U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Mass of Water Seeping into Drifts Over Time

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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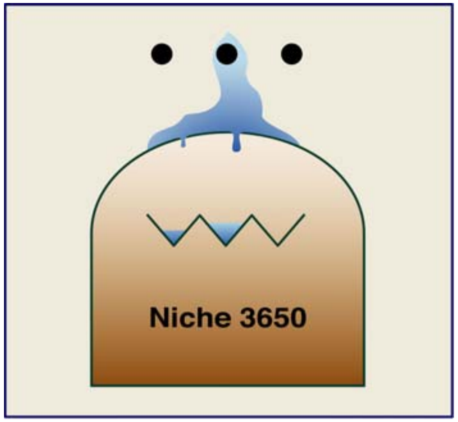
Outline

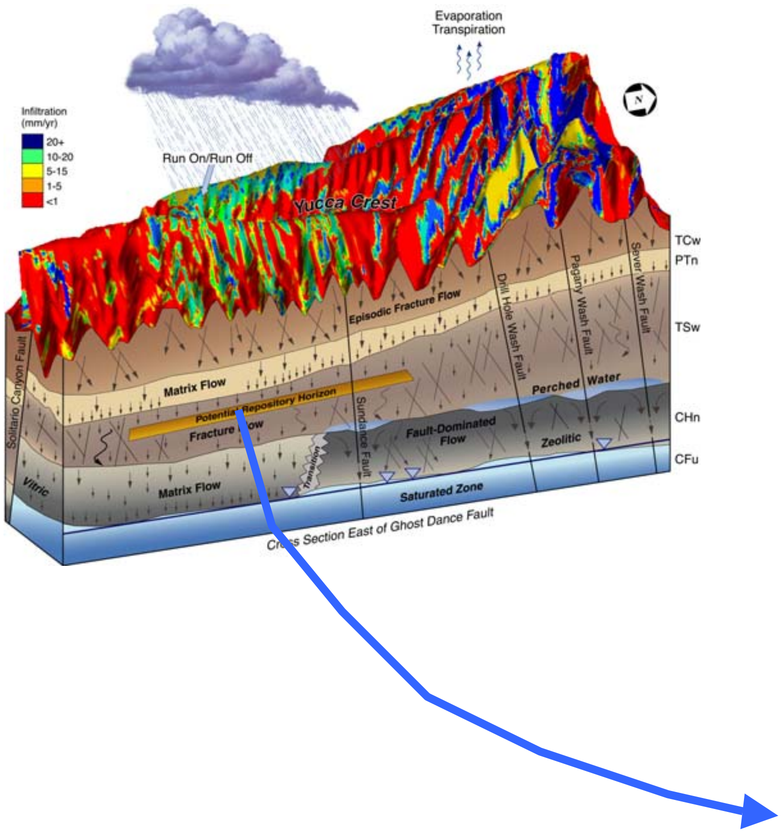
- Key processes affecting seepage
- Brief introduction to proposed approach for seepage calculations in TSPA
- Prediction of ambient seepage: technical basis, assumptions, uncertainties
- Prediction of thermal seepage: technical basis, assumptions, uncertainties
- Discussion of seepage calculation results
- Conclusions

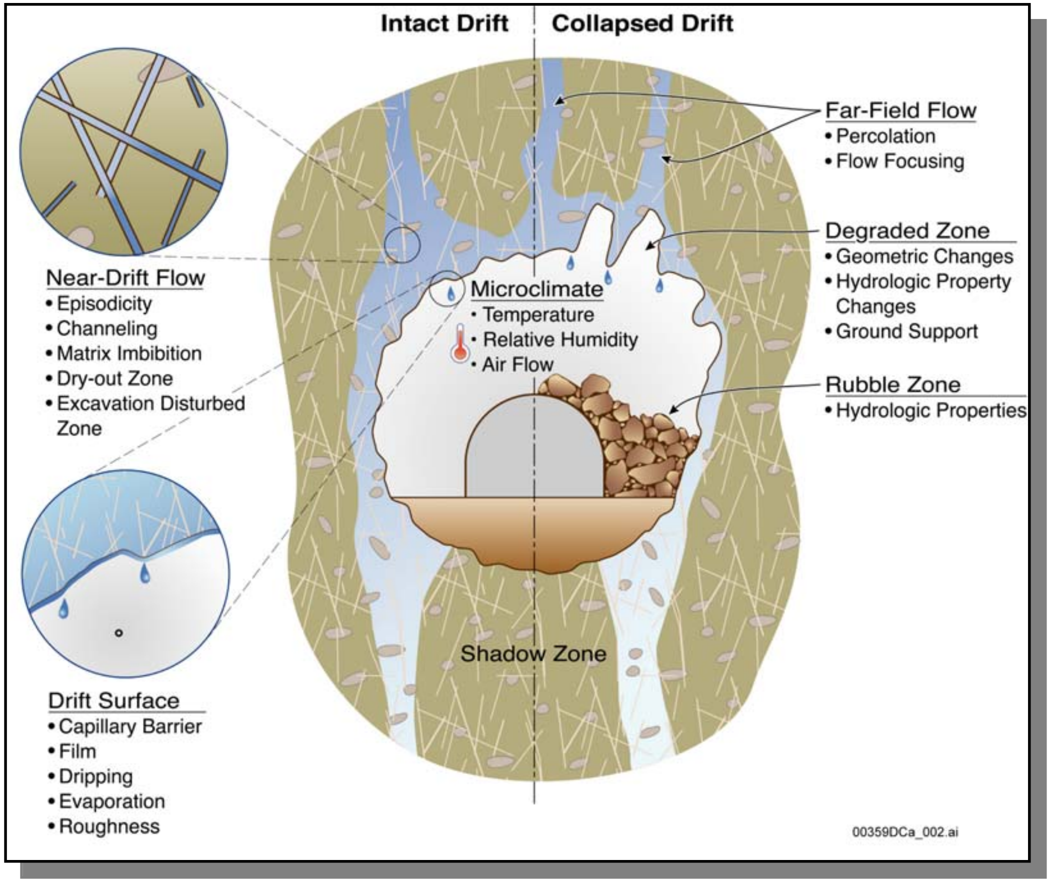
Definitions



- **Seepage:** dripping of liquid water from the formation into an underground opening (<< percolation flux)
- **Seepage rate:** mass of seepage water per time, given for drift section containing one waste package
- **Seepage percentage:** ratio of seepage rate divided by percolation flux across drift footprint
- **Seepage fraction:** fraction of waste packages affected by seepage

Processes and Factors Affecting (Back-to) Ambient Seepage

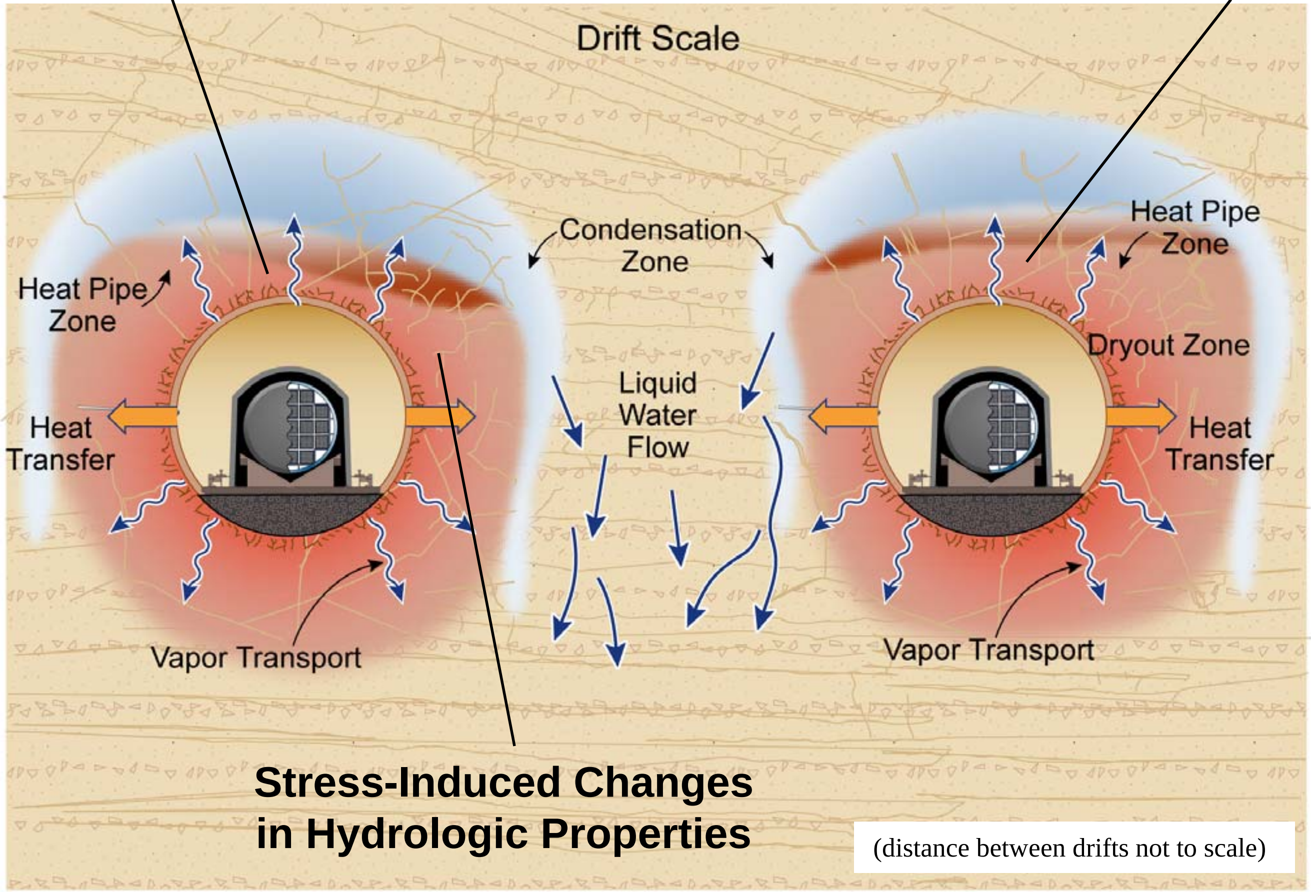




Impact of Heat-Induced Coupled Processes on Seepage

Vaporization Barrier

Mineral-Alteration Changes in Hydrologic Properties



Stress-Induced Changes in Hydrologic Properties

(distance between drifts not to scale)

00318DC_049c.ai

Seepage Estimation: General Approach

- **Seepage is a complex process depending on various factors occurring on different scales**
- **Key processes and parameters have been evaluated with in-situ experiments and modeling studies**
- **Seepage estimation in TSPA must incorporate relevant factors in a realistic yet simplified manner, accounting for spatial variability and uncertainty**

Seepage Abstraction

Defines the seepage calculation methodology to be used in TSPA, integrating the input from various sources

Provides parameter distributions and look-up tables

Proposed Seepage Calculation in TSPA

Step 1: Probabilistic Analysis of Ambient Seepage

- Loop over time, realization, and location in repository
- Use model-derived look-up tables for seepage as a function of key rock properties, local percolation flux (with flow focusing), drift shape (intact or collapsed)
- Calculate seepage rate (with uncertainty) and seepage fraction

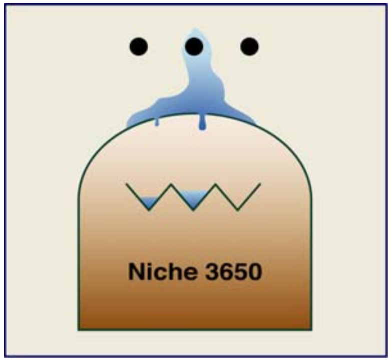
Step 2: Simplified Treatment of Coupled-Processes

- Adjust ambient seepage rates for heat-induced flow changes (vaporization barrier)
- Account for changes in hydrologic properties as a result of mechanical or chemical effects (no adjustment made because effects are small)

➡ **Seepage is function of location as a result of spatial variability in rock properties and percolation flux, geologic unit, and TH conditions**

➡ **Seepage is a function of time as a result of climate changes, duration of boiling**

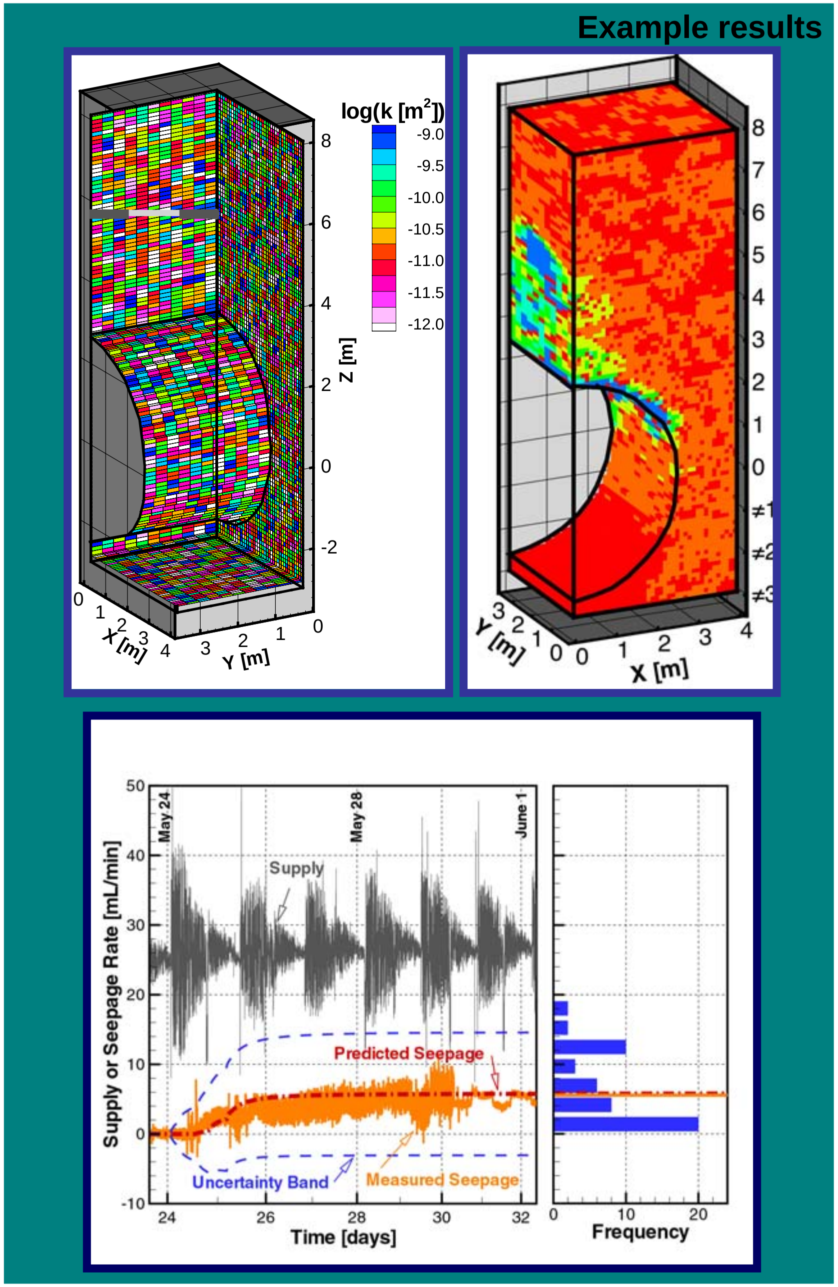
Ambient Seepage Testing and Calibration



- Perform liquid-release tests to capture all seepage-relevant mechanisms (about 100 tests)
- Develop drift-scale heterogeneous fracture continuum model
- Use inverse modeling to estimate seepage-related parameters for test location
- Provide conceptual model and calibrated parameters for seepage prediction model

Testing and Calibration: Main Findings

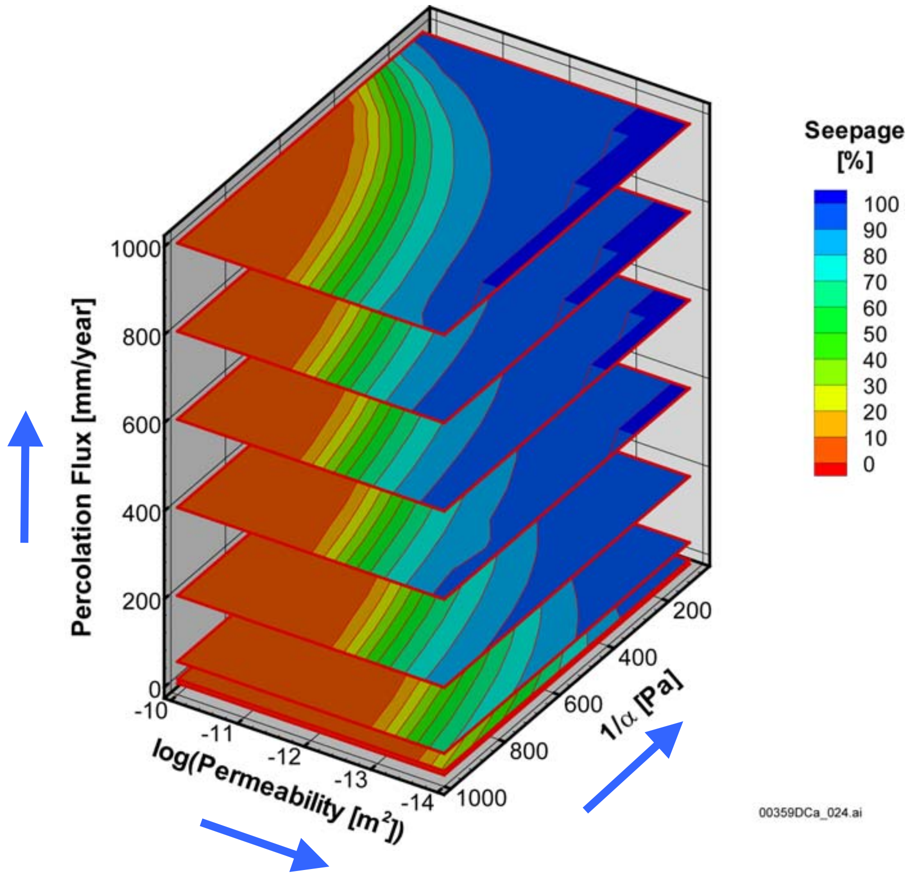
- **Test results demonstrate capillary barrier behavior and flow diversion at drift crown**
- **Model accurately captures or predicts seepage data for all test sites**
- **Seepage can be described as a function of three key seepage parameters: permeability, capillary strength, and percolation flux**
- **Calibrated effective capillary strength accounts for physical capillarity plus various small-scale effects**



Ambient Seepage Prediction Model

- Same conceptual framework as calibration model
- Actual drift geometry considered
- No evaporation (see ongoing work in S&T program)
- Systematic seepage predictions varying the three key parameters for seepage
- Model provides look-up table of seepage rates (and uncertainty) for seepage interpolation in TSPA
- Separate look-up tables for intact drifts (including moderate degradation) and fully collapsed drifts

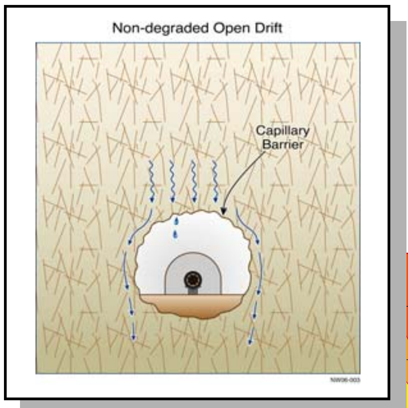
Seepage Look-up Table



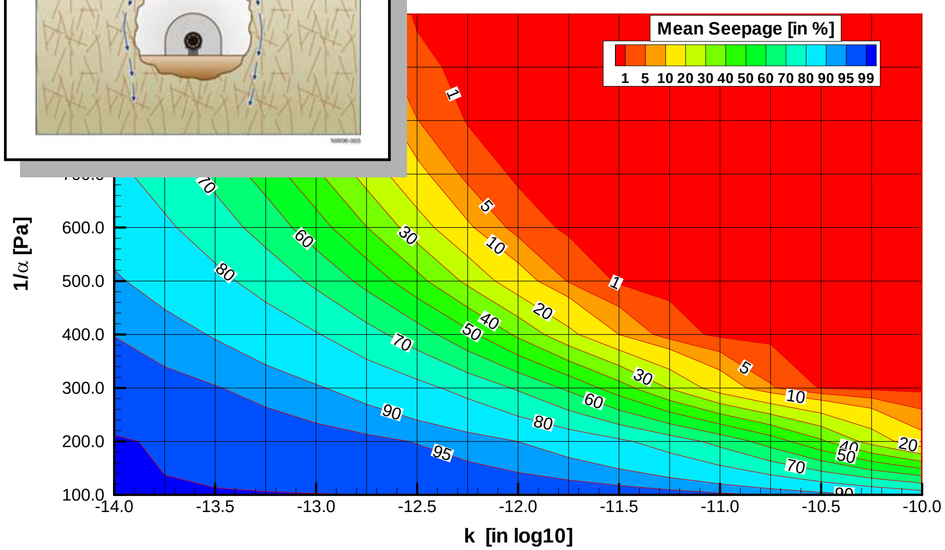
blue arrow: increasing seepage

Intact vs Collapsed Drifts

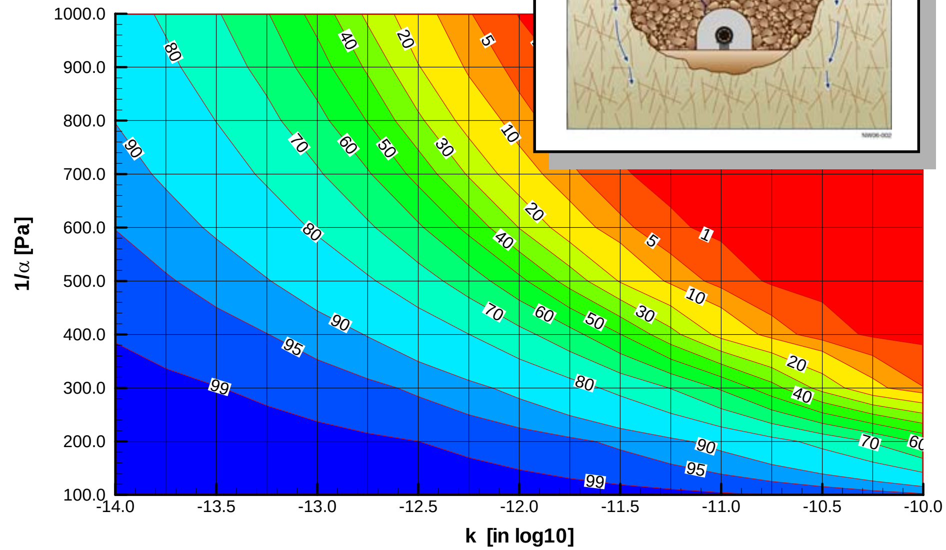
- Drift collapse may occur in case of extreme (low-probability) seismic events
- Collapsed drifts will have roughly doubled in size and will be filled with fragmented rock material (from drift degradation analysis)
- Capillary-strength difference between intact rock and rubble-filled drift remains important factor for flow diversion

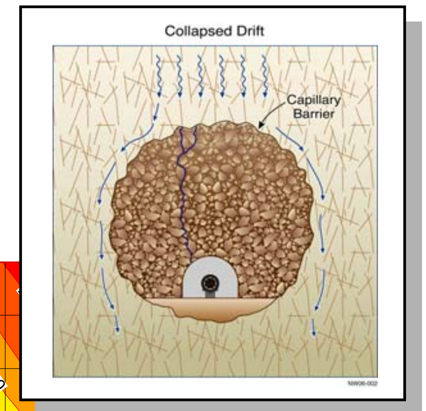


Look-Up Table for Intact Drift



Look-Up Table for Collapsed Drift

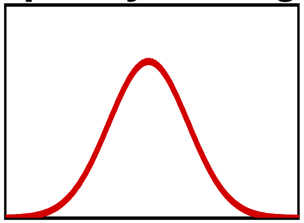




Seepage Percentage Contour Plot for Percolation Flux of 50 mm/yr

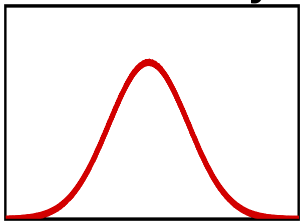
Parameter Distributions for Input in Look-Up Tables

Effective Capillary-Strength



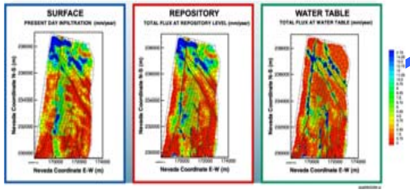
(calibration data)

Permeability



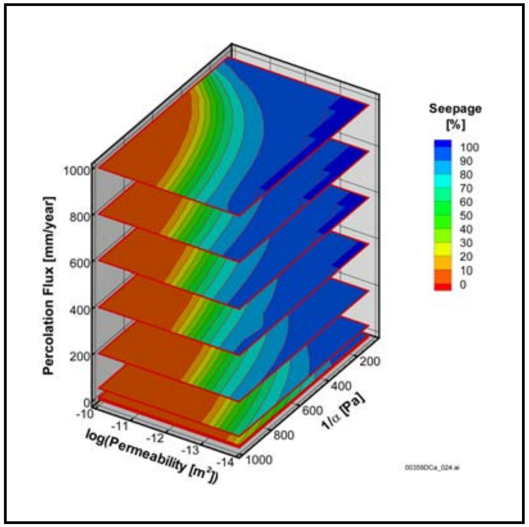
(site characterization data)

Percolation Flux Maps



(UZ Flow Model data)

Seepage Look-up Table



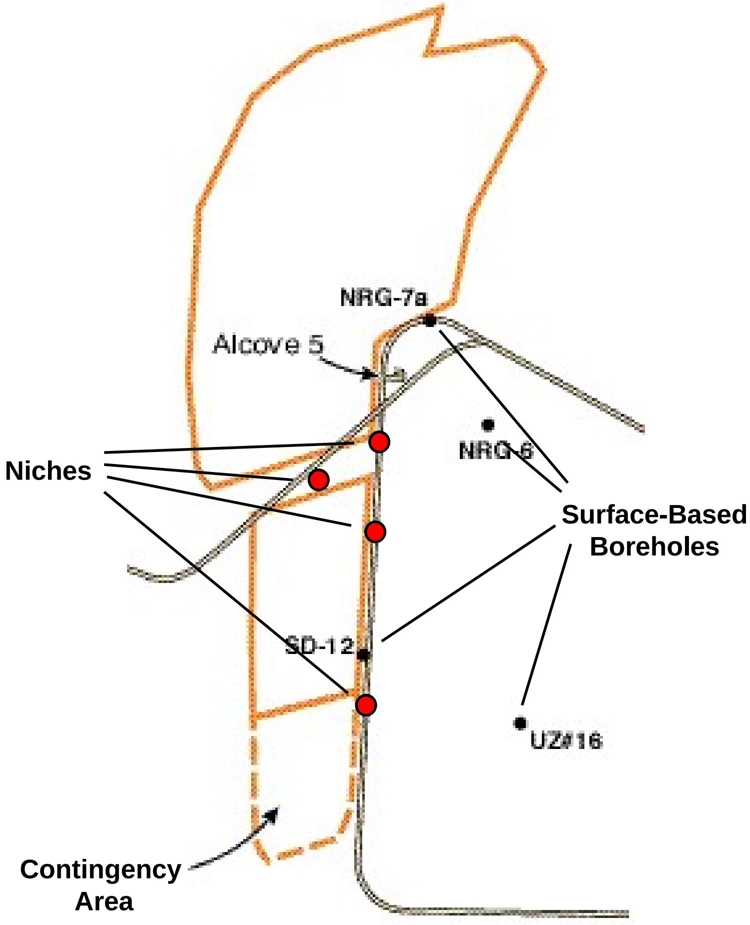
(intact or collapsed)

Ambient Seepage rates and seepage fraction in TSPA

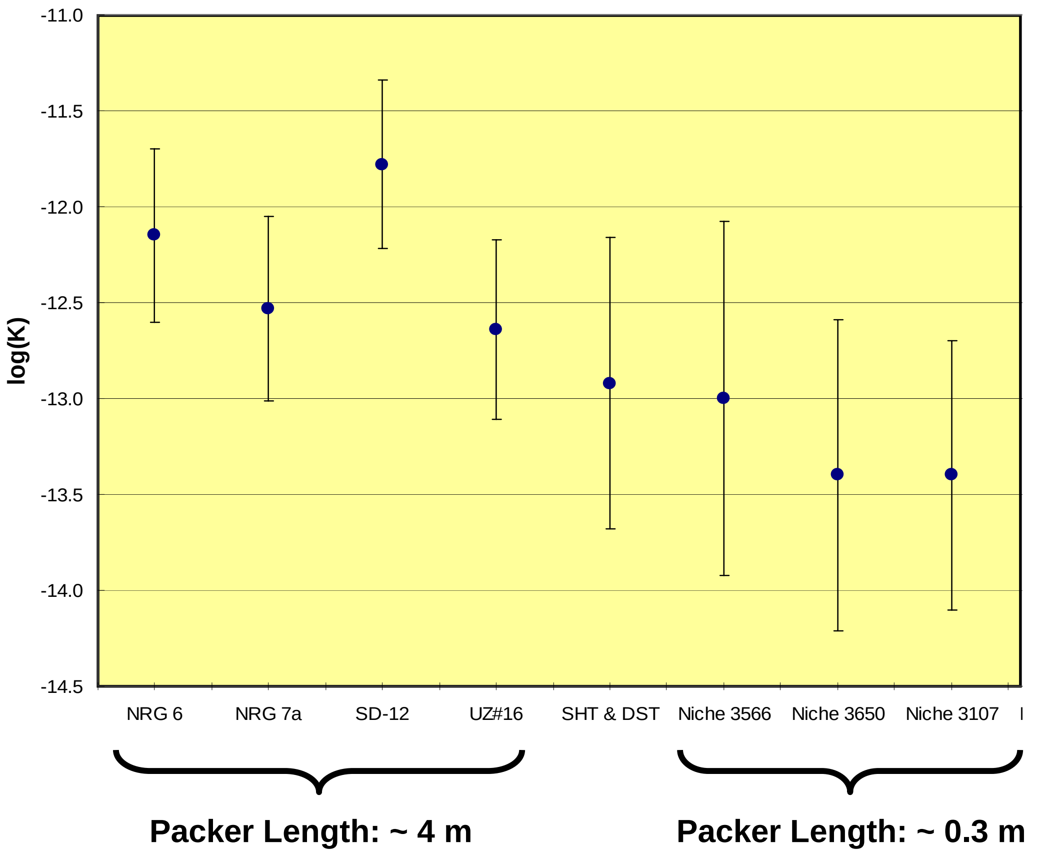
Account for spatial variability and uncertainty

Permeability: Spatial Variability over Repository

Air Permeability Measurement Locations



Mean Fracture Permeability for Different Locations in Topopah Spring Middle Nonlithophysal Unit (Tptpmn)

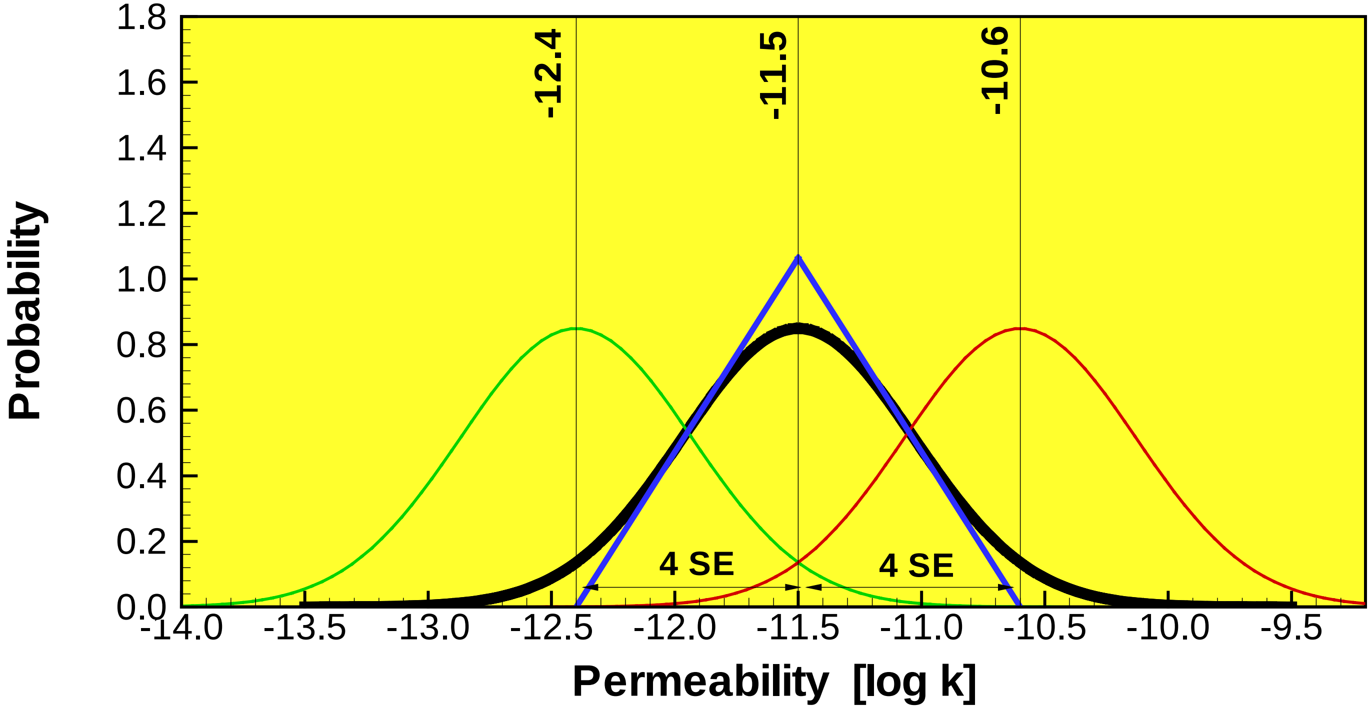


Permeability: Spatial Variability over Repository

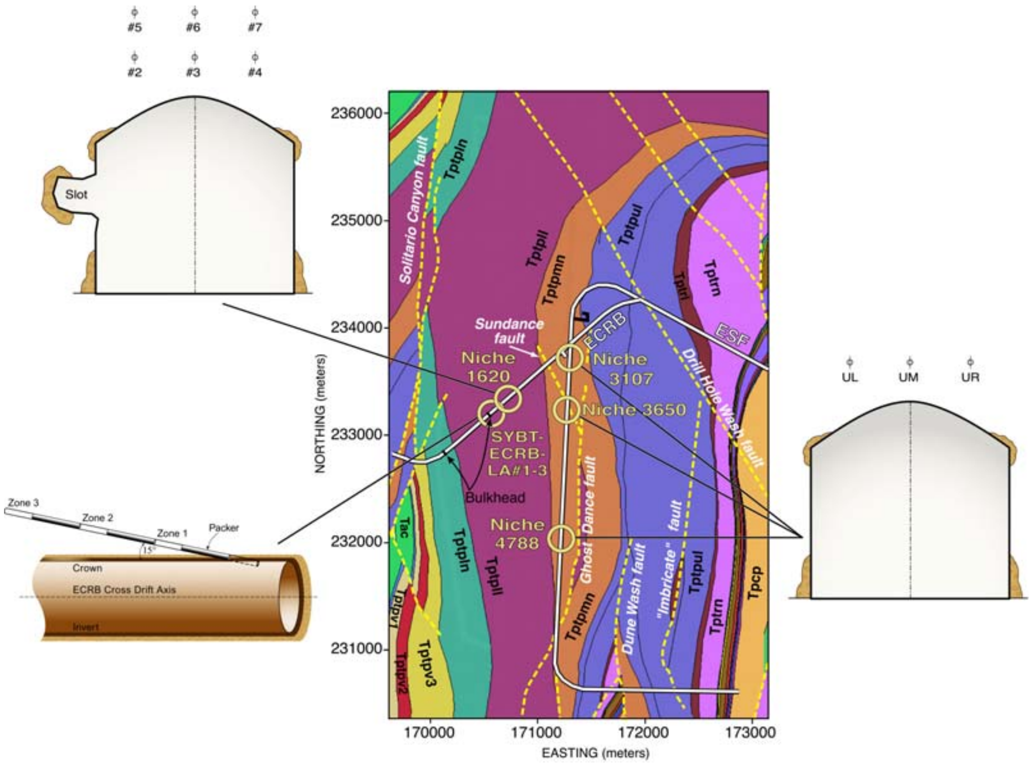
- Use information from as many air permeability locations as possible, starting with ESF/ECRB test locations and adding surface-based boreholes
- Perform scaling analysis for measurements conducted with different packer length
- Adjust measurements in intact fractured rock for impact of drift excavation
- Distinguish between geological units because of different fracture permeability characteristics
- Account for uncertainty in spatial variability (small sample size) by appropriate uncertainty distributions

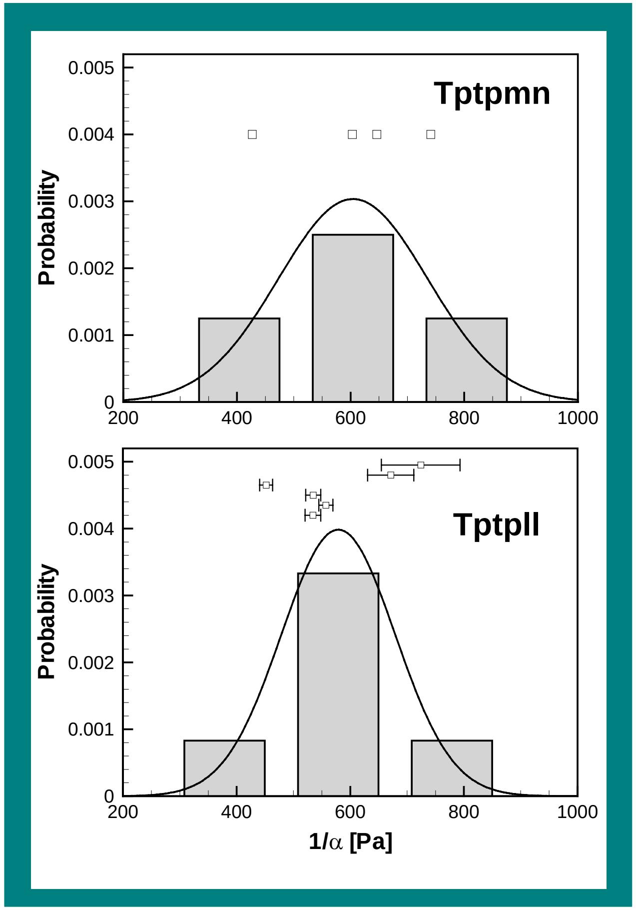
Example: Topopah Spring Lower Lithophysal Unit (Tptpll)

- Spatial variability distribution:
  Log-normal with mean of –11.5 and sigma of 0.47 (in $\log_{10}$)
- Uncertainty distribution (accounting for small sample size):
  Triangular with range of ± 0.9 (in $\log_{10}$)



Effective Fracture Capillary Strength: Spatial Variability over Repository

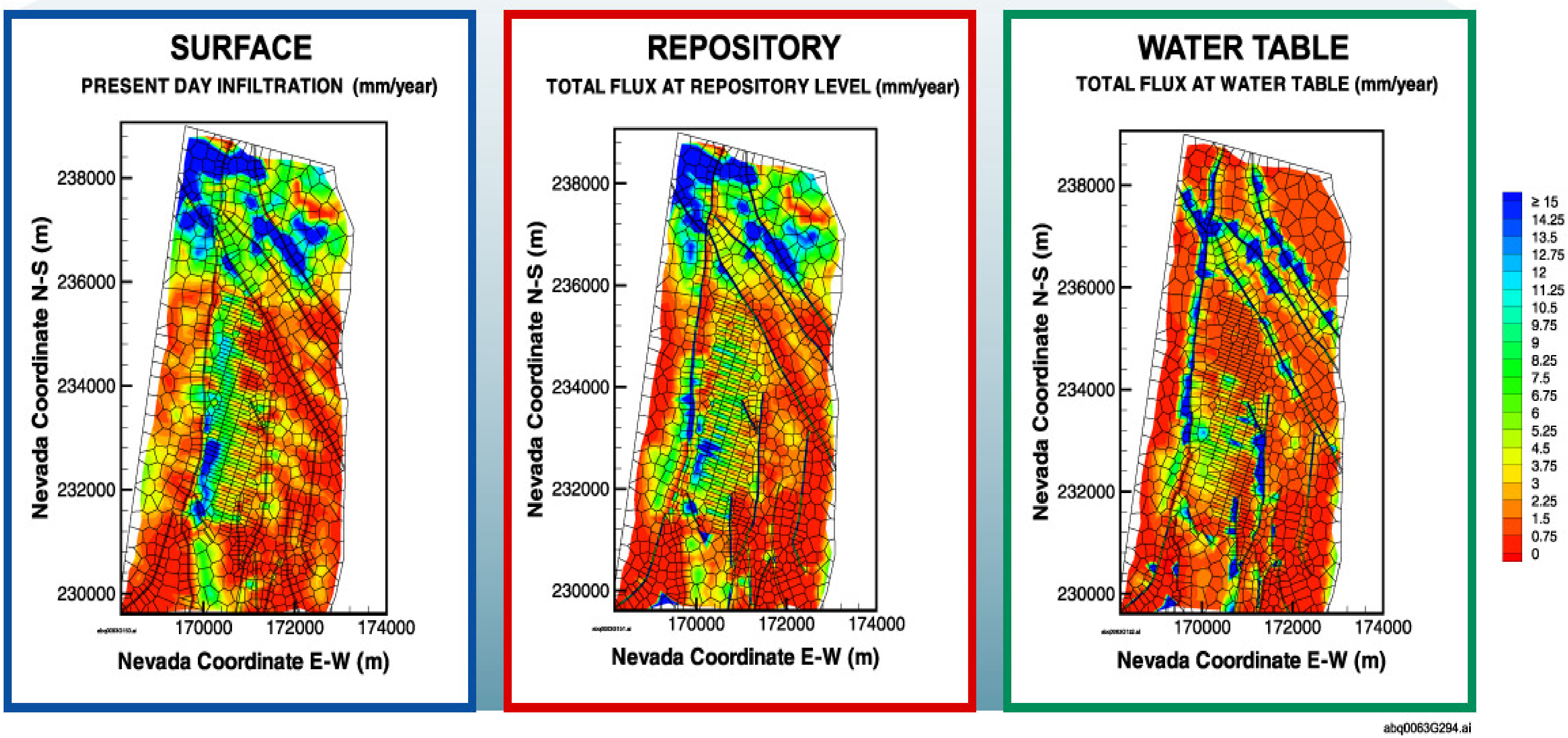




- Ten calibration values
- Spatial variability and uncertainty described by appropriate distributions

Percolation Flux: Spatial Variability over Repository

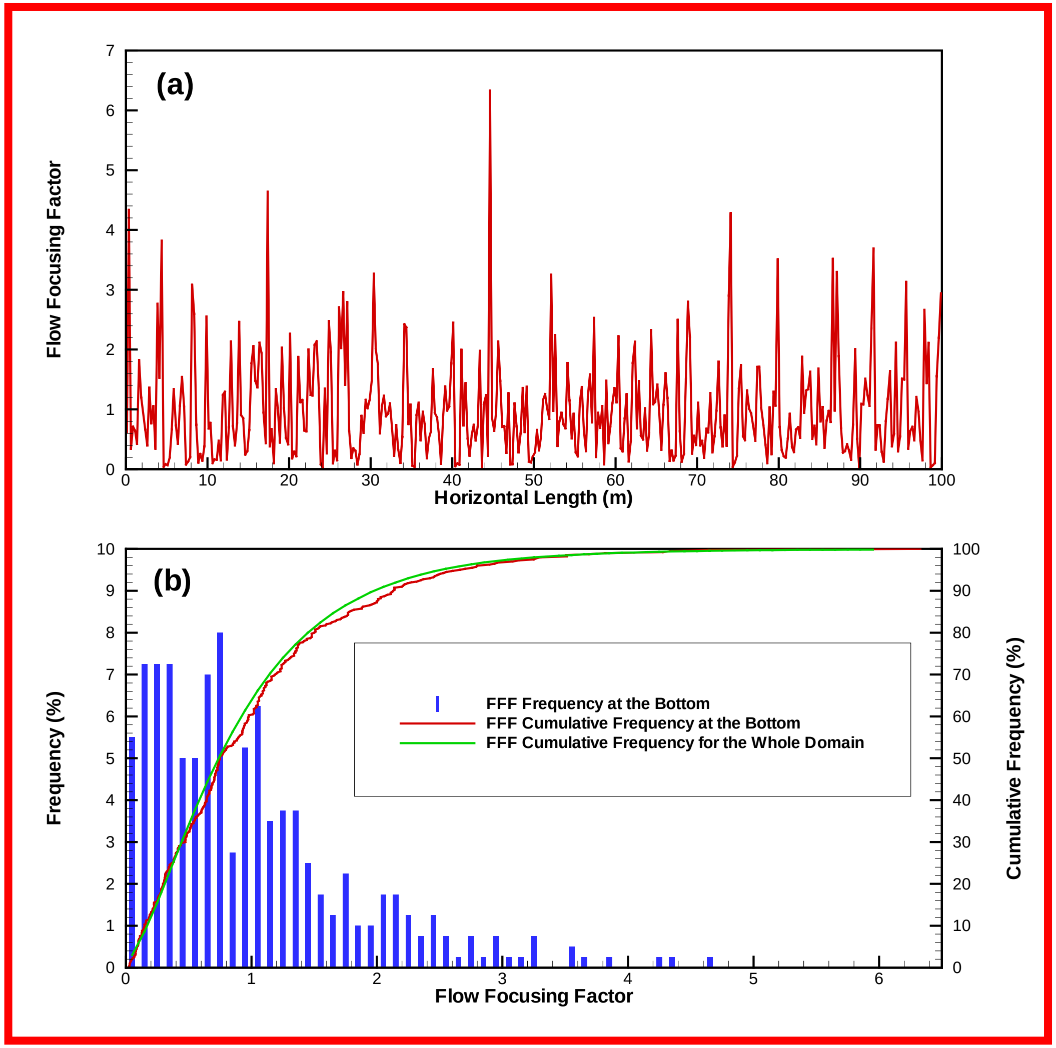
Steady-state Flow Fields Provided by 3D Mountain Scale UZ Flow Model



- For three climate states (present, monsoon, and glacial transition), with instantaneous transition from one state to the other
- For three alternative infiltration scenarios (mean, upper- and lower-bound)

Flow Focusing: Sub-Grid Heterogeneity

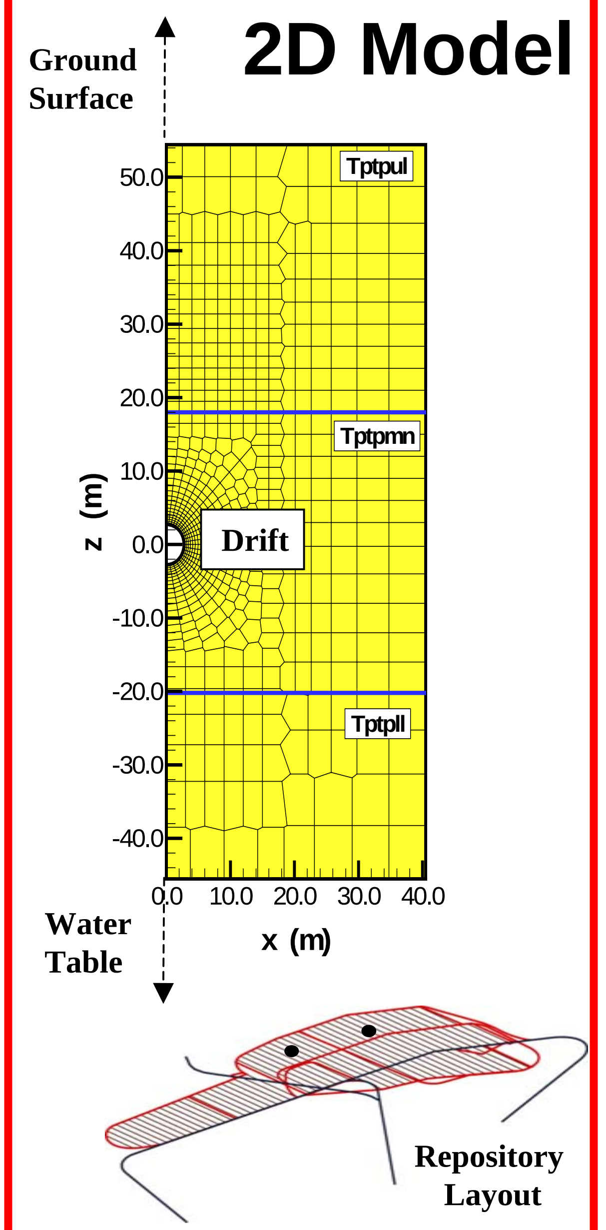
- Flow focusing accounts for percolation flux variability below grid size of UZ model
- Distributions of flow focusing factors are developed by sub-grid heterogeneous flow models, for wide range of parameters and conditions
- Factors are randomly sampled and multiplied with percolation fluxes interpolated from UZ Flow Model
- Resulting distribution of percolation fluxes is wider than original



Coupled Processes Modeling and Testing

- **Thermal Seepage Model: Predicts seepage during thermal period for different locations in repository**
- **Conceptual model validated against seepage tests and Drift Scale Test**
- **Conceptual model is supported by alternative finger-flow model and by application to CNWRA* heater test**
- **In-drift vapor transport is neglected (see ongoing work in S&T program)**

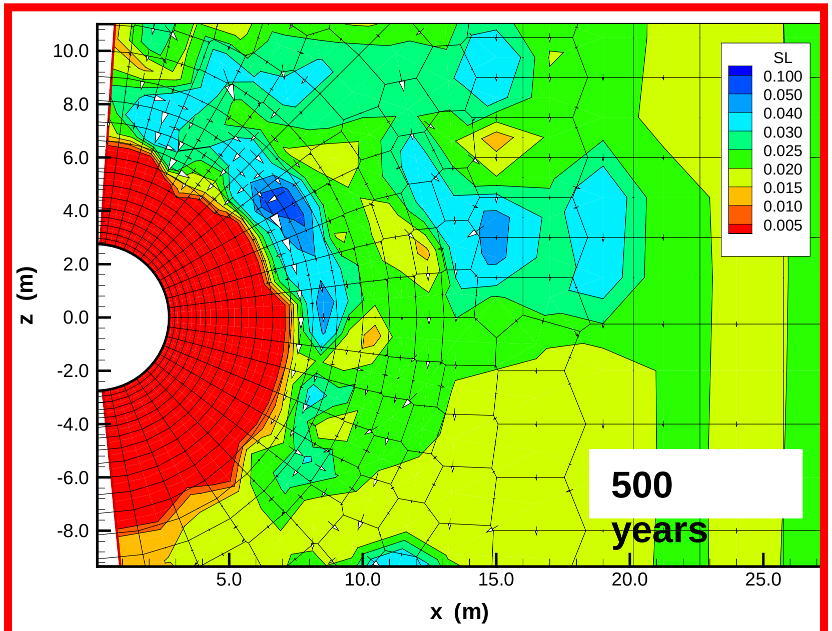
➢ **Thermal Seepage Model is complemented by geomechanical/geochemical models**

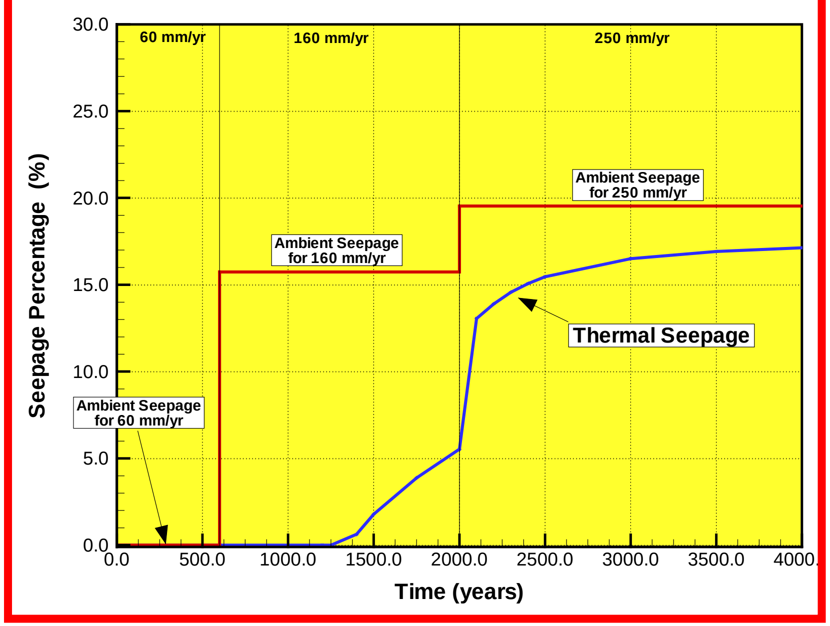


*** Center for Nuclear Waste Regulatory Analysis, Southwest Research Institute**

Thermal Seepage Model Results

- Vaporization barrier is effective for above-boiling conditions
- Thermal seepage is always less than ambient seepage
- Resaturation leads to "delayed" seepage initiation
- Consistent result over wide range of seepage-relevant parameters and conditions





Example results

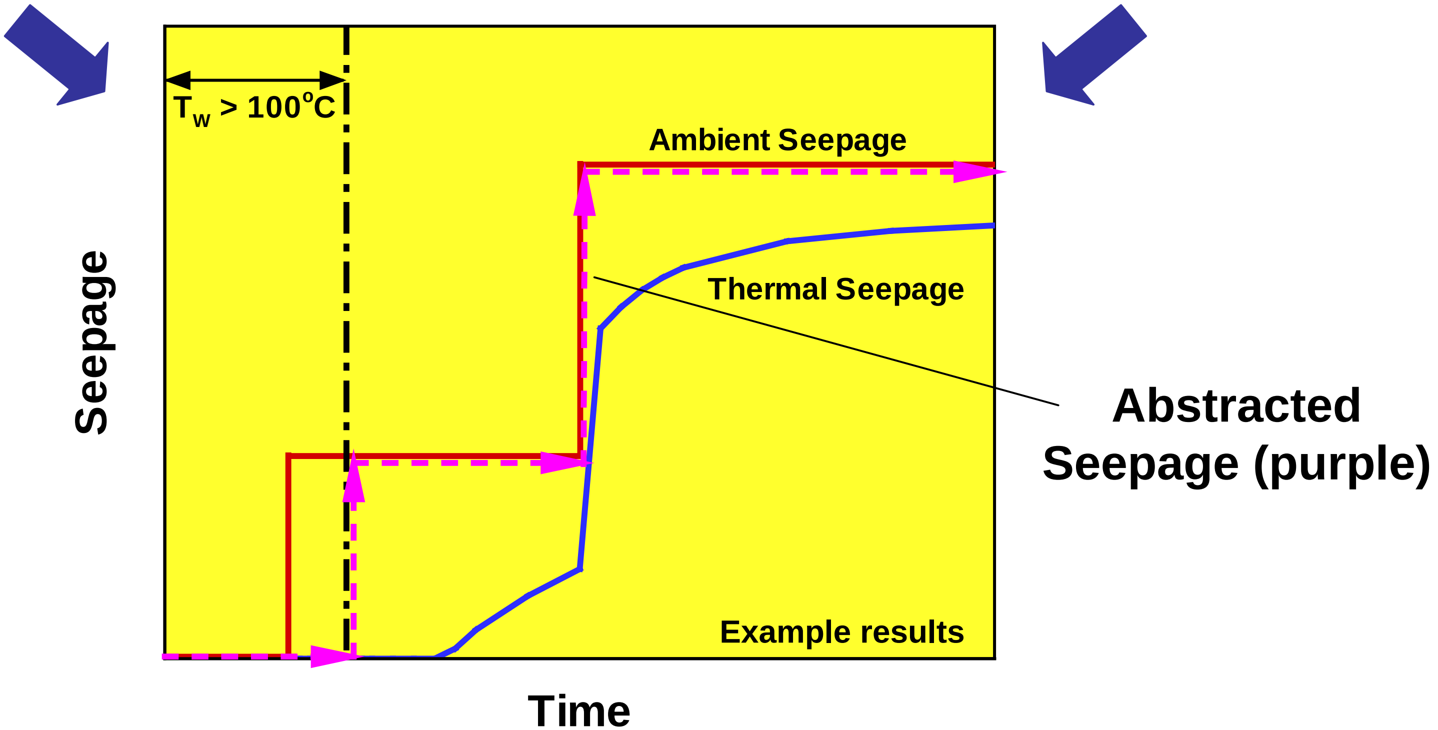
Thermal Seepage Abstraction Method

Seepage Look-up Table

Provides quantitative estimates of ambient seepage

TSPA EBS TH Model

Provides quantitative estimates of drift wall temperature



Vaporization barrier is NOT considered for collapsed drifts (uncertainties regarding properties of rubble material)

Seepage Abstraction Summary

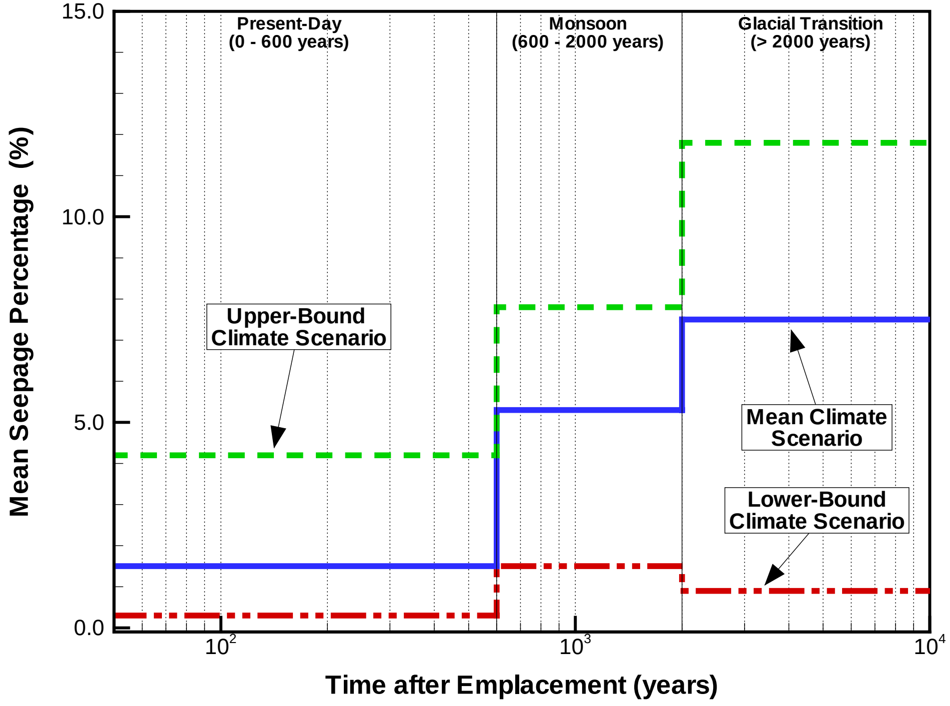
- Ambient seepage is calculated from seepage look-up tables using parameter distributions for permeability, effective capillarity, and percolation flux (including flow focusing)
- Intact and moderately degraded drifts have different look-up table than collapsed drifts
- Lithophysal and nonlithophysal units have different parameter distributions
- No seepage occurs at drift wall temperatures above 100°C
- Thermal seepage is equal to ambient seepage for drift wall temperatures below 100°C
- No seepage changes due to geomechanical/geochemical processes
- No flow diversion for the case of volcanic intrusion
- No seepage during preclosure
- No seepage increase from rock bolts

Seepage Sensitivity Study

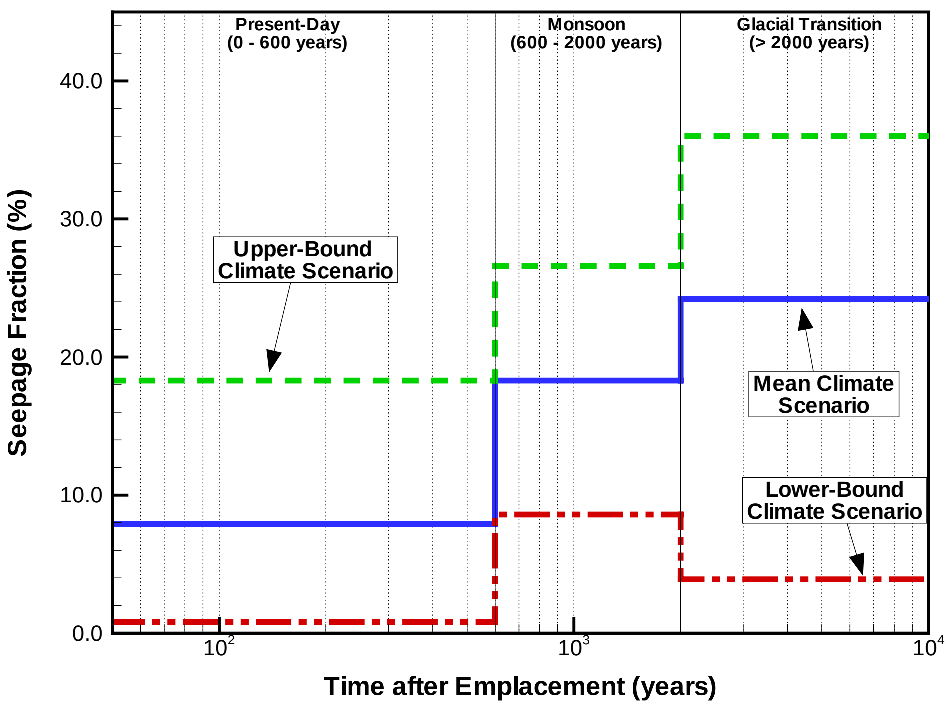
- Probabilistic calculation of seepage using a Mathcad spreadsheet
- Simplified random procedure with sample size 10,000
- No explicit consideration of drift location, vaporization barrier, and drift collapse

- ➢ Demonstrate barrier capabilities of UZ
- ➢ Evaluate sensitivities in abstraction process
- ➢ Similar probabilistic evaluation showed qualitative agreement with South Ramp seepage observations

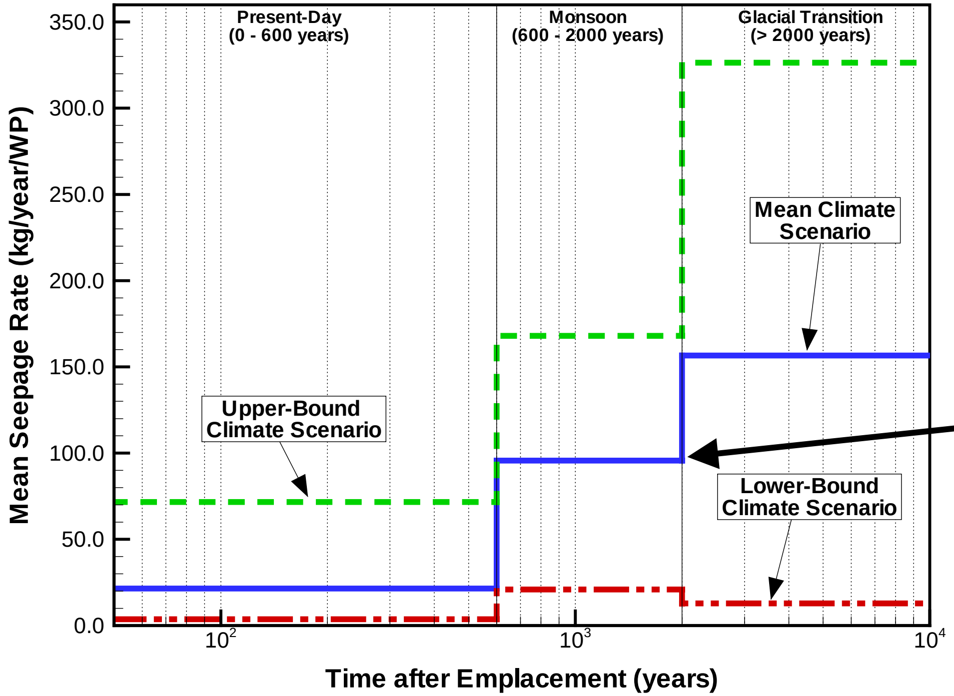
Mean Seepage Percentage (for intact drift in Tptpll)



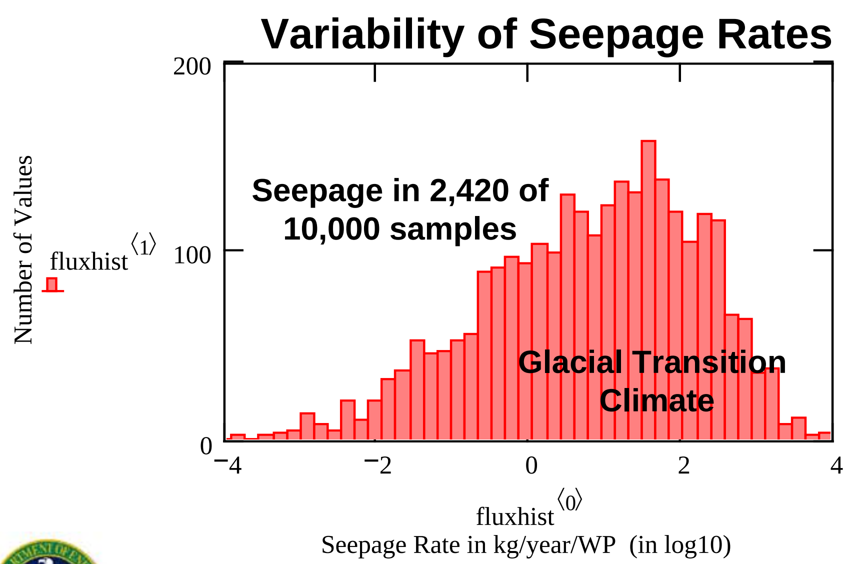
Mean Seepage Fraction (for intact drift in Tptpll)



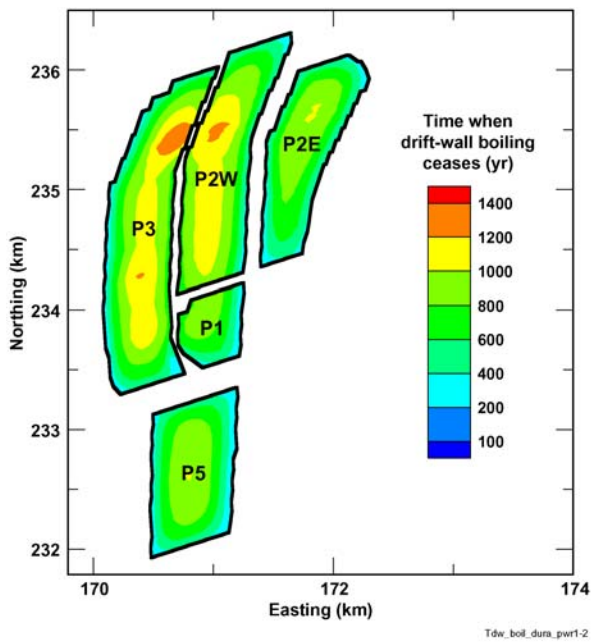
Mean Seepage Rate of all Non-Zero Seepage Samples (for intact drift in Tptpll)

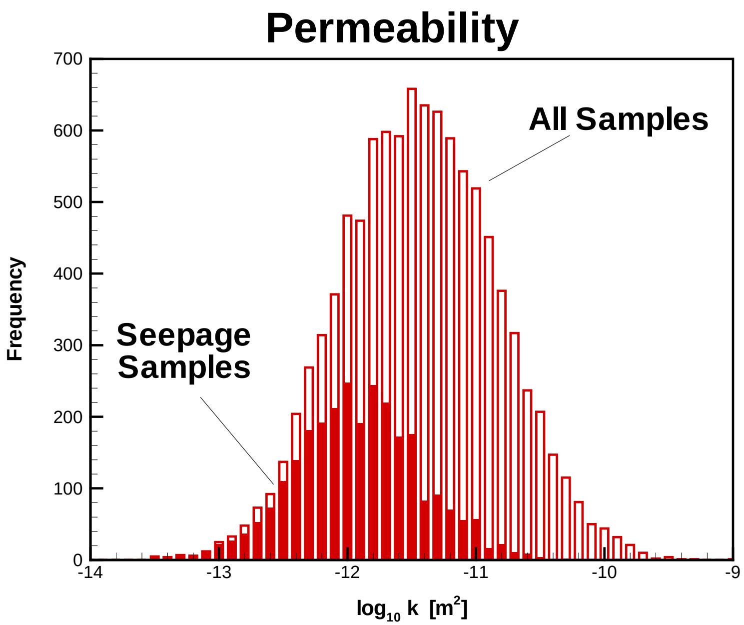


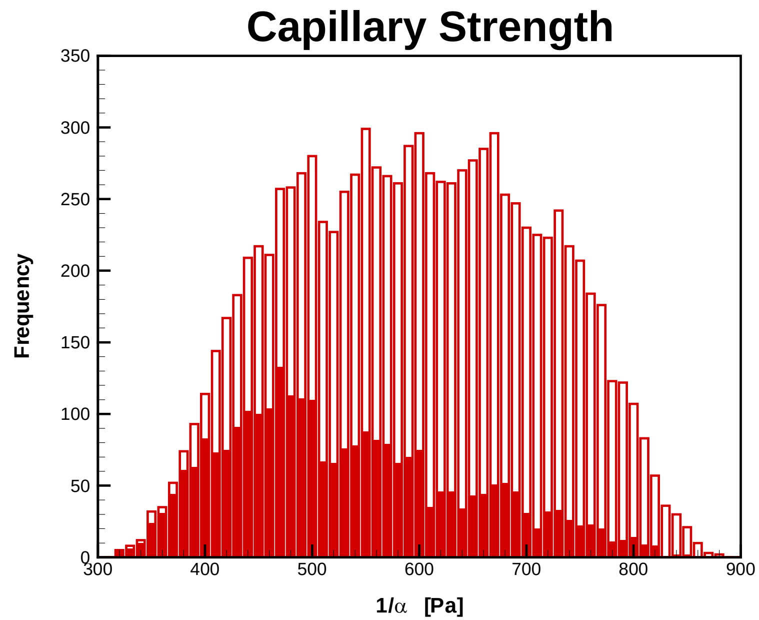
95.6 kg/yr per waste package translates into 1 drop of water every 50 seconds

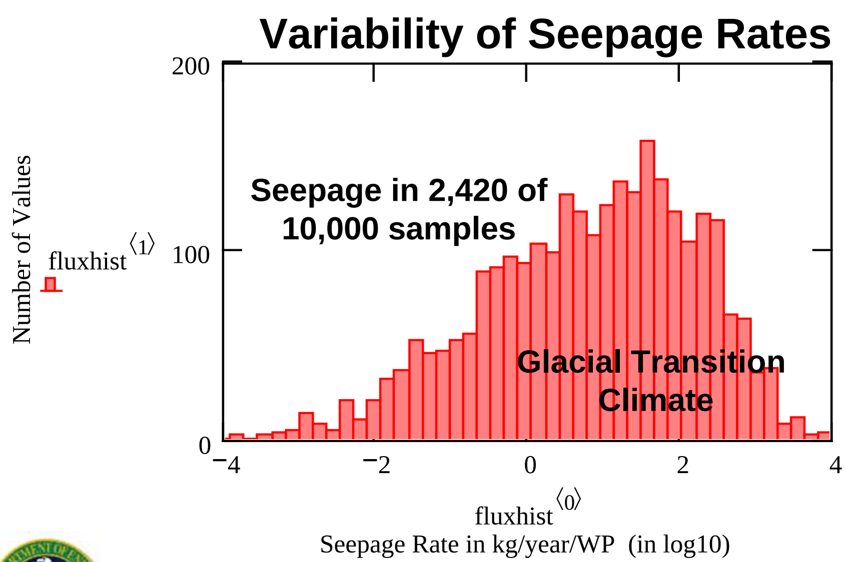


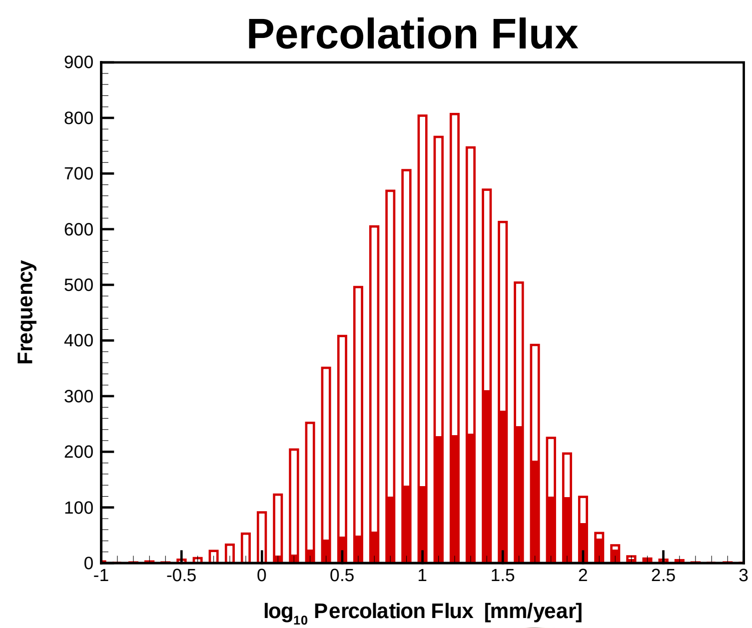
Zero-Seepage Period




Permeability
All Samples
Seepage Samples
Frequency
0
100
200
300
400
500
600
700
-14
-13
-12
-11
-10
-9
log10 k [m2]


Capillary Strength
Frequency
0
50
100
150
200
250
300
350
300
400
500
600
700
800
900
1/α [Pa]


Variability of Seepage Rates
Seepage in 2,420 of 10,000 samples
Glacial Transition Climate
Number of Values
fluxhist⟨1⟩
0
100
200
−4
−2
0
2
4
fluxhist⟨0⟩
Seepage Rate in kg/year/WP (in log10)


Percolation Flux
Frequency
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
2.5
3
log10 Percolation Flux [mm/year]

Sensitivities

(mean infiltration scenario, glacial transition climate)

Intact vs Collapsed Drifts

	Intact Drift	Collapsed Drift
Seepage Percentage	7.5	17.5
Seepage Fraction	24.2	49.3
Seepage Rate*	156.6	358.2

Tptpll vs Tptpmn

	Tptpll	Tptpmn
Seepage Percentage	7.5	18.8
Seepage Fraction	24.2	50.1
Seepage Rate*	156.6	205.7

*** in kg/yr per waste package for all non-zero seepage samples**

Sensitivities

(mean infiltration scenario, glacial transition climate, Tptpll)

Spatial Variability in k and α

	Considered	If not considered
Seepage Percentage	7.5	3.0
Seepage Fraction	24.2	16.4
Seepage Rate*	156.6	90.9

Uncertainty in k and α

	Considered	If not considered
Seepage Percentage	7.5	5.7
Seepage Fraction	24.2	21.0
Seepage Rate*	156.6	136.2

*** in kg/yr per waste package for all non-zero seepage samples**

Conclusions

- Seepage predictions in TSPA will be soundly based on abstraction of various input sources, including field tests, process models, and site characterization
- Ambient seepage is sampled using predictive seepage estimates without further simplification
- Impact of heat-induced coupled processes is accounted for by bounding-case treatment
- Spatial variability and uncertainty of key processes and key parameters are adequately considered
- Seepage varies in time and space
- Flow diversion and vaporization barrier above waste emplacement drifts are effective in preventing seepage