be less than 30 ppb

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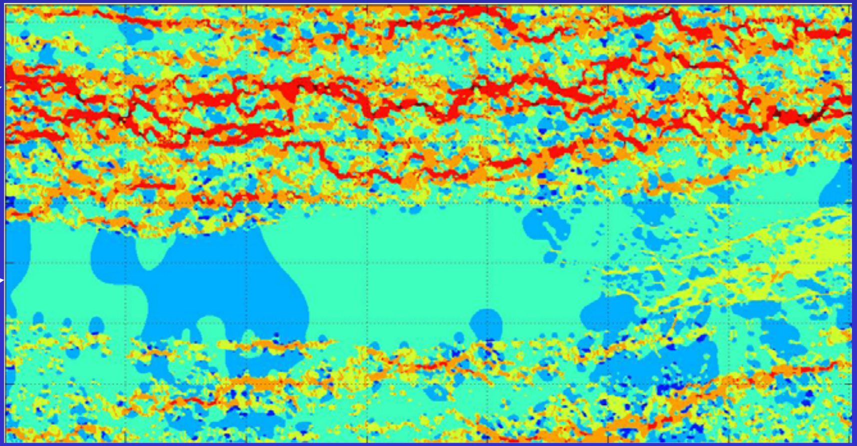
Factors that influence uncertainty

- Heterogeneous geology
- Heterogeneous flow and geochemistry
- Unknown geochemical reactions
- Scale (add or reduce complexity?)
- Overall system representation

Fast flow

Slow flow



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How to quantify uncertainty

- Use multiple conceptual models
  - Uncertain geology
  - Alternate geochemical reactions
- Use Monte Carlo simulations
  - Add “random” heterogeneity
- Inverse Modeling
  - Understand parameter sensitivities
  - Calculate prediction uncertainty

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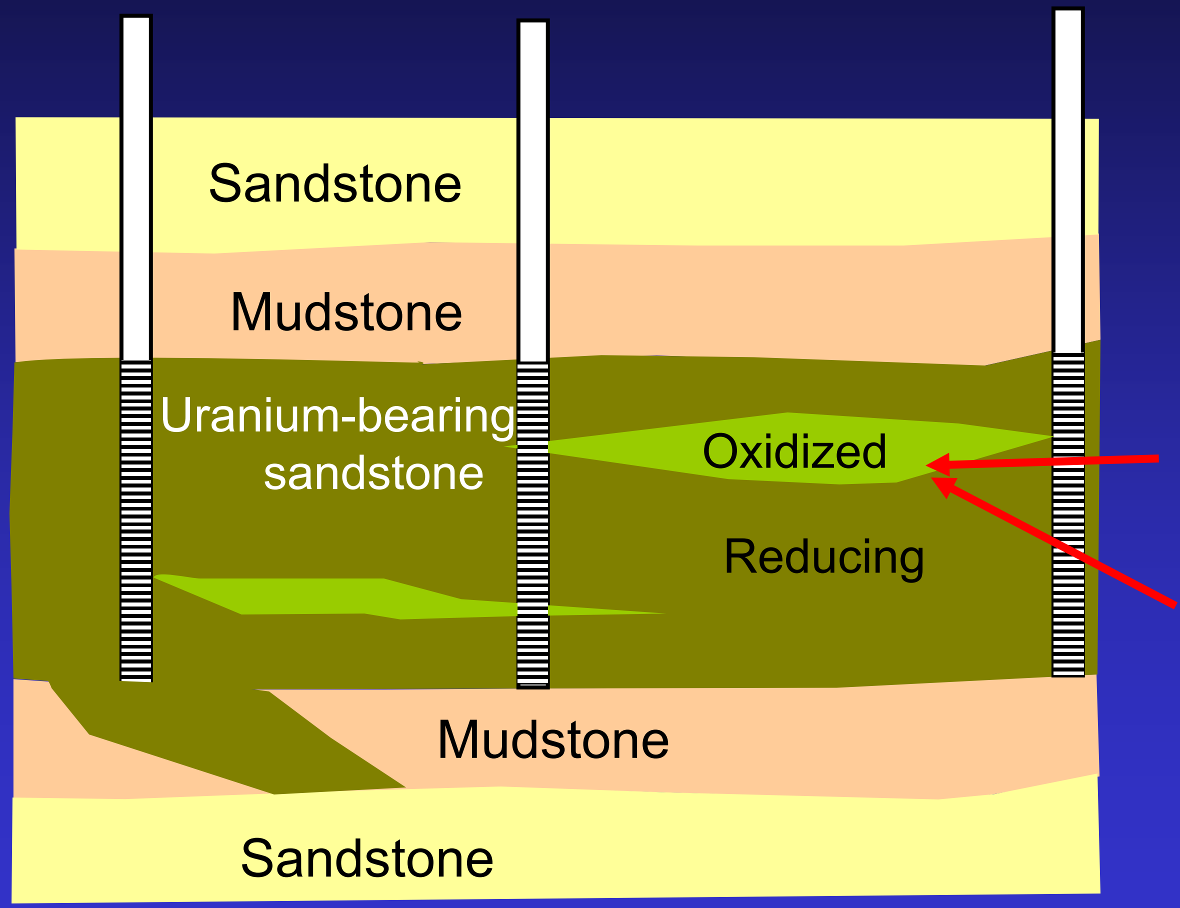
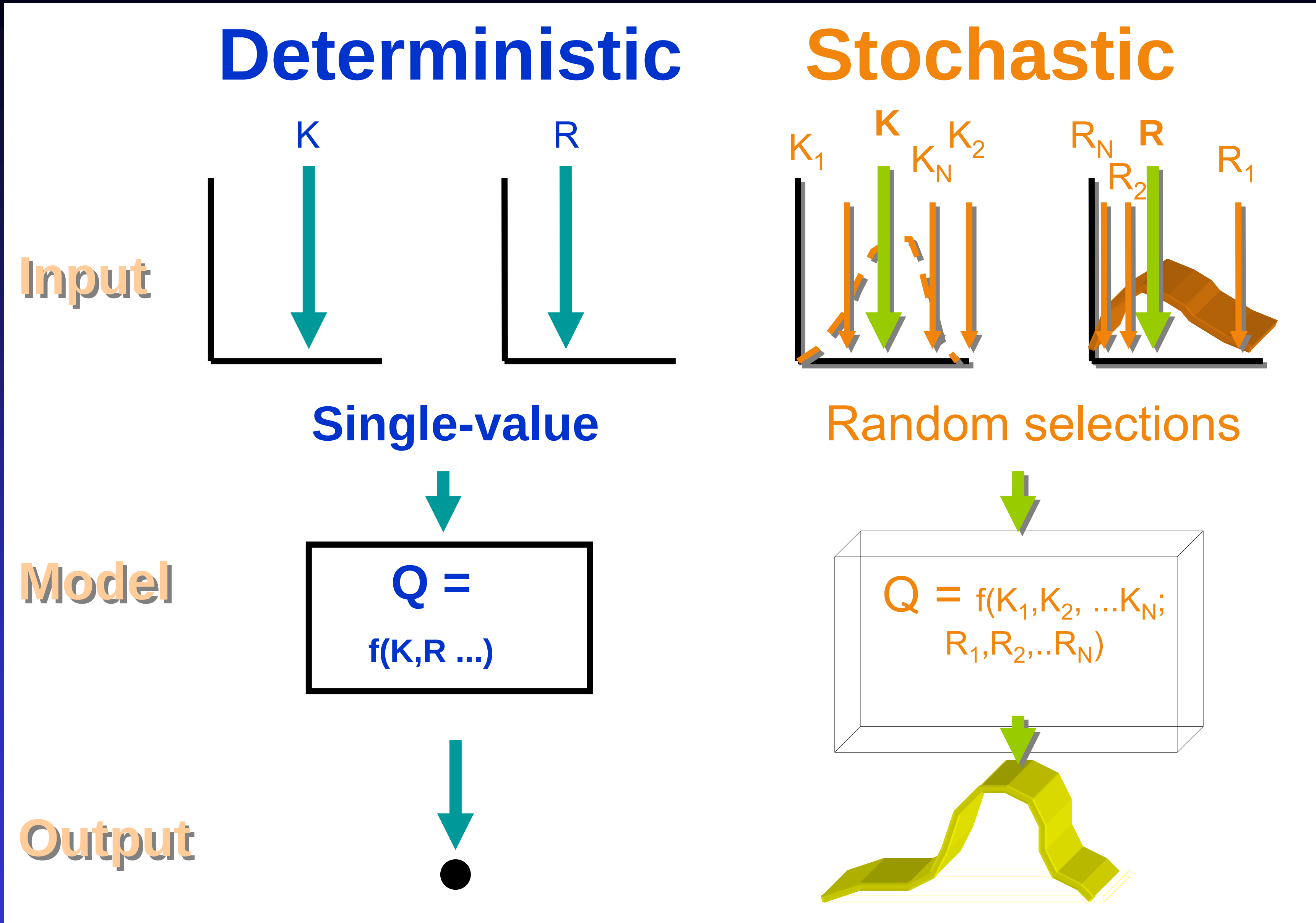
Multiple conceptual models

Scale



Oxygen

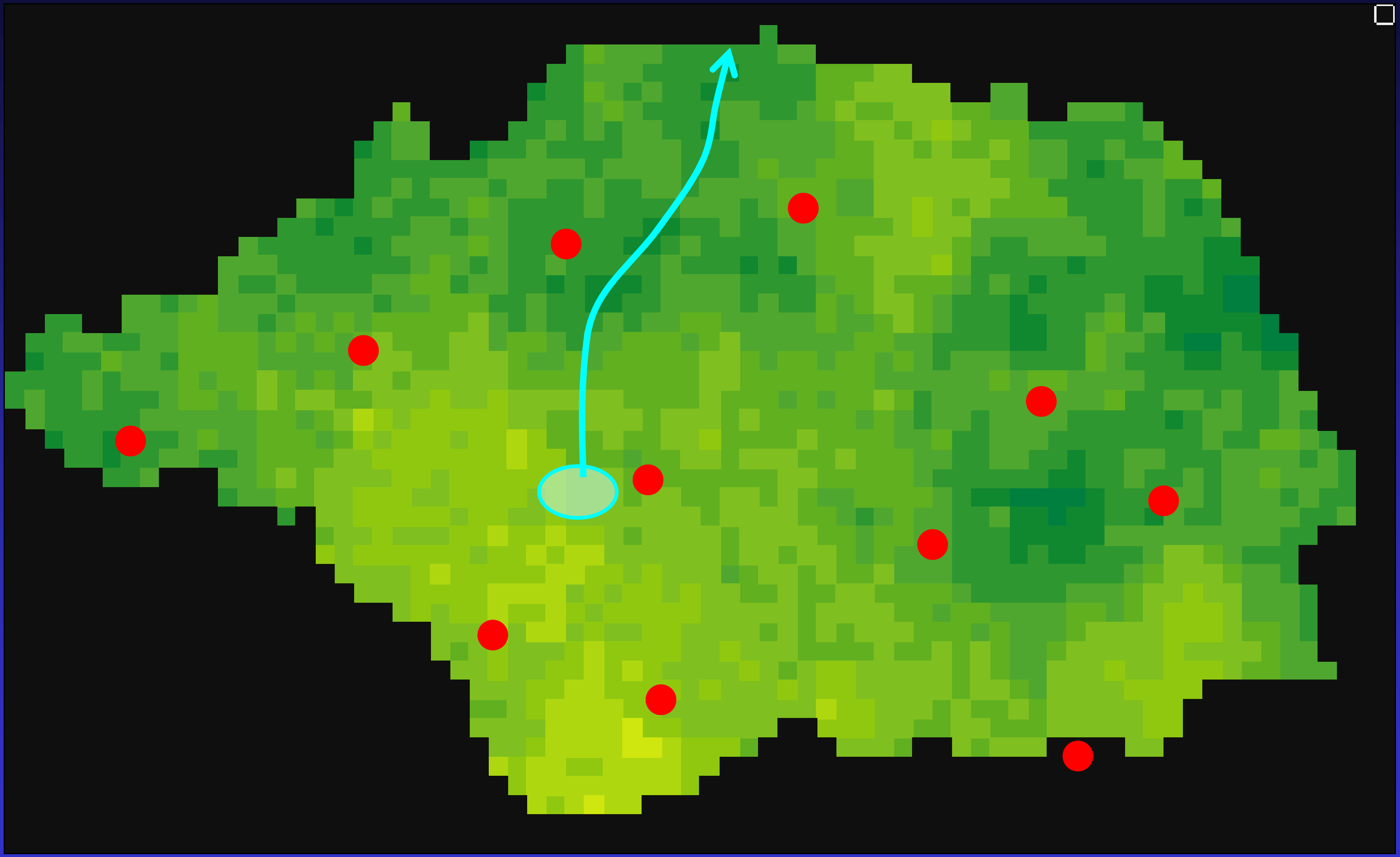
Fe (III)



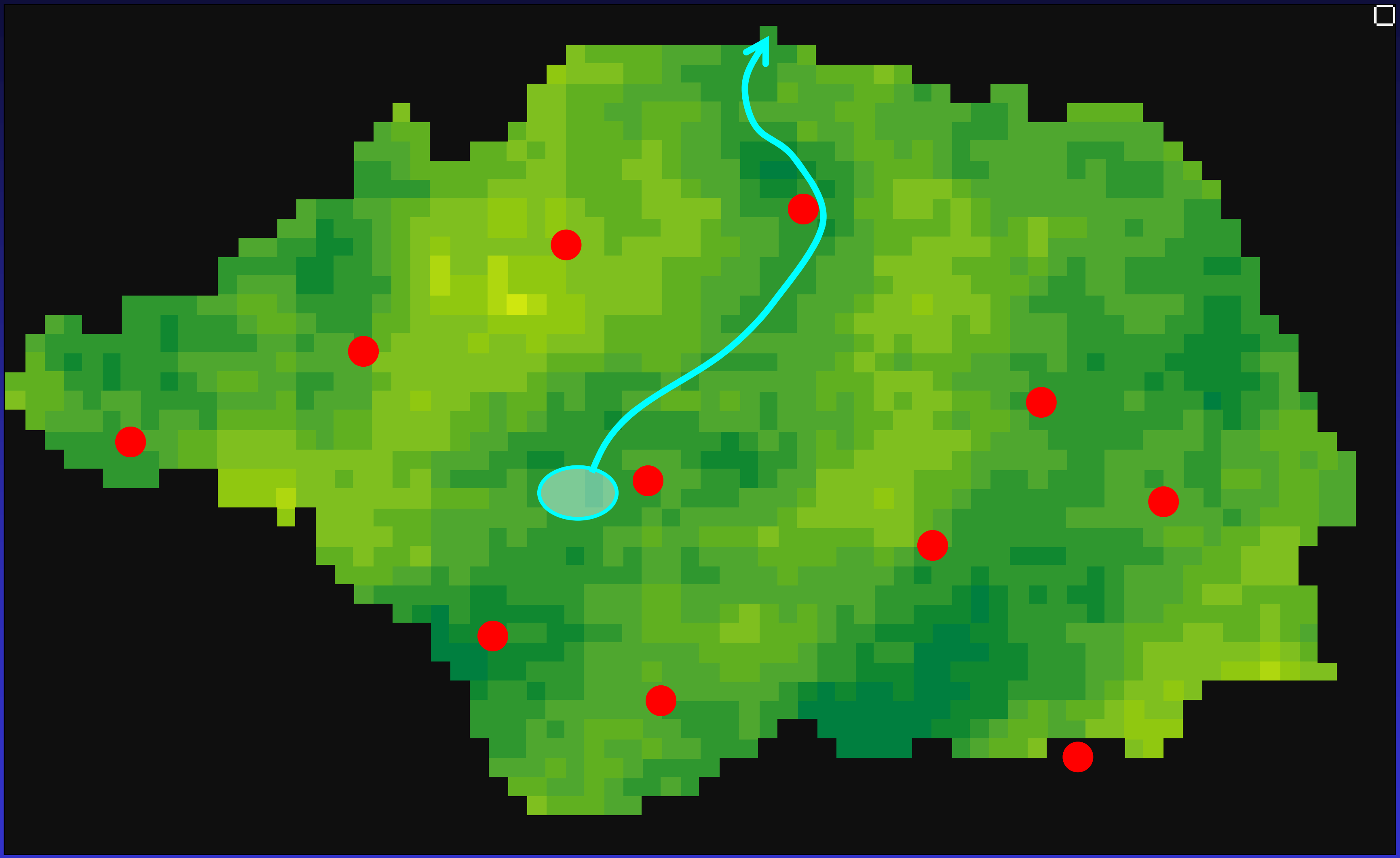
One conceptual model

Monte Carlo

Hydraulic property realization 1

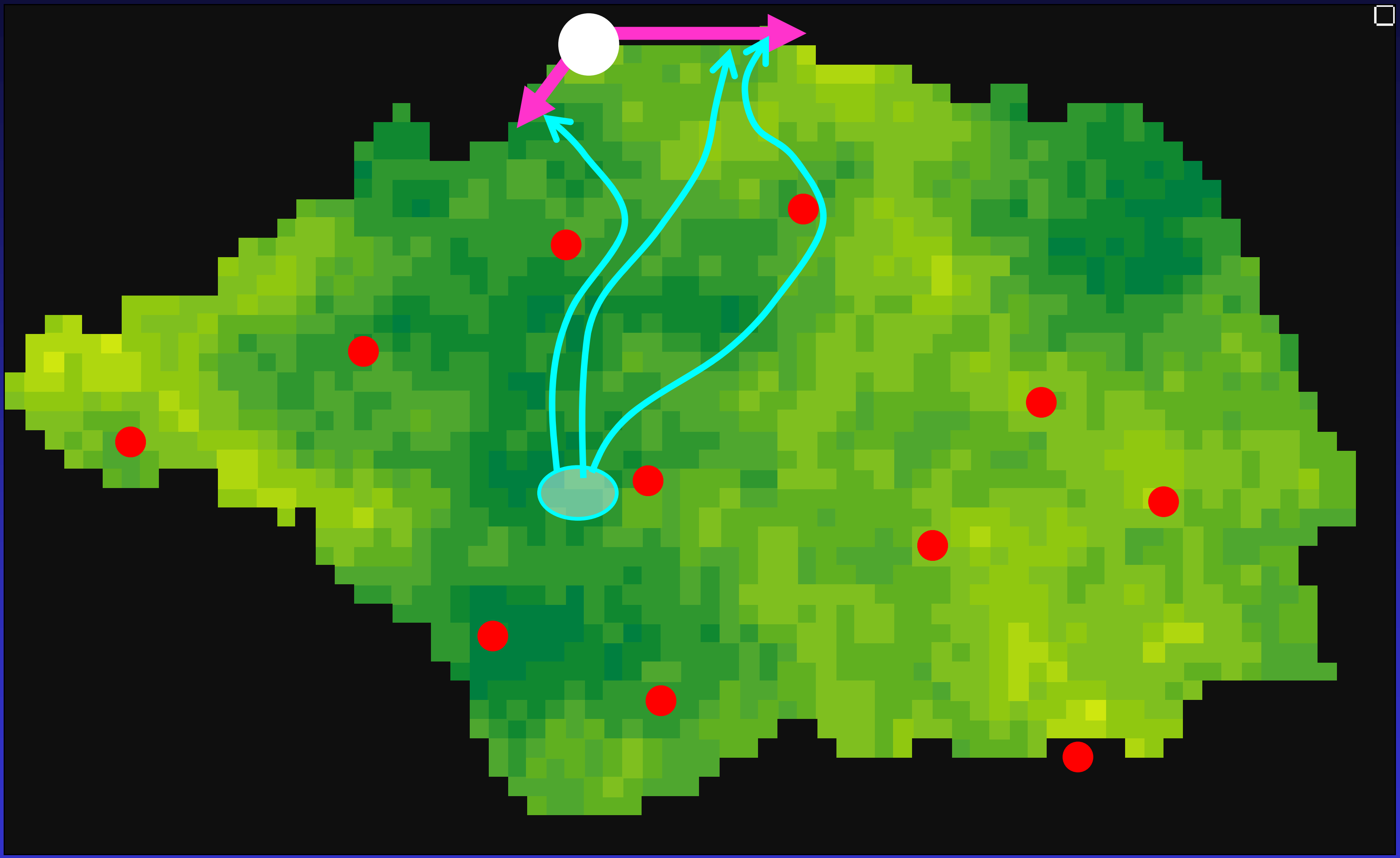


Hydraulic property realization 33

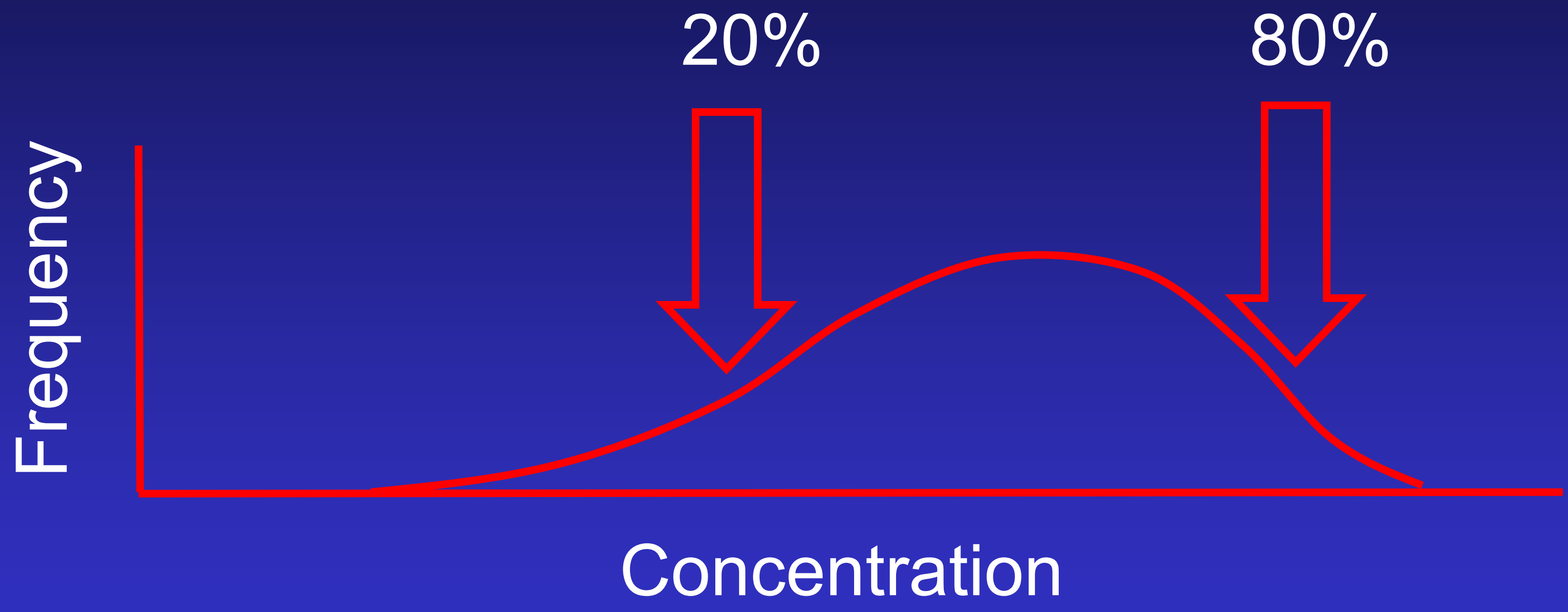


Likelihood of a concentration at a point

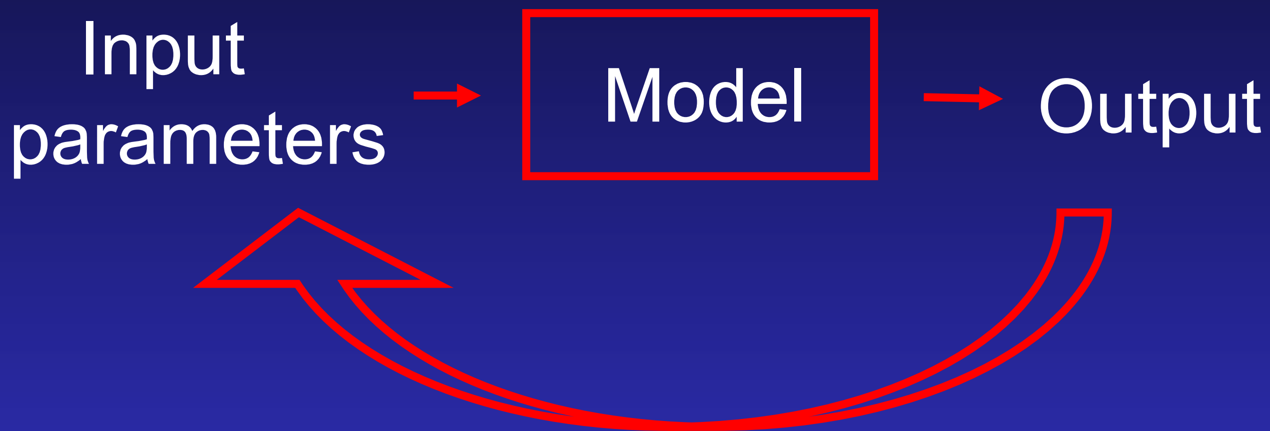
Likely region of discharge to stream



Probability density function



Inverse modeling



Look at calibration quality

Updates parameters

Calculates sensitivities

Calculates prediction uncertainties

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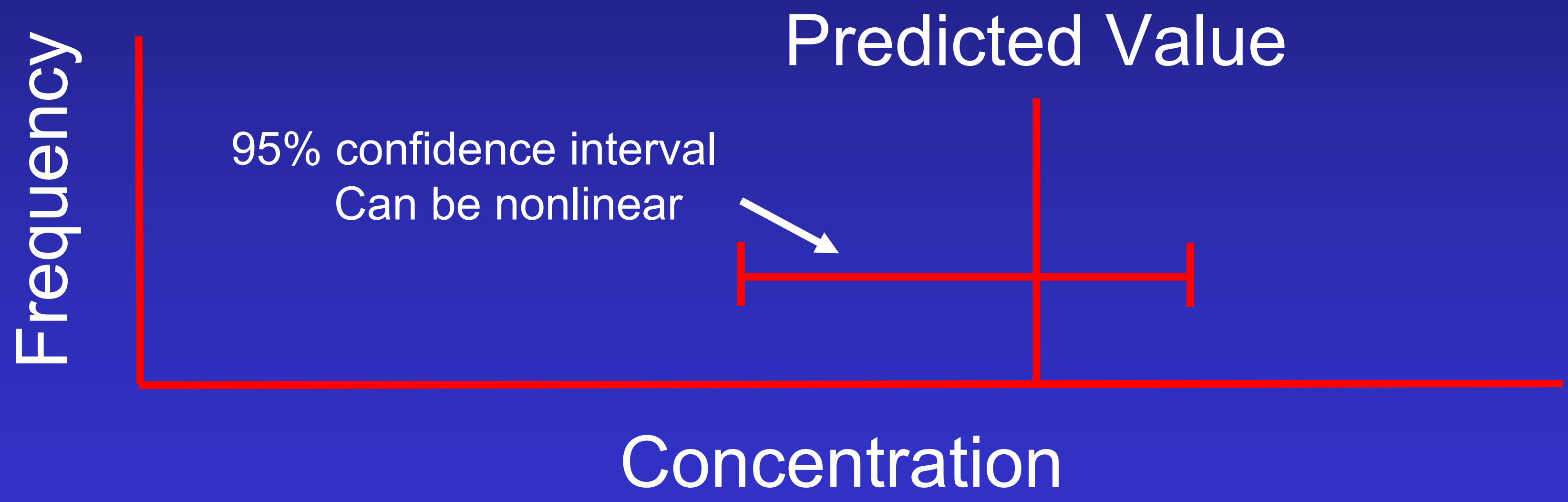
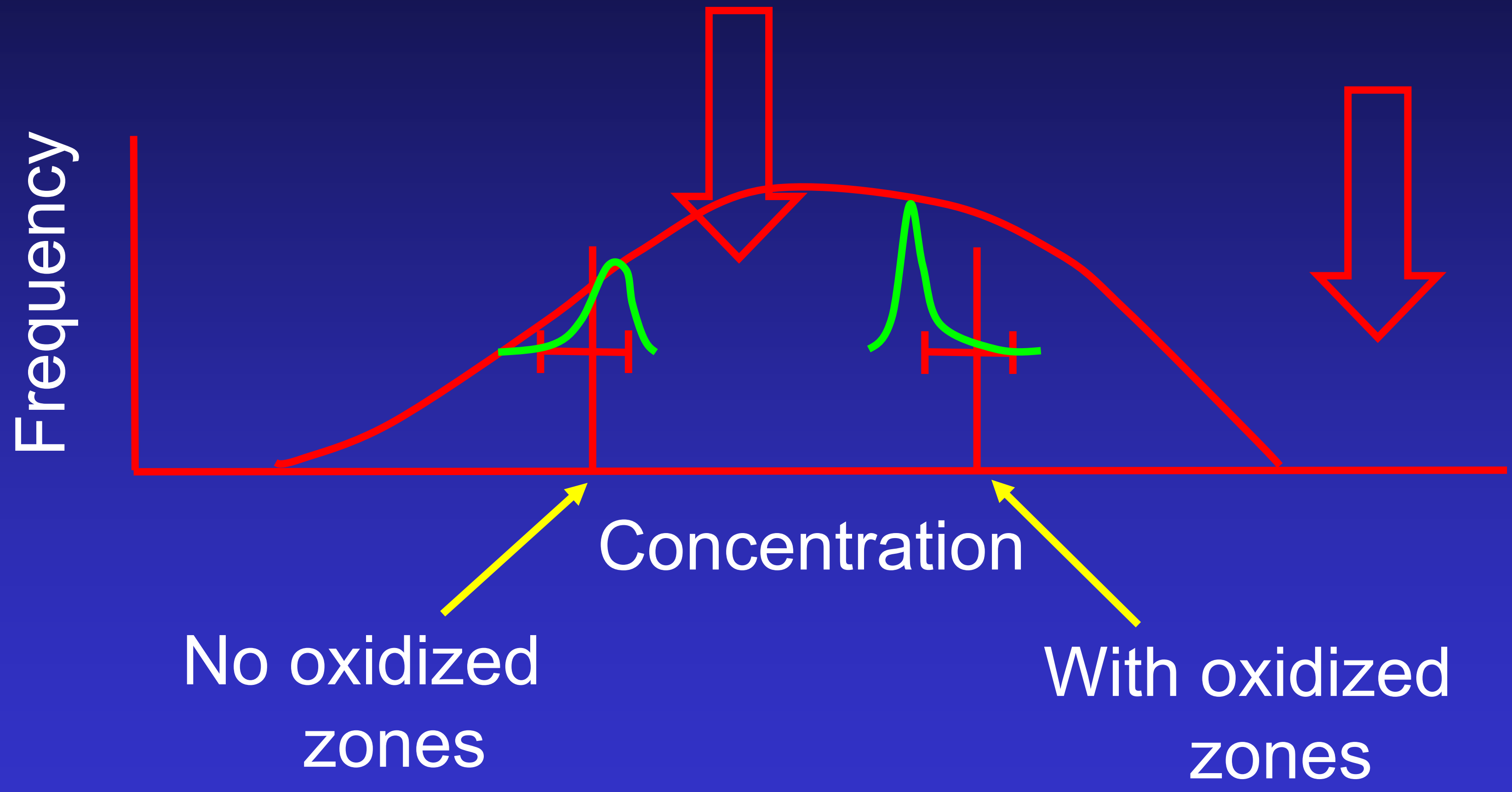
Prediction uncertainty

- Measurement uncertainty
- Sensitivities



Put it all together



After diagram by Eileen Poeter

End goal

- Predictions that adequately account for uncertainty
- Use these predictions to evaluate environmental risk with different restoration options

To conclude

- Future research will be tackling these goals
- Just doing basic restoration modeling at ISL mines will be complex!
- BUT - don't forget uncertainty

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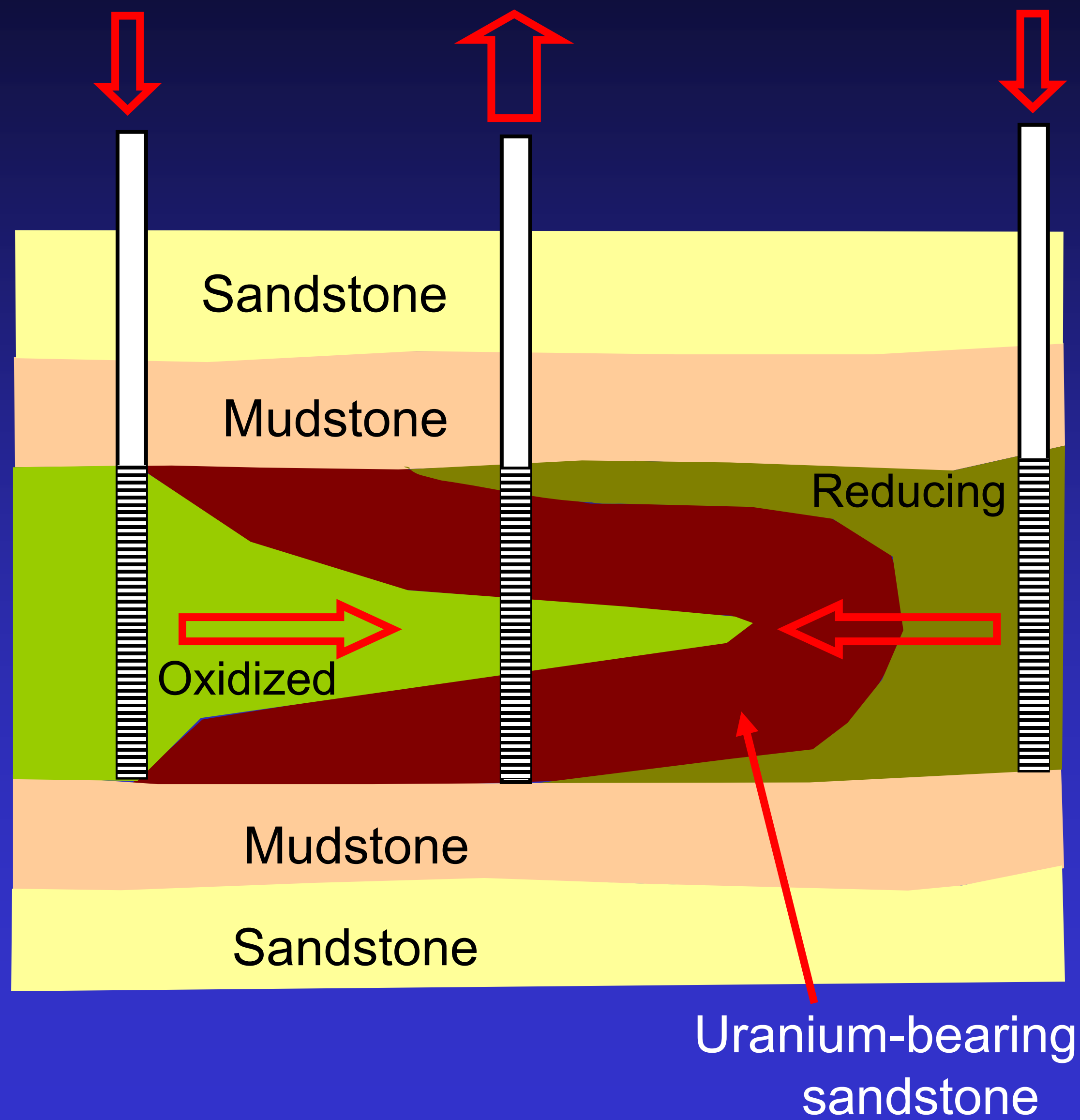
Questions?


Sandstone
Mudstone
Reducing
Oxidized
Mudstone
Sandstone
Uranium-bearing
sandstone