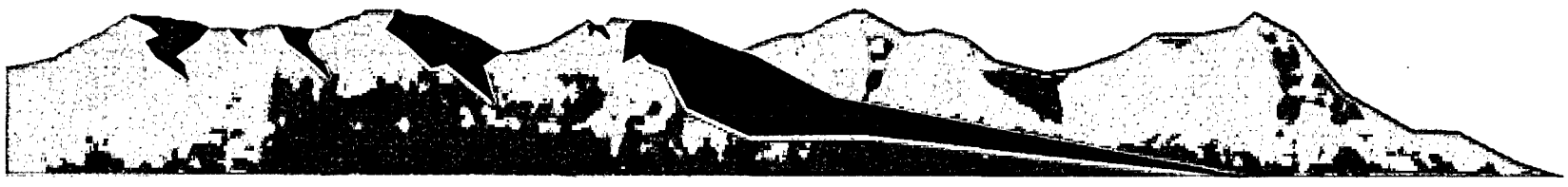
VZ Monitoring Technologies
Quantities to Measure

- Moisture change
  - Neutron Probes
  - Time Domain Reflectometry [TDR]
  - Thermocouple Psychrometer
  - Electromagnetic Induction [EMI]
  - Electrical Resistivity Tomography [ERT]
  - Fiber optic cable
  - Flux measurements with SP

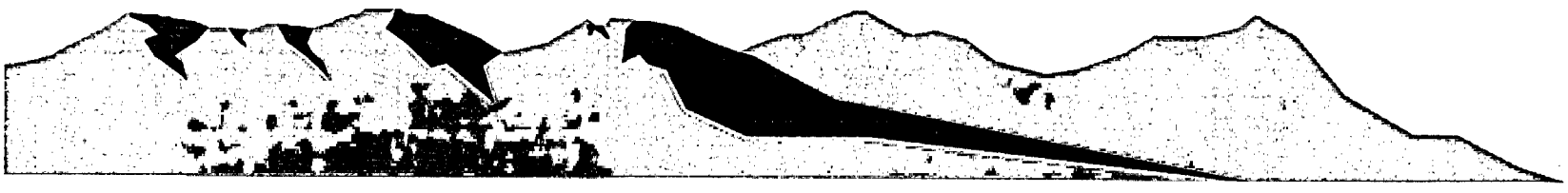


Moisture Sampling Methods

- Suction Lysimeter
- Absorbent Pads
- Sodium Iodide Gamma Detector
- Basin Lysimeter
- Associated Chemical Analyses

Trends in developing technologies

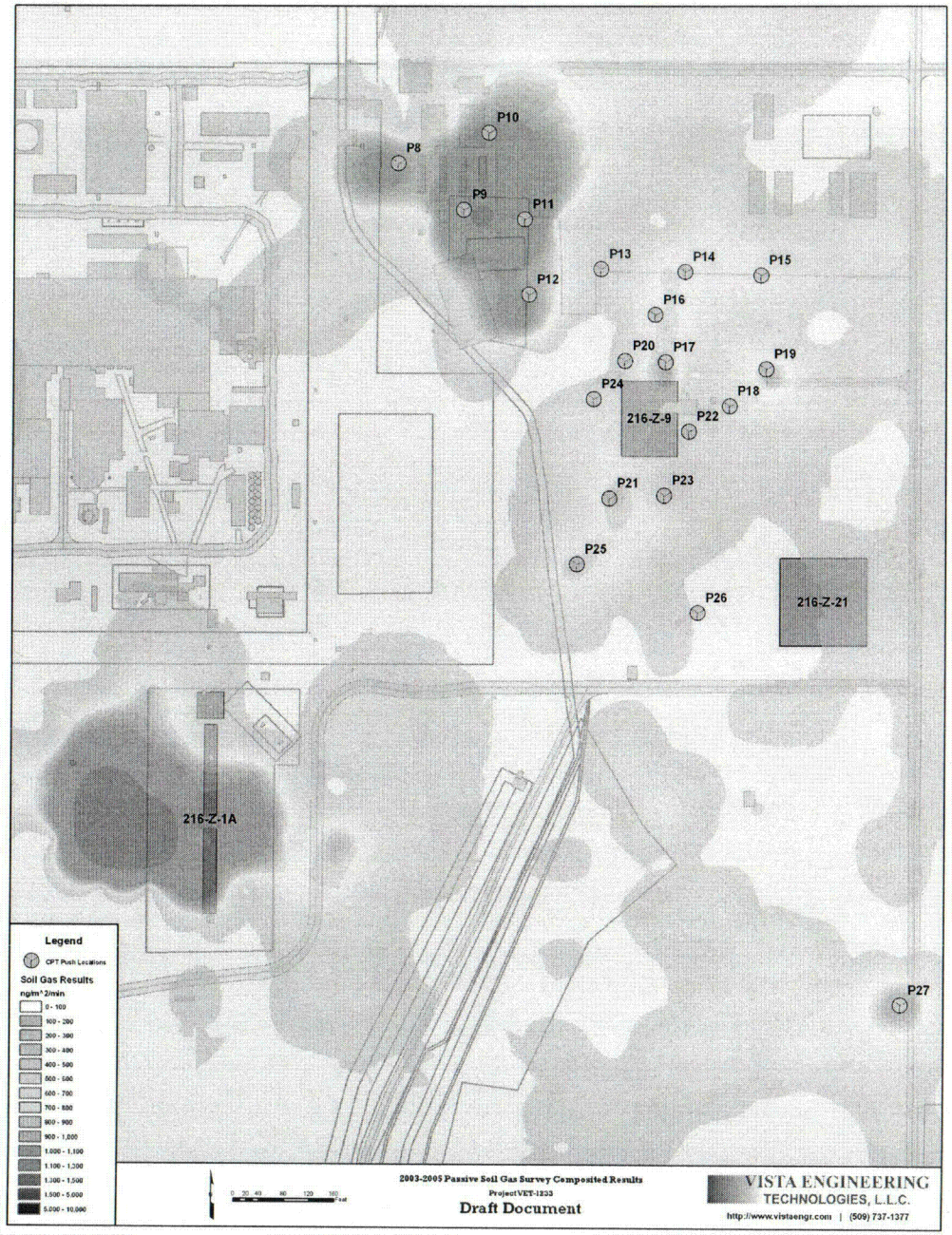
- More volume integrating
- Better sensitivity
- Better remote sensing [less intrusive]



CPT Investigation at 216-Z-9 of Carbon Tetrachloride

20 Locations

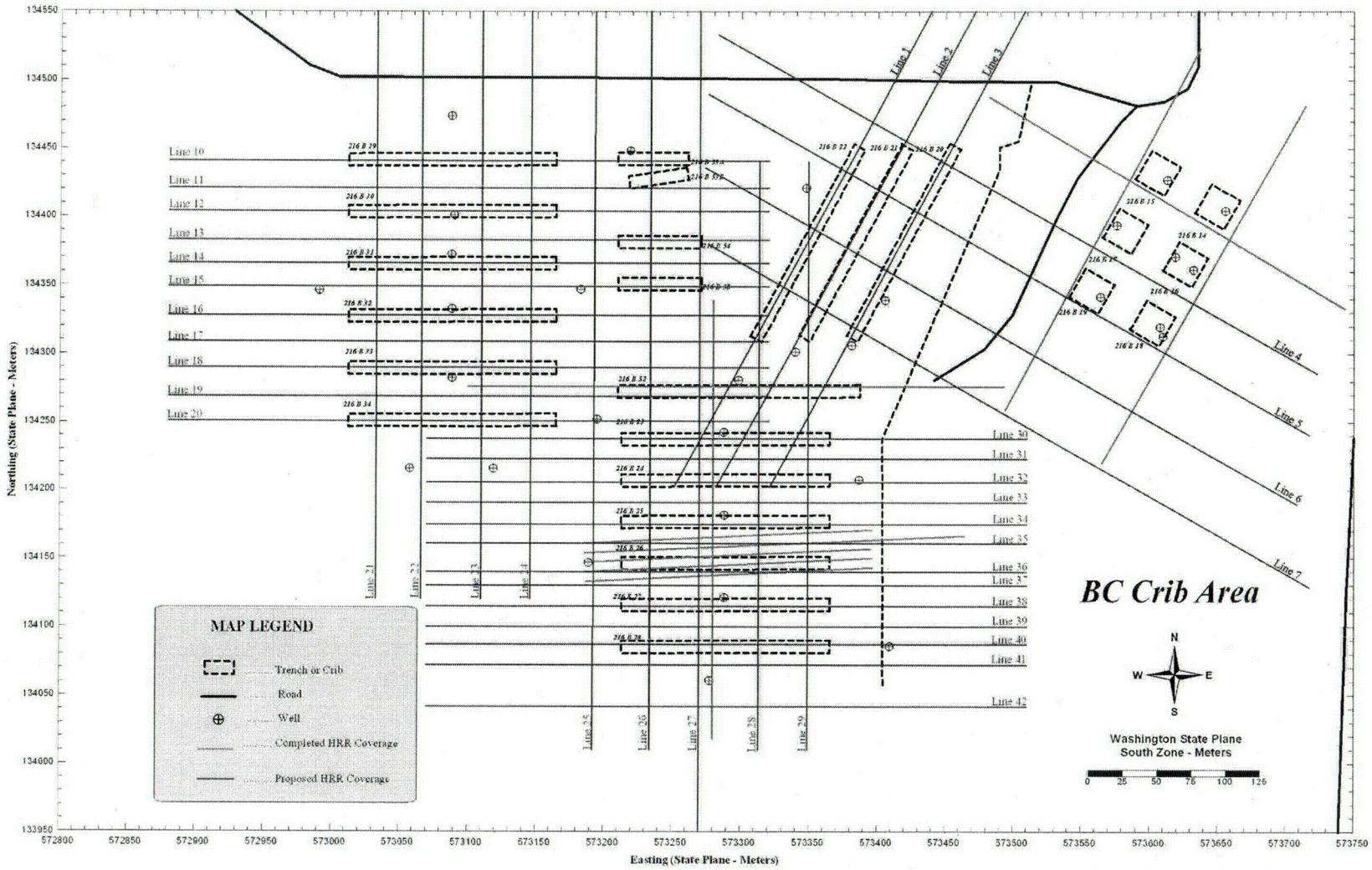
Tip and Sleeve Stress
Total Gamma
Resistivity
Active Soil Gas
Soil Sampling
DNAPL Ribbon Samplers



Active Soil Gas Measurements

High Resolution Resistivity

hydroGEOPHYSICS, Inc.



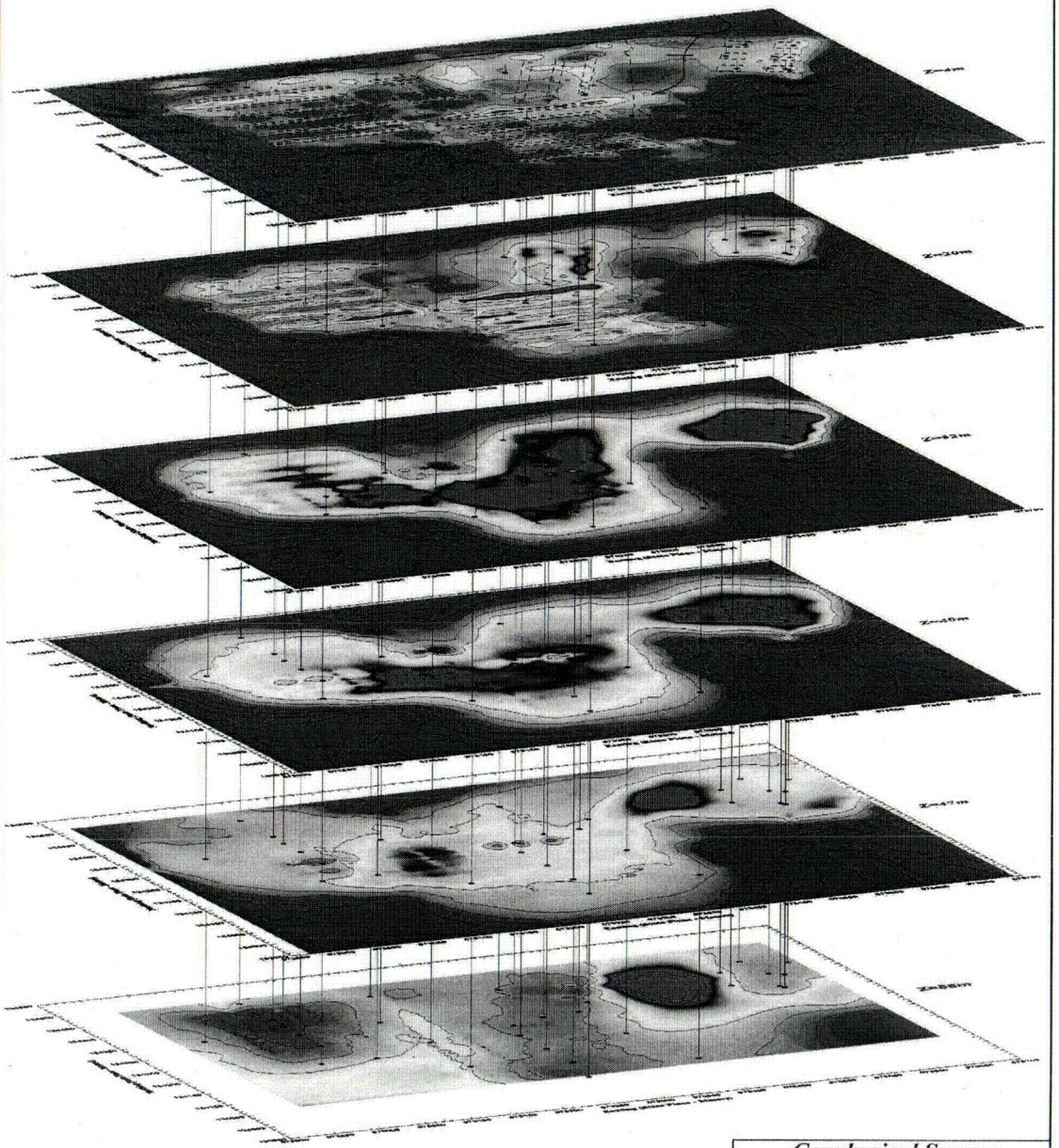
HRR Coverage for the BC Crib and Trenches Area

Geophysical Survey	
14742	PNNL / FLUOR BC Cribs Hanford, WA
	Date: May 2005

FILE: HRR Coverage for 2005 licensed.srf | 2005-005 | 05/19/05 12:13:21 | 2302 N. Forbes Blvd. • Tucson, AZ 85745 • (520) 647-8315

hydroGEOPHYSICS, Inc.

BC Cribs and Trenches HRR Data



Apparent Resistivity (ohm-m)

60 160 260 360 460 560 660 760 860 960 1060 1160 1260 1360 1460

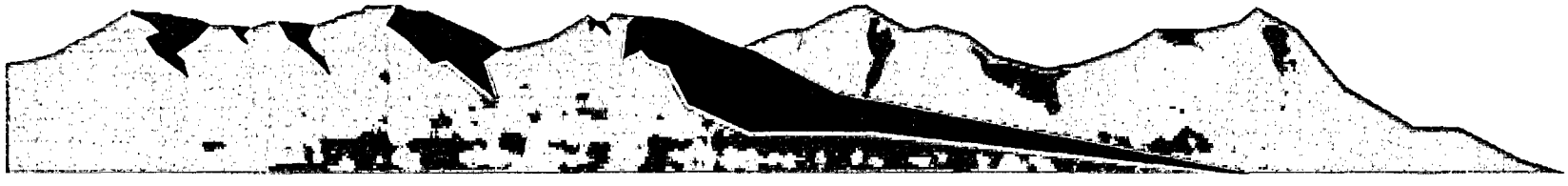
Geophysical Survey

PNNL / FLUOR
BC Cribs
Hanford, WA

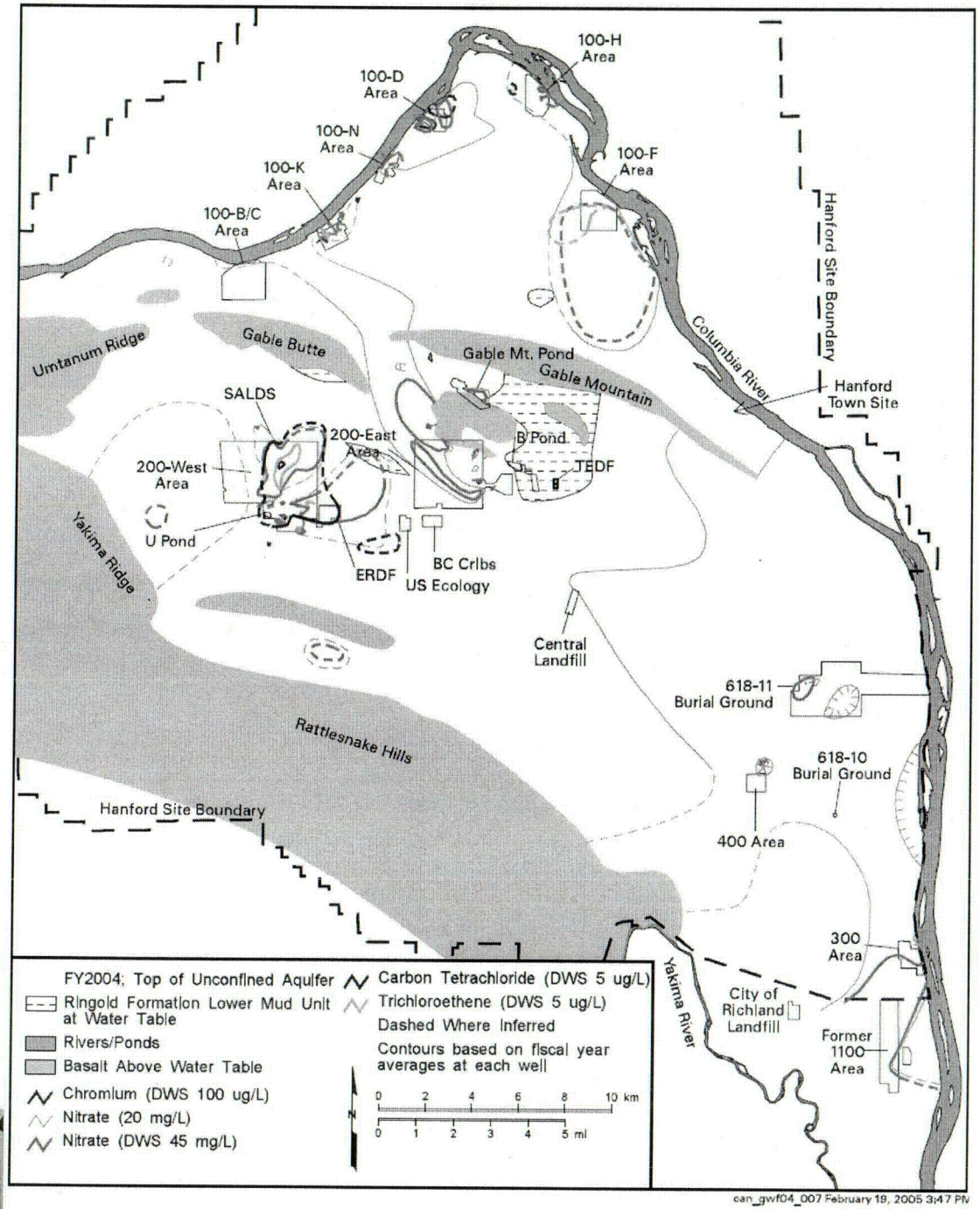
Date: *June 2005*

Review of Geophysical Techniques to Define the Spatial Distribution of Subsurface Properties or Contaminants

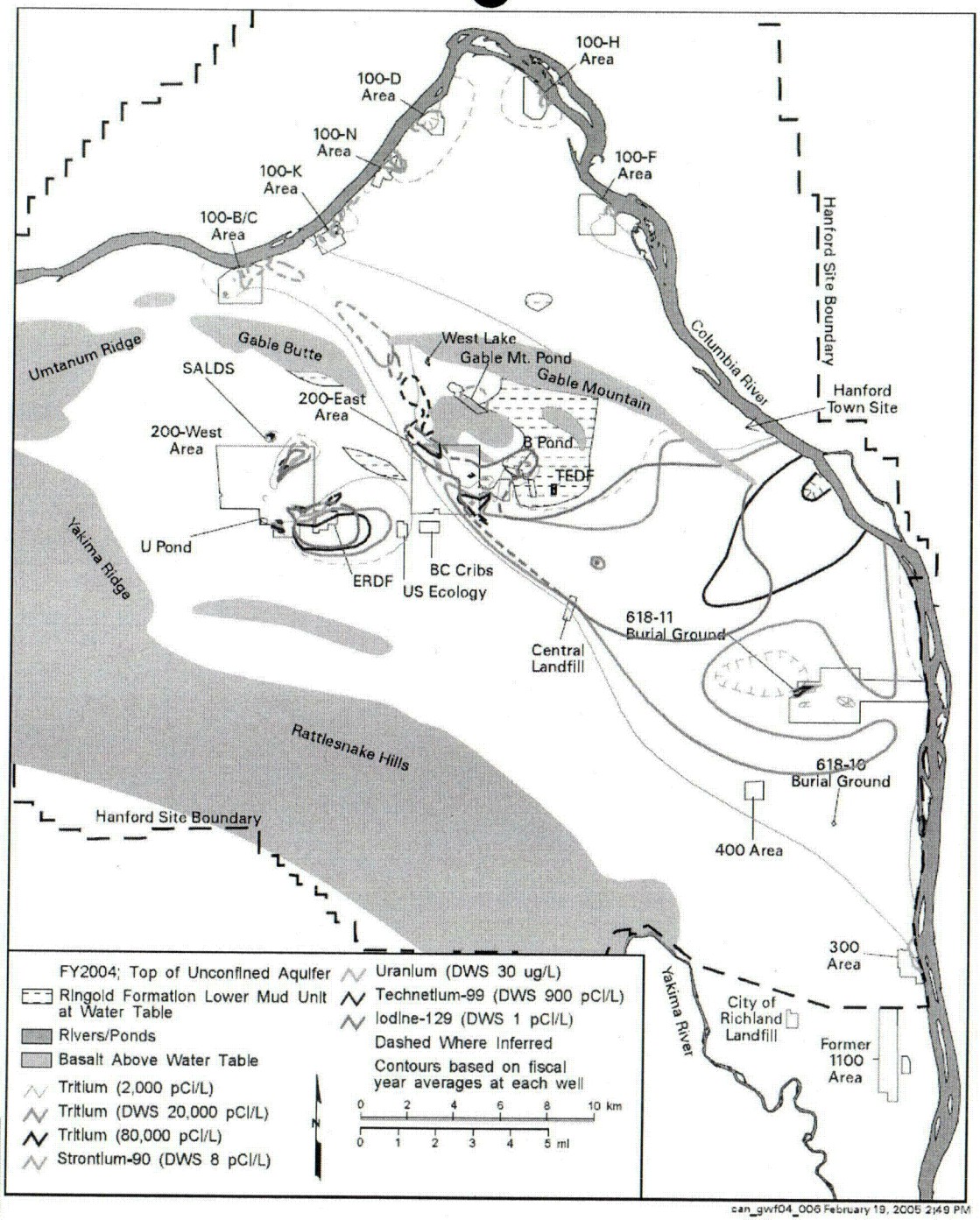
Technology	Characterization Target	Use Platform	State of Development	Relative Cost	DataSource
Surface ground penetrating radar (GPR)	DNAPL, LNAPL, hydrocarbons, conductive inorganic plumes	Surface	Commercial – widely available 1.• Sisson and Lu Site 2.• Clastic Dike Site	Medium	http://vadose.pnl.gov/; http://fate.clu-in.org/gpr_main.asp; http://costperformance.org/monitoring/#38; Knight 2001; Olhoeft 1992; Sneddon et al. 2002; Guy et al. 2000
Cross-borehole radar tomography	Conductive inorganic plumes	Borehole	Commercial – limited 1.• Sisson and Lu Site	Medium to High	Majer et al. 2001
Seismic reflection amplitude vs. offset (AVO)	DNAPL	Surface	Emerging – research 1.• 200 West CT plume 2.• Savannah River Site	Medium	http://www.clu-in.org/conf/tio/geophysical_121201/chp_3.pdf;
Time domain electromagnetics (TDEM)	Conductive inorganic plumes	Surface	Commercial – widely available	Low	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1802/c-4.pdf; McNeill 1994
Terrain conductivity (a frequency domain electromagnetics [FDEM] method)	Conductive inorganic plumes	Surface	Commercial – widely available	Low	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-1802/c-4.pdf; McNeill 1990
DC resistivity soundings and profiling	Moisture/conductive plumes	Surface	Commercial – widely available	Low to Medium	http://www.hydrogeophysics.com; http://vadose.pnl.gov (Barnett et al. 2002); http://www.epareachit.org



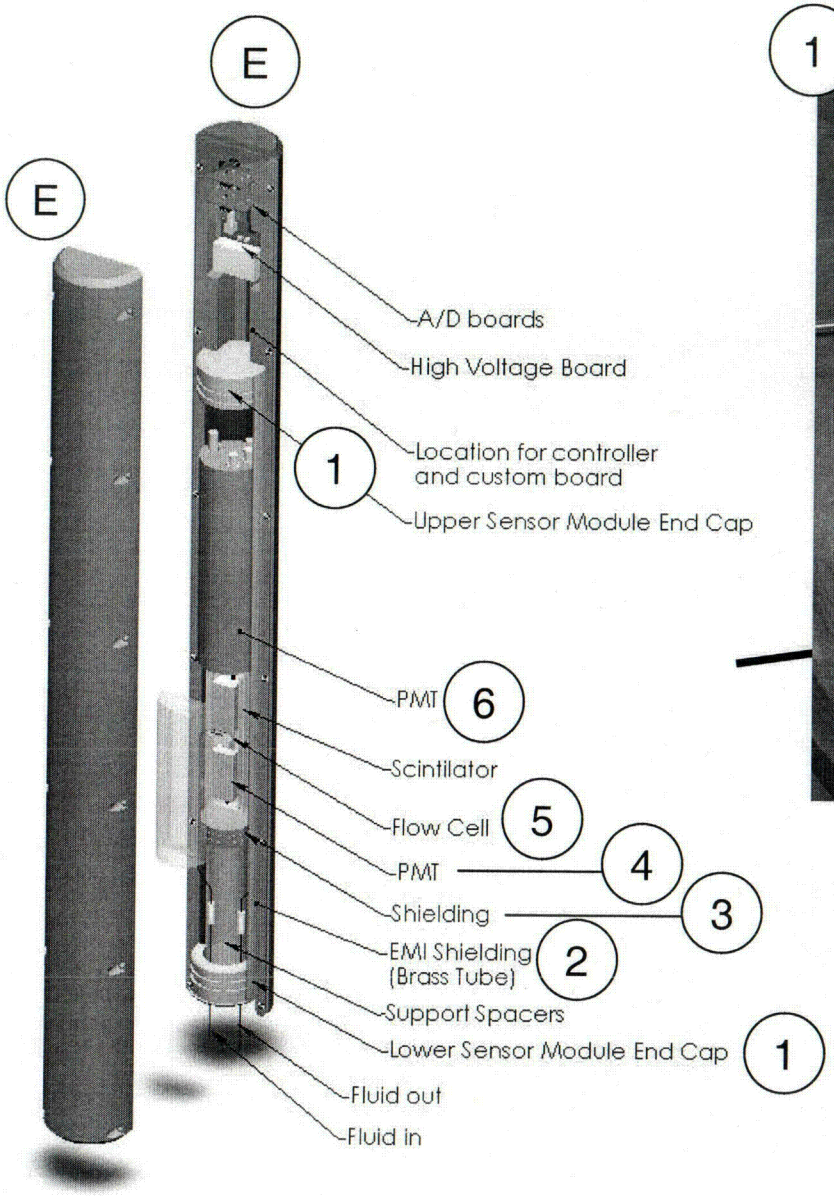
Technology	Characterization Target	Use Platform	State of Development	Relative Cost	DataSource
3D resistivity imaging (including high resolution resistivity [HRR] and HRR-steel casing resistivity technology)	Moisture/conductive plumes	Surface and borehole	Commercial – widely available 1.• Mock Tank (223-E) 2.• Sisson and Lu Site 3.• BC cribs and trenches	Medium to High - $200K - 50 acres (60 m depth)	http://vadose.pnl.gov; Ward and Gee 2000; Barnett et al. 2002
Electrical resistivity tomography (ERT)	Moisture/conductive plumes	Borehole	Commercial – widely available 1.• Mock Tank (223-E)	Medium to High	http://vadose.pnl.gov; Ward and Gee 2000; Barnett et al. 2002
Electrical impedance tomography	Moisture/conductive plumes	Borehole	Emerging – research 1.• Mock Tank (223-E)	Medium to High	http://vadose.pnl.gov; Ramirez et. al. 1998
Complex resistivity (including spectral induced polarization)	Organic contaminants and inorganic contaminants	Surface and/or cross-borehole	Emerging – deployed 1.• A-14 Outfall at SRS 2.• Hill Air Force Base	Medium to High	Morgan and Lesmes 2004; Brown et. al. 2003; EPA 1998; Versteeg 1997
Equipotential and mise-a-la-masse	Moisture/Conductive Plumes and Organic Contaminants	Surface and borehole	Commercial – widely available 1.• Mock Tank (223-E) 2.• Sisson and Lu Site	Medium to High	http://www.clu-in.org/programs/21m2/spotlight/080304.pdf; Barnett et al. 2002
Self potential	Metallic constituents	Surface or	Commercial – limited	Medium - Can be	Versteeg 1997



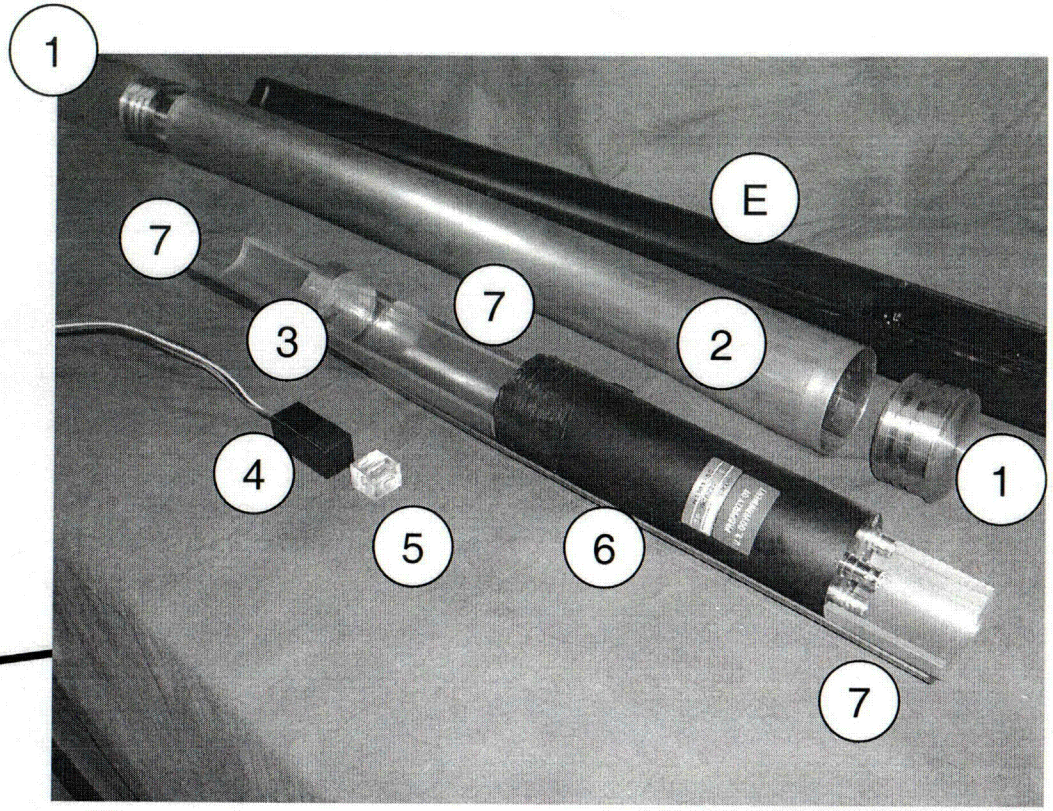
This map shows the distribution of hazardous chemicals in groundwater at concentrations above drinking water standards during FY 2004 at the top of the unconfined aquifer.



This map shows the distribution of radionuclides in groundwater at concentrations above drinking water standards during FY 2004 at the top of the unconfined aquifer.



Tc-99 Sensor Module

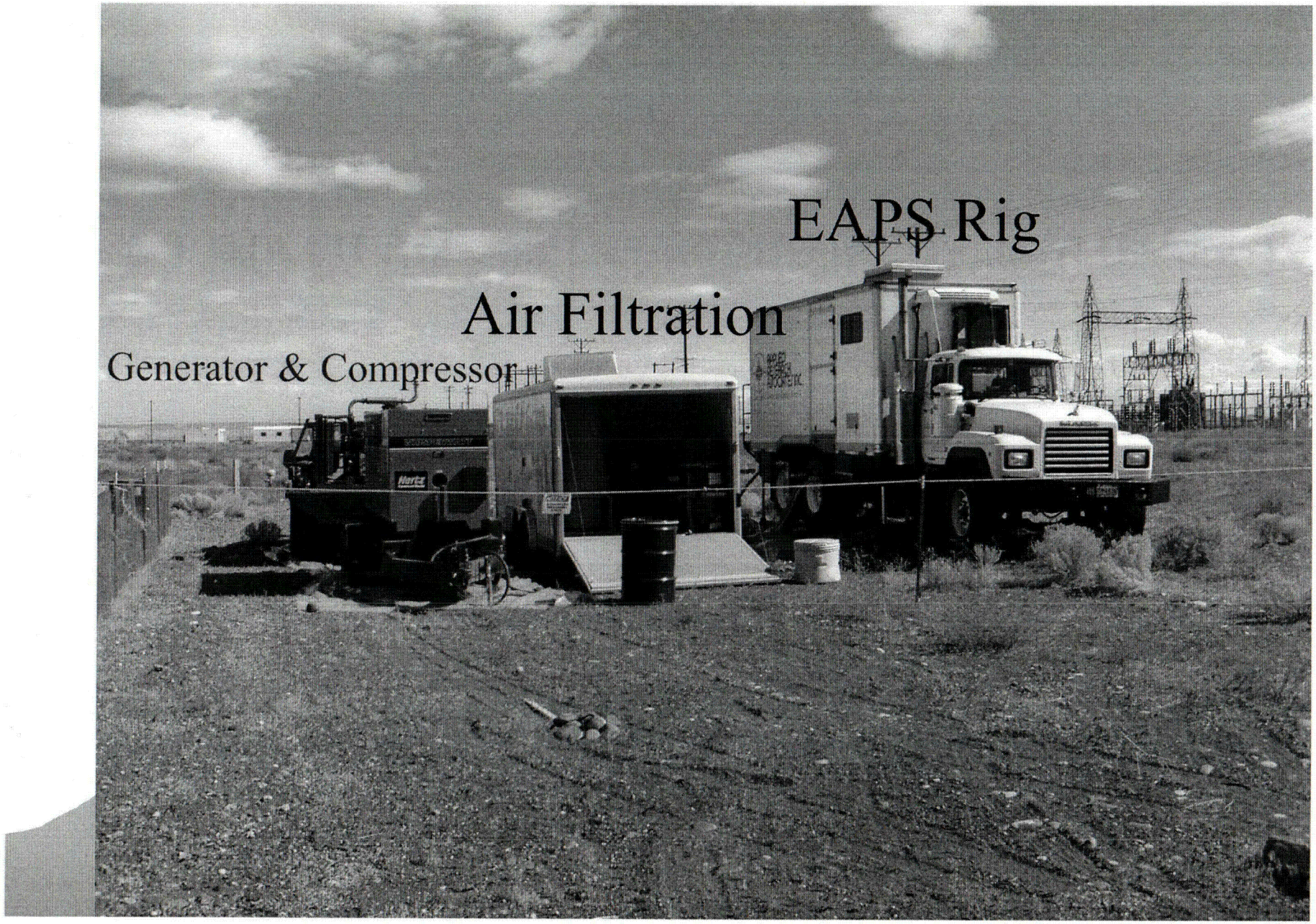


Key:

E – Sensor module enclosure
1 – Sensor module end cap
2 – Light tight, EMF shield
3 – Lead shielding
4 – Tc-99 sensing PMT
5 – Sensor cell
6 – Anti-coincidence PMT
7 – Spacers

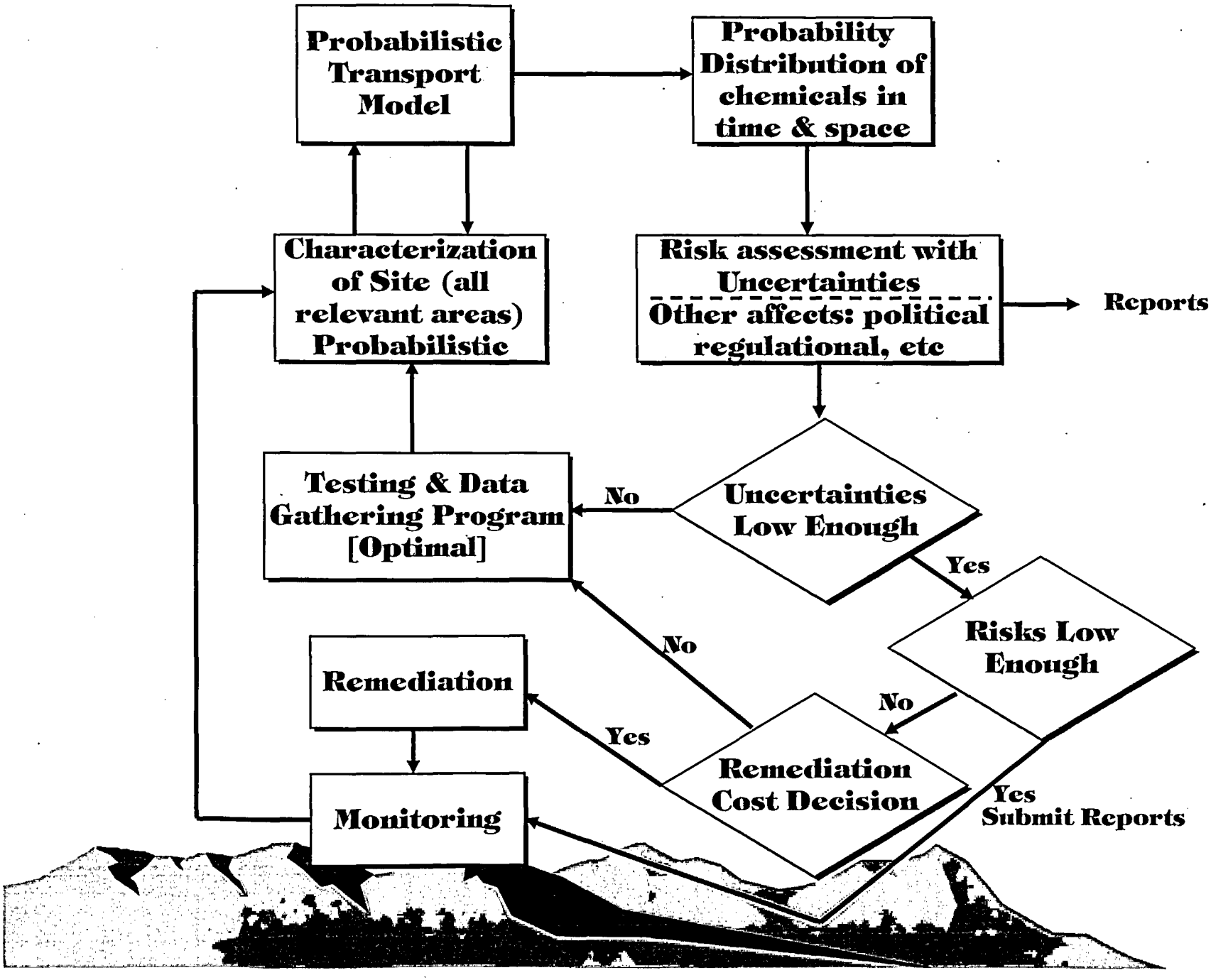
Remote Chromium Sensor at 100-D

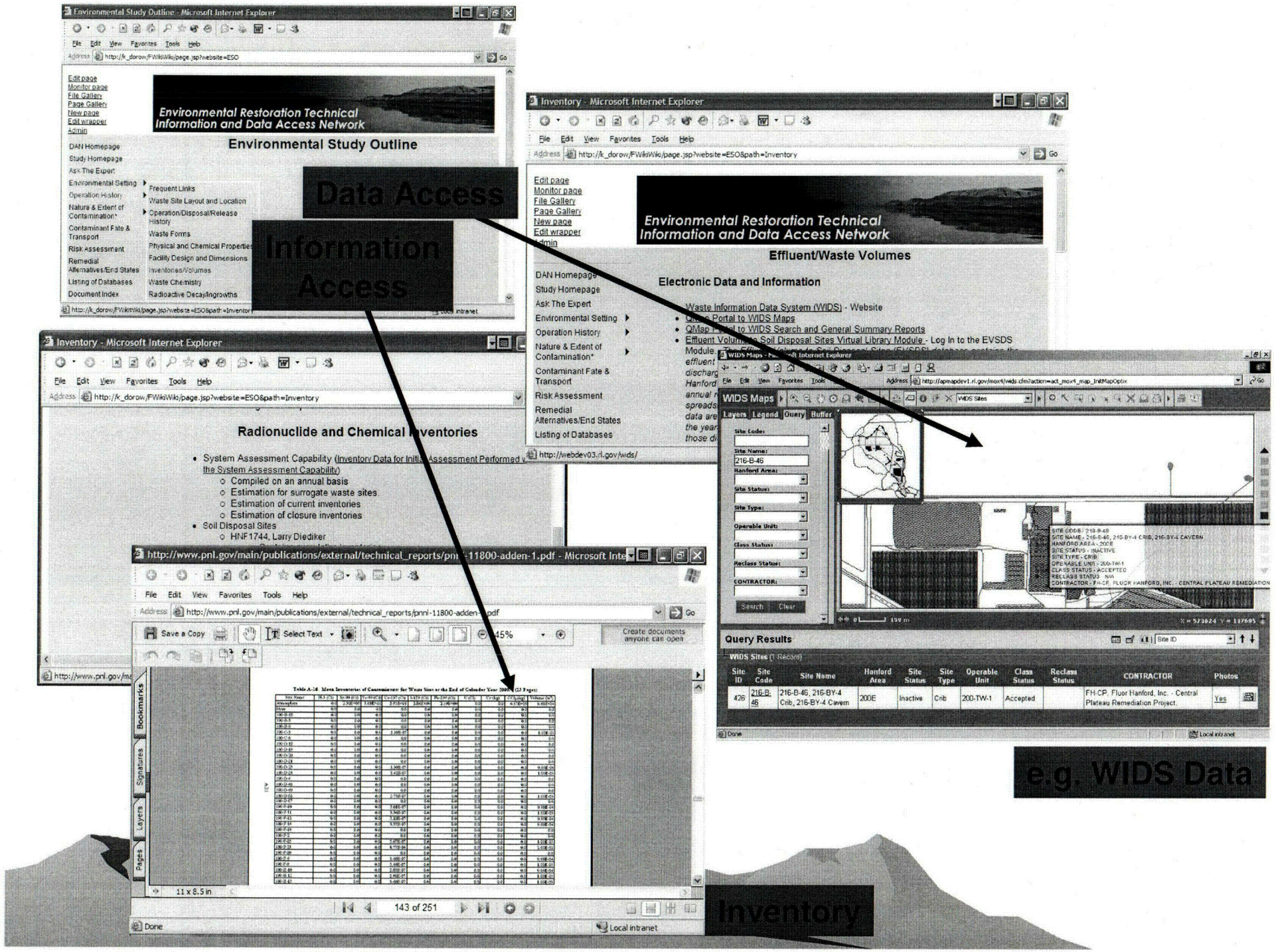
Enhanced Access Penetrometer System (EAPS)



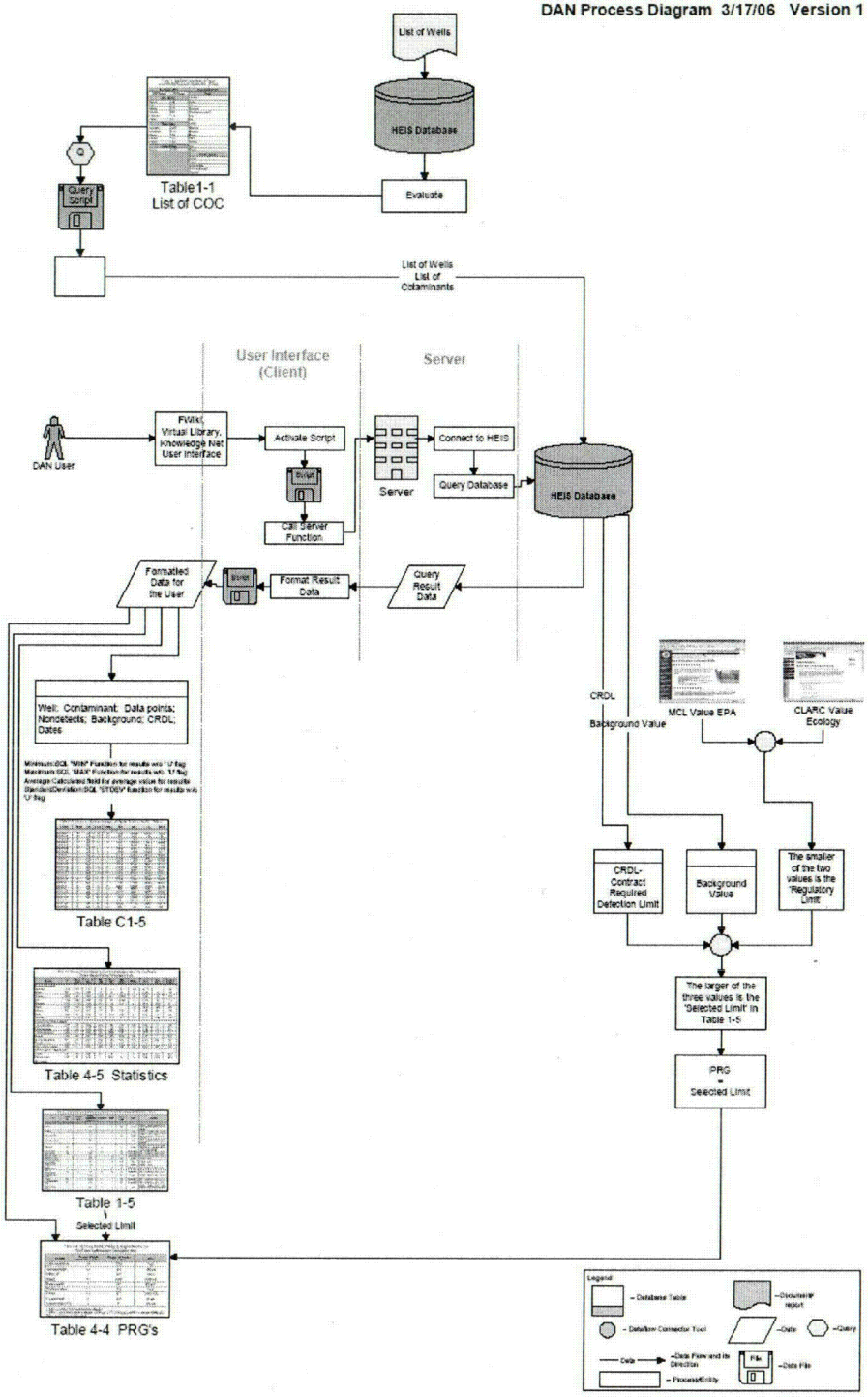
Future Monitoring

- Beneath TSDs (lysimeters, tubes, etc.) (during operations)
- Liquid retention ponds (mass balance approaches)
- Caps and barriers (integrity, survey methods, etc.) (after closure)
- Protection and monitoring for rapidly decaying constituents
- Continued characterization
- Groundwater Monitoring


Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
Remediation
No
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

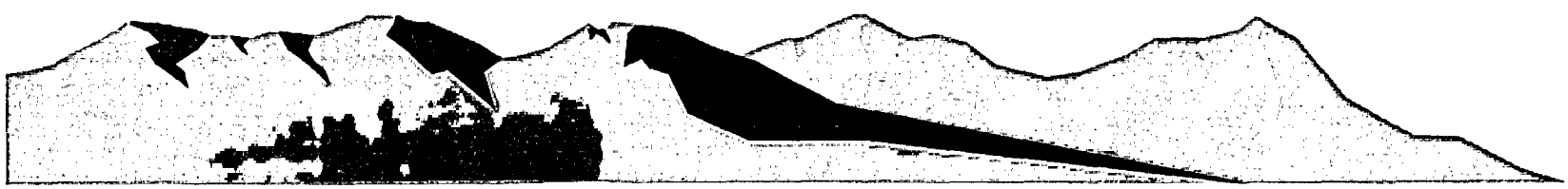

Environmental Study Outline - Microsoft Internet Explorer
Environmental Restoration Technical Information and Data Access Network
Environmental Study Outline
Data Access
Information Access
Inventory - Microsoft Internet Explorer
Effluent/Waste Volumes
Electronic Data and Information
Waste Information Data System (WIDS) - Website
Radionuclide and Chemical Inventories
System Assessment Capability
Soil Disposal Sites
HNF1744, Larry Diediker
WIDS Maps
Query Results
e.g. WIDS Data
Inventory

DAN Process Diagram 3/17/06 Version 1

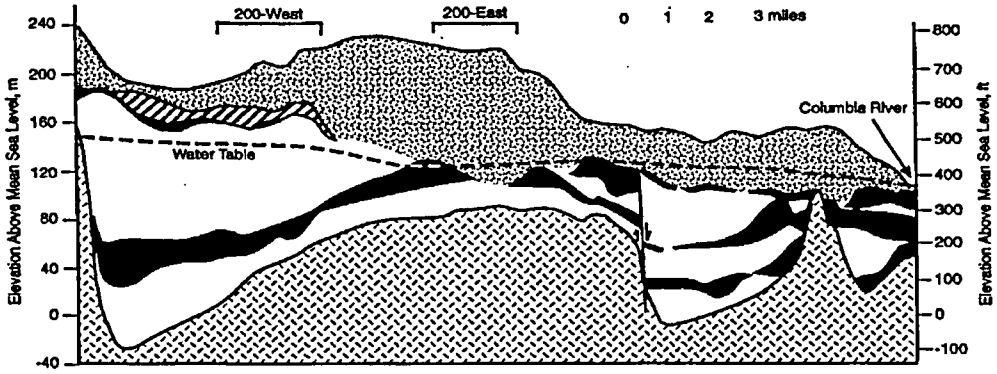


Identified Technology Needs Relative to Contaminant Migration

- Characterization Issues
- Transport Issues
- Risk Issues
- Monitoring Issues
- Cost Issues (Better Remediation Technologies)
- Dissemination Issues



Characterization Issues



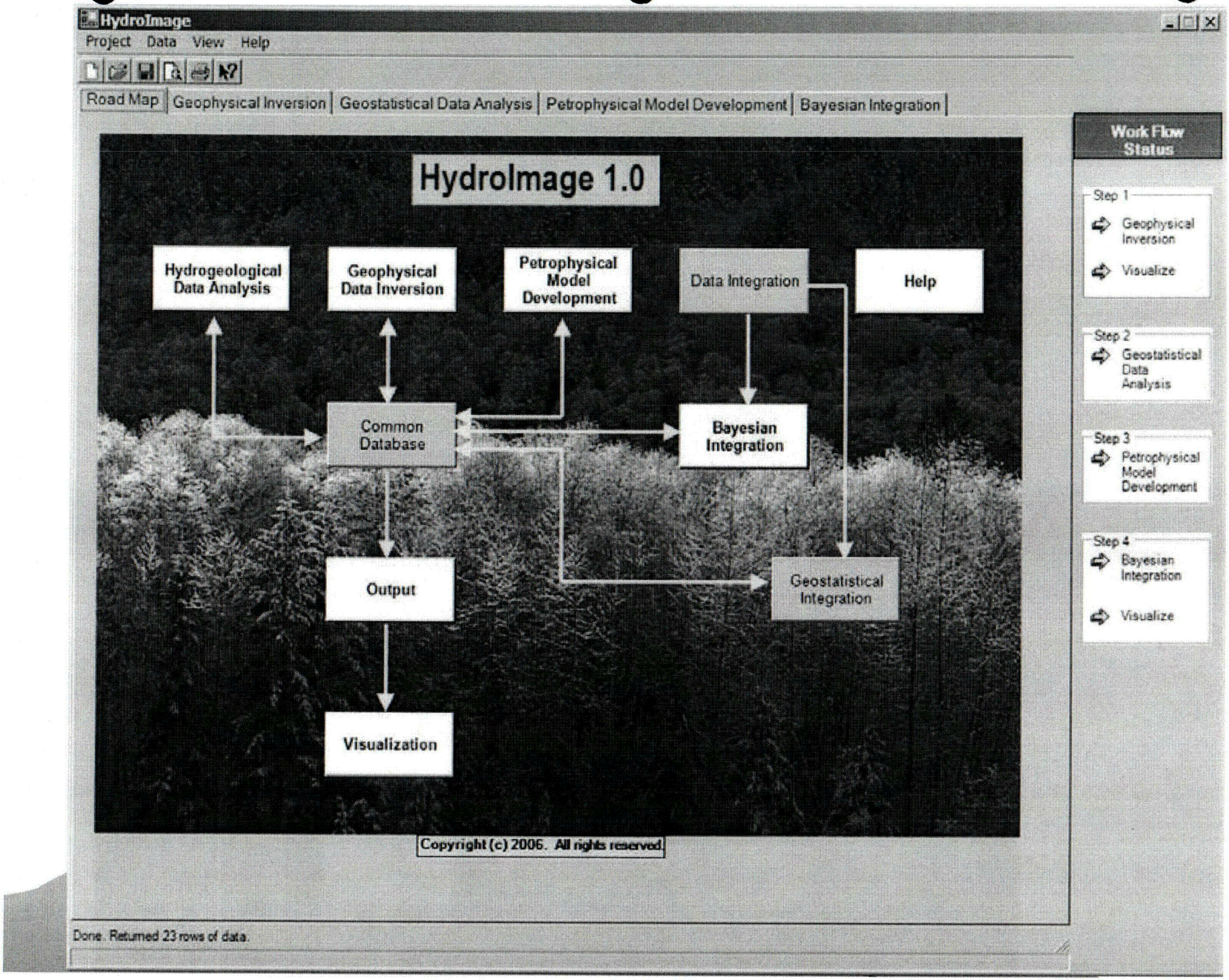
- Technetium – 99 – Difficult to analyze in radiation samples. Transport properties.
- Uranium – Transport properties. Chemical speciation.
- Carbon Tetrachloride – Inventory. Phase? Movement with water or without. Degradation questions. Transport properties.
- Access to locations in groundwater – limits numbers of samples and increases costs.
- Non-intrusive hydro-geological characterization of larger areas.
- Scaling issues.
- Data integration, consistency, and presentation

Monitoring Issues

- Optimization strategies for monitoring
- Unsaturated zone monitoring (better methodology).
  - What types of monitoring
  - Types of instrumentation, detection methods, etc.
- Monitoring in long-term stewardship mode. Feedback to modeling
- Reduce monitoring costs

Example: HydroImage, A User-friendly Hydrogeophysical Characterization Software Package

Integrates continuous geophysical data with limited borehole data to estimate hydrogeological parameters of interest in the subsurface was developed. The software package can be used to significantly enhance site conceptual models and improve design and operation of remediation systems.


HydroImage
Project Data View Help
Road Map
Geophysical Inversion
Geostatistical Data Analysis
Petrophysical Model Development
Bayesian Integration
HydroImage 1.0
Hydrogeological Data Analysis
Geophysical Data Inversion
Petrophysical Model Development
Data Integration
Help
Common Database
Bayesian Integration
Output
Geostatistical Integration
Visualization
Copyright (c) 2006. All rights reserved.
Work Flow Status
Step 1
Geophysical Inversion
Visualize
Step 2
Geostatistical Data Analysis
Step 3
Petrophysical Model Development
Step 4
Bayesian Integration
Visualize
Done. Returned 23 rows of data.

Project Data View Help

Geophysical Inversion | P

Select Input Files:

Prior data file:

C:\hydroimage\bin\ex

Tomographic data fi

C:\hydroimage\bin\ex

Petrophysical model

C:\hydroimage\bin\ex

Output File:

C:\hydroimage\bin\ex

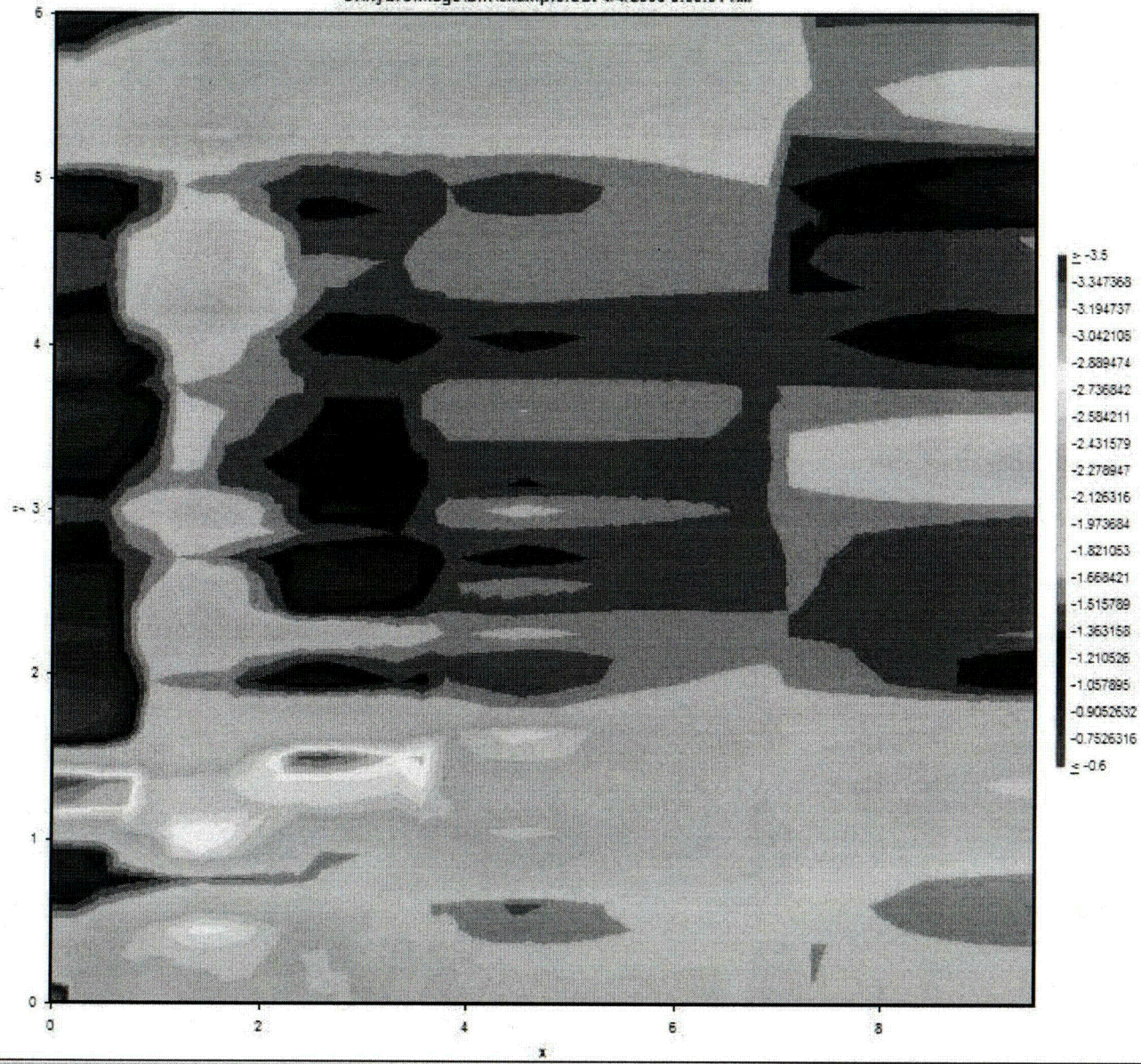
Prior File	
	X
▶	41
	0.0000
	0.2372
	0.4745
	0.7117
	0.9490
	1.1863
	1.4235
	1.6607

Bayesian Output	
	x
▶	0.0000
	0.2372
	0.4745
	0.7117
	0.9490
	1.1863
	1.4235
	1.6607
	1.8980

DPlot Jr - [Bayesian Integration Output]

File Edit Text Options View Window Help

C:\hydroimage\bin\example.out 4/4/2006 9:53:31 AM



Computational Environments for Integration of Geophysics and Reservoir Simulation

THE OHIO STATE UNIVERSITY

THE STATE UNIVERSITY OF NEW JERSEY RUTGERS

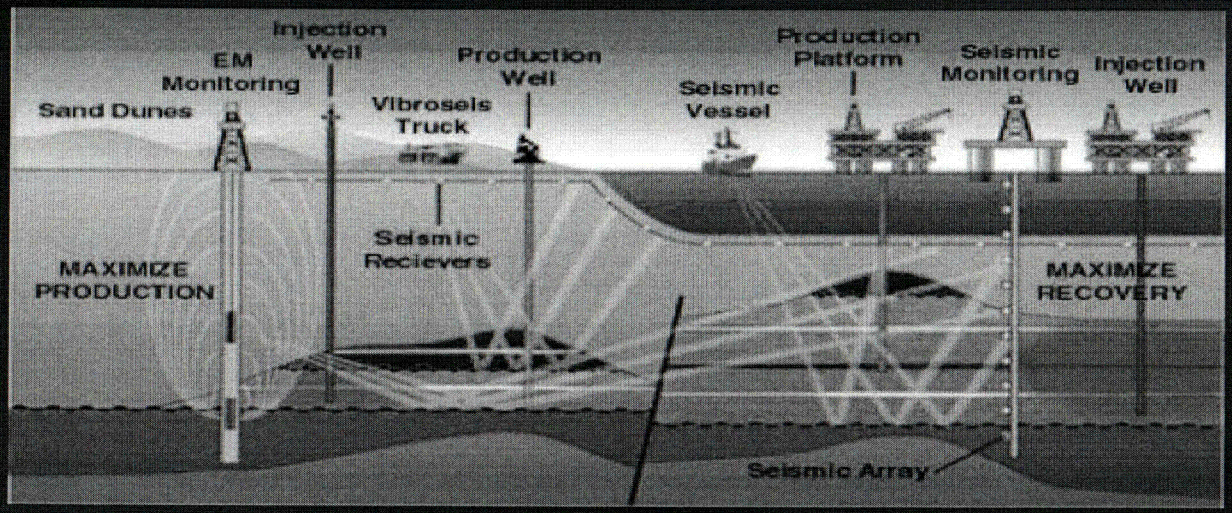
THE UNIVERSITY OF TEXAS AT AUSTIN

An overview of the NSF/ITR projects:

The Data Intense Challenge: The Instrumented Oil Field of the Future (2001-2005)

Data Driven Simulation of the Subsurface: Optimization and Uncertainty Estimation (2004-2007)

The Instrumented Oil Field



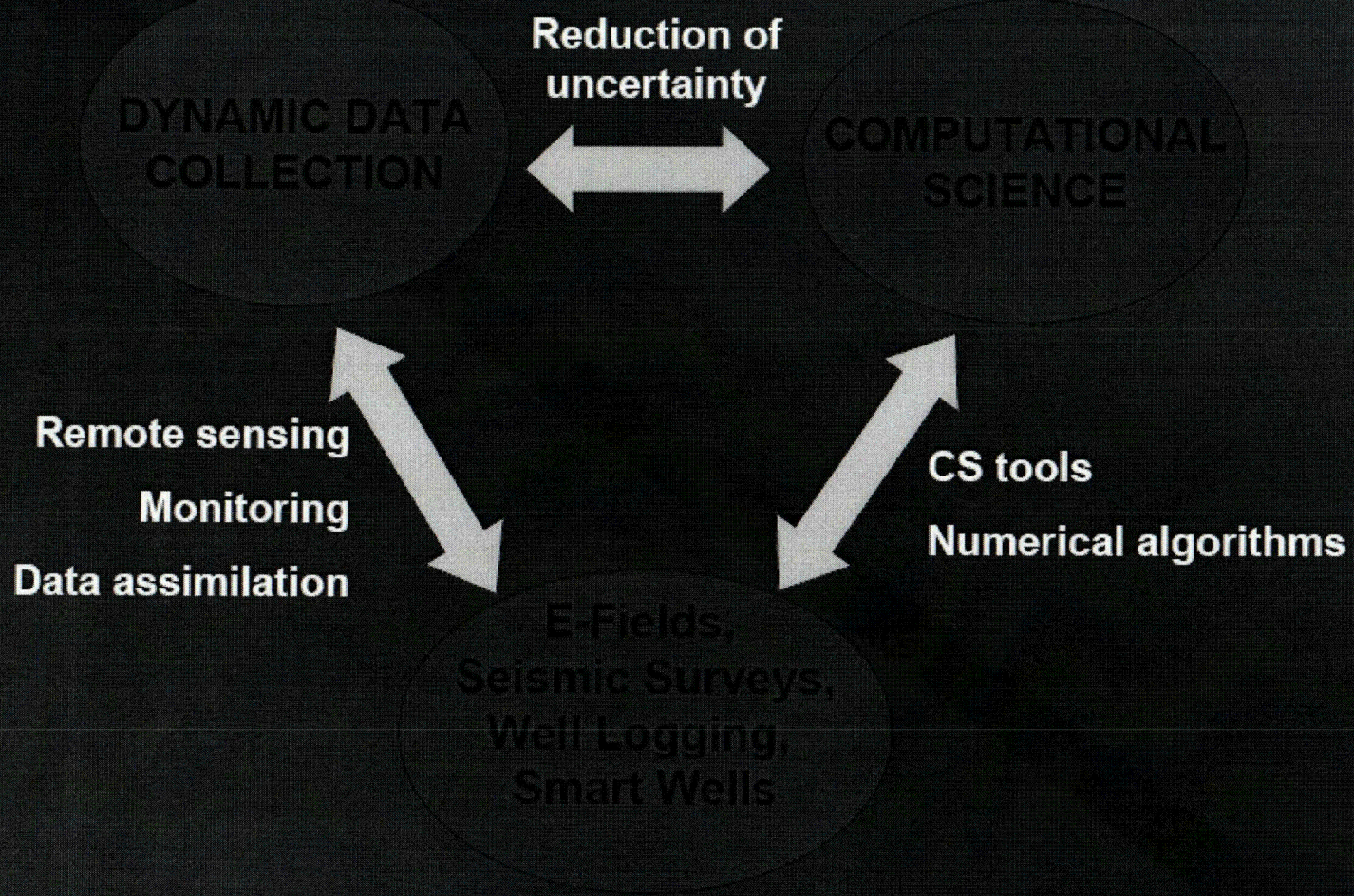
Model Driven

Assimilate data & reservoir properties into the evolving reservoir model

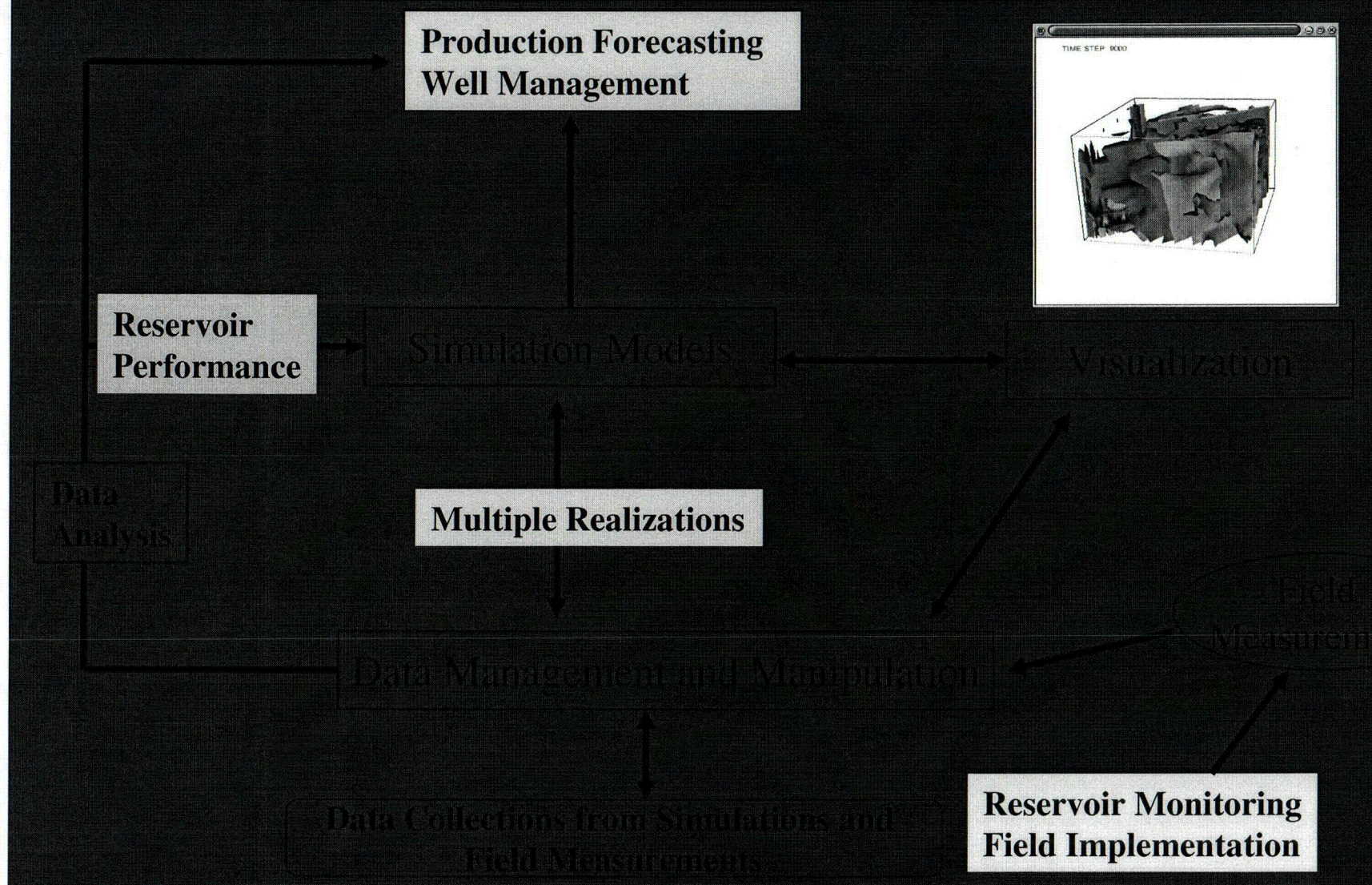
Detect and track changes in reservoir changes during production

Data Driven

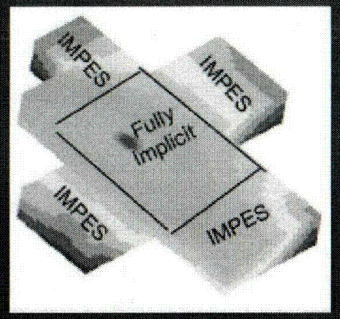
DDDAS: Integration of Data, Models, and IT



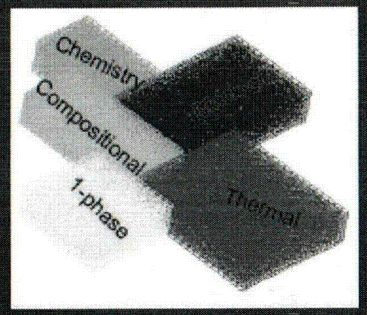
Economic Modeling and Well Management



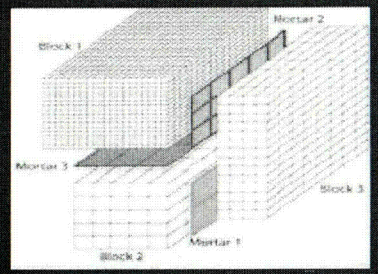
Accomplishments



Multialgorithmic



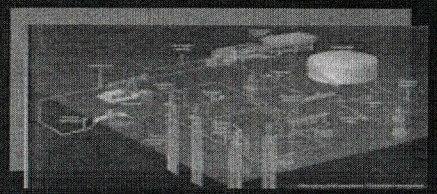
Multiphysics



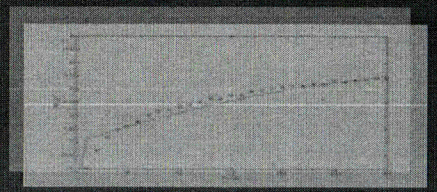
Multiscale

Models | **Simulation**

Optimization | **Data**

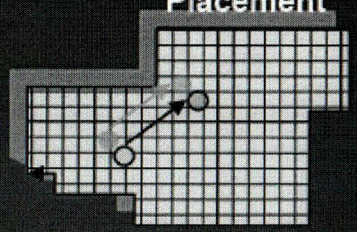


Optimal Scheduling

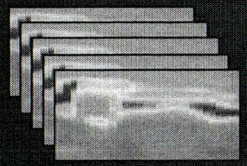


History Matching

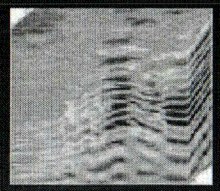
Optimal Well Placement



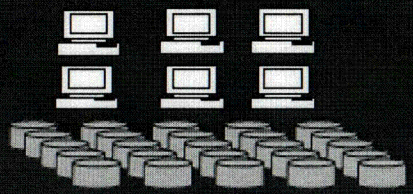
Visualization



Flow data



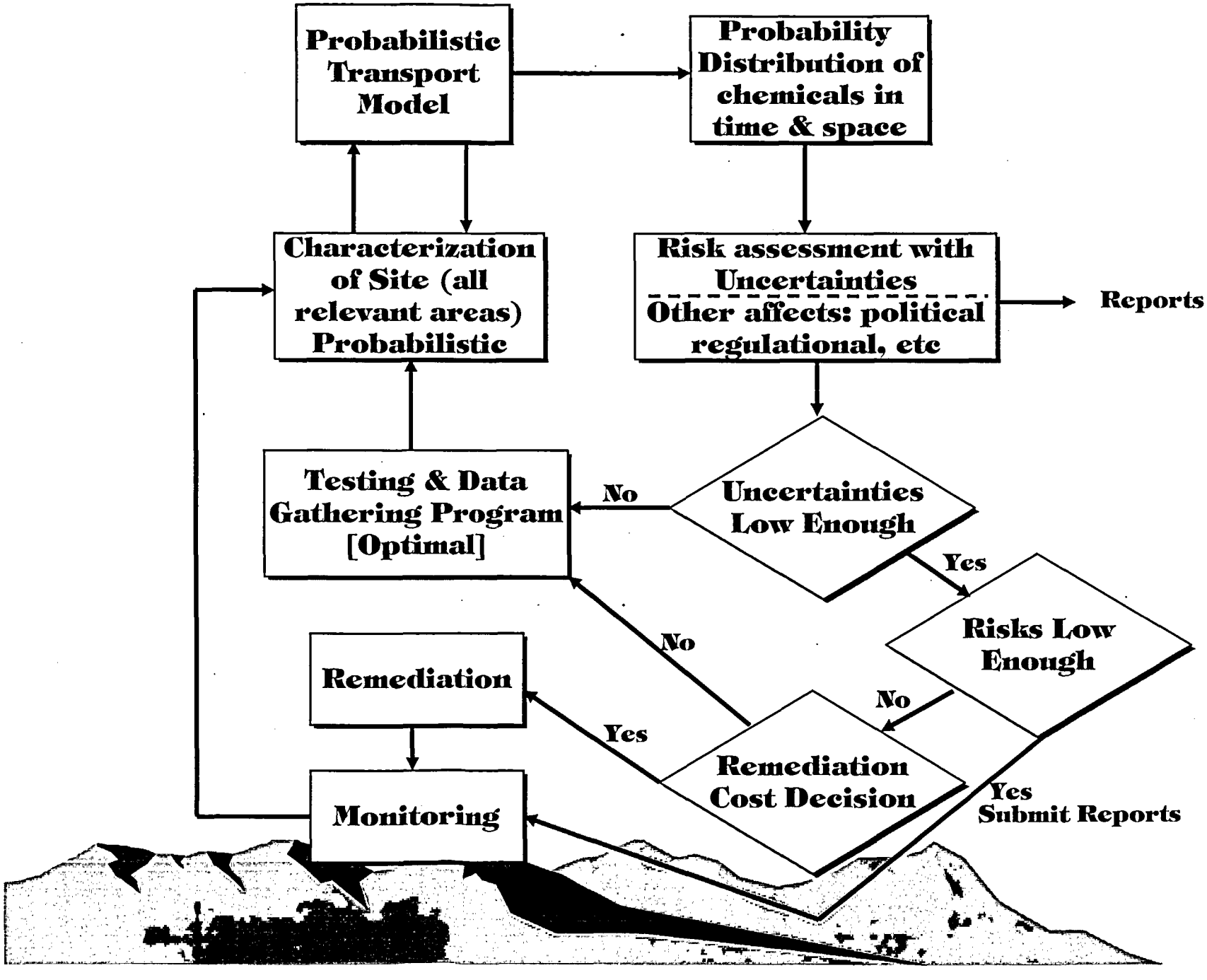
Seismic data



Data Management

Two More Examples

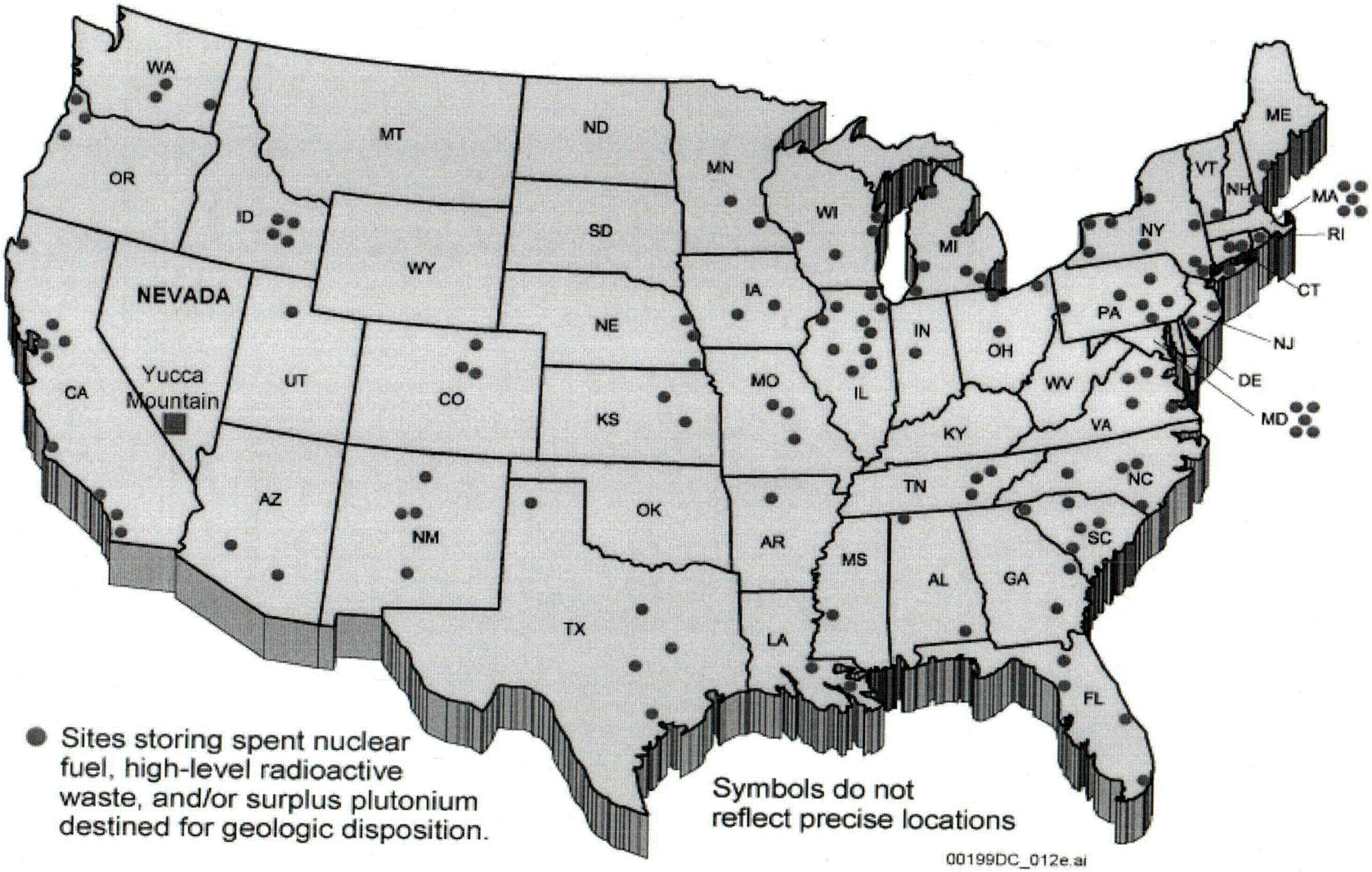
- Collaboration between INEL and PNNL: End goal is to be able to click on a location or well and bring up geophysical (surface and borehole), as well as grain size distributions and estimated hydraulic properties etc.
- SAIC's automated knowledge management and production integration system.


Probabilistic Transport Model
Probability Distribution of chemicals in time & space
Characterization of Site (all relevant areas) Probabilistic
Risk assessment with Uncertainties
Other affects: political regulational, etc
Reports
Testing & Data Gathering Program [Optimal]
No
Uncertainties Low Enough
Yes
Risks Low Enough
No
Remediation
No
Yes
Remediation Cost Decision
Yes
Submit Reports
Monitoring

Future Development Efforts for Analysis of Contaminant Migration

- Better characterization of chromium source in D-Area
- Mapping of top of basalt for better flow direction determination
- Analyze abiotic degradation potential for carbon tetrachloride
- Develop fingerprinting methods for isotope source identification
- Develop better characterization methods
- Develop better conceptual model of the Hanford Site (Simulations)
- Develop better data retrieval and analysis methods
- Continue developing instrumentation and monitoring technology
- Reduce price of instrumentation and deployment of monitoring technology
- Increase reliability of instrumentation and monitoring technology
- Allow current designs to incorporate future technology
- Directions in future technologies deployment (redundancy, developing standards, less intrusive)
- Integrate Modeling and Monitoring to provide long-term control of contaminants

U.S. Locations of Sites



Coupling Monitoring Programs to Modeling

Thomas J. Nicholson[1], Ralph Cady[1] and Jacob Philip[1]
James Shepherd[2] and Jon Peckenpaugh[3]
[1]Office of Nuclear Regulatory Research
[2]Office of Nuclear Material Safety and Safeguards
[3]Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission

Contact: TJN@NRC.GOV or (301) 415-6268

Outline

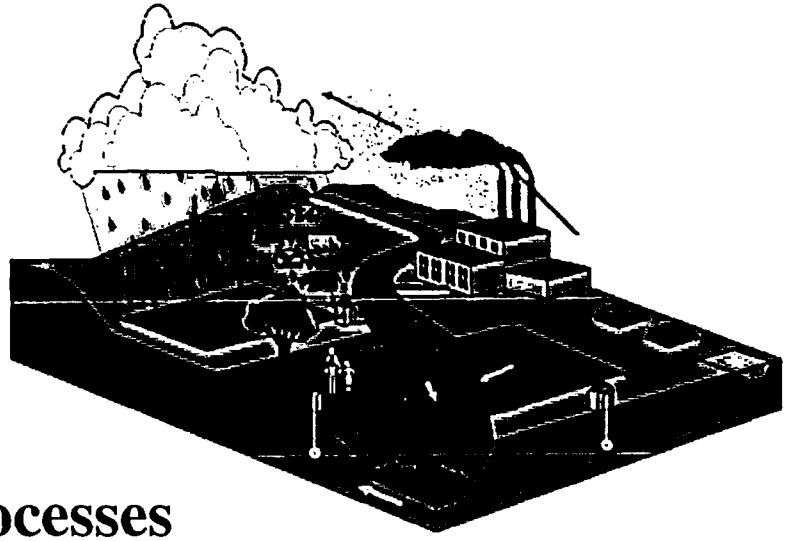
- Objectives in Monitoring and Modeling
- Monitoring and Model Interface
- Generic Technical Issues
- Opportunities to Build Confidence in Modeling
- References

Objectives in Monitoring and Modeling

- ✓ **Characterize system**
- ✓ **Demonstrate understanding of the system**
- ✓ **Confirm site and engineered system behavior**
- ✓ **Demonstrate compliance**
- ✓ **Design remediation for non-compliance**

Objectives in Monitoring and Modeling

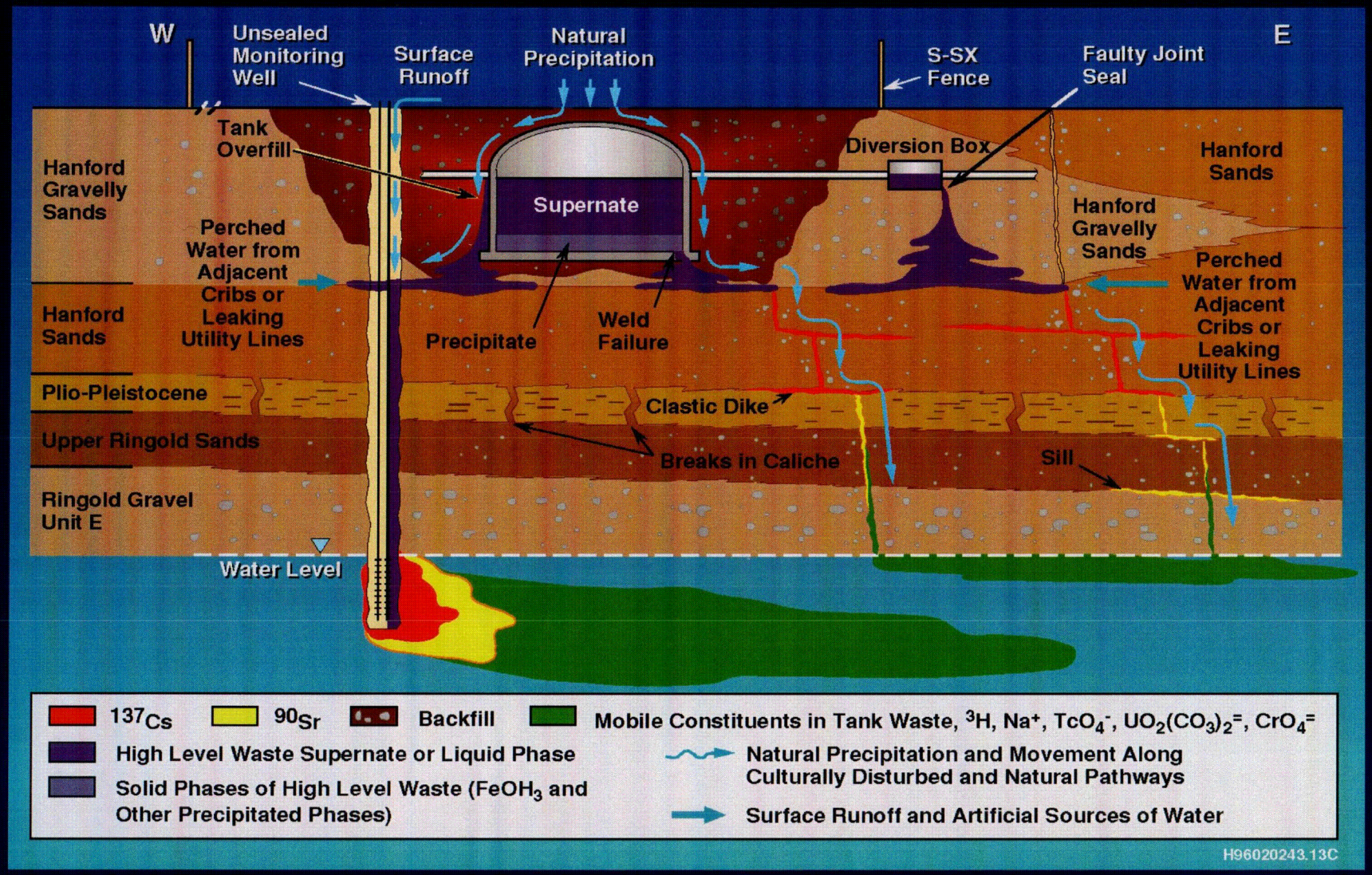
Why monitor and model?



Characterize natural and engineered systems:

- ✓ **Collect information to identify significant Features, Events and Processes**
- ✓ **Develop and evaluate site conceptual models**
- ✓ **Guide data collection including monitoring, sampling and geophysical surveys**

Conceptual Model of a Complex Site



from Ward et al. (1997) after Caggiano et al. (1996)

Objectives of Monitoring and Modeling

✓ **Confirm behavior is within envelope of expected performance**

- of engineered structure, systems and components
- of natural systems

Site-Specific Model

- will probably not be simplified (abstracted) version used in PA
- may include state variables not in abstracted version
- state variables are potential ***Performance Indicators***

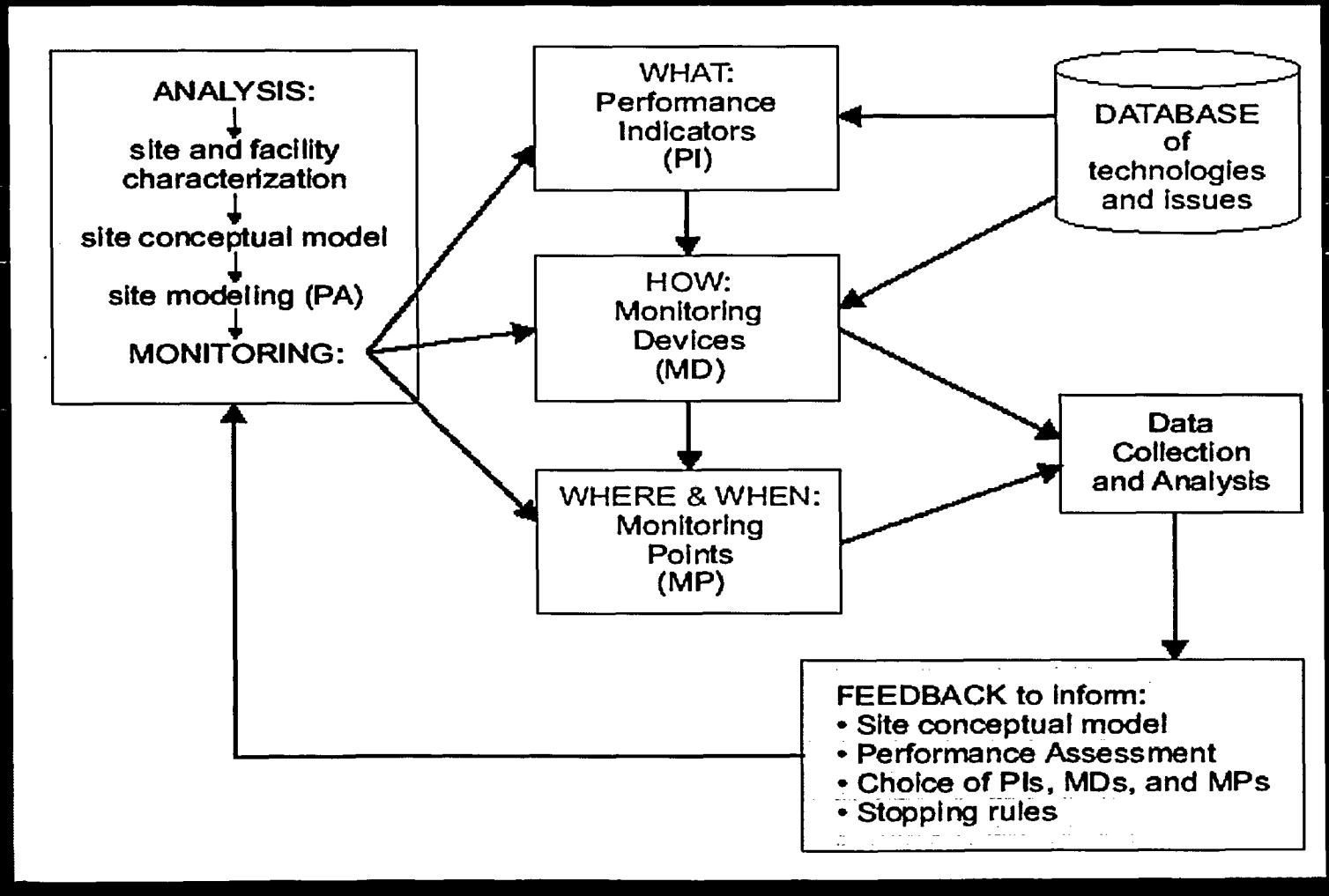
Objectives in Monitoring and Modeling

- ✓ Assure compliance
  - with regulatory requirements
  - with proposed site-specific criteria (e.g., NEI voluntary guidelines such as H-3 concentrations and specified volume release notifications)

Model is useful to:

- demonstrate understanding of the system being monitored
- infer from point monitoring data to:
  - compliance boundary or
  - other receptor location
- Decisions on whether and how to remediate non-compliant excursions
  - monitoring and modeling during remediation to evaluate efficacy

Monitoring and Model Interface



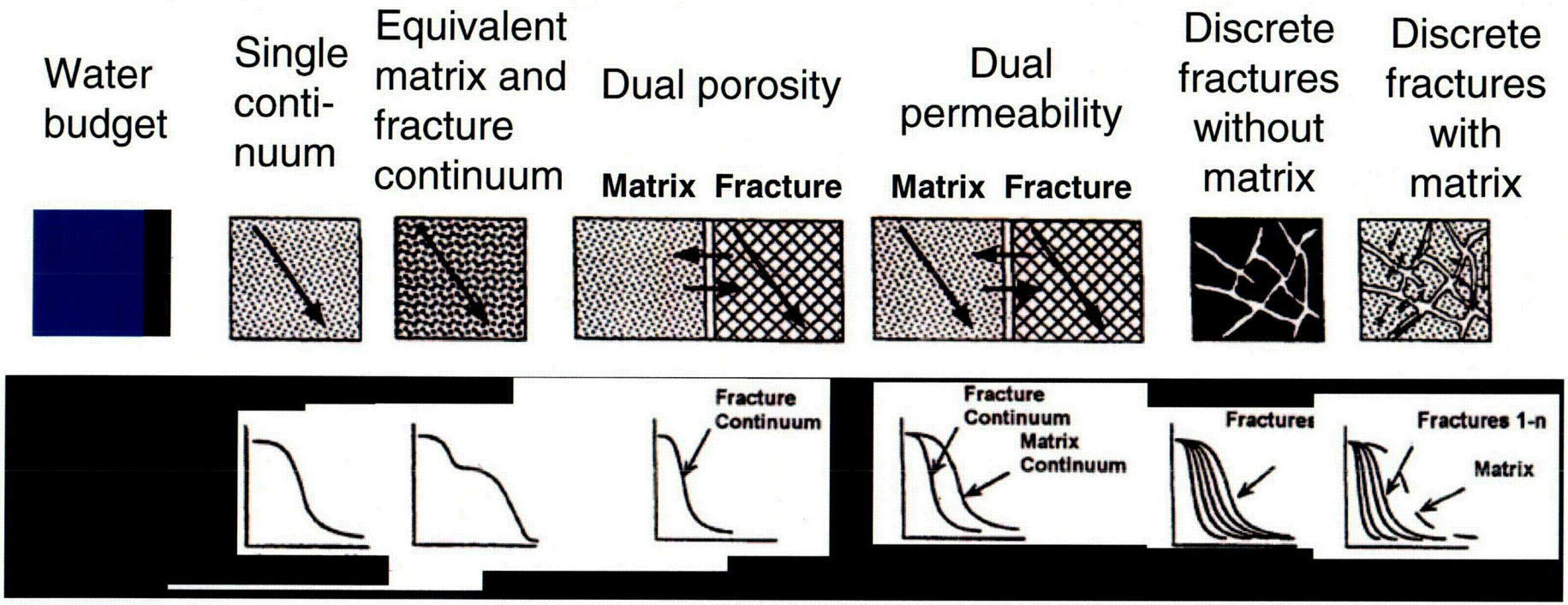
after AES, 2006

Generic Technical Issues

- Modeling to assess monitoring data-quality objectives (DQO's)
  - Required quality constraints may be beyond current sensor technology
  - Stopping values?
- Couple monitoring to conceptual model and site performance assessment (PA) by:
  - Assessing monitored conditions to confirm that performance is within the envelope of the model
- Identify alternative conceptual flow and transport models

Hierarchy of Conceptual Flow Models

Models to simulate flow in soils, sediments, unsaturated fractured rock (after Altman et al., 1996)



Complexity

Model abstraction

Generic Technical Issues

- ***What to monitor and model*** is defined by the site-specific PI's which are derived from:

  - ✓ regulatory compliance criteria
  - ✓ performance assessment predictions
  - ✓ need to ***quantify system behavior*** and to ***detect changes affecting radionuclide transport***

  (e.g., water contents, hydraulic gradients, flow velocities, contaminant concentrations and fluxes)

Generic Technical Issues

- ***Where to monitor*** is defined by the FEP's scales, system interfaces, and receptors' points of exposure:

  - ✓ facility structures, systems and components (e.g., telltails, concrete curtain walls, drains and sumps)
  - ✓ dynamic interface between facility and surrounding environment
  - ✓ surrounding environmental zone (e.g., pumping wells, springs, and discharge to surface-water bodies)

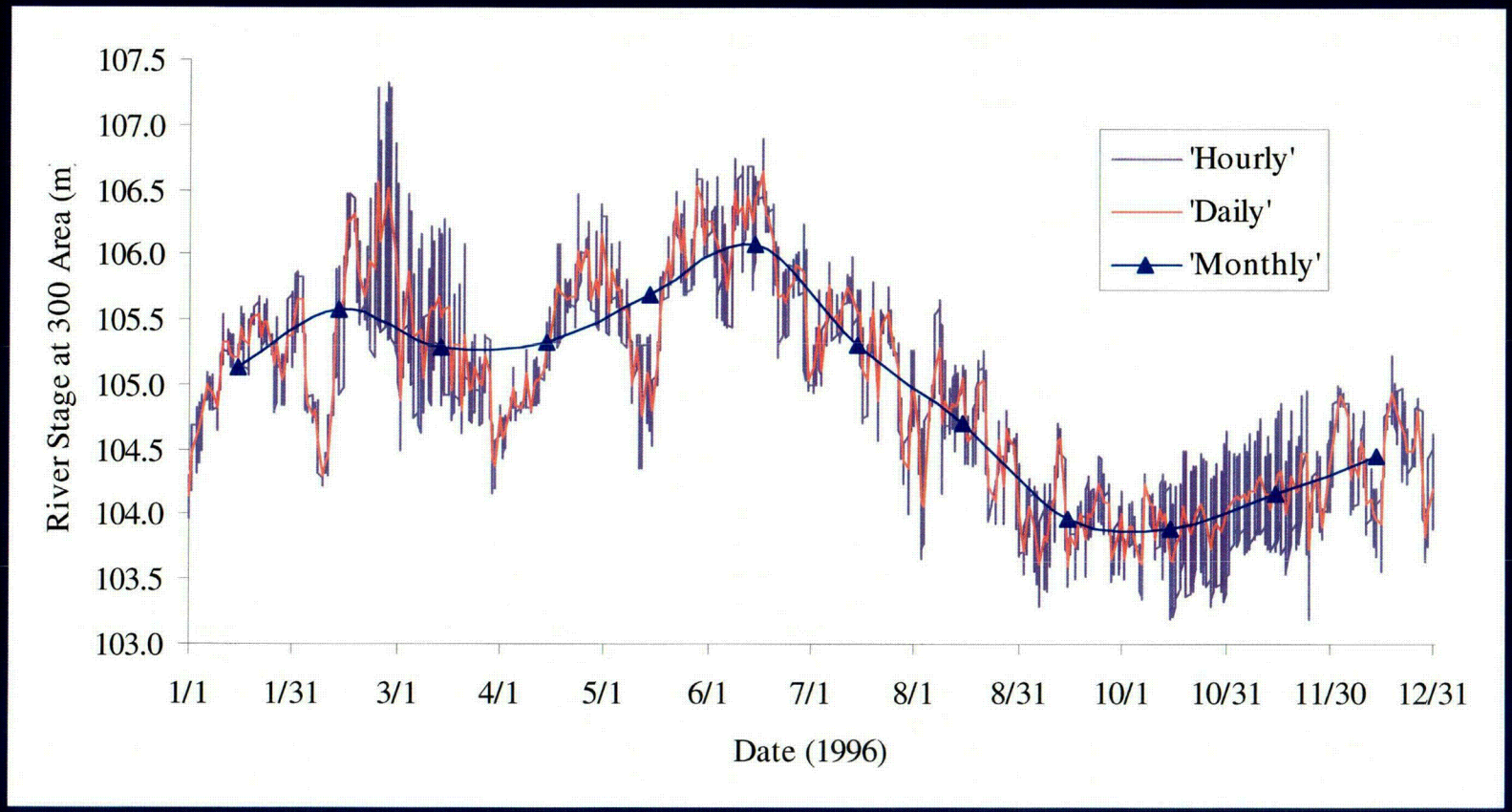
Generic Technical Issues

- ***When to monitor*** is defined by the system behavior (i.e., event and processes' timescales) and PA model assumptions to be tested:

identify timescales for events and processes of:

- ✓ facility release events
- ✓ dynamic processes in interface zone (e.g., percolation)
- ✓ environmental processes (e.g., unsaturated-saturated zone processes, surface- and ground-water interaction)

Temporal Scales for River-Level Fluctuations



from Meyer et al., 2006

Generic Technical Issues

- ***How to monitor*** relates to the ability to properly select, and capabilities of monitoring systems and instrumentation.

- EPA, NGWA, SSSA, ASTM and USGS guidance exists

- Innovative technologies such as fiber optics and geophysical methods evolve from performance and model analysis criteria (e.g., geochemical indicators and GIS-based indicators)

Opportunities to Build Confidence in Models (after Philip Meyer, PNNL)

Can monitoring strategies be improved by considering uncertainties in parameters, conceptual models, and scenarios?

- maximize probability of detecting contaminants while minimizing the number of monitoring wells
- since model probability is conditioned on observations, monitoring strategies should be designed to obtain observations that improve estimates of model uncertainty
- consider conceptual uncertainty initially in monitoring design
- identify important monitoring locations and data as input to PA models for parameter estimation, model calibration and uncertainty analyses

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Advanced Environmental Solutions, A Strategy for Ground-Water Monitoring of NRC-Licensed Facilities and Sites, Lexington, SC, 2006

Chien, C.C. et al., Barrier Systems for Environmental Contaminant Containment and Treatment, CRC-Taylor and Francis Group, Boca Raton, FL, 2006

EPA, Performance Monitoring of MNA Remedies for VOCs in Ground Water, EPA/600/R-04/027, Cincinnati, OH, 2004

Meyer, P. et al., Combined Estimation of Hydrogeologic Conceptual Model and Parameter Uncertainty, NUREG/CR-6843, U.S. Nuclear Regulatory Commission, Washington, DC, March 2004

EPA National Air and Radiation Environmental Laboratory Web site http://www.epa.gov/narel for Environmental Radiation Data Reports

Performance Monitoring and Sustainability of Engineered Covers for Uranium Mill Tailings

ACNW WG Meeting on Integrating Monitoring and Models
To Enhance Confidence in Model Results

September 19-20, 2006

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S.M. Stoller Corporation*
Office of Legacy Management
U.S. Department of Energy
Grand Junction, Colorado

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Alternative Cover Assessment Project

Collaborators:

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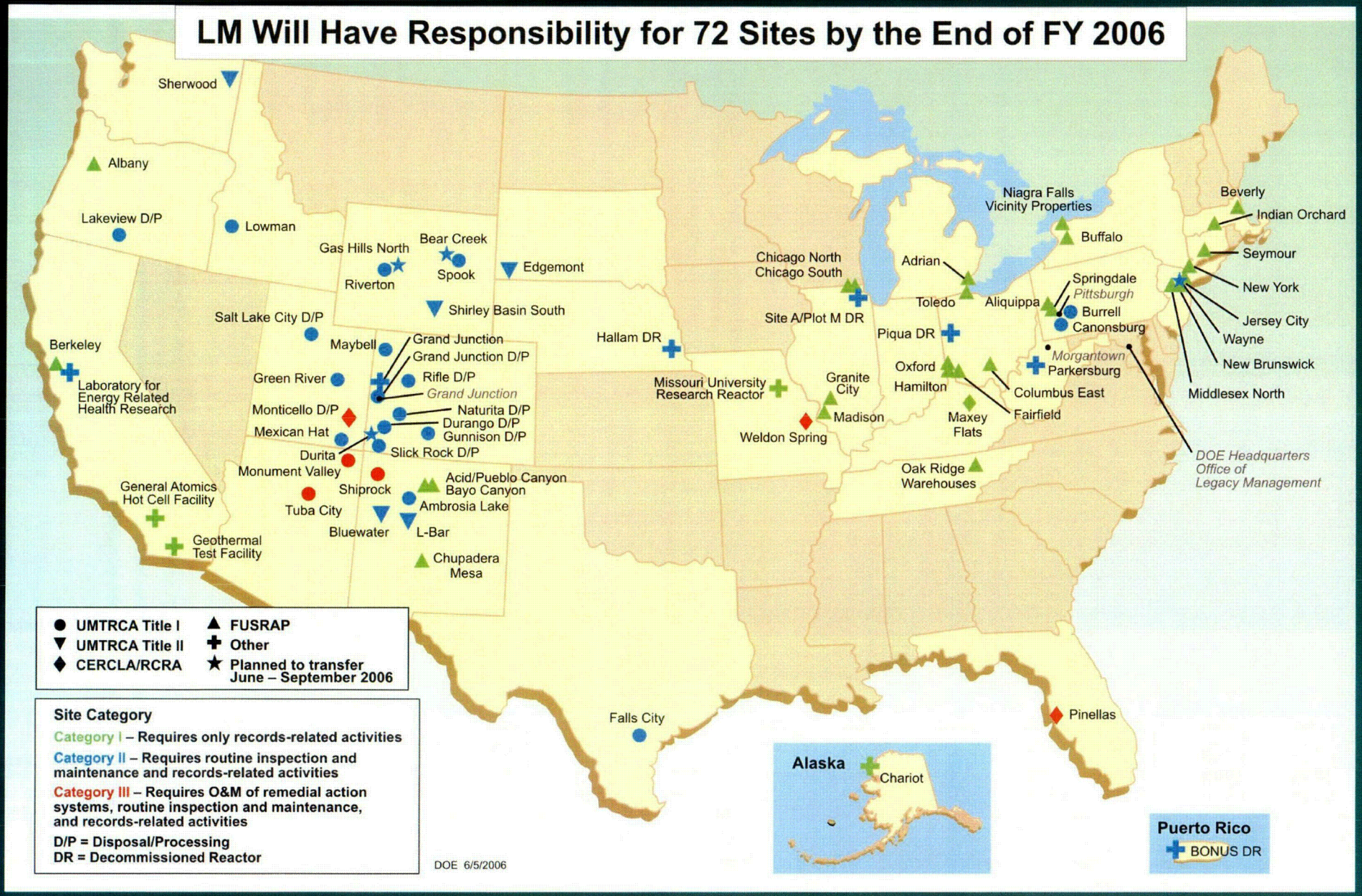
Craig Benson, University of Wisconsin

Bill Albright, Desert Research Institute

Cliff Ho, Sandia National Laboratory

Daniel B. Stephens & Associates, Inc.

DOE Office of Legacy Management (LM) Sites



Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- What and how do we monitor to show that it is working?
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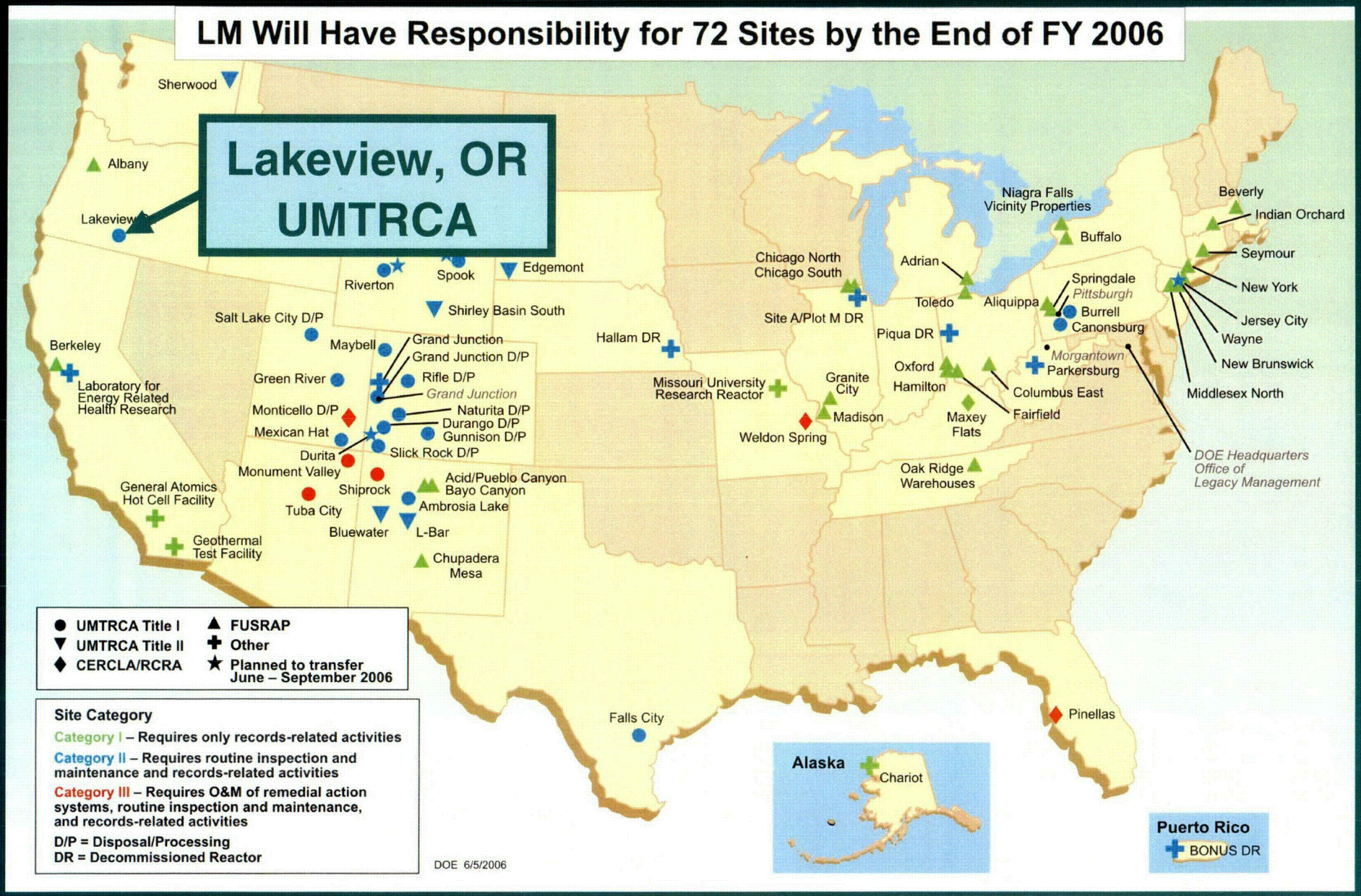
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

Lakeview Case Study



Site Transfer to LM: Cover Stewardship Questions

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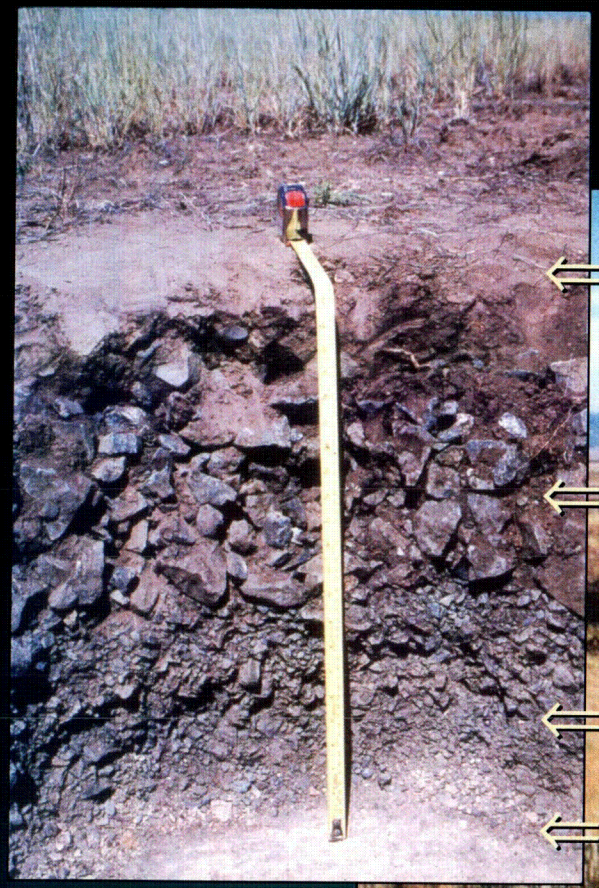
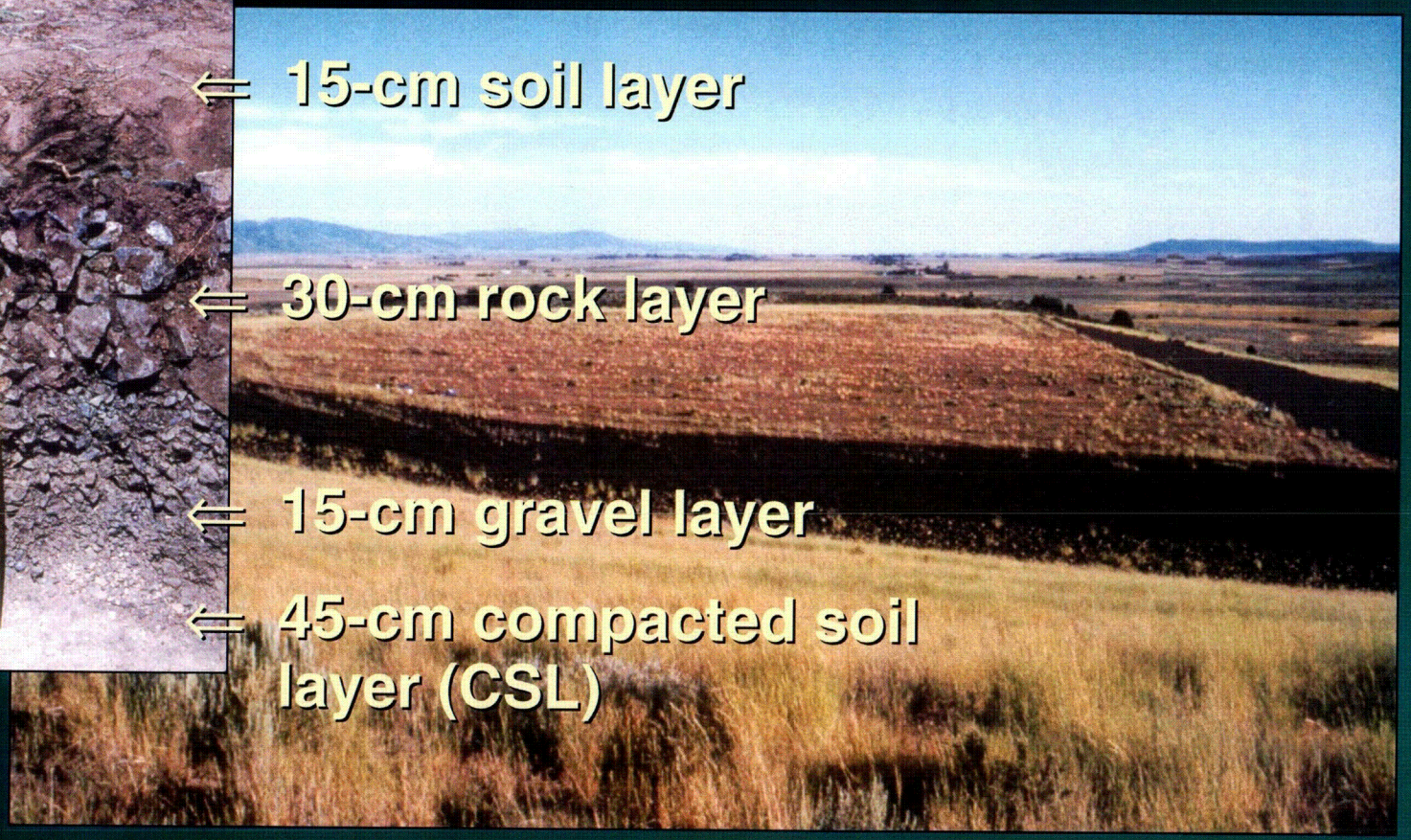
How was the cover designed and constructed?

Lakeview, OR
Precip. ~ 380 cm/yr





⇐ 15-cm soil layer

⇐ 30-cm rock layer

⇐ 15-cm gravel layer

⇐ 45-cm compacted soil layer (CSL)

Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- **How is it supposed to work?**
- What and how do we monitor to show that it is working?
- What types of maintenance are required (and at what cost) to keep it working as designed?
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

How is it supposed to work?
(Design Standards)

Permeability (40 CFR 264.301, 40 CFR 192)

- Satisfy ground water protection standards
- $< 1 \times 10^{-7}$ cm s^{-1} maximum K_{sat} and flux rate (target)

Longevity (40 CFR 192)

- 1000 years to the extent reasonably achievable
- At least 200 years

Site Transfer to LM: Cover Stewardship Questions

- How was the cover designed and constructed?
- How is it supposed to work?
- **What and how do we monitor to show that it is working?**
- What types of maintenance are required (and at what cost) to keep it working as designed?
- What are the *risks* if its not working as designed?
- Could we design sustainable repairs or renovations *if needed*?
- Can we expect the cover to continue working for 200 to 1000 years?

What and how do we monitor to show that it is working?

Routine cover monitoring <u>not required</u> by NRC!

Ground Water Monitoring

- Monitor POC wells every 5 years
- Demonstrate compliance with GW protection standards
- *Measure of the performance of the disposal cell*

Annual *Visual* Inspections

- *Identify changes or new conditions that may impact long-term performance of disposal cells*
- *Determine need for maintenance, follow-up investigations, or corrective actions*

Follow-up Investigations
(non-routine monitoring)

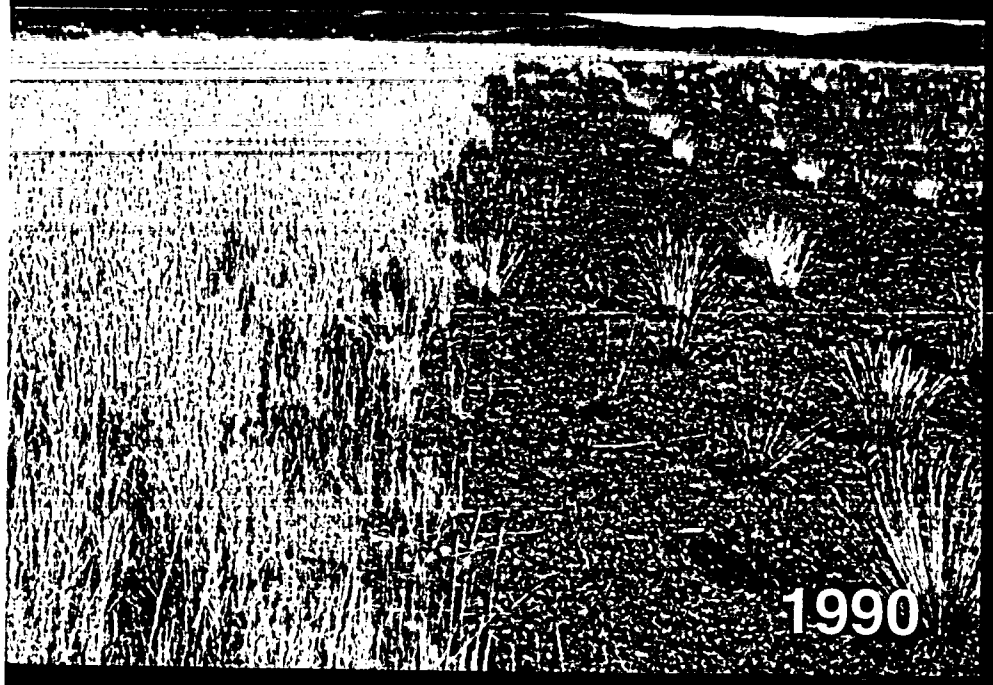
Objective:

Identify changes or new conditions that may impact long-term performance of disposal cells

Observations / Issues:

- Encroachment by Deep-Rooted Shrubs
- Effects on cover *permeability*, radon flux, bio-uptake

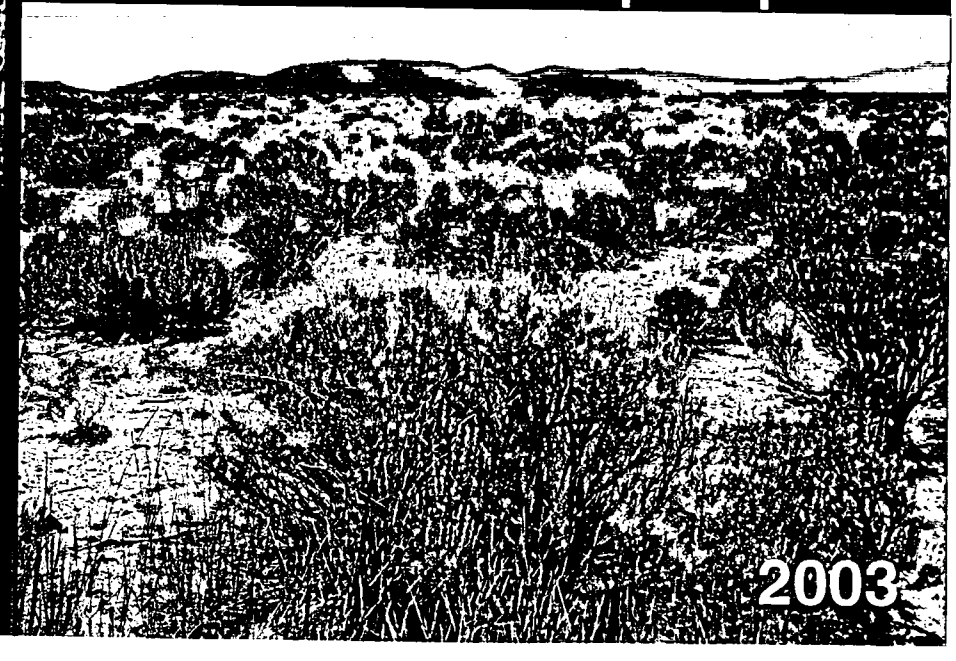
Shrub Encroachment Observations



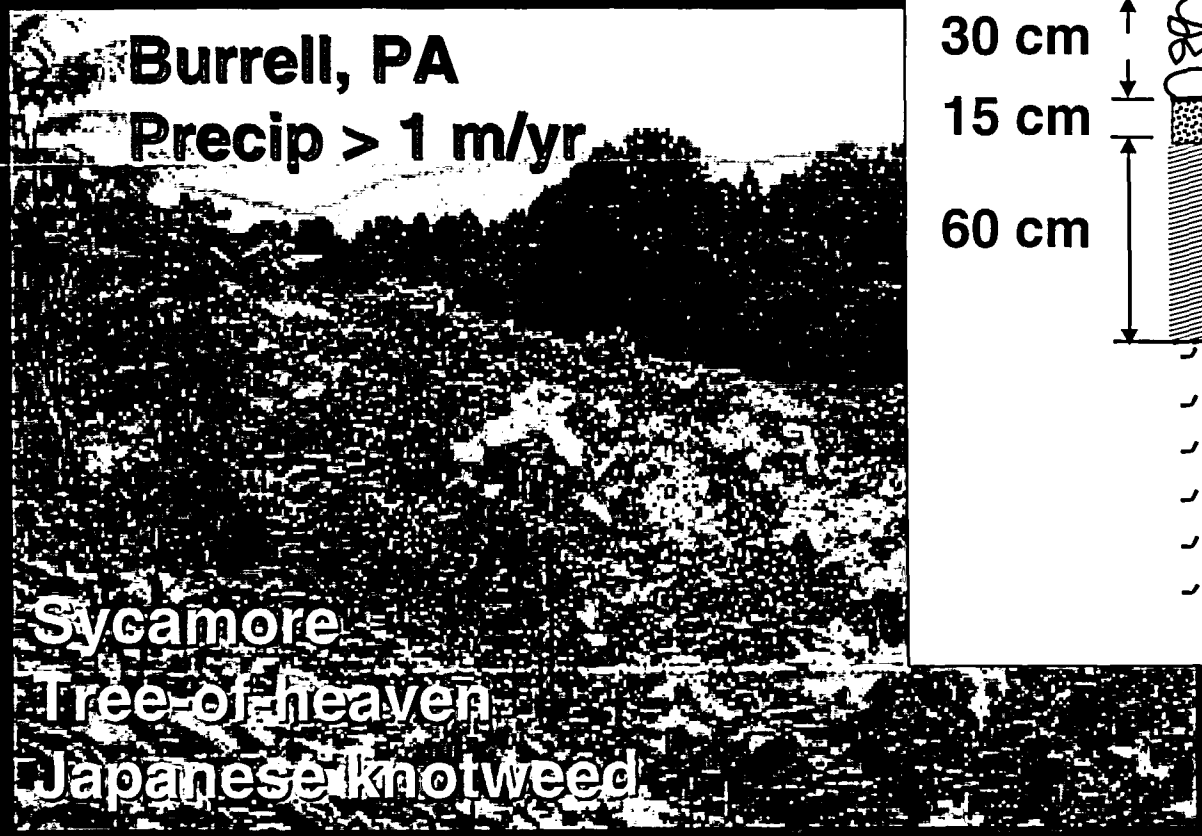
Sparse grass on top slope

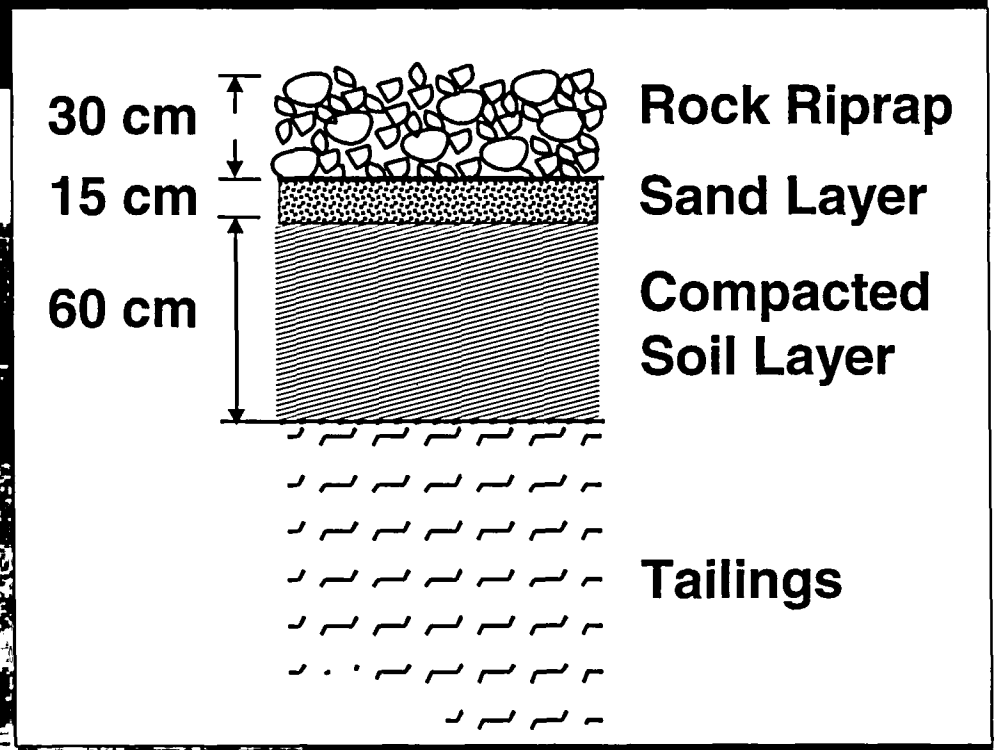
Thin soil over rock created habitat for deep-rooted shrubs

Sagebrush and rabbitbrush encroachment on top slope

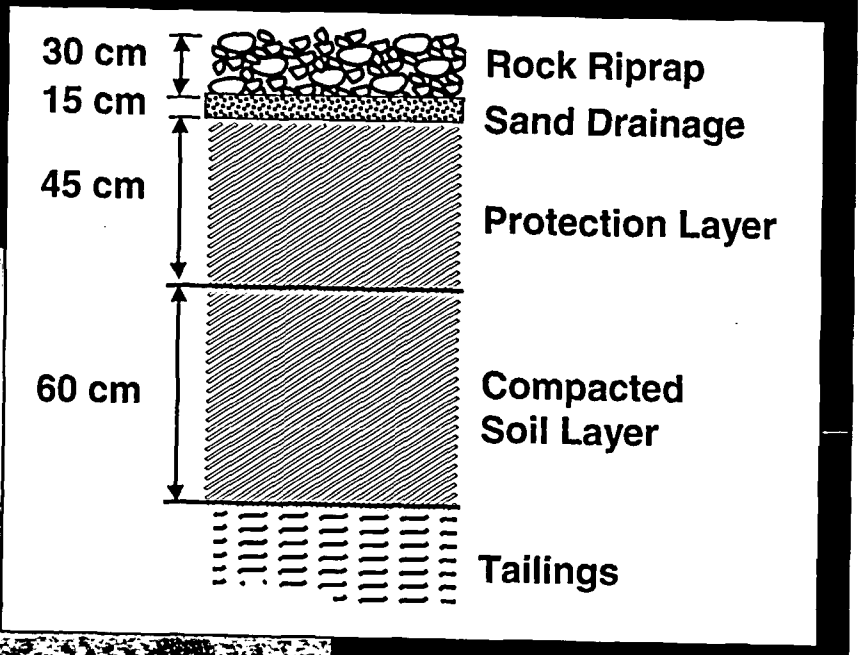


Shrub Encroachment: Burrell, PA





Shrub Encroachment: Grand Junction, CO



Shrub Encroachment: Follow-up Investigations

Root Intrusion: Are roots penetrating the compacted soil layer (CSL)?

↓

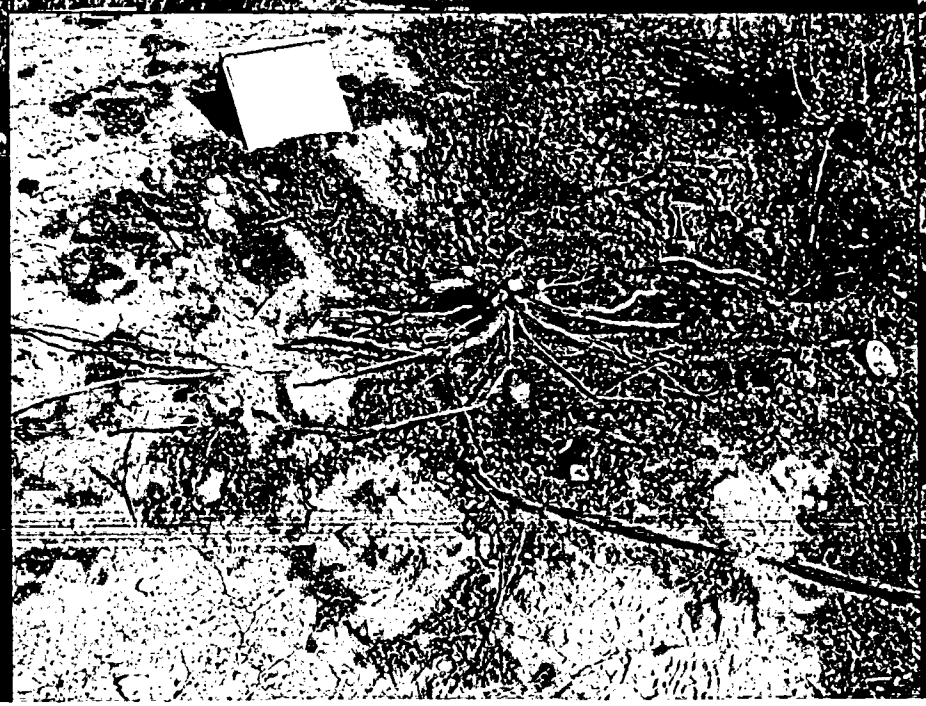
Permeability: Has root intrusion increased the saturated hydraulic conductivity (K_{sat})?

↓

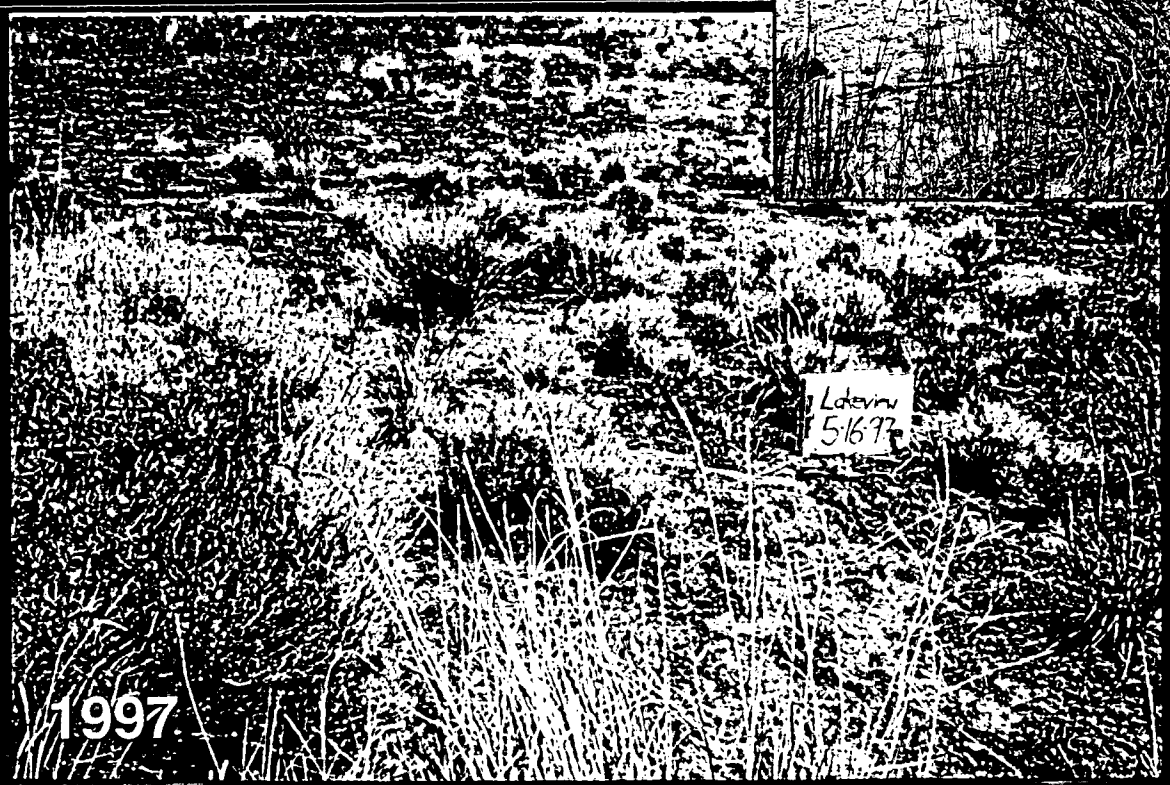
Percolation: Has greater permeability caused significant movement of rainwater into tailings?

Lakeview Sagebrush Root Intrusion

Sagebrush root intrusion of CSL



Shrub Recruitment



Sagebrush,
Rabbitbrush,
Antelope bitterbrush

Permeability

Objective

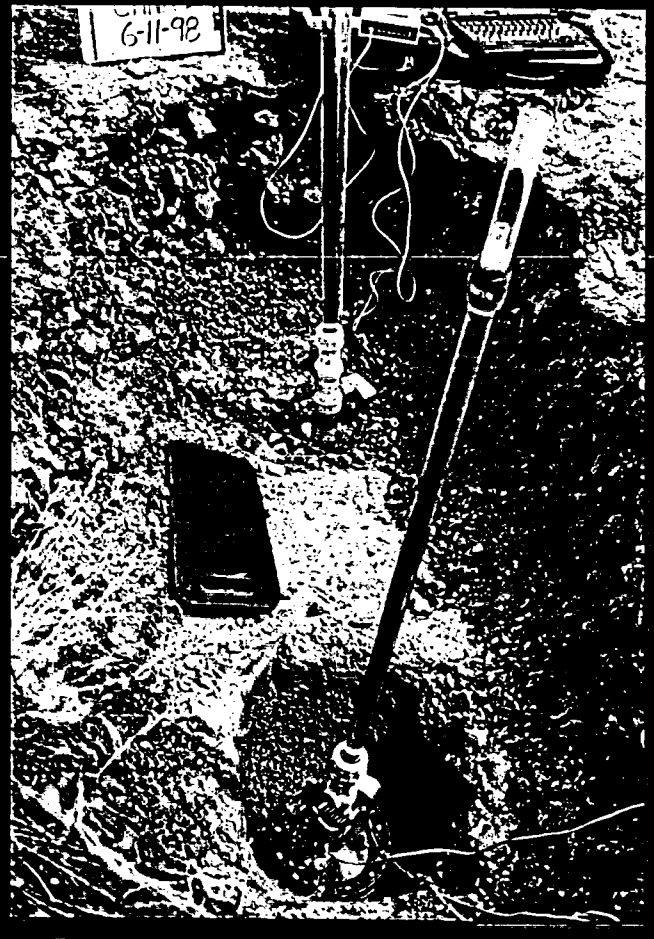
Measure root intrusion effects on saturated hydraulic conductivity (K_{sat}) of the CSL

Tests

- Measure K_{sat} with air-entry permeameters (DBSA)
- Compare CSL K_{sat}
  - with and without roots
  - top slope and side slope
  - upper and lower CSL

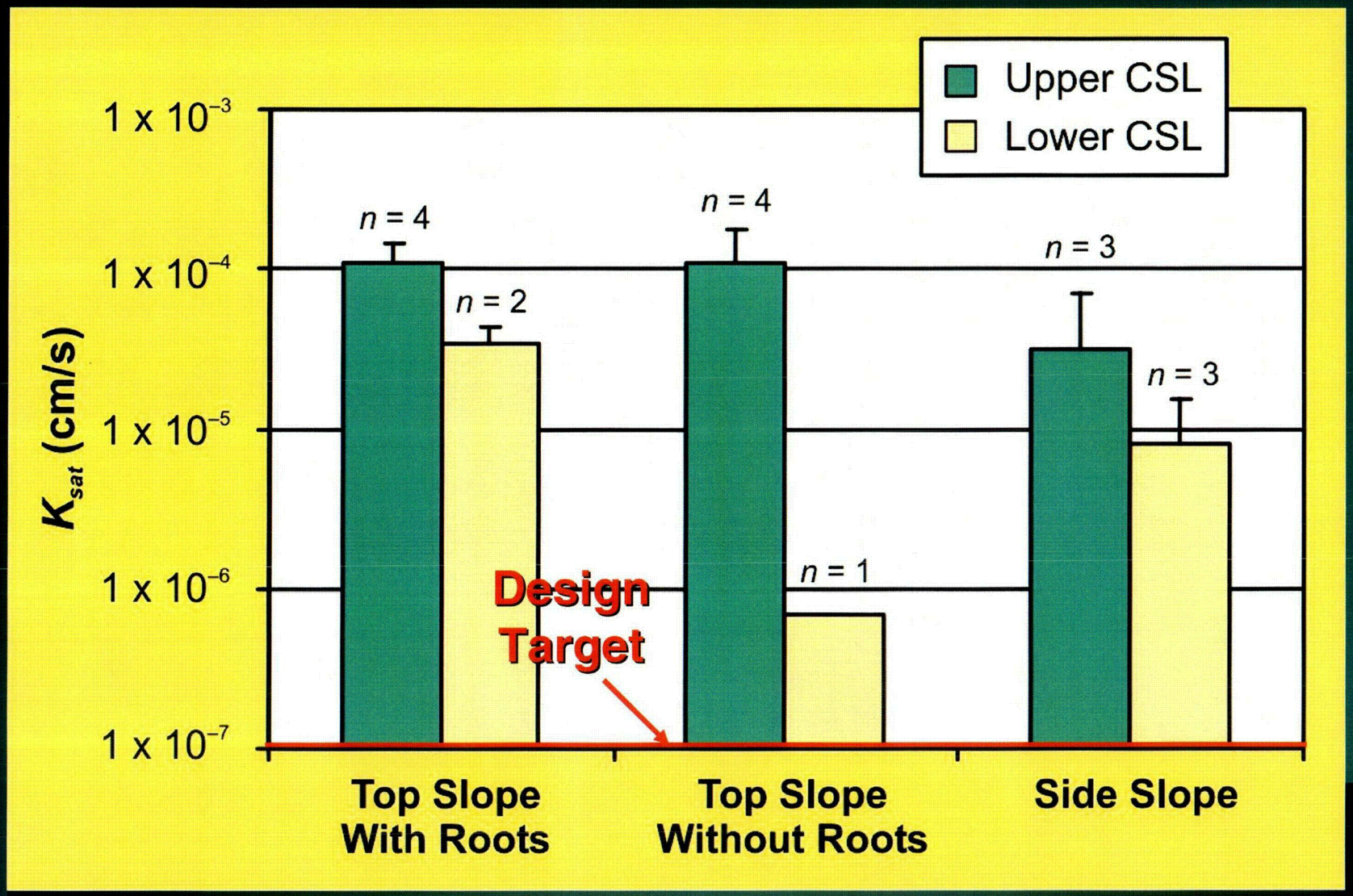
K_{sat} Measurement: Air-Entry Permeameters (AEP)

Manual AEP on side slope

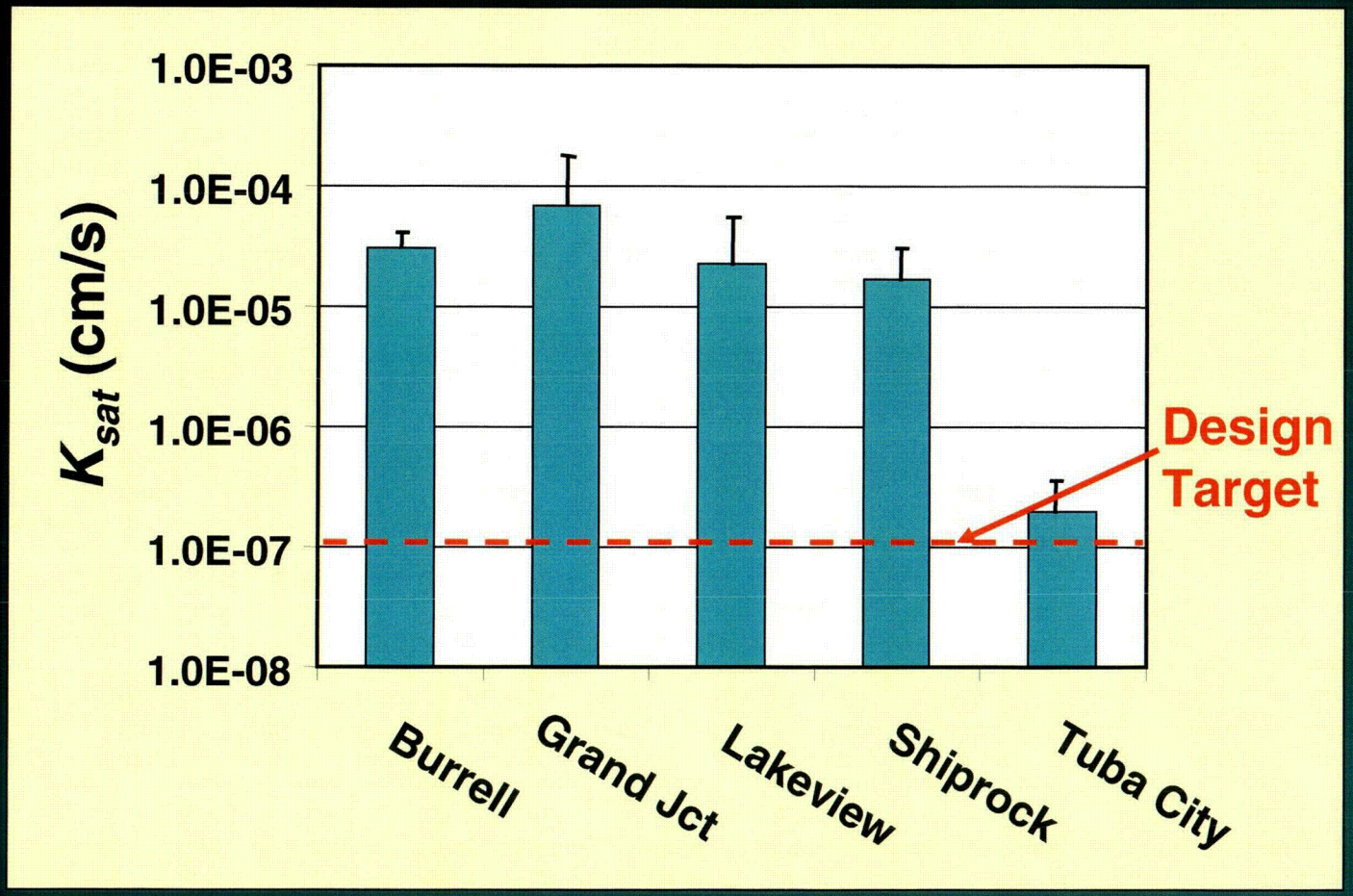


Automated AEPs on top slope

Lakeview — K_{sat} Results



K_{sat} Results: Comparison with Other Sites



Permeability

Likely causes of preferential flow in CSLs

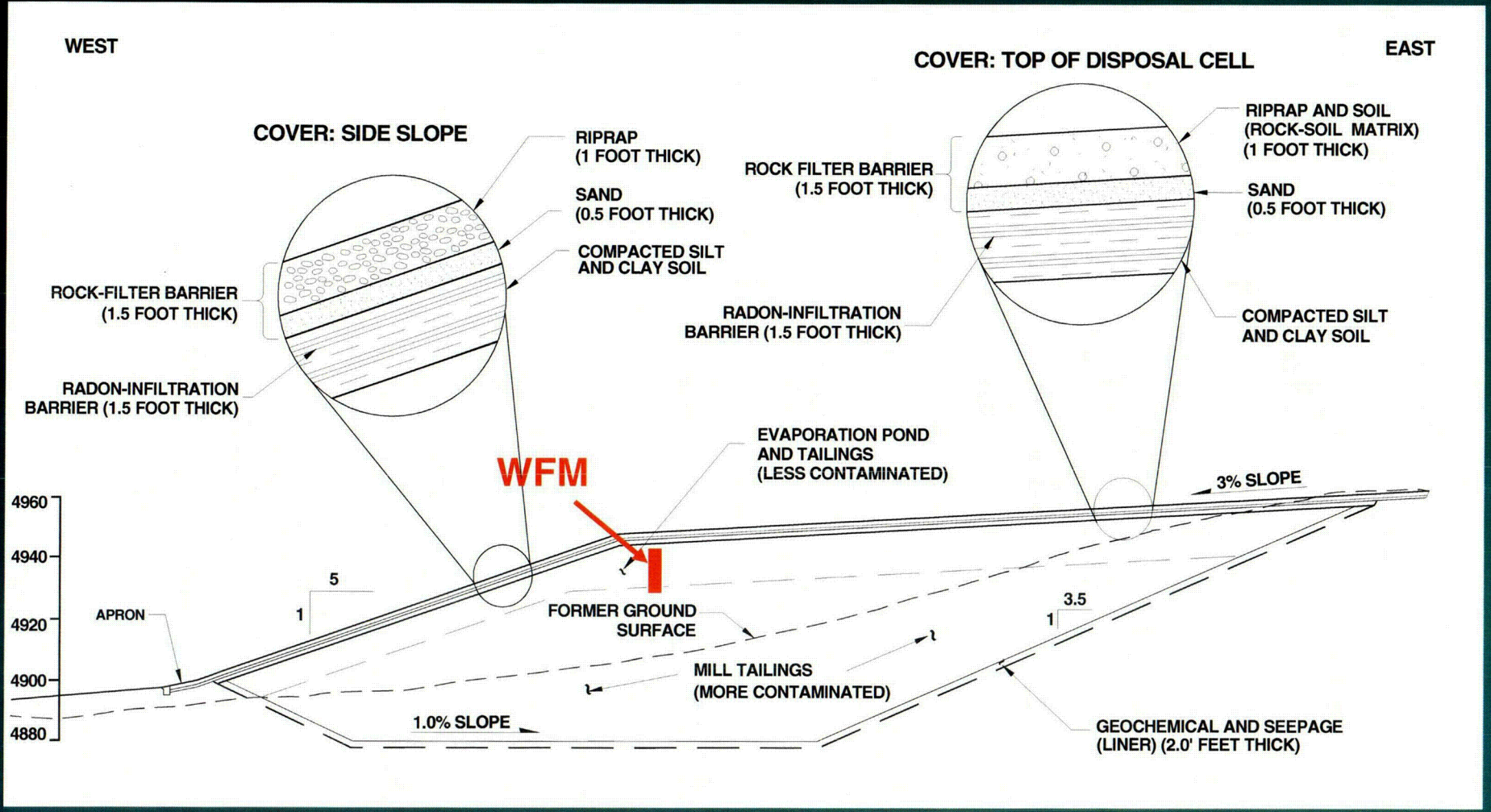
- Soil structure in CSL developing faster than expected
- Plant roots and burrowing/tunneling animals
- Freeze-thaw cracking and desiccation
- *Well-developed structure of borrow soils*

Test dye at structural planes

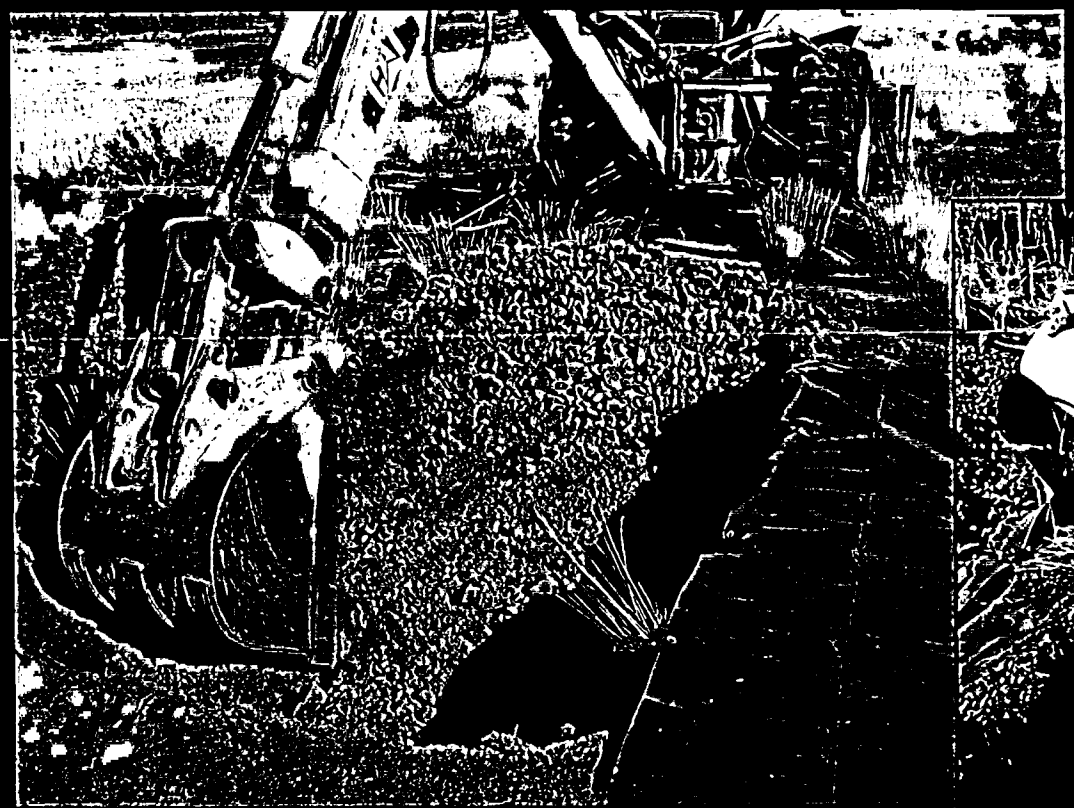
Sagebrush roots in CSL

Percolation
Water Flux Meters (PNNL wicking lysimeters)

Down-gradient locations on cover topslope



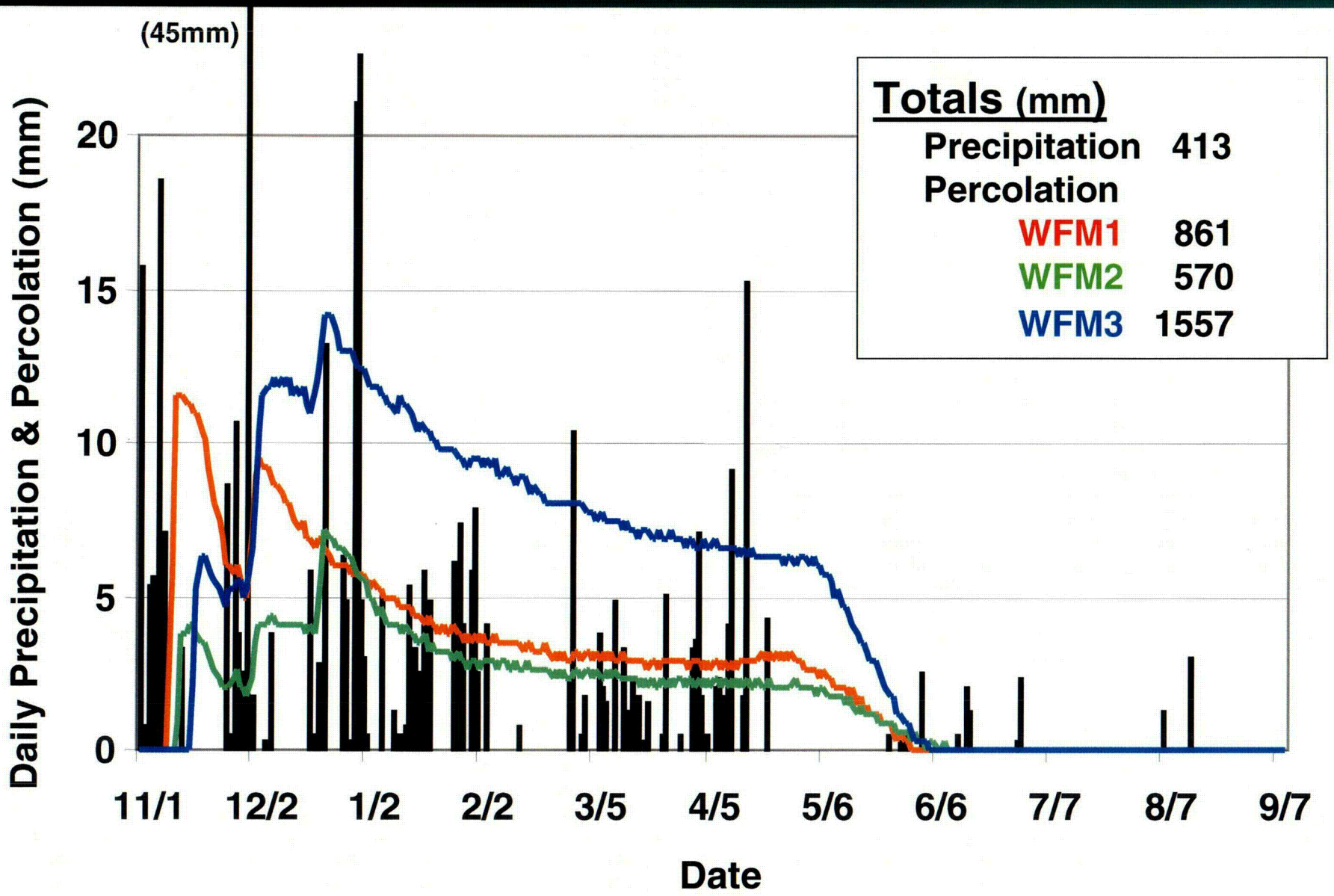
Water Flux Meter Installation



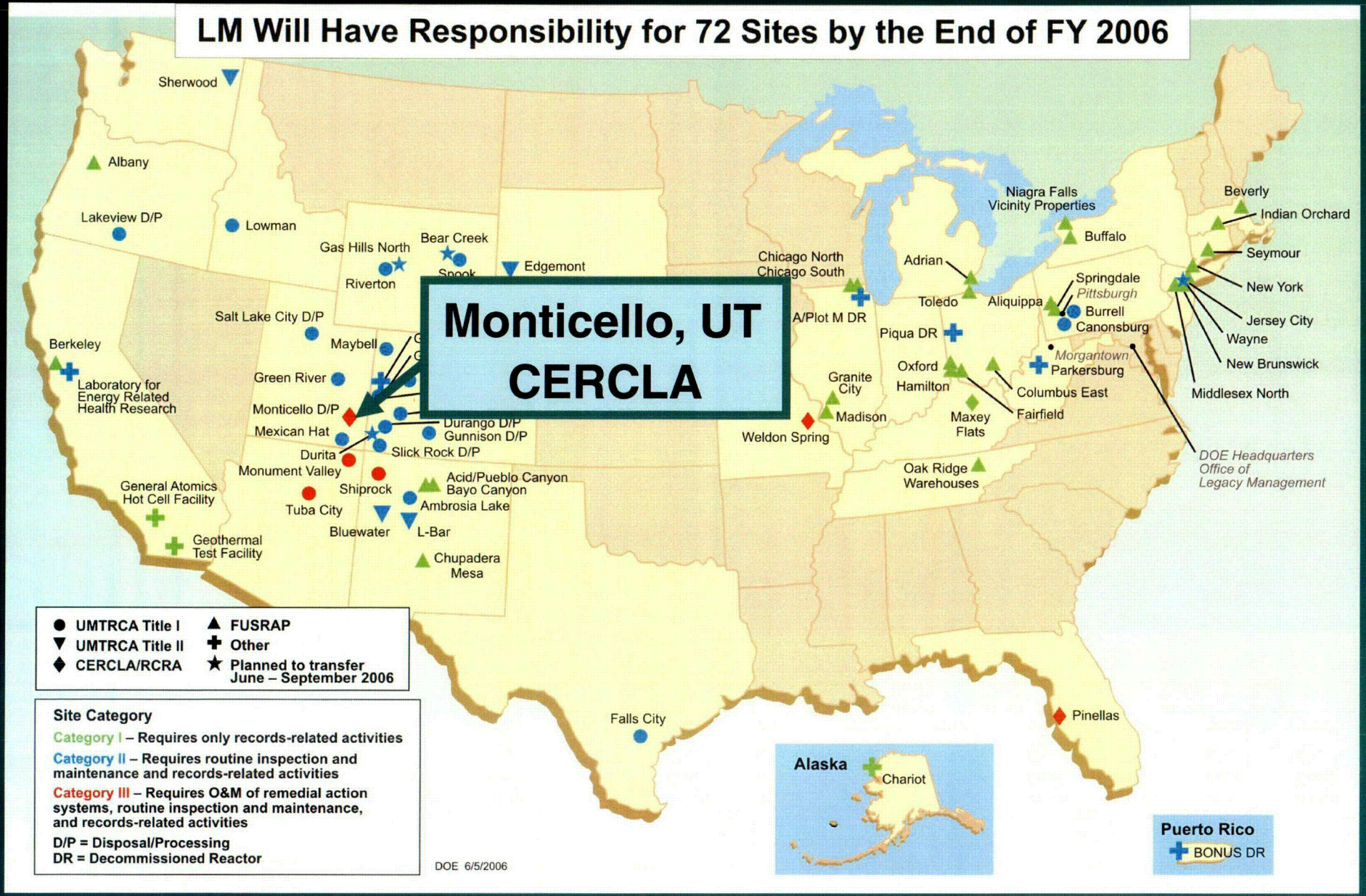
Flux meters installed
just below CSL in top slope

Pits opened:
- 3 on top slope
- 2 on side slope

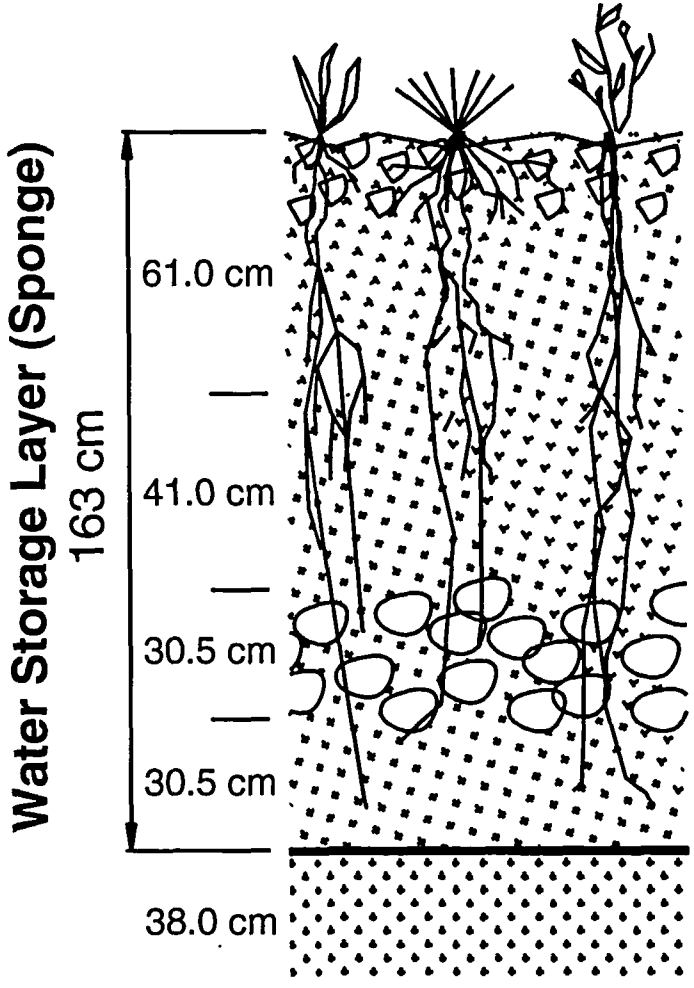
Lakeview: Water Flux Meter Results



Monticello, Utah, Superfund Site
(Alternative Cover)



Monticello Alternative Cover Design: ET / Capillary Barrier



Vegetation (ET)

Gravel Admixture in Upper 20 cm

Topsoil

Growth Medium and Frost Protection (Fine-Grained Soil)

Animal Intrusion Layer (Cobbles Filled w/ Soil)

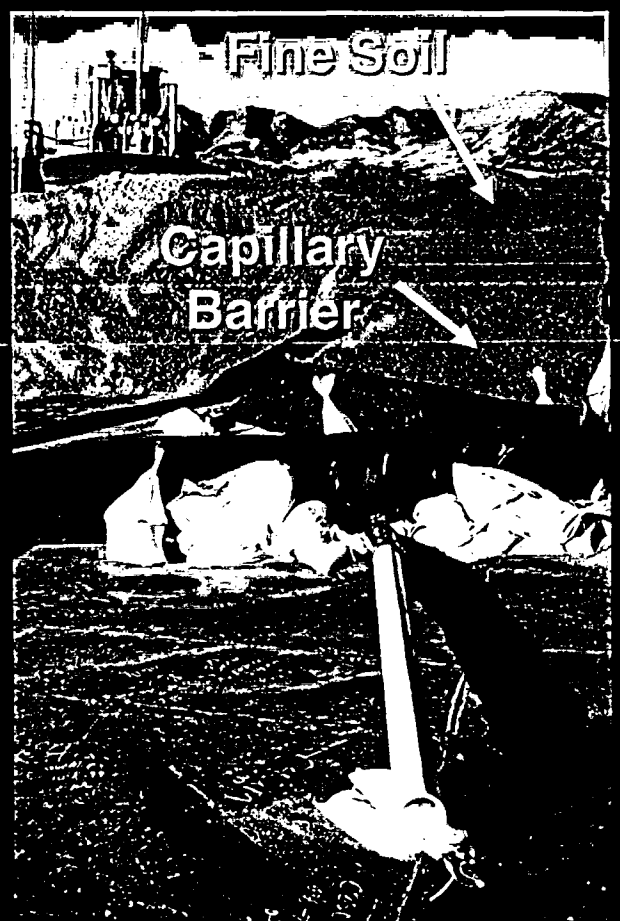
Fine-Grained Soil

Geotextile Separator

Capillary Barrier (Coarse Sand)

Embedded Lysimeter Instrumentation

(3-hectare lysimeter)

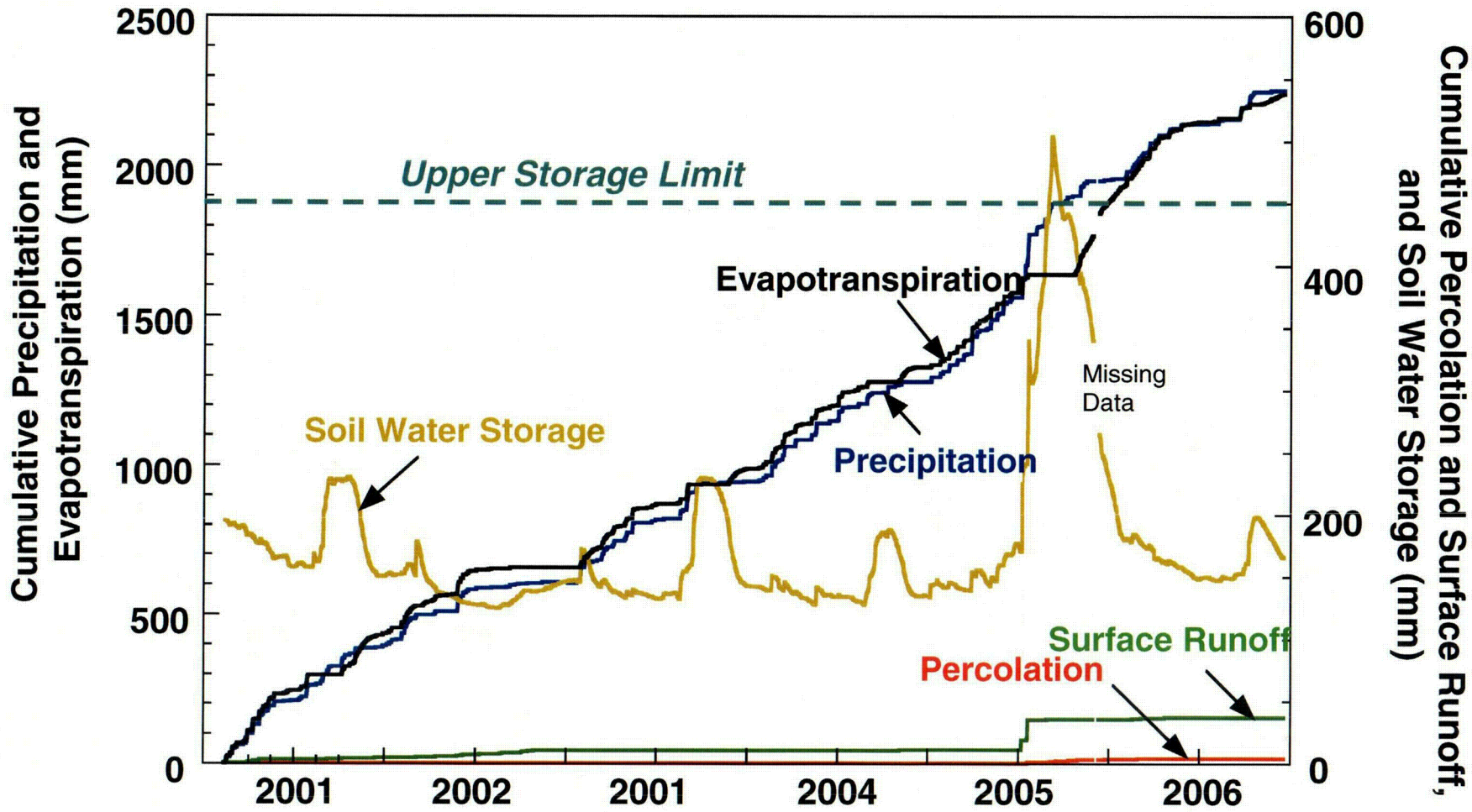


Drainage collection system

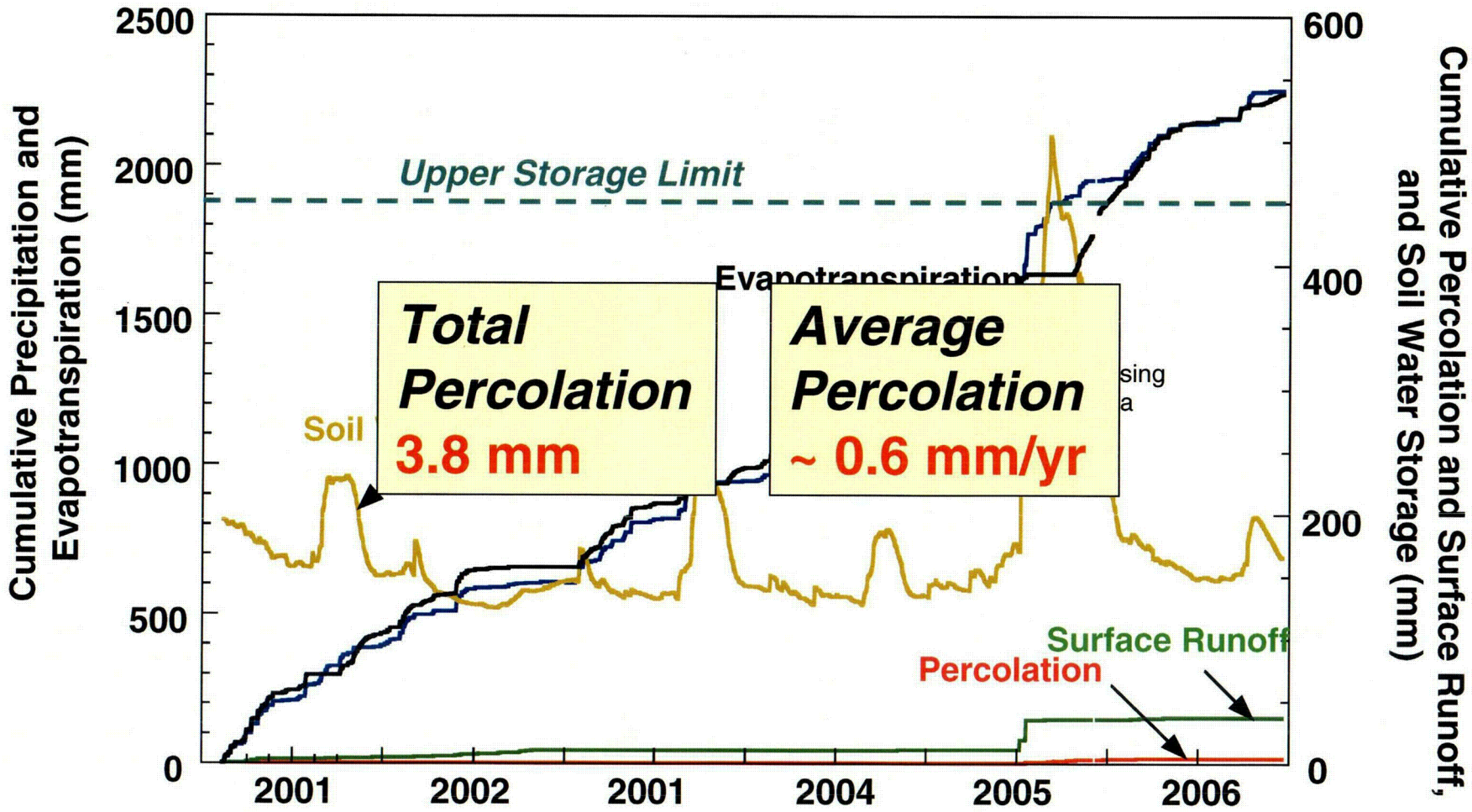
Drainage and Runoff:
Dosing siphons

Soil Moisture Nests:
- Water content TDR
- Water potential HDU

Embedded Lysimeter Water Balance



Embedded Lysimeter Water Balance



Site Transfer to LM: Cover Stewardship Questions

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- **Could we design sustainable repairs or renovations *if needed*?**
- Can we expect the cover to continue working for 200 to 1000 years?

Could we design sustainable repairs or renovations if needed?

Lakeview:
Shrub encroachment may be the *solution*, not the *problem*!

LTS&M Vegetation Management Options:

- Control plant growth
- Let them grow
- Facilitate beneficial ecological succession (*cover renovation*)

Without intervention, Mother Nature will eventually transform low-permeability covers into ET-type covers.

Site Transfer to LM: Cover Stewardship Questions

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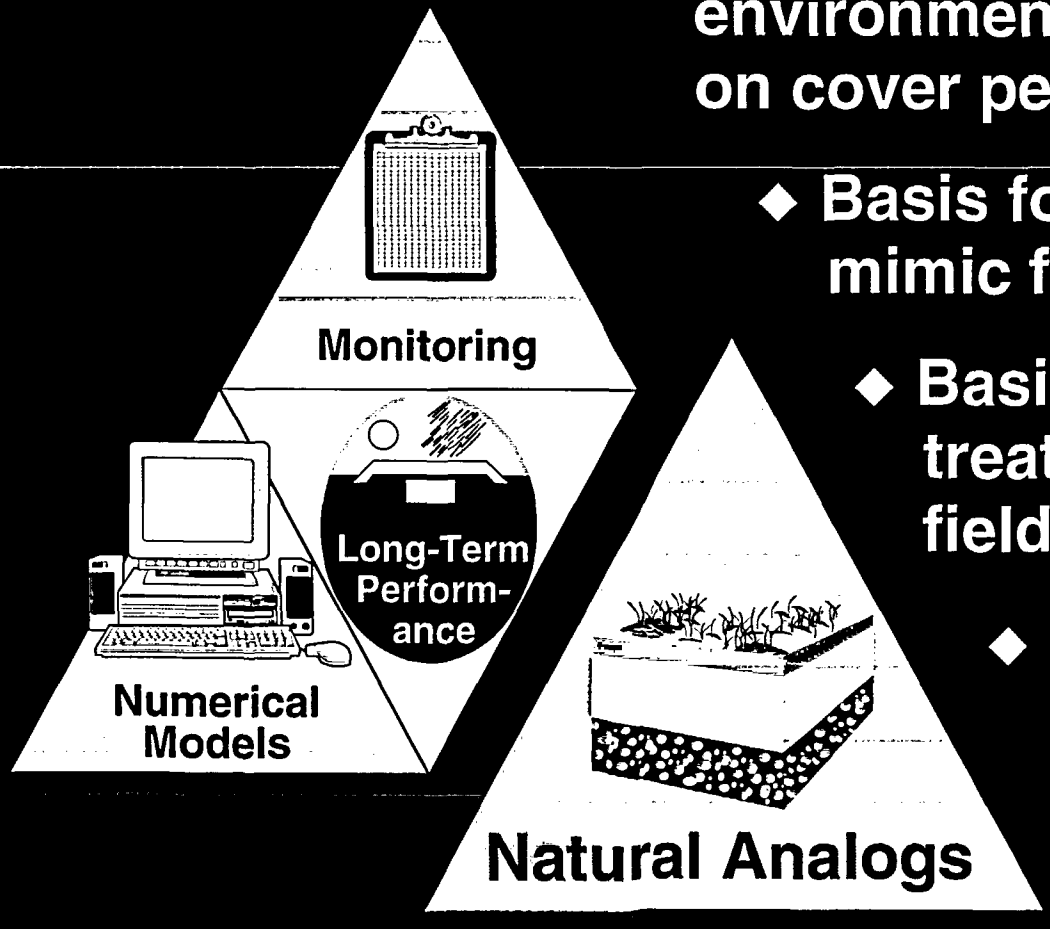
Long-Term Performance Evaluation Tools

Role of Natural Analogs



- Tangible clues about future environmental conditions and effects on cover performance
- Basis for designing covers that mimic favorable natural settings
- Basis of hypotheses and treatments for short-term field studies (e.g. lysimeters)
- *Basis for inferring future environmental scenarios for input to models*

Risk-Based Performance Modeling Process

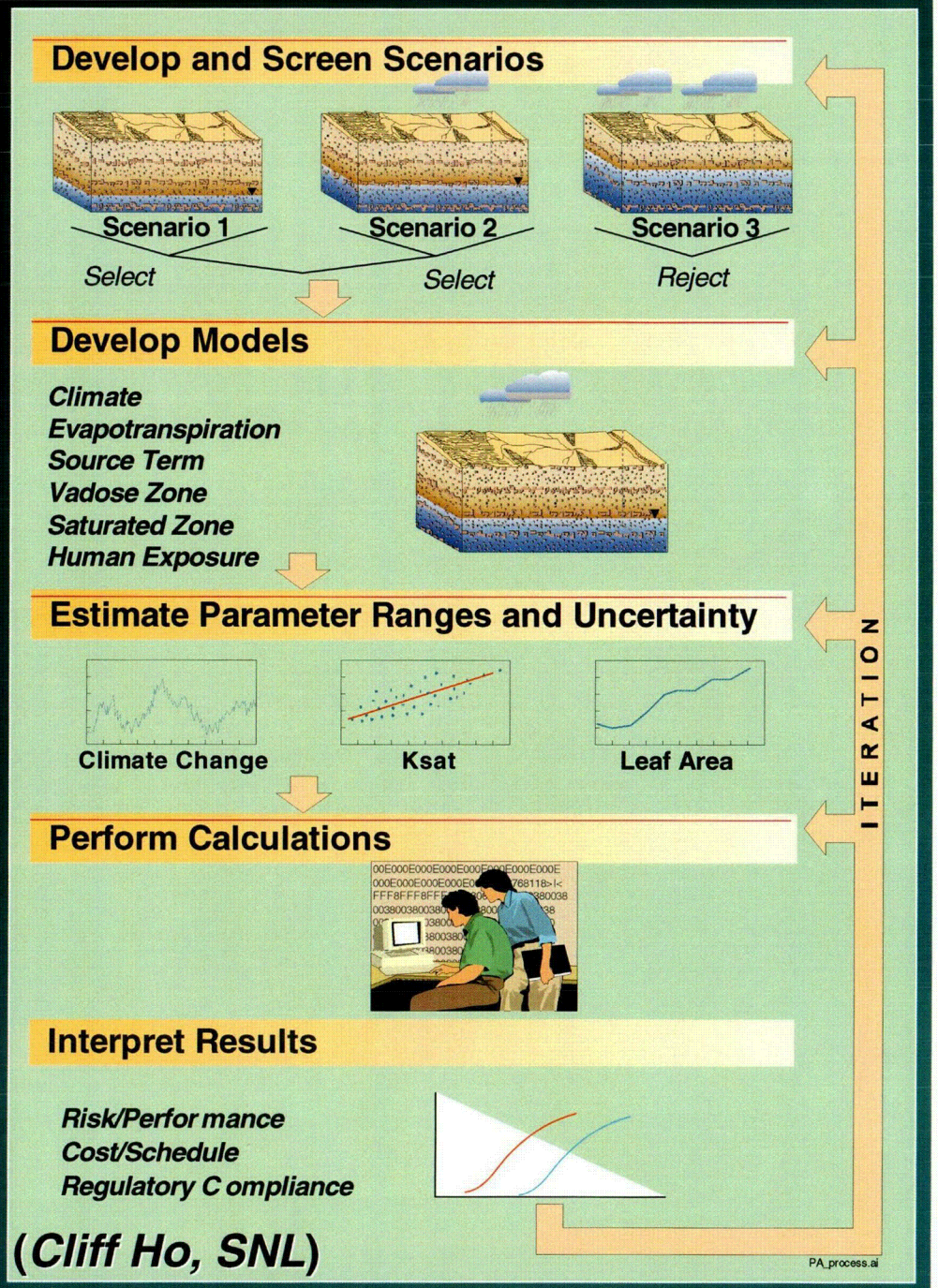
Natural Analog Data

- Develop scenarios for modeling future performance
- Estimate parameter ranges and uncertainty

Demonstration

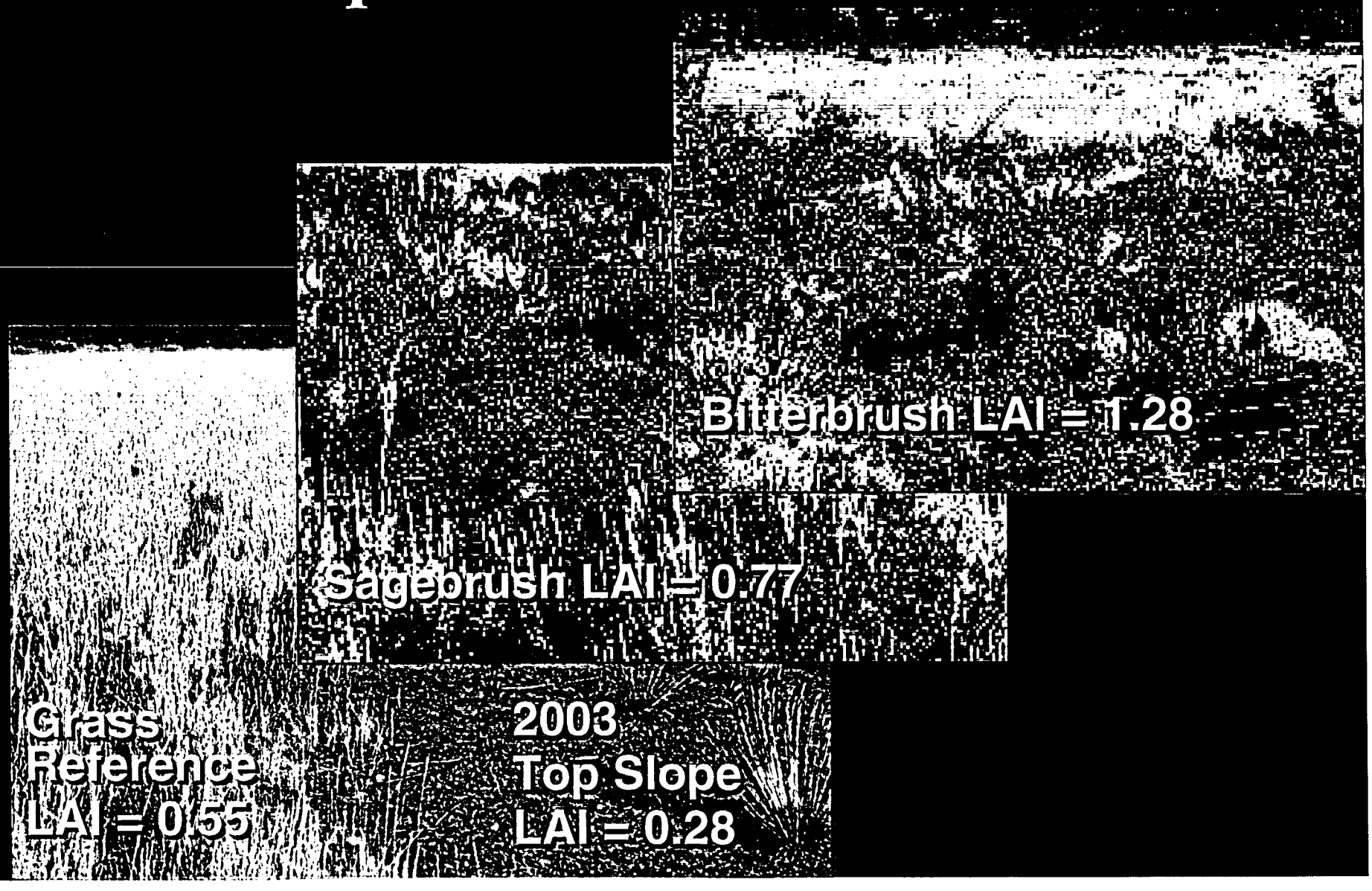
FRAMES (PNNL)

- Probabilistic modeling platform
- Links cover water flux, source-term release, vadose-zone transport, saturated-zone transport, & exposure pathways
- Uncertainty/sensitivity analyses used to identify important monitoring parameters

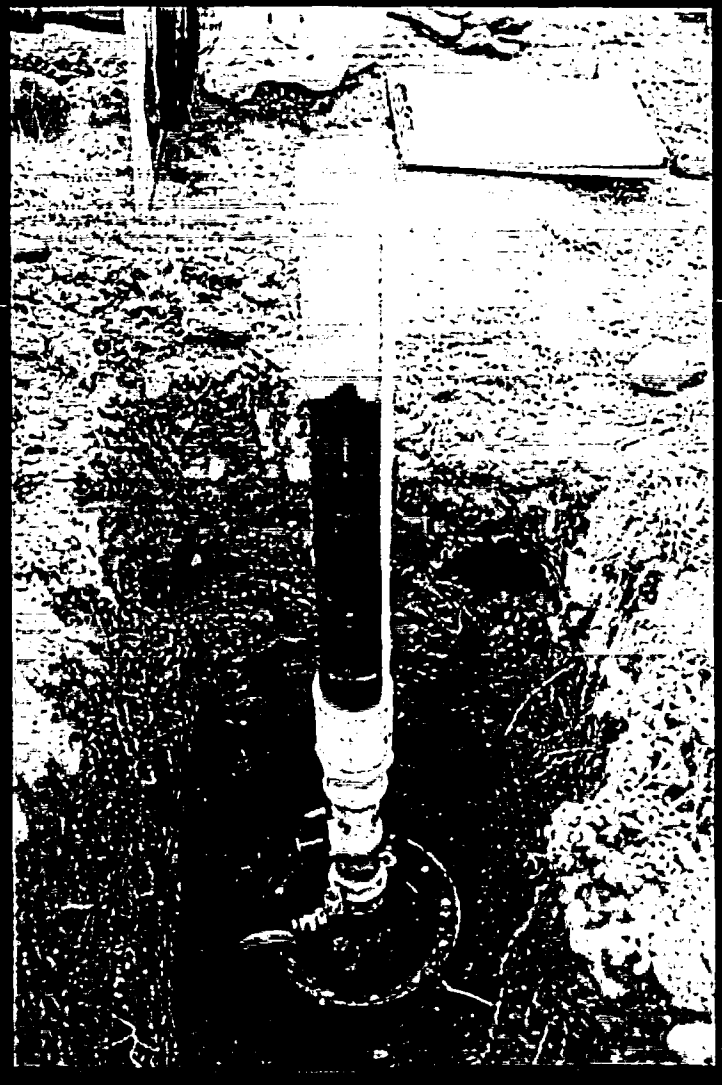


(*Cliff Ho, SNL*)

Lakeview Leaf Area Index (LAI) Chronosequence



Lakeview Soil Analog: Permeability



Air-entry permeameter measurements of K_{sat} in lake sediment soil profiles (borrow source)

K_{sat} 1.6×10^{-5} cm/s

8.2×10^{-5} cm/s

2.9×10^{-4} cm/s

Lakeview Climate Change: Wet and Dry Ecology Analogs

Lakeview Conifer Site, OR

Soil: Drews loam

Vegetation: Mixed conifer

LAI: 1.62

Guano Basin Site, NV

Soil: Spangenburg loam

Vegetation: Big sagebrush

LAI: 0.43

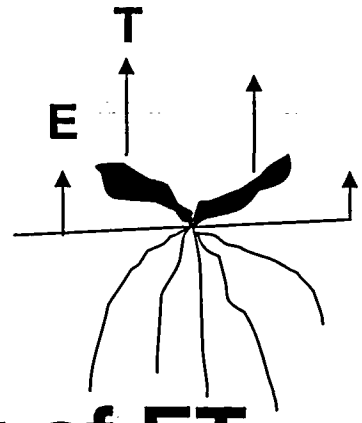
Addressing Focus Questions:

Summary

- Routine monitoring and modeling of cover performance are *not* required by NRC for DOE LM uranium mill tailings.
- Limited non-routine soil hydrology and ecology monitoring:
  - Older covers *not* performing as designed (modeled)
  - Monticello ET cover *is* performing as designed
  - Data not used for model improvement

Recommendations

- Monitor and model ecological and hydrological performance of covers as early warning of ground water non-compliance
- Use ecology and soil analog site data to develop scenarios for modeling long-term cover performance
- FRAMES improvements:
  - Use Richard's Equation model of unsaturated flow in cover
  - Link soil water balance with vegetation dynamics model (e.g. TerreSIM)
- Long-term instrumentation monitoring of covers not feasible



Monitoring and Modeling of ET Covers

Glendon W. Gee

Sept. 20, 2006

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Battelle

Outline

- ET Cover Concepts
- ET Monitoring and Modeling Needs
- Indirect Measurements
- Direct Measurements
- Modeling Issues
- Summary

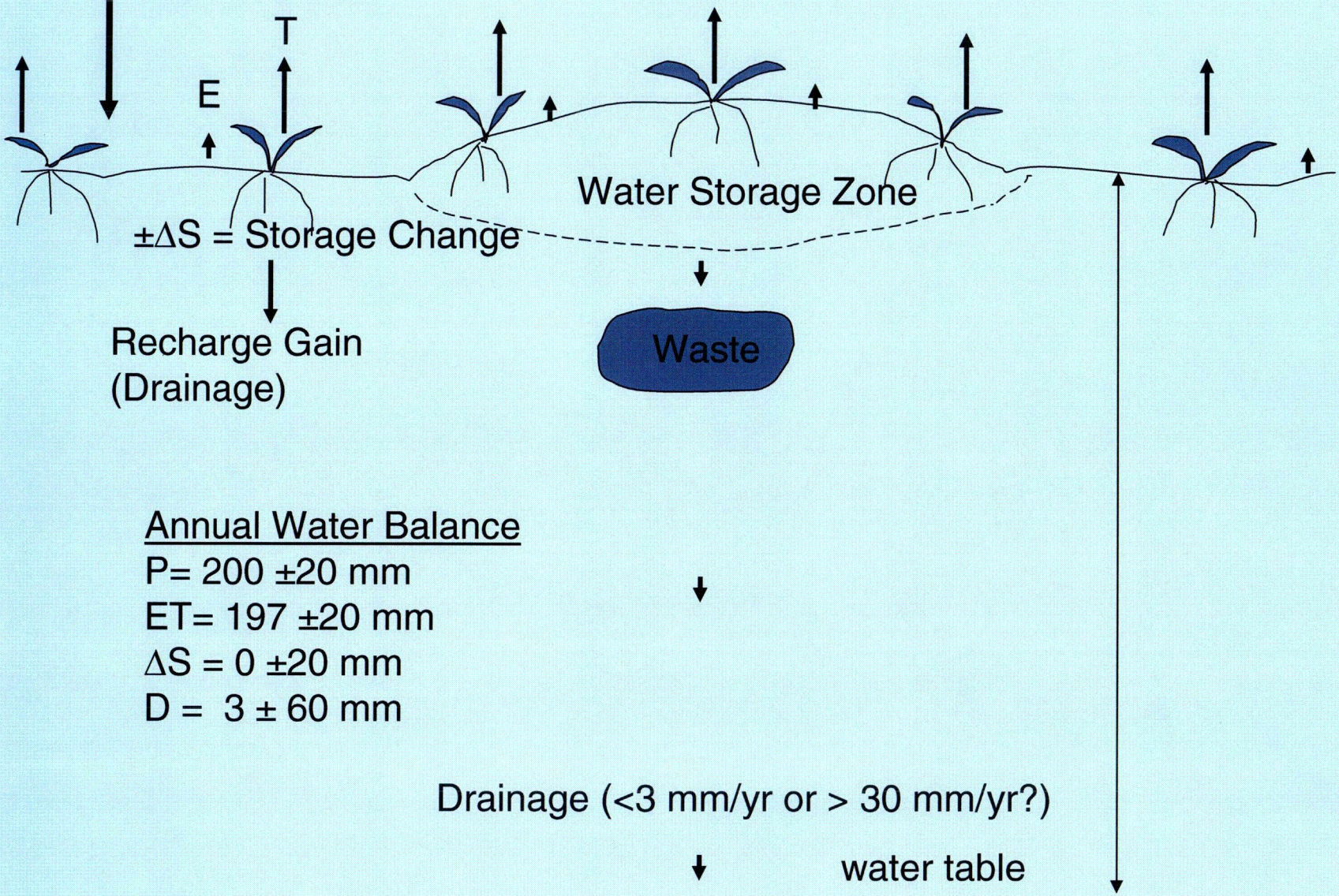
ET Cover Concepts

- Evapotranspiration (ET) limits water intrusion
- Virtually All Covers are ET covers (i.e.,vegetated)
- Multilayer ET Covers (RCRA, Hanford, etc.)
  - Provides Redundant Protection
  - Long-Term Performance Considered in Design
  - Cost Typically High (more engineering)
- Simple ET Covers (monofill soil with vegetation)
  - Water Infiltration Control
  - Biotic Dynamics and Intrusion Issues
  - Erosion and Long-Term Issues

Approach to ET Water Balance

- Drainage is Estimated from Mass Balance of Water Inputs/Losses from Soil Volume
- Model Inputs (with associated uncertainties) Include:
  - **Precipitation**
  - **Evaporative Demand (Climate and Surface)**
  - **Runoff Potential (Surface Characteristics)**
  - **Water Storage (Soil Hydraulic Properties)**

ET Cover



<u>Annual Water Balance</u>

P= 200 ±20 mm

ET= 197 ±20 mm

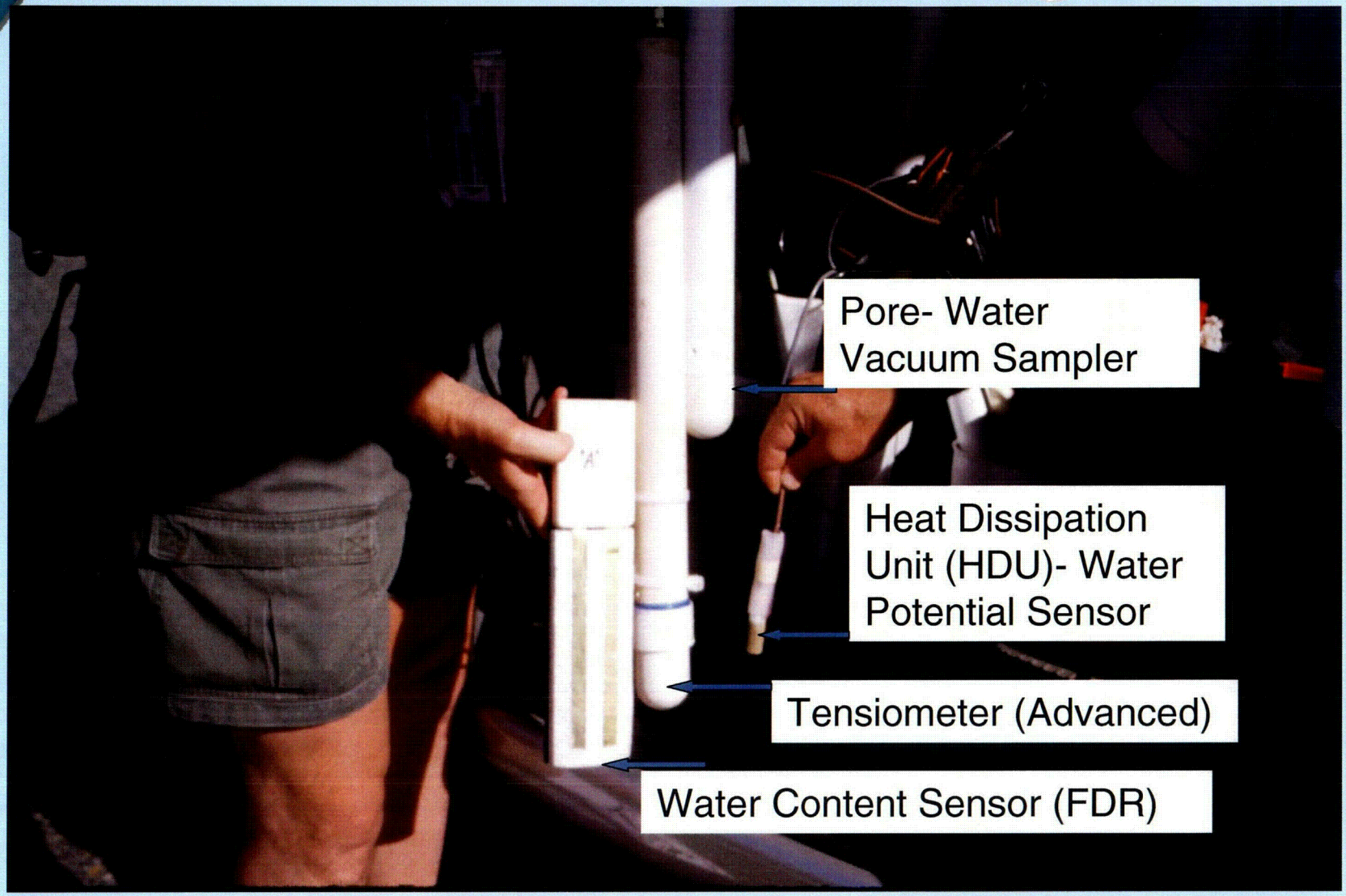
ΔS = 0 ±20 mm

D = 3 ± 60 mm

Cover Monitoring Requirements

- Surface Inspections
  - erosion
  - subsidence
  - isolation, biotic intrusion, and plant cover
- Ground Water
  - up-gradient wells (2) - water chemistry
  - down-gradient wells (3) – water chemistry
- Vadose Zone – Water Balance
  - water intrusion limits (1 to 3 mm/yr or less)
    - water content
    - water potential
    - water flux (indirect or direct measurements)

Soil Water Monitoring



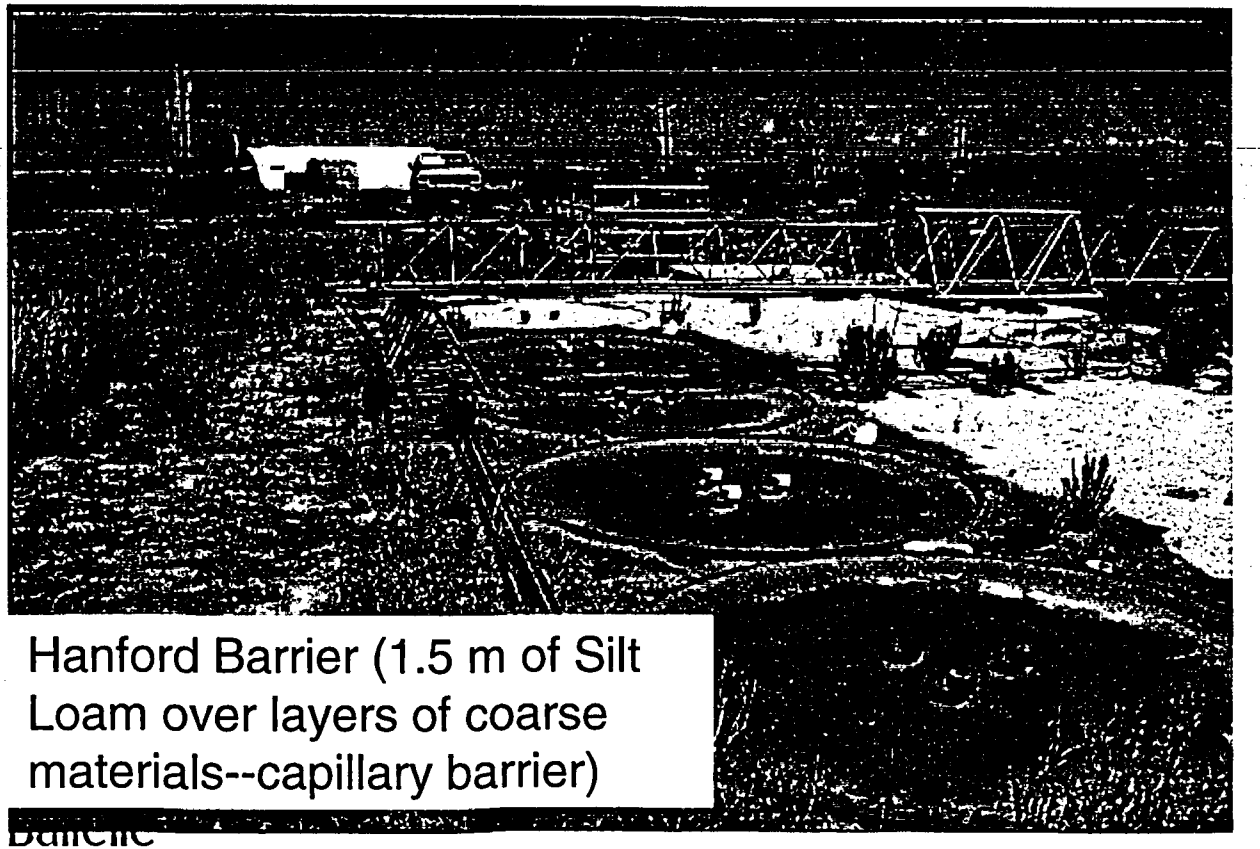
Drainage Monitoring

- Drainage Flux Estimates (Indirect)
  - Assumes that drainage can be estimated from water content or water potential measurements and an estimate of the unsaturated hydraulic conductivity
    - Drainage Flux = $-K(\theta)\ [\Delta\psi/\Delta z]$
      - $K(\theta)$ = unsaturated hydraulic conductivity
      - $\Delta\psi/\Delta z$ = water potential gradient
      - $\psi = f(\theta)$ through the soil water retention characteristic
    - $K(\theta)$ typically uncertain by more than an order of magnitude
    - Water content can be used to estimate water potential
    - More uncertainties in monitoring water contents or potentials

Monitoring- Direct

Lysimetry

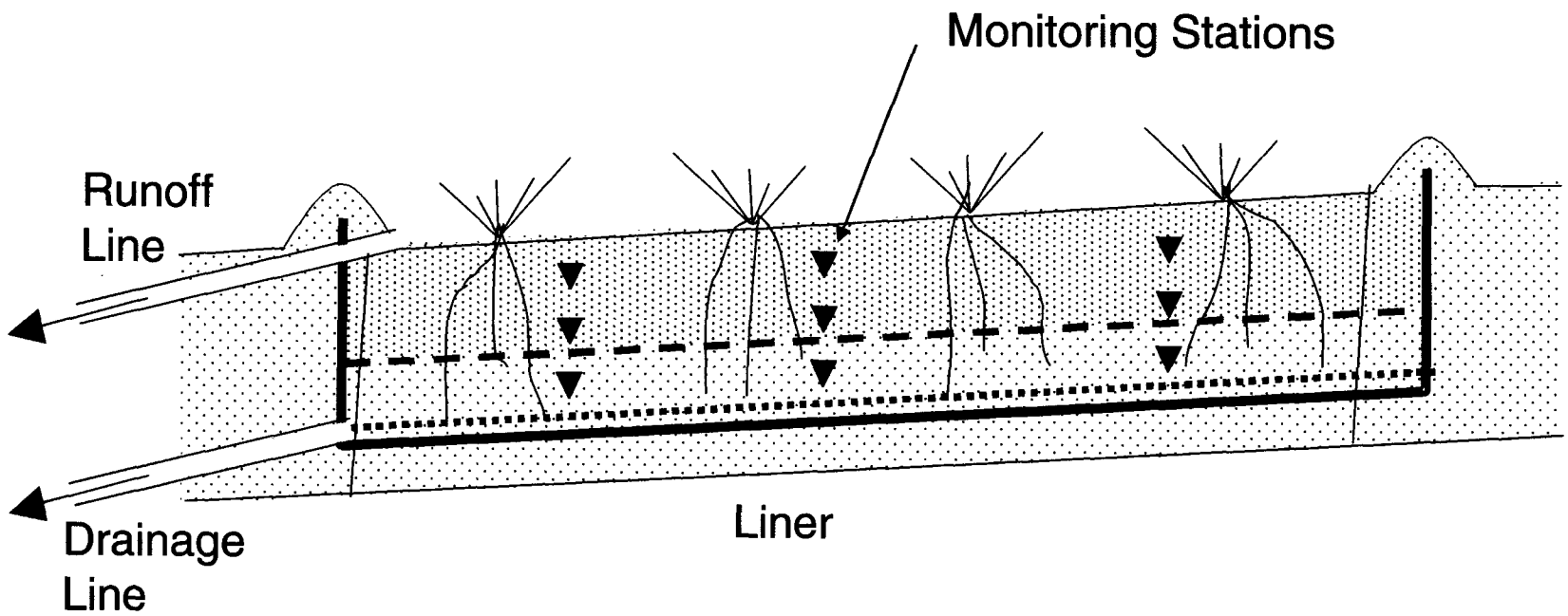
- Controlled soil volume
- Direct measure of drainage



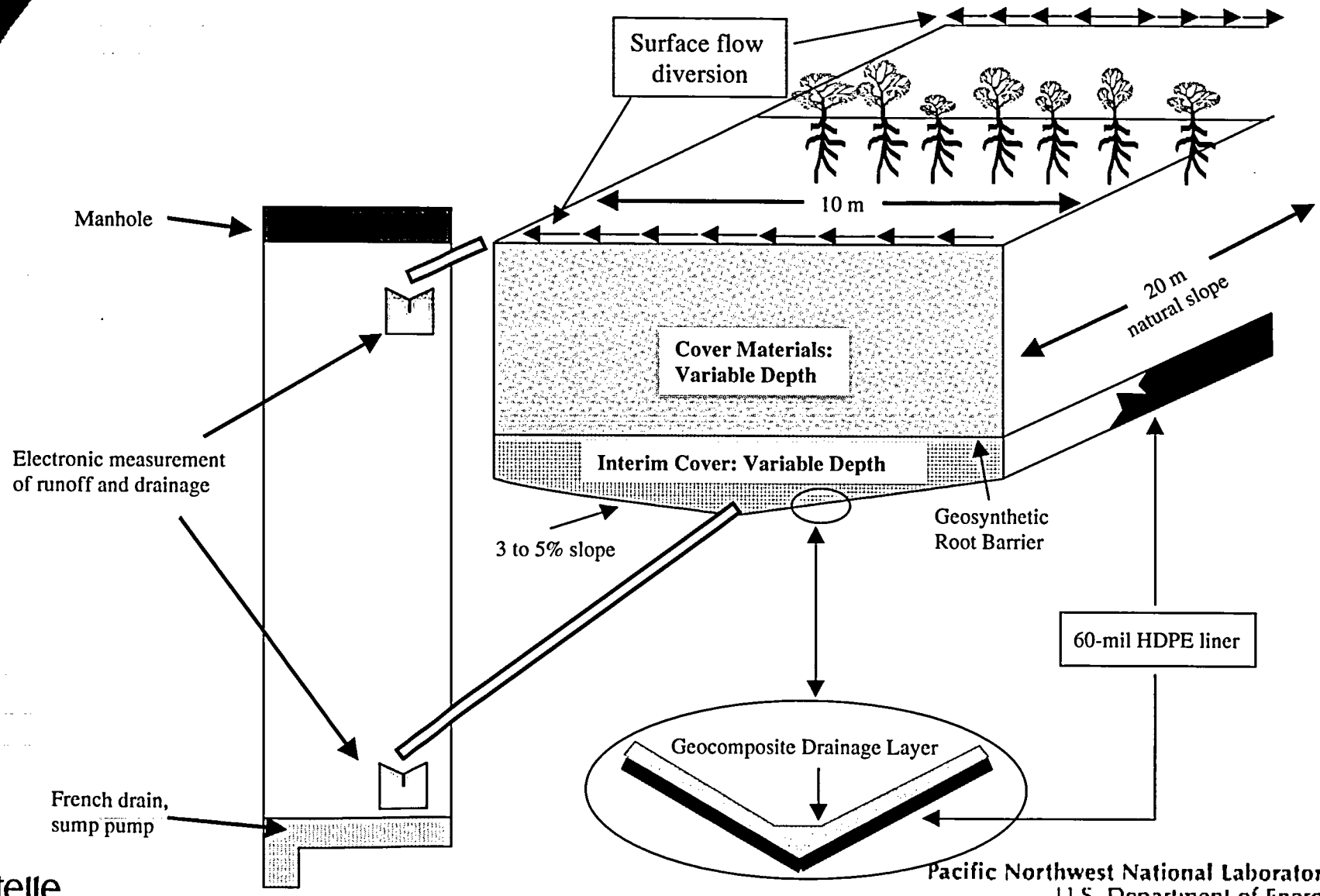
Hanford Barrier (1.5 m of Silt Loam over layers of coarse materials--capillary barrier)

Direct Monitoring

Lysimeter Test Pad –ACAP Sites



ACAP Runoff/Drainage Collection



Automatic-Drainage Collection
(Resolution of <0.01 mm)

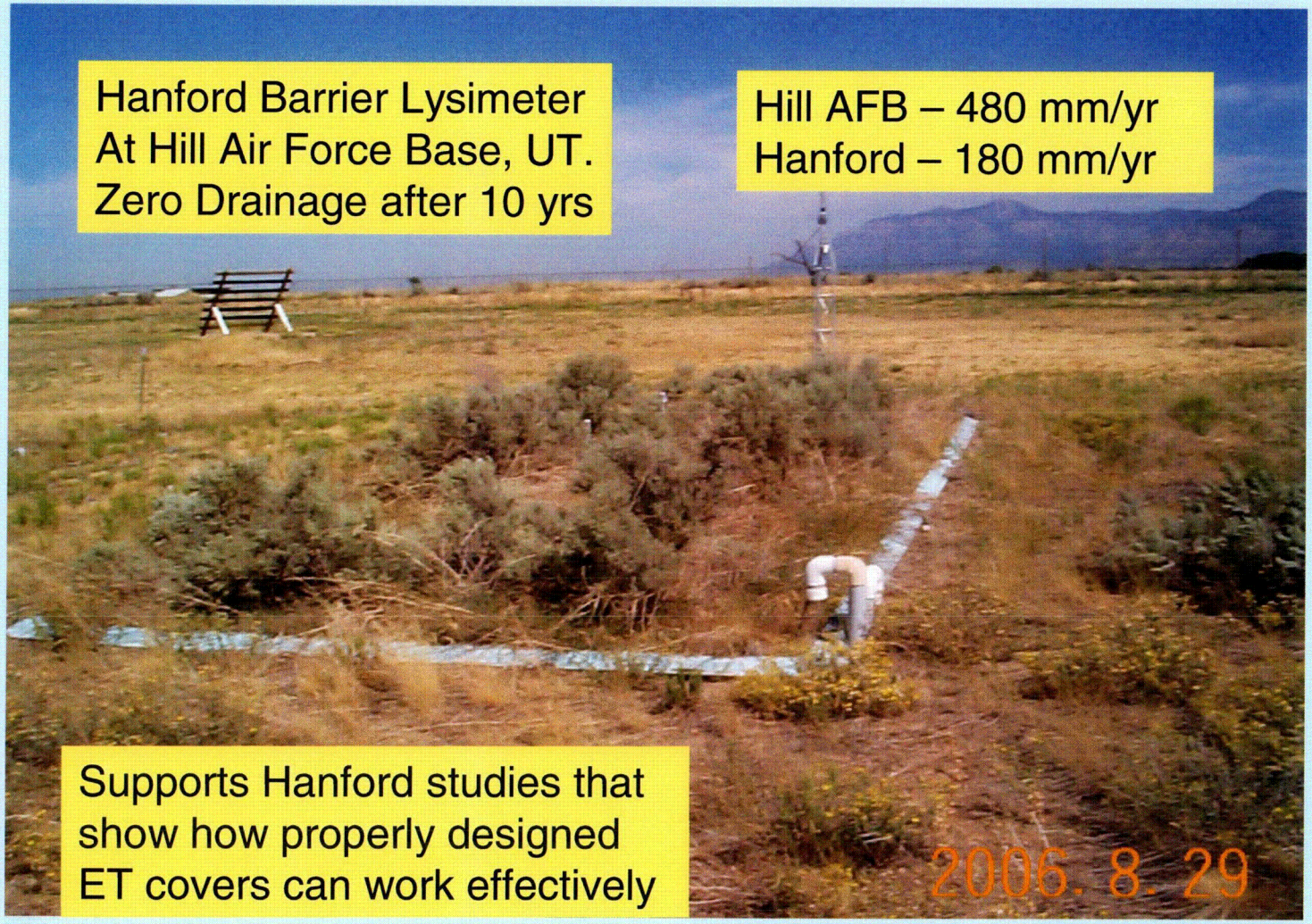
Modeling Requirements for Landfill Covers

- Modeling Requirements (Minimum)
  - Precipitation (and weather station records)
  - Soil Hydraulic Properties
  - Plant Leaf and Root Dynamics
- Simplest models use default parameters based on general characteristics- soil, plant, weather records
- Complex models require detailed on-site data.
  - Precipitation, wind speed, solar radiation, temperature, humidity, soil hydraulic properties, leaf area, rooting density and depth and plant phenology, etc.

ET Model Complexity

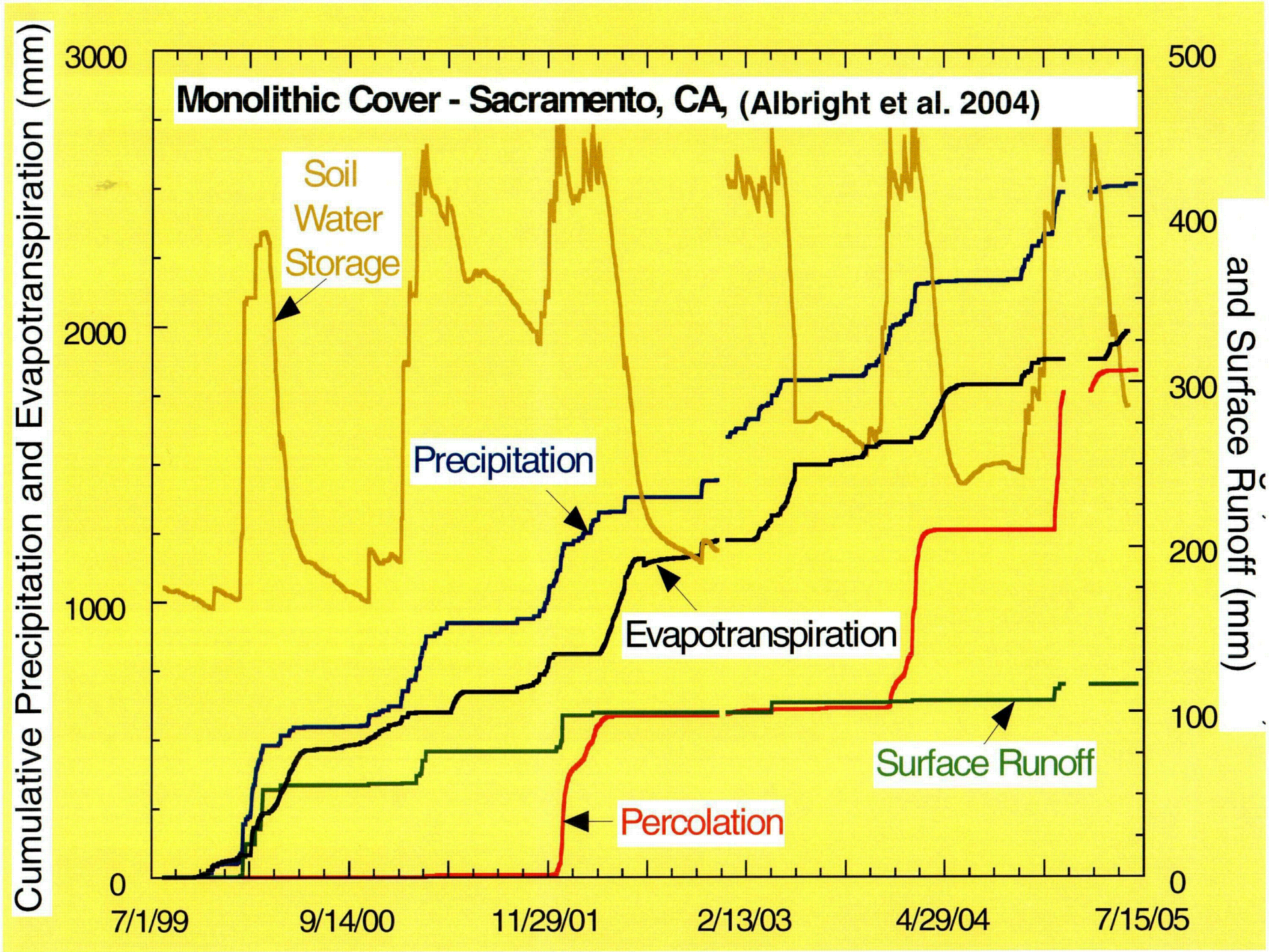
- Simple
  - HELP (EPA Cover Design Code)
  - STEWB-Modified KIM (NRC, Infiltration Code)
- Intermediate
  - EPIC (ARS- Crop Productivity Code)
- Complex
  - UNSAT-H (PNNL, 1D Richards Based)
  - HYDRUS-1, 2D
  - STOMP-2, 3D
- [Note: All ET models are limited by uncertainties in plant parameters and dynamics]

Hill Air Force Base Lysimeter (Example of ET Cover after 10 years)



Hill Air Force Base Monitoring and Modeling Results

- Water Balance Models (HELP, EPIC and UNSAT-H) adequately described results from the Hill AFB tests.
- Snowmelt caused LANL-type capillary barriers to drain at rates exceeding 50 mm/yr (water storage capacity of soil layer inadequate).
- Snowmelt captured in Hanford Barrier due to increased storage capacity of silt loam soil. Models show Hanford ET barrier effective under elevated precipitation conditions. Plant dynamics predictable at Hill Air Force Base (10 year test).


Monolithic Cover - Sacramento, CA, (Albright et al. 2004)
Cumulative Precipitation and Evapotranspiration (mm)
and Surface Runoff (mm)
3000
2000
1000
0
500
400
300
200
100
0
7/1/99
9/14/00
11/29/01
2/13/03
4/29/04
7/15/05
Soil Water Storage
Precipitation
Evapotranspiration
Surface Runoff
Percolation

Measured and Modeled Drainage at a Landfill in Sacramento, CA

Year	Precip. (mm)	Measured Drainage (mm)	Modeled Drainage (mm)
2000	650	0	0
2001	410	0	0
2002	430	100	0
2003	490	0	0
2004	400	110	0
2005	420	95	0

Summary

- Monitoring of an ET Cover for long-term performance will be a challenge
- Erosion Control – observable, repairable
- Biointrusion Control- likely repairable
- Water Intrusion – the greatest challenge – drainage control will be site and design specific. Time dependence of the plant (biotic) system will continue to be difficult to quantify. Redundancy in control should not be ignored.

Summary Cont.

- Water intrusion (drainage) monitoring
  - Indirect methods are too imprecise:
    - Water content sensing (TDR, Nprobes, electrical) is not flux
    - Water potential sensing (tensiometers, HDUs) is not flux
    - Water balance modeling (HELP, UNSATH, EPIC) uncertain
  - Direct methods are required:
    - Test-pad lysimeters are generally reliable to test minimal drainage rates of less than a few mm/yr, for extended times (>10 yrs).
- ET (Water Balance) Modeling
  - Plant dynamics are the largest uncertainty and plague all current models, from the simplest to the most complex. Plant parameters unfortunately cannot be readily engineered and have no safety factors built into them.