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Long-Term Performance of Engineered Systems in Nature

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Overview

- FEPs Analysis – George Alexander
- Uranium Mill Tailings Sites – Doug Mandeville
- Closure Cap Monitoring – Vicky Freedman

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Performance Assessment and FEPs Analysis

How are we making progress in incorporating natural processes, features and conditions in our conceptual and numerical models, and in designing monitoring networks?

- NUREG-2175 Guidance for Conducting Technical Analyses for 10 CFR Part 61, Draft Final Report, October 2016.
- Performance Assessment (PA) is a type of risk analysis that addresses: (1) what can happen, (2) how likely it is to happen, and (3) what are the resulting impacts (Eisenberg et al., 1999)
- A PA shall consider Features, Events, and Processes (FEPs) that might affect demonstration of compliance (with the performance objective in 10 CFR 61.41

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What is a FEPs Analysis

How are we making progress in incorporating natural processes, features and conditions in our conceptual and numerical models, and in designing monitoring networks?

- **F**eature – An object, structure, or characteristic that has a potential to affect system performance (e.g., rocks within an erosion layer of a cover)

- **E**vent – A natural or human-caused phenomenon that has a potential to affect system performance and occurs over a short period of time relative to the period of performance (e.g., earthquakes, floods, well drilling, excavation)

- **P**rocess – A natural or human-caused phenomenon that has the potential to affect repository system performance and occurs over a significant part of the period of performance (e.g., erosion, leaching, transport, differential settlement)

- Risk-informed approach – FEPs analysis (and documentation) commensurate with risk

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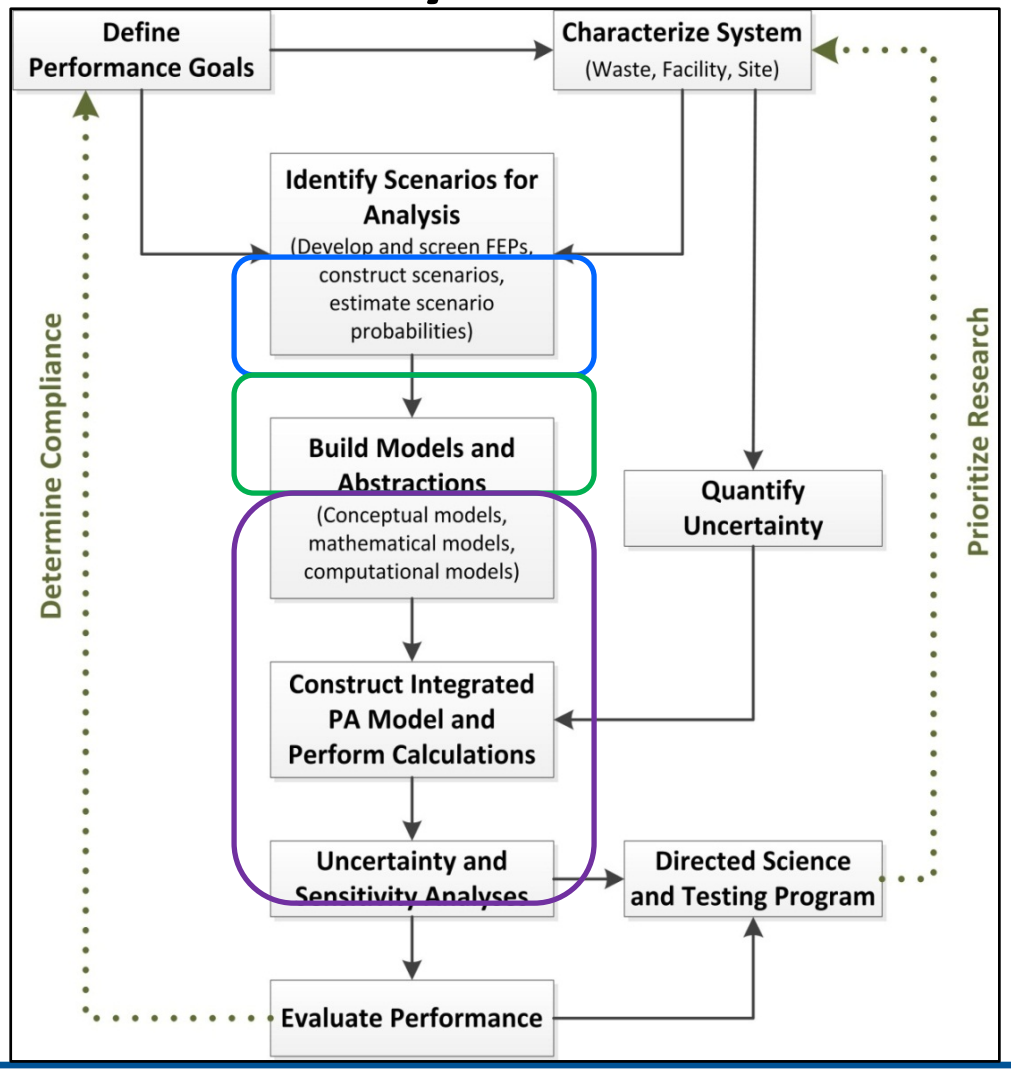
What is a FEPs Analysis

- Formal FEP analysis for performance assessment of disposal systems consists of the systematic implementation of the following steps:
  - FEP Identification
  - FEP Screening
- FEP analysis supports:
  - Scenario Development
  - Implementation in a Model
- These steps are performed and refined over multiple iterations



Freeze, G. Features, Events, and Processes (FEPs) Analysis for Radioactive Waste Disposal: Rationale and Application. NRC Workshop on PA of Near Surface Disposal. August 29, 2012. ML13053A280

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FEP Identification and Screening

Are we explicitly considering human processes and behaviors, and consequent natural responses?

FEP Identification (i.e., comprehensiveness of the FEP List)

- A comprehensive set of FEPs should capture all of the features and phenomena that are potentially relevant to system performance
- Formal FEP analysis provides objective evidence that all potentially relevant FEPs have been addressed

How do we determine the natural processes, features, and conditions to include in conceptual models and monitoring programs?

FEP Screening (i.e., model completeness)

- The process of using regulatory, probability, and consequence criteria to eliminate FEPs from further consideration that will not significantly impact the performance of the disposal system
- Screened in FEPS are combined to form a limited number of scenarios for consequence analysis
- If a FEP cannot be excluded, then it must be included

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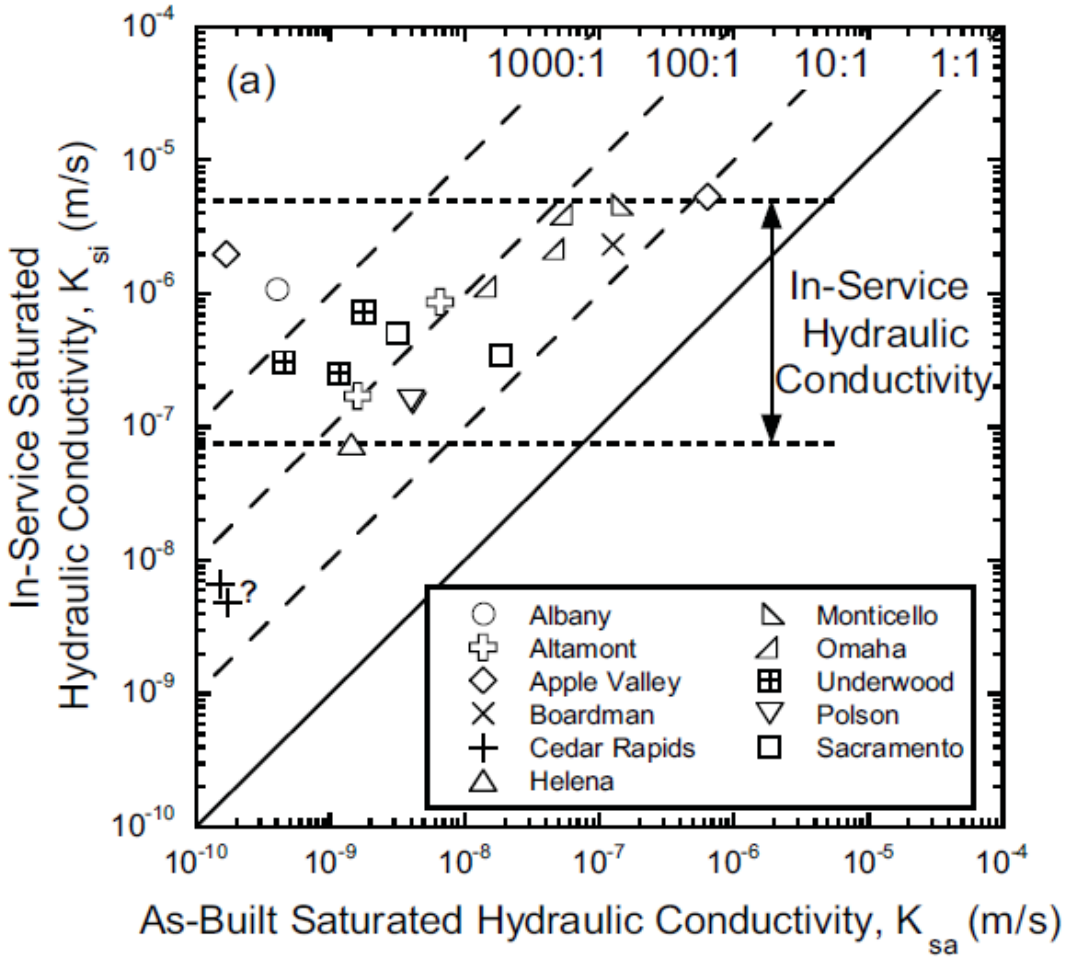
Evolution of Engineered Systems



- Engineered systems evolve towards local equilibria
- Often, the further the system is from equilibrium, the faster the evolution of properties towards the surrounding environment
- Designing with nature can:
  - Reduce changes to the system over time
  - Reduce long-term maintenance

Benson, C. et al., "Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment," NUREG/CR-7028, 2011. ML12005A110

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Uranium Mill Tailings Sites

- Doug Mandeville
- U.S. Nuclear Regulatory Commission

Source – Wyoming Mining Association, Kennecott Sweetwater Mill - under licensee control

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Regulatory Requirements

- Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA)
  - Title I - inactive uranium mill tailings piles (circa 1978)
  - Title II – facilities with NRC licenses after 1978

- Regulations
  - 40 CFR Part 192 (EPA) Generally Applicable Standards
  - 10 CFR Part 40
  - Appendix A to Part 40

- What NRC regulates
  - Milling – any activity that produces byproduct material
  - Byproduct Material – tailings or wastes produced by extraction of U or Th for its source material content
  - NRC does not regulate mining or exploration

UMETCO site near Gas Hills, WY – under licensee control

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Goals

- Permanent isolation of tailings and associated contaminants
- Minimize disturbance and dispersion by natural forces
- No reliance on ongoing maintenance
- 10 CFR Part 40 Appendix A has 13 Criteria that address these goals

Homestake site near Grants, NM - under licensee control

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Goals – Working with Nature

"While isolation of tailings will be a function of both site and engineering design, overriding consideration must be given to siting features given the long-term nature of tailings hazards." from Criterion 1 in 10 CFR Part 40 Appendix A

Canonsburg site, PA – under long term surveillance by DOE

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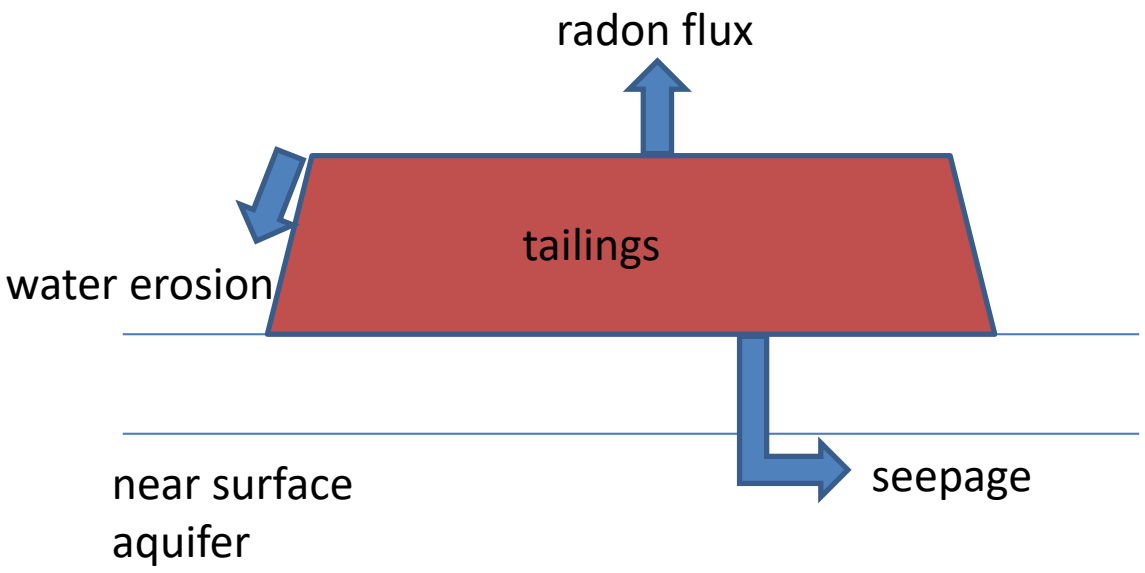
Risks



- Wind and water erosion of cover
- Groundwater contamination from tailings liquids in the near surface aquifer
- Radon flux from tailings
- Embankment stability
- Chemical toxicity of uranium

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Past Approach

Ambrosia Lake, NM site - under long term surveillance by DOE

- Resistive Barriers
- Armored Rock Covers
- Construction completed in mid to late 1990's
- Similar to many of the covers from that time period
- Research on near term performance of covers identified changes in engineering properties of soils

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Transition to ET Covers

- Recognition that working with nature may be more effective in the long run
- Licensees and DOE-LM trending towards evapotranspirative (ET) covers
- Thicker cover with vegetation to remove water from the cover system
- Try to mimic surroundings
- Both rock covers and vegetative covers can meet NRC regulations

Crescent Junction Disposal Cell, UT – DOE EM relocating tailings from Moab, UT

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Monitoring

- DOE/licensee develop long term surveillance plans prior to termination (NRC reviews and accepts)
- Surveillance is site specific, depending on the features of the site
- Cover performance (qualitative)
- Groundwater monitoring at many sites
- Annual reporting to NRC
- Increased interest from DOE in pursuing remote monitoring for cover performance
  - Settlement
  - Water storage in cover system
  - Vegetation
- Open to other ideas and approaches
- When does a change in performance indicate a problem?

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Monitoring the Prototype Hanford Barrier

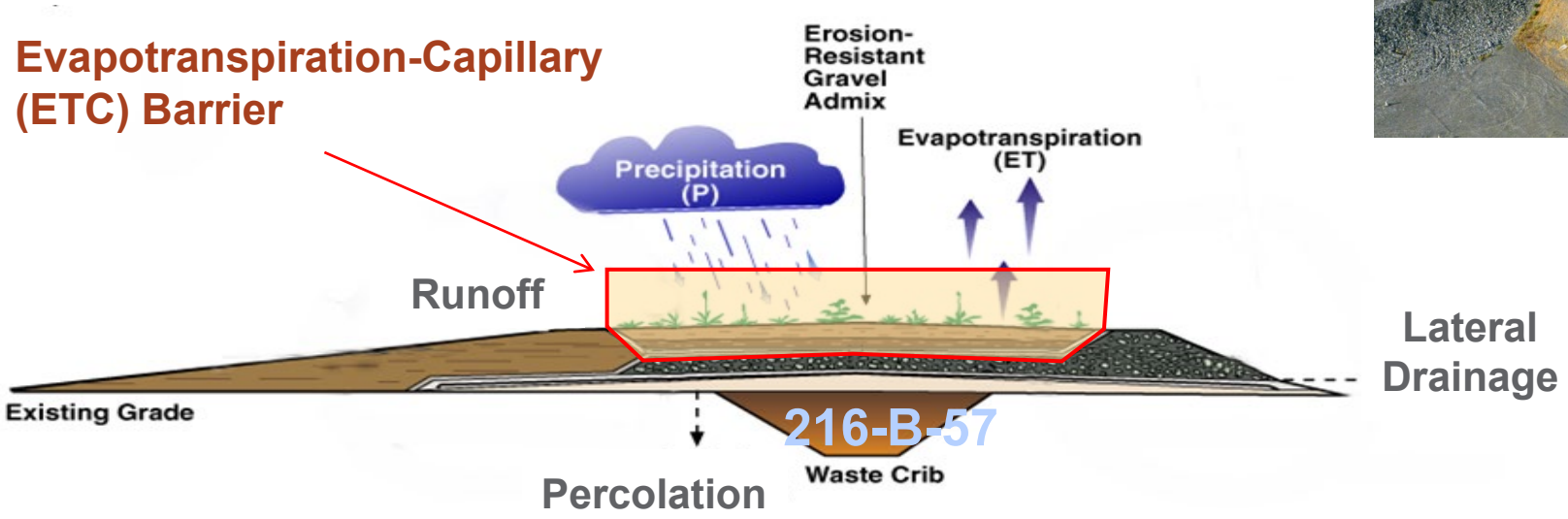
Vicky Freedman and Fred Zhang

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Prototype Hanford Barrier (PHB)

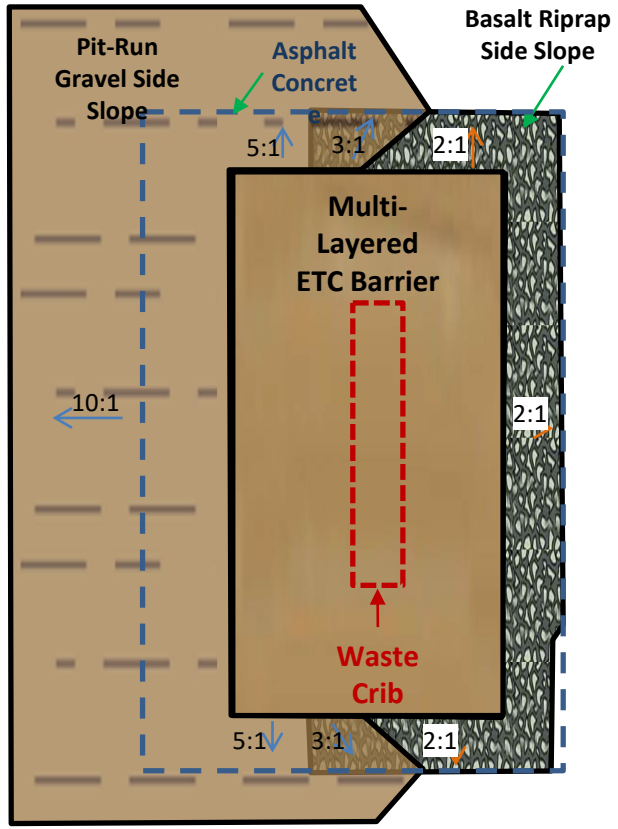
- Constructed over an existing waste site in 1994
  - Formal treatability testing (1994 – 1997)
  - Demonstrate hydrological, ecological and stability performance
- Stress Tests
  - Irrigated the northern half to about 3x the average precipitation (3x160 = 480 mm/yr)
  - Controlled burn on northern half in Sept 2008



Size: 80x40 m

Requirements

- Regulatory
  - Meet or exceed RCRA criteria
- Functional
  - Function in a semiarid environment
  - Limit drainage to less than 0.5 mm yr^{-1}
  - Limit runoff
- Longevity
  - Minimize erosion
  - Minimize biotic intrusion
  - Have a design life of 1000 years
  - Be maintenance free



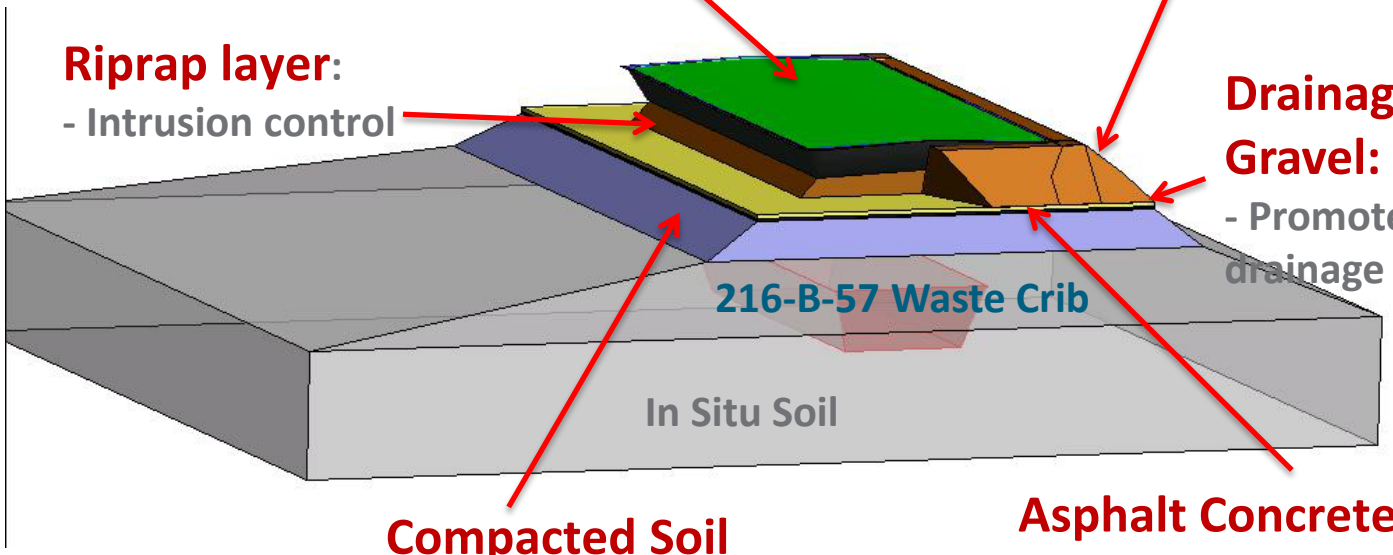
Controlled burn (2008)

Barrier Components

Silt Loam + Gravel:
- Vegetation growth
- Precipitation storage and release
- Erosion control

Riprap Side Slope:
- Intrusion control

Riprap layer:
- Intrusion control



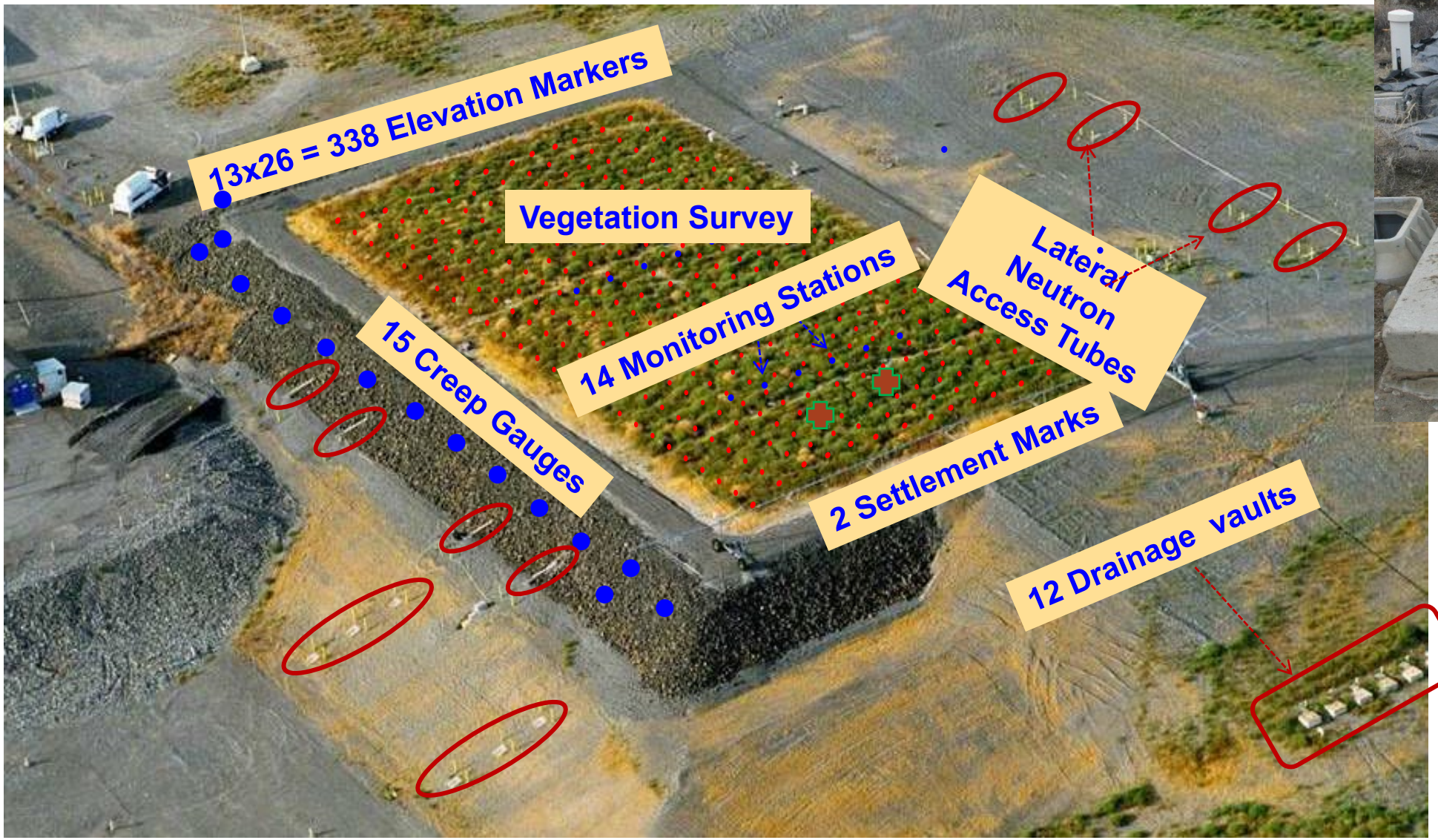
Drainage Gravel:
- Promote lateral drainage

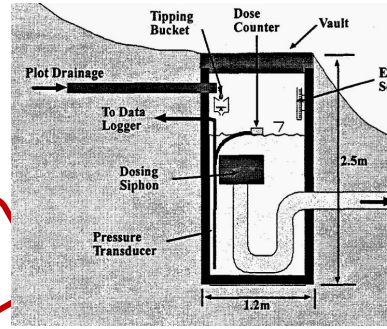
Compacted Soil
- Settlement control

Asphalt Concrete
- Drainage interception
- Noxious gas control

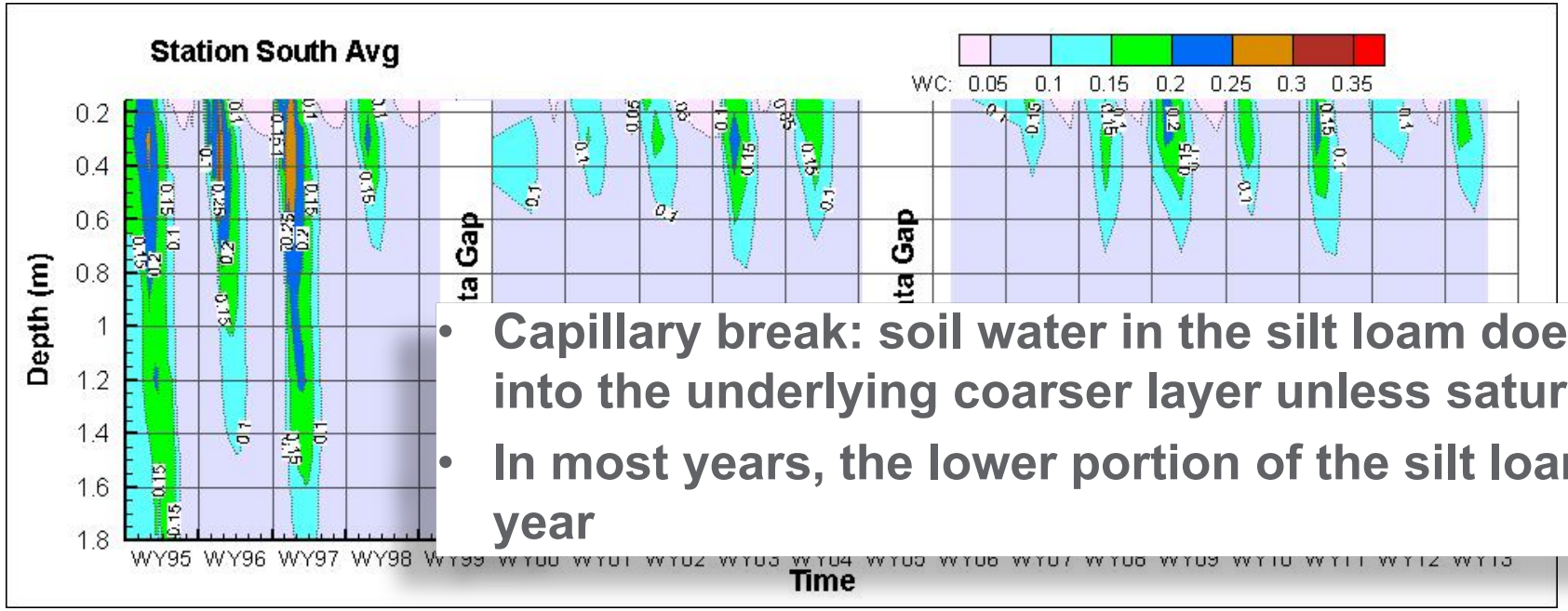
2X vertical exaggeration

Monitoring Systems

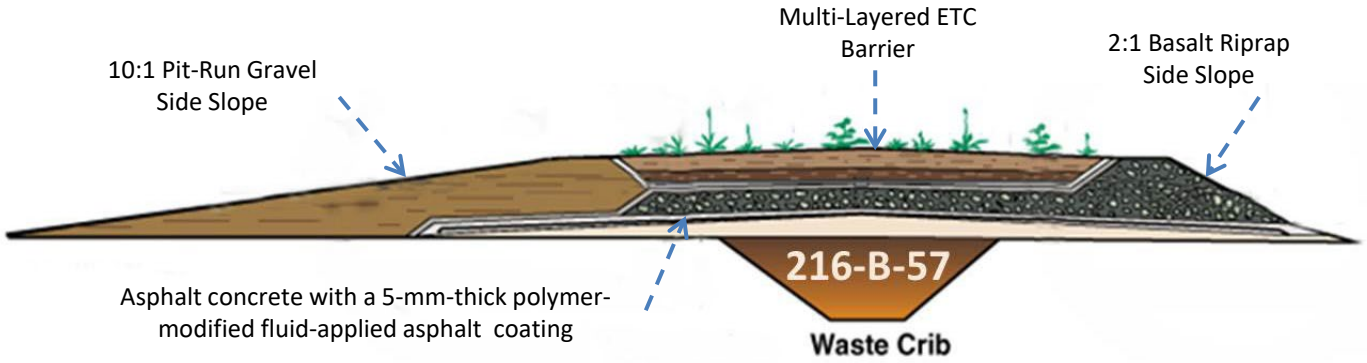




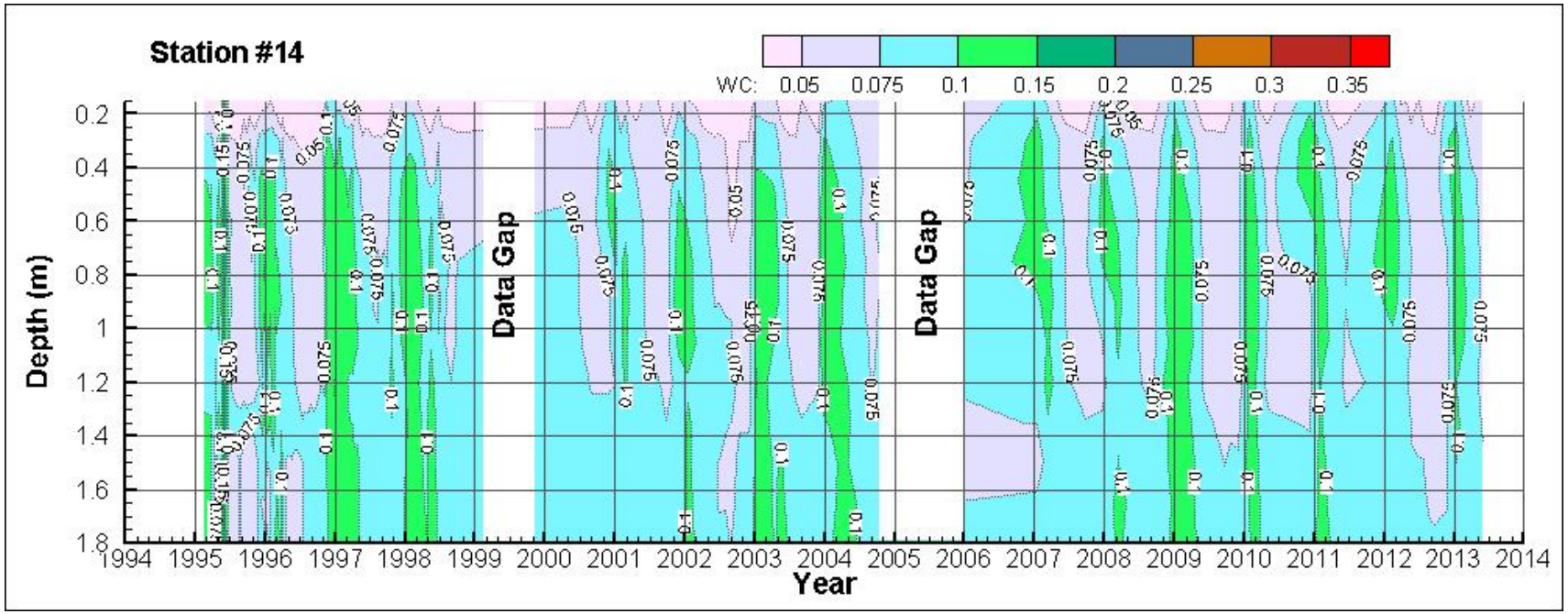
Silt Loam Moisture Content



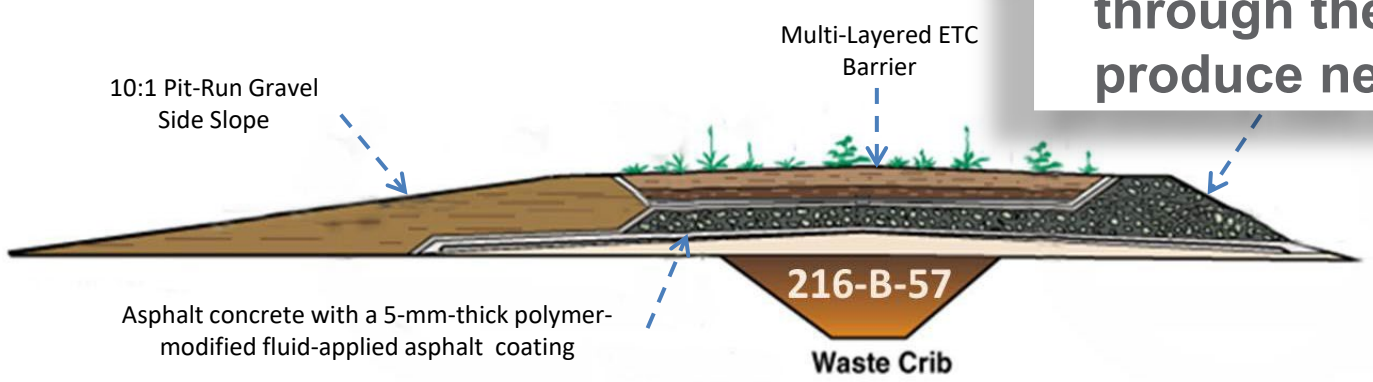
- Capillary break: soil water in the silt loam does not enter into the underlying coarser layer unless saturation occurs
- In most years, the lower portion of the silt loam stays dry all year



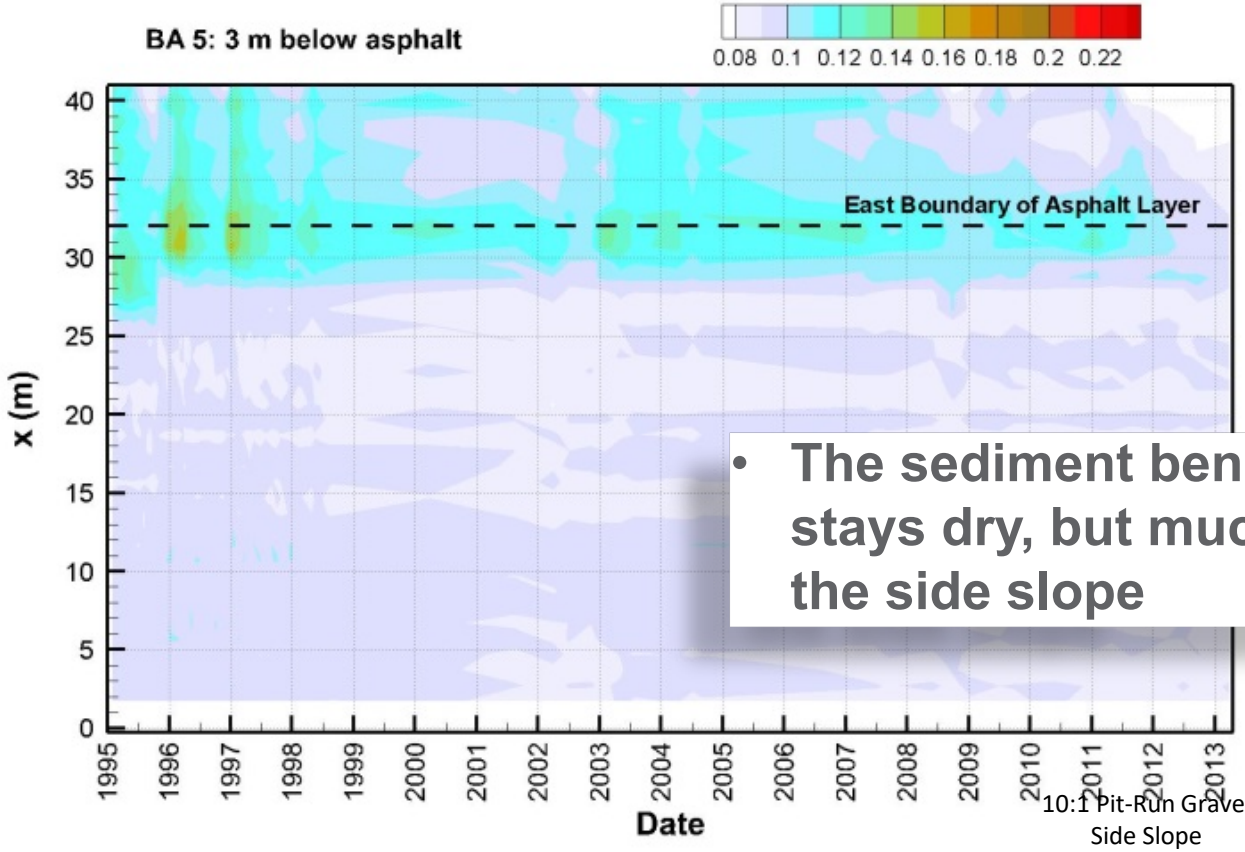
Gravelly Soil Side Slope Moisture Content



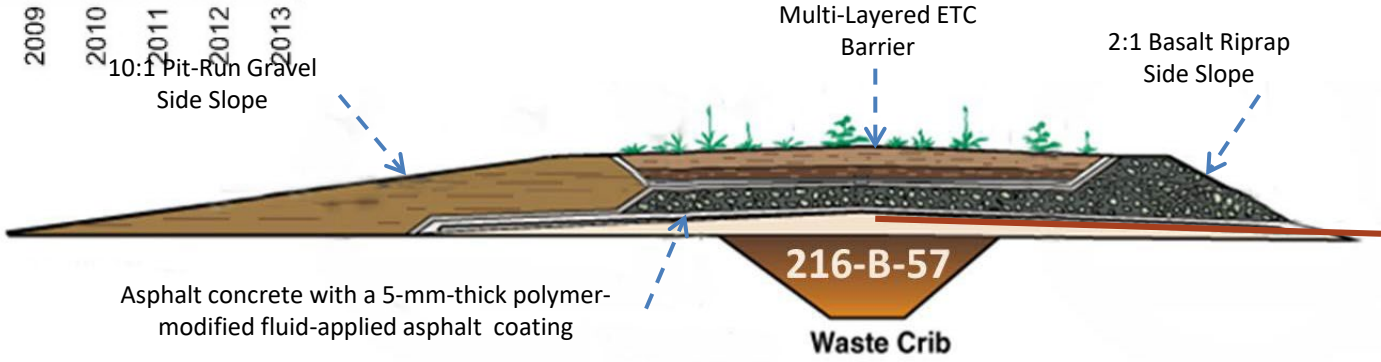
- **Precipitation can infiltrate through the side slope and produce net recharge**



Compacted Soil Moisture Content

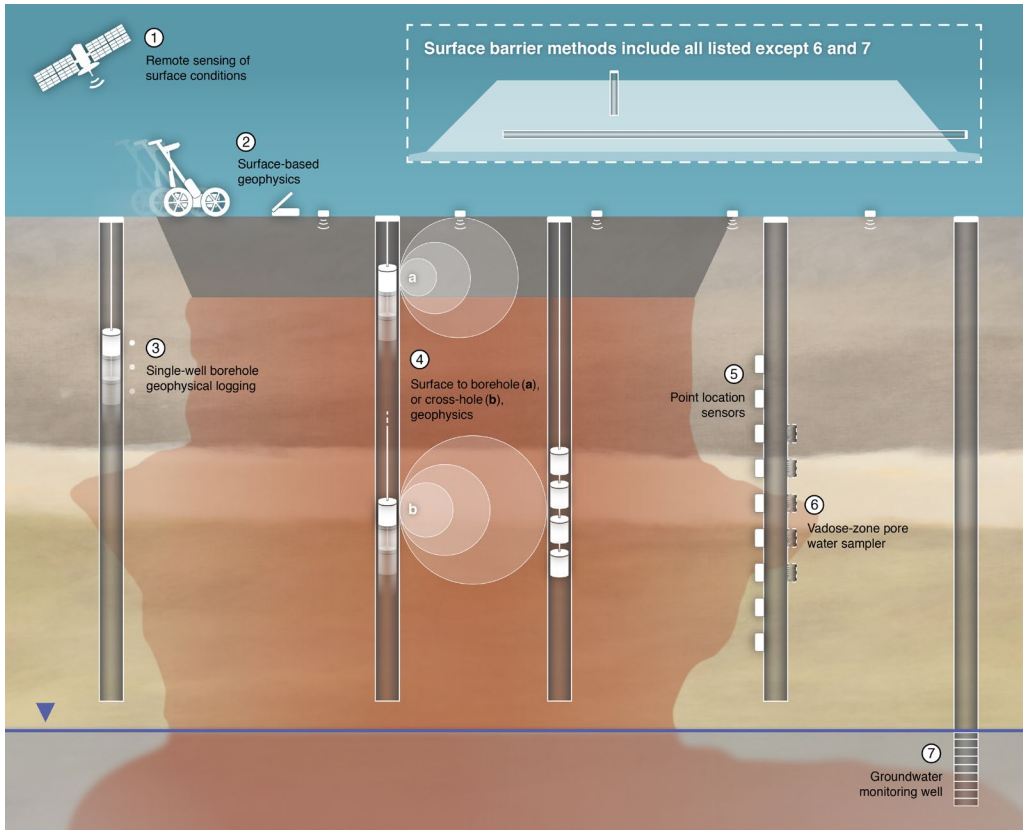


- The sediment beneath the barrier stays dry, but much wetter beneath the side slope



Long-Term Monitoring of Surface Barriers

- PHB initially warranted a high level of monitoring
- Long-term, cost effective monitoring for PHB and a wide range of future Hanford barrier designs is needed
- Evaluating surface geophysics for moisture conditions
  - Electrical resistivity tomography (ERT)
    - ✓ Cross-borehole needed to image with depth
  - Ground penetrating radar (GPR)
    - ✓ Appropriate for shallow moisture content
  - Electromagnetic induction (EMI)
    - ✓ Surface/single-borehole/cross-borehole applications
  - Seismic
    - ✓ Appropriate for dry conditions beneath surface barriers



Summary

- **Effective.** ETC component of the PHB based on the store-and-release mechanism performs as intended
  - **Low Winter ET**. Fairly constant ET rate comparable to the seasonal PET
  - **High Summer ET.** ET in the summer season is approximately the sum of the stored water in the previous winter and the precipitation in the summer
- **Mechanically Stable**. No settlement or compression or translocation has occurred at the ETC barrier and side slopes.
- **Negligible Erosion/Intrusion**. Water and wind erosion and intrusion by plants or animals has been minimal.
- **Limited Fire Impact**. Vegetation gradually reestablished after the controlled fire in 2008

Current Focus

- Cost-effective geophysical surveys to monitor barrier performance
- Compile and develop relevant barrier design option information based on the decades long PHB treatability test and elsewhere for
  - Functional multi-layered ETC barrier
  - Protective side slopes
  - Region surrounding a barrier
- Support monitoring and future barrier designs with modeling
  - Evaluate performance of barrier design options using **eSTOMP** to support selection of suitable barrier designs for target sites
  - Non-intrusive geophysical monitoring support using **E4D** (3D modeling and inversion code designed for subsurface imaging and monitoring)

Recent Publications

- Zhang, Z.F. 2015. Field Soil Water Retention of the Prototype Hanford Barrier and Its Variability with Space and Time. Vadose Zone Journal 14: 1-10. doi:10.2136/vzj2015.01.0011.
- Zhang, Z.F. 2016. Evaluating the long-term hydrology of an evapotranspiration-capillary barrier with a 1000 year design life. Water Resources Research 52. doi:10.1002/2015WR018167.
- Zhang, Z.F. 2017. Long-Term Drainage from the Riprap Side Slope of a Surface Barrier. Water 8: 156-164.
- Zhang, Z.F., C.E. Strickland and S.O. Link. 2017. Design and Performance Evaluation of a 1000-year Evapotranspiration-Capillary Surface Barrier. Journal of Environmental Management 187: 31-42.

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Thank you