Sustainability of Conventional and Alternative Landfill Covers

Designing, Building, and Regulating ET Covers
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Topics

- Long-Term Stewardship Perspective
- Landfill Disposal Dilemma
- Performance of Conventional Covers
- Monticello, UT, Case Study
- Natural Analogs of Long-Term Performance
- Ecosystem Engineering Paradigm

Long-Term Stewardship Perspective

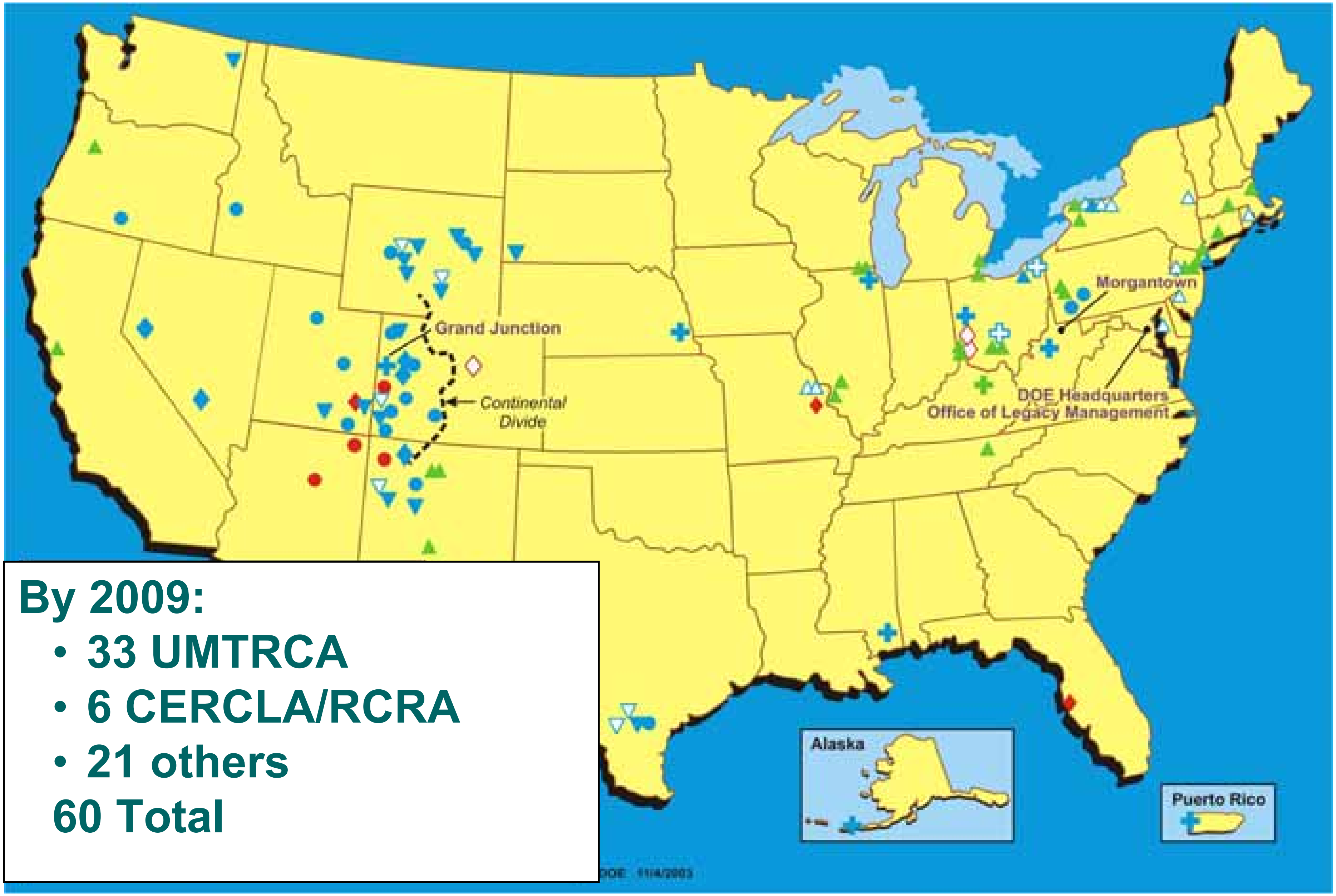
U.S. Department of Energy
Office of Legacy Management (LM)

Mission:

Long-term stewardship of nuclear production “legacy waste”

- **Monitoring**
- **Maintenance**
- **Long-term Performance**

DOE Legacy Management Sites



By 2009:

- 33 UMTRCA
- 6 CERCLA/RCRA
- 21 others

60 Total

Office of Legacy Management: Long-Term Stewardship Perspective

Fundamental Questions

- **How was the cover designed and constructed?**
- **How is it supposed to work?**
- **What do we monitor to show that it is working?**
- **How much will maintenance cost to keep it working as designed?**
- **What are the risks if its not working as designed?**
- **How do we design sustainable repairs or replacements *if needed*?**
- **Can we expect the cover to continue working for 10s to 100s to 1000s of years?**

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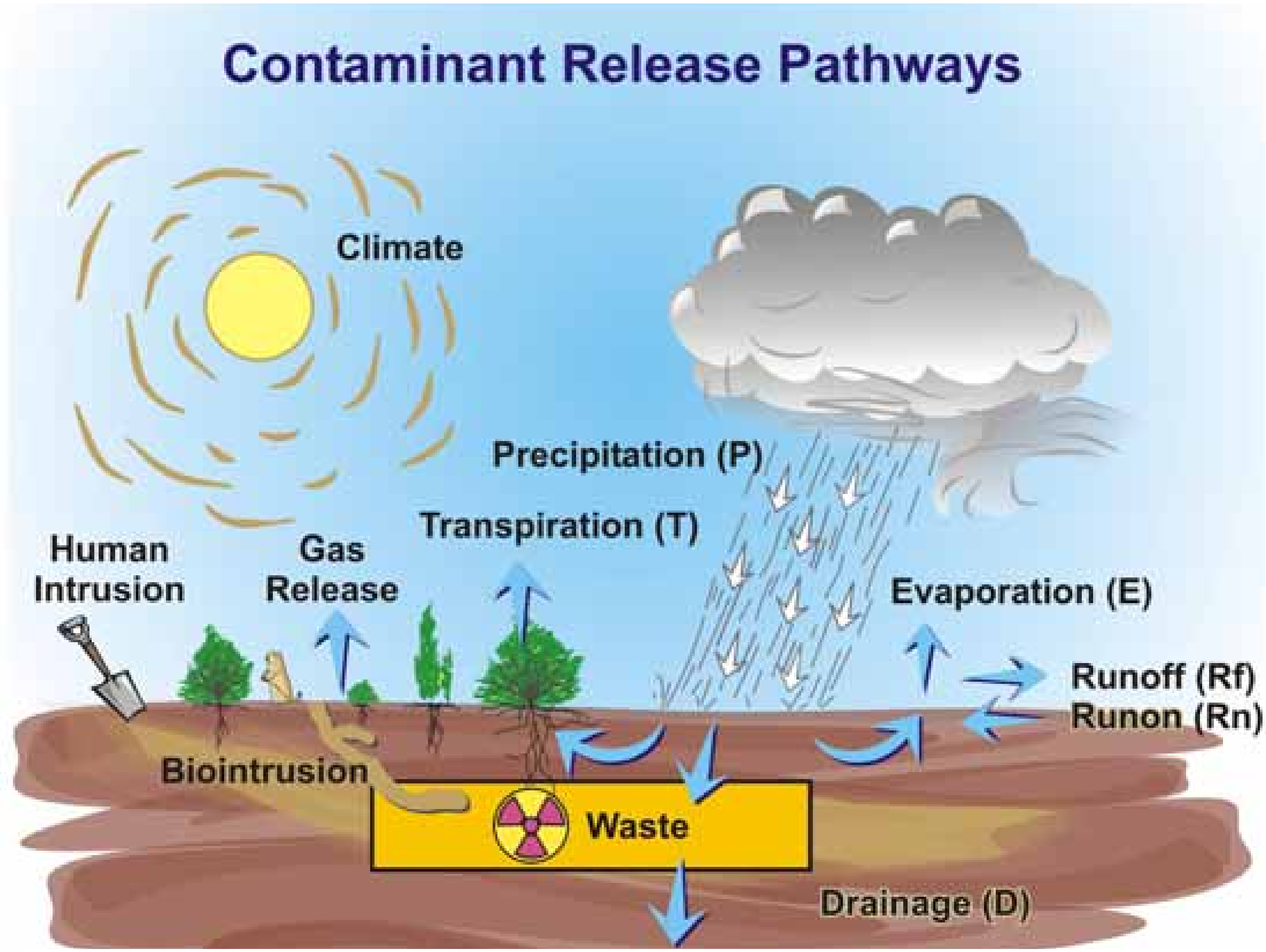
Landfill Disposal Dilemma



$$D = P - E - T + Rn - Rf - \Delta S$$

Landfill Disposal Dilemma

Landfill covers must limit human and ecological exposure for *10s to 100s to 1000s of years* and do so while natural processes are acting to mobilize contaminants

> ***—an unprecedented engineering challenge!***

Topics

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- **Performance of Low-Permeability Conventional Covers**
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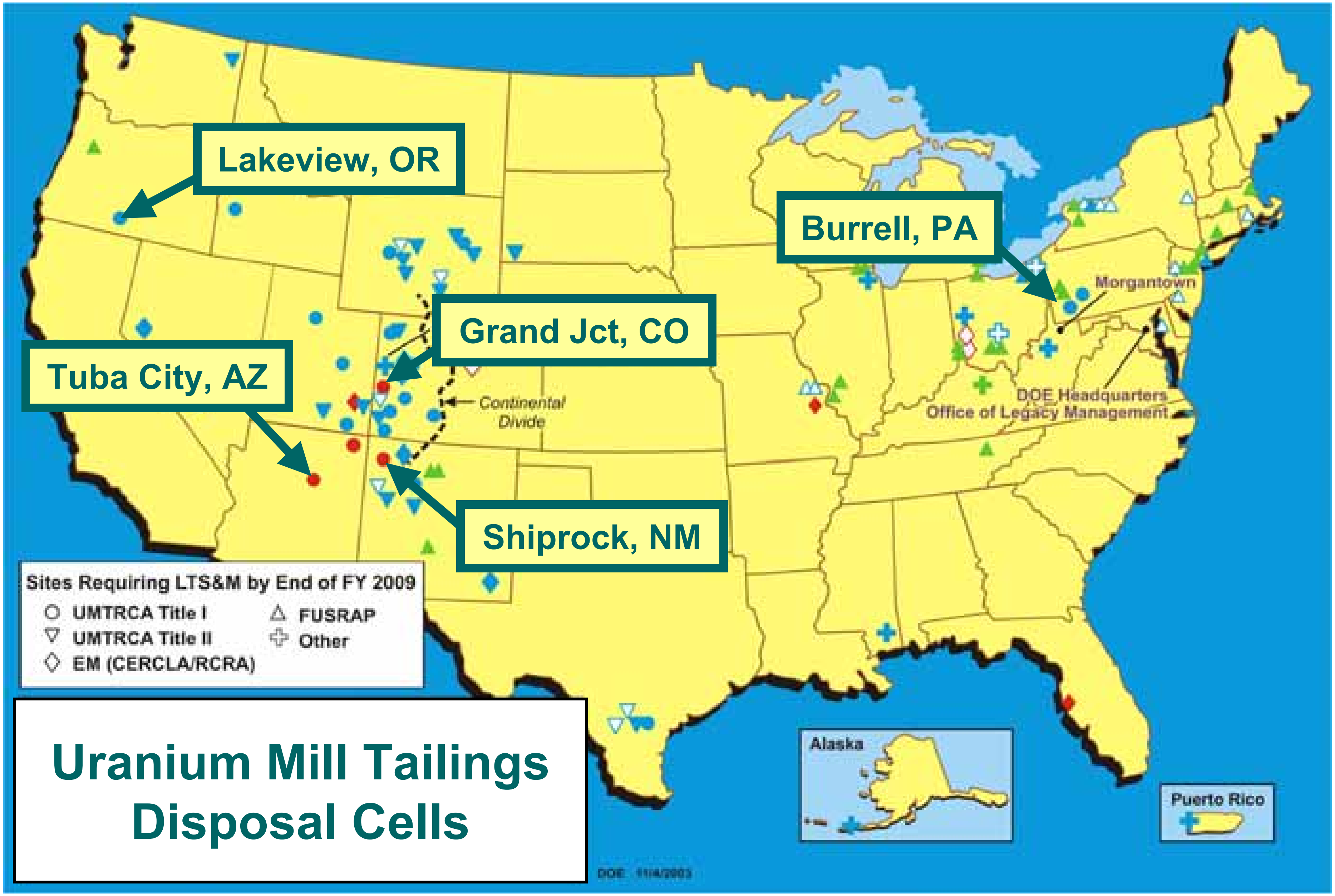
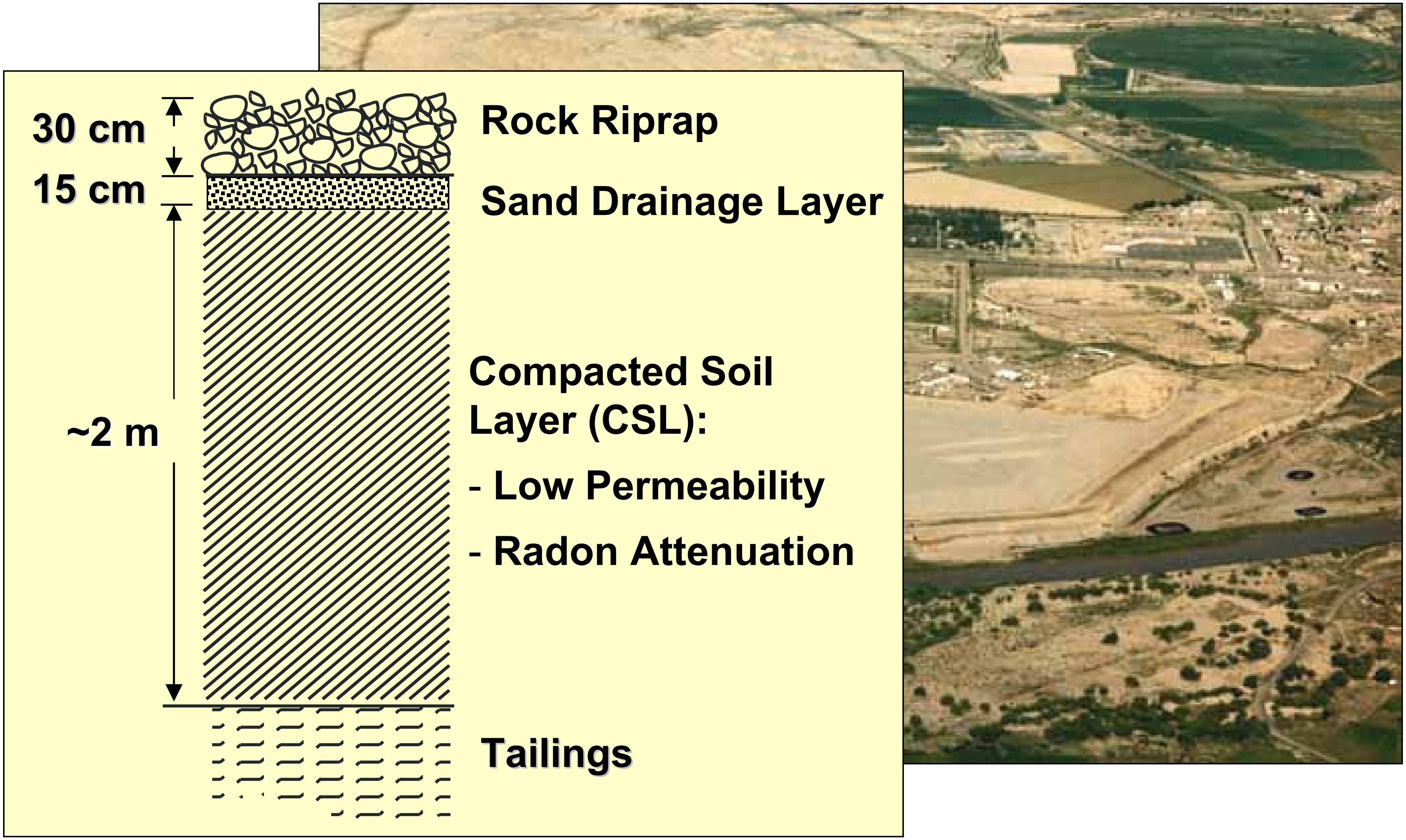
LM Conventional Cover Sites

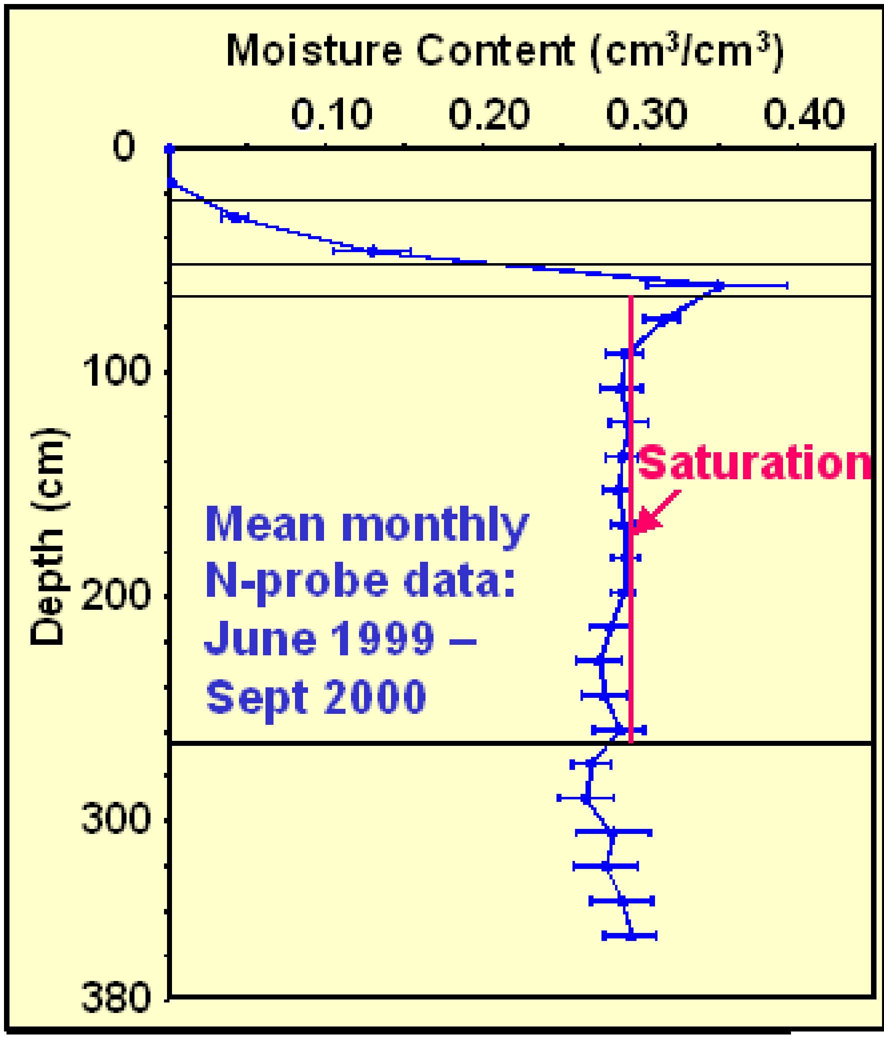


Uranium Mill Tailings Disposal Cells

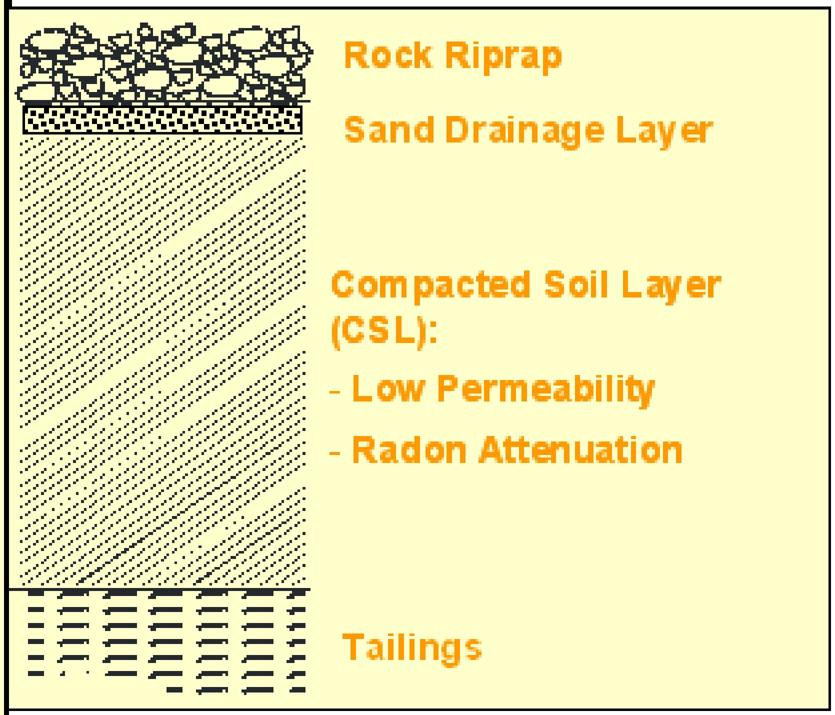
Conventional Cover Example: Shiprock, New Mexico



Some Lessons Learned



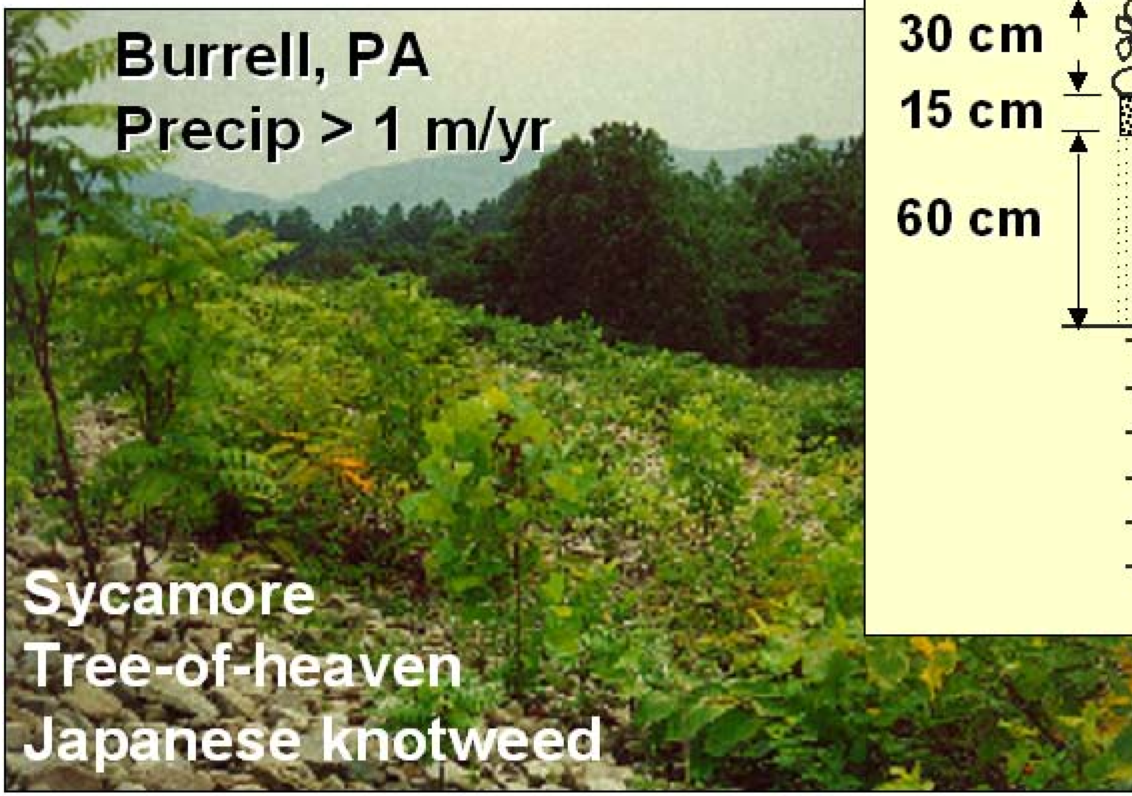
1. Rock riprap can cause saturation of compacted soil layers (CSL)

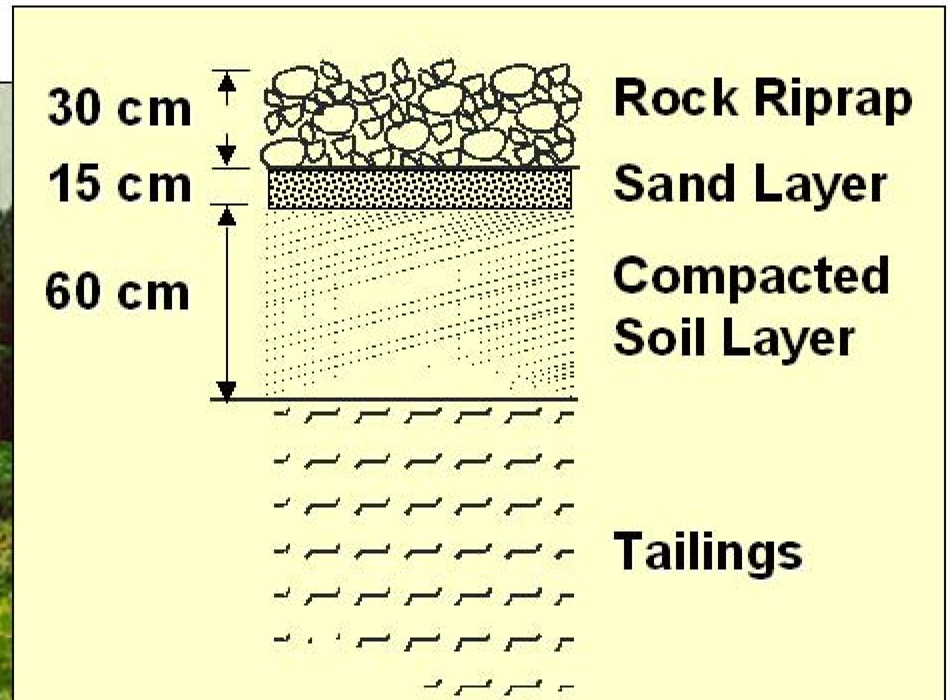


Precip. ~ 150 mm/yr

Some Lessons Learned

2. Designers failed to consider ecological consequences of designs





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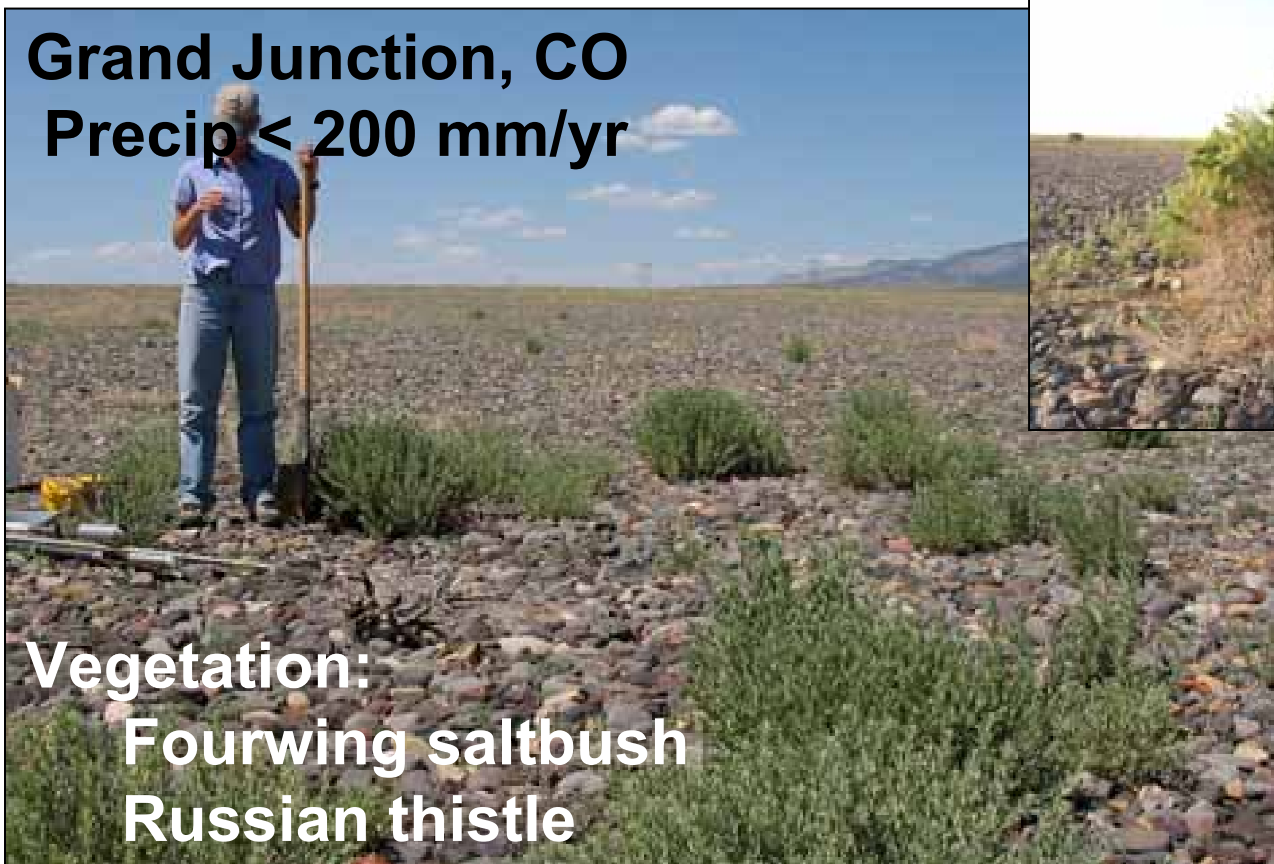

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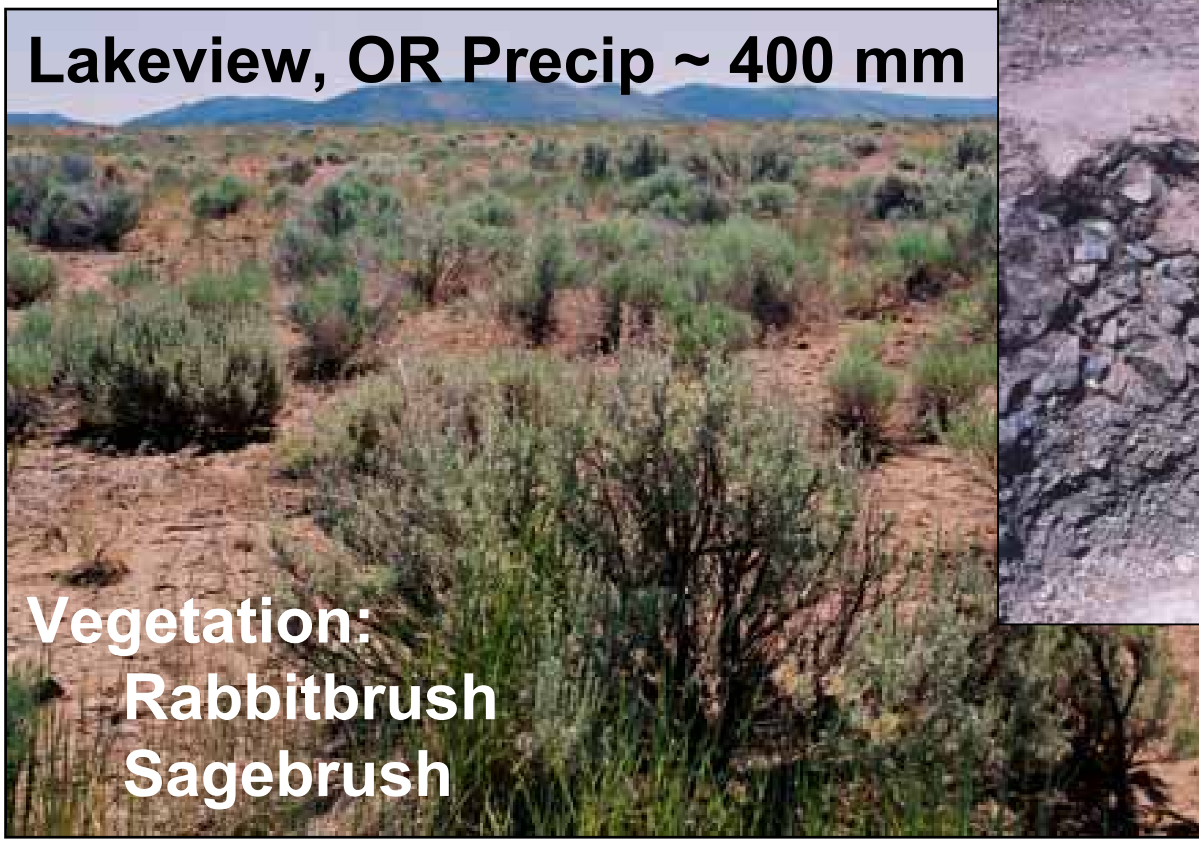
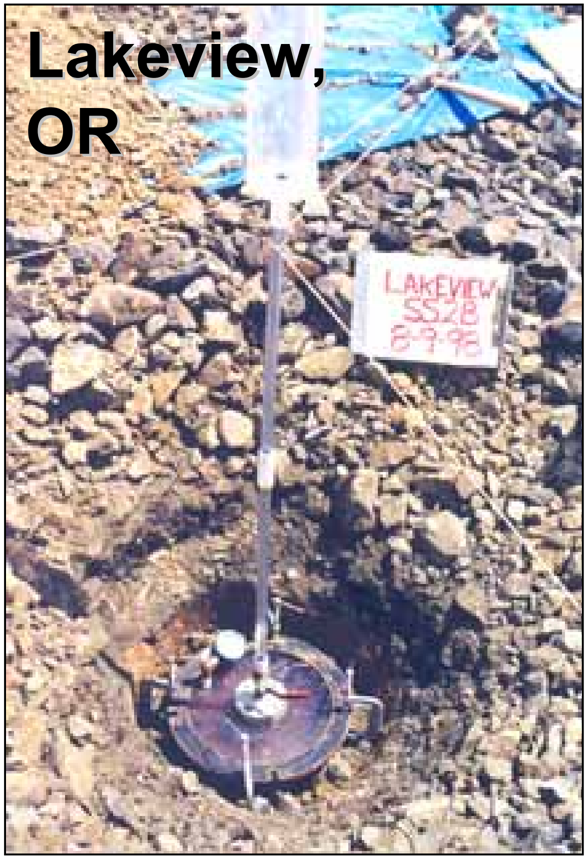


Some Lessons Learned

3. K_{sat} of CSL is higher than expected as measured with air-entry permeameters (AEPs)



Some Lessons Learned

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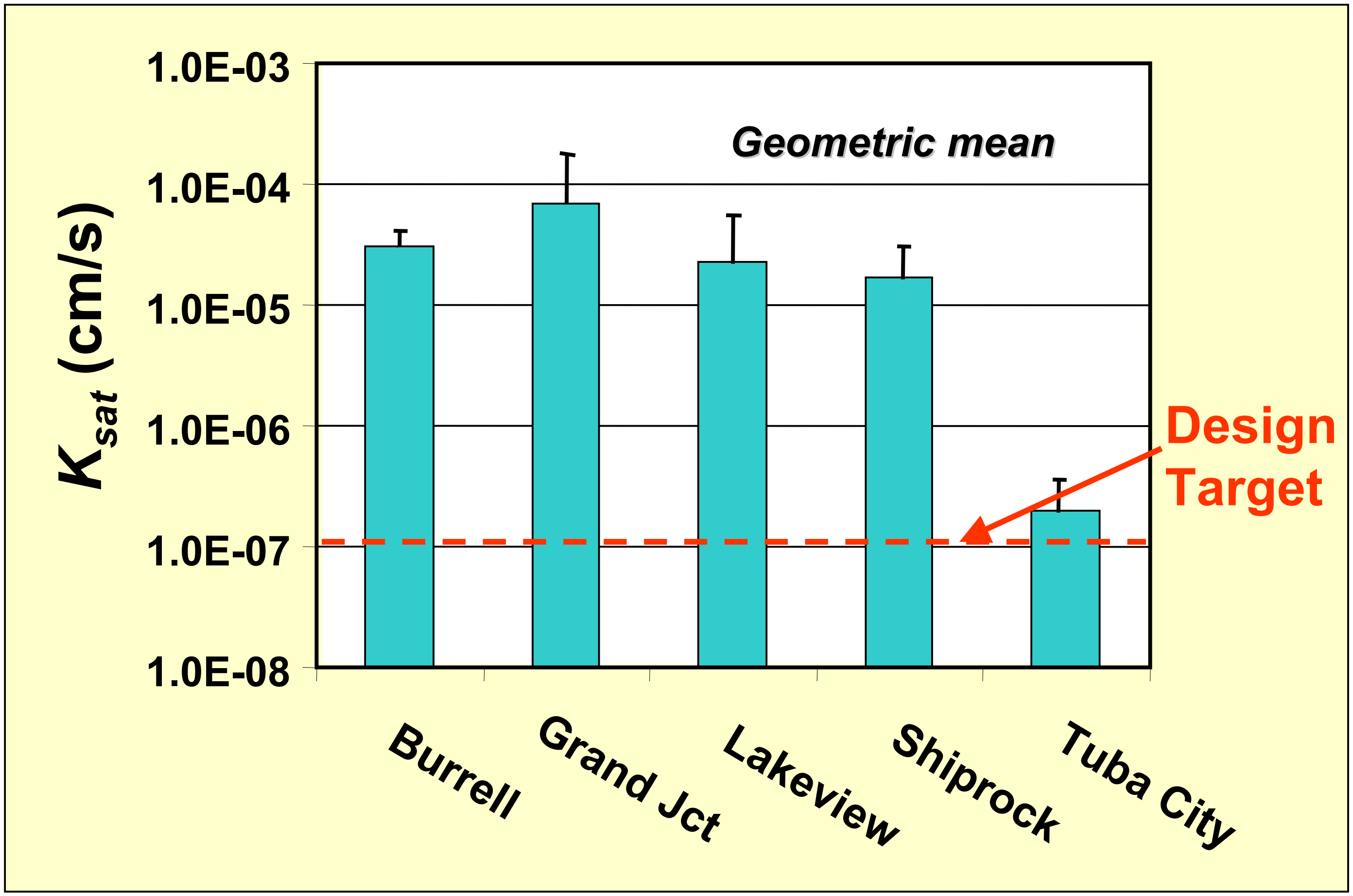

Some Lessons Learned

Causes of preferential flow in CSLs

- Soil structure in CSL developing faster than expected
- Plant roots and burrowing/tunneling animals
- Freeze-thaw cracking and desiccation
- Well-developed structure of *borrow* soils

Test dye at structural planes

Saltbush roots in CSL

Conventional
Low-Permeability Covers

Designed to *resist natural processes* rather than working with them.

- **Fail to consider ecological consequences**
- **Rock riprap causes saturation of compacted soil layers (CSLs) even in the desert**
- **Soil development and biointrusion cause preferential flow in CSL**
- **Require high maintenance or retrofitting over long-term**

Equivalency?
Alternative cover need to do better!

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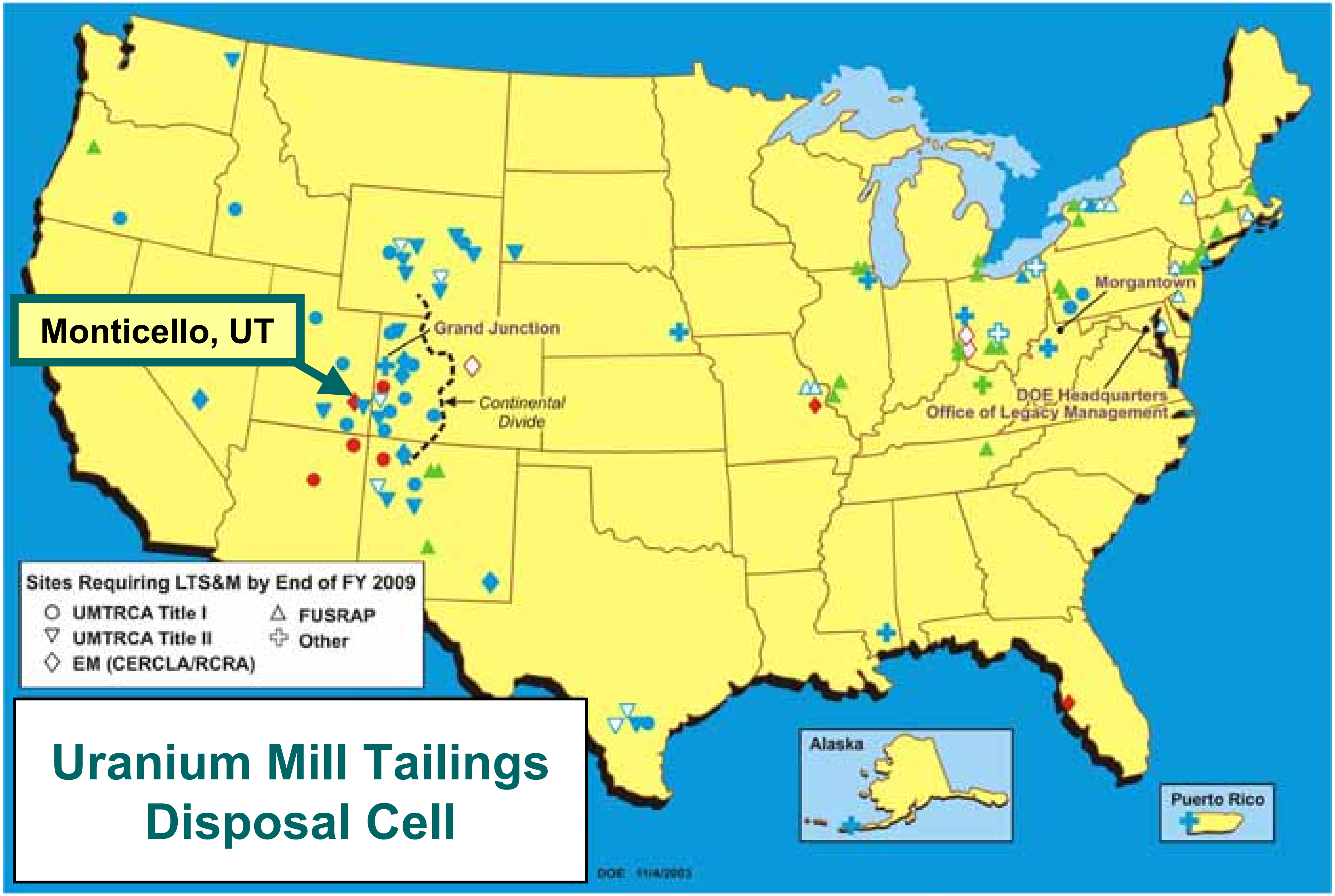
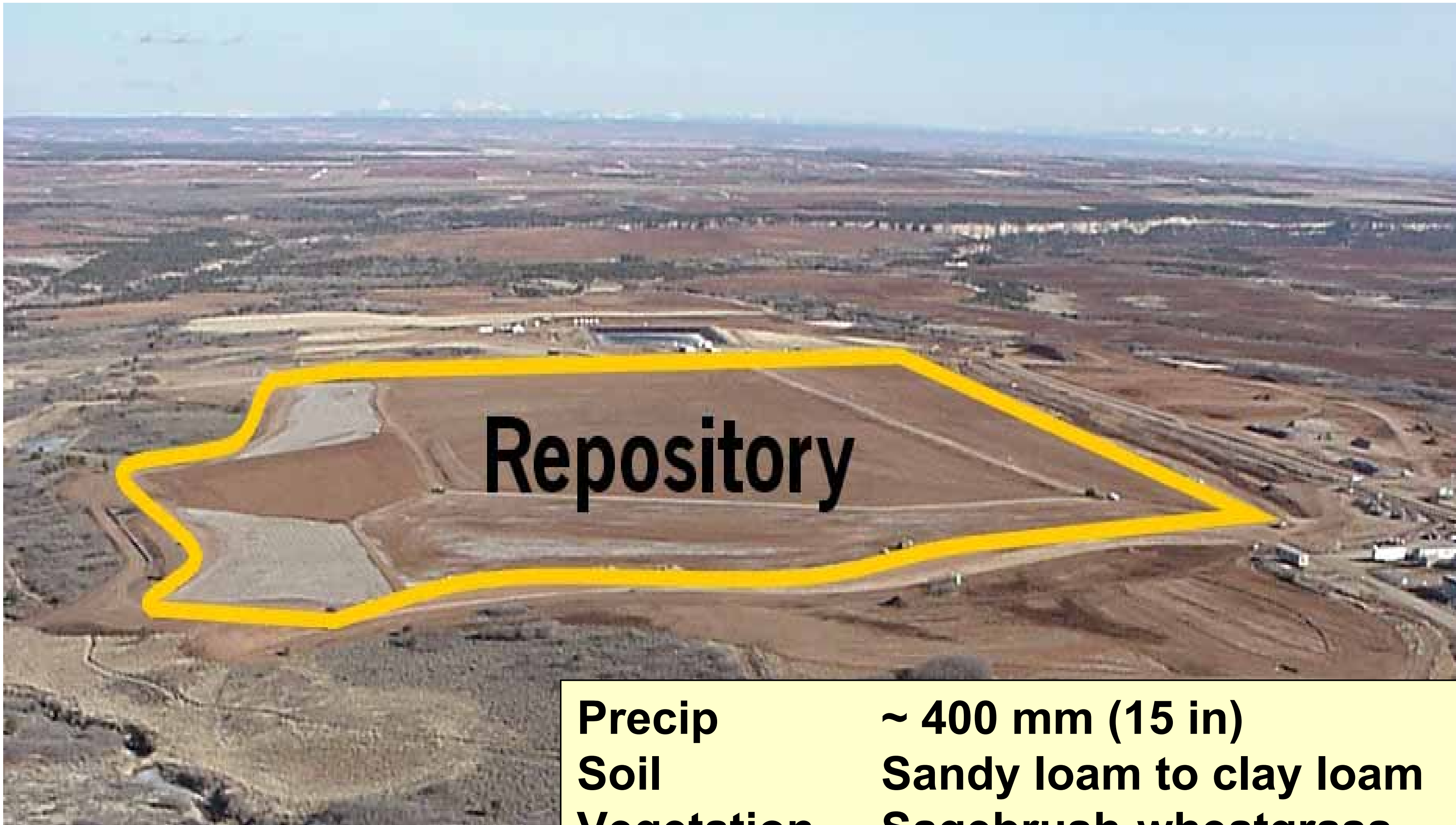
Monticello, Utah, Superfund Site



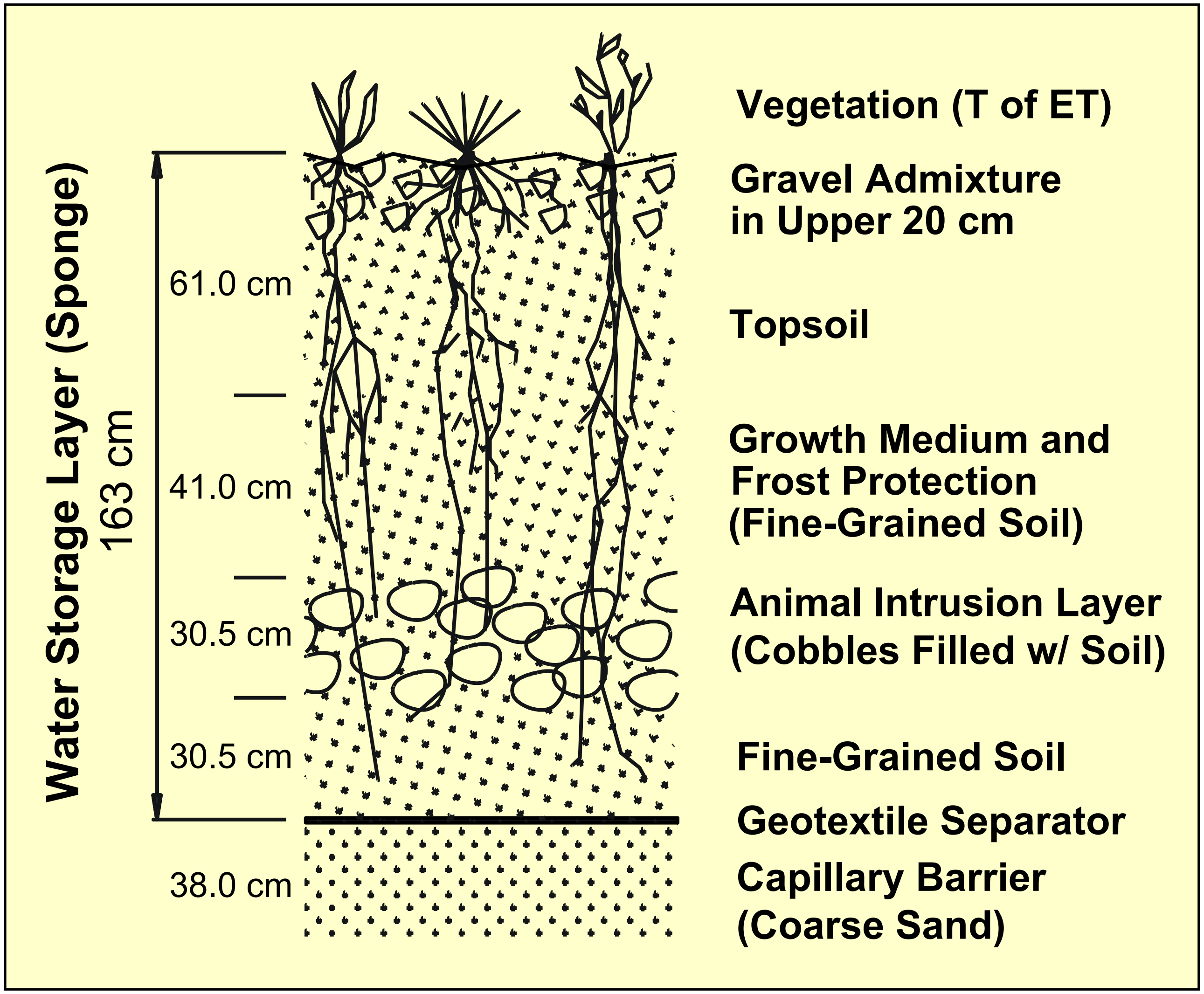
Uranium Mill Tailings Disposal Cell

Monticello U Tailings Landfill - 1999

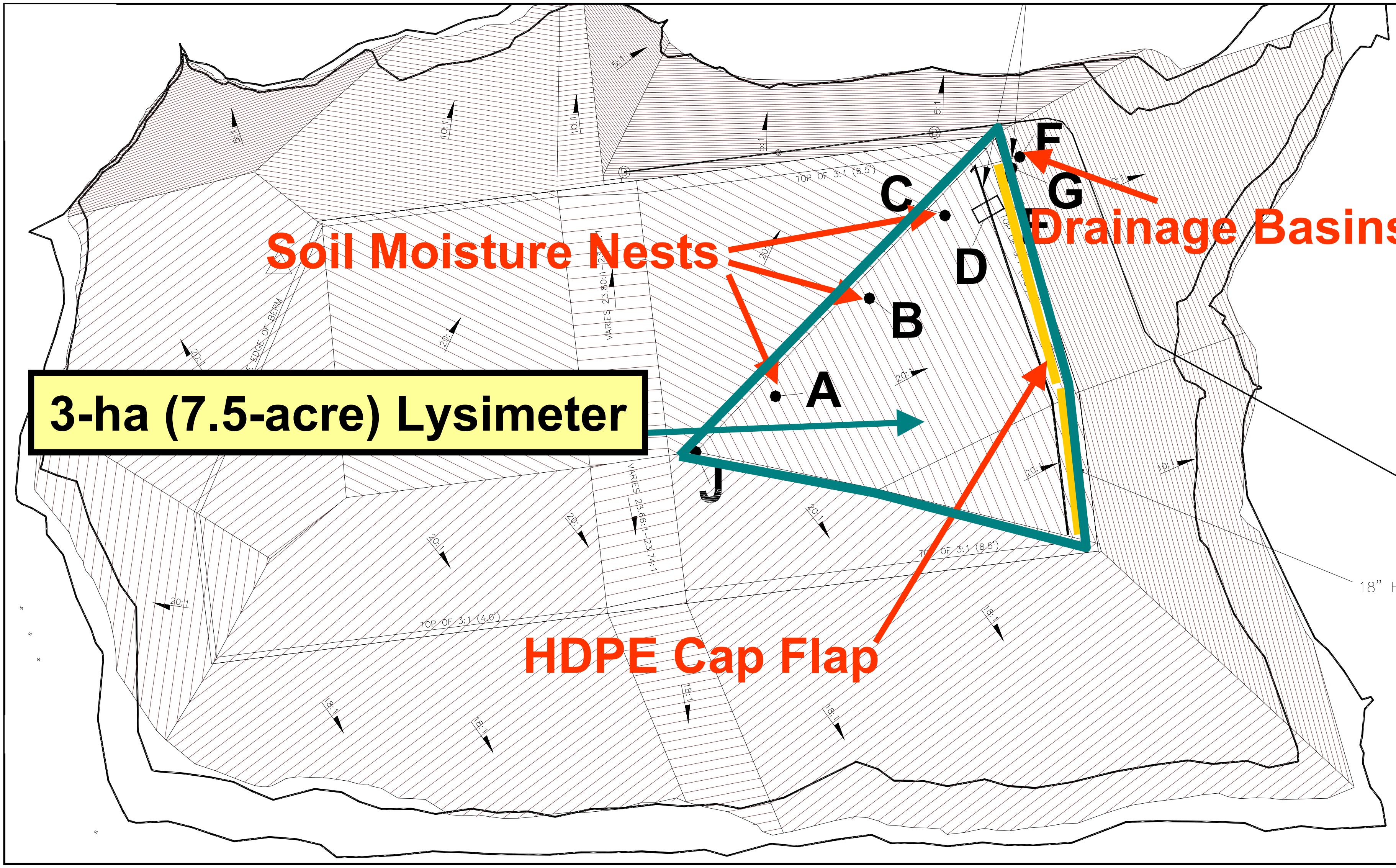


Precip	~ 400 mm (15 in)
Soil	Sandy loam to clay loam
Vegetation	Sagebrush-wheatgrass

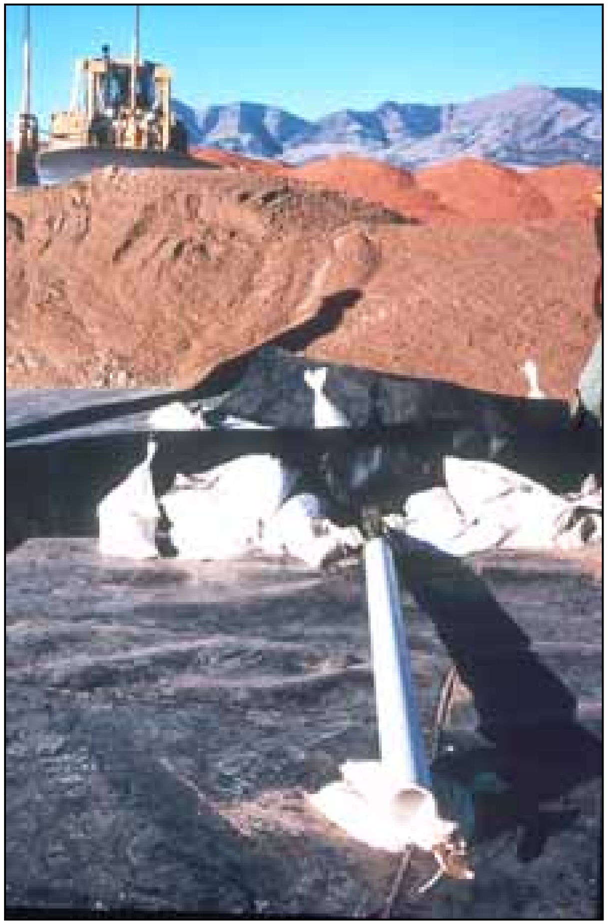
Monticello Cover Design: ET / Capillary Barrier



ACAP Cover Lysimeter



ACAP Performance Monitoring



HDPE drainage collection system

Dosing siphon measure drainage

Water content reflectometer and heat dissipation unit

Monticello ACAP Vegetation

Shrubs

- Big sagebrush
- Rabbitbrush
- Antelope bitterbrush

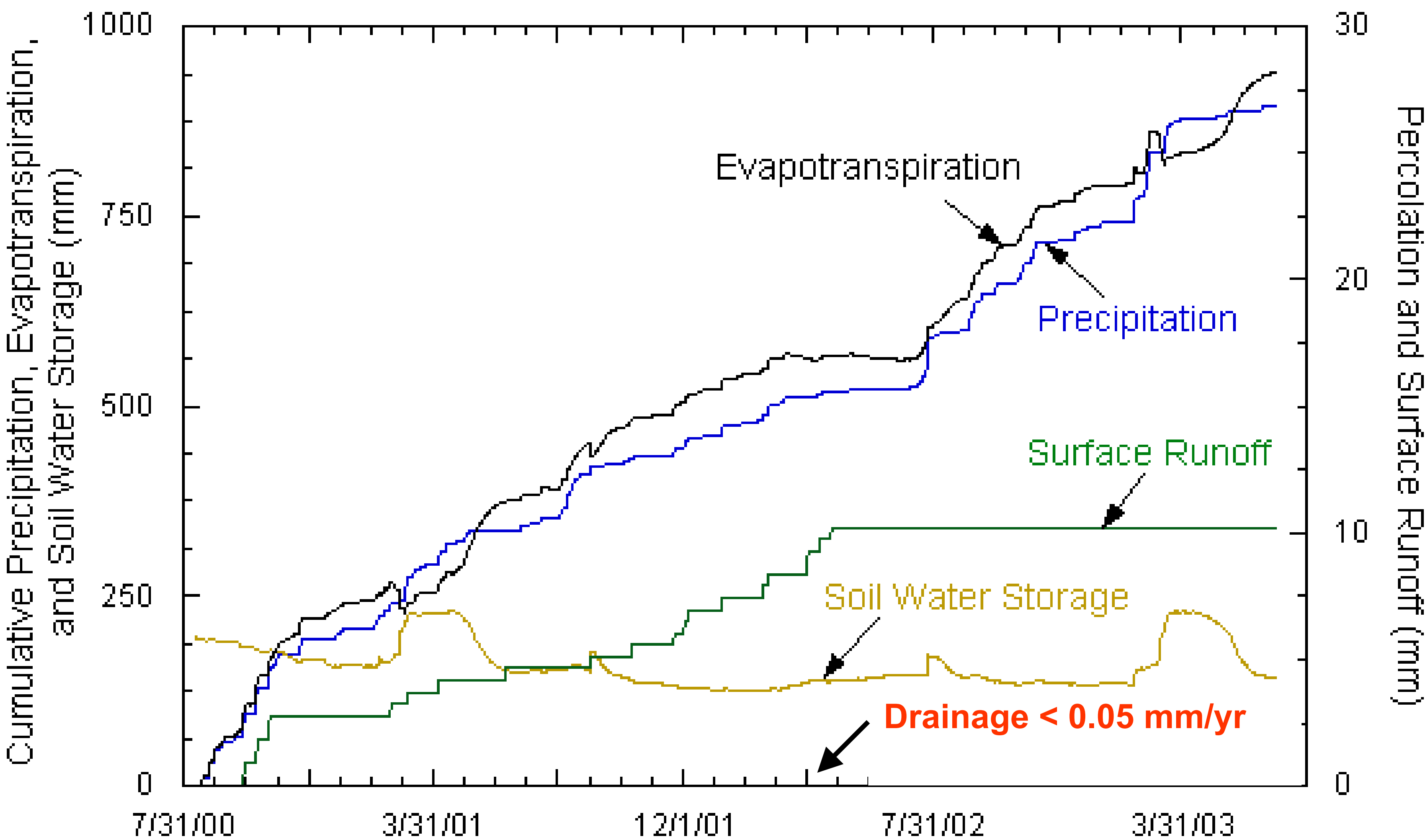
Grasses

- Western wheatgrass
- Thickspike wheatgrass
- Blue grama

Forbs

- Blue flax
- Scarlet globemallow
- Common yarrow

ACAP Lysimeter Water Balance



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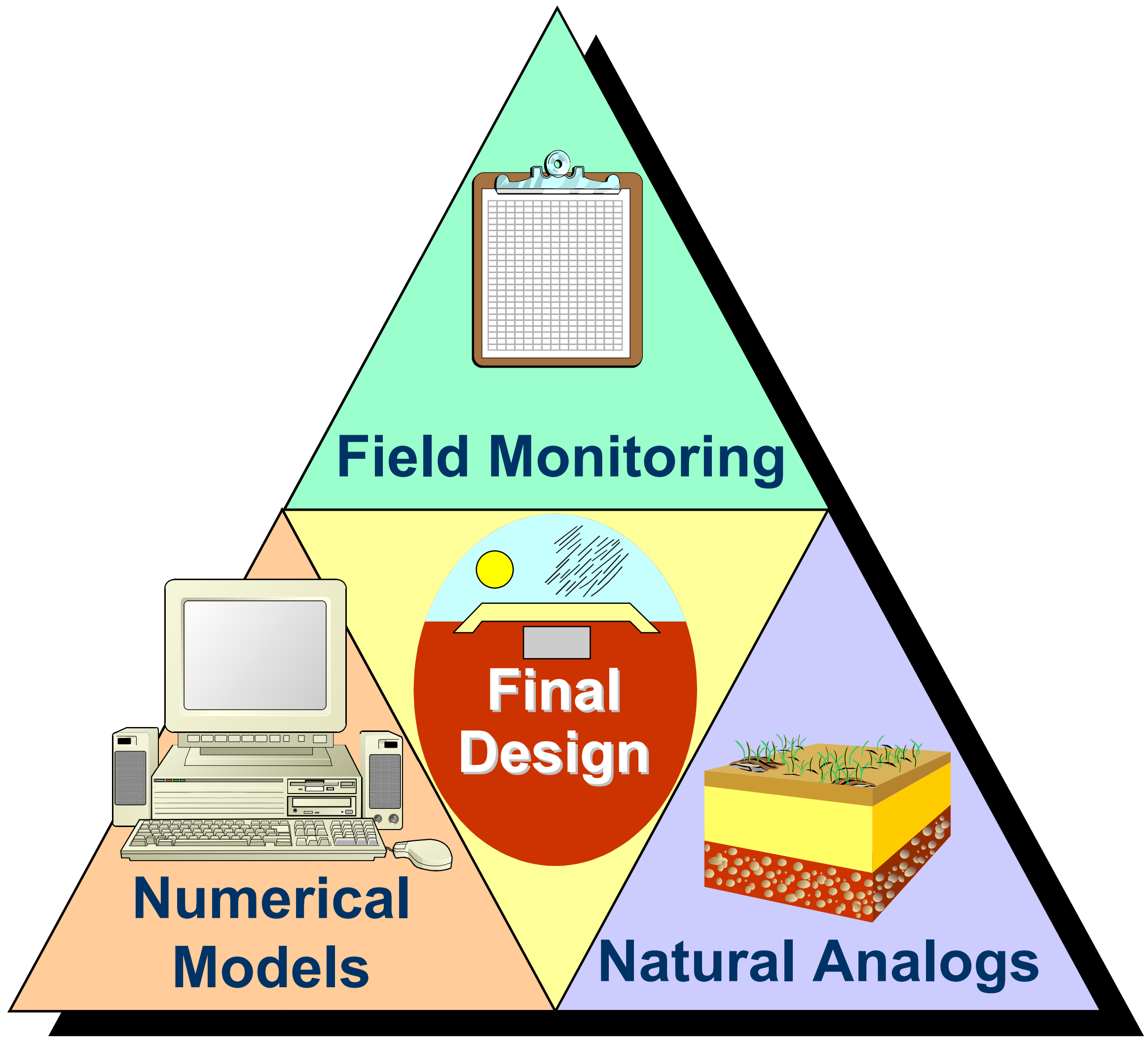
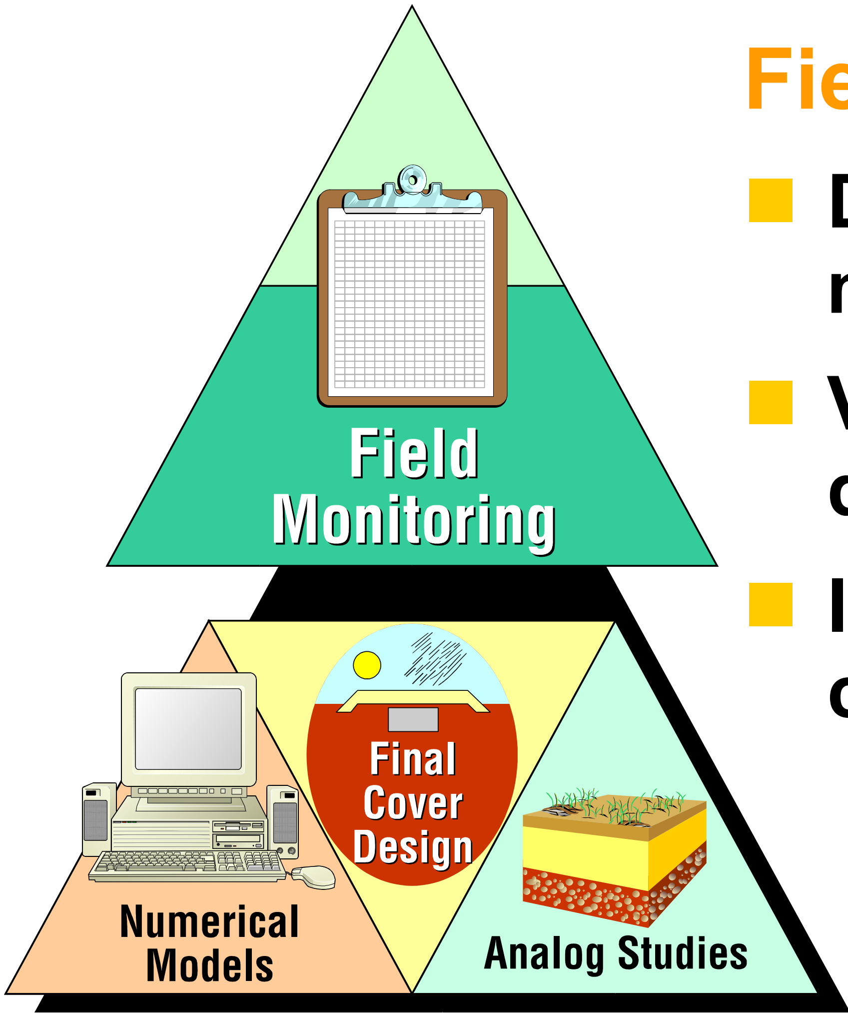
Performance Evaluation Tools



Performance Evaluation Tools



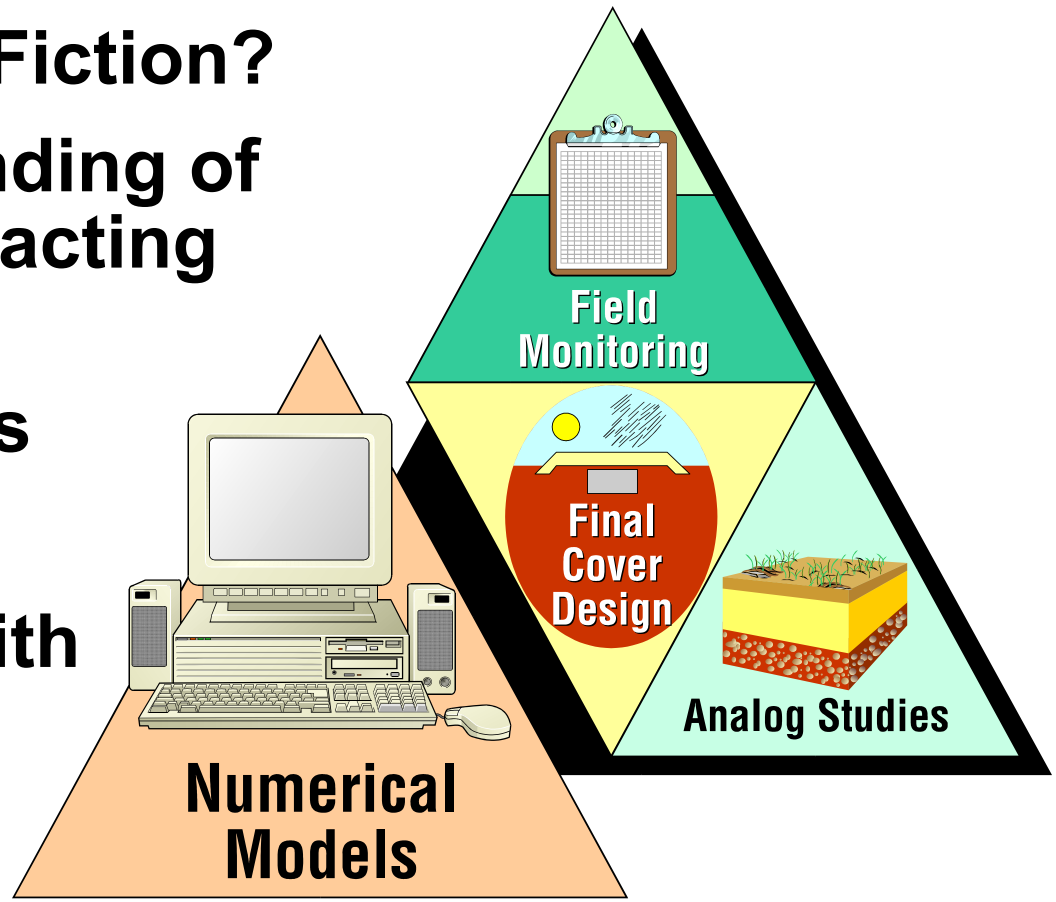
Field Tests and Monitoring

- **Direct but *short-term* measures of performance**
- **Verify that cover satisfies design standards**
- **Input to performance calculations and models**

Performance Evaluation Tools

Numerical Models

- Prediction: Fact or Fiction?
- Engender understanding of complex processes acting on covers
- Uncertainty analyses
- Sensitivity analyses
- Link performance with risk assessment

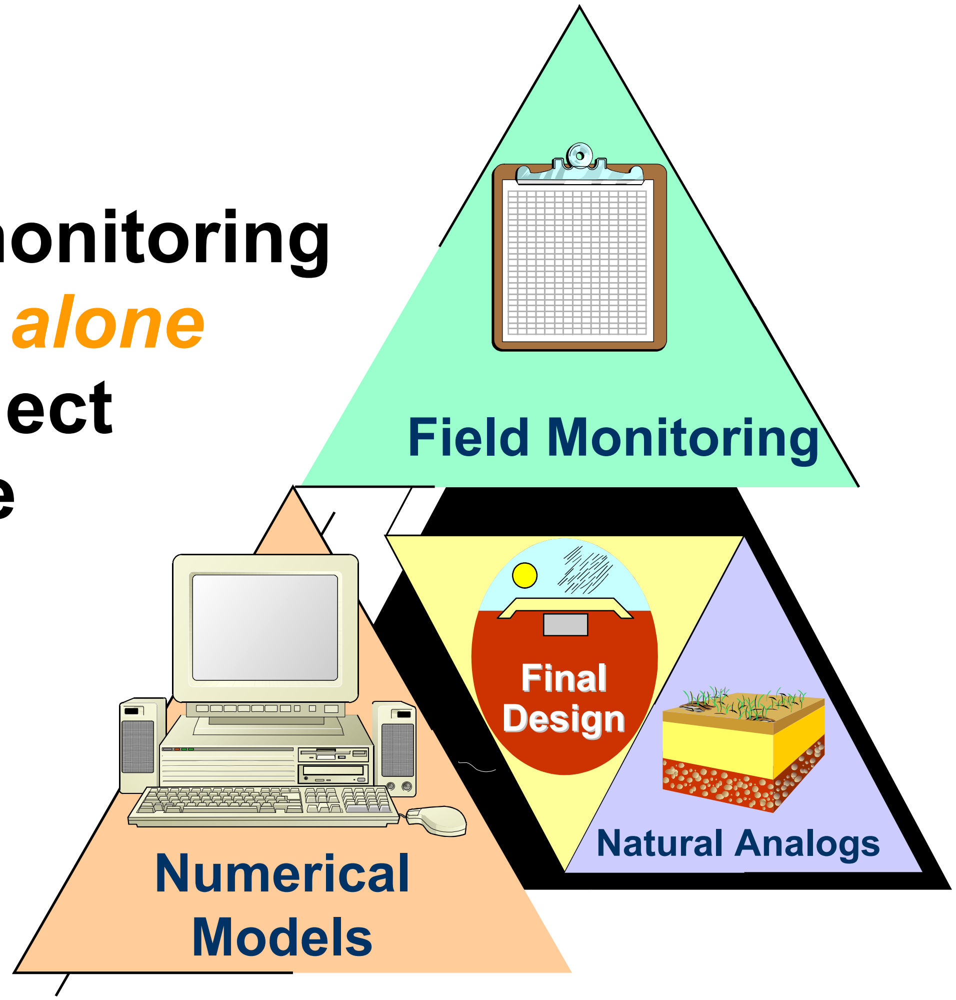


Performance Evaluation Tools

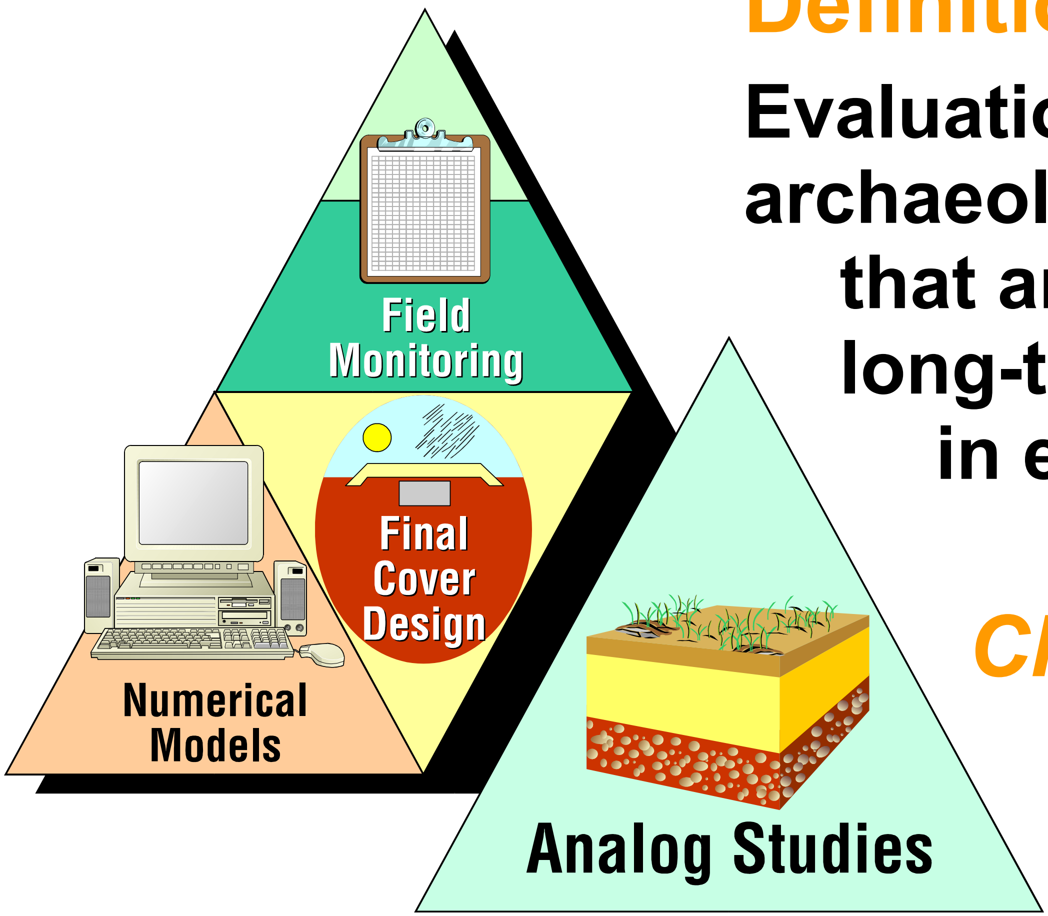
Problem

Combination of field monitoring and numerical models *alone* is not sufficient to project *long-term* performance of ET covers

Extrapolation of initial conditions!



Natural Analogs

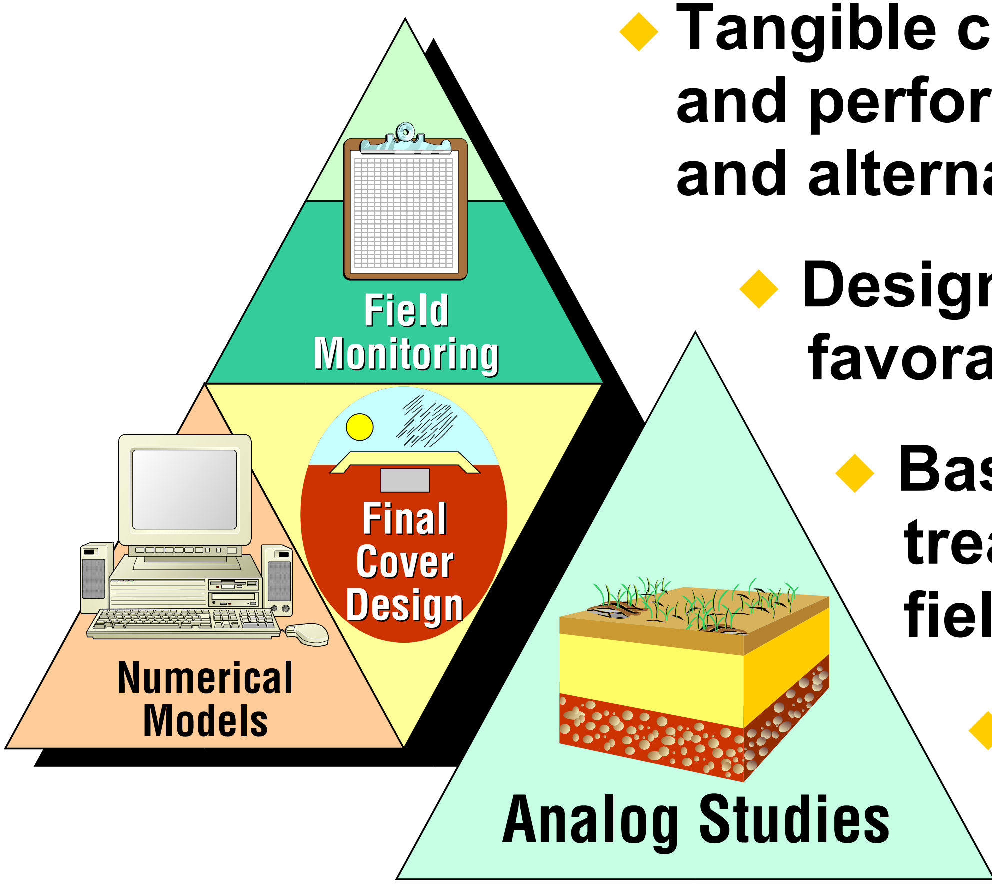


Definition

Evaluation of natural and archaeological settings that are indicative of long-term changes in engineered covers

Change is inevitable!

Natural Analogs



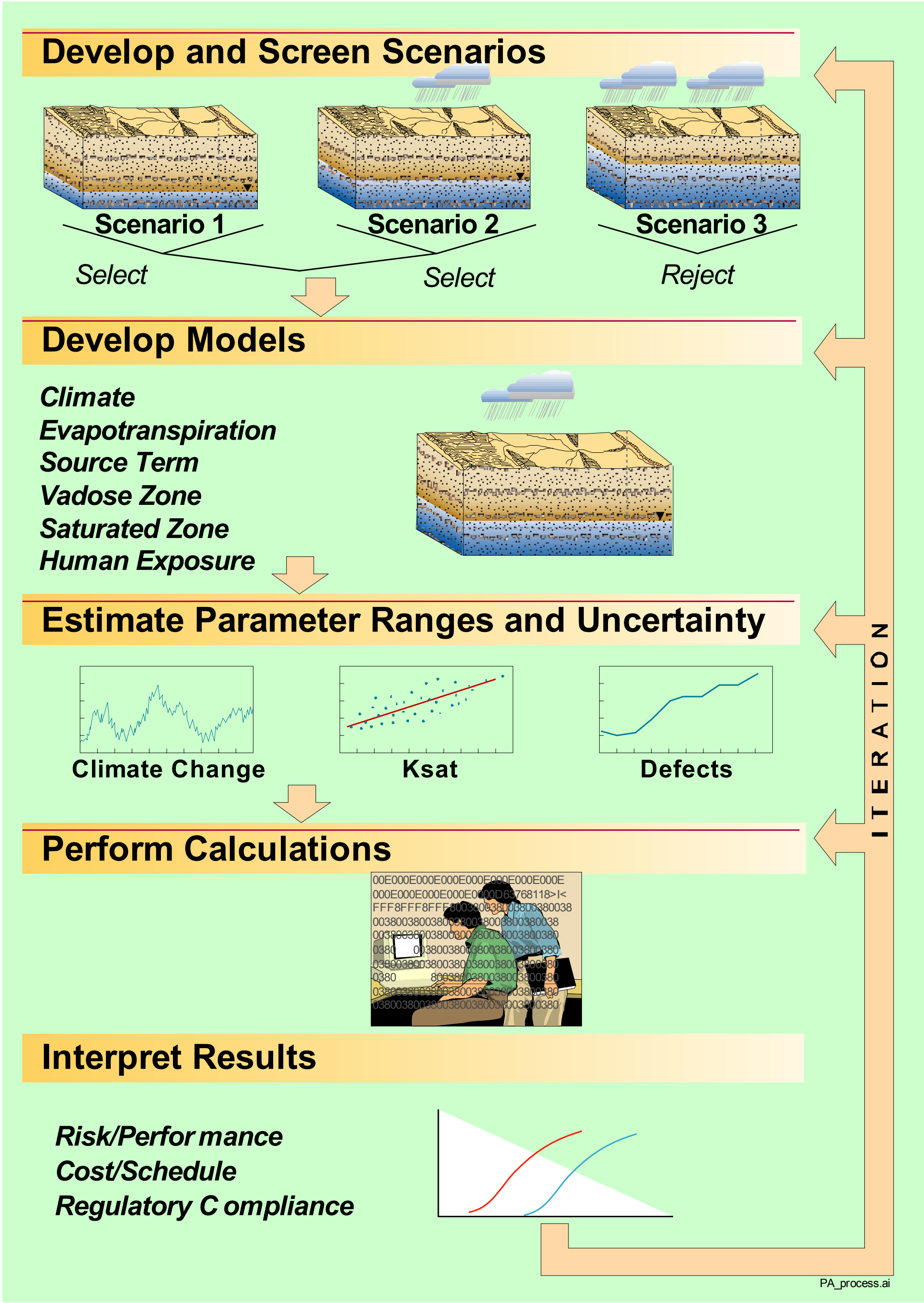
Need for Natural Analogs

- Tangible clues of future conditions and performance of conventional and alternative covers
- Design covers that mimic favorable natural settings
- Basis for hypotheses and treatments in short-term field studies (lysimeters)
- Data on future scenarios for input to models

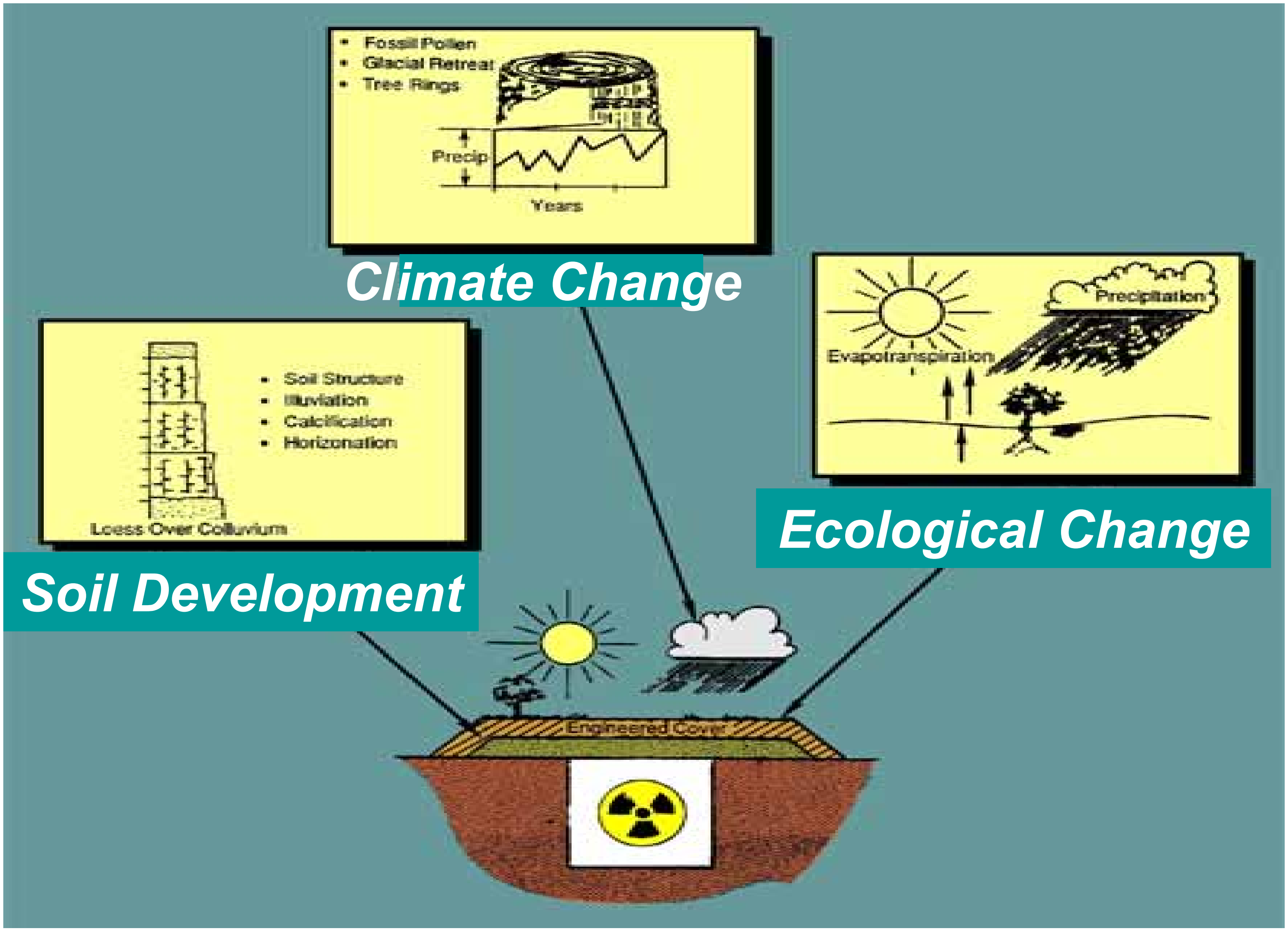
Performance Modeling Process

Natural Analog Data

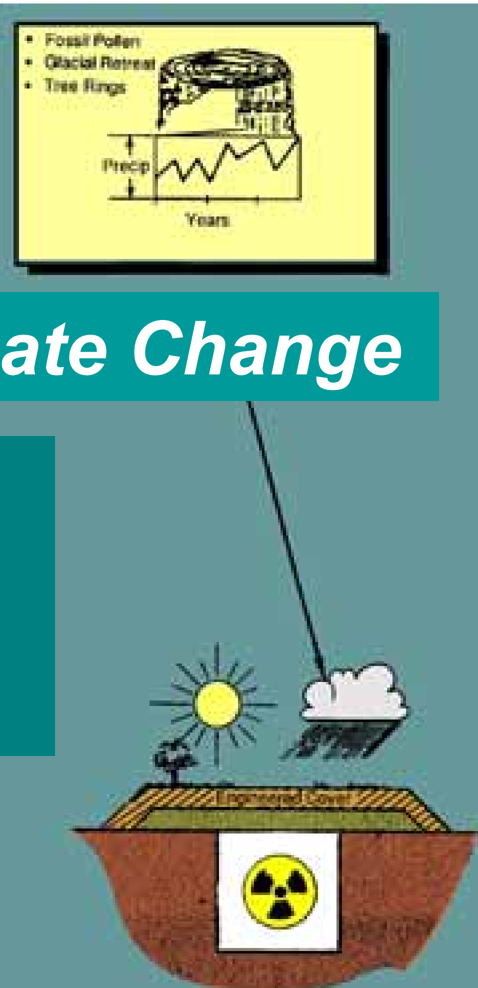
Bound *reasonable* ranges of long-term environmental settings to define possible future scenarios for modeling



Long-Term Performance Issues and Analogs



Issues and Analogs: Climate Change



Climate Change

Issue

Long-term Shifts and Variability

Climate Models

Analogs

Proxy Paleoclimate Records:

- Tree rings
- Packrat middens
- Lake pollen
- Ice cores
- Archaeology

Instrumental records from climate analog sites

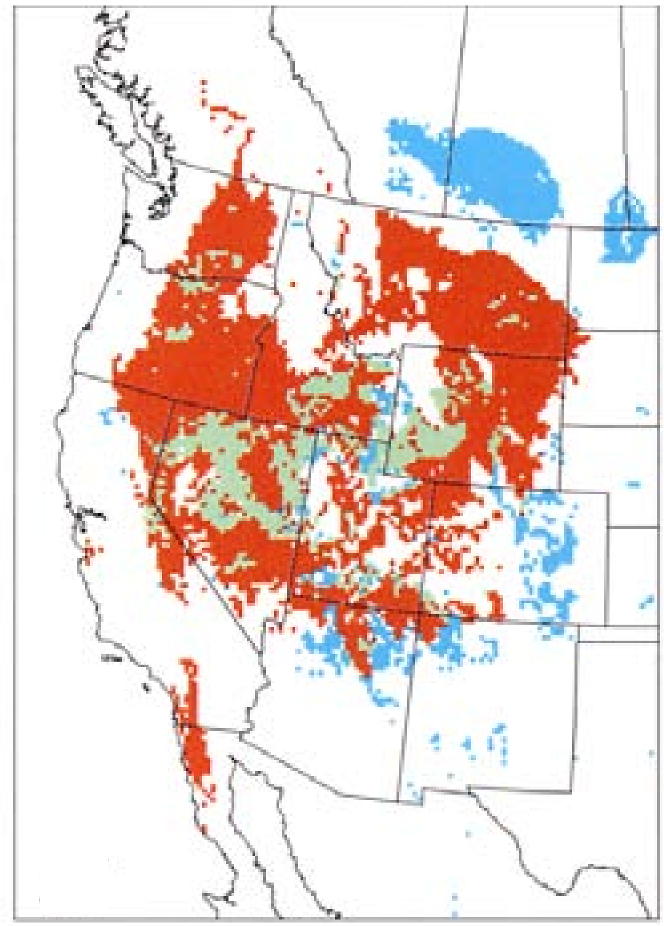
Monticello
Climate Change Scenarios

Selected climate analogs sites for range of global model and paleoclimate (Holocene) scenarios

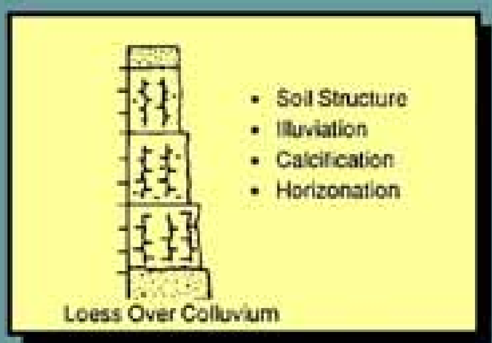
- **Same soil type as Monticello cover**
- **Instrumental record**

	Precip (mm)	Temp (ºC)
Monticello, UT	390	7.8
Blanding, UT Warm/Dry	340	10.1
Fort Lewis, CO Cold/Wet	470	6.1

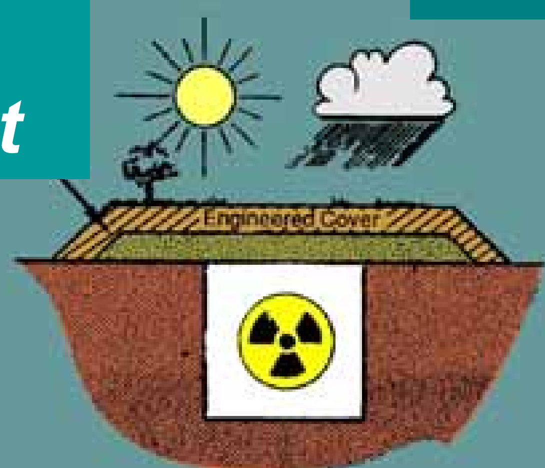
Big Sagebrush Distribution: Global Warming Scenario



Issues and Analogs: Soil Development



Soil Development



Issue

Effects of soil development on hydraulic and edaphic properties

- **Soil structure**
- **Illuviation/eluviation**
- **Bioturbation**
- **Soil erosion/deposition**

Analog

Measured properties for natural and archaeological soils

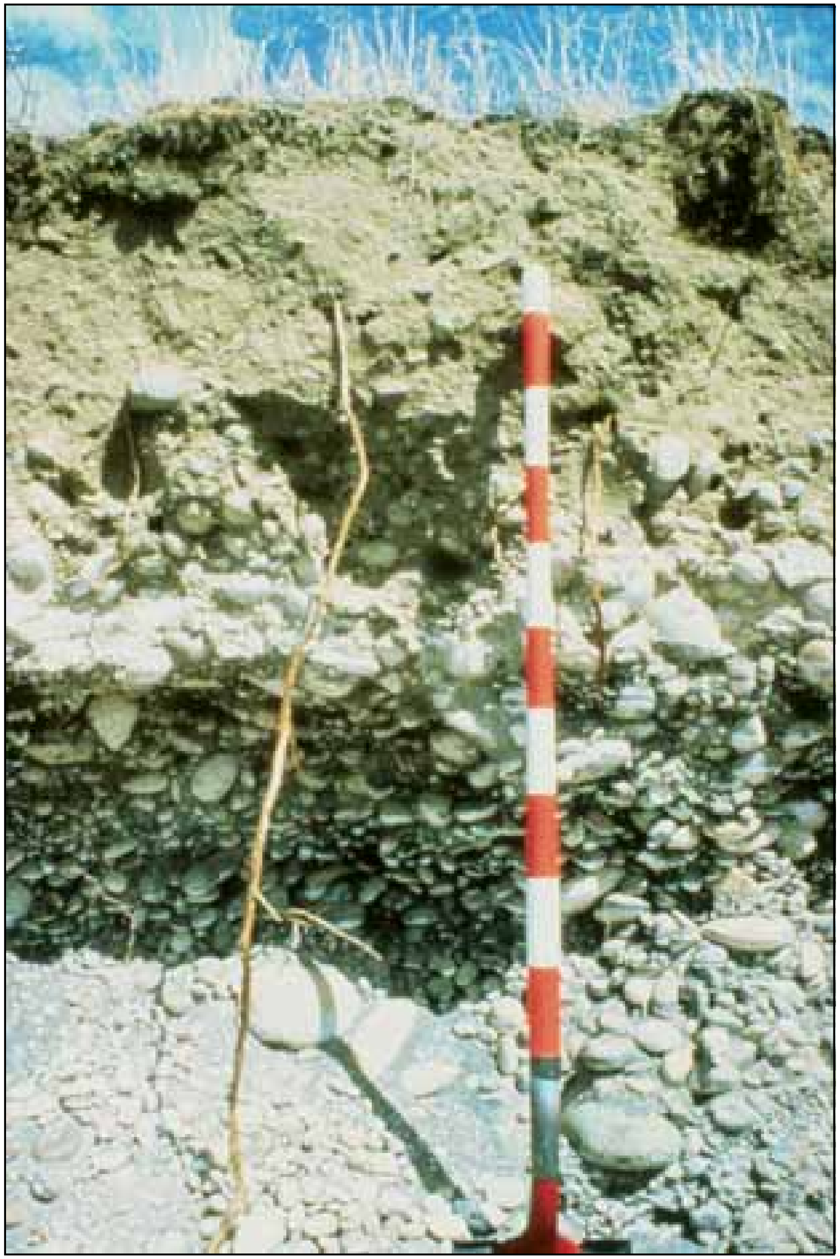
Archaeological Analog: Soil Morphology and Hydrology

Blanding, Utah

Warm/dry Climate Analog

Anasazi Kiva Excavation

Capillary Barrier Analog
Hanford, WA



Pedogenic carbonates: Indicator of 13,000-year soil water balance

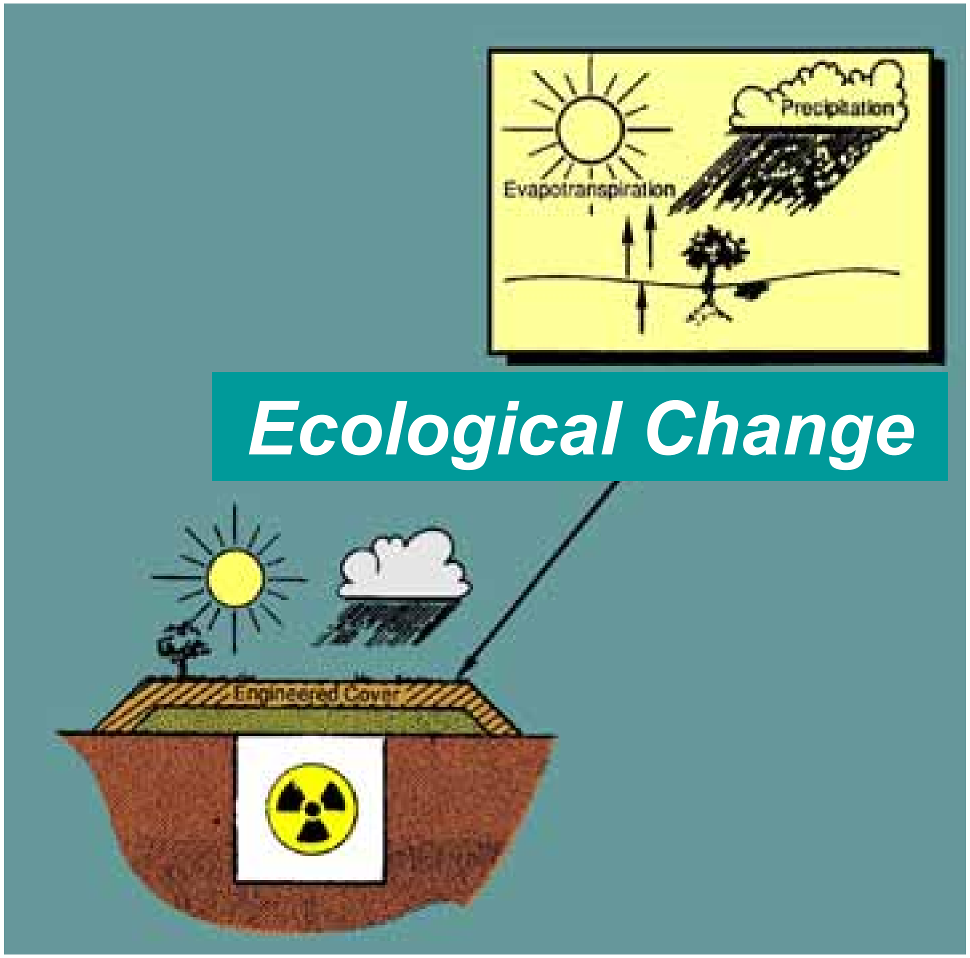
Issues and Analogs: Ecological Change

Issue

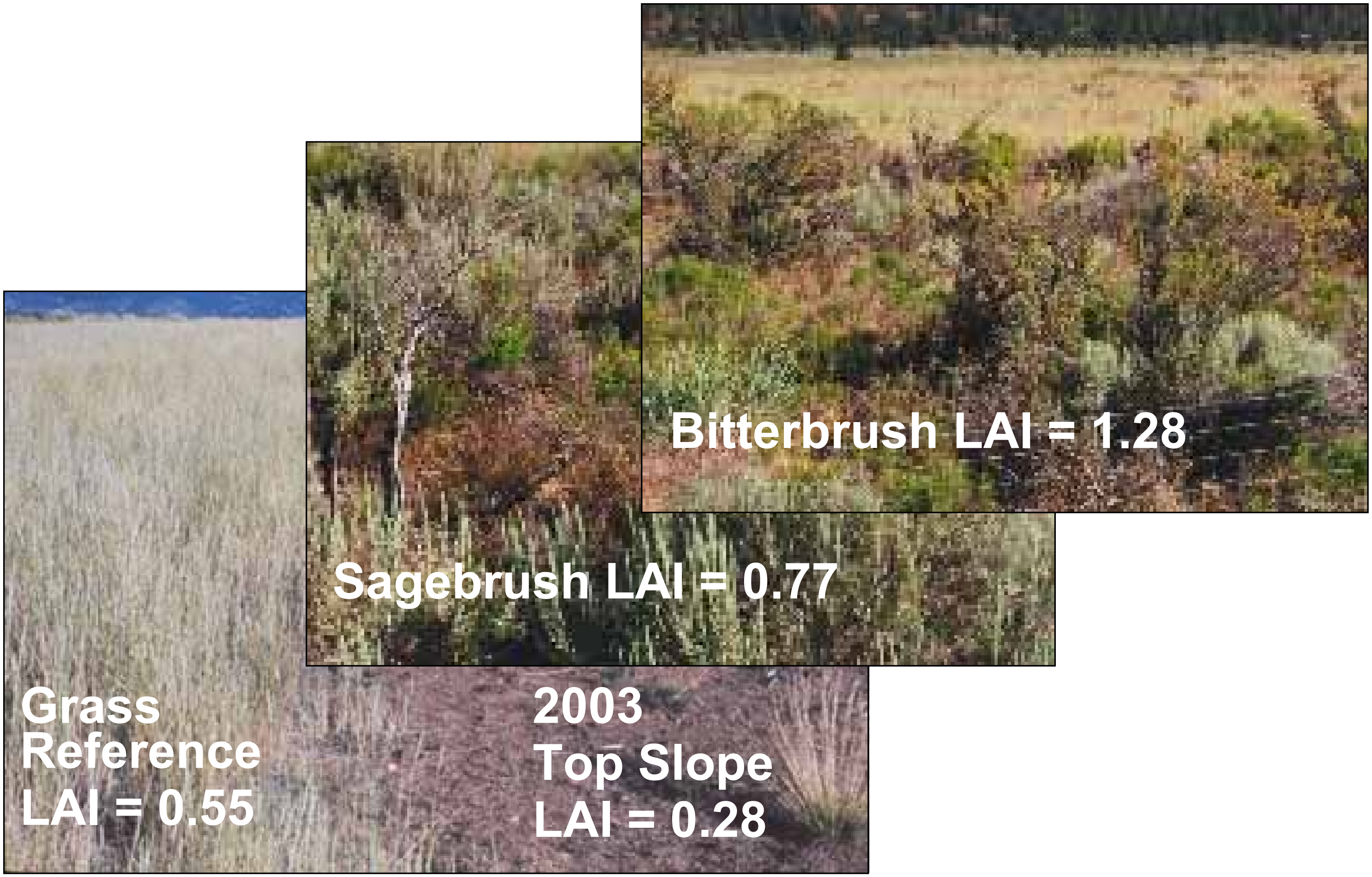
Effects of disturbance (e.g. fire, grazing) or climate change on plant ecology

Analog

Functional ecology of successional chronosequences



Lakeview, OR, Leaf Area Index Fire Chronosequence



Lakeview, OR, Climate Change: Wet and Dry Ecology Analogs

Lakeview Conifer Site, OR

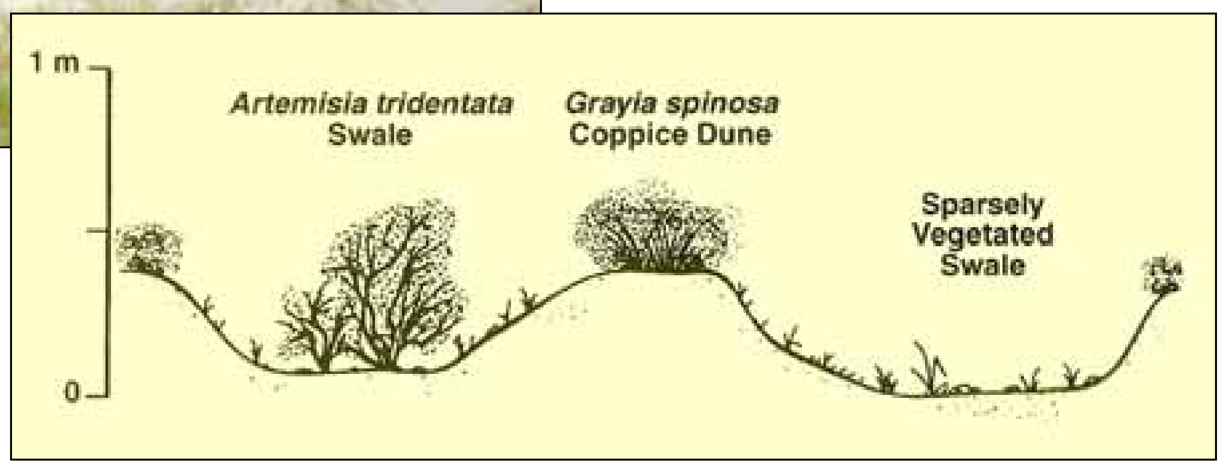
Soil: Drews loam
Cold/Wet
Vegetation: Mixed conifer
LAI: 1.62

Guano Basin Site, NV

Soil: Spangenburg loam
Warm/Dry
Vegetation: Big sagebrush
LAI: 0.43

Ecological Mosaics
Coppice Dune Ecology, Hanford, WA

Borrow source for ET cover soil:
Warden silt loam



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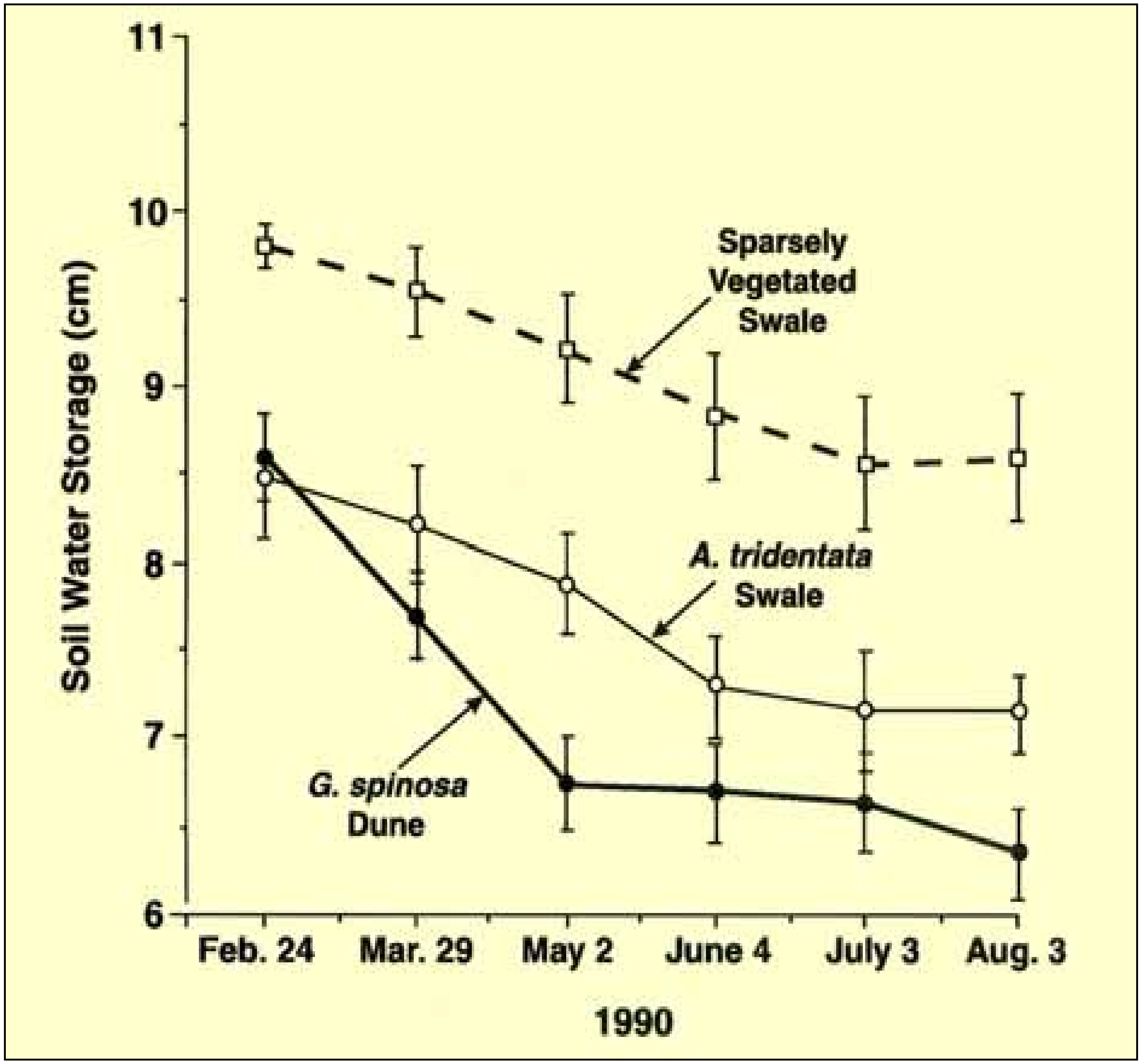
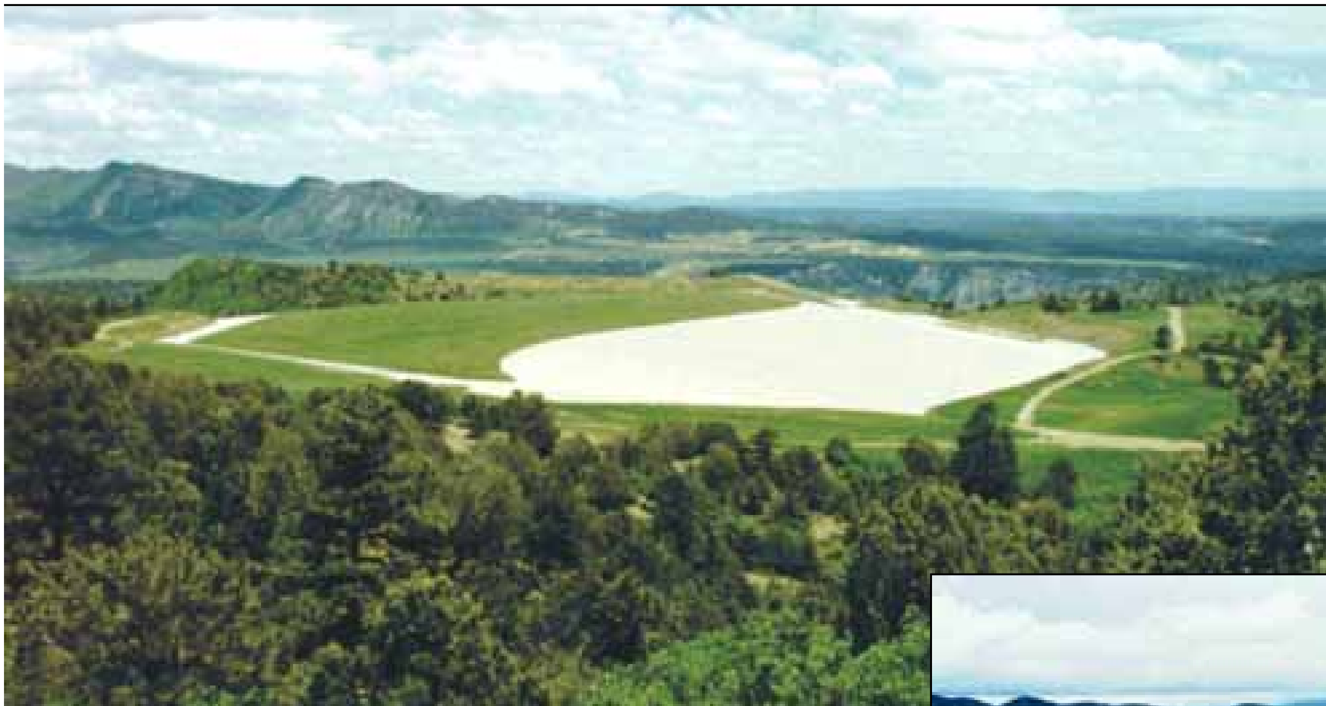


Water storage changes in dune and swale soil profiles

Existing Cover: Durango, CO
Side Slope Ecology Analog



- **ET top slope design**
- **Rock side slope design**

Durango, CO
Side Slope Analog

Durango cover rock side slope

Analog: Duckett Ridge slide rock

Durango, CO
Side Slope
Analog

Plant
Successional
Chronosequence

Mimic Natural Setting: Rock-Armored ET Side Slope Analog

Beaver Gulch, Colorado
Glacial debris flow near Grand Junction U-tailings disposal cell

Side Slope Analog: Evidence of Slope Age, Stability, and Water Balance

Late Pleistocene
>10,000 years old

Rock varnish, soil lines, and lichen growth on basalt stones

Glacial debris soils with argillic and calcic horizons

Relatively high plant cover and low soil water below the roots

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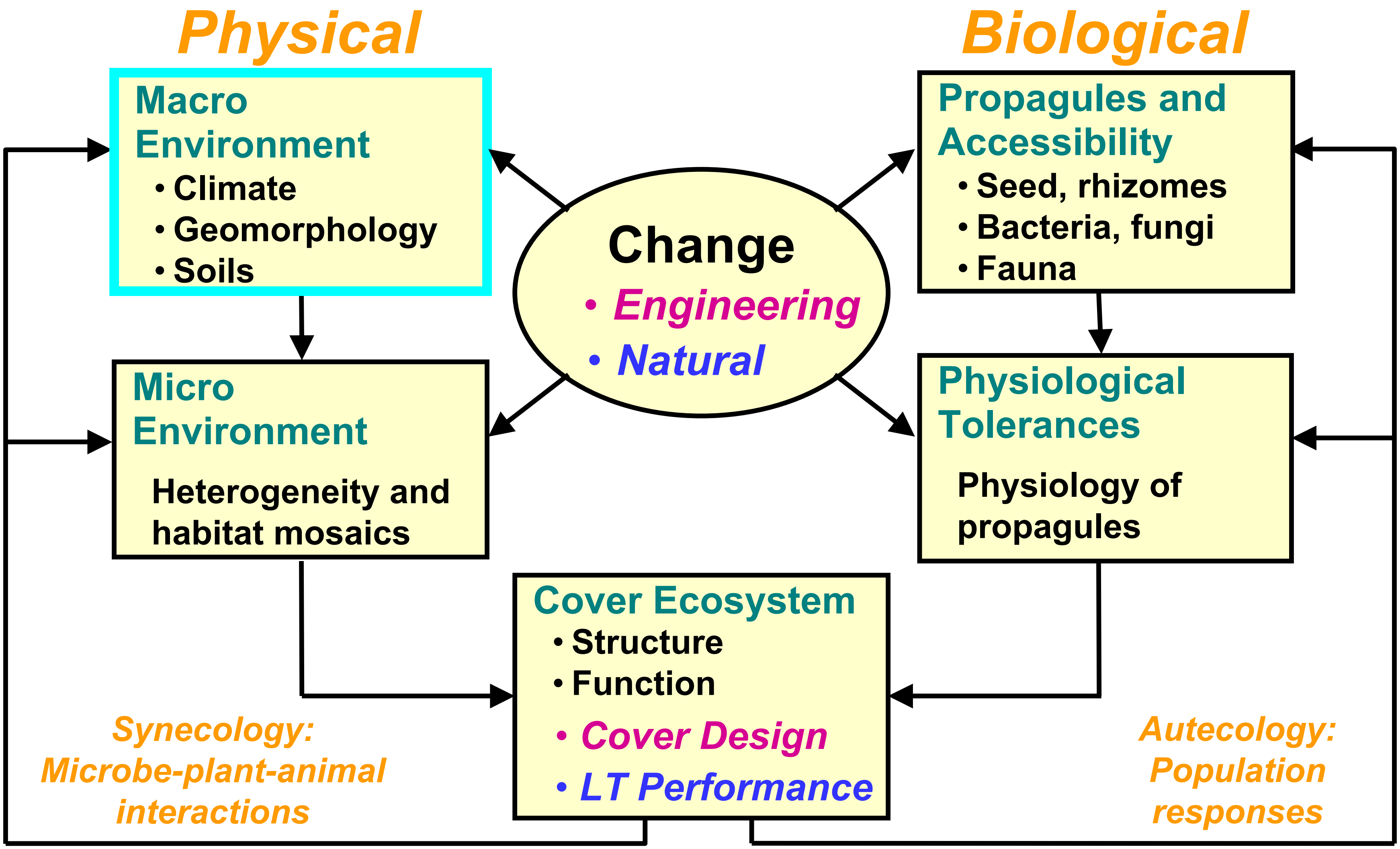
Ecosystem Engineering Paradigm: Thinking Outside the BOX



Acknowledgements

Contributors

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DOE Office of Legacy Management

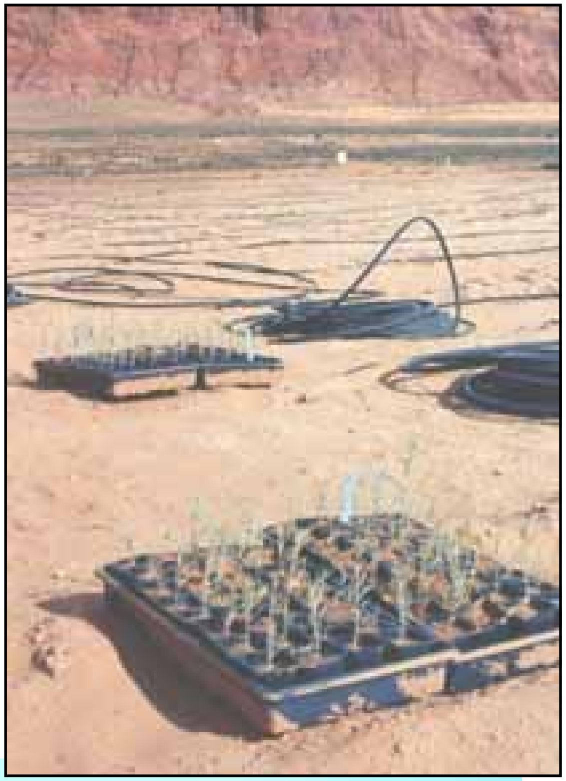
DOE Science and Technology Program

EPA Region 8

EPA ACAP

Monument Valley, AZ, Desert Phytoremediation Cover

- Tailings pile was hauled to off-site disposal cell
- Subpile soils, high in NH_3 and NO_3, are source of alluvial NO_3 plume
- Recharge occurs through denuded soil (eolian fine sand)
- Subpile was planted with fourwing saltbush and deficit irrigated



Monument Valley, AZ, Desert Phytoremediation Cover

- Water flux monitoring shows fouwing saltbush are controlling recharge below 4 m

- Rapid soil NO_3 loss caused by plant uptake and microbial denitrification

- Fourwing seeds are harvested for coal mine revegetation

Monument Valley, AZ, Desert Phytoremediation

Passive NO_3 Plume Phytoremediation

$\delta^{18}O$ / δD signatures show that planted fourwing saltbush are extracting plume water at 12 m depth

The End

Questions?