SAND2022-16681C

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Spent Fuel and Waste Science and Technology (SFWST)

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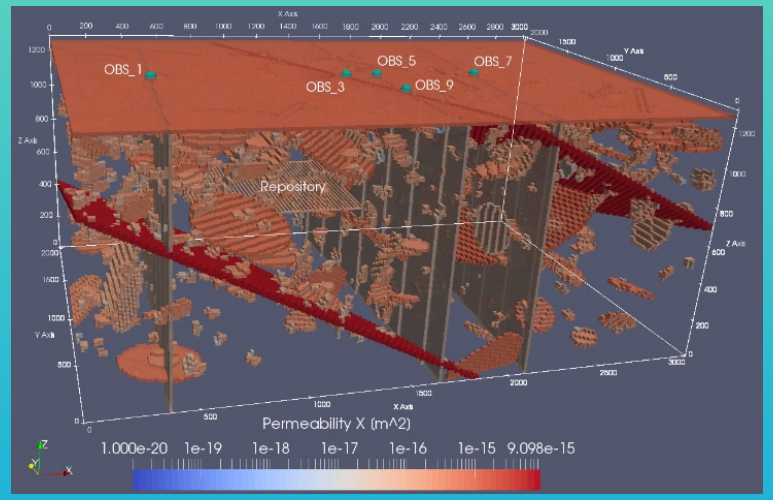

Sensitivity analysis for deep geologic repository simulations in crystalline rock

AGU Fall Meeting December 12-16, 2022
Chicago, IL, USA

Slides courtesy of Dusty Brooks

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Purpose of Sensitivity Analysis (SA)

- Identify features, events, and processes (FEPs) and their related parameters important to
  - Performance (safety)
  - Uncertainty (confidence)
- Quantify the relative importance of these inputs and FEPs
- Use the results to
  - Improve understanding of the system
  - Identify FEPs and inputs that require careful characterization (and data collection)
  - Identify weaknesses in the system that might be averted by a change in repository design or site

Crystalline Reference Case Investigation

- Generic, hypothetical site
- Crystalline rock similar to Forsmark
  - Decreasing fracture density with depth
  - Established hydraulic conductor domains (HCDs)
- In-drift emplacement
  - Non-copper waste packages
    - Most or all fail by 1 million years
  - Buffer surrounding waste packages
- Ref: Swiler et al. (2021a)

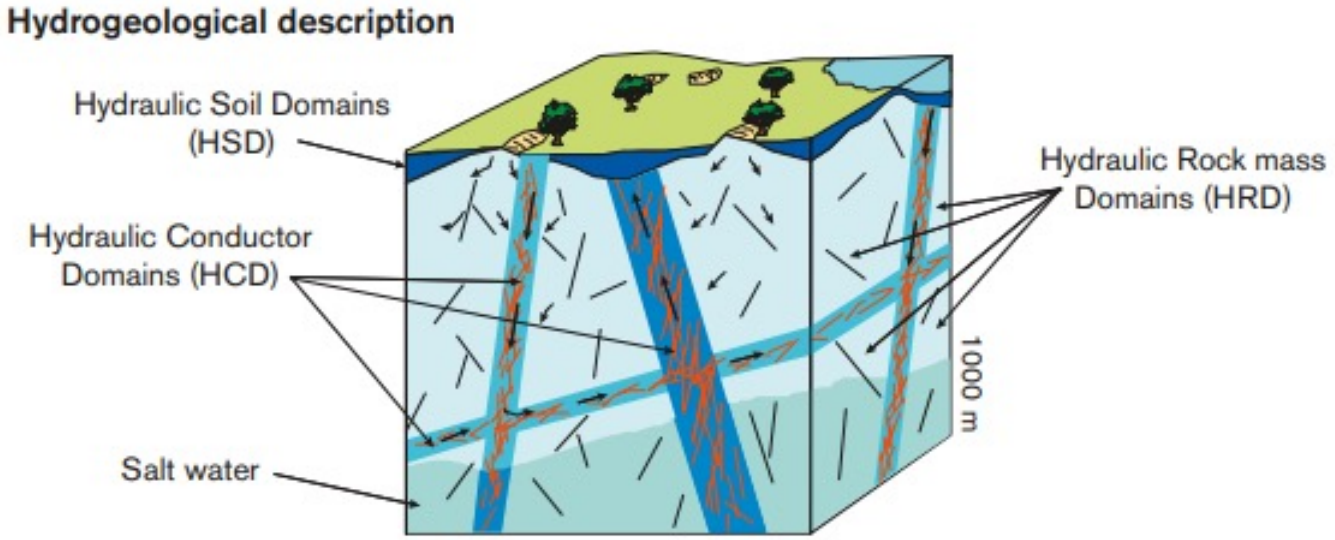


Figure 8-1. *Cartoon showing the division of the crystalline bedrock and the regolith above it (Quaternary deposits mainly) into three hydraulic domains.*

SKB (2008)

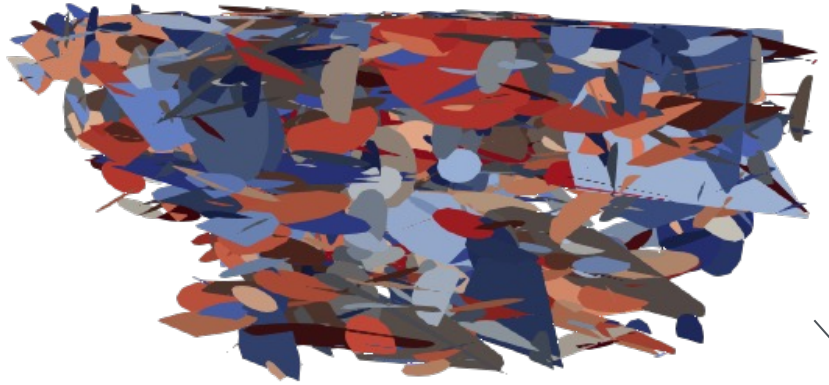
Discrete Fracture Network Implementation

$$r \sim p_r(r)$$
$$\theta \sim p_\theta(\theta)$$
$$P_{32} \approx P_{32}^{target}$$

Statistical models

dfnWorks DISCRETE FRACTURE NETWORK

Los Alamos NATIONAL LABORATORY EST. 1943



Discrete Fracture Networks (DFNs)

mapDFN

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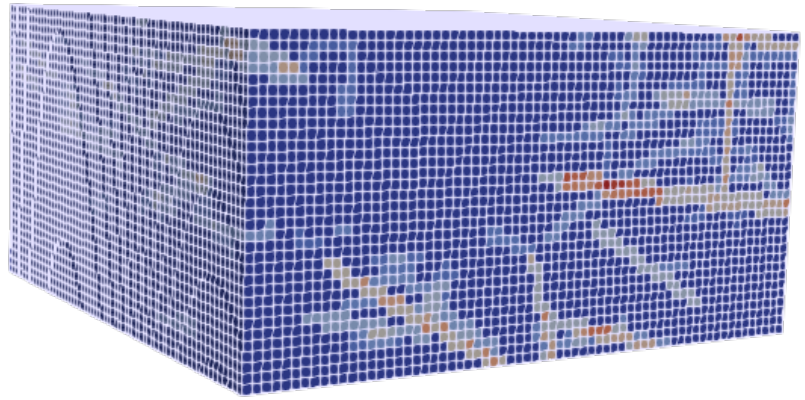
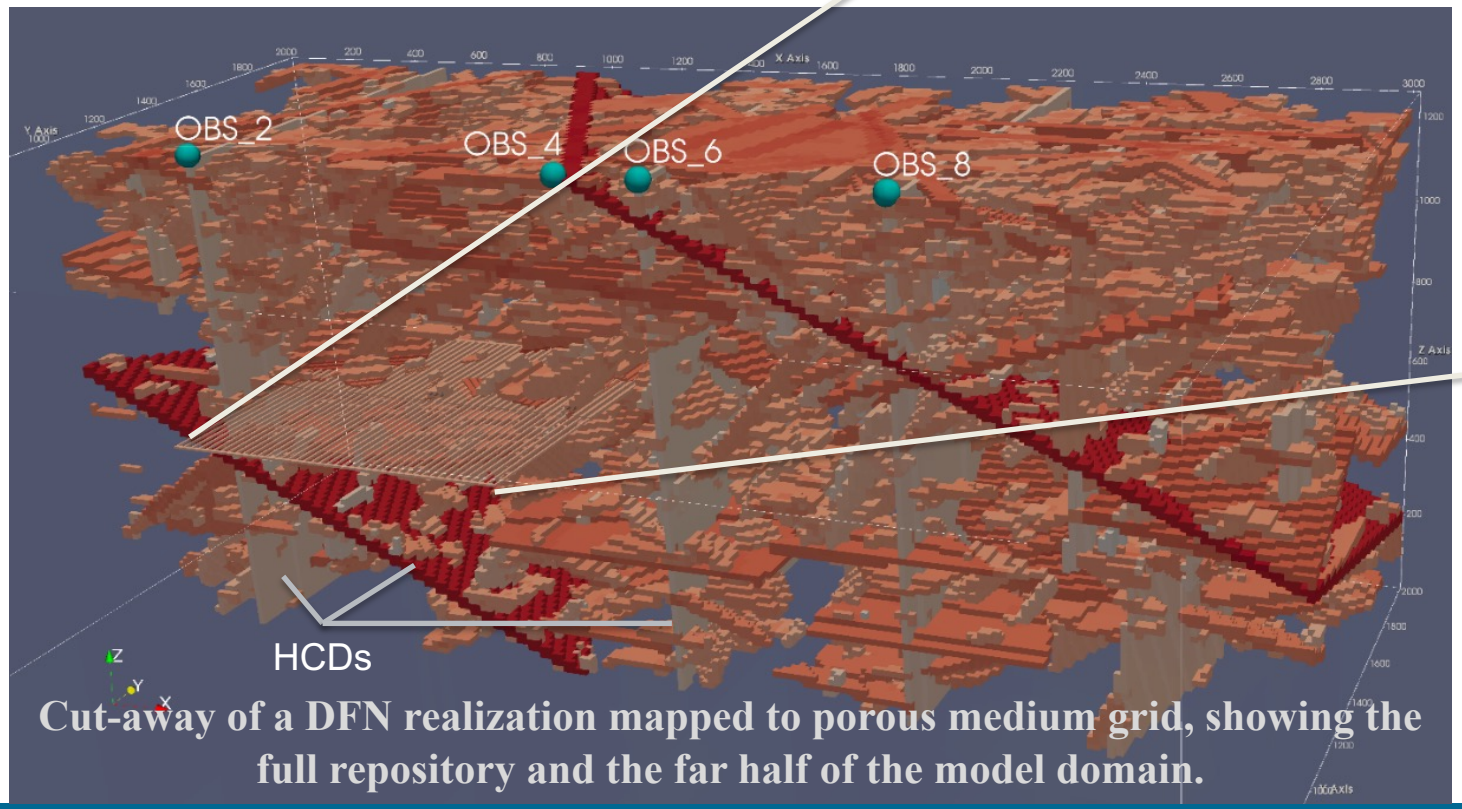


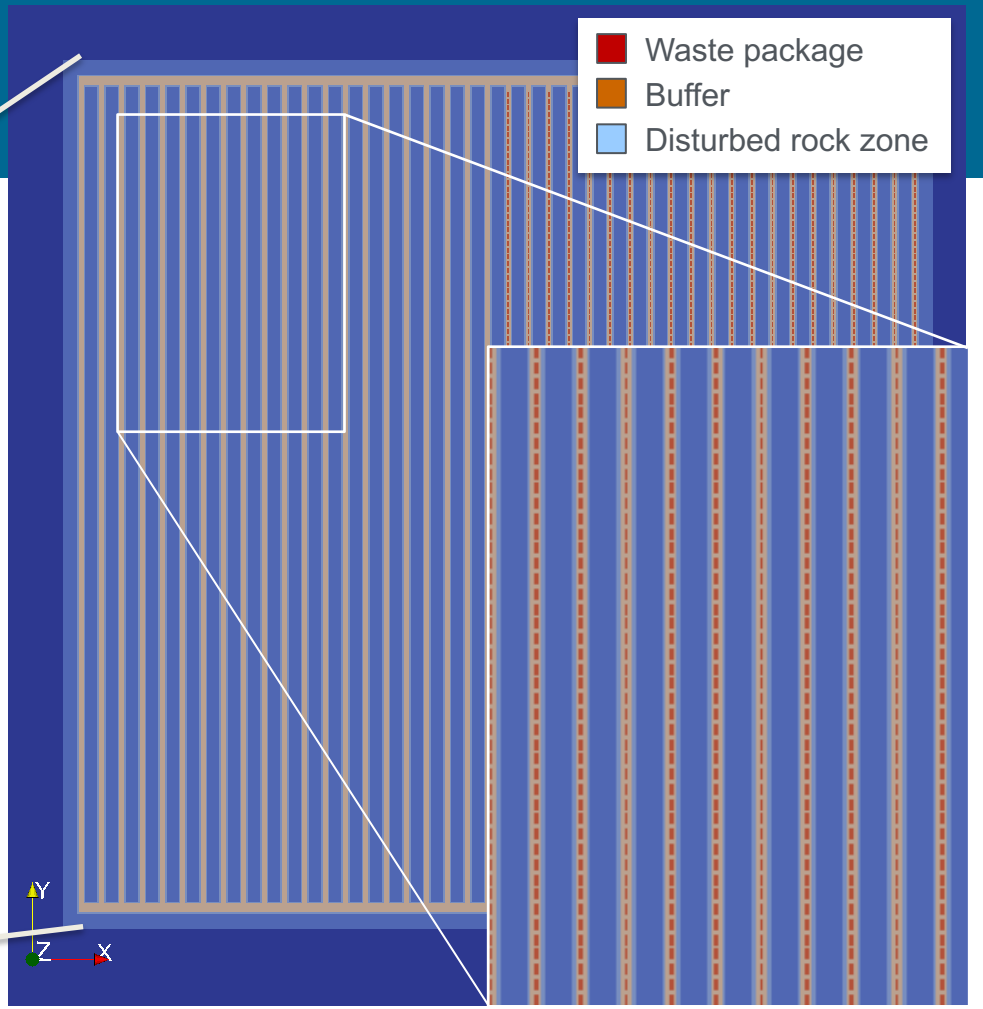
Equivalent Continuous Porous Media (ECPMs)

Domain and Mesh

- Repository located at a depth of 585 m
- Domain: 3000 × 2000 × 1260 m
- 4.8 million grid cells



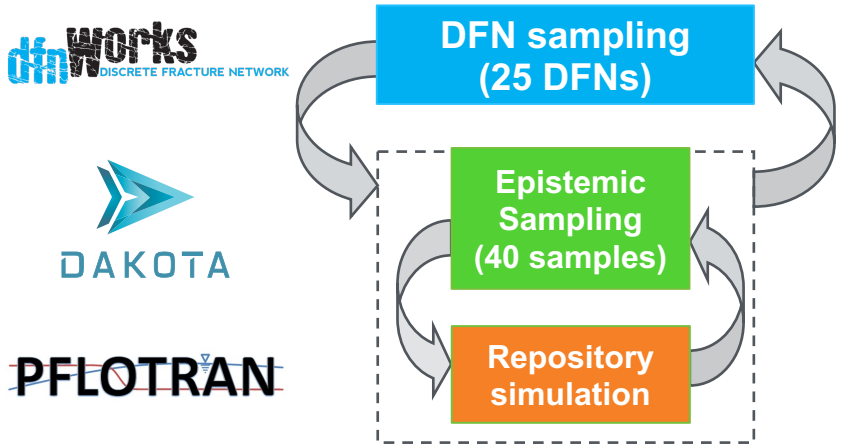
Cut-away of a DFN realization mapped to porous medium grid, showing the full repository and the far half of the model domain.



- 1680 total waste packages
- 1.67 m cells in repository region
- 15 m cells in far field

Crystalline Reference Case

- Nested sampling to understanding the relative importance of spatial variability vs epistemic uncertainties. 1000 PFLOTRAN runs.

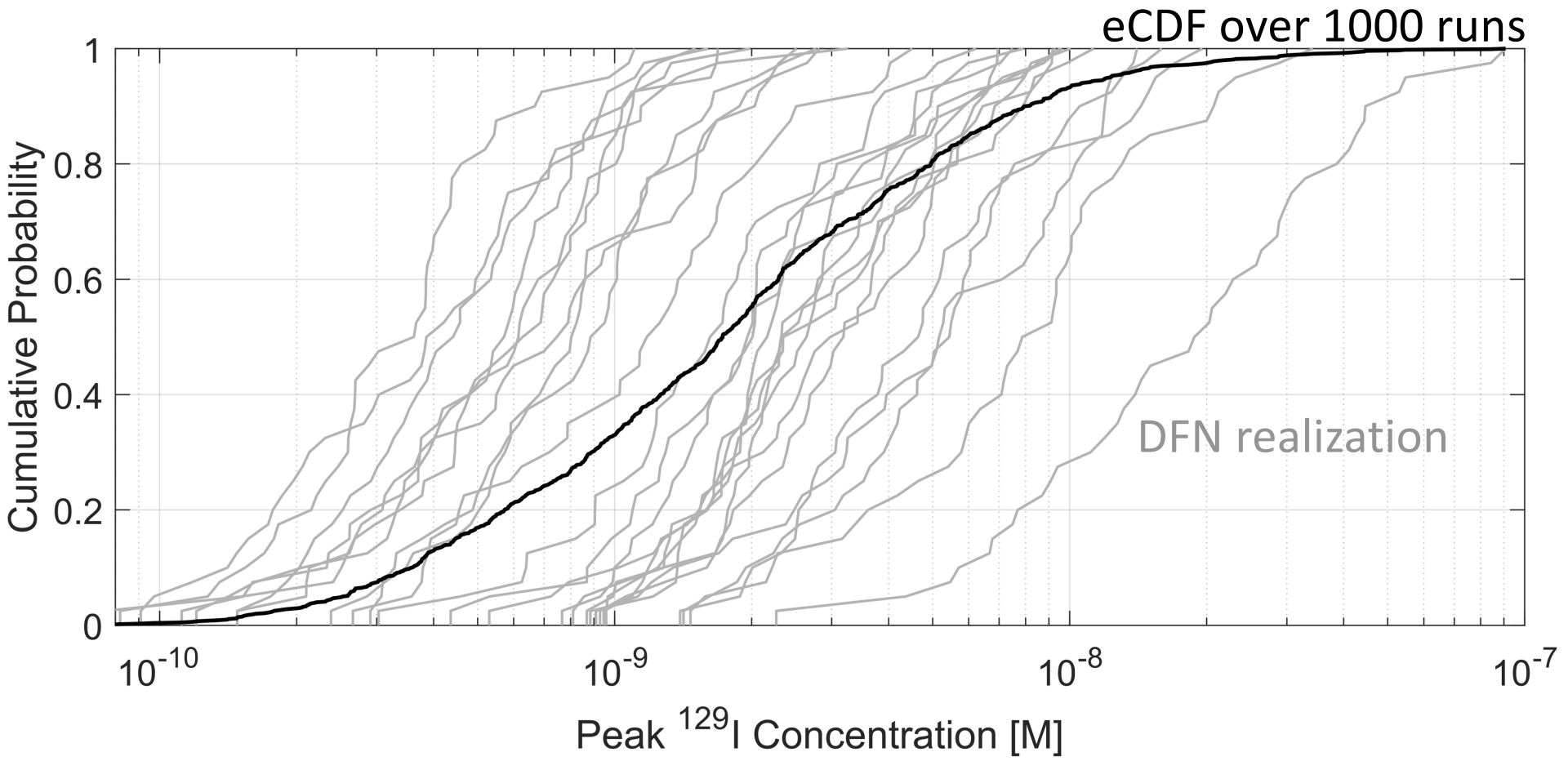


Epistemic Variables	
Input	**Description**
rateUNF	Fractional dissolution rate of spent (used) nuclear fuel
kGlacial	Glacial till permeability
pBuffer	Buffer porosity
permDRZ	DRZ permeability
permBuffer	Buffer permeability
meanWPrate	Mean of the waste package corrosion rate
stdWPrate	Standard deviation of the waste package corrosion rate
IRF	Instant release fraction

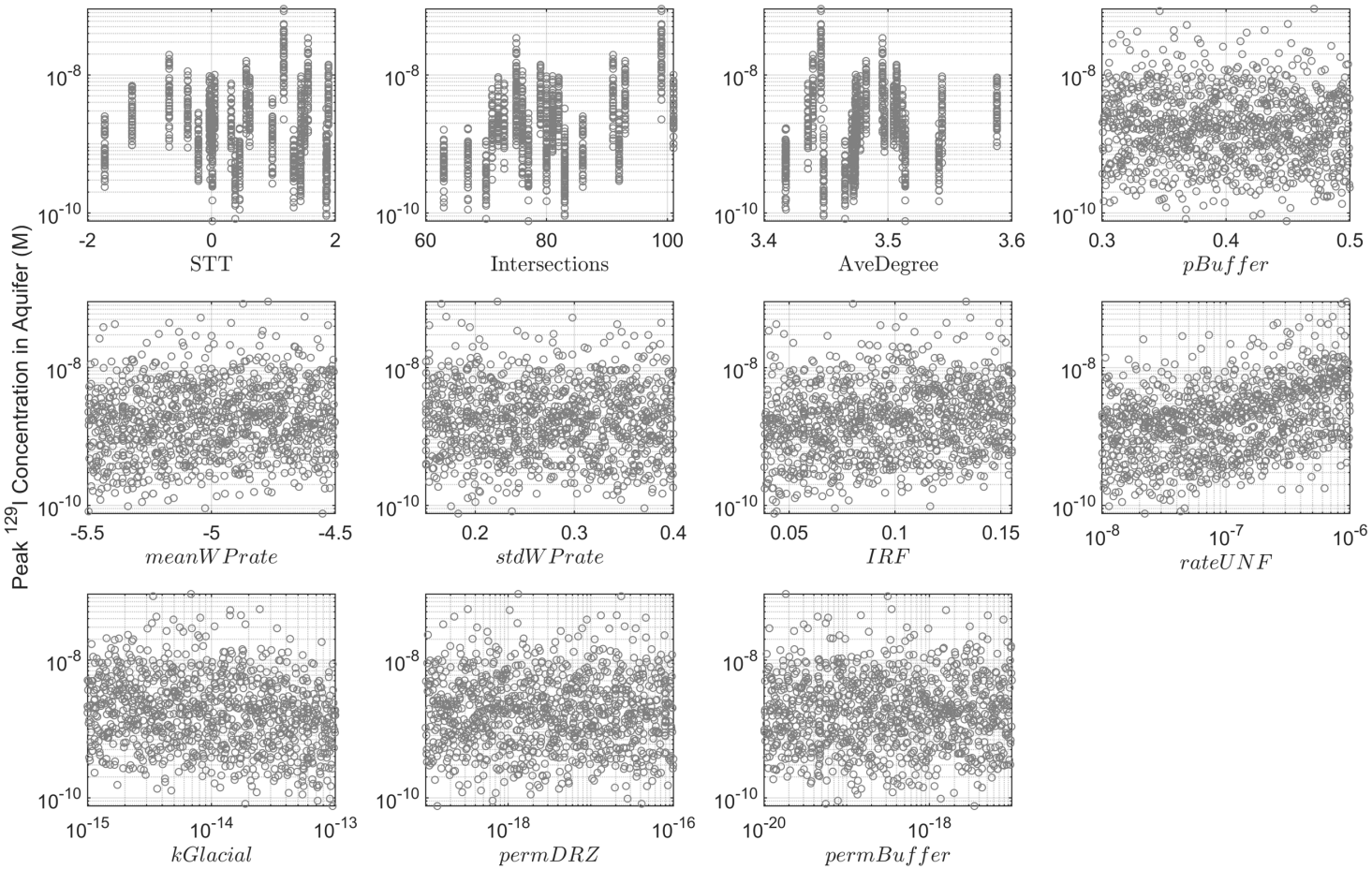
Measures of Spatial Heterogeneity (Graph Metrics)	
Graph Metric	**Description**
STT	The relative shortest travel time between repository and aquifer.
aveDegree	Average number of inter-sections per fracture. A measure of how connected the network is over the entire domain.
Intersections	Number of fractures intersecting the repository. A measure of number of potential flow pathways out of the repository region.

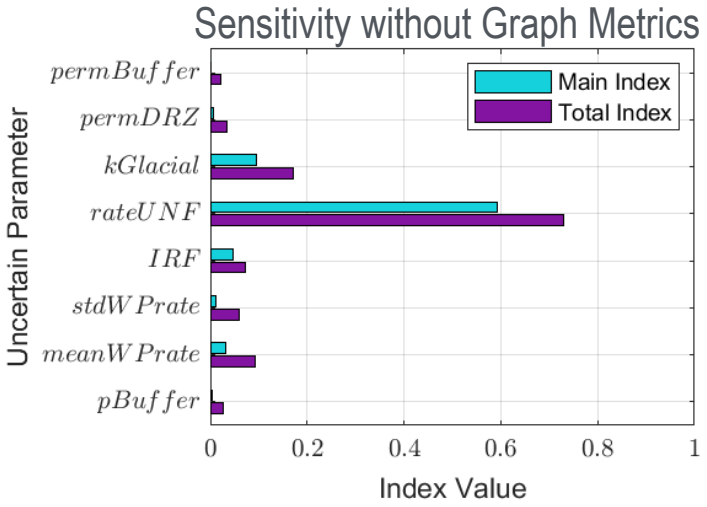
Quantities of Interest (QoI)	
QoI	**Description**
Peak_I129_M [M]	Peak I-129 concentration in the aquifer.
Fractional Mass Flux from Repo_1Myr [-]	Instantaneous fractional loss rate of tracer remaining in repository at 1 Myr. Indicator of repository retention.
Rock Aq_Rock Eb_1Myr [-]	Ratio of rock-to-aquifer vs. rock-to-east-boundary water fluxes at 1 Myr. Indicator of hydrological behavior.
MdRTofSpikeinRepository [yr]	Time when half an initial mass of tracer is flushed from repository. Indicator of repository retention.

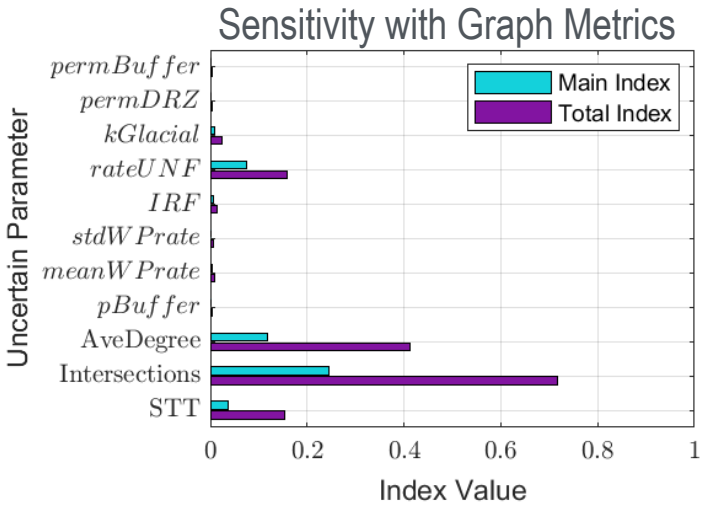
DFN realizations strongly affect performance QoI probabilities



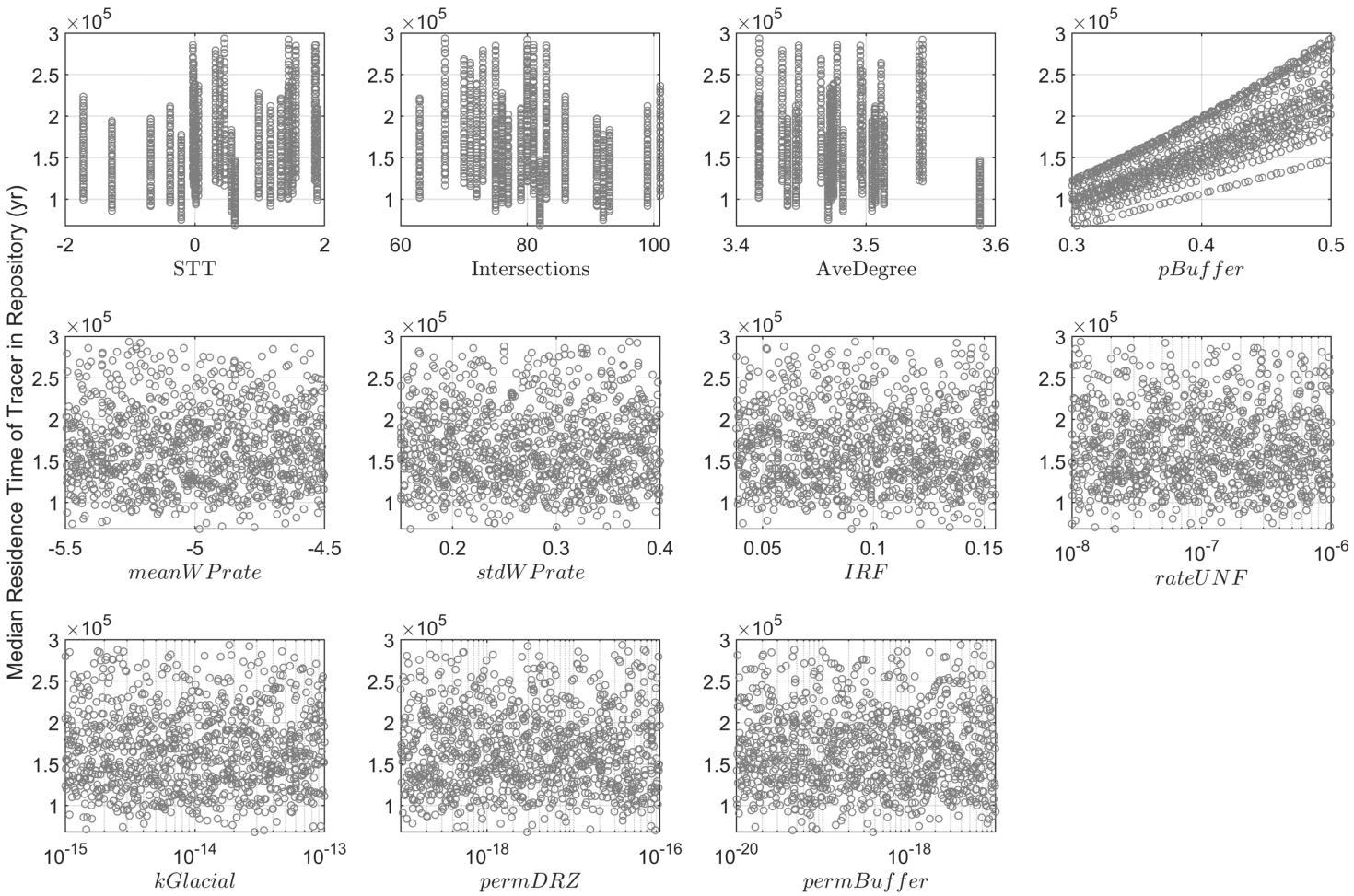
Peak ^{129}I concentration most sensitive to spatial heterogeneity and rateUNF

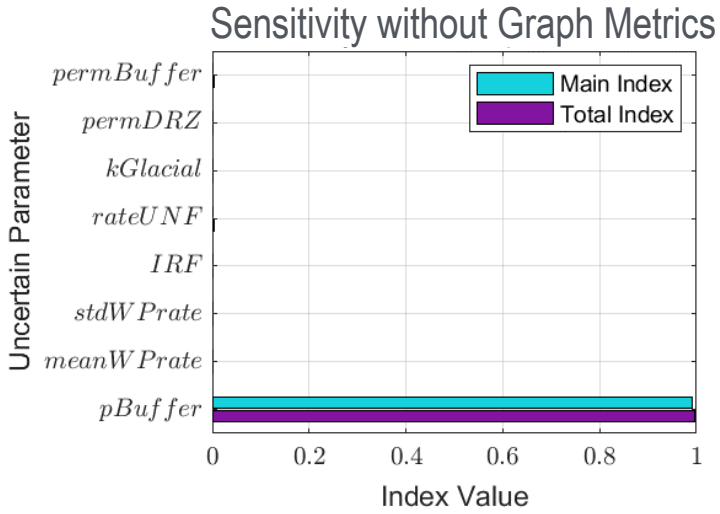


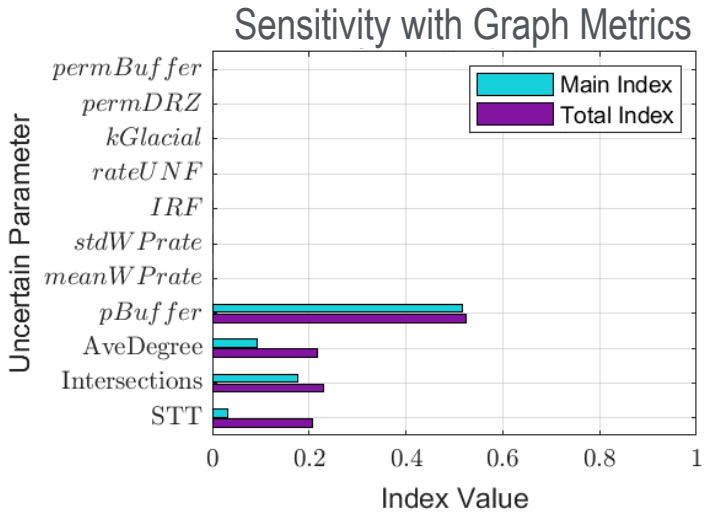




Mean Residence Time sensitive to spatial heterogeneity and pBuffer



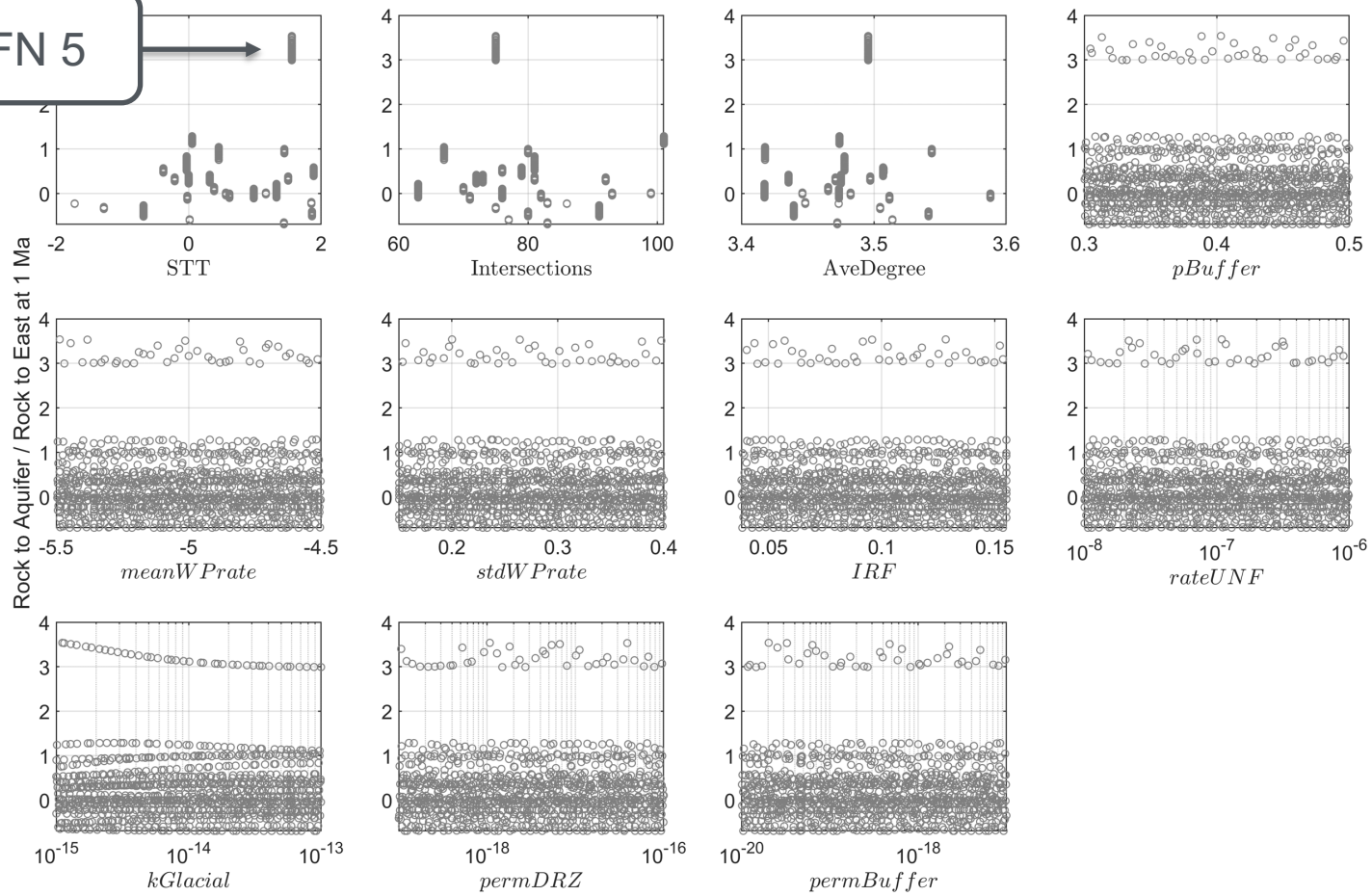


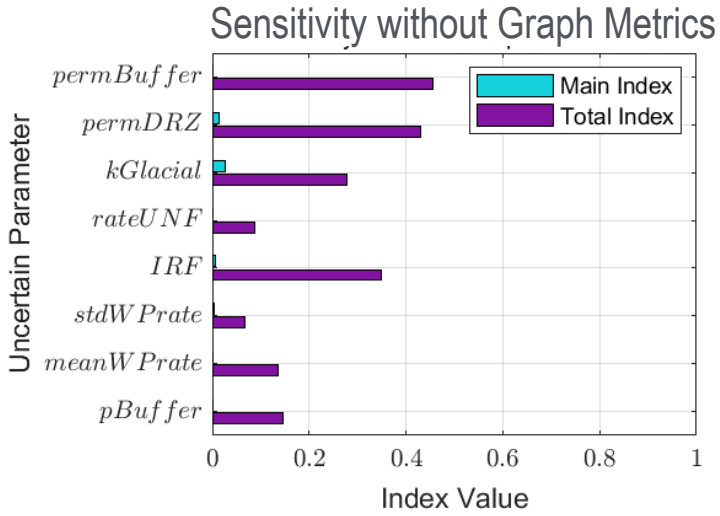


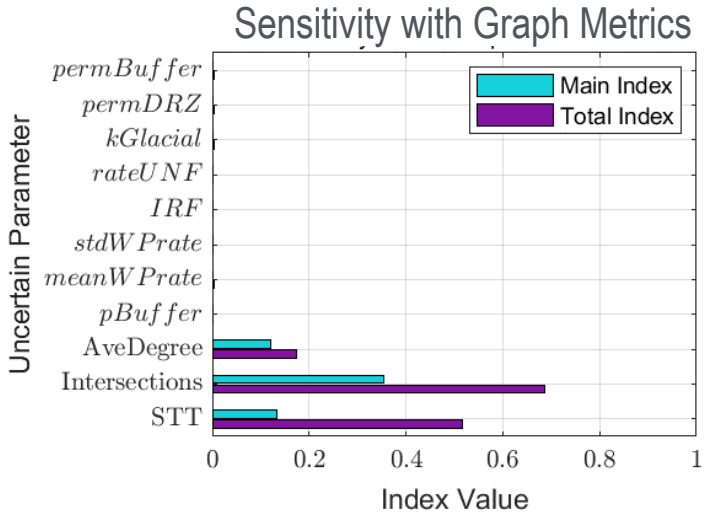
Rock to Aquifer : Rock to East Water Flux Ratios sensitive to spatial heterogeneity

- Method may underestimate sensitivity to kGlacial
- Graph metrics don't fully explain why DFN 5 has uniquely high values for this flux ratio

DFN 5







Expanded set of graph metrics for 100 DFNs don't show strong correlation with Peak ^{129}I Concentration

Graph Metric	Correlated Depth Dependent
Average Degree (average # intersections per fracture)	0.104
Length of Shortest Path Between Repo & Aquifer	-0.098
Number of Intersections with Repository	0.116
Number of Intersections	**-0.325**
Number of Fractures	**-0.307**
Shortest Travel Time Between Repo & Aquifer	0.085

Conclusions

- Spatial heterogeneity from stochastically generated DFNs dominates uncertainty in QoIs
- QoIs also sensitive to some epistemic uncertainties (rateUNF, pBuffer)
- Current graph metrics imperfectly represent effect of spatial heterogeneity
- Dual loop structure separates spatial + epistemic uncertainties
  - Further development needed to fully capture spatial heterogeneity's effect in sensitivity analysis

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