U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Unsaturated Zone Flow and Transport

Presented to:
DOE/NRC Technical Exchange on Total System Performance Assessment (TSPA) for Yucca Mountain
San Antonio, Texas

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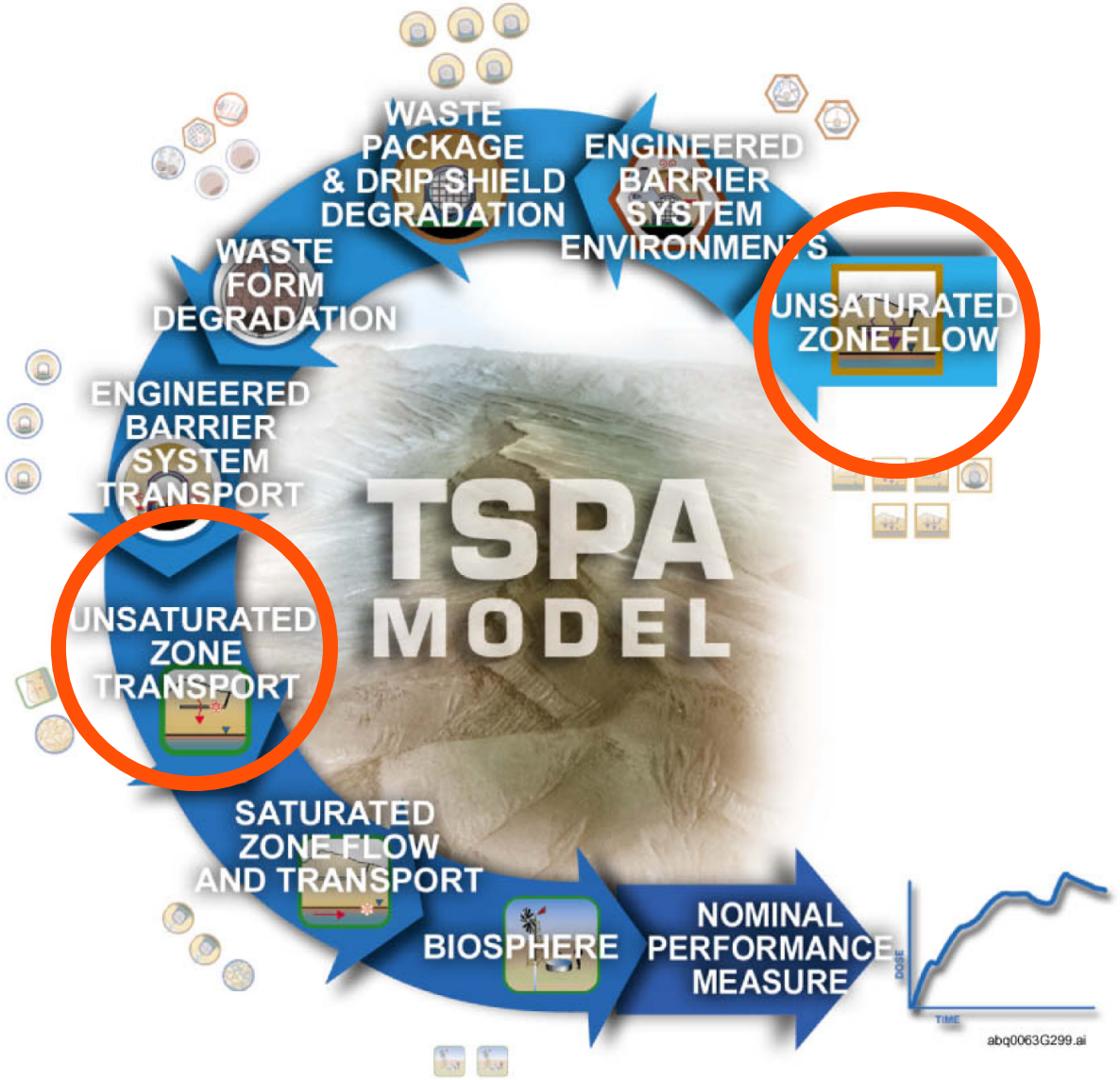
YUCCA MOUNTAIN PROJECT

TSPA-SR Nominal Scenario



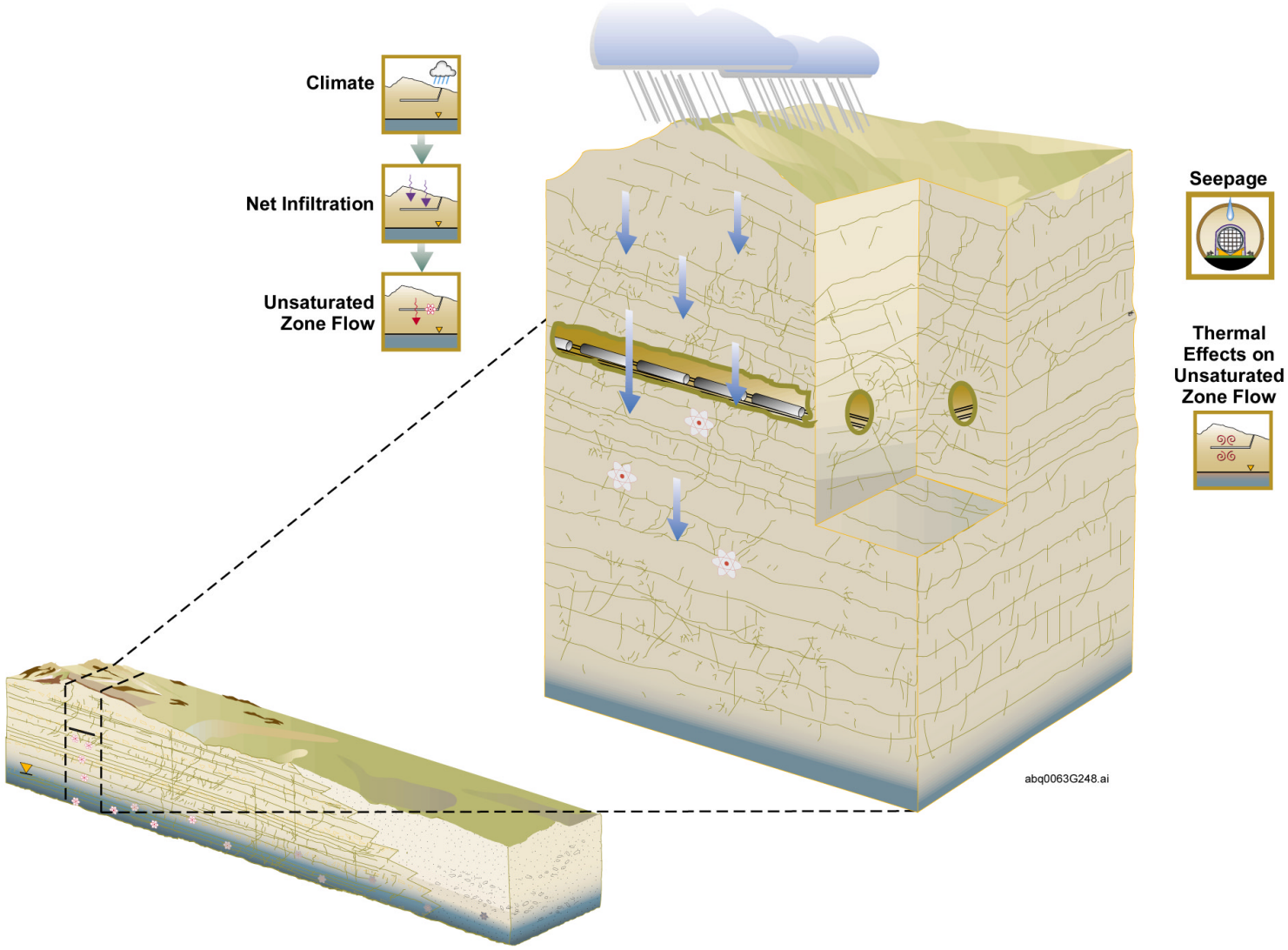
Key Technical Issues

- **Relevant Integrated Subissues from the Total System Performance Assessment and Integration Issue Resolution Status Report Rev. 2 include:**
  - **Spatial and Temporal Distribution of Flow**
  - **Flow Paths in the Unsaturated Zone**
  - **Radionuclide Transport in the Unsaturated Zone**
- **Unsaturated and Saturated Flow Under Isothermal Conditions and Radionuclide Transport also contain relevant acceptance criteria**
- **The Unsaturated Zone Flow and Transport (UZFT) Process Model Report (PMR) addresses acceptance criteria related to this topic**
- **The UZFT PMR Technical Exchange is scheduled for July 12 and 13, 2000**

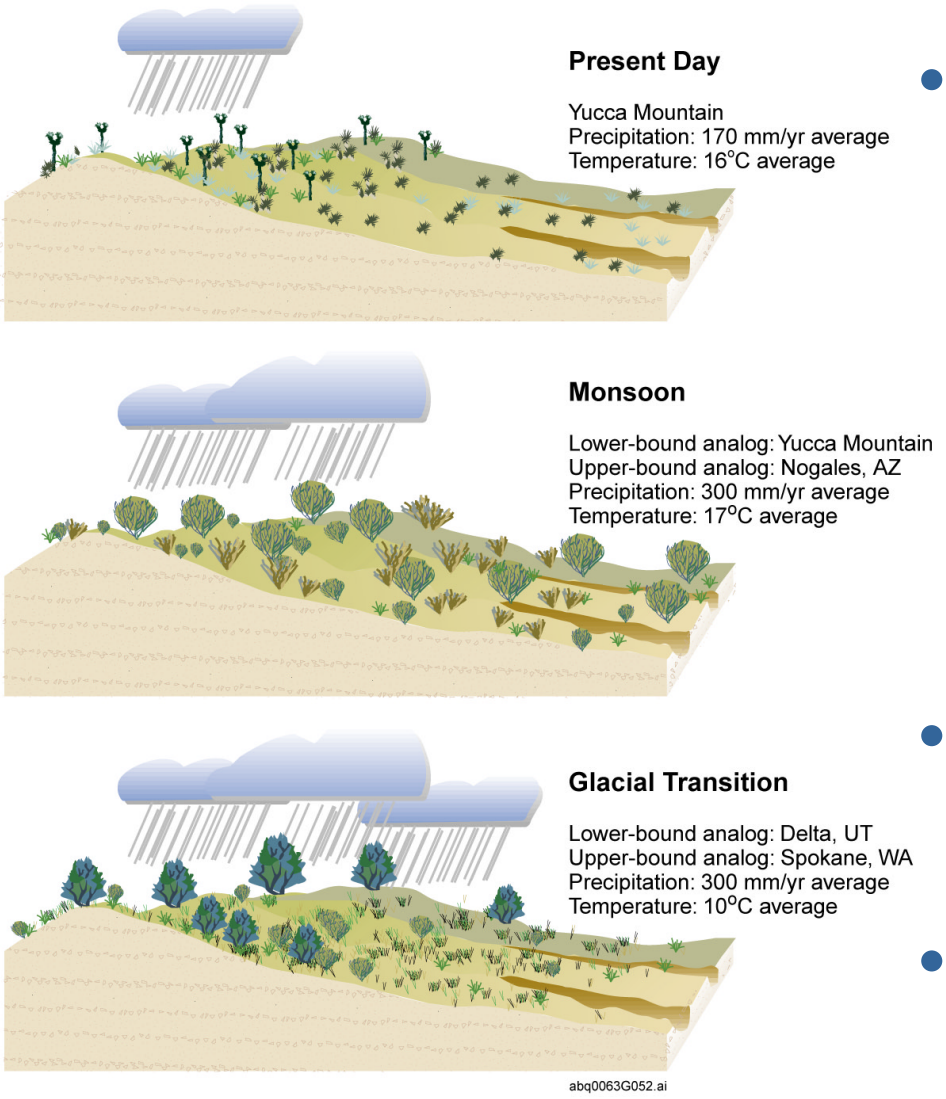
Outline

- Climate
  - AMR ANL-NBS-GS-000008
- Infiltration
  - AMRs ANL-NBS-GS-000032, ANL-NBS-HS-000027
- Unsaturated Zone (UZ) Flow
  - AMRs MDL-NBS-HS-000006, ANL-NBS-HS-000023
- Seepage
  - AMRs MDL-NBS-HS-000002, ANL-NBS-MD-000005
- Thermal Effects on Unsaturated Zone Flow
  - AMRs MDL-NBS-HS-000007, MDL-NBS-HS-000001
- Unsaturated Zone Radionuclide Transport
  - AMRs ANL-NBS-HS-000026, ANL-NBS-HS-000024

Water Contacting Waste Packages

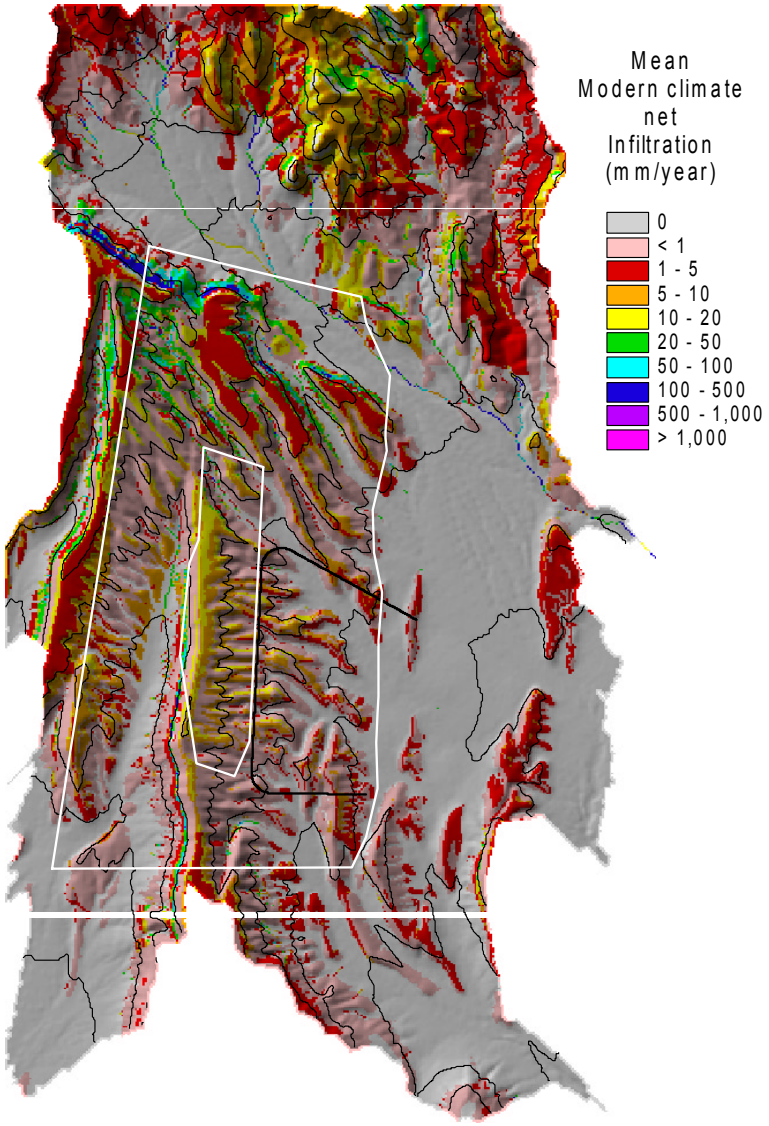


Climate



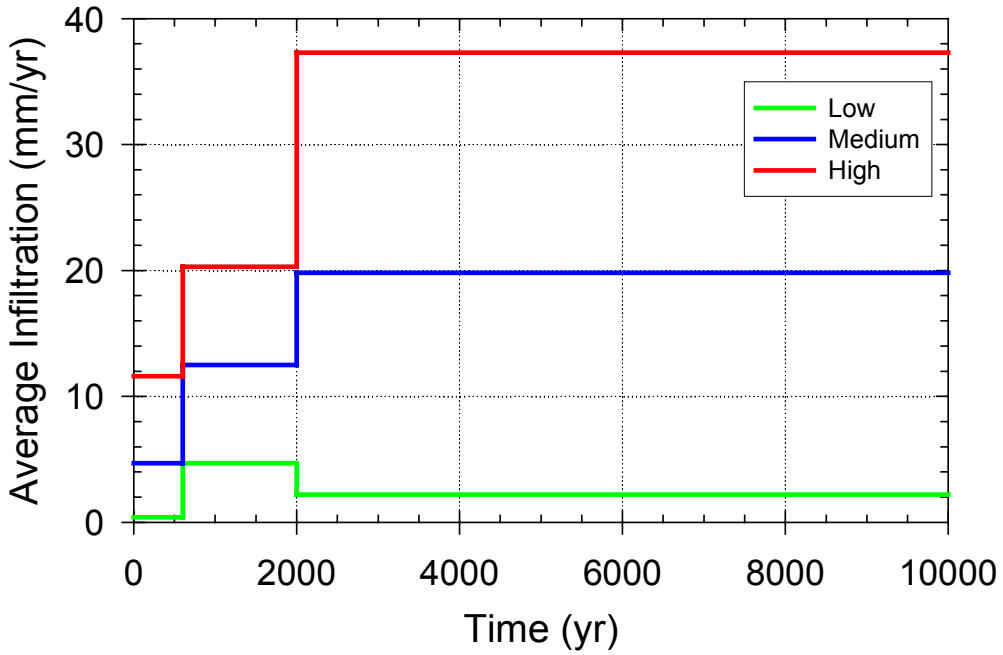
- **Three climate states modeled**
  - **Present-day climate for first 600 years**
  - **Wetter and warmer "monsoon" climate for 600–2,000 years**
  - **Wetter and cooler "glacial-transition" climate for 2,000–10,000 years**
- **Weather records from analog sites used to define upper and lower bounds of climate**
- **Beyond 10,000 years assume that glacial-transition climate continues**

Infiltration



- **Function of precipitation, temperature, evapo-transpiration, run-on, run-off, soil conductivity, etc.**
- **Infiltration uncertainty captured by using three infiltration maps for each climate**
  - **High (upper-bound climate analog)**
  - **Low (lower-bound climate analog)**
  - **Medium (average of high and low)**

Infiltration: Abstraction

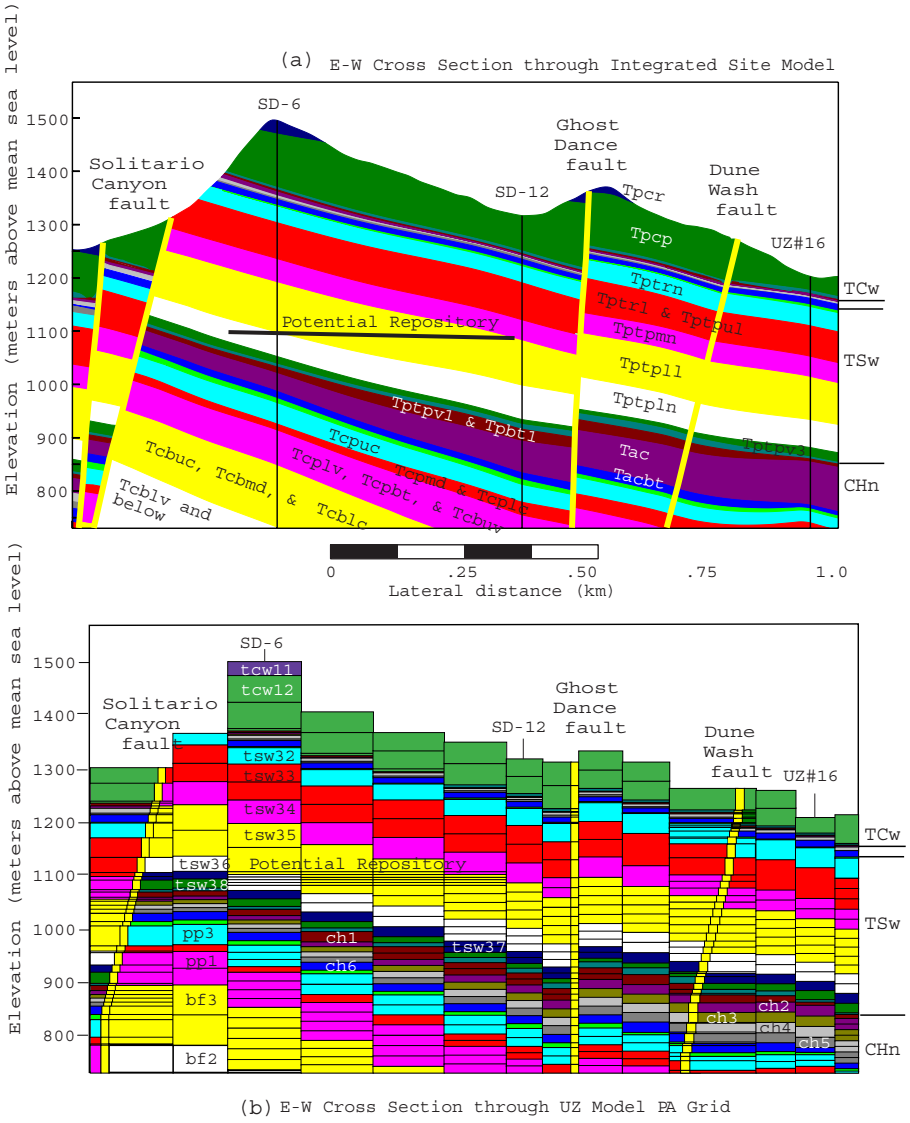


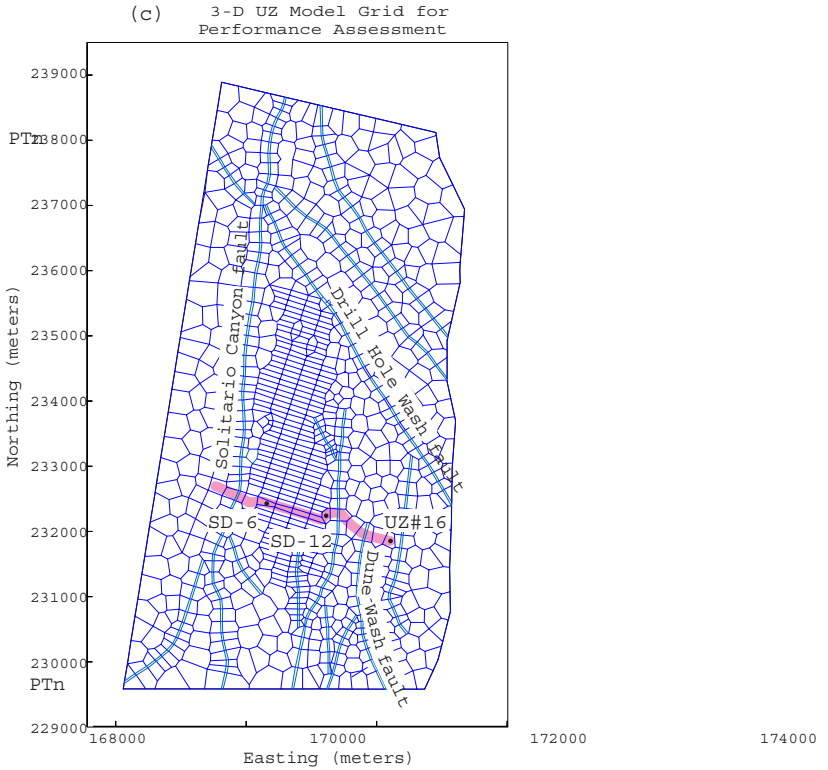
- Infiltration maps are used directly in UZ flow calculations
- Monte Carlo method was used to analyze infiltration uncertainty and assign weights:
  - 35% probability of high infiltration
  - 48% probability of medium infiltration
  - 17% probability of low infiltration

Unsaturated Zone Flow

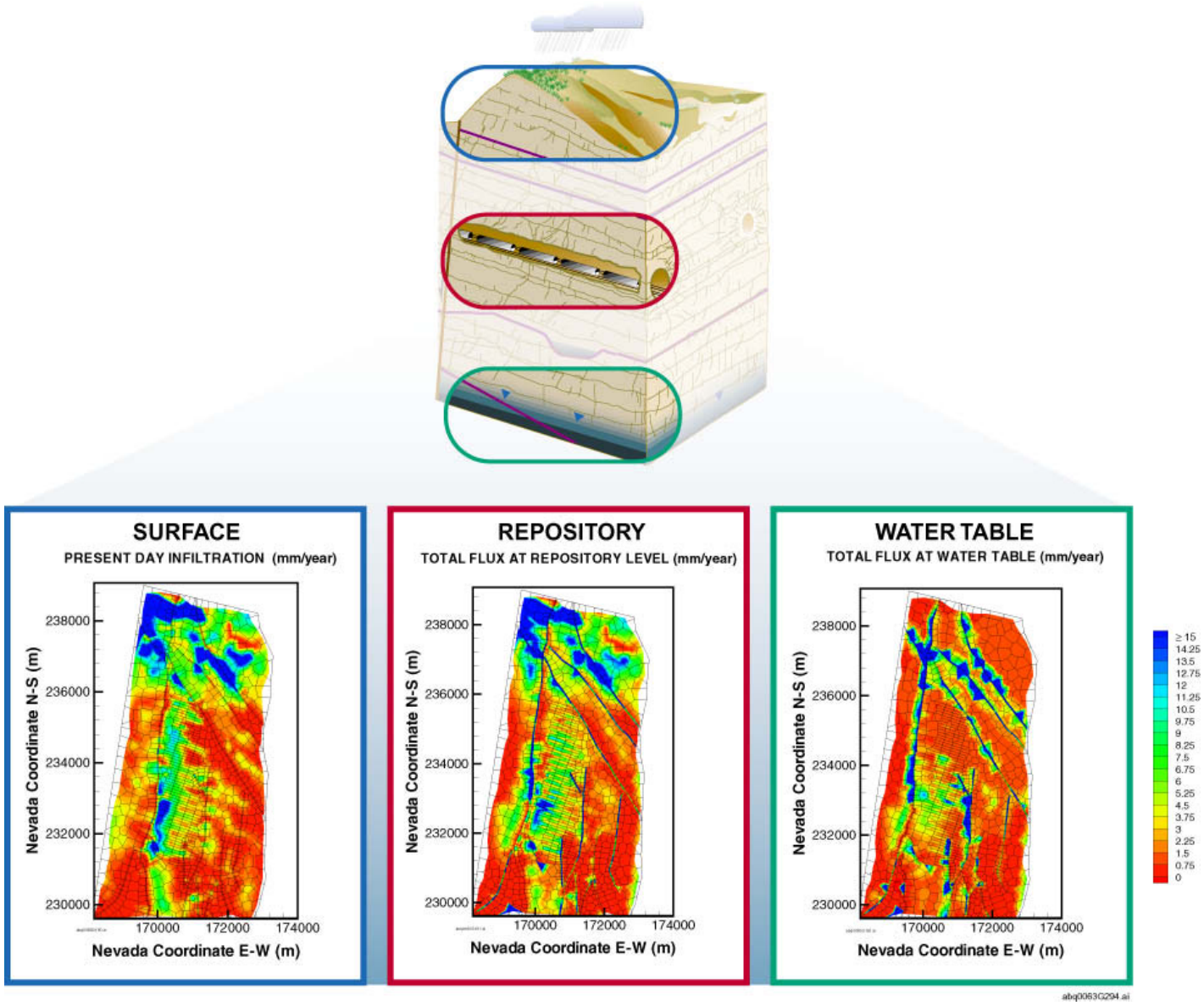
- Revised TSPA-VA model to include more rigorous fracture-matrix interaction model
- Flow fields are used directly in UZ transport calculations
- UZ flow was calculated for three infiltration cases and three climates—total of nine flow fields
- An alternative conceptual model of perched water was developed, but not used in TSPA (the more conservative model was used)
- Water table elevation increased by 120m for all future climates

Model Discretization

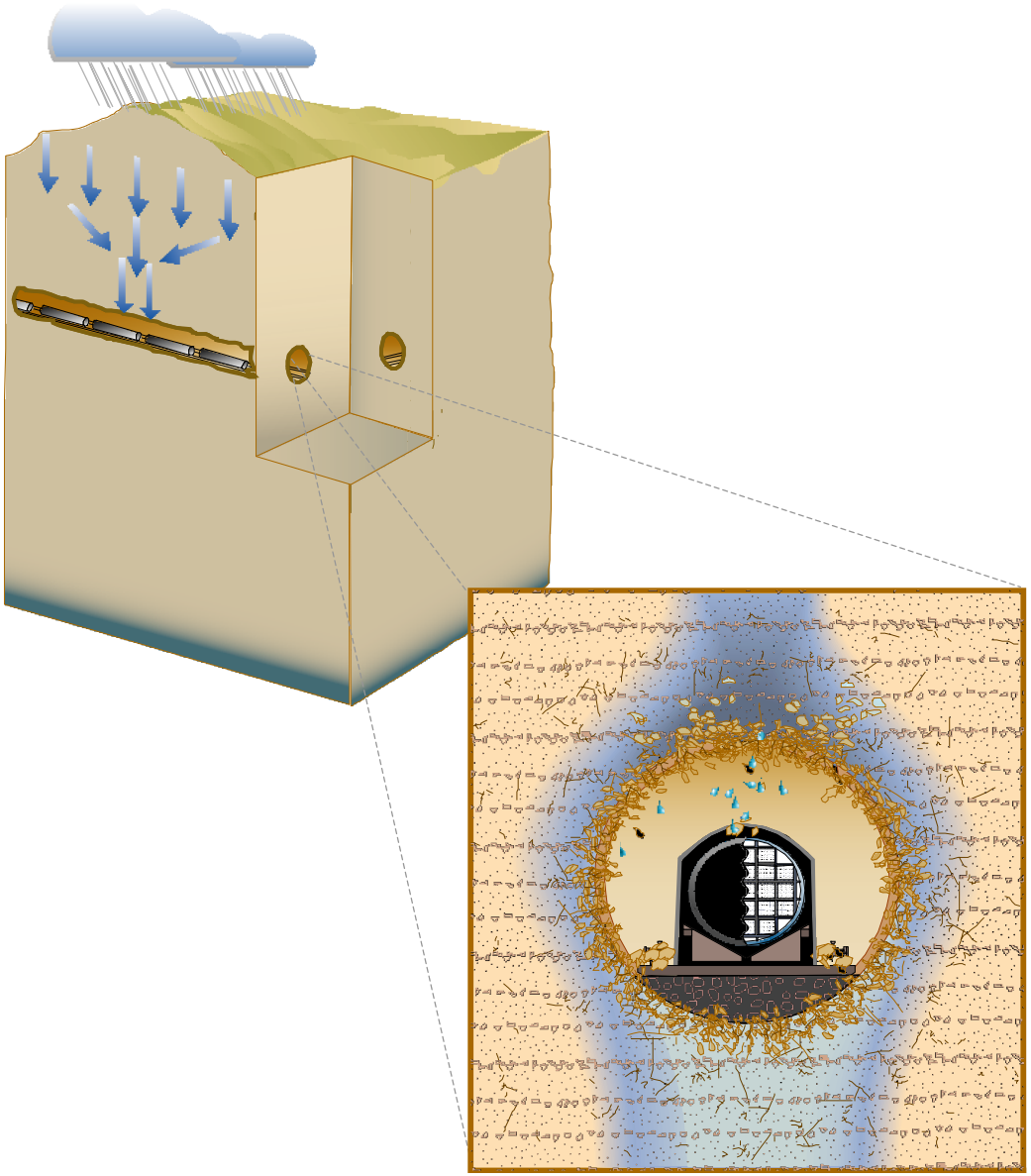




Percolation Flux at Three Elevations

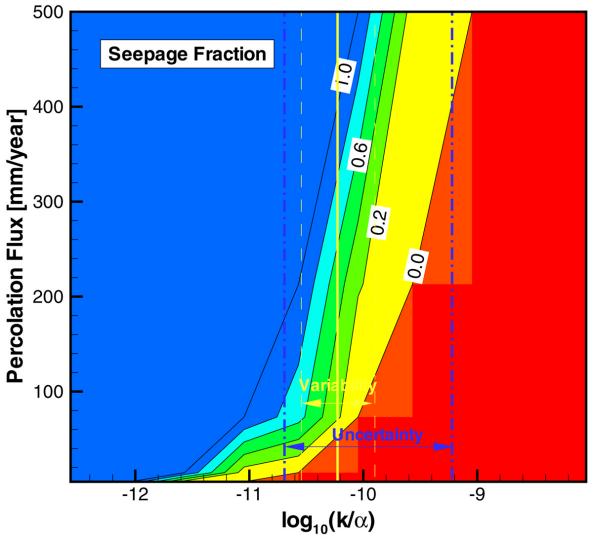


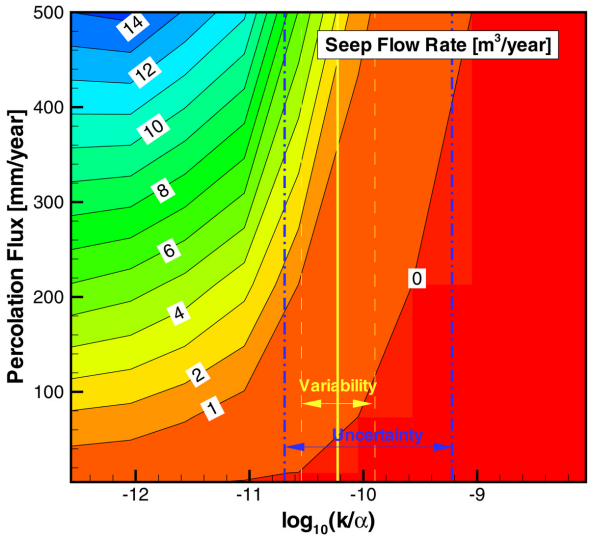
Seepage into Emplacement Drifts



- Focusing of flow above drifts
- Heterogeneity of hydrologic properties
  - Fracture permeability and capillarity
- Drift geometry and degradation
  - Excavation-disturbed zone
- Drift acts as capillary barrier (water is diverted around drift)
- Thermal perturbation from waste

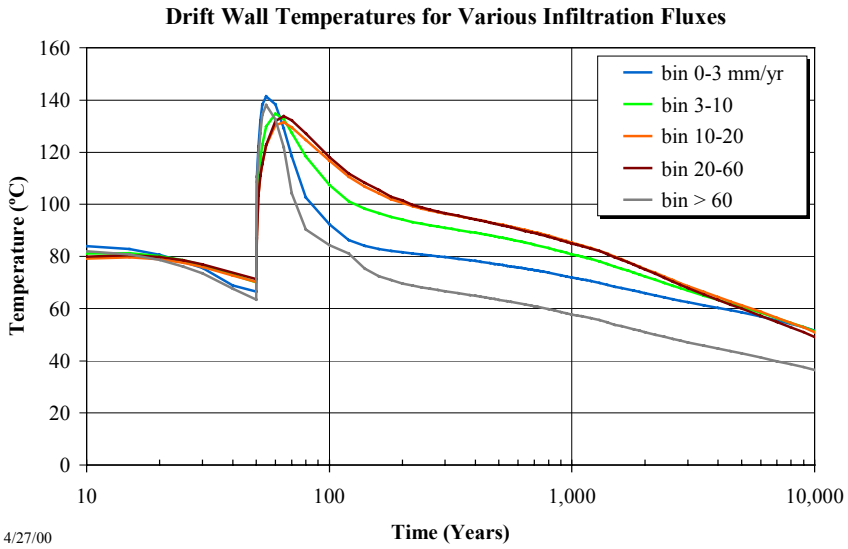
Seepage: Abstraction

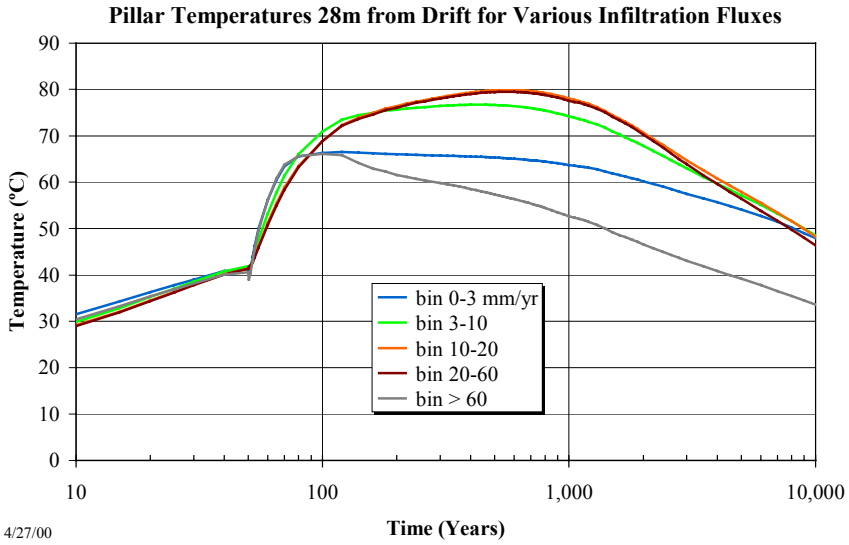




- Similar approach as in Viability Assessment (VA)
- Seepage model applied over range of fracture characteristics, percolation flux, and drift shapes
- Distributions developed for spatial variability and uncertainty of permeability (*k*) and capillarity (1/α) using data from Exploratory Studies Facility niche tests
- Seepage adjusted for flow focusing and drift degradation

Thermal Effects on Unsaturated Zone Flow





- **Site Recommendation design reduces effect of coupled processes**
  - **Lower mass loading (60 MTU/acre vs. 85 MTU/acre for VA)**
  - **Wider drift spacing (81 m vs. 28 m for VA)**
- **Boiling conditions limited to a few meters around drifts for a few hundred years**
- **Thermal-hydrologic-chemical changes in hydrologic properties have been found to be negligible**

Thermal Effects on Seepage

Seep Flow Rate, Averaged Over Locations with Seepage

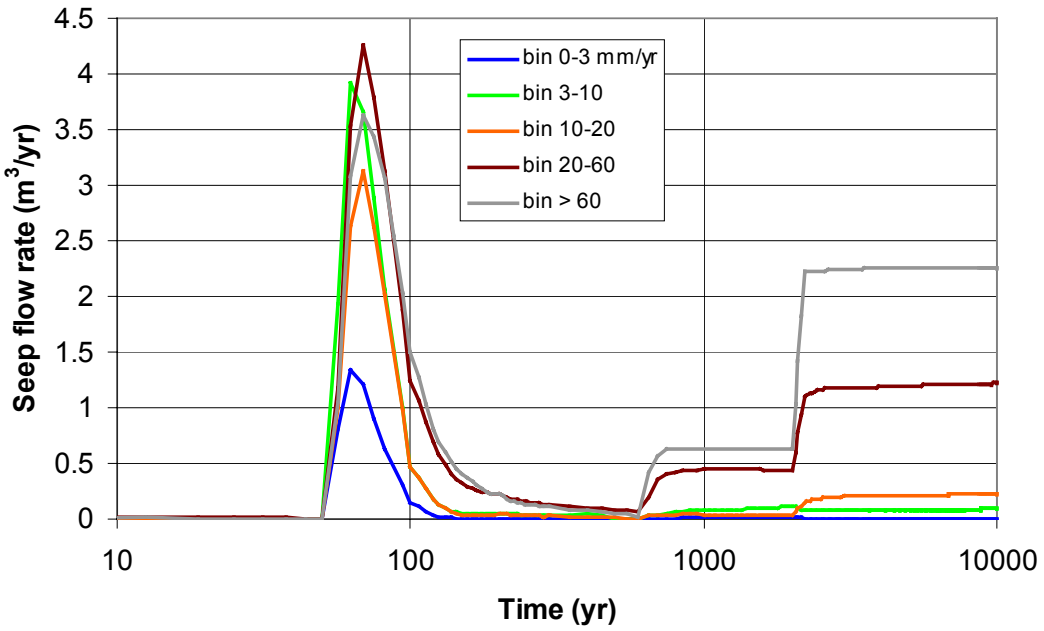
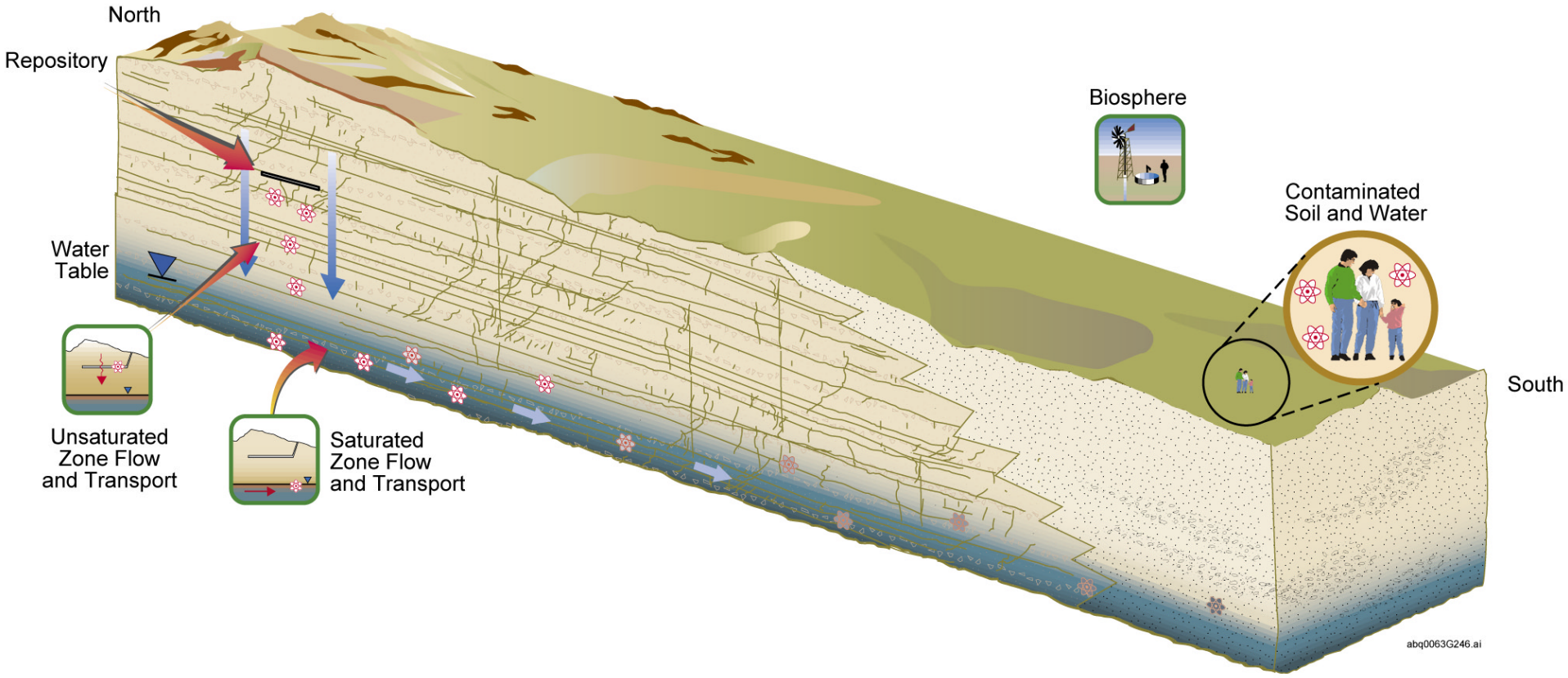


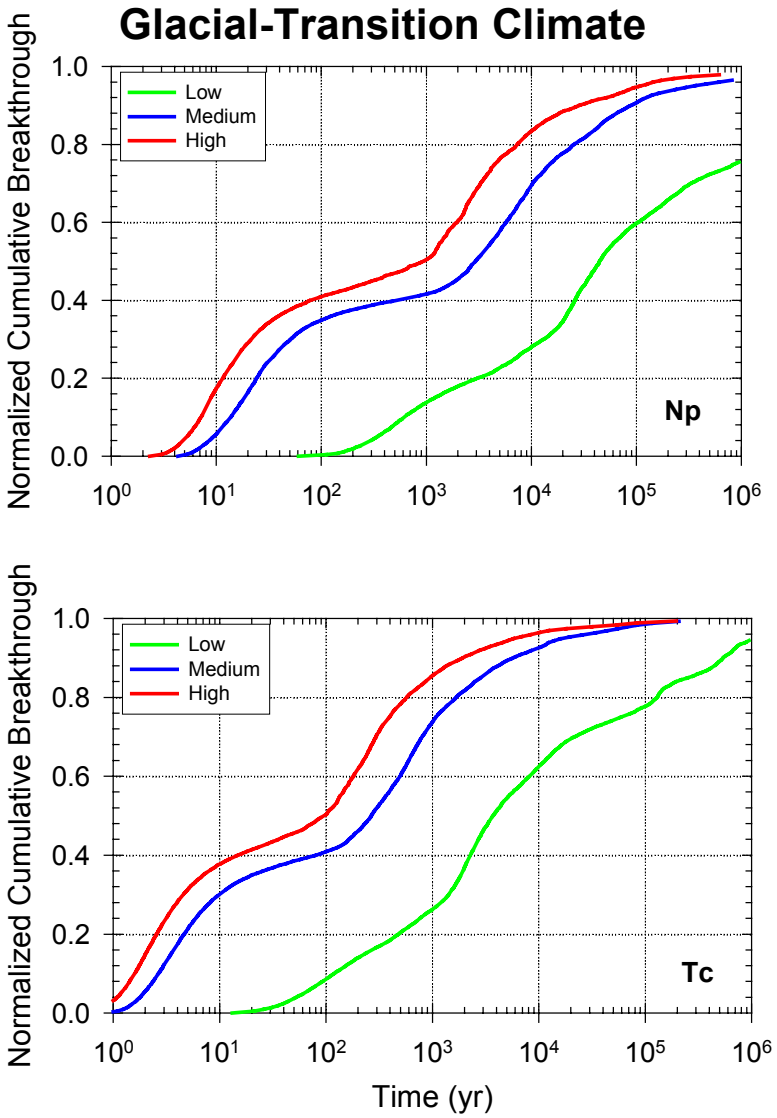
Figure Only Shows Averages; Variability and Uncertainty Are Included in Model

- **Percolation flux 5 m above the drift is used to calculate seepage**
- **Drainage of thermally mobilized water produces a pulse of seepage at around 100 years**
- **Seepage also varies with time because of climate changes**

Radionuclide Transport Away from Engineered Barriers

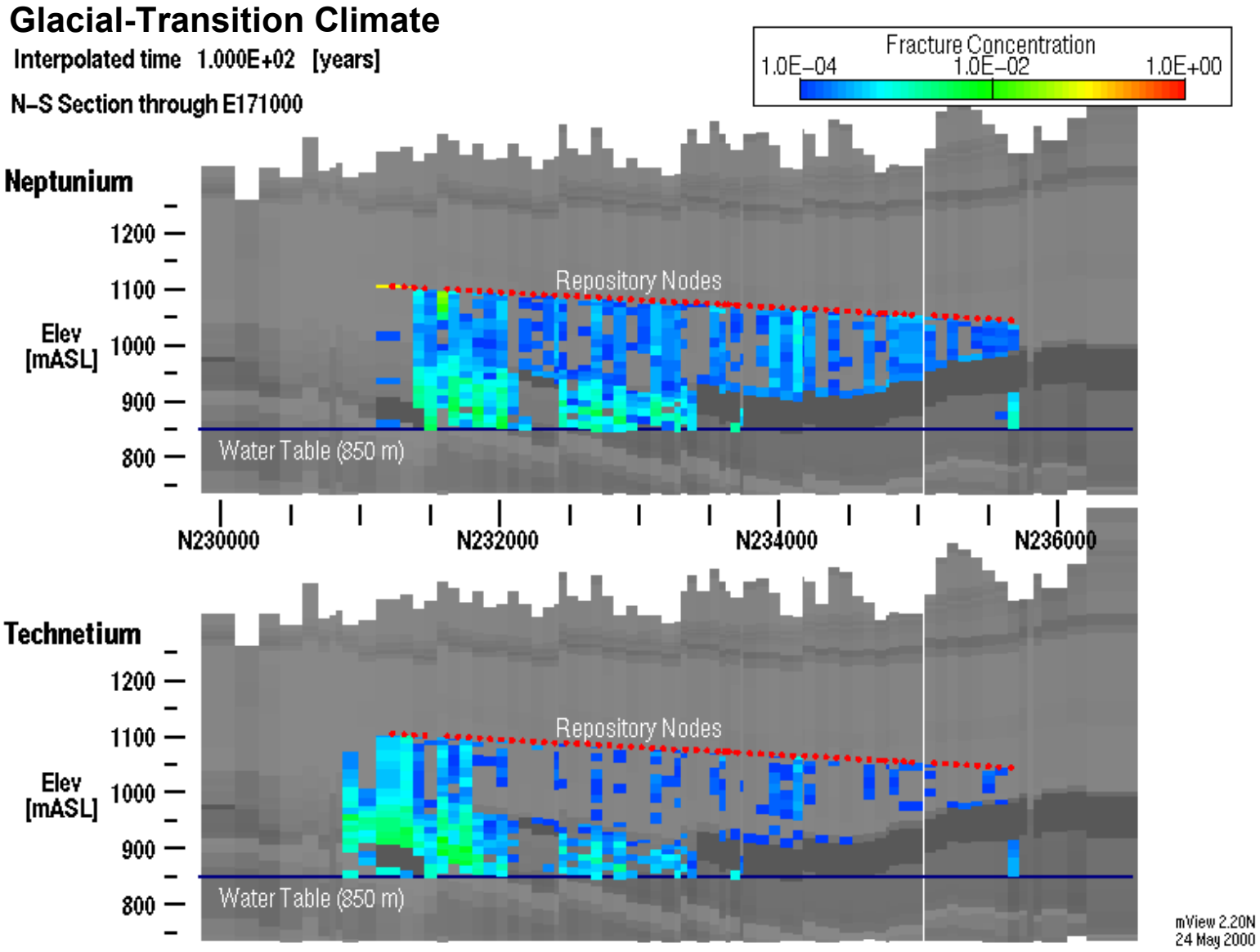


Unsaturated Zone Radionuclide Transport



- Similar approach and assumptions as TSPA-VA
- Matrix diffusion included, with active-fracture concept
- Transport of two kinds of colloids: radionuclides attached reversibly or irreversibly
- Uncertainty distributions are included for several key transport parameters
- Mass flux at water table is passed to saturated zone model at selected points

Sample Transport Simulation

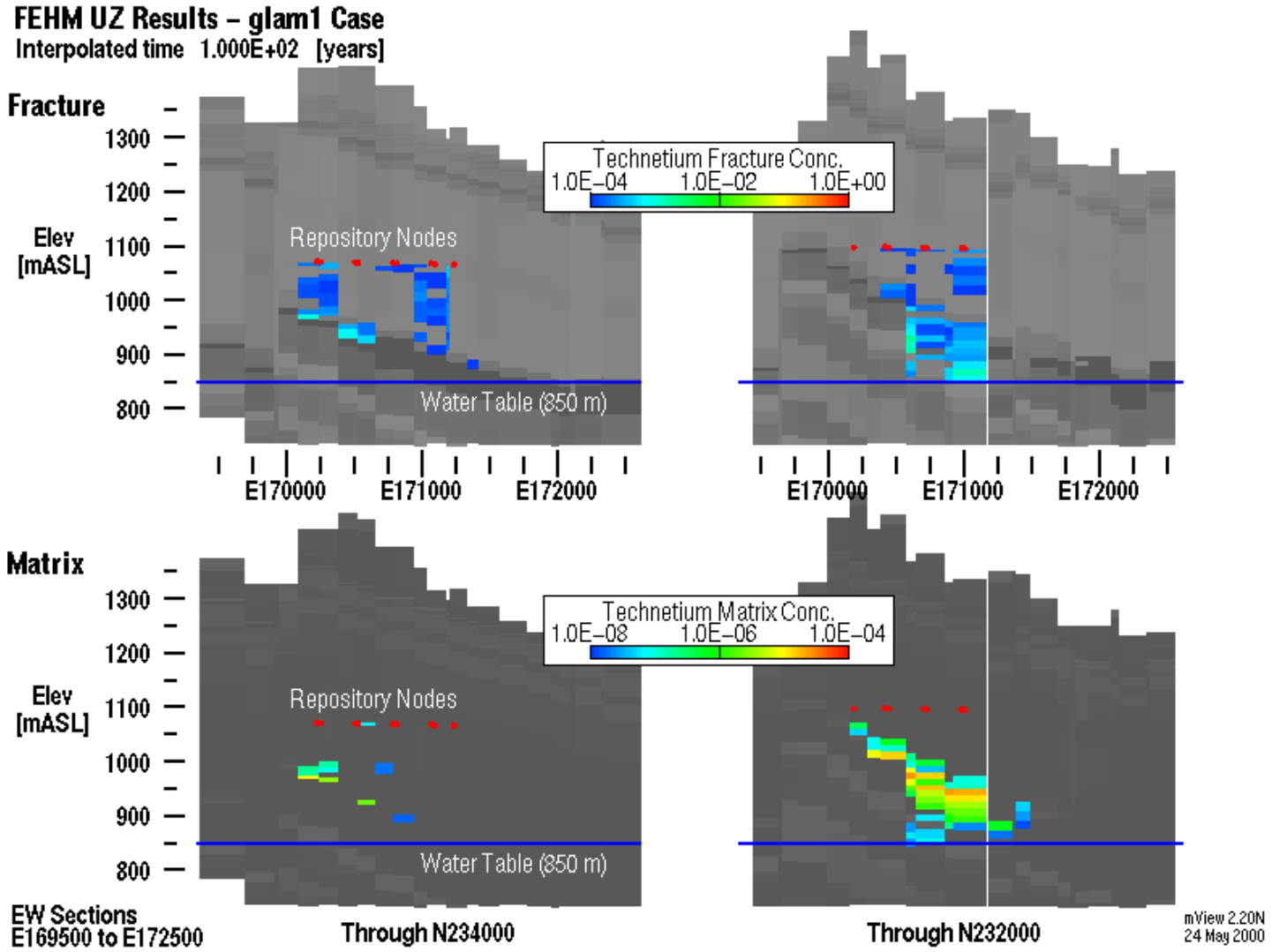


Summary

- Climate states are represented using analog sites
- Infiltration and UZ flow are simulated for three climates; range of uncertainty is represented using high, medium, and low cases
- Seepage abstraction takes into account spatial variability and uncertainty in percolation flux and hydrologic properties around the drifts
- Thermal effects on seepage are included in the TSPA; thermal effects on UZ flow and transport have been screened out
- Radionuclides are transported as solute or attached to colloids; uncertainty of several key parameters is included

Technetium Transport Simulation

(East-West Cross Section, Glacial-Transition Climate)



Technetium Transport Simulation

(North-South Cross Section, Glacial-Transition Climate)