Predicting Saturated Hydraulic Conductivity over Time for Degrading Saltstone Vault Concrete – 20376

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WM2020, Phoenix, AZ
11 March 2020

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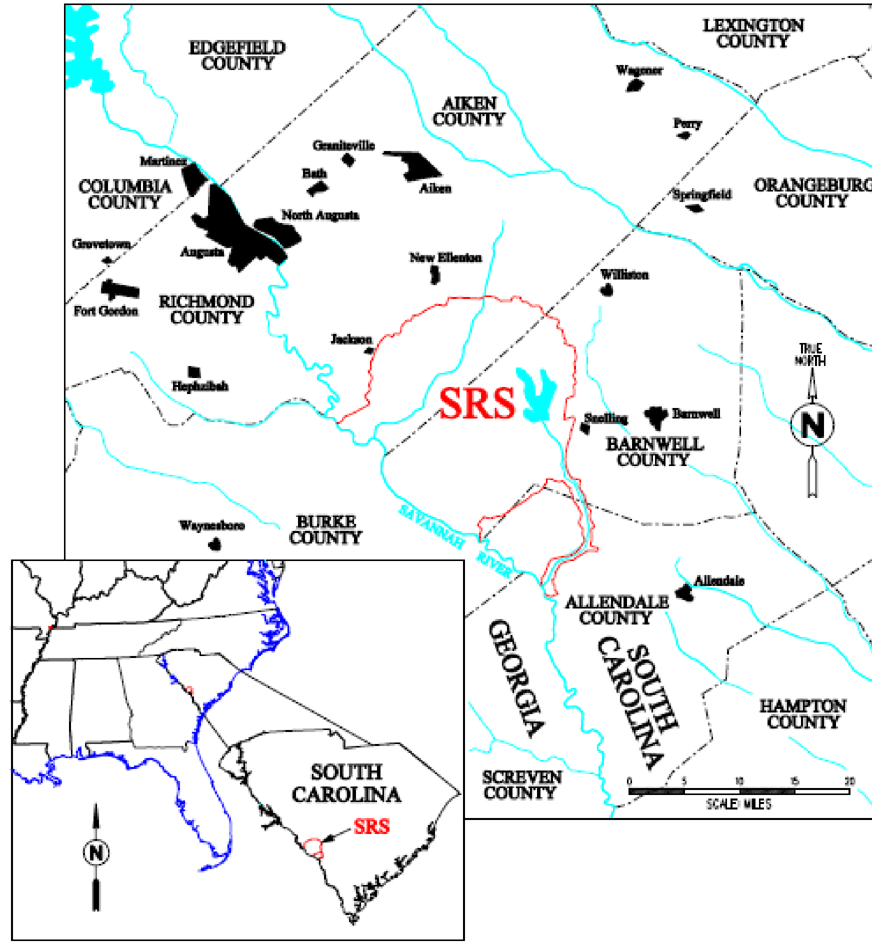
Presentation Outline

- Motivation
- Objective
- Background
- Results
- Summary and future directions



Source: SRR-CWDA-2009-00017, Rev. 0

CRESP
Consortium For Risk Evaluation with Stakeholder Participation

Motivation for this Research

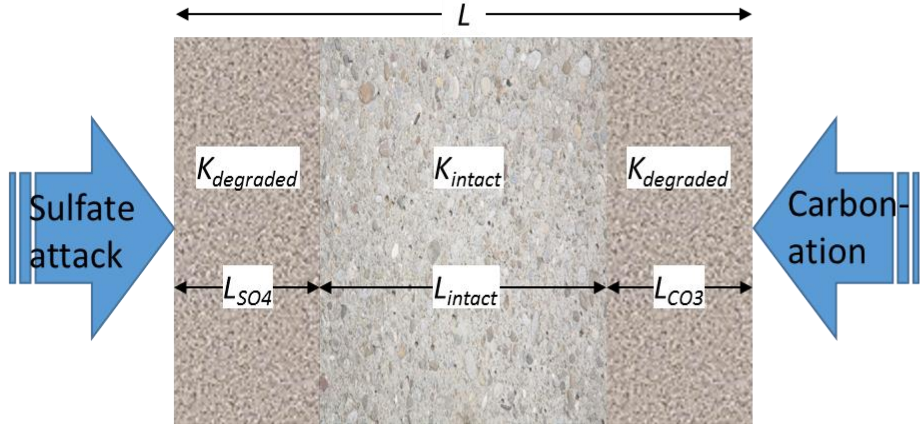
- US DOE has disposed of tank waste on-site at the Savannah River Site (SRS) as low-level radioactive waste (LLW) since 1990.
- The low-activity fraction of SRS tank waste is separated and stabilized with grout in a waste form denoted saltstone.
- Saltstone is disposed of in the Saltstone Disposal Facility (SDF) in very large concrete vaults denoted Saltstone Disposal Units (SDUs).
- The performance of the saltstone and vaults (SDUs) is evaluated in the SDF Performance Assessment (SRR-CWDA-2009-00017, Rev. 0), updated in 2019.

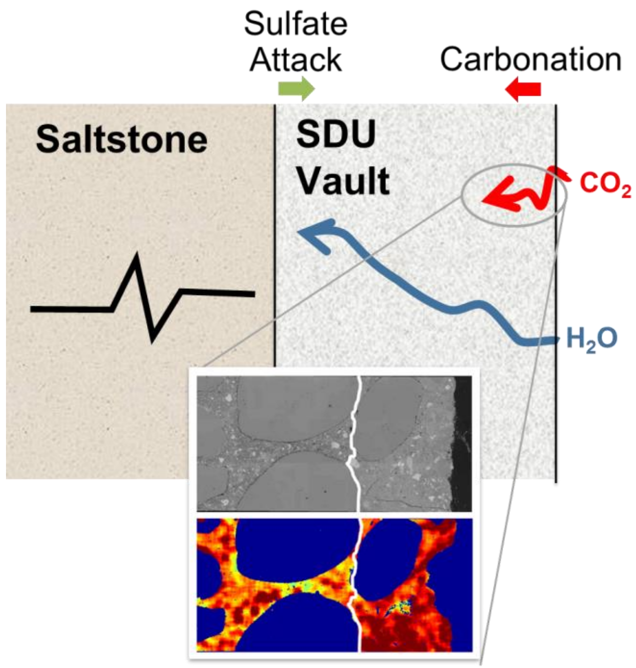

Source: SRR-CWDA-2009-00017, Rev. 0

Source: SRR-CWDA-2014-00006, Rev. 2

Motivation for this Research

- Predicting long-term performance of saltstone and SDU concrete essential to understanding release of radionuclides to environment.
- Rate at which SDU concrete degrades to where it offers no additional hydraulic resistance to fluid movement (compared to surrounding soil) is very important.
- SDU concrete degradation occurs from interaction of
  - interior surfaces with saltstone material (*sulfate attack*)
  - exterior surfaces with surrounding environment (*carbonation*)
- Established SDU concrete degradation mechanisms and predicted impact of degradation on time-dependent resistance to hydraulic flow of the SDU concrete.





Objective

"The *current SDU concrete hydraulic degradation profile is represented as linear degradation* that occurs over a long period.

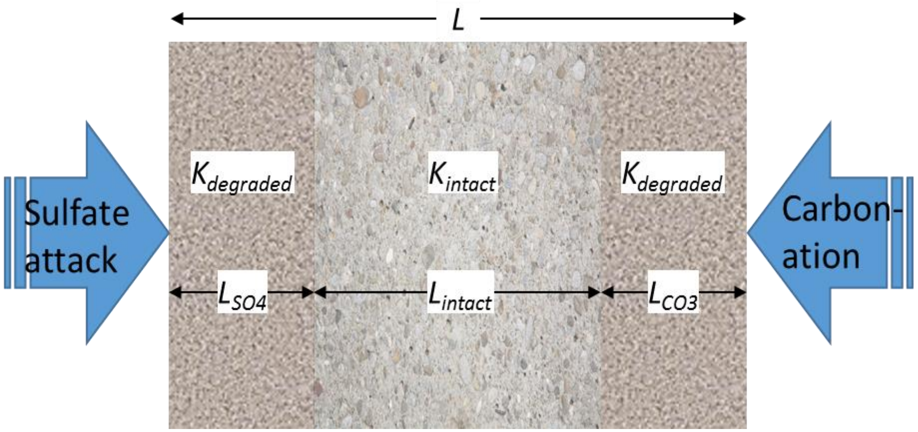
The intent of the work defined in this scope of work is for the Subcontractor to gain an enhanced understanding of mechanisms potentially associated with the degradation of SDU concrete and utilize that information ***to recommend an alternative degradation profile to the currently utilized, and conservative, linear profile***.

For example, while chemical species may diffuse into the SDU concrete, it is not known if said chemical diffusion ultimately results in reduced physical integrity and increased hydraulic conductivity." [Emphases added]

Source: SRR Statement of Work (2016)

Background

- Previous linear degradation profile was based on assumed, worst-case, linear averaging of water movement through parallel layers of degraded vault concrete.
  - This was a change from the harmonic mean (perpendicular flow) previously considered.
  - Layer extents based on predicted degradation of vault concrete from ingress (and attack) of sulfate ions from saltstone and from ingress (and reaction) of carbon dioxide from the atmosphere and soil gas.
- Using predicted degradation rates, hydraulic properties of vault were previously degraded linearly over time until vault hydraulic properties were equal to the those of surrounding soil (backfill material).
  - Use of soil / backfill properties as an end state is a conservative assumption.
  - Use of linear degradation is conservative in early time.

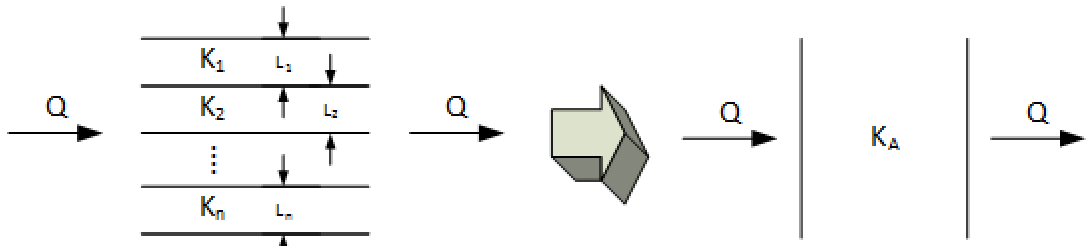


Alternatives to movement of water through parallel layers of degraded and intact vault concrete are available.

Porous Media Flow Scenarios

Equivalent
Hydraulic Conductivity

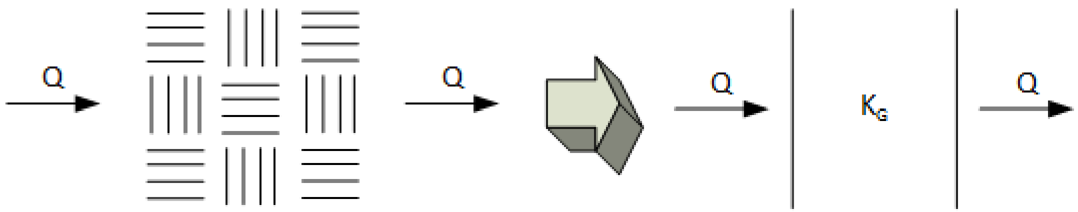
Most Bounding (SDF 2009)



Parallel flow

$$K_E = K_A = \frac{\sum_{i=1}^{n} K_i L_i}{\sum_{i=1}^{n} L_i}$$

Proposed

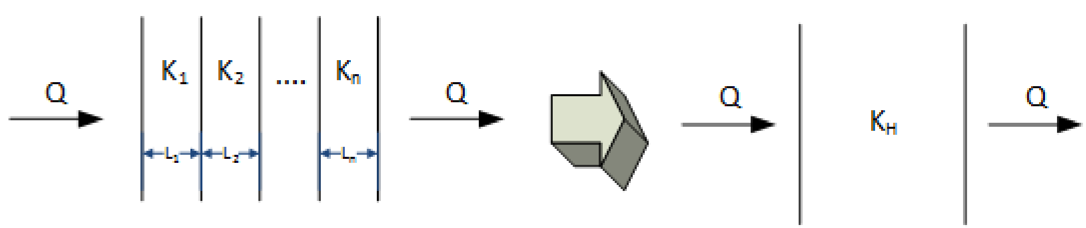


Combination flow

$$K_E \approx K_G = \exp\left(\frac{\sum_{i=1}^{n} L_i ln(K_i)}{\sum_{i=1}^{n} L_i}\right)$$

Geometric mean

Least Bounding (original)



Perpendicular flow

$$K_E = K_H = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} \frac{L_i}{K_i}}$$

Harmonic mean

Source: (Donald 1990) as modified by Brown, *et al*.

Results

- Geometric mean (combination flow) provides more realistic estimate of effective hydraulic conductivity for a layered system considering variability in material properties.
  - Geometric mean has been used as starting point for approximating effective hydraulic conductivity in areas with variable conductivities.
  - For soils, field-measured saturated hydraulic conductivities found to be similar to geometric mean hydraulic conductivities for specimens collected in sampling tubes.
  - Geometric mean used to estimate effective hydraulic conductivity for unsaturated flow through layers of sand with different hydraulic conductivities.
- Two aspects to evaluate: 1) media with variable hydraulic properties and 2) layered media with different hydraulic properties.

Source: SRR Statement of Work (2016)

Results – Medium with Variable Properties

- How to provide a representative value of the hydraulic conductivity for a medium (layer) with variable hydraulic properties?
  - In soils and clay, measured hydraulic conductivity is often highly variable and typically considered log-normally distributed.
  - Typical metrics include arithmetic, harmonic, and geometric means.
  - For systems with highly variable and skewed hydraulic properties, geometric mean typically used to represent hydraulic conductivity.
- Ability of geometric mean (K_g) to represent effective hydraulic conductivity (K_e) is related to variance (σ^2) of log-transformed measured hydraulic conductivities.
  - $\frac{K_e}{K_g} = f\left(\sigma_y^2\right) \approx 1 + \frac{\sigma_y^2}{6}$ where $y = ln[K(cm/s)]$ (3-dimensional)
  - Using measured results for SDF vault concrete (Dixon, *et al*. 2008), the departure of K_e from K_g would be less than 25%.
  - For comparison, using arithmetic averages instead of geometric means for starting hydraulic conductivities provides estimates 60-140% high.
- Recommendation: Use geometric mean without modification to represent the effective saturated hydraulic conductivity for individual layers.
  - Consider using geometric means for starting hydraulic conductivities.
  - Reassess correcting value from geometric mean if higher variation estimated.

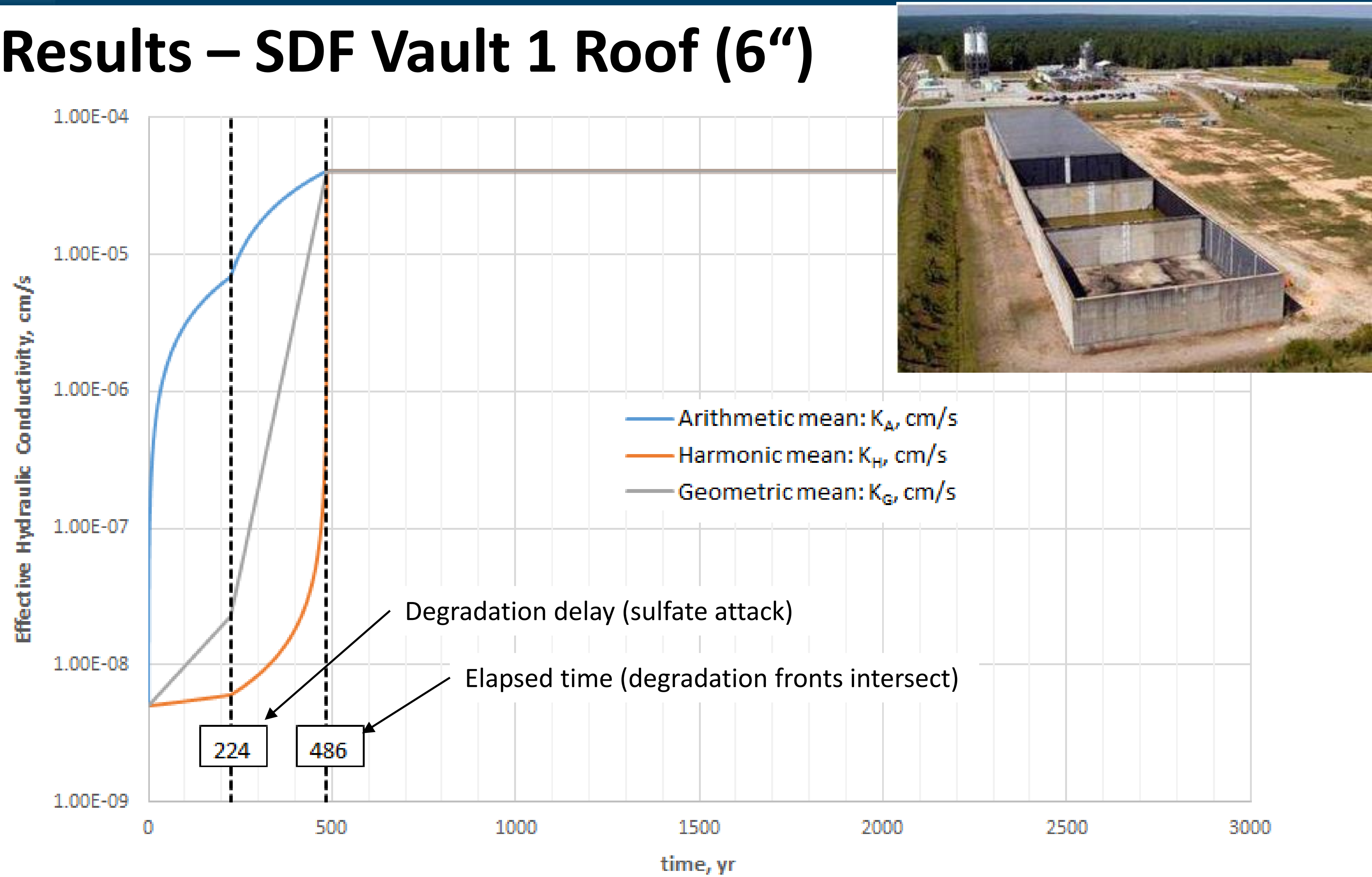
Results – Layered System

- How to provide a representative value of the hydraulic conductivity for a layered, heterogeneous system (*i.e.*, variation from layer to layer)?
  - Thickness-weighed arithmetic (K_A) and harmonic (K_H) means bound effective hydraulic conductivity for parallel and perpendicular flow, respectively.
  - Unlike these, corresponding geometric mean (K_G) has no physical significance but does represent median of log-normal distribution.

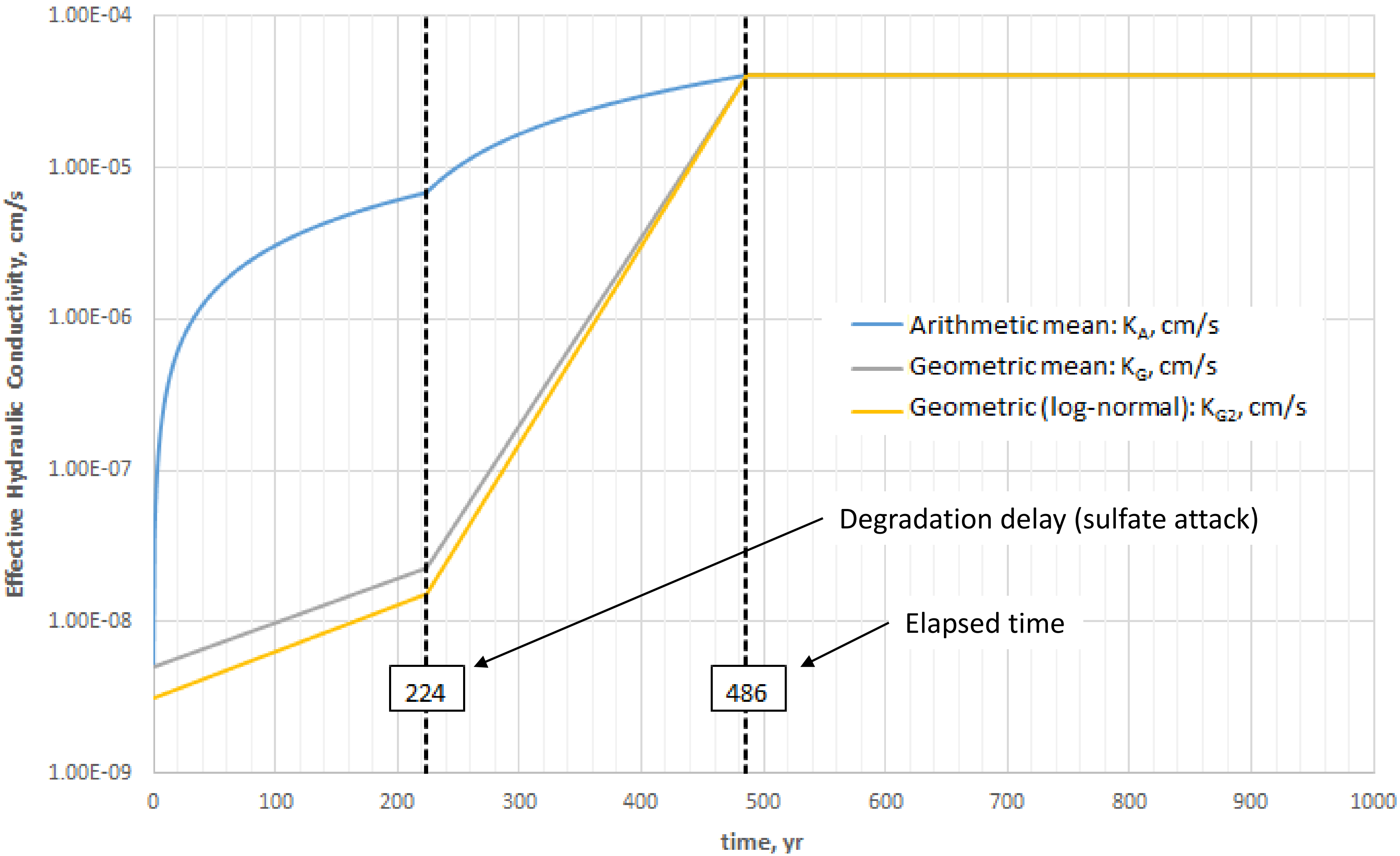
$$K_G = \exp\left(\frac{\sum_{i=1}^{n} L_i ln(K_i)}{\sum_{i=1}^{n} L_i}\right) = \exp\left(\frac{1}{L}\sum_{i=1}^{n} L_i ln(K_i)\right) = \prod_{i=1}^{n} K_i^{\frac{L_i}{L}}$$

  - Thickness-weighted geometric mean typically used to represent the effective hydraulic conductivity for a layered system.
- Recommendation: Use thickness-weighted geometric mean for layered system
  - Geometric mean also should be used to represent effective saturated hydraulic conductivity within individual layers.

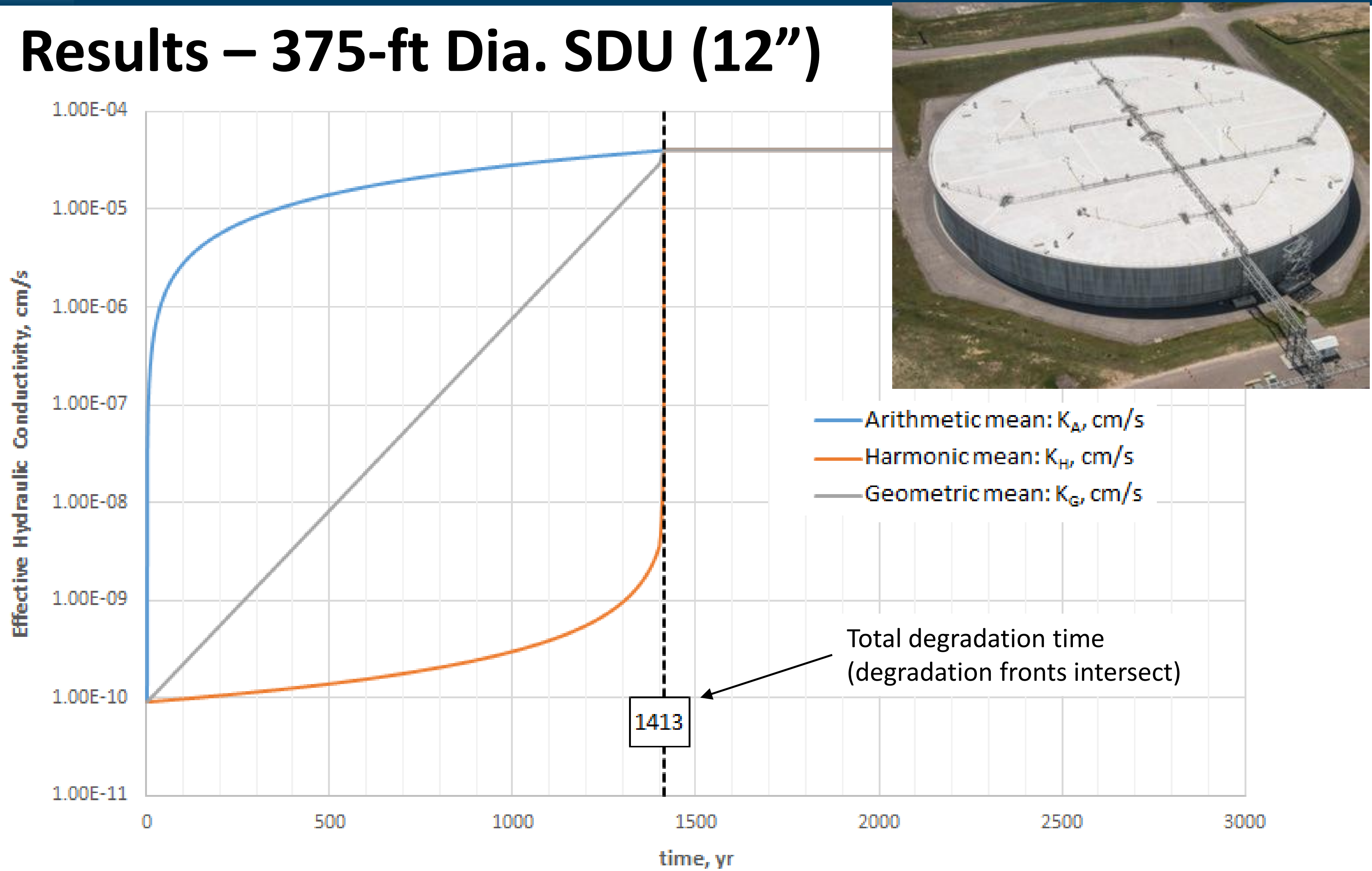
Results – SDF Vault 1 Roof (6“)



Results – SDF Vault 1 Roof (Geometric mean)

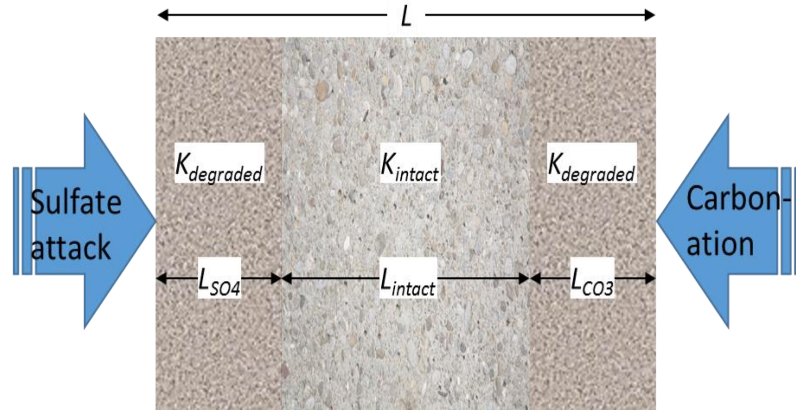


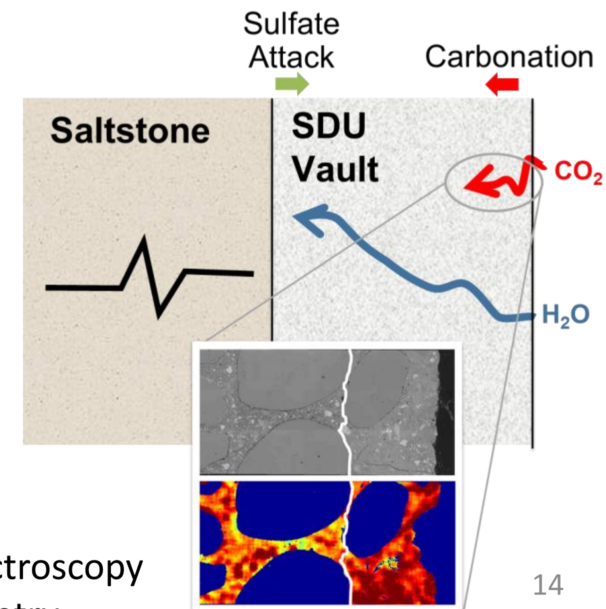
Results – 375-ft Dia. SDU (12”)



Summary and Future Work

- **Addressing conservative assumptions**
  - Worst-case linear degradation profile for hydraulic conductivity previously assumed
  - Recommended effective hydraulic conductivity uses *weighted geometric mean*
  - More realistic and defensible estimate; decreases effective hydraulic conductivity by up to several orders of magnitude
  - Implemented in 2019 SDF PA (under review)
- **Degradation at interfaces**
  - Simulate interfacial layered system within LeachXS/ORCHESTRA
  - Supplement model with analysis of interfaces using SEM/EDS, LA-ICP-MS
  - Potential for degradation of SDU vault concrete after contact with saltstone





SDF = Saltstone Disposal Facility SDU = Saltstone Disposal Unit
SEM/EDS = Scanning Electron Microscopy/Energy Dispersive X-Ray Spectroscopy
LA-ICP-MS = Laser Ablation Inductively Coupled Plasma Mass Spectrometry

Acknowledgements

Savannah River Remediation

- Savannah River Remediation
- Consortium for Risk Evaluation with Stakeholder Participation
- Department of Energy (DOE) Environmental Management

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