General

Long Term Monitoring Strategy
Material Disposal Areas
Los Alamos National Laboratory

August 9, 2000
Presentation / Workshop

LANL ER Project
MDA Focus Area

13428

Long Term Monitoring Strategy
Material Disposal Areas
Los Alamos National Laboratory

Meeting Agenda
August 9, 2000
9:00 AM to 3:00 PM
LAAO Main Conference Room

John Hopkins, LANL ER, MDA Focus Area Leader (10 minutes): johnhopkins@lanl.gov
- Introductions and Safety Awareness (Peace March)
- Problem Statement: Long Term Monitoring strategy for material disposal areas (MDA) proposed for evapotranspiration (ET) covers.

Diana Hollis, LANL ER (20 minutes): dhollis@lanl.gov
- Regional geology
- Mesa geology
- Regional hydrology
- Mesa hydrogeology

Diana Hollis, LANL ER (15 minutes)
- MDA G Performance Assessment
- Site-specific Groundwater Modeling
- Groundwater corrective-action strategy

Everett Springer/Brent Newman, LANL EES-15 (30 minutes)
- Insights on Monitoring Strategies from the Los Alamos Pilot Studies

Break (15 minutes)

Steve Dwyer, P.E., Consultant (30 minutes)
- Draft – revised EPA Technical Guidance for RCRA/CERCLA Final Covers

Scott McMullen or Steve Dwyer (30 minutes)
- Overview of DOE's Long-term Risk-based Landfill Closure Guidance.

Lunch Break (60 minutes – approximately 11:30-12:30)

Mark Ankeny, Ph.D., Daniel B. Stephens & Associates, Inc. (15 minutes)
- Monitoring strategy: performance vs. risk

Daniel B Stephens, Ph.D., Daniel B. Stephens & Associates, Inc. (15 minutes)
- Vadose zone road map

Daniel B Stephens, Ph.D., / Mark Ankeny, Ph.D. (60 minutes)
- State of the art in monitoring technologies, existing and emerging technologies

Representative Projects with Site Specific Monitoring Technologies (60 minutes):

- SNL CAMU, Scott Den-Baars
- LANL MDA J, Scott Den-Baars
- EPA, Alternative Cover Performance, Steve Dwyer
- UMTRA, Monticello, Steve Dwyer
- Alternative Landfill Cover Demonstration project, Steve Dwyer
- NTS, Dan Leavitt

John Hopkins, LANL ER (15 minutes)

- Closing remarks

Developing Temporal and Spatial Monitoring Strategies using Spectral Analysis: An example using the LANL Protective Barrier Landfill Cover Demonstration Data

Brent Newman, LANL

Christopher Duffy, Penn St.

Jack Nyhan, LANL

Everett Springer, LANL

LANDFILL COVER STUDIES AT LOS ALAMOS

- The Environmental Science Group at Los Alamos has data and information on many factors that affect surface covers. These include
- Engineering factors:
  - Surface runoff and erosion
  - Subsidence
  - Engineered barriers for water diversion
  - Geotechnical and hydrological properties of cover materials
- Environmental factors:
  - Water balance
  - Animal burrowing
  - Biological barriers - materials and design
- Assessment:
  - Modeling
  - Monitoring equipment

LANDFILL COVER STUDIES AT LOS ALAMOS

The Environmental Science Group has performed studies that can support monitoring system development at:

- TA-51 Pinyon-Juniper site (> 10 yr.): soil moisture, vegetation, runoff
- ITP Demonstration (10 yr.): soil moisture seepage, interflow, vegetation
- MDA B (8 yr.): runoff, erosion, soil moisture, vegetation
- Ponderosa Pine site (≈ 5 yr.): runoff, interflow, tracer studies, soil moisture
- Protective Barrier Plots (8 yr.): runoff, soil moisture seepage, interflow
- Bandelier site (> 7 yr..): runoff, erosion
- Hill Air Force Base (≈ 5 yr.): runoff, soil moisture, interflow, seepage, vegetation

Water Balance Example

- Conventional Cover Landfill Design
  - Crushed tuff and topsoil, no plants
  - 5, 10, 15, 25% slopes
- Water Balance Parameters
  - $\Delta S = P - R - S - I - E$
  - Intensive sampling of volumetric moisture
    - Time Domain Reflectrometry
      - measured at 3 positions along slope and at 3 depths
      - measured 4 times daily

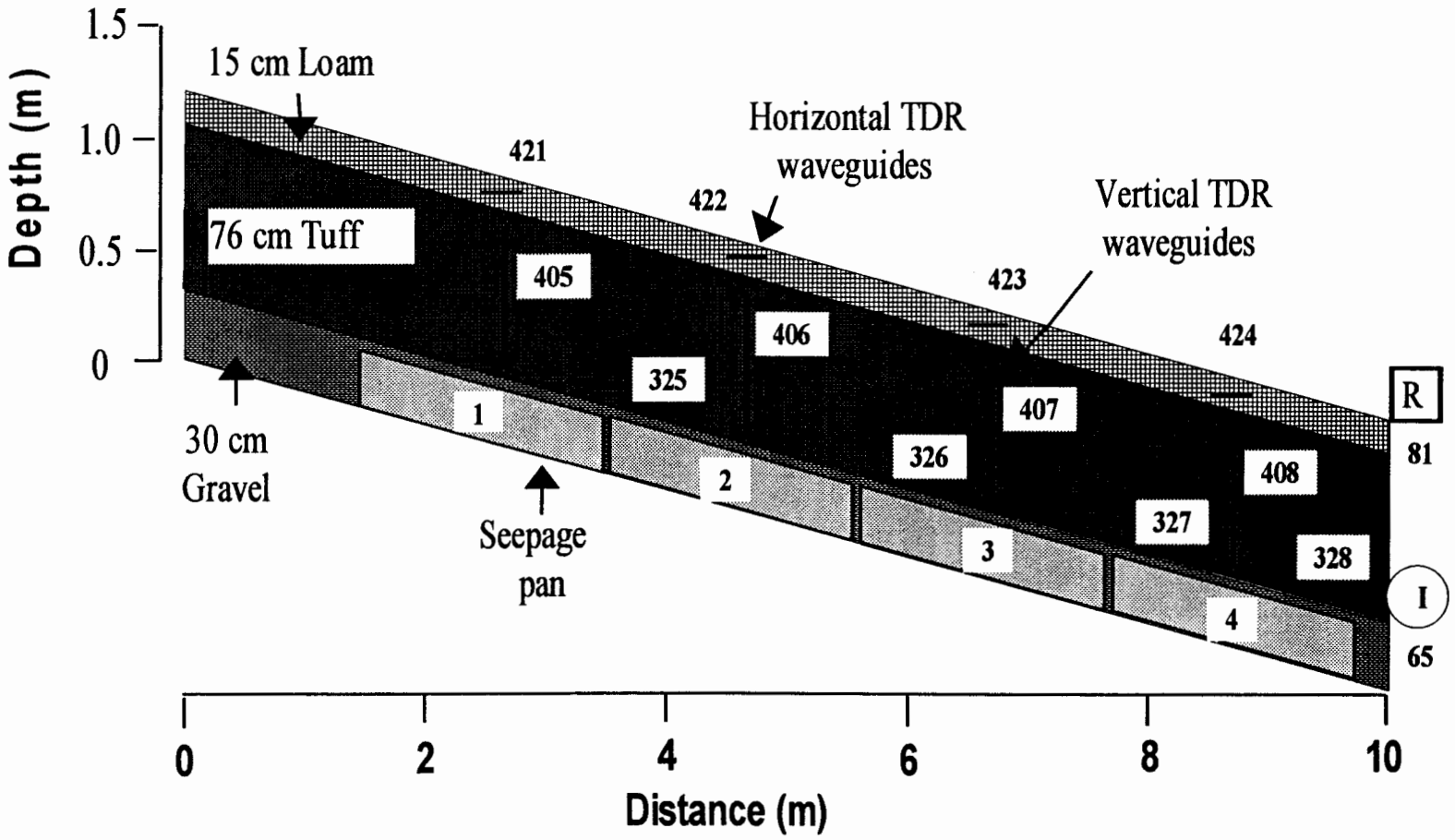
General Observations

- Seepage only occurs Feb.-June and is always accompanied by interflow

- Runoff mainly occurs in July-Aug. with minor spring runoff

- Evaporation peaks July-August

Conventional Landfill Cover Design
(5% slope)



Singular Spectrum Analysis

- Examine Temporal and Spatial Data
  - We examine time here, but can use spectral analysis for spatial data as well.
    - The method can be shown to be optimal in the sense that it captures the maximum variance with the fewest statistically independent (orthogonal) components
    - Objective is to estimate the independent variance contributions from periodic, nearly periodic, and random components in the soil moisture record.
  - In simple terms, we want to identify the different hydrologic time modes in the data
  - Once the time modes are identified, then a temporal sampling strategy can be developed to "capture" the temporal variability in volumentric moisture for example .

A Few Names.....

PCA: Principal Components Analysis
SSA: Singular Spectrum Analysis
POD: Principal Orthogonal Decomposition
MSSA: Multi-Channel Singular Spectrum Analysis
EOF: Empirical-Orthogonal Function Analysis
K-L: Karhunen-Loev Decomposition
.....

Singular Spectrum Analysis

- After we have identified the dominant time modes, how do we deterimine how often to sample?
  - –The minimum sampling interval for any period is:

    $\Delta t = T_{period}/2$
  - –In order to make sure an annual cycle is thoroughly resolved we may choose a monthly interval

    $\Delta t = T_{period}/12$
  - –However, we know that some of the harmonics of the annual cycle are important so we would need to sample more frequently:

    $\Delta t = T_{period}/12k$ where $k = 1, 2, 3\ldots.$
  - –So for the second harmonic we would need to sample twice per month, the third would be weekly and so on.

PCA attempts to reveal underlying structure in a multivariate data set.

Let X_{ij} be a matrix of data: i=1, 2, 3,...n rows of observations
j=1,2,3,...m columns of variables

$$\boldsymbol{R} = \boldsymbol{X}^T\boldsymbol{X}$$

R is then a square m×m matrix of the sums of squares and products. If the ***X*** are standardized (subtract mean and divide by variance), then we have a correlation matrix.

Eigenvalue problem

The principal directions of ***R*** are found by solving the eigenvalue problem

$$(\boldsymbol{R}-\lambda \boldsymbol{I})\boldsymbol{E}=0$$

λ are the eigenvalues and ***E*** are the eigenvectors. Note that eigenvalues λ represent the variance contribution of each "component".

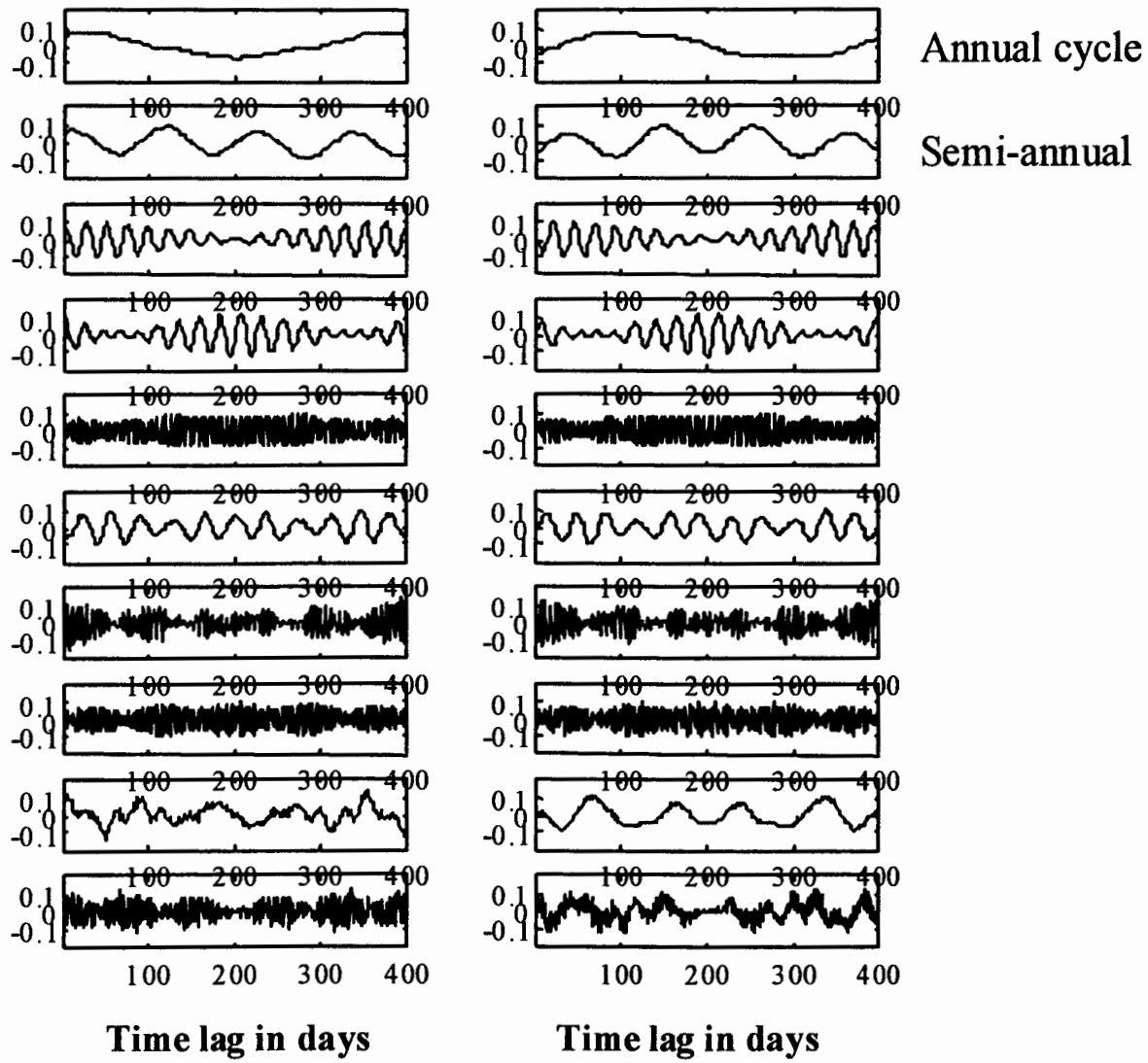
Summary

- For continuously varying responses such as moisture content, spectral analysis indicates that a daily sampling will capture the variability in the cover experiments

- For intermittent responses such as interflow and seepage, an adaptive sampling based on the continuously varying parameters would be best.
  - Because of threshold behavior

- Spatially, sampling at two depths at the upper-, mid-, and lower-slope positions will capture spatial variability in water balance parameters.

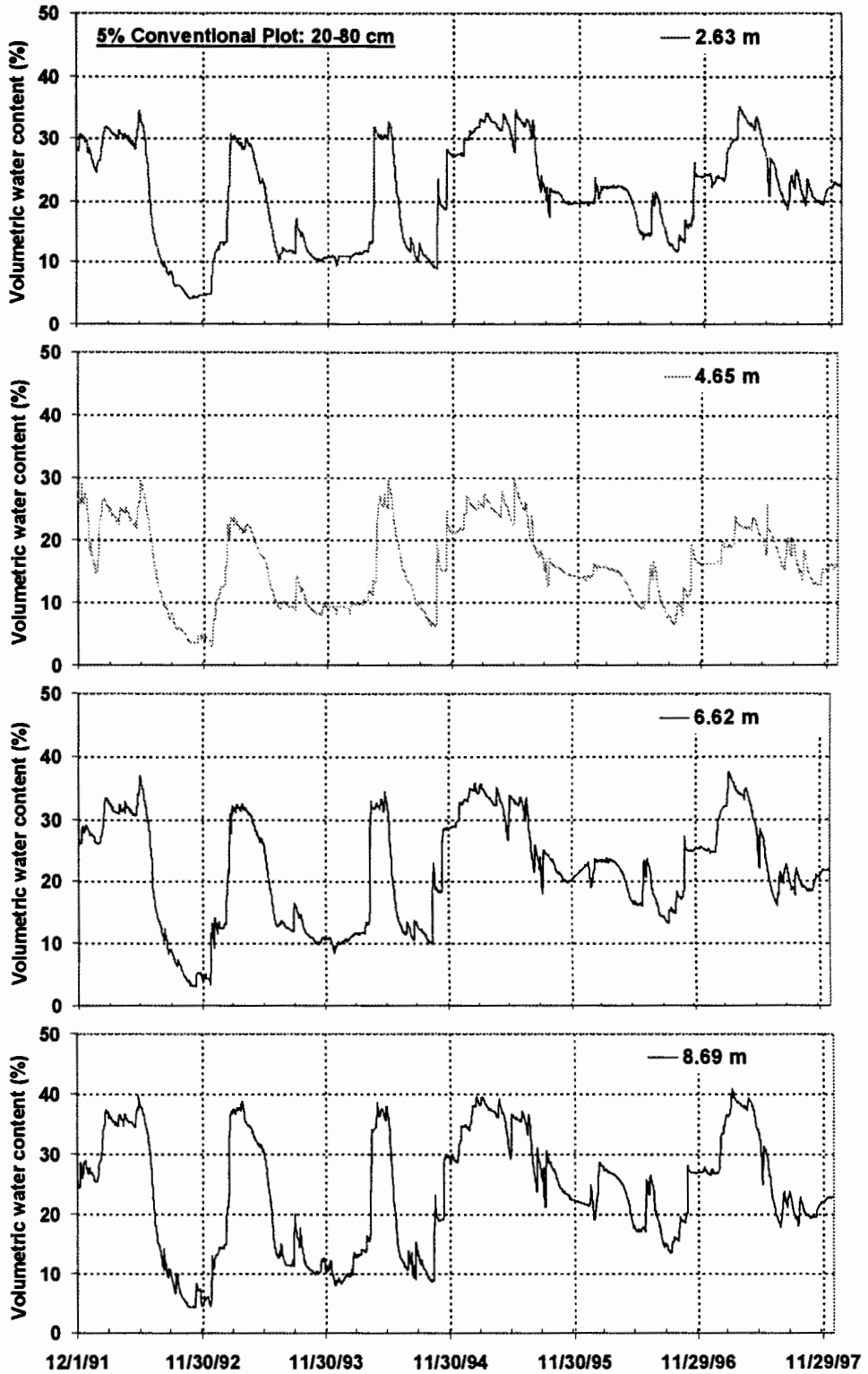
The First 20 Eigenvectors



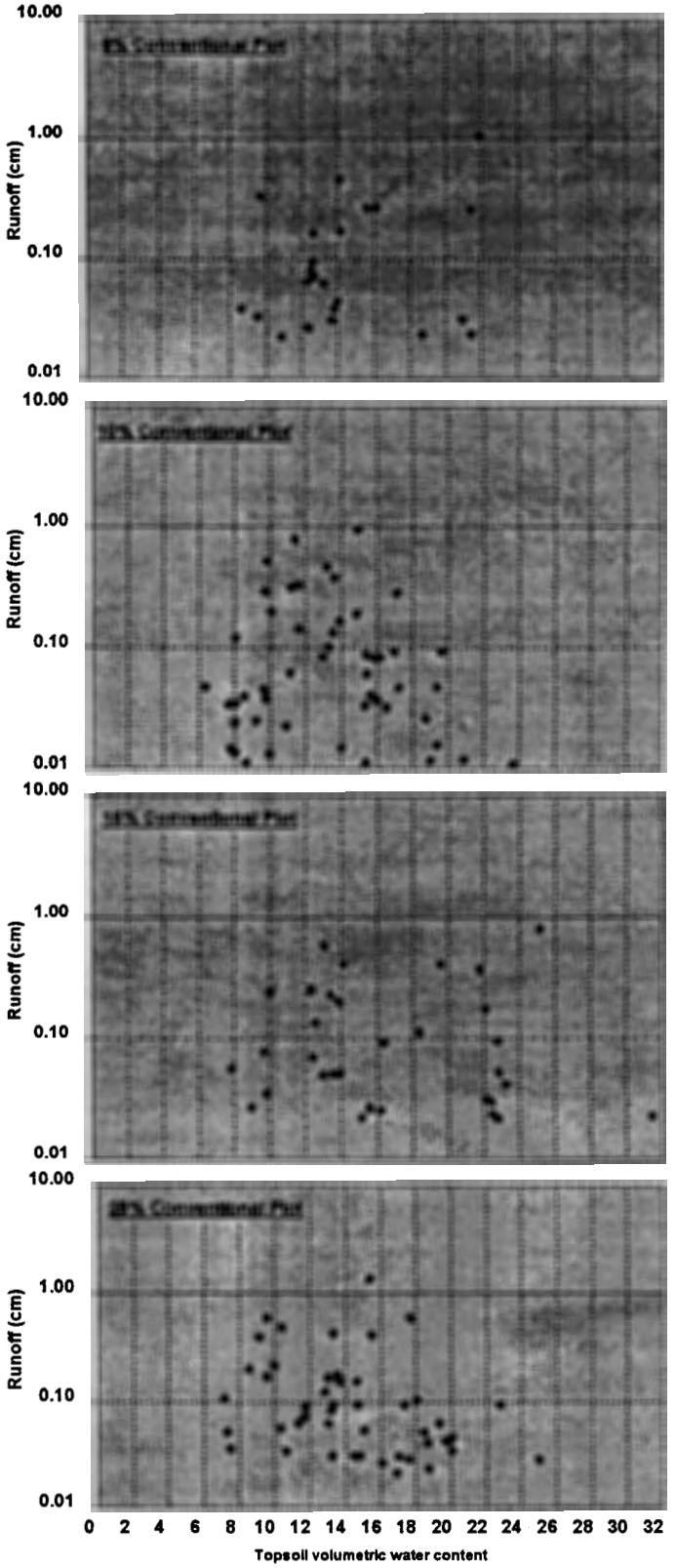
Summary (continued)

- Experimental data is critical for spectral analysis and for other cover modeling approaches
  - Data intensive both in frequency and duration

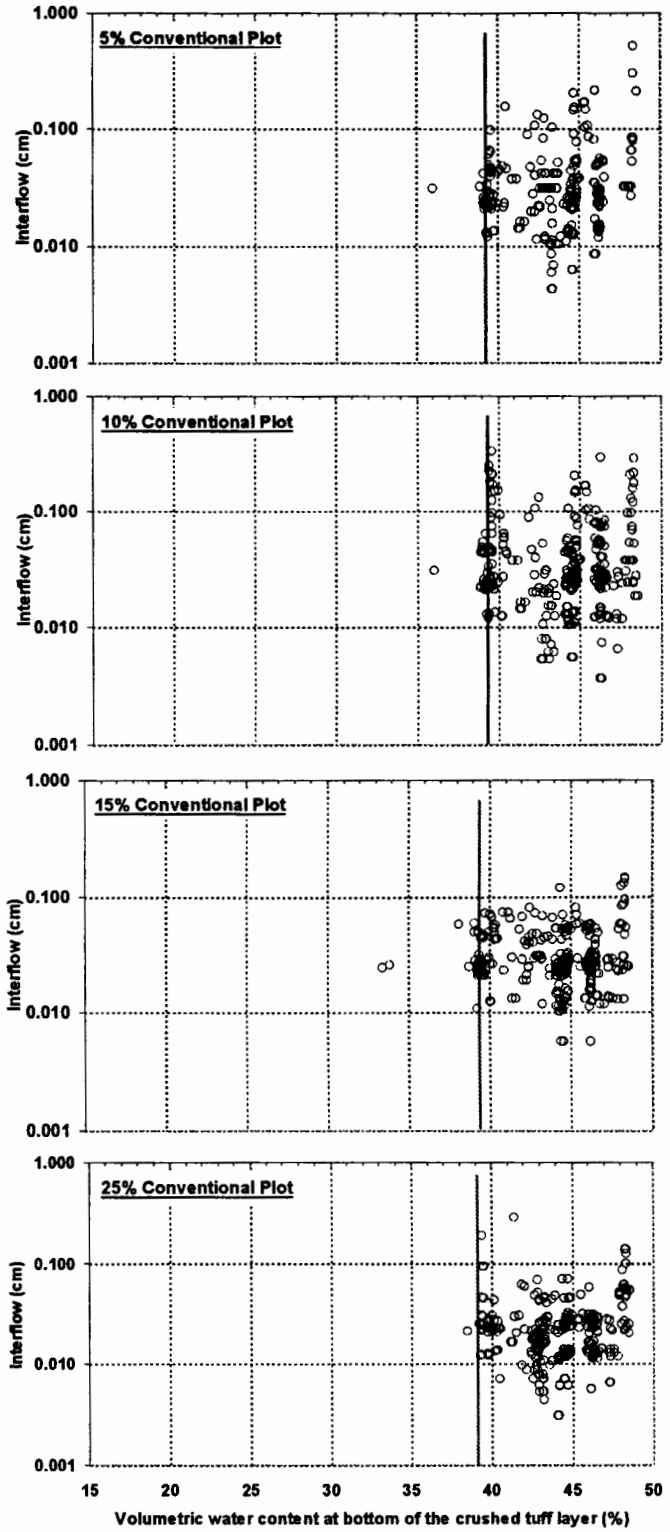
- Experimental data is also required to evaluate intermittent type response and identify thresholds



Volumetric water content of the crushed tuff at the 20-80 cm sampling depth at downslope distances of 2.63, 4.65, 6.62, and 8.69 m (Conventional Landfill Cover Design with 5% slope).



Daily runoff as a function of topsoil volumetric water content for the Conventional Landfill Cover Design at slopes of 5, 10, 15, and 25% (n=2223).



Daily interflow as a function of crushed tuff volumetric water content for the Conventional Landfill Cover Design at slopes of 5, 10, 15, and 25% (n=2223).

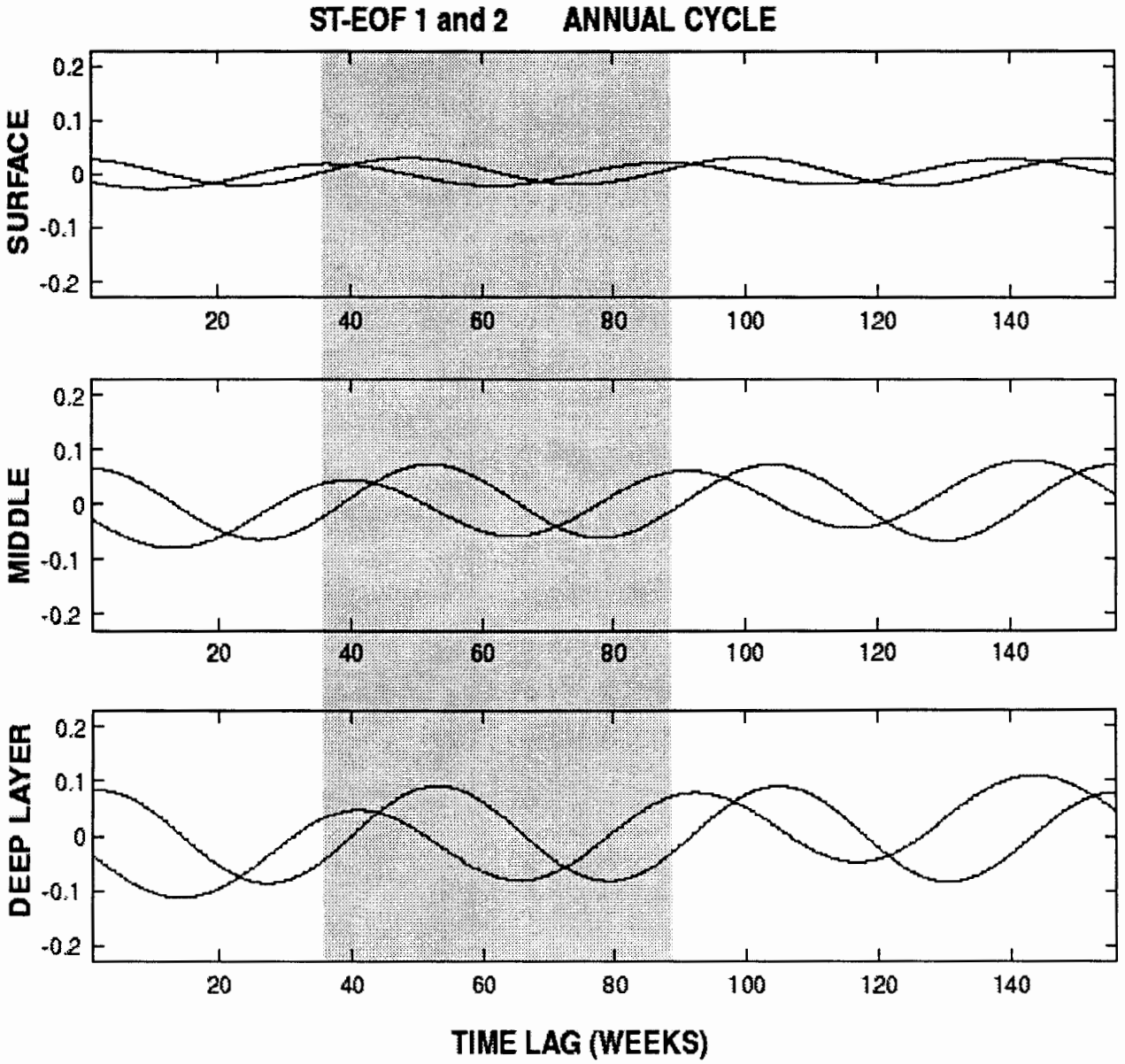


Figure 19. The eigenmodes representing the annual cycle for soil volumetric water content (Conventional Design with the 5% slope) averaged over the 4 soil water sampling locations at each depth in the landfill cover. The shaded area spans 1 year and demonstrates the time lag of the annual cycle with depth. The lag from the surface topsoil to the deep layer in the crushed tuff is ~4 weeks.

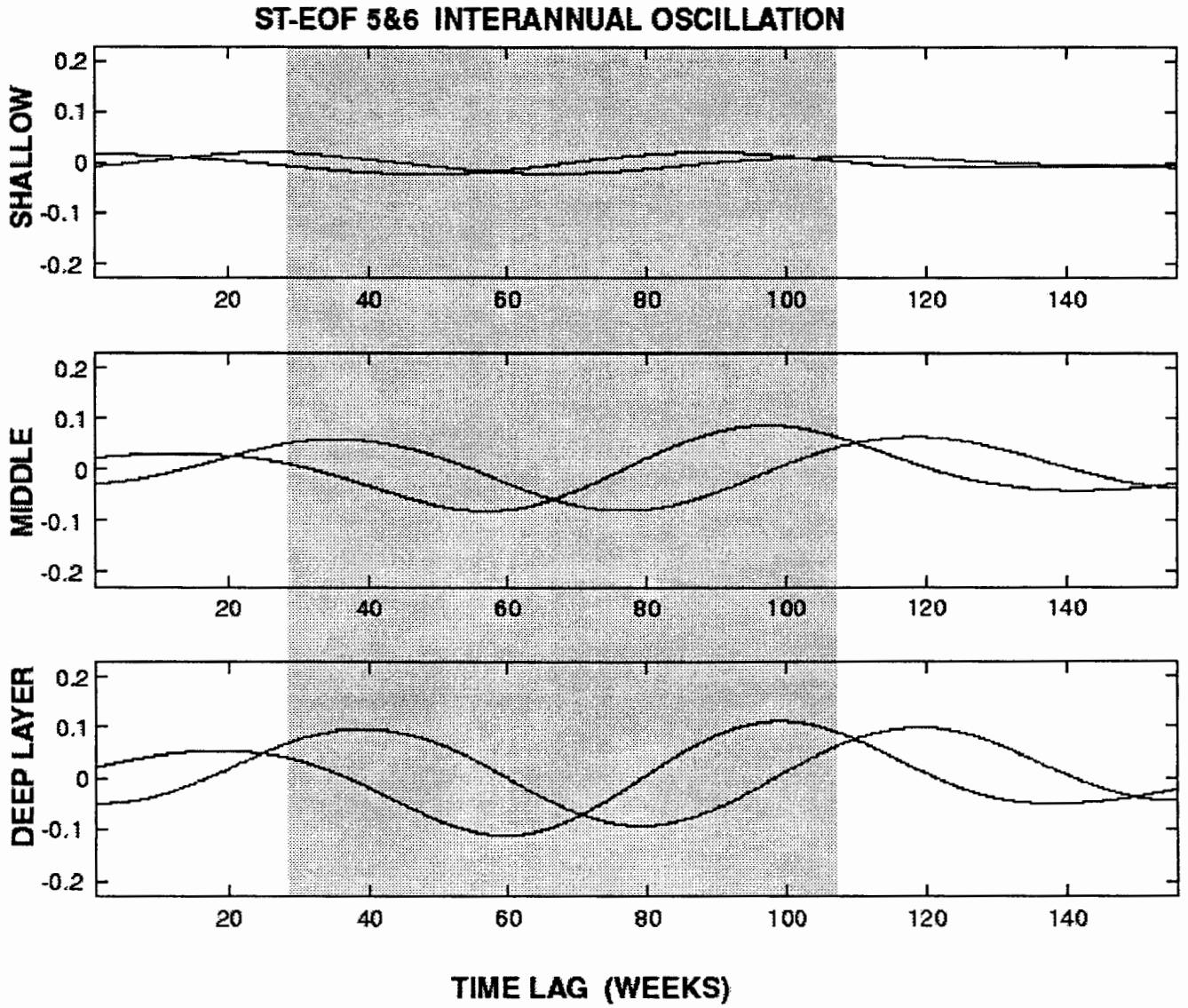


Figure 20. The eigenmodes representing an interannual oscillation for soil volumetric water content (Conventional Design with the 5% slope) over the soil depth in the landfill cover. The data were averaged over the 4 soil water sampling locations at each depth. The shaded area spans 1 cycle (80 weeks) and demonstrates the time lag of the oscillation with depth. The lag from the surface topsoil to the deep layer in the crushed tuff is ~10 weeks.

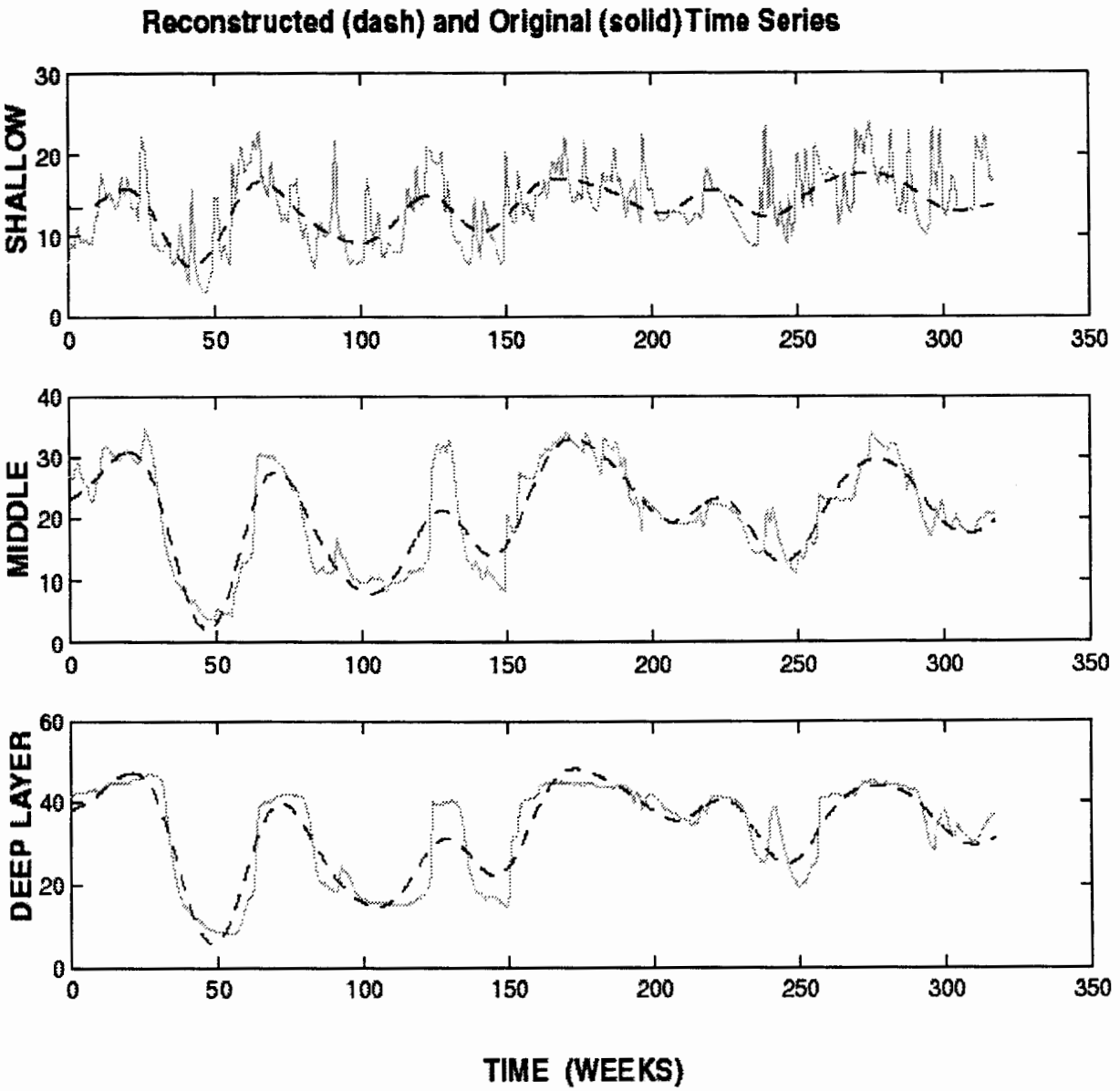


Figure 21. The reconstructed and original soil volumetric water content for the Conventional Design with the 5% slope averaged over the 4 soil water sampling locations in the shallow, intermediate and deep layers of the landfill cover. The reconstruction is based on 8 principal components.

Revised EPA Landfill Closure Guidance Document

Key Note: A *very important point involves the review of alternative cover systems. It is highly recommended that a subject expert or panel of experts be retained to review alternative cover systems submitted for permit approval. There are many areas in the design inputs that are subjective or generally out of the expertise of many design civil engineers and should be reviewed for reasonableness. In addition, since few alternative cover systems are installed to date, those that are put forth early will serve as precedences for others to follow. Ensuring early successes should translate to subsequent successes.*

Alternative Covers Assessment Program (ACAP)

United States Environmental Protection Agency

Superfund Innovative Technology Evaluation (SITE) Program

Program: ACAP is part of the EPA's National Risk Management Research laboratory's Superfund Innovative Technology Evaluation Program (SITE).

Goal: Develop field scale performance data for landfill cover systems; both prescriptive and alternative cover designs.

Phases: ACAP is divided into 2 phases:

Phase 1: (completed in August 1999) involved the assessment of potential sites and research facilities, existing designs, existing modeling methods, and recommendations for implementing Phase 2.

Phase 2: In construction phase, will establish a network of demonstration field sites nationwide. Field data will be collected from these respective sites for 5 years.

20. Albuquerque, New Mexico: Sandia National Lab

Precipitation (average annual): 22 centimeters/snow
Temperature (low minimum and maximum monthly means): 2-26°C

Six covers have been installed at this site:

RCRA "D" cover. This cover consists of topsoil underlain by compacted soil. Information obtained will help form a baseline for prescriptive cove performance.
RCRA "C" cover. This cover consists of (1) topsoil, (2) native sand, (3) geotextile, (4) sand, (5) geomembrane, and (6) native soil with 6% bentonite. Information obtained will help form a baseline for prescriptive cover performance.
Geosynthetic clay liners (GCL) design. This cover consists of (1) topsoil, (2) native soil, (3) geotextile, (4) sand, and (5) a geomembrane.
ET cover. This cover consists of (1) gravel, (2) topsoil, and (3) compacted soil.
Anisotropic barrier. This cover consists of (1) topsoil/pea gravel; (2) compacted native soil, (3) sand, and (4) gravel.
Capillary barrier. This cover consists of (1) topsoil, (2) sand, 93) gravel; (4) compacted native soil, and (5) sand.

1. Atlanta, Georgia: Live Oak Landfill

Precipitation (average annual): 125 centimeters
Temperature (low minimum and maximum monthly means): 6-26°C
A resistive barrier-vegetated cover has been installed at this site. The cover consists of two layers: (1) vegetated silt and (2) compacted clay.

2. Beltsville, Maryland: National Research Council (NRC)

Precipitation (average annual): 100 centimeters
Temperature (low minimum and maximum monthly means): 2-26°C
Four covers have been installed at this site:

Bioengineering barrier: Before a water-containment system was put in place, water pooled in this area and traveled upward through waste layers. An impermeable barrier, much like a rain gutter, has been installed and shrubs have been established between the gutters. The impermeable barrier is underlain by an uncharacterized fill. To date, results indicate that the shrubs successfully dewatered the area and that they effectively capture water that escapes the rain gutters. Resistive barrier-vegetated: This cover consists of (1) vegetated topsoil, (2) pea gravel, and (3) compacted clay. Resistive barrier-armored: This cover acts much like a one-way valve (i.e., water goes in, but does not come out). It consists of the following layers: (1) rock armor, (2) pea gravel, and (3) compacted clay. Conductive layer barrier: This cover is effective for small cells, where the aim is to move water laterally around wastes. It consists of the following layers: (1) vegetated topsoil, (2) pea gravel, (3) compacted clay, (4) diatomaceous earth, (5) geotextile, and (6) compacted clay.

3. Denver, Colorado: Rocky Mountain Arsenal

Precipitation (average annual): 39 centimeters/snow
Temperature (low minimum and maximum monthly means): -1B23 EC
Four ET-type barriers have been installed:

Three covers consist of >50% silt and clay, with each cover using a different depth (i.e., ranging from 1.1 to 1.5 meters).
One cover consists of 1.1 meters of >35% and <50% silt and clay.

4. Hanford, Washington: Pacific Northwest National Laboratory

Precipitation (average annual): 16 centimeters/snow
Temperature (low minimum and maximum monthly means): -1-26°C

An ET capillary barrier has been installed. It consists of the following layers: (1) silt loam/pea gravel, (2) silt loam, (3) sand/gravel filter, (4) basalt riprap, (5) drainage gravel, (6) composite asphalt, and (7) structural fill.

5. Hill AFB, Utah

Precipitation (average annual): 44 centimeters/snow
Temperature (low minimum and maximum monthly means): -3-24°C
Four covers have been installed at this site:

Control (ET) Cover: This cover consists of a sandy loam and natural grasses.
Capillary barrier cover: This cover consists of (1) sandy loam with grasses and shrubs (2) geotextile, and (3) gravel.
Hanford-type cover: This cover consists of (1) silt loam/pea gravel, (2) silt loam, (3 geotextile, and (4) sand/gravel.
Modified RCRA cover: This cover has the following layers: (1) sandy loam with grasses, (2) geotextile, and (3) clay. Collecting prescriptive cover performance data is important because very few lysimeter-based tests have been conducted for RCRA C and RCRA D covers. Scientists need more information to establish baseline performance standards.

6. Idaho National Engineering and Environmental Lab

Precipitation (average annual): 23 centimeters/snow
Temperature (low minimum and maximum monthly means): -9-20°C
Four covers have been installed at this site:

RCRA-type design cover: This cover consists of (1) loess, (2) geomembrane, and (3 compacted clay.
Thick monolayer: This cover consists of loess.
Biobarrier designs: Two barrier design covers have been installed, each consisting of (1) loess, (2) capillary barrier, and (3) loess. The depth of the bottom loess layer differs between the two covers.

7. Kalamazoo, Michigan: National Council for Air and Stream Improvement

Precipitation (average annual): 89 centimeters/snow
Temperature (low minimum and maximum monthly means): -5-23°C
This site is testing an alternative low-permeability material, paper sludge. Investigators are comparing the performance of paper mill sludge with that of compacted clay. Tw covers have been established, each with a vegetated topsoil that is underlain by native soil. Under the native soil, one cover has a compacted clay, while the other has a compacted paper mill sludge. For both covers, the bottom layer consists of compacted sand.

8. Los Alamos National Laboratory, New Mexico

Precipitation (average annual): 47 centimeters/snow
Temperature (low minimum and maximum monthly means): 2-20°C
Four covers have been installed at this site:

Conventional cover: This cover consists of topsoil, underlain by crushed tuff.
Loam capillary barrier: This cover consists of loam topsoil, underlain by fine sand.
Clay loam capillary barrier: This cover consists of clay loam, underlain by fine sand.
EPA-recommended design: This cover consists of (1) topsoil, (2) geotextile, (3) medium sand, and (4) compacted soil.

Some interesting plant and animal intrusion experiments have been conducted at this site Researchers have tried to quantify how much gravel and cobble is needed to resis penetration by plant roots and burrowing animals.

9. Milwaukee, Wisconsin: Omega Hills Landfill

Precipitation (average annual): 81 centimeters/snow
Temperature (low minimum and maximum monthly means): -7-22°C

Three covers are being evaluated. Two of the covers have topsoil underlain with compacted till; each of these covers differs in its layer depths. The third cover has fou layers (1) topsoil, (2) compacted till, (3) sand, and (4) compacted till.

10. Monticello: U.S. Department of Energy (DOE)

Precipitation (average annual): 38 centimeters/snow
Temperature (low minimum and maximum monthly means): -4-20°C

Several types of capillary barrier configurations are being tested at this site.

11. Nevada Test Site

Precipitation (average annual): 17 centimeters
Temperature (low minimum and maximum monthly means): 3-30°C

A cover with 2 meters of native soil has been installed at this site.

12. Oahu, Hawaii: Marine Corps Base Hawaii

Precipitation (average annual): 193 centimeters
Temperature (low minimum and maximum monthly means): 22-25°C

Before a water containment system was put in place, water pooled in this area and traveled upward through waste layers. An impermeable barrier, much like a rain gutter, has been installed and plants have been established between the gutters. The impermeable barrier is underlain by compacted soil. To date, results indicate that the plants successfully dewatered the area and that they effectively capture water that escapes the rain gutters.

13. Reedsburg, Wisconsin: Grede Foundries

Precipitation (average annual): 79 centimeters/snow
Temperature (low minimum and maximum monthly means): -8-22°C

This site is using an alternative material, foundry sands. Investigators are testing the material's performance by using it in a variety of covers and at different depths. The sands are compacted in some of the test covers and uncompacted in others.

14. San Bernardino County, California

Precipitation (average annual): 14 centimeters (Milliken site) and 44 cm (Phelan site)
Temperature (low minimum and maximum monthly means): 7-26°C (Milliken site) and 11-24°C (Phelan site)

Two lysimeter-based facilities are located in San Bernardino County. Both sites have covers composed of locally derived soil. At the Milliken site, the cover consists of silty sands. A the Phelan site, the materials are gravelly sands with silt.

15. Savannah River, South Carolina: DOE

Precipitation (average annual): 120 centimeters
Temperature (low minimum and maximum monthly means): 8-28°C

Investigations at this site have focused on subsidence impacts.

16. Sheffield, Illinois: NRC

Precipitation (average annual): 94 centimeters/snow
Temperature (low minimum and maximum monthly means): -6-24°C
At this site, four complex multilayer capillary barriers are being investigated:

One cover consists of (1) topsoil, (2) compacted till, (3) geofabric, (4) pea gravel, (5 compacted till, (6) geofabric, and (7) pea gravel.
One cover consists of (1) topsoil, (2) compacted loess, (3) compacted till, and (4) pea gravel.
Two of the covers consist of (1) topsoil, (2) compacted loess, (3) geofabric, (4) pea gravel, (4) compacted till, (5) geofabric, and (6) pea gravel. The depths of each laye differs between the two test covers.

17. Sierra Blanca, Texas

Precipitation (average annual): 32 centimeters
Temperature (low minimum and maximum monthly means): 7-28°C

Two covers have been installed at this site: (1) a capillary barrier and (2) a more sophisticated design, with a layer of clay, asphalt, and concrete in the middle.

18. Twenty-nine Palms, California: Marine Corps Air and Ground Combat Center

Precipitation (average annual): 10 centimeters
Temperature (low minimum and maximum monthly means): 9-32°C

A monofill cover design, consisting of 1.85 meters of silty sand, has been installed.

19. Wenatchee, Washington

Precipitation (average annual): 23 centimeters/snow
Temperature (low minimum and maximum monthly means): -2-23°C

Two covers have been installed at this site:

Capillary barrier. This cover consists of vegetated topsoil, underlain by sand.
Resistive barrier. This cover consists of vegetated topsoil, underlain by compacted silty clay.

SUBSURFACE CONTAMINANTS FOCUS AREA

LONG TERM CAPPING/COVER SYSTEM STRATEGY

Source Term Containment and Remediation Product Line

SUITE OF BARRIER TECHNOLOGIES

Surface Barriers

Stabilization

Subsurface Barriers

Cover System

- Conventional Design
- Alternative Design
- Long Term Design

Low -- High Pressure Grouting
Alternative Grouting Formulations

Buried Waste Containment System

Purpose

The Long Term Capping/Cover System Strategy outlines the programmatic strategy for the technical resolution of long term surface barriers. Future surface barrier technology development activities necessitate addressing 'Long Term' performance issues to meet the DOE 2006 Accelerated Cleanup Plan Goals.

Issues

- Current Guidance is focused on a short term monitoring period - < 100 years
- DOE Standards projects cover system performance sustainment as:
  - 100 years beyond loss of active institutional controls
  - Risk mitigation to external receptors at 1000 years (under review)
- 2006 Accelerated Clean Up Goals projects ##'s of surface barrier systems to be installed.
- Four EM Installation Closures by 2006 - Rocky Flats, Mound, Fernald,

Development Process

- Snowbird - Capping Workshop, 1993
- Park City - Long Term Containment/Stabilization Technology Performance Issues Workshop, 1997
- Salt Lake City - Long Term Cover Systems Technical Working Group Meeting, 1998
- Cover System Information Gathering ⇨ CD ROM Database

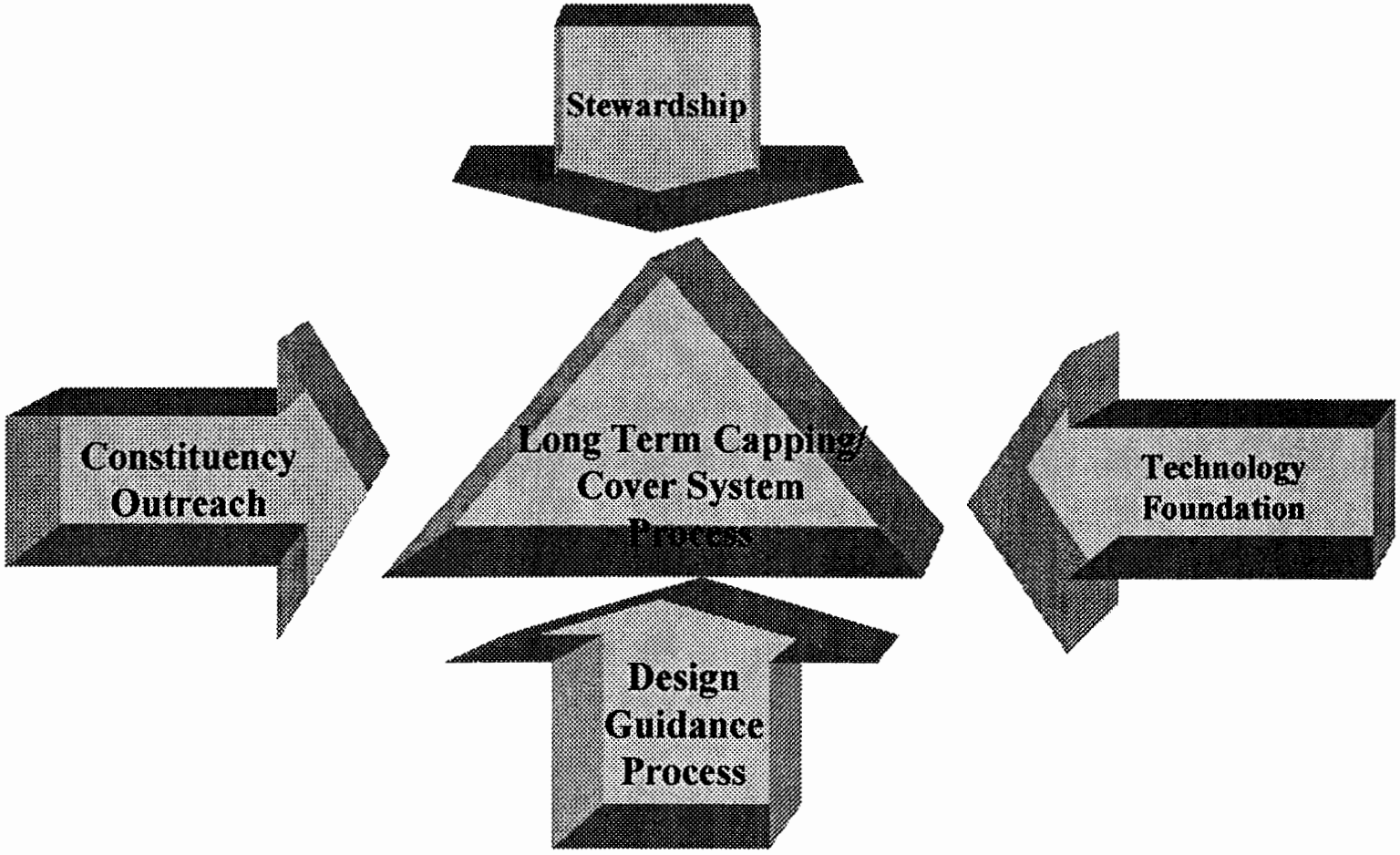
Goal

Develop a surface cover system design and implementation guidance established for DOE End Users and supported by governing regulators that limit contaminant migration consistent with long term (> 100 years), risk based performance criteria for contaminated waste units.

Objectives

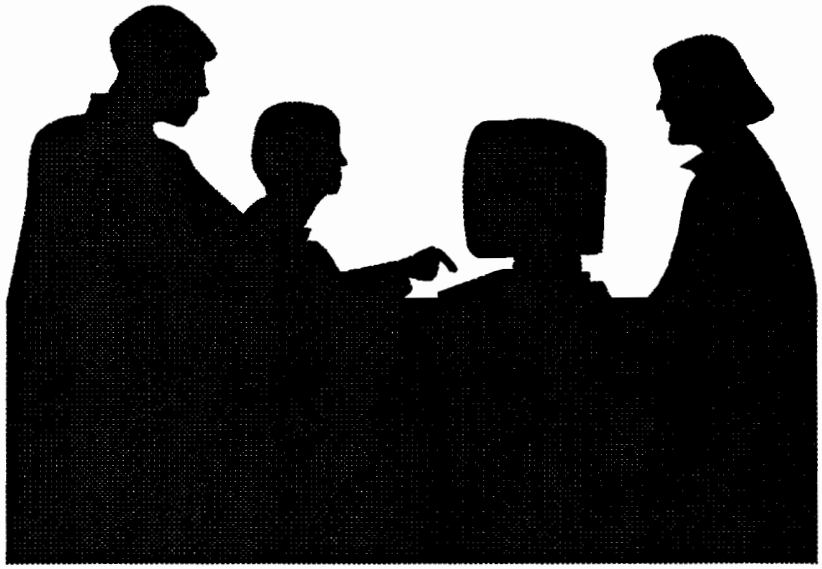
- Long term Capping/Cover System performance parameters coupled to overall risk.
- Design Guidance focused on varied life-cycle performance.
- Installation performance verification.
- Long term performance monitoring coupled to overall system interaction to mitigate risk.

Process Flow Chart



Constituency Outreach

(identify technical gaps & boundaries)

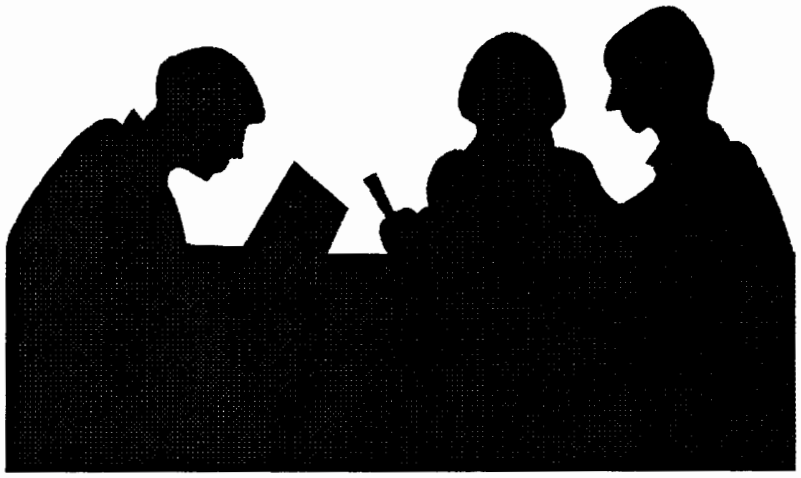


- **End User Interaction**
  - technical assistance
  - technology need statements
- **Regulatory Participation**
  - stakeholder interaction
  - SSEB, WGA, WAZA, CAB
- **Interagency Dialogue**
  - RTDF-ACAP
  - Army COE

SUBSURFACE CONTAMINANTS FOCUS AREA

Technology Foundation

(identify existing technical capabilities)



- **Indentify existing technical capabilities**
- **Formulate technical performance envelope**

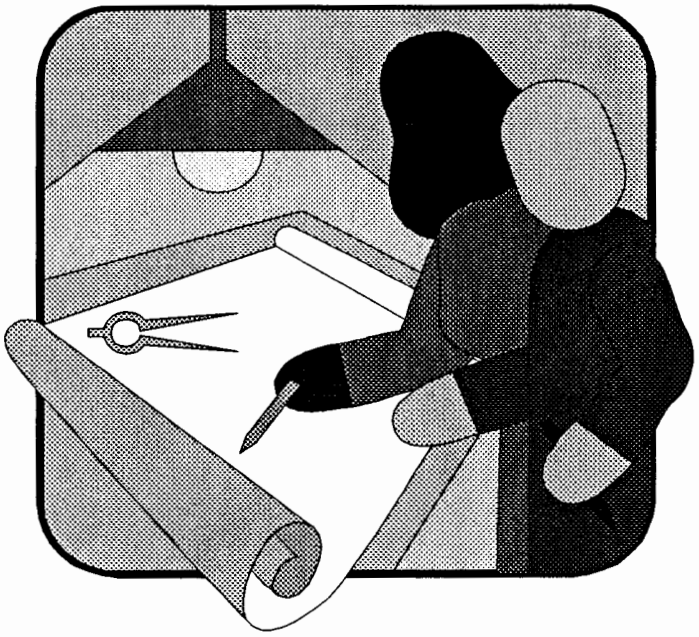
Stewardship

(long term performance system interaction & succession)

- **Active institutional control monitoring & surveillance**
- **Anomaly recognition for early intervention**
- **Environmental & habitat successional process development**

Design Process

(technical parameter development)



Six stage process

- justification
- characterization
- assessment
- design guidance
- deployment
- stewardship

Long Term Capping/Cover System Process

SUBSURFACE CONTAMINANTS FOCUS AREA

Outcome ⇨ **a surface cover system design and implementation guidance for contaminated waste units:**

- **established for DOE end users;**
- **supported by governing regulators & stakeholders;**
- **limit contaminant migration consistent with long term (> 100 years);**
- **based on risk performance criteria.**

LONG TERM CAPPING/COVER SYSTEM STRATEGY

Overview

The US Department of Energy (DOE) 2006 Accelerated Cleanup Plan for environmental cleanup identifies the use of surface barrier systems for source term containment as a vital remedial option. Current surface barrier systems (capping/cover systems) are focused on complying with regulatory guidelines (i.e., RCRA, CERCLA, NRC) to minimize infiltration through hydraulic isolation and surface runoff optimization. Key performance parameters for implementing these barrier systems are durability and sustained barrier performance in-concert with the waste layer longevity; i.e., hazardous and radiological constituents. Present regulatory guidelines highlight barrier system performance as a relatively short duration; i.e., < 100 years.

Regulatory requirements for (CERCLA, RCRA, and NRC) identifies surface barrier system (i.e., capping/cover system) performance objectives as minimized external exposure and containment protection 100 years beyond the loss of active institutional control measures. To support these performance objectives, a performance assessment model is required to evaluate exposure level estimates based on the selected surface barrier system configuration.

Draft

DOE Order 435.1, Radioactive Waste Management and Implementation Guidance Manual M 435.1 highlights containment durability and performance assessment results to evaluate a 1000 year period of performance for potential risk impacts to external receptors. 'Long Term' surface barrier system performance (i.e., >100 years) requires long-lived waste constituents containment (e.g., radionuclides) coupled to overall risk based performance for the waste unit, as promulgated by DOE Standards (DOE Order 435.1).

This Long Term Capping/Cover System Strategy outlines the programmatic strategy for the technical resolution of long term cover systems. To meet the DOE 2006 Accelerated Cleanup Plan Goals, future surface barrier system technology development activities necessitate addressing 'Long Term' performance issues.

LONG TERM CAPPING/COVER SYSTEM STRATEGY

Purpose

The DOE end-users consistently identify long term capping/cover system issues as an unaddressed technology need. This unresolved technical issue requires the ability to design and construct a surface cover system containing the performance attributes for long term durability; i.e., >100 years. To meet these technical issues improved design and construction practices, along with an integrated verification and monitoring scheme must be developed.

The DOE-EM assessment of current operational technical needs highlights long lived caps (Work Package 4) and remedial system performance verification and long term performance monitoring (Work Package 11) as an emerging technical gap, see Figure 1.

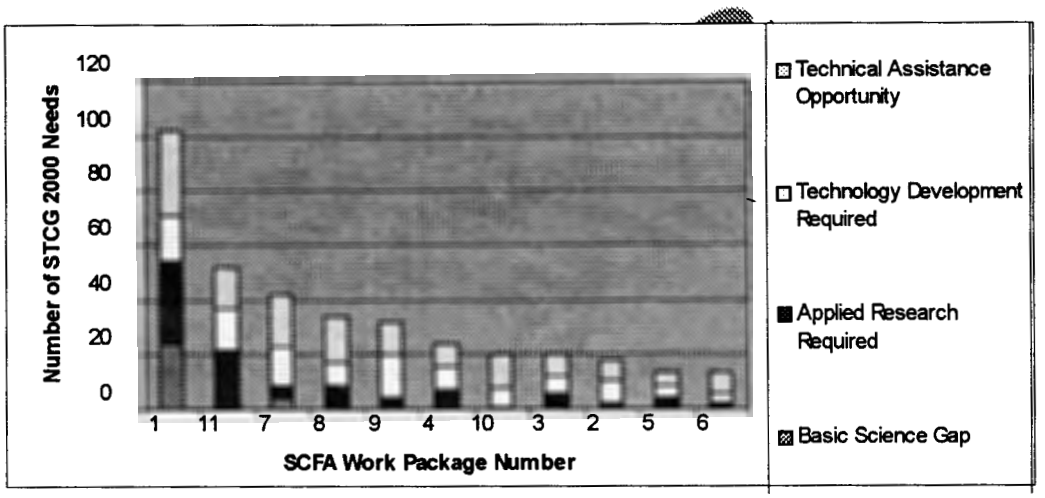


Table 1 outlines the operational technical needs and displays the categories of technical needs.

Work Package No.	SCFA Work Package Title	Basic Science Gap	Applied Research Required	Technology Development Required	Technical Assistance Opportunity	Total
4	SS-04 Long Lived Caps	0	7	9	8	24
11	SS-11 Validation, Verification, and Monitoring of Containment and Treatment	0	22	15	15	53

Table 1 – EM End-User Technical Needs by Category

LONG TERM CAPPING/COVER SYSTEM STRATEGY

Technology developmental and applied research activities encompass 67% of the operational technical needs for Work Package 4 – Long Lived Caps. Work Package 11 – Validation, Verification, and Monitoring of Containment and Treatment Systems emphasis the necessity of performance monitoring development activities to project long term performance scenarios in a creditable fashion for stakeholder concurrence. Long term capping design guidance technical protocols establishes the framework to address long term cover system durability issues and ultimately secure regulatory acceptance.

The impacts from not addressing long term cover system issues are evasive ex-situ remedial strategy and/or a series of interim actions will be pursued, land use modifications to release institutional controls can not be realized, and an increased waste unit maintenance cost due to an extended duration of owner/operator oversight. This issues directly impacts the ability to accomplish DOE Cleanup Goals, but more importantly increased mortgaged costs are required for additional remedial actions.

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Strategy Goal

Develop surface cover system design and implementation guidance established for DOE End-Users and supported by governing regulators that limit contaminant migration consistent with long term (> 100 years), risk based performance criteria for contaminated waste sites.

Objectives

Highlighted below are several areas of focus to address the long term capping/cover system issues.

- Long term capping/cover system performance parameters coupled to overall risk based performance for the waste unit
- Varied Design Guidance to address long term performance parameters (i.e., 100 years to 1000 years).
- Verification/acceptance of cover system construction-installation

- Post-acceptance verification and monitoring of cover system performance and durability.

Strategy Development Process

The Strategy Development Process is focused to address the long term capping/cover system issues identified in the objectives highlighted above. The Strategy Process is based from several workshops conducted from the past several years. The Park City, UT Workshop, conducted in 1997 identified several key areas requiring further development.

- Long Term Capping Performance Criteria
- Performance Modeling
- Prevention and Mitigation of Failures
- Natural Analog Interface
- Existing Cap/Cover System Data Review
- Regulatory Coordination/Interface

A follow-on Long Term Capping Workshop was conducted in 1998 at Salt Lake City, UT. The results of the 1998 Salt Lake City Workshop identified the following key areas for addressing Long Term Capping issues.

- Risk Based Cover System Development
- Identify and Incorporate Natural Analogs
- Gemorphology Affecting Long Term Containment Process
- Design Guidance Outline

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Review of the existing technical baseline for capping resulted in the following general subject areas impacting long term capping issues: Engineering, Environmental Setting, Performance Assessment, Verification, Long Term Monitoring/Stewardship and Regulatory Issues. Key subtopic areas were identified for each of the general areas outlined in Attachment A. Review of the current general subject areas revealed the following conclusions related to long term capping implementation:

LONG TERM CAPPING/COVER SYSTEM STRATEGY

Regulatory

- DOE Regulatory Design Basis:
- Applicable to LLRW Disposed after 9/26/88
- Dose Based Performance Objective (Acceptable Risk)
- "Reasonable Expectation" of Performance over 1000 years
- Design back up from Performance Assessment (modeling)
- EPA Regulatory Design Basis (currently in flux):
- Applicable to LLRW Disposed prior to 9/26/88 and Mixed Waste
- Minimize Infiltration (Prescriptive Design based on Hydraulic Conductivity)
- 30 year Monitoring Period
- Design Lacks Integration with Risk (Risk used to Define Problem primarily)
- Lack of Integration and Compatibility between DOE and EPA Design Bases

Engineering

- Revised EPA RCRA/CERCLA Landfill Cover Design Guidance Document soon to be released, but document incorporates alternative design configurations.
- EPA Landfill Cover Design Guidance focused on hazardous waste, not radiological waste forms.
- Reference to long term cover life
- Lack of design factors of safety, potentially obtained from risk analysis
- Lack of addressing features outside of the landfill envelope (i.e., water table depth, lined or unlined landfill, harmful life of waste, nearby populations impacts, use after closure, etc.)

Environmental Setting

- Data Requirements:
- Soil physics, chemistry, biology, and pedogenic effects
- Average and extreme climate data, and climatic shifts
- Plant ecology, animal habitat, and ecological succession
- Effects of episodic events (e.g. fire, drought, disease, pests)
- Current and possible future land use and management
- Technical Gaps:
- Some gaps in site near-term environmental conditions
- Analogs of environmental change and cover performance
- Ecological succession, pedogenesis, and climate-change models linked to performance models

Performance Assessment

- Models of individual components (e.g., covers, waste form, vadose zone, groundwater, exposure, risk)
- Well-instrumented covers (e.g., SNL-ALCD, Hanford, INEEL, LANL, EPA-ACAP)
- Model implementation consistent with data collection and regulator needs
- Quantitative comparisons of multiyear predictions and field data for different environmental settings
- Common framework that links applicable models and allows for optimization of cover design relative to risk
- Incorporation of uncertainty

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Verification/Long Term Monitoring

- Currently failure detected through monitoring wells.
- Visual inspection capable of detecting only gross failure.
- Guidance on instrumentation and approaches needed for performance verification.:
- New caps
- Retrofit for existing caps
- Guidance on monitoring frequency
- Guidance on definition of cap failure
- Stakeholder acceptance of new verification approaches

The integration of these two workshop results, end-user input, and review of current technical methodologies are the basis for the Long Term Capping/Cover System Strategy. This strategy provides the framework for tackling Long Term Capping issues and identifies the path for development activities.

Long Term Capping/Cover System Strategy

The Long Term Capping/Cover System Strategy is a multi-staged program incorporating both stakeholder/end-user long term performance criteria interaction along with the technical development activities to address the performance criteria. The multi-stage program is outlined below in Figure 2.

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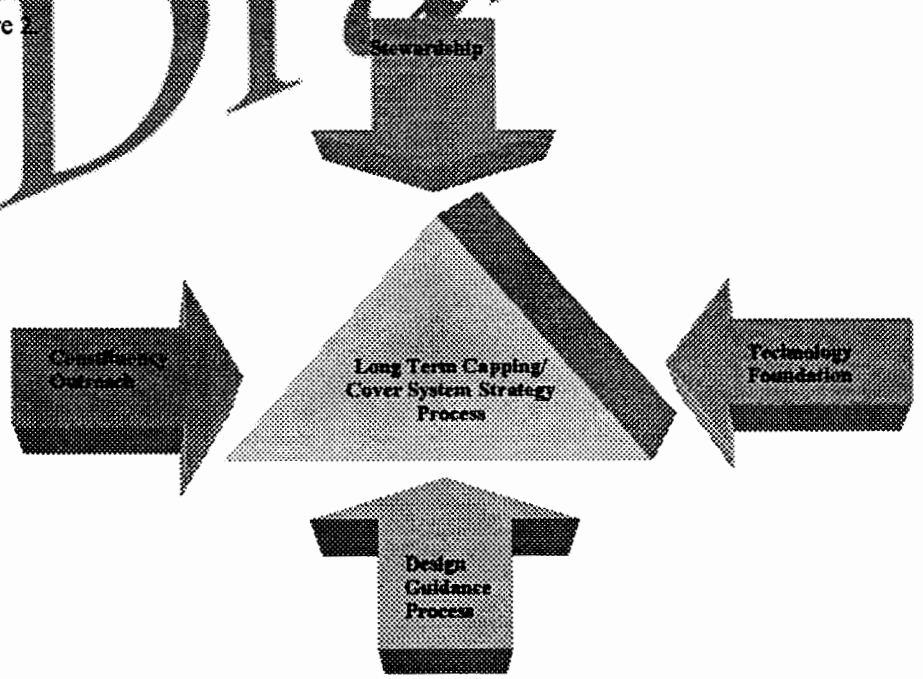

Figure 2 – Long Term Capping Strategy Process

LONG TERM CAPPING/COVER SYSTEM STRATEGY

The multi-stage program framework consists of four parallel paths:

- Constituency Outreach
- Design Process
- Technology Foundation
- Stewardship

The Constituency Outreach, Technology Foundation, and Stewardship paths provide data input and feedback as the Design Process, the primary path, progresses through the following phases. The Constituency Outreach path consists of regulatory, interagency, and end-user interaction. The Technology Foundation path links the design process with technology development; this path inputs existing and new data to fill gaps in the design process. The Stewardship path establishes the long term commitment to maintain containment performance standards and feedback to the design process for modification. The integration of these three paths provides the technical and end user/stakeholder input for the varied performance duration design process. The Long Term Capping Design Guidance is the end-user product to address long term durability and performance issues/projections.

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Designs Process (DOE long-term issues are in italics)

The Design Process follows a six stage process to develop design guidance to address varied performance requirements based on overall system risk potential. The first three stages are pre-design stages, the fourth and fifth are design stages, and the sixth is a post-design stage. Each stage discussed below emphasizes key topical areas requiring input to resolve cover system design issues. Key topical areas identified in *italics* highlight long term performance issues.

Stage I: Justification

The Justification Stage outlines the information inputs from both existing applicable regulatory requirements and statutes to identifying long term risk parameters for consideration and assessment of the overall containment system interaction with the surrounding ecosystem.

- Prescriptive designs – Design standards or performance standards are promulgated
- Risk-based designs – Site-specific performance requirements will be based on results of EPA human health and ecological risk assessments
- Other stakeholder requirements
- *Long-Term Performance Risks Parameters*
- *Design Life Performance Standards*

Key to developing this justification is end user and stakeholder input. The common end user containment technology need is development of a long term capping design process. Critical to developing an acceptable end user/stakeholder process is identifying the risk parameters impacting/influencing long term containment. Once the long term risk parameters are identified, existing promulgated design standards are assessed against the long term parameters and end user concurrence gained, then Long Term Design Life Performance Standards can be developed. The goal for developing the Long Term Design Life Performance Standards is to provide a design process that addresses variable performance duration (i.e., 100 year to 1000 years). The containment system and its influence/impacts to the surrounding ecosystem formulate the basis for the long term risk parameters.

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Stage II: Characterization

The Characterization Stage outlines the overall system characterization information inputs for identifying long term risk parameters. The information input categories are Waste Conditions, Environmental Conditions, and Institutional Conditions.

Waste Conditions

- Source term nature and extent (geochemistry, mobility, etc.)
- *Long-term changes in source term*
- Waste and waste-site geometry and stability

Environmental Conditions

- Average and extreme climate
- Present ecology and habitat characteristics
- Soil and material properties: physical, hydrological, biological
- Geomorphology
- *Possible long-term changes in climate, ecology, soils, and geomorphology*

Institutional Conditions

- Present land use and institutional controls
- *Potential long-term changes in land use and institutional controls*

The characterization stage evaluates the long term performance changes affecting the waste layer (source term) composition and configuration. The source term changes and surrounding environment influences as a result of long term containment performance progression establishes boundary conditions for the cap/cover system design.

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Stage III: Assessment

The Assessment Stage highlights key contaminant release pathways impacting the stability and long term progression of the containment system. Evaluation of these release pathway responses is direct inputs to the EPA Risk Assessment Framework. The Assessment Stage areas for consideration are the physical and hydrogeologic impacts to contaminant release pathway responses and the projected long-term changes in key release pathways.

Physical and Hydrogeologic impacts to contaminant release pathway responses.

- Water infiltration and leaching

- Wind and water erosion
- Plant and animal intrusion and transport
- Gas diffusion and escape
- Subsidence
- Seismic events

Project long-term changes in key release pathways in responses.

- *Climate extremes and long-term changes*
- *Ecological variability and long-term succession*
- *Pedogenesis (soil development)*
- *Episodic events (fire, overgrazing, etc.)*
- *Catastrophic events (major earthquakes, floods, comets)*

Results from the contaminant release pathway responses combined with the characterization information (Stage II) provide a comprehensive depiction of the long term containment system progression. These results are the necessary inputs to the EPA Risk Assessment Framework. Outlined below are the major categories for the Risk Assessment Framework.

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EPA Risk Assessment Framework:

- Exposure assessment: Identify human health and ecological exposure pathways
- Risk characterization: Characterize risks associated with exposure pathways – Points of Exposure
- *Long-term changes in risk associated with changes in source term and exposure pathways*

The conclusions resulting from the Risk Assessment Framework provides the ability to establish the Data Quality Objectives (DQOs) for long term containment system performance.

A key aspect in formulating the DQOs is recognition/identification of the points of exposure. The DQOs establishes the performance setting to develop the long term capping/cover system design guidance.

Stage IV: Long Term Design Guidance (refinement of EPA design guidance)

The Long Term Design Guidance Stage is a refinement of present regulatory design guidance. The design guidance incorporates information/data gathered from characterization and assessment efforts (Stages II & III) and combines it with the overall end user remedial justification for the long term risk parameters and performance standards (Stage I). These design guidance components are made up from identifying expected long term performance criteria, cost criteria, verification requirements.

- Performance Criteria: Either prescribed or based on site-specific release processes and exposure pathways.
- Cost Criteria
- Performance Assessment

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Several design tools and considerable data input from the Technology Foundation path:

- Performance models: water balance, transport, erosion, ecological succession
- Test pads and interagency studies (e.g., RTDF-ACAP and WAZA)
- Existing SCFA database
- *Natural analog studies*

- Design Criteria
  - Design Elements: foundation, topslope, sideslopes, etc.
  - Factors of Safety to mitigate anticipated failure conditions.
  - Functional Performance Requirements

- Verification/Monitoring Requirements
  - Installation Quality Assurance/Control Measures: components and materials verification testing.
  - Overall System Performance Verification/Monitoring: quantified containment capability/characteristics.

The Long Tem Design Guidance establishes the technical boundary conditions for long source term containment performance. This design guidance incorporates a varied life cycle approach to accommodate site specific release and exposure pathways. Design guidance validation is an integrated effort through technology development activities, and end-user and stakeholder input. The validation effort is focused on providing quantifiable data for the cover system components and the overall system containment capability/characteristics. Validation results confirm the design guidance capability.

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Stage V: Deployment (Construction)

The Deployment Stage is implementation of Long Tem Design Guidance and validation of the installation specifications to provide credible performance data. An important aspect to design guidance deployment is adaptability to site specific conditions and addressing end-user and stakeholder issues for source term containment.

Stage VI: Stewardship

The Stewardship Stage of the Long Term Capping/Cover System Strategy validates the design guidance boundary conditions and formulates the containment system performance envelope. The performance envelope is critical to an end user's operational scheme and directly affects long source term containment capabilities. Development of the performance envelope is a combination of the data collected from both direct and indirect monitoring methods and techniques. Inherent to the data collected is a detailed assessment of the overall system performance and its interaction within the environmental

setting, presently and future long term duration. Overall system performance signatures recognition is a key aspect of this detailed performance assessment. Performance signature recognition provides the means to identify anomalies early-on to either repair the system and/or continue monitoring. Anomaly recognition allows repair intervention impacting a small area versus repair intervention for a catastrophic failure.

Monitoring

- Cover system monitoring strategy and use of direct and indirect methodologies
- Overall remedial system performance monitoring and influence on surroundings
- Points of exposure monitoring related to remedial system performance

Maintenance

- Vegetative cover stability
- Overall remedial system stability
- Preventative maintenance measures

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Repairs and Mitigation

- System components anomaly recognition/pattern
- Early intervention to minimize evasive repair activities
- Engineered controls for anticipated failure scenarios

Institutional Memory (records) and Controls

- Detailed facility configuration representation
- Diverse field data storage and data synthesis methodology

Summary

The Long Term Capping/Cover System Strategy is a multi-staged program incorporating both stakeholder/end-user long term performance criteria interaction along with the technical development activities to address the performance criteria. The multi-staged program is outlined below in Figure 3.

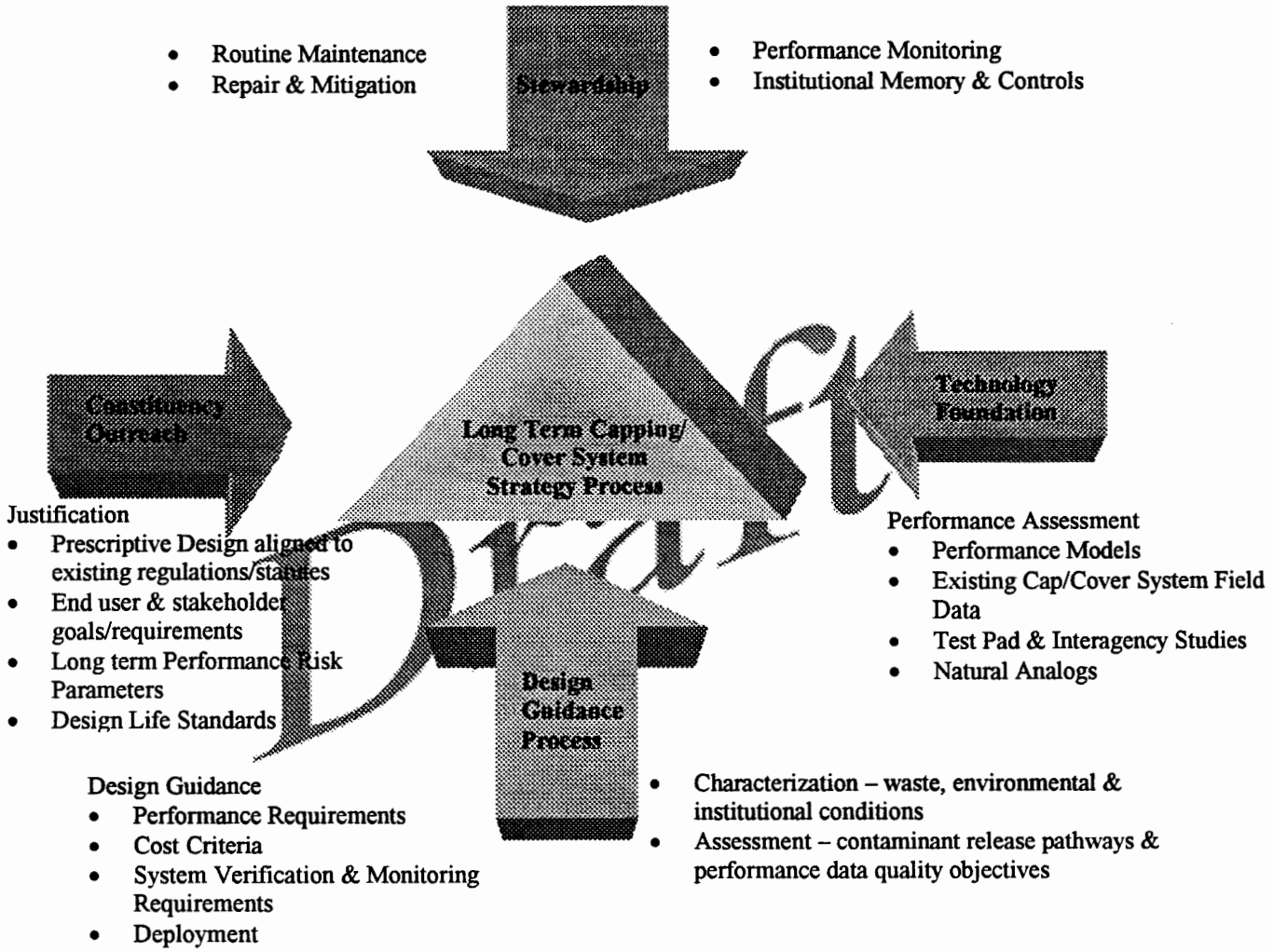

Figure 3 - Long Term Capping/Cover System Strategy Process Outline

Future Developmental Activities

The Long Term Capping Design Guidance formulation effort hinges upon establishing the technical boundaries for long term performance projections. Key technical issues remain unresolved hampering the stakeholder confidence in source term containment performance. General subject areas impacting long term capping design configurations are Engineering, Environmental Envelope, Performance Assessment, and Verification and Long Term Monitoring areas. Identified below are technical areas requiring developmental activities to resolve long term capping performance issues.

Engineering – development activities to address key performance characteristics to formulate and implement a risk based design protocol for long term capping

- identification of engineering parameters critical to designing a long term cover system configuration;
- investigate long term cover system design functional factors of safety ranges to formulate a barrier system factor of safety envelope, e.g., side slope configuration, seismic-spectra response, and structural—flux interaction e.g. subsidence, gaseous/hydraulic flux, etc.;

Environmental Setting – development activities to address environmental dynamic processes impacting long term cover system durability

- investigate ecosystem dynamic processes impacting containment longevity;
- investigate natural analog correlation and/or existing field data to projected field performance longevity

Performance Assessment – development activities leading to formulation of risk based design protocol for long term capping configurations

- investigate of field performance input parameters leading to formulation of regional performance assessment models;
- investigate regional design input parameters/functional performance envelope leading to a risk based design protocol;
- Investigate regional functional performance envelope/input parameters to validate performance assessment models for long term capping.

Verification and Long Term Monitoring – development activities to establish verification and monitoring technologies and methods to validate long term capping system performance and the risk based design protocol both single system and as a integrated entity with a evolving environmental setting/conditions.

- Investigate barrier/system verification technologies to validate capping system installation;
- Investigate monitoring parameters and correlated environmental signatures to monitor overall system performance;
- Investigate verification/monitoring technologies/methods to cross over to long term monitoring techniques based on the risk based design process;

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- Investigate long term monitoring system and diverse data set blending to depict capping system performance to support longevity/durability projections.

The results from these developmental activities formulates the technical baseline for the long term capping design guidance, but resolution of these areas does not constitute final resolution of long term capping issues. Follow-on developmental activities are anticipated to enhance overall design guidance implementation. Technical areas for subsequent development consideration are refinement of performance monitoring protocols, remedial system repair and maintenance protocol, and field data set synthesis. Further refinement of these technical areas is necessary to fully implement the Long Term Capping Design Guidance Protocol.

Conclusion

The Long Term Capping/Cover System Strategy outcome is a varied design and implementation guidance established for DOE End-Users and supported by governing regulators that limits contaminant migration consistent with long term (> 100 years), risk based performance criteria for contaminated waste units. Deployment of the Long Term Capping/Cover System Strategy positively impacts the 2006 Accelerated Cleanup Plan Goals through implementing a long term risk based source term containment options and reduces long term mortgaged costs.

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Attachment A –

Engineering – *design guidance protocol implementation to incorporate risk and long term performance projections.*
- Review feasibility of implementation
- Engineering parameters
- System Integration
- Factor of Safety
- Functional requirements developed from PA results
- Cap configuration and component(s) functions
- Design specification for cap components
- Cap components factors of safety
- Systems engineering assessment for functionality
- Verification and monitoring instrumentation-methodology accommodation in cap design
- Cap constructability evaluation

Performance Assessment – *simulation of potential design configurations and performance projections.*
- *Risk protocol for capping*
- Performance assessment model validation
- Field performance database vs. model validation
- Initial boundary conditions
- Physical properties
- Climatic conditions
- Average conditions – best estimate for performance results
- Upper bounding conditions
- Lower bounding conditions
- Model sensitivity and levels of uncertainty
- Model results compared to EPA-HELP Model results for regulatory familiarity
- Monitoring results used validate PA results and/or modifications
- Failure mechanism(s) definition for barrier system performance impacts

Environmental Setting - *evaluated during characterization; establishing initial boundary conditions.*
- Environmental envelope
- Ecosystem dynamics
- Climate
- Habitat
- Vegetation
- Surface soil pedigenesis
- Natural analog
- Structural geology (UCRL 1590)

Waste form longevity
Average and extreme climatic changes
Hydrogeology impacts – Active zone, vadose zone, and surface impacts
Current physical, geochemical, and biological conditions leading to pediogenous
Current plant ecology and animal habitat development
Future land use/institutional controls
Geomorphic evolutions
Catospheric events and impacts
Episodic events

Verification - *constructed barrier system functional assessment; initial barrier system quality assurance check.*
- Installation/construction QA
- Overall System Test
- Cross-over to long term monitoring
- Individual component functional performance validation
- Verification results establishes baseline data set for monitoring and PA validation

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Attachment A – Continued

Long Term Monitoring/Stewardship – *overall long term system performance validation.*
- System longevity
- Monitoring parameters/methods
- System performance to surroundings
- Confirmation of performance projections
- Integral part of cap design

Developing monitoring results level of confidence with stakeholders
Monitoring frequency and duration comparable to risk PA validation
Monitoring instrumentation survivability
Barrier system degradation and corrective action implementation
Monitoring system flexibility leading to upgrades and repairability

Regulatory Issues – *regulatory requirements and guidance impacting long term performance projections.*
Federal, State, Local, Tribal Regulations/Policies
NRC Regulations/Policies
DOE Orders/Standards
Identify generic Long Term Capping Issues
Identify regional Long Term Capping Issues
Assess current prescriptive design vs. risk based design
Barrier System Design Process Acceptance
Monitoring System Acceptance – Transition to Stewardship
Hazardous Waste CERCLA/RCRA Regulations integrated with DOE Order 435.1 – Radiological Waste and 40 CFR 191 TRU Waste
Future Regulatory Organizations – NRC??
Stakeholder Acceptance with self imposed regulations – PA
Regulators additional ARAs – PA input, Monitoring System and Design inputs
Regulatory agency variability

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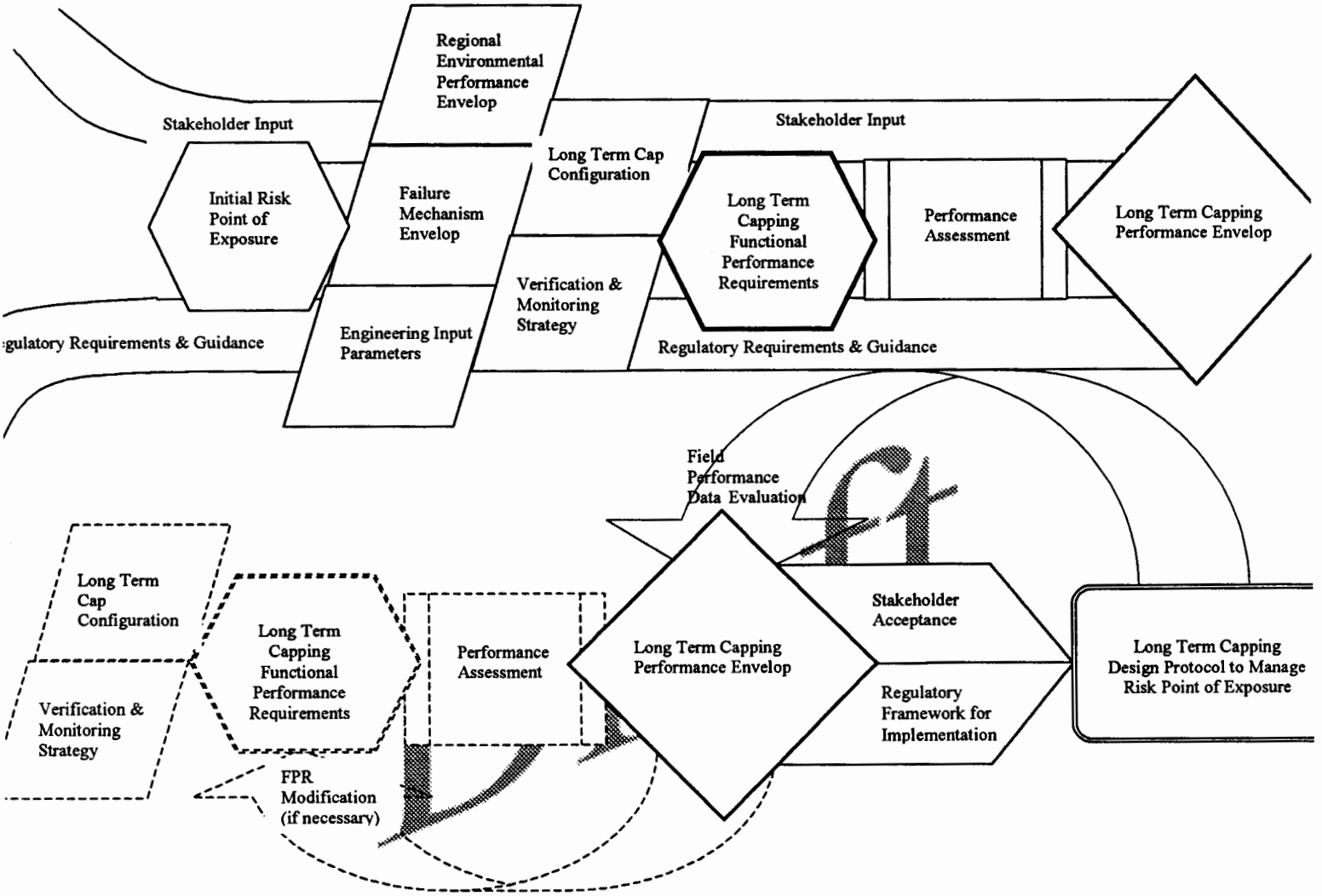
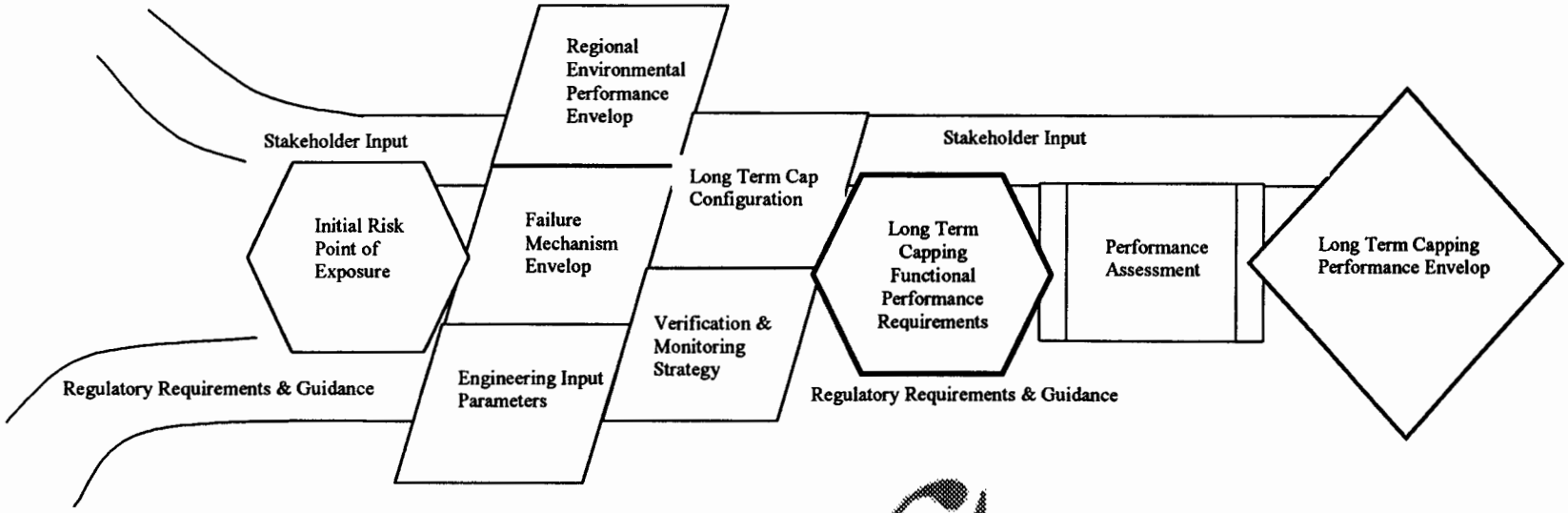
LONG TERM CAPPING/COVER SYSTEM STRATEGY




Regional Environmental Performance Envelop
Stakeholder Input
Initial Risk Point of Exposure
Failure Mechanism Envelop
Long Term Cap Configuration
Stakeholder Input
Long Term Capping Functional Performance Requirements
Performance Assessment
Long Term Capping Performance Envelop
Verification & Monitoring Strategy
Regulatory Requirements & Guidance
Engineering Input Parameters
Regulatory Requirements & Guidance

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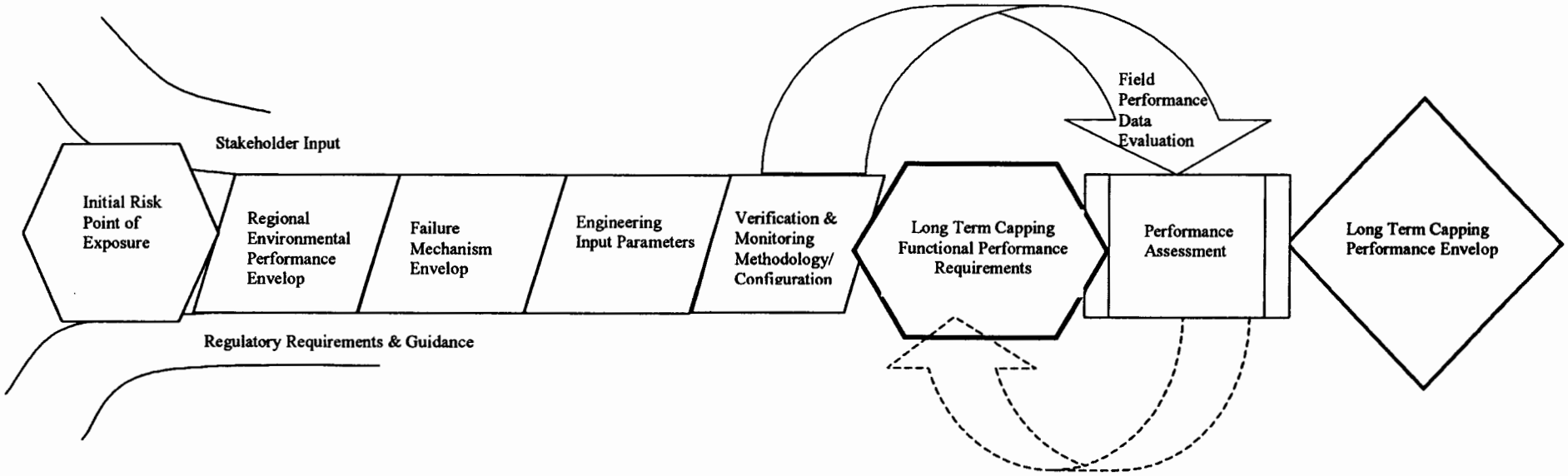
LONG TERM CAPPING/COVER SYSTEM STRATEGY



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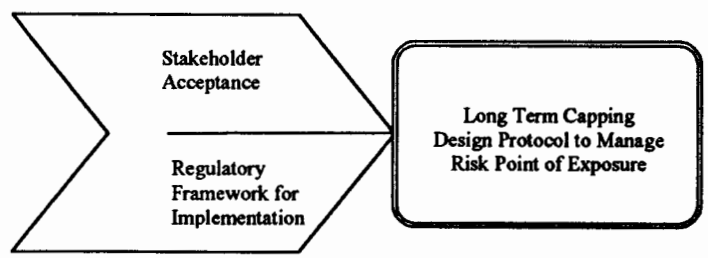


Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites (2000)

- http://books.nap.edu/books/030907181X/html/1.html

NAS:Findings

- Almost all sites will require future oversight
- Engineered barriers have limited lives
- Institutional controls will fail
- Conduct "institutional performance assessments"
- Remediation efforts do not always account for long-term institutional management needs
- Present remediation should aim to facilitate possible re-remediation
- Models used in remediation decisions are inadequate
- Basic research is needed to improve long-term remediation effectiveness
- Assessment of long-term impacts of private-sector reindustrialization is needed

NAS: Recommendations (p.93)

- plan for uncertainty
- plan for fallibility
- develop appropriate and substantive incentive structures
- undertake scientific, technical, and social R&D
- plan to maximize follow-through on phased, iterative, and adaptive long-term approaches

NAS: p 6

- The lack of experience with the long-term performance of engineered barriers, coupled with the heavy reliance being placed upon them at DOE sites, is another factor that necessitates an approach to long-term institutional management that actively seeks out and applies new knowledge.

Performance Monitoring of Engineered Barriers and Stabilized Waste-- NAS: p. 37

- *These physical measurement techniques include groundwater monitoring (probably the most common), vadose zone monitoring, and cover and barrier monitoring (usually some form of vadose zone monitoring, but this can also include physical inspection). There is presently no well-established, reliable, and economic technology available to monitor effectively the vadose zone and heterogeneous media. This observation applies also to fractured subsurface media.*

Stewardship Reports

http://lts.apps.em.doe.gov/stewlink2.asp?showsub=A#disptitle

Many reports and papers have been written by a wide range of authors on the numerous issues surrounding long-term care of DOE sites. The purpose of this section of the DOE Long Term Stewardship Information Center is to provide central access to these documents.

•Cover Monitoring and Long-Term Performance Project

http://www.doegjpo.com/programs/ltsm/general/98report/index.htm#Cover Monitoring and Long-Term Performance

Performance Assessment Framework—Development of a decision framework is under way to provide a consistent approach for evaluating cover performance. The goal is to produce a step-wise guideline for the LTSM Program (1) to project the performance of individual covers for the design lives of disposal cells and (2) to identify appropriate monitoring parameters and instrumentation to track leading indicators of long-term performance as part of routine inspections. The framework links performance and monitoring criteria with potential exposure pathways and risks. It also emphasizes methods for evaluating possible changes in contaminant levels, cover environments, regulatory drivers, exposure pathways, and risks during the design life of disposal cells.

Compliance Report Example:
UMTRA, Durango

http://www.doegjpo.com/programs/ltsm/general/tech_doc/i-an-report/dur.pdf

- Annual Inspection/Report
- Groundwater Monitoring
- Maintenance
- Corrective Actions Taken
- Photo Log

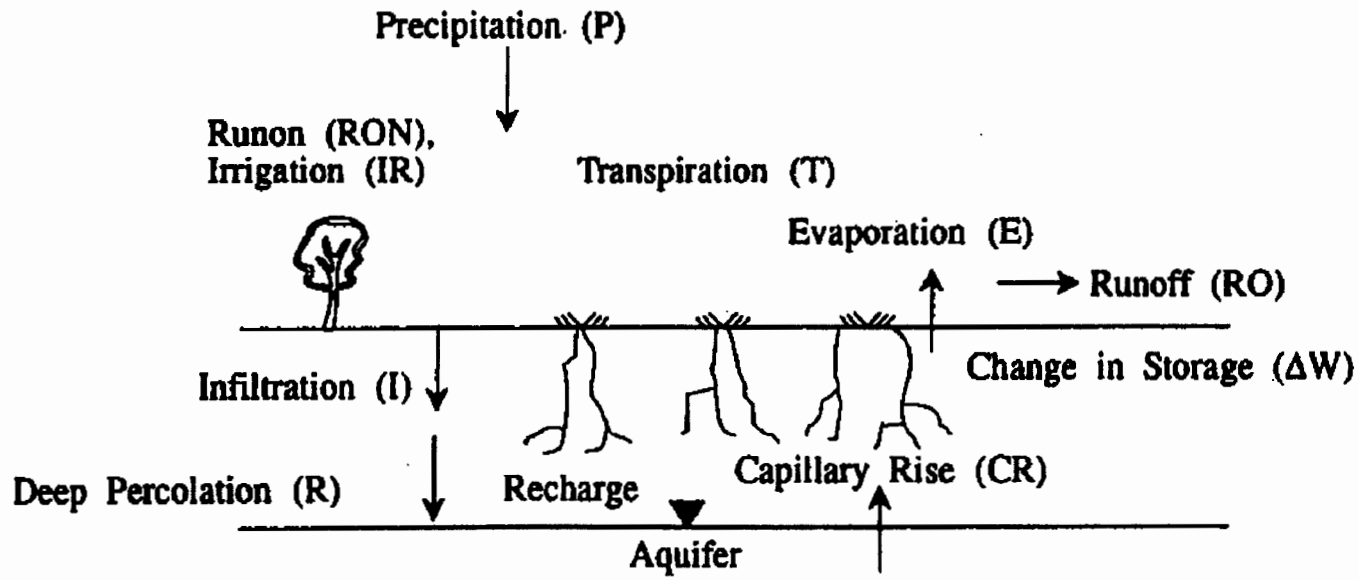
Example Monitoring Program

Medium	Type	Locations	Frequency
ESH-17, Air Quality			
Air	H-3 & particles:	11 Area G perim.	Bi-weekly
	Gross α,β,γ	3 pop.receptors[1]	
	Particles, isotopic:	14 Area G perim.	Quarterly
	γ, U, Pu, Am	3 pop.receptors[1]	
Direct Dose	TLD	27 in&perim.G	Quarterly
ESH-18, Water Quality[22]			
Sediments	Radiologic[3]	9 in drainages	Annually
NPDES storm	Radiologic[3], PCBs	6 from Area G	Bi-annually
Alluvial waters	Radiologic[3]	3 in PC, 2 in CdB[4]	Annually
ESH-19, Waste Site Study			
Perimeter soil	Radiologic[3],inorg[5]	~80 perim.	Annually
Air-source soil	Radiologic[3],inorg[5]	~80 in G (1/200')	TBD
Mesa run-off	Radiologic[3],inorg[5]	~60 in drainages	TBD
TRU / TWISP	Radiologic[3],inorg[5]	~100	TBD
ESH-20, Biota			
Small mammals	Radiologic[3]	2 grids in G, 1 background	Annually
Vegetation	Radiologic[3]	6 locs in G, background	Annually
Honey / bees	Radiologic[3]	1 loc in G, background	Annually

Water Balance in the Vadose Zone

Water Balance in the Vadose Zone

- **Definition:** A statement of mass conservation over a given time.



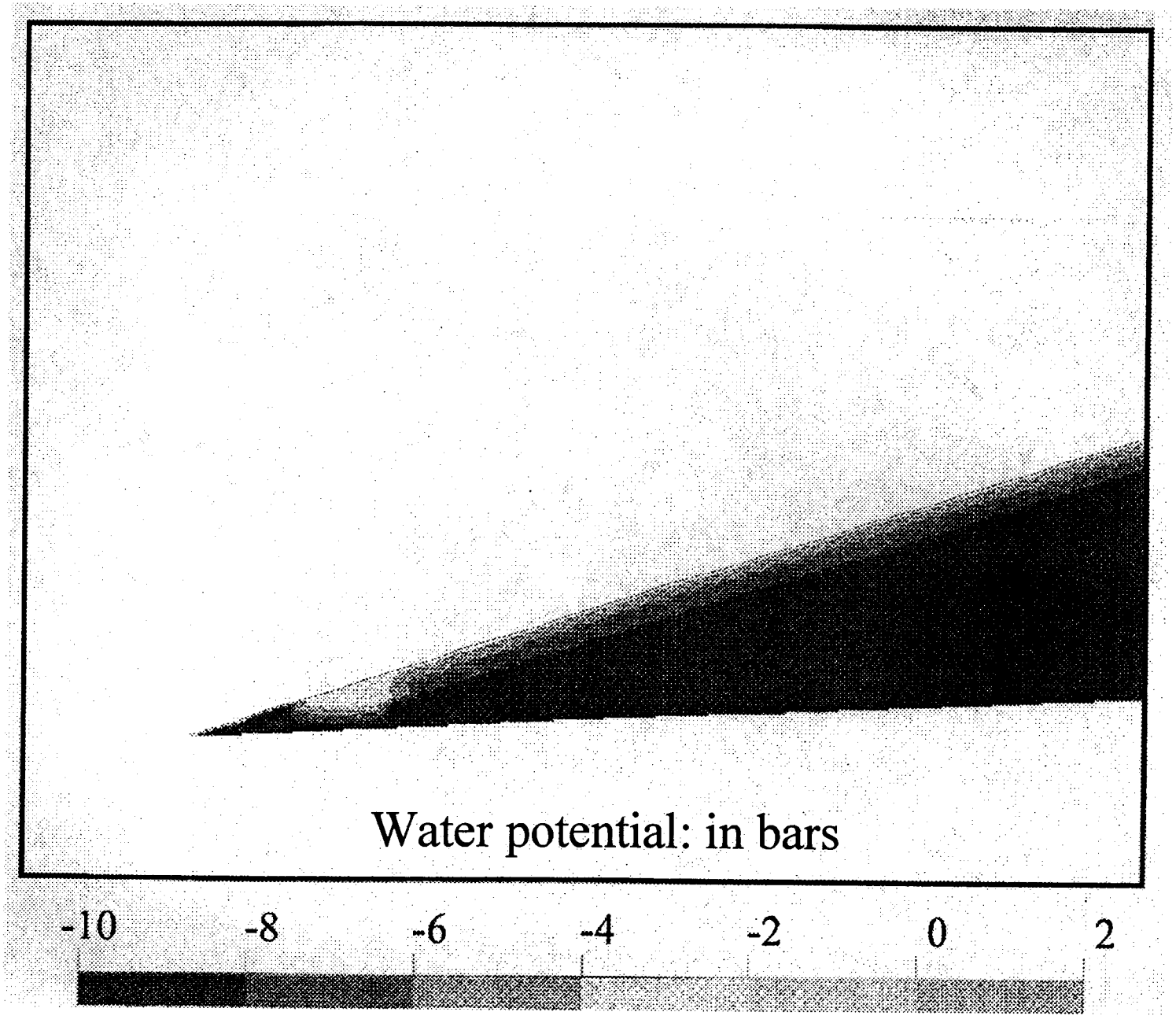
- **Outputs/Inputs:** Units of volume/area in a specified period

Water in: $W_{in} = P + IR + RON$

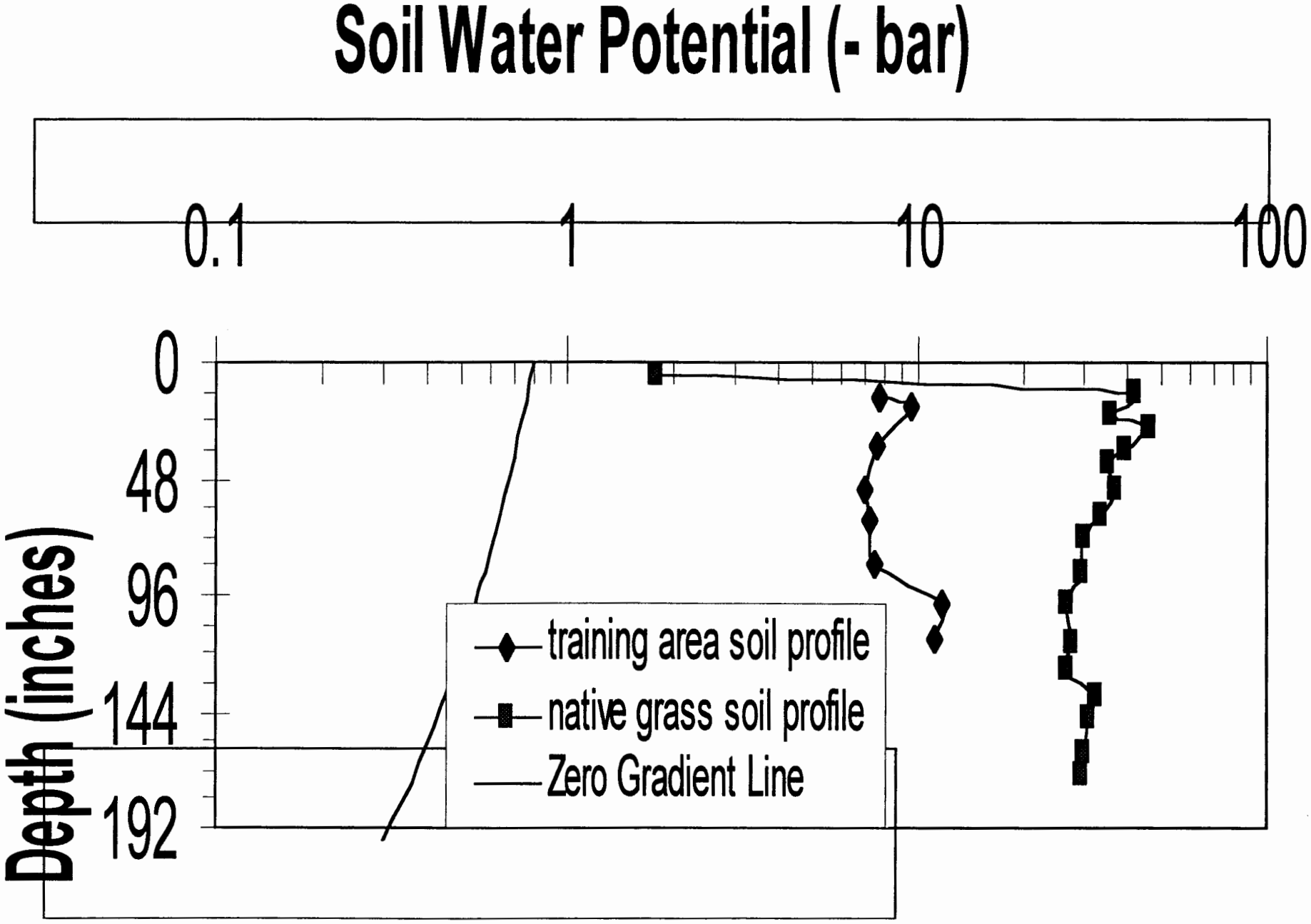
Water out: $W_{out} = RO + R + (E + T)$

$$\therefore \Delta W = P + IR + RON - RO - R - (E + T)$$

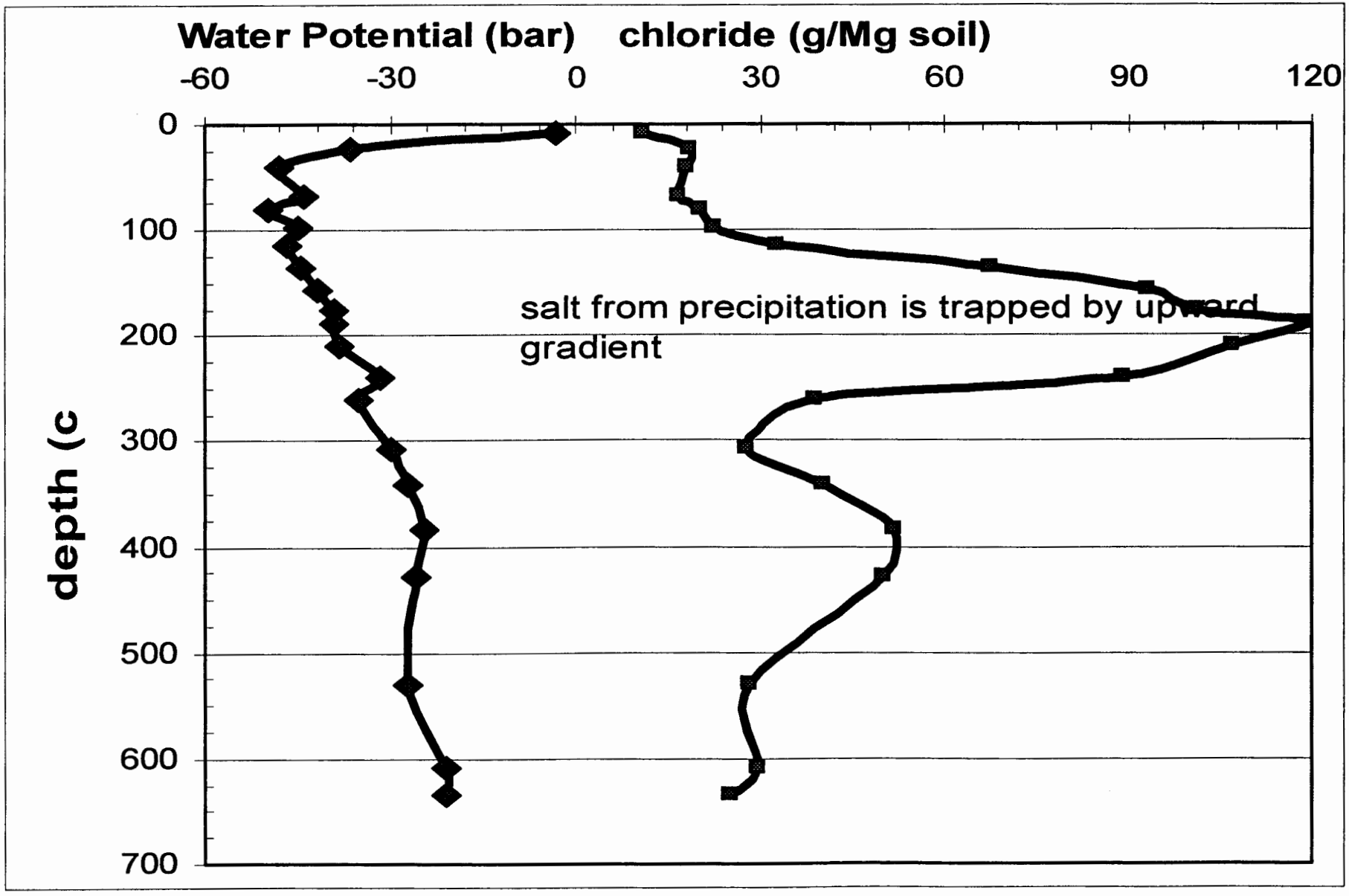
Overland Flow/Infiltration



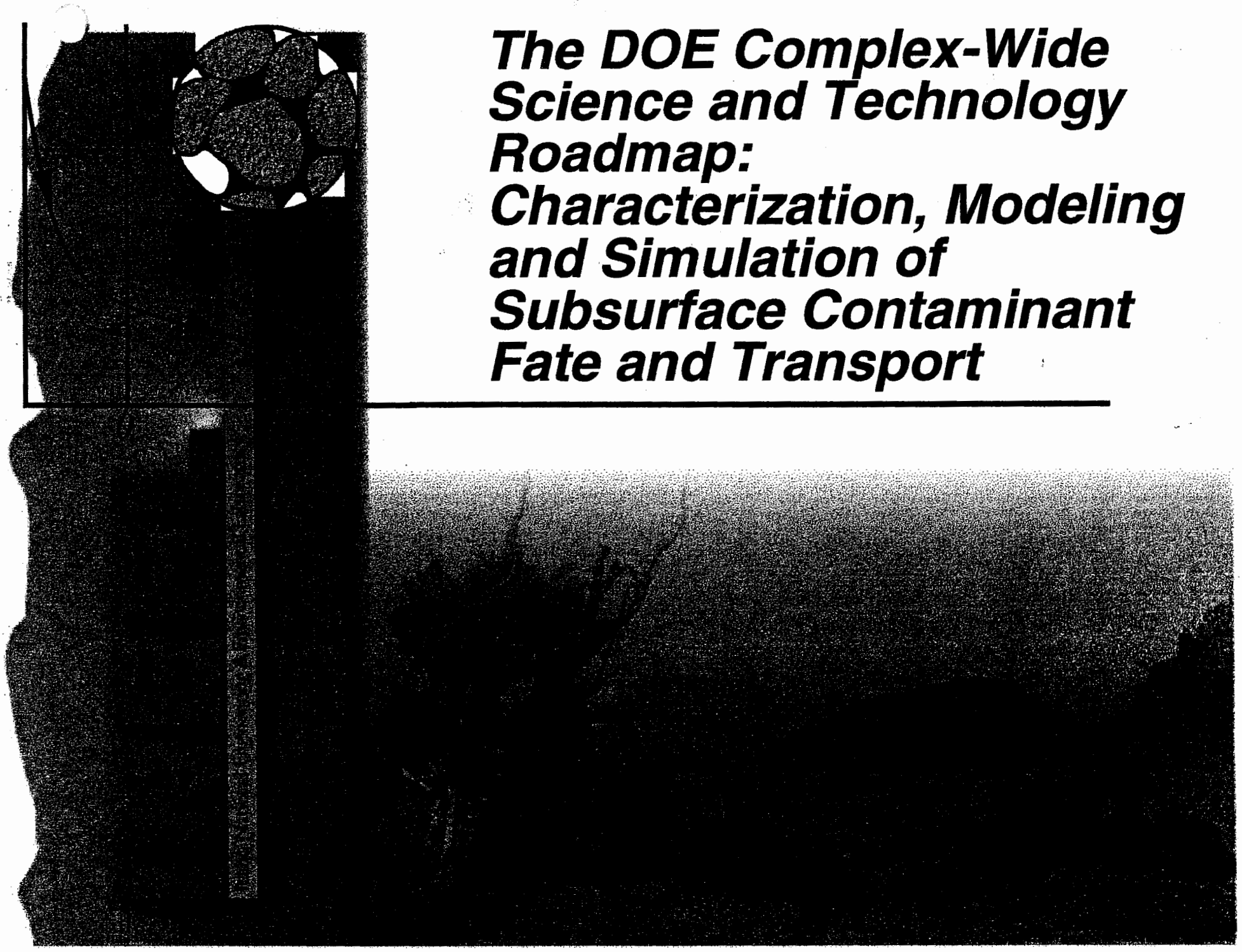
Water Potential Profile: Grassland



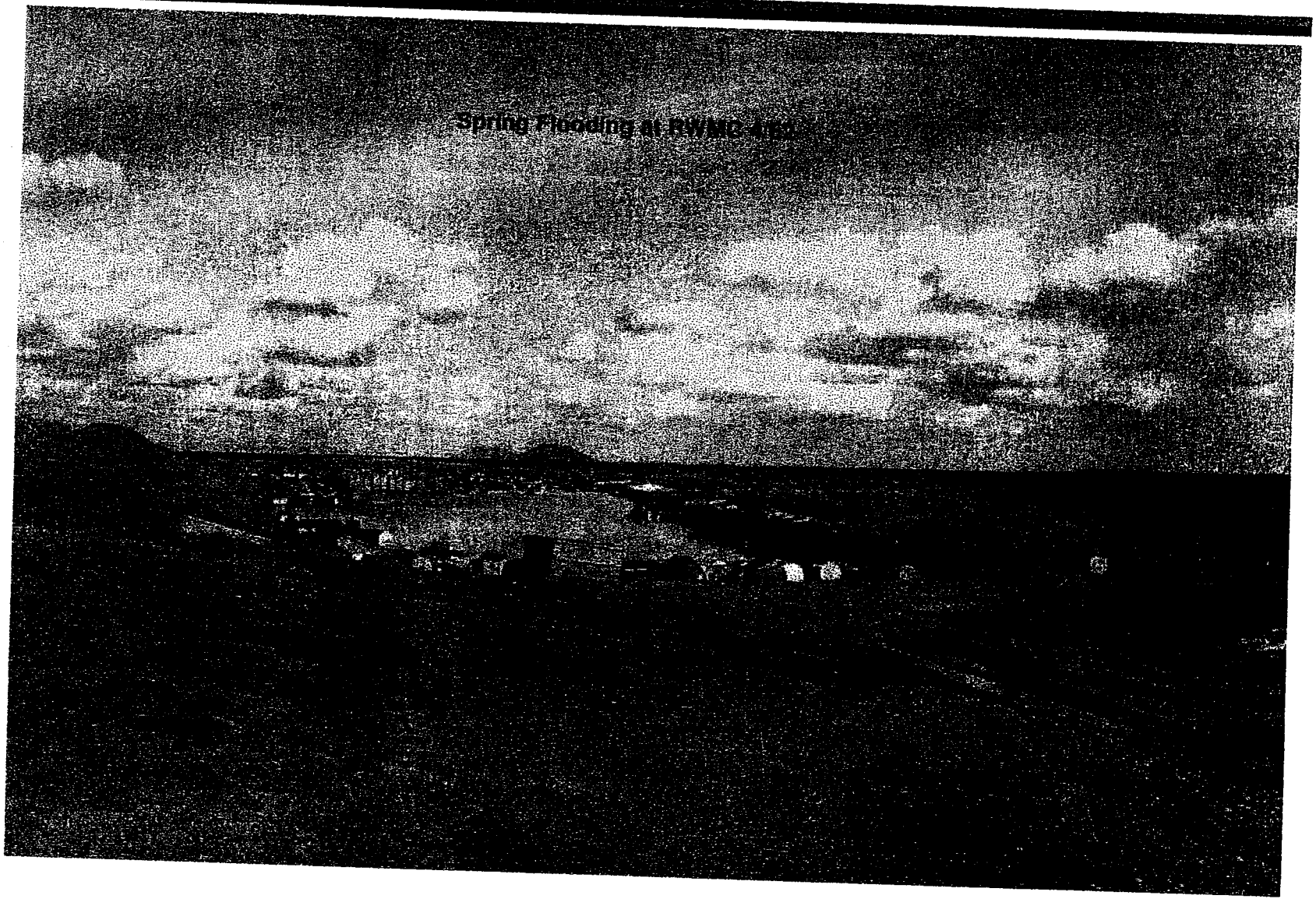
Salt Trapping



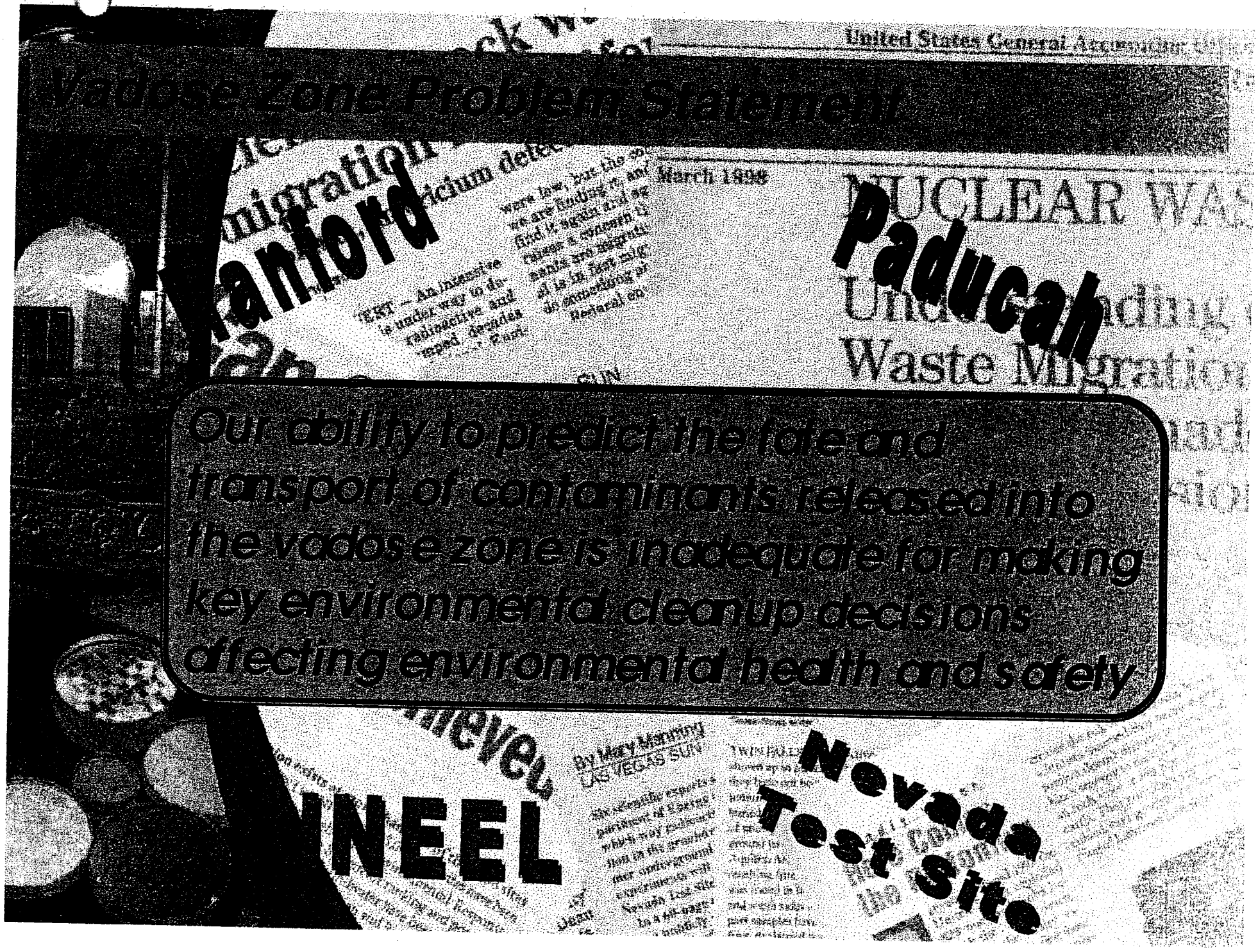
The DOE Complex-Wide Science and Technology Roadmap: Characterization, Modeling and Simulation of Subsurface Contaminant Fate and Transport



Why Are We Here?



Vadose Zone Problem Statement



Our ability to predict the fate and transport of contaminants released into the vadose zone is inadequate for making key environmental cleanup decisions affecting environmental health and safety

Vision

A long-term basic research focus will allow the EM science program to sponsor fundamental research on (vadose zone) subsurface contamination (fate and transport) that can lead to significant knowledge and technical breakthroughs (necessary to make key decisions).

-- Modified from "Research Needs in Subsurface Contamination," NRC 2000, p.118

Thus, DOE Needs:

A path forward to identify science needs and research areas that can accomplish the above

i.e., **a Roadmap.**

What is a Science & Technology Roadmap?

It is: A tool to facilitate science and technology investment decisions.

It is not: A solution to a technical problem.

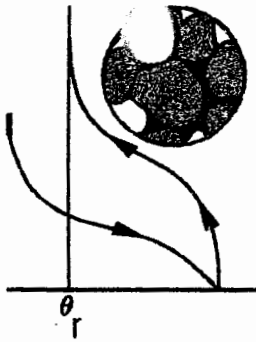
It is also: An iterative process.

The Roadmapping Process Helps Clarify:

- Where you are
- Where you want to go
- How to get there

Roadmapping Facilitates the Creation of a Research Program that is:

- Justified
- Fully Integrated
- Comprehensive
- Solution Driven
- Credible and Defensible



VZ Roadmap Conceptual Approach

Framework for the Roadmap considers:

1) **The needs** of three levels of users (the public, DOE-HQ and site managers, and the research community.)

2) **The time frame** in which remedial/ stewardship decisions must be made (now through 2025+.)

3) **Four necessary components** of understanding and predicting contaminant behavior in the vadose zone:

- understanding processes,
- characterizing and monitoring parameters and variables,
- synthesizing/ interpreting data, and
- assessing models and data.)

Complex-Wide Vadose Zone Roadmap Executive Committee

Dan Stephens, Chair
Daniel B. Stephens & Associates

Steve Kowall, Co-Chair
INEEL

Integration & Communication

E. Weeks	*L. Everett*	*F. Parker*	*C. Enfield*	*C. Vogel*
USGS	IT CORPORATION ~~ARCADIS G&M~~	Vanderbilt	EPA	DoD-SERDP

Content Development

R. Van Genuchten	*D. Borns*	*D. Ellis*	*J. Wilson*
USDA, Chair	SNL, Chair	Schlumberger, Chair	NM Tech, Chair
Physical Processes Work Group	**Invasive Characterization Work Group**	**Non-Invasive Characterization Work Group**	**Simulation & Modeling Work Group**

3/14/00

Invasive Characterization Workgroup

Chair: Dave Borns, SNL
Vice Chair: Everett Springer, LANL

Pat Brady, SNL
Alan Flint, USGS/WRD
Glendon W. Gee, PNNL
Bob Glass, SNL
Susan Hubbard, LBL
Earl Mattson, INEEL
Brent Newman, LANL
Bridget Scanlon, Texas Bureau of Economic Geology
Buck Sisson, INEEL
Scott Tyler, University of Nevada, Reno
Peter Wierenga, WRRC, University of Arizona

Physical Processes Workgroup

Chair: Martinus Th. van Genuchten, USDA
Vice Chair: Brian Looney, SRS

Fred Brockman, PNNL
Markus Flury, WSU/INRA
Bill Glassley, LLNL
Bob Lenhard, PNNL
Peter Lichtner, LANL
Dani Or, Utah State
Kate Scow, UC-Davis
Leslie Smith, University of British Columbia, Vancouver
Robert Smith, INEEL
David Stonestrom, USGS
Ed Sudicky, University of Waterloo, Canada
Andy Tompson, LLNL

Non-Invasive Characterization Workgroup

Chair: Darwin Ellis, Schlumberger
Vice Chair: Ernie Majer, LBL

Pat Berge, LLNL
Michael D. Knoll, BSU/INRA
Mike Powers, USGS
Annette Schafer, INEEL
Tim Scheibe, PNNL
Don Steeples, University of Kansas
Mike Wilt, EMI
Jim Yeh, University of Arizona
Harold Vinegar (consultant), Shell
Rosemary Knight (consultant), Stanford University

Simulation and Modeling Workgroup

Chair: John Wilson, New Mexico Tech.
Vice Chair: John Ullo, Schlumberger

Todd Arbogast, University of Texas, Austin
Alexander Dykhne, Russian Academy of Sciences
Boris Faybishenko, LBL
Andy Felmy, PNNL
Tim Ginn, UC Davis
Larry Hull, INEEL
Cass T. Miller, UNC
Jirka Simunek, University of California, Riverside
Wendy Soll, LANL
Laura Toran (reviewer), Temple University

Where We Fit Into the Framework For Site Remediation and Stewardship*

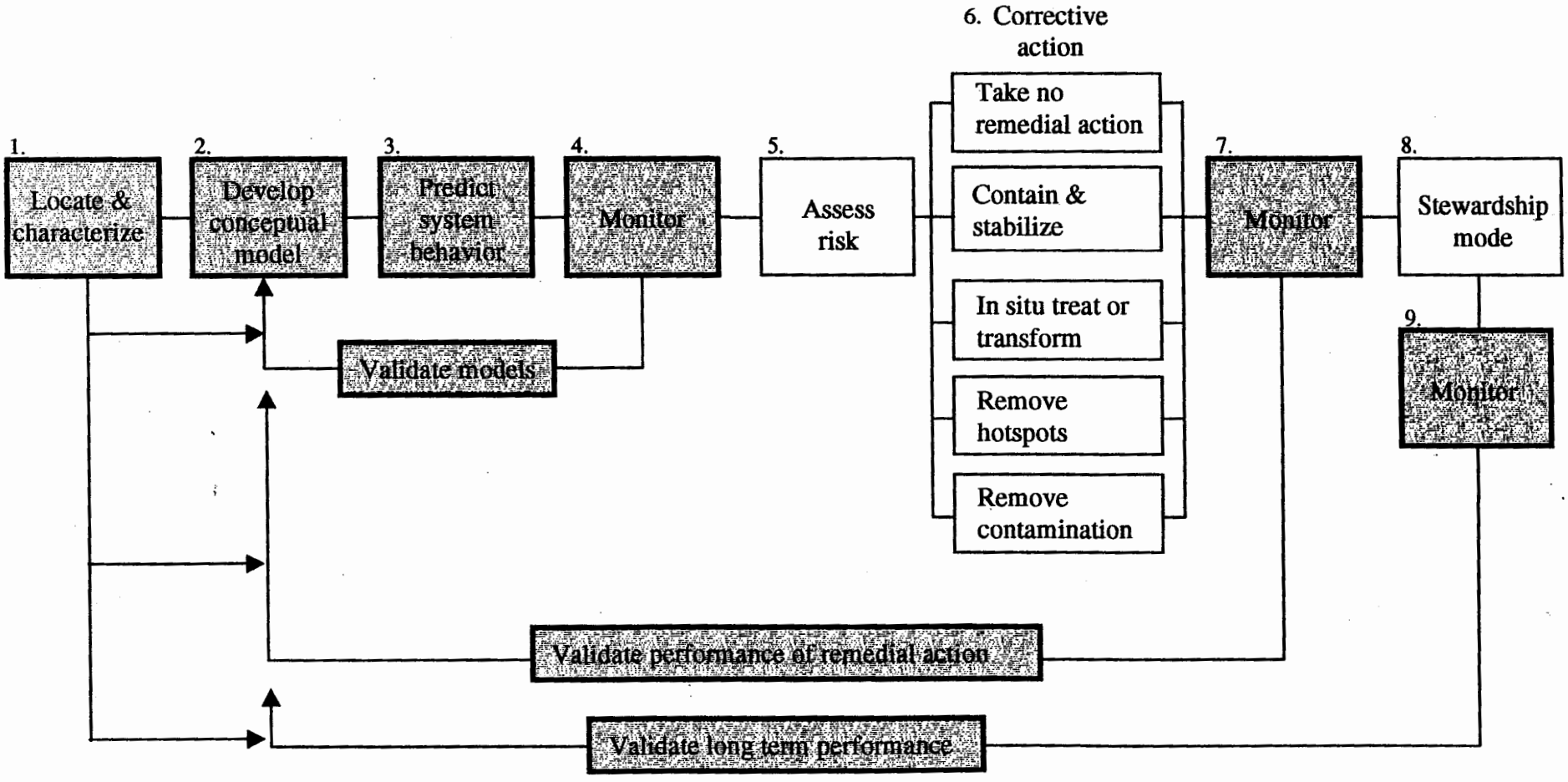
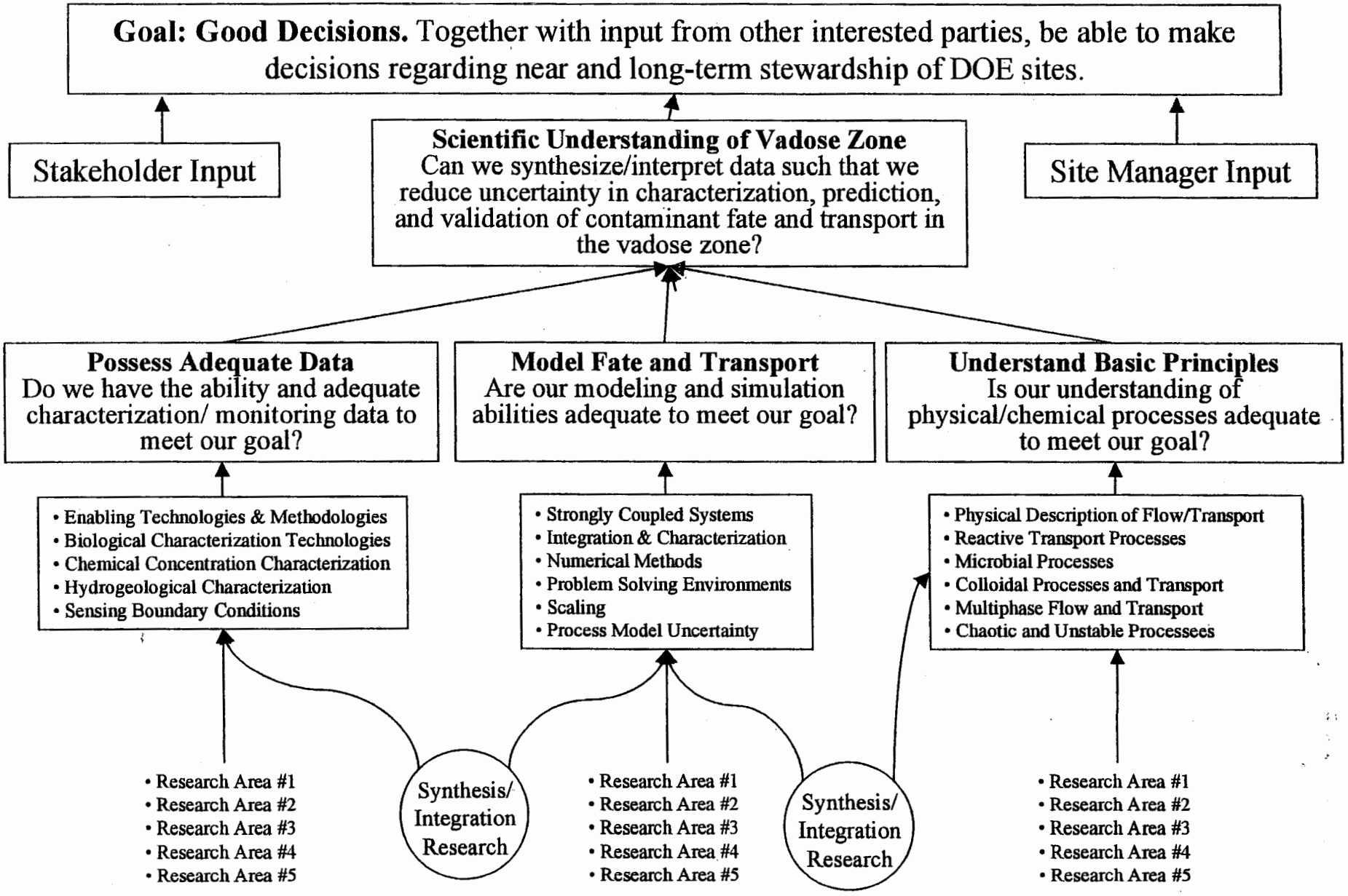


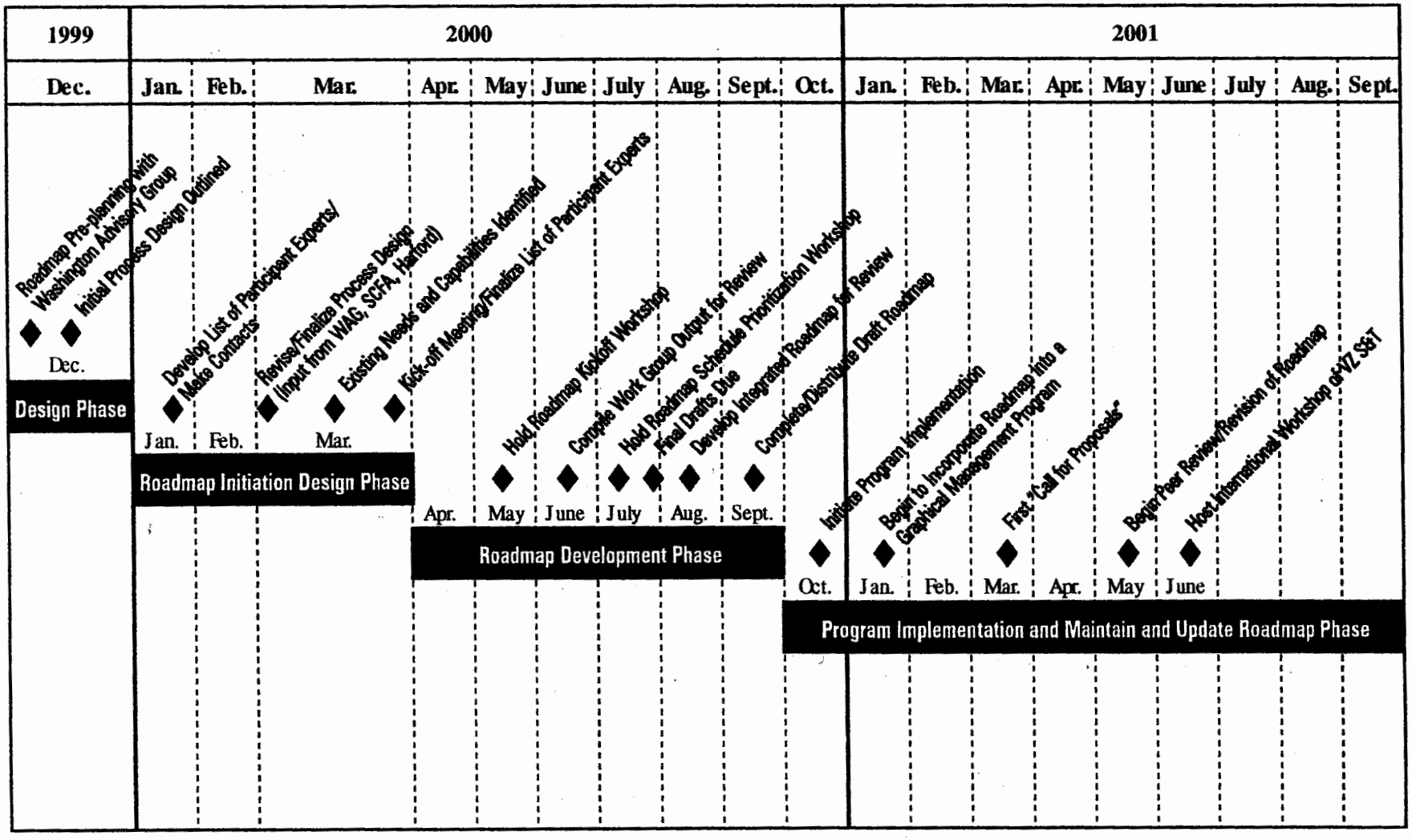
*Figure recreated from *Research Needs in Subsurface Science,* figure 5.1, pg. 95


Goal: Good Decisions. Together with input from other interested parties, be able to make decisions regarding near and long-term stewardship of DOE sites.
Stakeholder Input
Scientific Understanding of Vadose Zone
Can we synthesize/interpret data such that we reduce uncertainty in characterization, prediction, and validation of contaminant fate and transport in the vadose zone?
Site Manager Input
Possess Adequate Data
Do we have the ability and adequate characterization/ monitoring data to meet our goal?
Model Fate and Transport
Are our modeling and simulation abilities adequate to meet our goal?
Understand Basic Principles
Is our understanding of physical/chemical processes adequate to meet our goal?
• Enabling Technologies & Methodologies
• Biological Characterization Technologies
• Chemical Concentration Characterization
• Hydrogeological Characterization
• Sensing Boundary Conditions
• Strongly Coupled Systems
• Integration & Characterization
• Numerical Methods
• Problem Solving Environments
• Scaling
• Process Model Uncertainty
• Physical Description of Flow/Transport
• Reactive Transport Processes
• Microbial Processes
• Colloidal Processes and Transport
• Multiphase Flow and Transport
• Chaotic and Unstable Processees
• Research Area #1
• Research Area #2
• Research Area #3
• Research Area #4
• Research Area #5
Synthesis/ Integration Research
• Research Area #1
• Research Area #2
• Research Area #3
• Research Area #4
• Research Area #5
Synthesis/ Integration Research
• Research Area #1
• Research Area #2
• Research Area #3
• Research Area #4
• Research Area #5

Bringing Goals (Endstates) into Focus

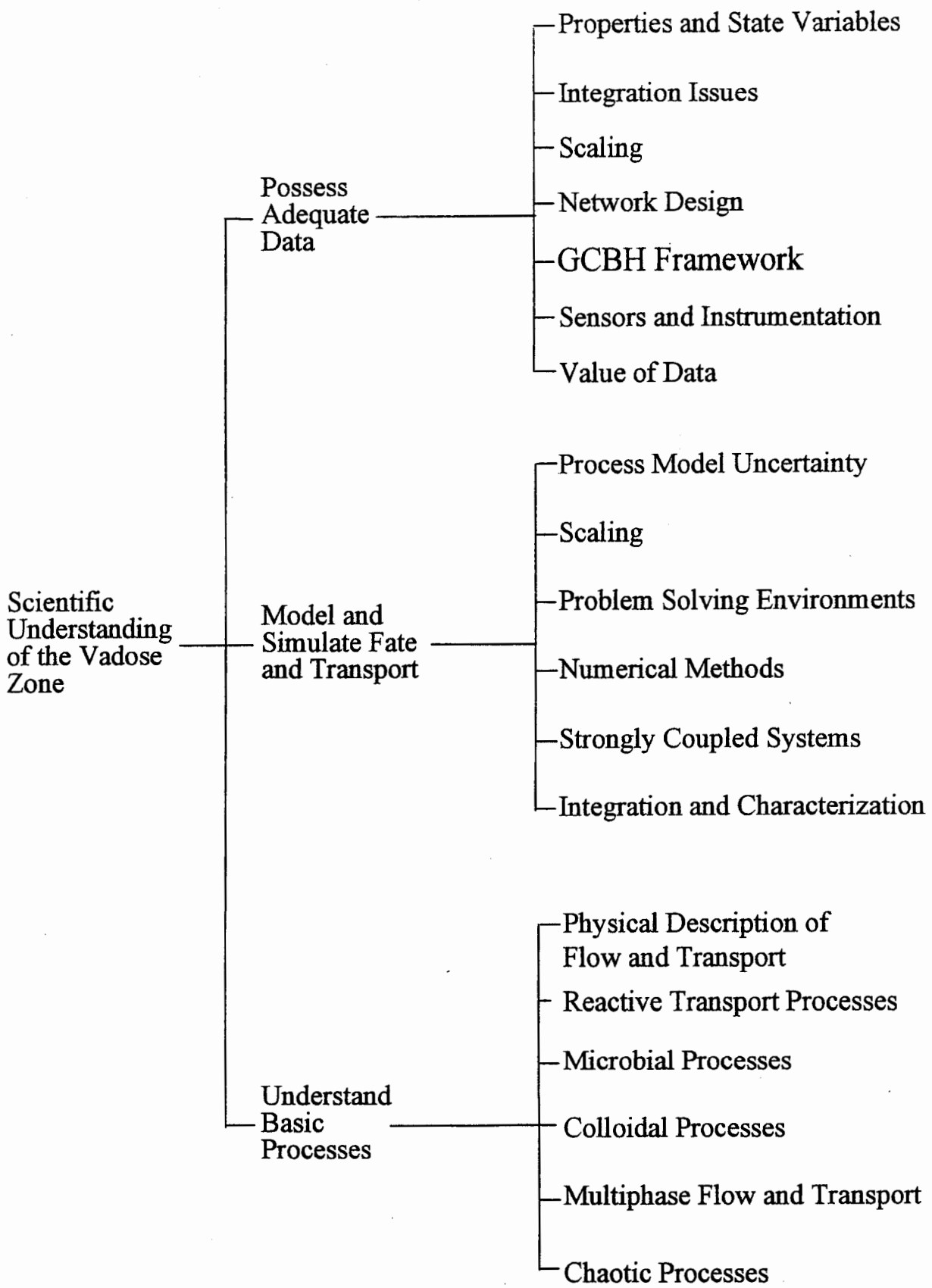
	By 2004 we will have…	By 2010 we will have…	By 2025 we will have…
Characterization & Monitoring	Begun to develop technologically advanced instrumentation and methodology for site characterization and monitoring planned for field demonstration projects.	Installed prototype sensors, applied site characterization technology in field demonstration sites.	Proven methodologies to characterize and monitor sites to ensure the public/stakeholders that unanticipated migration is not occurring (centuries) and to collect field data on parameters and processes at an appropriate scale for simulation.
Modeling	Identified the best available simulation tools for predicting fate and transport at the field scale and for evaluating uncertainty in predictions.	Developed enhanced software and hardware to simulate complex coupled processes at field demonstration and surrogate DOE sites.	A comprehensive numerical code or suite of codes with validated capability to simulate field-scale transport of chemically, biologically, and hydrologically complex, 3-D systems in both short (year) and long (century) timeframes.
Basic Processes	Identified and prioritized all known processes relevant to transport at DOE sites. Initiate basic scientific research in chemical, biological, and hydrological processes.	Integrated existing basic research with site characterization, monitoring, and simulation efforts. Continue basic research.	Comprehensive understanding of basic principles and environmental processes relevant to fate and transport to ensure we can characterize, monitor, and model DOE sites at acceptable levels of uncertainty to stakeholders.

The DOE Complex-Wide Vadose Zone S&T Roadmap: Characterization, Modeling and Simulation of Subsurface Contaminant Fate and Transport



FY01 Activities

- Broaden and Deepen Scientific Consensus Through National Research Council Peer Review
- Broaden Stakeholder Involvement Through Focused Briefings at DOE HQ, etc., and Presentations at National Meetings
- Coordinate With Other Relevant INEEL and DOE Initiatives, Especially Stewardship and EMSP
- Develop a Framework for a National Call for Vadose Zone Science
- Host Gordon Research Conference on Vadose Zone Science
- Update and Publish Complex-Wide Vadose Zone Roadmap


Scientific Understanding of the Vadose Zone
Possess Adequate Data
Properties and State Variables
Integration Issues
Scaling
Network Design
GCBH Framework
Sensors and Instrumentation
Value of Data
Model and Simulate Fate and Transport
Process Model Uncertainty
Scaling
Problem Solving Environments
Numerical Methods
Strongly Coupled Systems
Integration and Characterization
Understand Basic Processes
Physical Description of Flow and Transport
Reactive Transport Processes
Microbial Processes
Colloidal Processes
Multiphase Flow and Transport
Chaotic Processes

External Peer Review

- National Research Council Board on Earth Sciences and Resources, FY 2001
- Fifth International Symposium on Environmental Contamination, Prague, September 2000
- DOE TIE Conference, Augusta, November 2000

Links to Other Programs/Initiatives

- INEEL Subsurface Science Initiative
- INEEL Groundwater/Vadose Zone Roadmap
- INEEL ICES Program
- INEEL Physics Department Environmental Sensors and Long Term Monitoring Initiative
- INEEL Complex-Wide Stewardship S&T Roadmap
- INEEL EMSP
- SubCon Vadose Zone Book
- Hanford Groundwater/Vadose Zone Integration Project
- DOE-Russian Vadose Zone Project
- DoD SERDP-ESTCP Program

VADOSE ZONE MONITORING SYSTEM
CORRECTIVE ACTION MANAGEMENT UNIT (CAMU)
SANDIA NATIONAL LABORATORY

Presented by: Scott Den-Baars, P.E.
IT Corporation

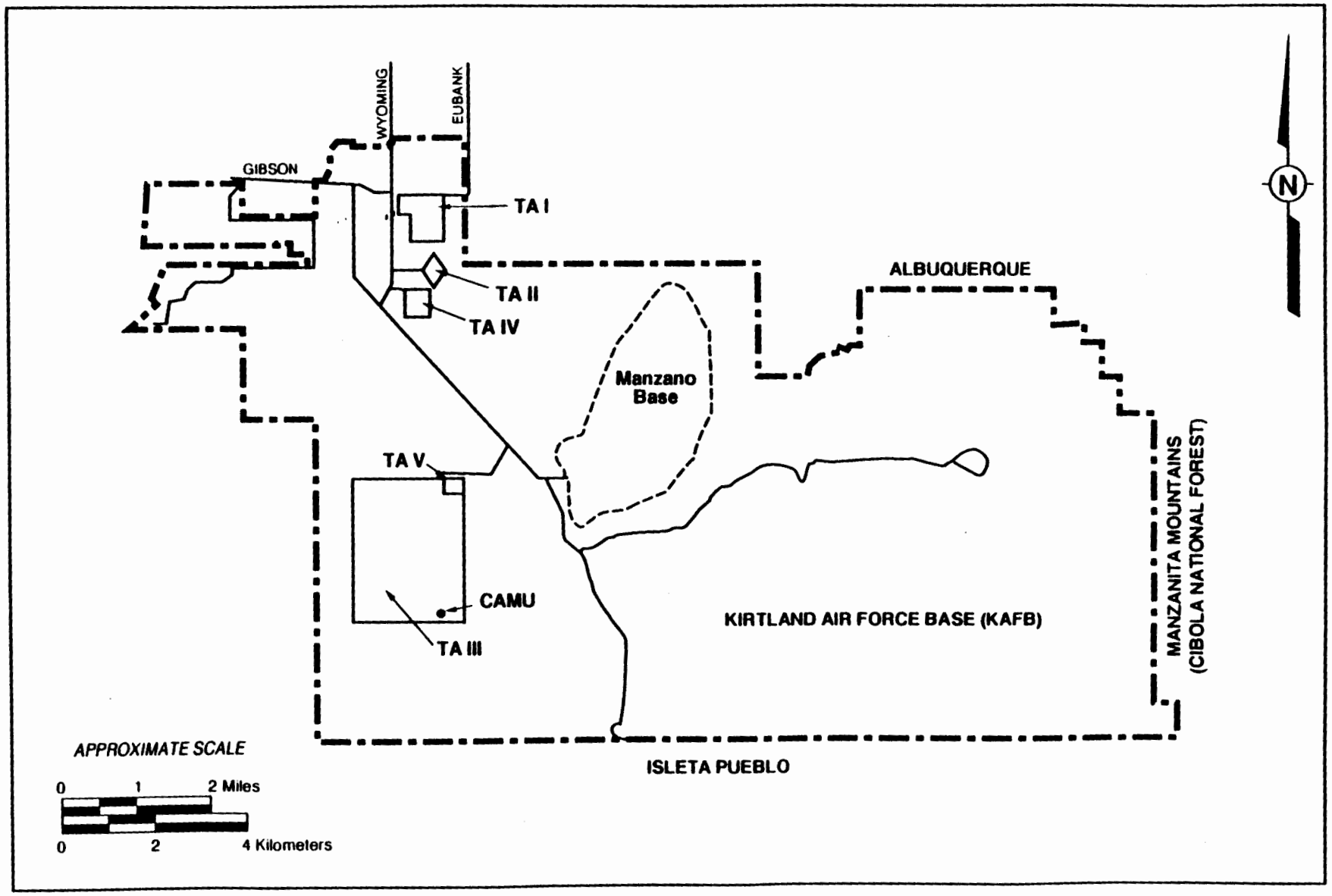


Figure 2-1
Sandia National Laboratories/New Mexico Technical Areas (TA) and the Corrective Action Management Unit (CAMU) in Relation to KAFB

- REGULATORY FRAMEWORK
  - CAMU DESIGNED AND PERMITTED PER 40 CFR 264.552
  - REGULATIONS REQUIRE GROUNDWATER MONITORING FOR CAMU WASTES REMAINING IN PLACE AFTER CLOSURE
  - VADOSE ZONE MONITORING SYSTEM (VZMS) APPROVED AS AN ALTERNATIVE TO GROUNDWATER MONITORING

- GEOLOGY AT CAMU SITE
  - ALLUVIUM
  - SANDS, GRAVELS, SILT, CLAYS OF SANTA FE GROUP
  - DEPTH TO GROUNDWATER - APPROXIMATELY 485 FEET
  - IN-SITU MOISTURE CONTENT DECREASES WITH DEPTH FROM 4.1 TO 1.6 PERCENT (AT 48 FEET)
  - SATURATED HYDRAULIC CONDUCTIVITY RANGES FROM 7.0×10^{-6} TO 7.9×10^{-5} FEET PER SECOND
  - UNSATURATED HYDRAULIC CONDUCTIVITY APPROXIMATELY 3.2×10^{-12} FEET PER SECOND

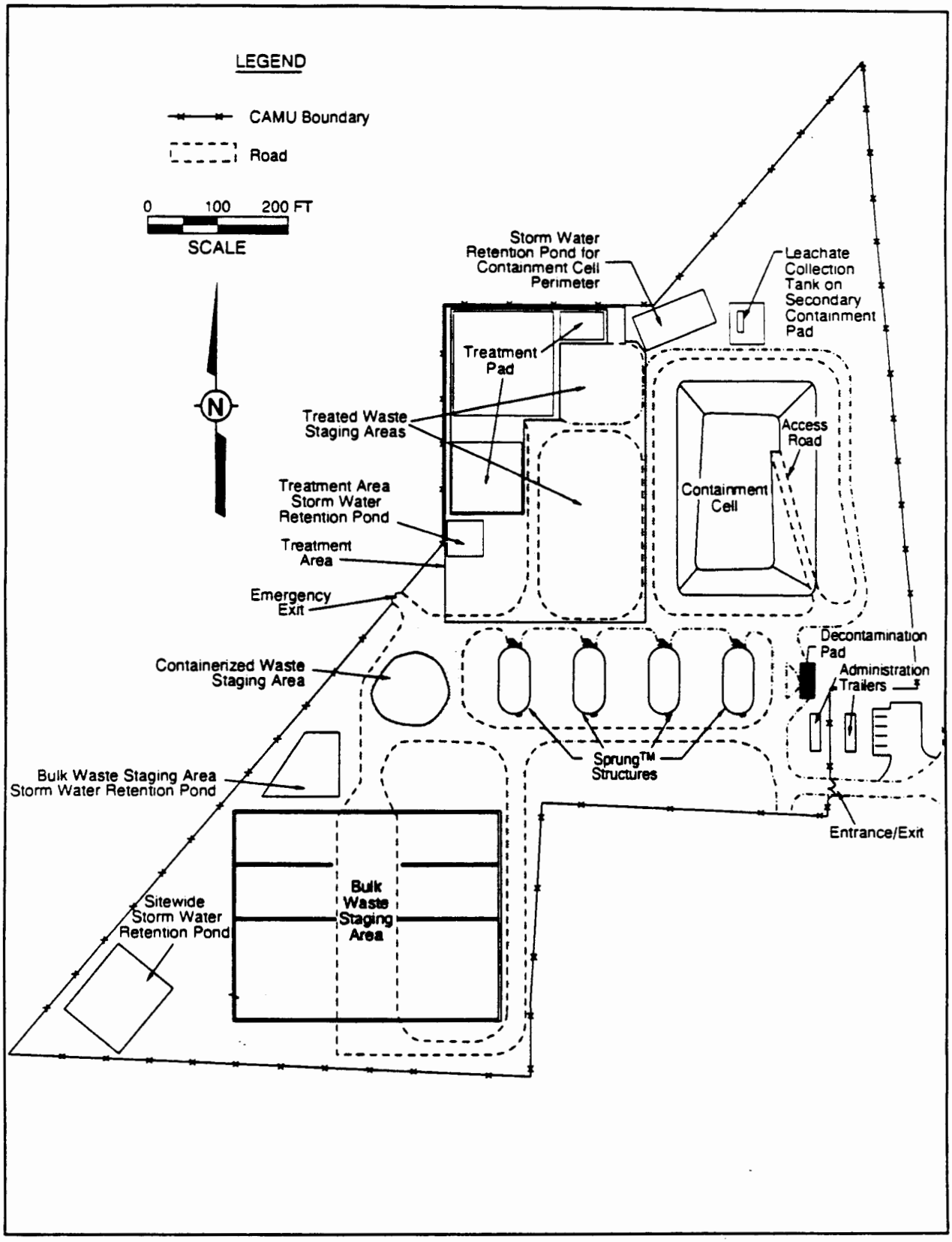


Figure 2-2
Sandia National Laboratories/New Mexico
Corrective Action Management Unit (CAMU) Areal Configuration

- CAMU CONTAINMENT CELL
  - 1,000,000 FT^3 CAPACITY
  - 2:1 (H:V) SIDE SLOPES
  - LINER SYSTEM
  - LEACHATE COLLECTION AND REMOVAL SYSTEM
  - VADOSE ZONE MONITORING SYSTEM
  - CAPILLARY BARRIER COVER SYSTEM

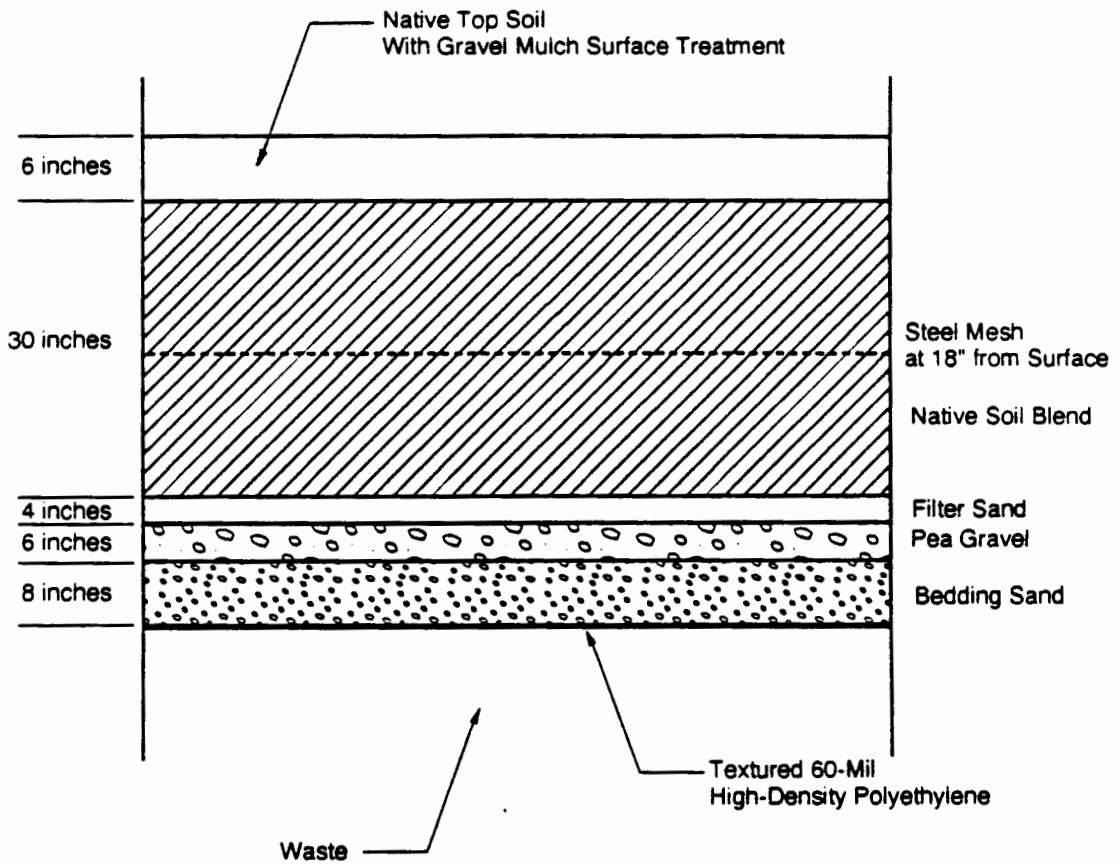


Figure 4-1
Side View of Final Cover System

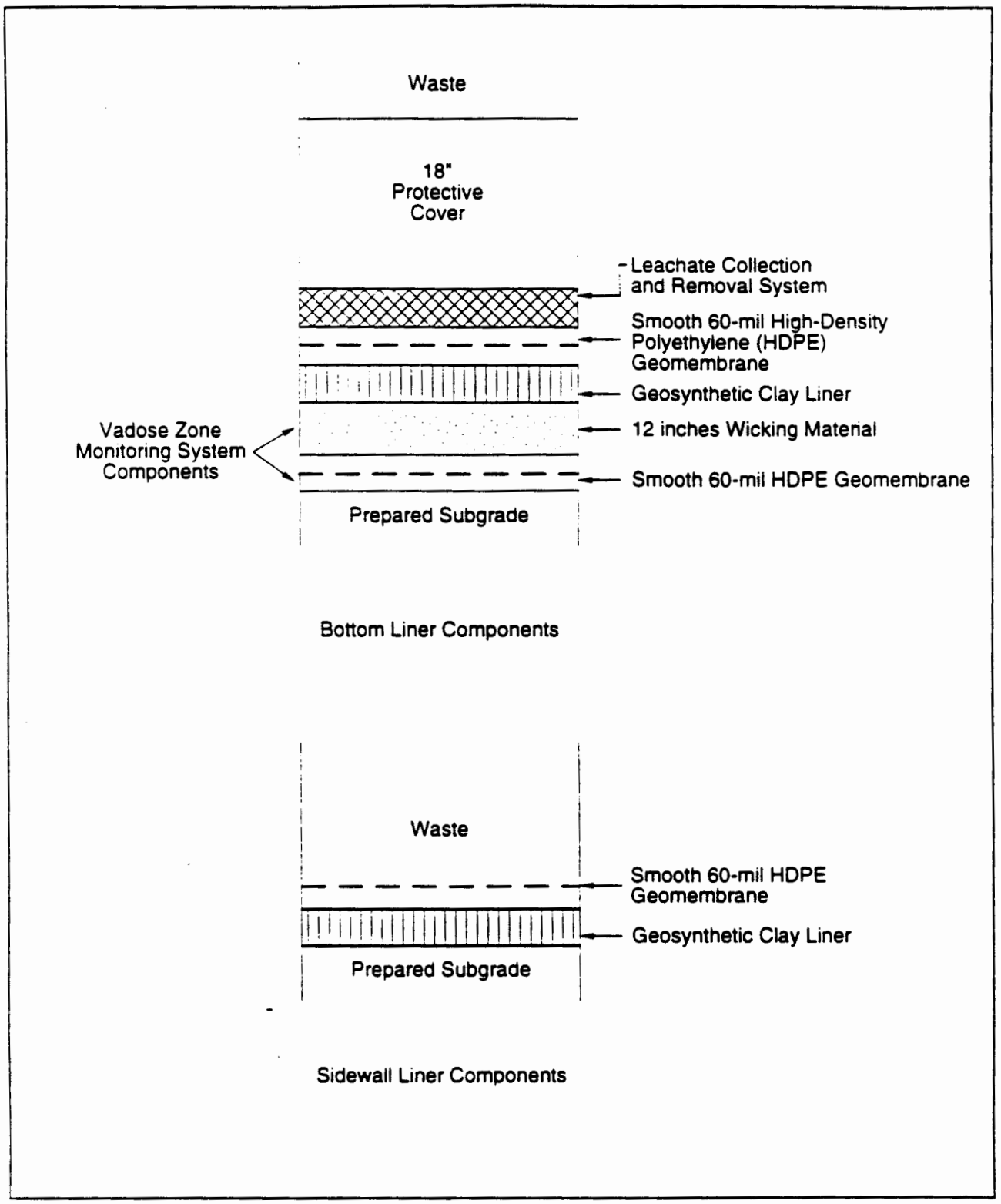


Figure 4-1
Side View of Bottom and Sidewall Liner Components

- VADOSE ZONE MONITORING SYSTEM
  - ALTERNATIVE TO GROUNDWATER MONITORING
  - ADVANTAGES
    - MORE RIGOROUS AND USEFUL RESULTS
    - CAPABILITY TO PROVIDE REAL-TIME DATA ON CONTAINMENT CELL PERFORMANCE
    - MORE TIMELY LEAK DETECTION (600 DAYS VS. 8,800 YEARS)
    - ABILITY TO HELP REMEDIATE OR CONTAIN A POTENTIAL LEAK
    - ABILITY TO DIFFERENTIATE BETWEEN CONTAMINANT SOURCES

- VZMS SUBSYSTEMS
  - PRIMARY SUBLINER MONITORING (PSL)
    - 5' SUBHORIZONTAL ACCESS TUBES
    - MONITOR MOISTURE CONTENT
    - CAPABILITY TO SAMPLE SOIL-WATER AND SOIL-GAS
  - VERTICAL SENSOR ARRAY (VSA) MONITORING
    - 11 VERTICAL BOREHOLES
    - MONITOR SOIL MOISTURE AND SOIL GAS
  - CHEMICAL WASTE LANDFILL (CWL) AND SANITARY SEWER LINE (CSS) MONITORING
    - 6 BOREHOLES BETWEEN CWL/SANITARY SEWER LINE AND CONTAINMENT CELL
    - MONITOR SOIL MOISTURE AND SOIL GAS

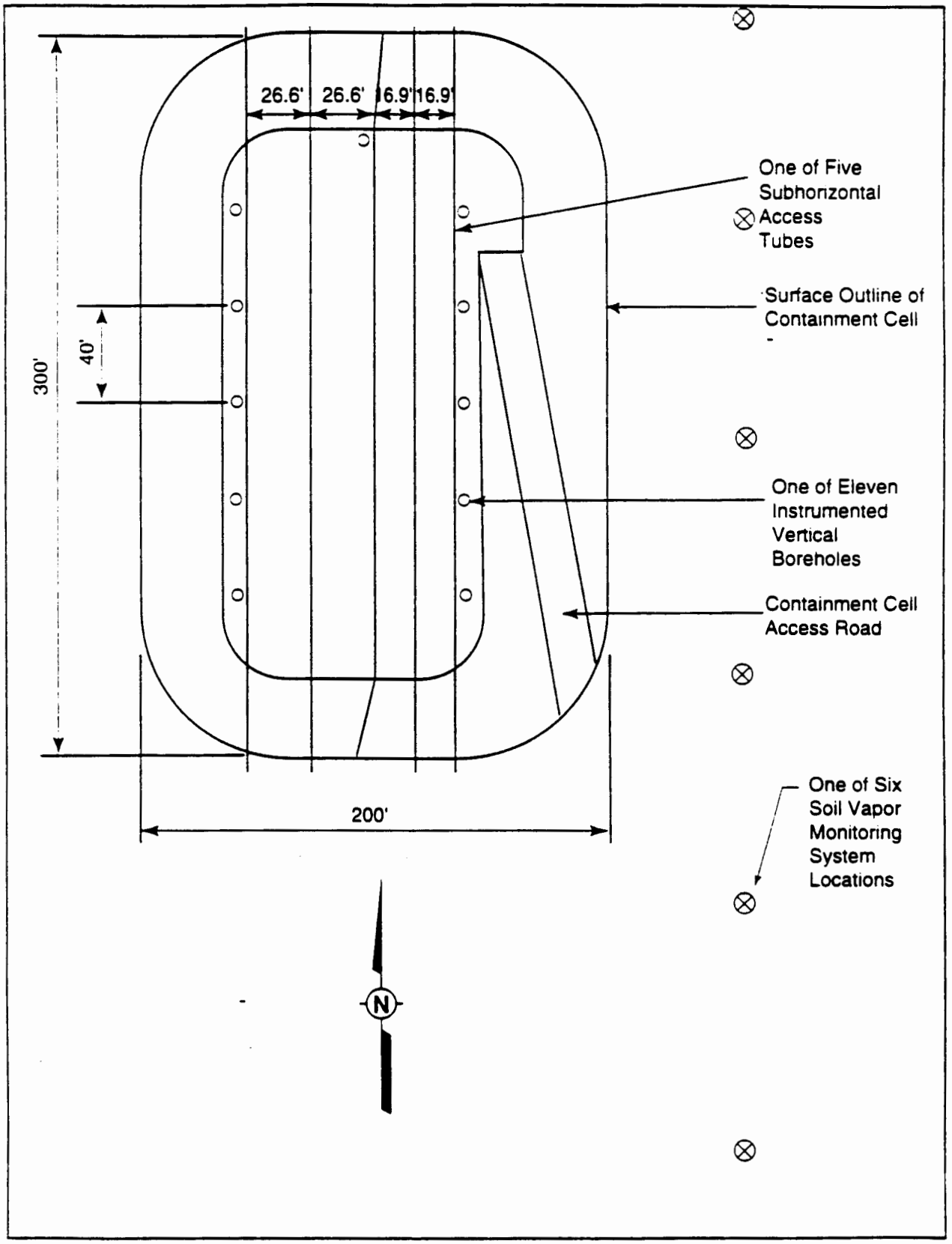
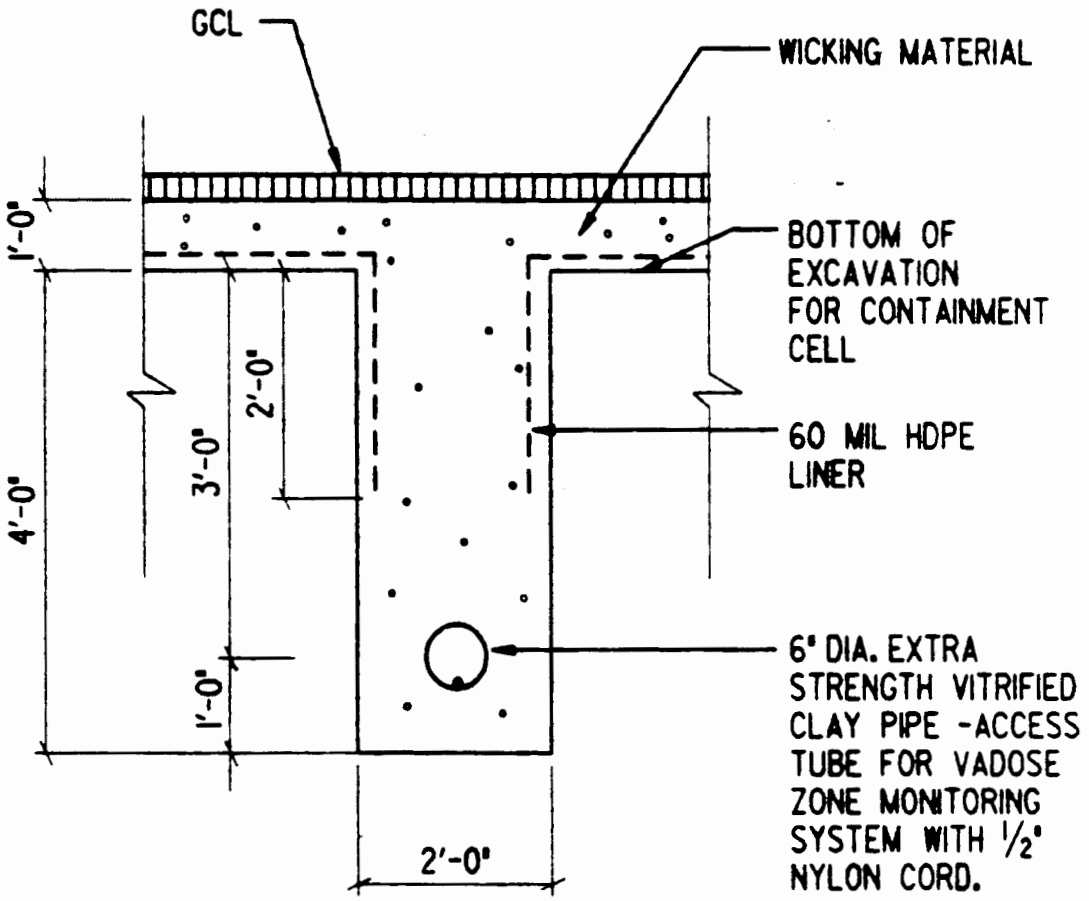


Figure 4-2
Plan View of Vadose Zone Monitoring System

- PSL MONITORING SUBSYSTEM
  - LOCATED WITHIN 5 FEET OF CONTAINMENT CELL LINER SYSTEM FOR EARLY LEAK DETECTION
  - SUBHORIZONTAL ACCESS TUBES OF HIGH STRENGTH VCP AS OPPOSED TO POINT-SPECIFIC BURIED INSTRUMENTATION
  - ACCESS TUBE TRENCHES BACKFILLED WITH ENGINEERED WICKING-LAYER TO FACILITATE MOISTURE TRANSPORT
  - MOISTURE MONITORING VIA NEUTRON PROBES IN ACCESS TUBES
  - FLEXIBLE EVERTING MEMBRANES CONTAINING SOIL-WATER AND SOIL-GAS SAMPLERS IN ACCESS TUBES
  - POTENTIAL FOR REMEDIATION OF LEAKS



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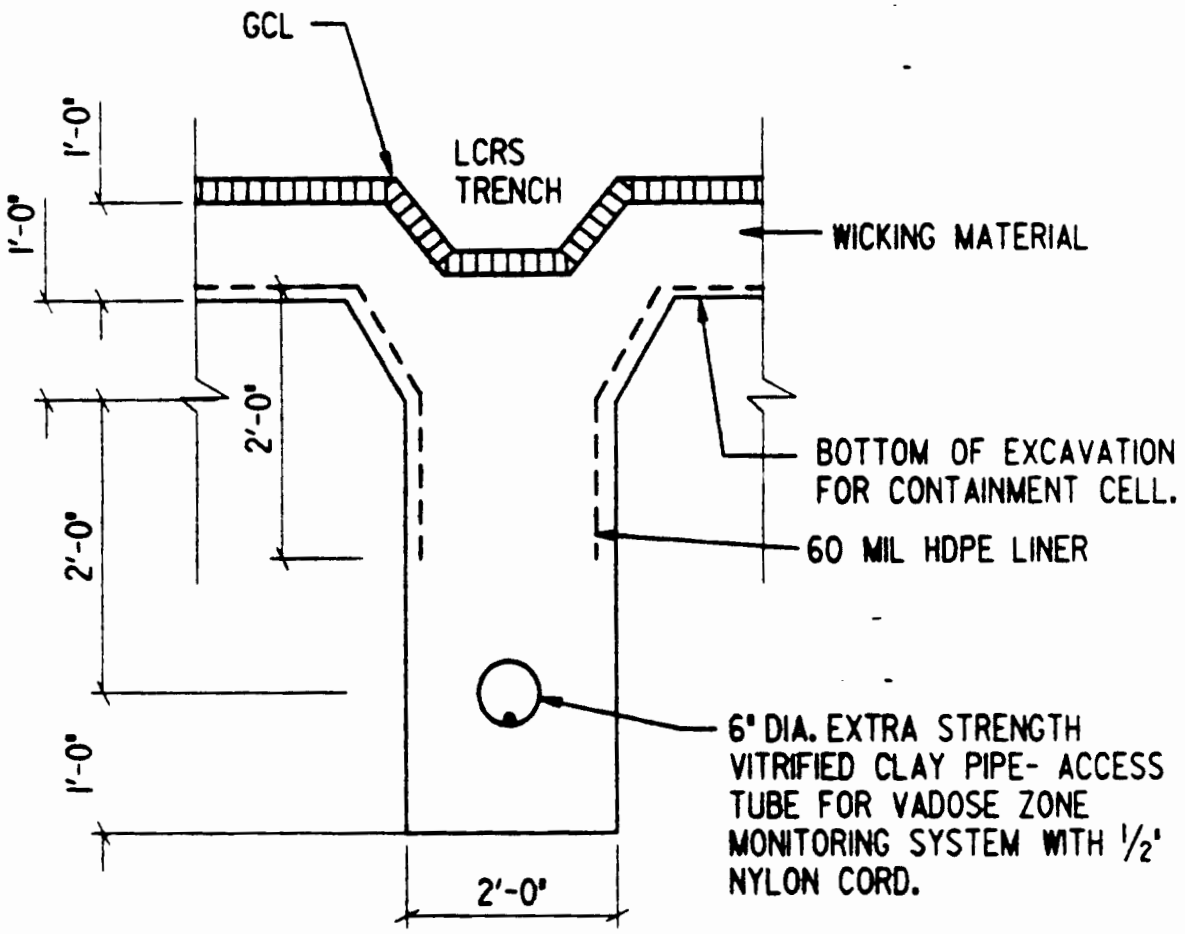
384/A4 385/A1

DETAIL OF ACCESS TUBE TRENCH

SCALE: NOT TO SCALE



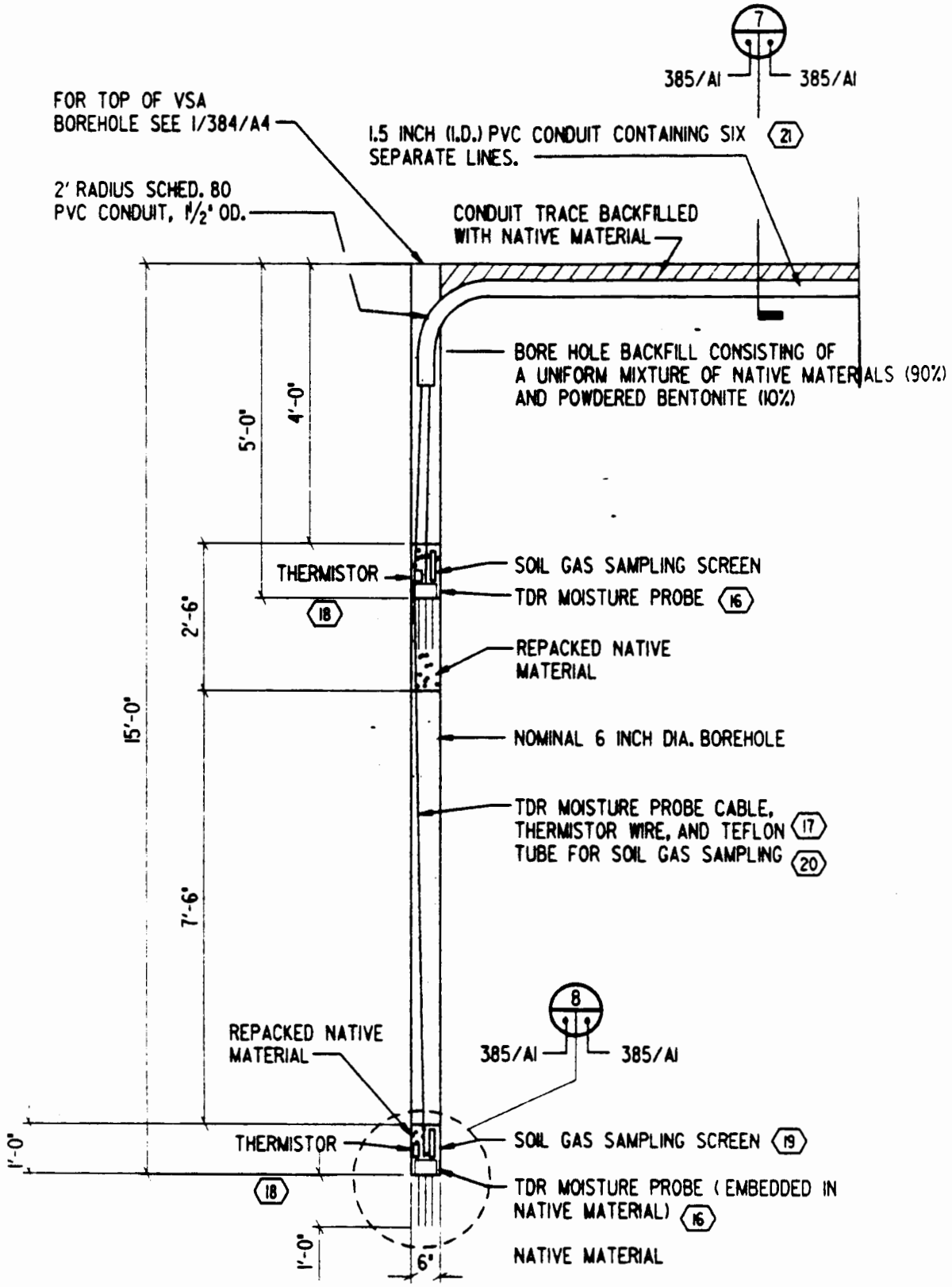
4

ACCESS TUBE BELOW LCRS TRENCH

SCALE: NOT TO SCALE

384/A4 385/A1

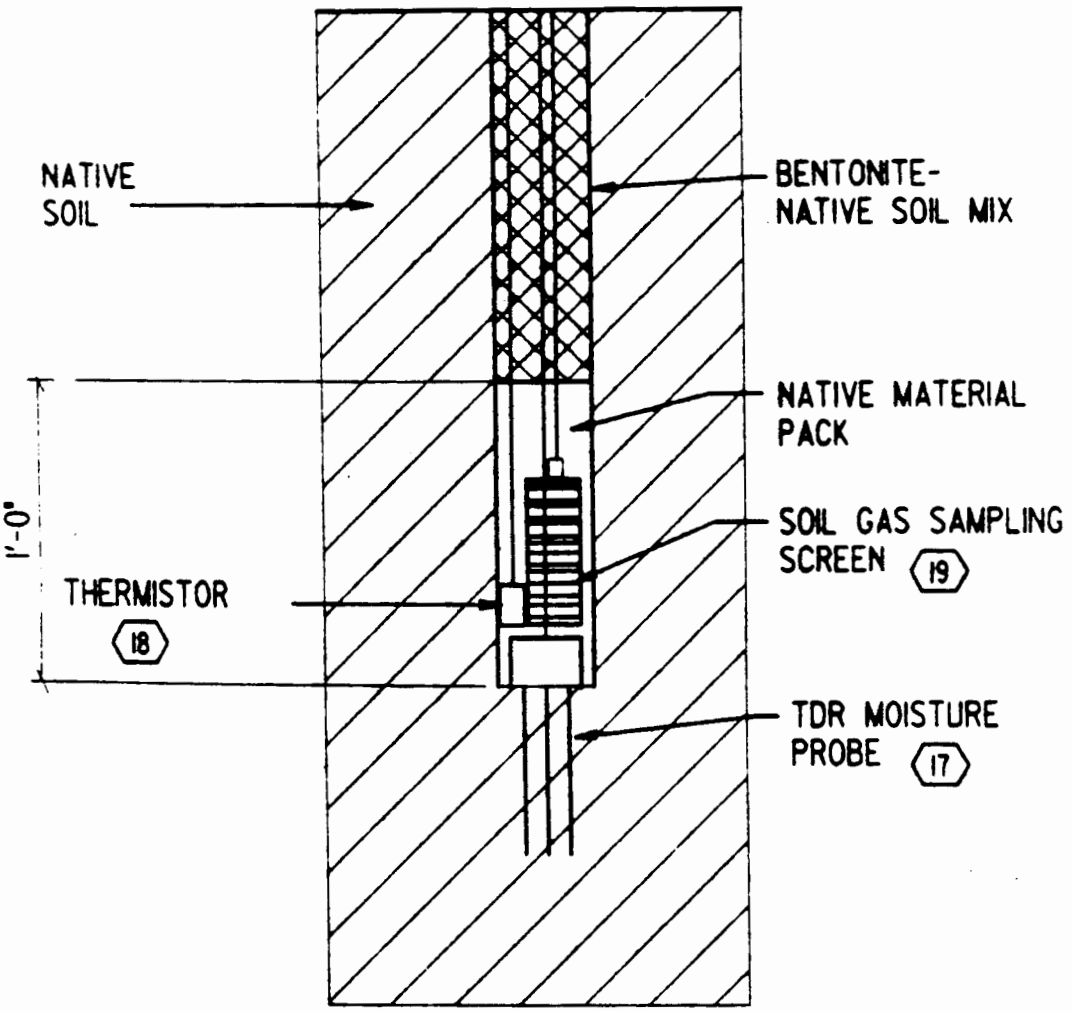
- VSA MONITORING SUBSYSTEM
  - 11 VERTICAL BOREHOLES BENEATH CONTAINMENT CELL INCLUDING LCRS SUMP
  - SAMPLING POINTS AT 5 AND 15 FEET BELOW CELL LINER
  - EACH SAMPLING POINT INCLUDES TDR SOIL-MOISTURE PROBE, TEMPERATURE SENSOR, AND AN ACTIVE SOIL-GAS SAMPLER
  - VSA PROVIDES REDUCED-SENSITIVITY BACKUP TO PSL
  - PRIMARY PURPOSE: DISTINGUISH LEACHATE LEAKAGE FROM MOISTURE CONTENT INCREASES DERIVED FROM FALSE-POSITIVE MOISTURE INCREASES (MOISTURE CONTENT GRADIENTS, VERTICAL TEMPERATURE GRADIENTS, CONDENSATION)



6 DETAIL OF INSTRUMENTED VERTICAL BOREHOLE

SCALE: .5"=1'-0"

384/A4 385/A1



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VSA SAMPLING PACKAGE

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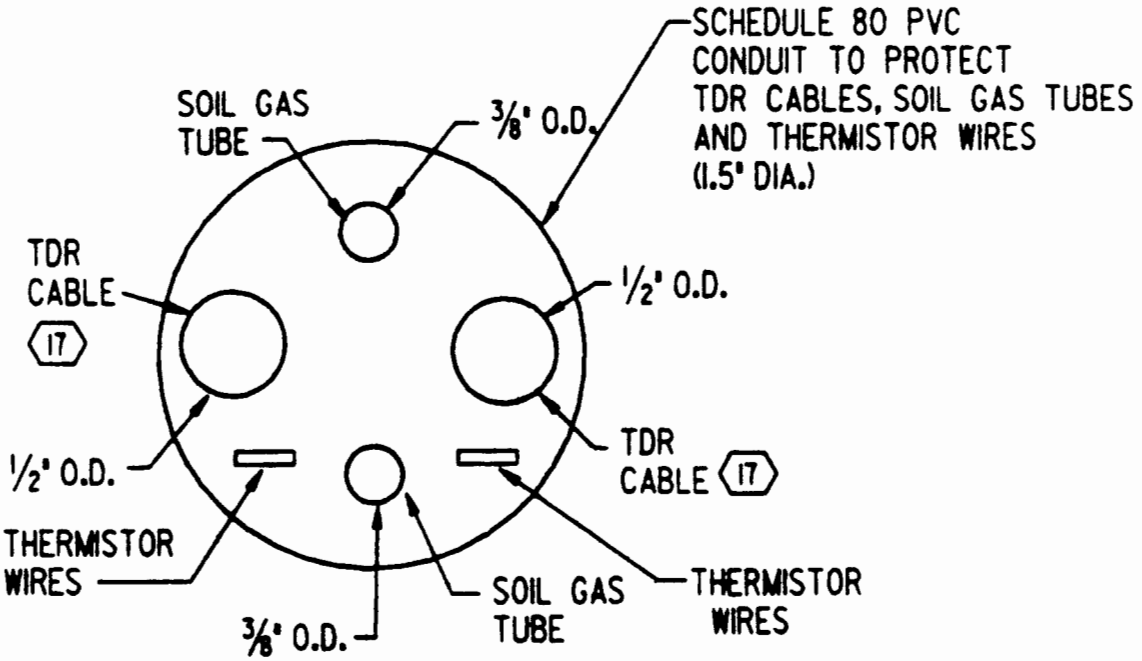
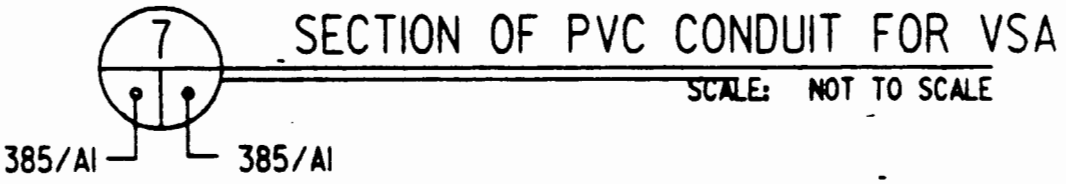
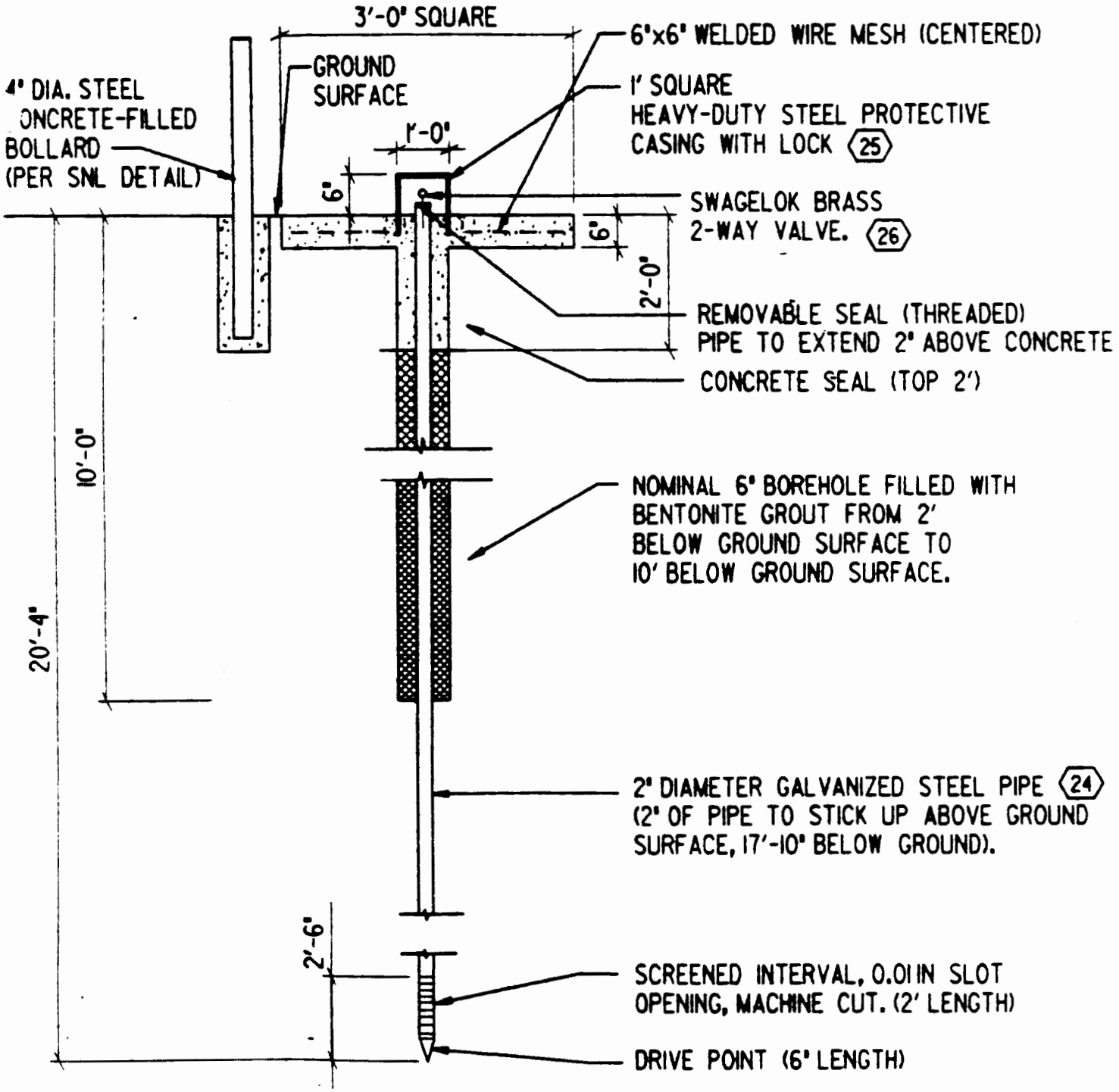

SCHEDULE 80 PVC CONDUIT TO PROTECT TDR CABLES, SOIL GAS TUBES AND THERMISTOR WIRES (1.5" DIA.)
SOIL GAS TUBE
3/8" O.D.
TDR CABLE
17
1/2" O.D.
1/2" O.D.
TDR CABLE
17
THERMISTOR WIRES
3/8" O.D.
SOIL GAS TUBE
THERMISTOR WIRES


7
SECTION OF PVC CONDUIT FOR VSA
SCALE: NOT TO SCALE
385/AI
385/AI

- CSS MONITORING SUBSYSTEM
  - 6 VERTICAL BOREHOLES BETWEEN CAMU CELL AND SANITARY SEWER LINE AND CWL
  - DETECT FALSE POSITIVES FROM CWL AND SANITARY SEWER LINE
  - EACH BOREHOLE WITH SOIL GAS-SAMPLING PORT AND SUITABLE FOR NEUTRON PROBE LOGGING



5

384/A4 385/A1

DETAIL OF CSS MONITORING SUBSYSTEM

SCALE: NOT TO SCALE

PROPOSED MONITORING APPROACH
MATERIAL DISPOSAL AREA - J
LOS ALAMOS NATIONAL LABORATORY

(2)

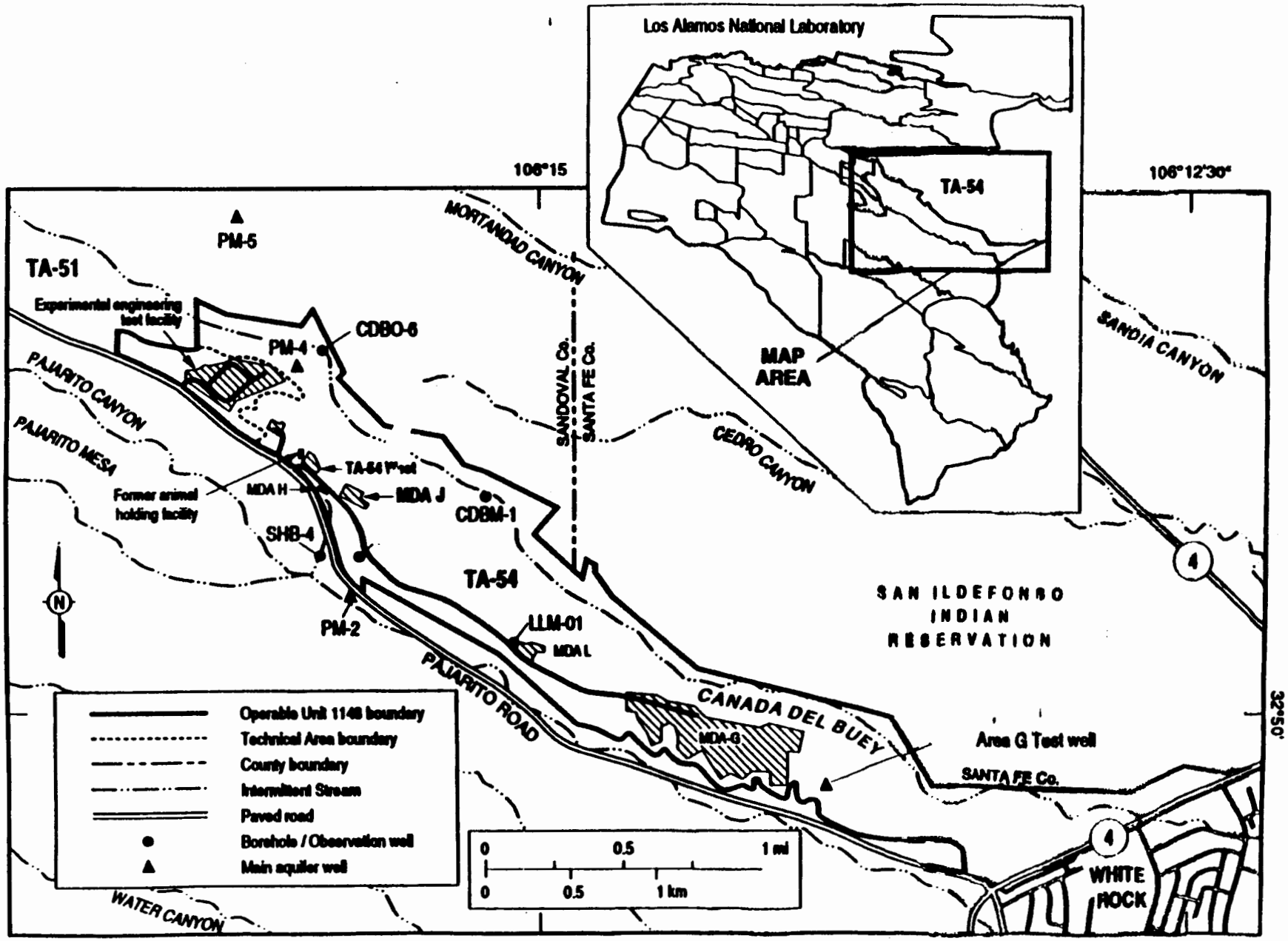
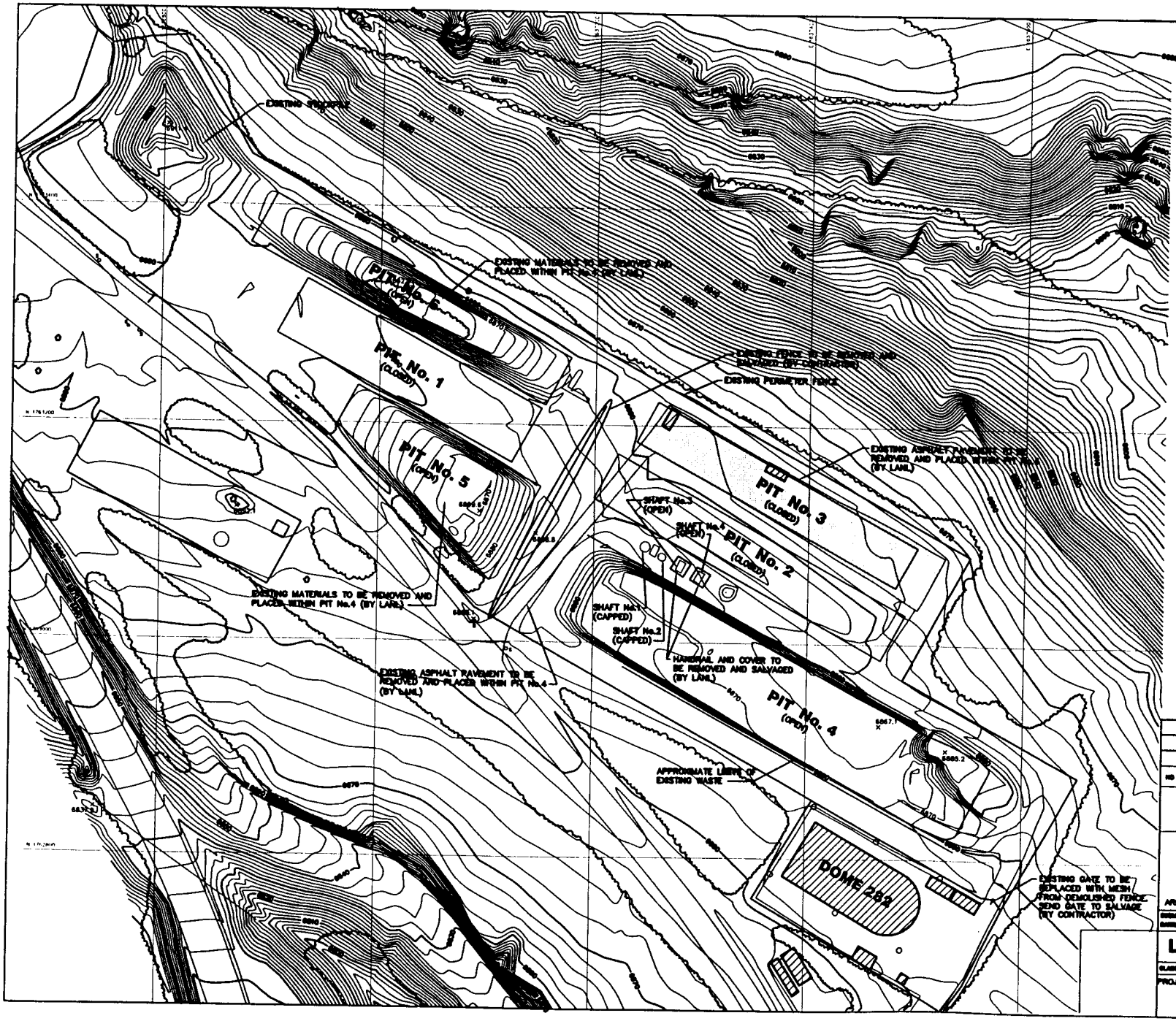


Figure 2. Area map of TA-54.



GENERAL NOTES:

1) BOUNDARIES OF PIT NOS. 1, 2, AND 3 SHALL BE VERIFIED PRIOR TO CONSTRUCTION BY LANL TO MAINTAIN A MINIMUM OVERLAP OF 18 INCHES FOR THE INFILTRATION LAYER.

LEGEND:

APPROXIMATE PIT BOUNDARY

LIMITS OF ASPHALT REMOVAL

N

GRAPHIC SCALE

NO	DATE	CLASS REV.	REVISIONS	DRAN	DES	CHKD	REL	SUB	REC	APP

INTERNATIONAL TECHNOLOGY CORPORATION

TA-54 AREA J
CLOSURE DESIGN
CIVIL: EXISTING CONDITIONS

AREA J — TA-54

DRAWN: G. JONES
DESIGN: P. [illegible]
CHECKED: P. [illegible]
DATE: 4/21/99

SUBMITTED: [illegible]
APPROVED FOR RELEASE: [illegible]

Los Alamos — Los Alamos National Laboratory, Los Alamos, New Mexico 87545

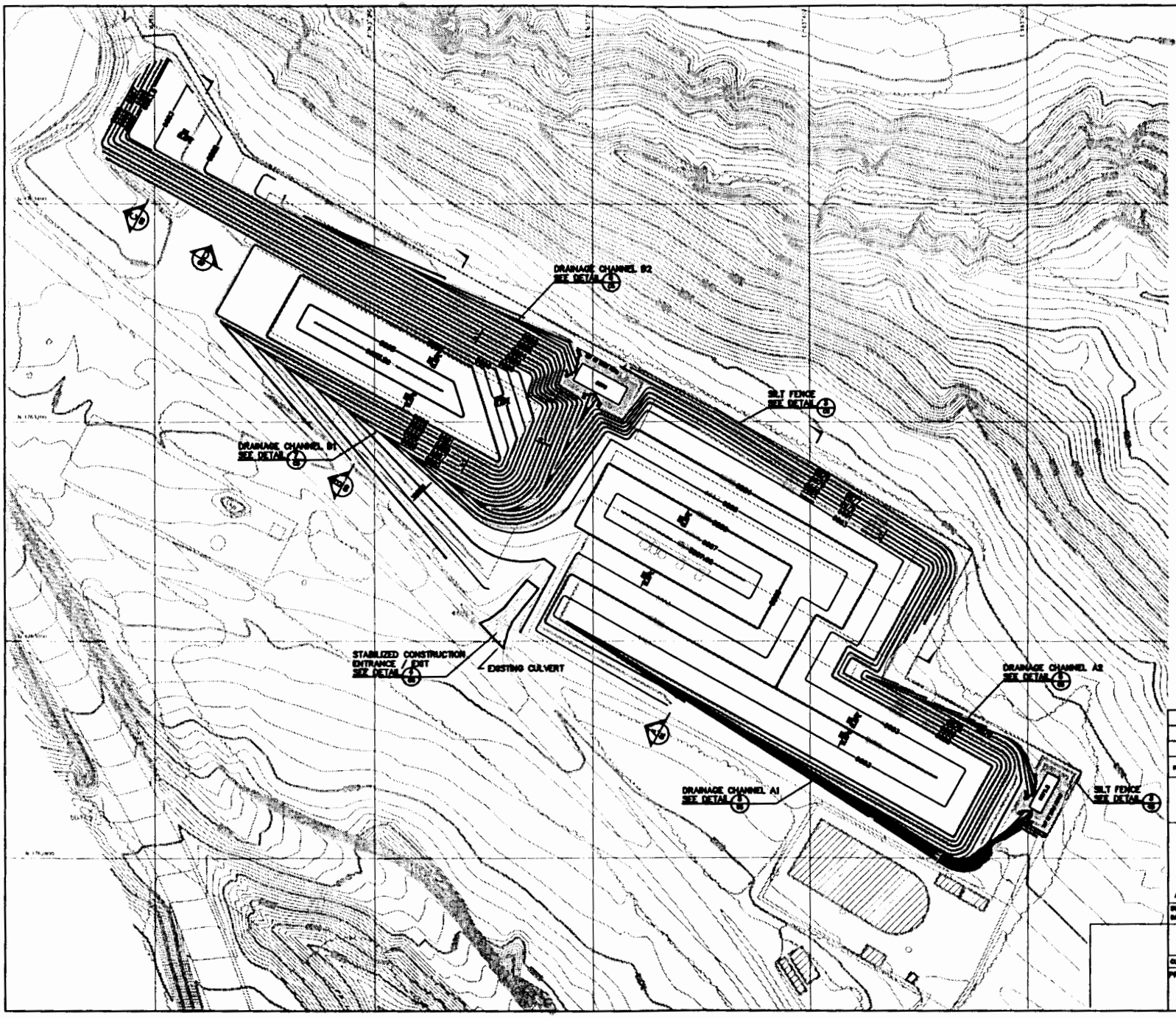
SHEET C1 — 2 OF 8

CLASSIFICATION — REVIEWER — DATE

PROJECT ID: 774830

DRAWING NO

REV



GENERAL NOTES:

1) BOUNDARIES OF PIT NOS. 1, 2, AND 3 SHALL BE VERIFIED PRIOR TO CONSTRUCTION BY LANL TO MAINTAIN A MINIMUM OVERLAP OF 18 INCHES FOR THE INFILTRATION LAYER.

LEGEND:

APPROXIMATE PIT BOUNDARY

SILT FENCE

N

GRAPHIC SCALE

NO	DATE	CLASS REV.	REVISIONS	DRN	DES	CHKD	REL	DAD	REC	APP

INTERNATIONAL TECHNOLOGY CORPORATION

TA-54 AREA J
CLOSURE DESIGN
CIVIL: FINAL GRADING PLAN

DRAWN: G. JONES
DESIGN: P. [illegible]
CHECKED: P. [illegible]
DATE: 4/21/99

AREA J | TA-54

SUBMITTED: DARREN MEADOWS
APPROVED FOR RELEASE: DENISE PAYNE

Los Alamos — Los Alamos National Laboratory, Los Alamos, New Mexico 87545

SHEET C3 4 of 8

CLASSIFICATION | REVIEWER | DATE

PROJECT ID 774830 | DRAWING NO | REV

- SUBTITLE - D SOLID WASTE LANDFILL

- VADOSE ZONE MONITORING PLAN SUBMITTED TO NMED IN OCTOBER 1994
  - NMED APPROVAL STILL PENDING

- CLOSURE PLAN SUBMITTED TO NMED MAY OF 1999
  - NMED APPROVAL STILL PENDING

- 1,000 FEET DEEP TO UPPERMOST AQUIFER
- 3.65 ACRES
- SIX EXCAVATED PITS
- PITS RANGE FROM 17 TO 60 FEET BELOW GRADE
- COVER DESIGN
  - 6-INCH EROSION LAYER
  - 1/4-INCH STEEL MESH (REPLACED WITH HDPE GEONET)
  - 18-INCH INFILTRATION LAYER (CRUSHED TUFF, SM OR SC AMENDED WITH 4% BENTONITE BY WEIGHT)
  - SATURATED PERMEABILITY SLOWER THAN 1 X 10^{-6} CM/SEC

- PROPOSED VADOSE ZONE MONITORING PLAN
  - DEMONSTRATE NO MIGRATION POTENTIAL
  - LIMITED TERM MONITORING
  - CONFIRM LOW MOISTURE PROFILES
  - CONFIRM LOW LEACHATE MIGRATION POTENTIAL

- MONITORING APPROACH
  - MONITOR MOISTURE PRESENCE AND MIGRATION
  - COMBINATION OF LYSIMETERS AND
  - NEUTRON ACCESS PROBES
  - WORST CASE SCENARIO
    - EVALUATE OLDEST PIT #1 (SINCE 1961)

- TWO LYSIMETERS AT PIT #1 AND #4
  - ADJACENT TO PITS
  - COMPLETED 5 FEET BELOW BOTTOM OF ADJACENT PITS

- FOUR NEUTRON PROBE ACCESS TUBES
  - 3 ADJACENT TO PITS
  - 1 IN NORTH CORNER FOR BACKGROUND MEASUREMENTS
  - ESTABLISH MOISTURE PROFILES
  - WILL DETERMINE WHEN TO SAMPLE LYSIMETERS

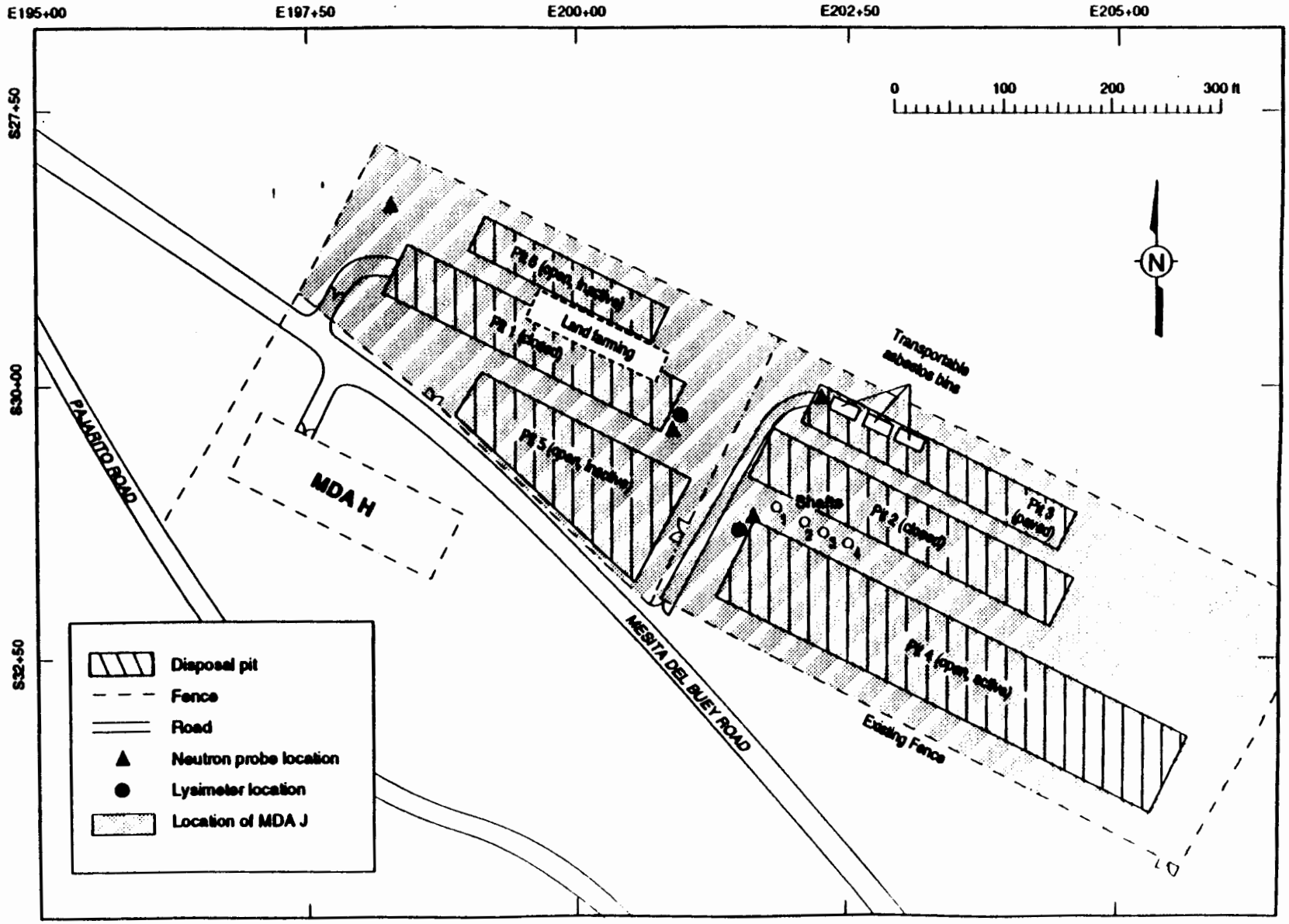


Figure 8. Proposed monitoring sites at Area J.

- SAMPLE FREQUENCY

- NEUTRON PROBES TWICE A MONTH DURING THE MONSOON AND DAILY AFTER SIGNIFICANT PRECIPITATION EVENTS

- IF SIGNFICANT MOISTURE INCREASE
  - COLLECT SAMPLES FROM LYSIMETERS

- SAMPLES TO BE ANALYZED FOR APPENDIX K CONSTITUENTS

Alternative Covers Assessment Program (ACAP)

United States Environmental Protection Agency

Superfund Innovative Technology Evaluation (SITE) Program

Program: ACAP is part of the EPA's National Risk Management Research laboratory's Superfund Innovative Technology Evaluation Program (SITE).

Goal: Develop field scale performance data for landfill cover systems; both prescriptive and alternative cover designs.

Phases: ACAP is divided into 2 phases:

Phase 1: (completed in August 1999) involved the assessment of potential sites and research facilities, existing designs, existing modeling methods, and recommendations for implementing Phase 2.

Phase 2: In construction phase, will establish a network of demonstration field sites nationwide. Field data will be collected from these respective sites for 5 years.

20. Albuquerque, New Mexico: Sandia National Lab

Precipitation (average annual): 22 centimeters/snow
Temperature (low minimum and maximum monthly means): 2-26°C

Six covers have been installed at this site:

RCRA "D" cover. This cover consists of topsoil underlain by compacted soil. Information obtained will help form a baseline for prescriptive cove performance.
RCRA "C" cover. This cover consists of (1) topsoil, (2) native sand, (3) geotextile, (4) sand, (5) geomembrane, and (6) native soil with 6% bentonite. Information obtained will help form a baseline for prescriptive cover performance.
Geosynthetic clay liners (GCL) design. This cover consists of (1) topsoil, (2) native soil, (3) geotextile, (4) sand, and (5) a geomembrane.
ET cover. This cover consists of (1) gravel, (2) topsoil, and (3) compacted soil.
Anisotropic barrier. This cover consists of (1) topsoil/pea gravel; (2) compacted native soil, (3) sand, and (4) gravel.
Capillary barrier. This cover consists of (1) topsoil, (2) sand, 93) gravel; (4) compacted native soil, and (5) sand.

16. Sheffield, Illinois: NRC

Precipitation (average annual): 94 centimeters/snow
Temperature (low minimum and maximum monthly means): -6-24°C
At this site, four complex multilayer capillary barriers are being investigated:

One cover consists of (1) topsoil, (2) compacted till, (3) geofabric, (4) pea gravel, (5 compacted till, (6) geofabric, and (7) pea gravel.
One cover consists of (1) topsoil, (2) compacted loess, (3) compacted till, and (4) pea gravel.
Two of the covers consist of (1) topsoil, (2) compacted loess, (3) geofabric, (4) pea gravel, (4) compacted till, (5) geofabric, and (6) pea gravel. The depths of each laye differs between the two test covers.

17. Sierra Blanca, Texas

Precipitation (average annual): 32 centimeters
Temperature (low minimum and maximum monthly means): 7-28°C

Two covers have been installed at this site: (1) a capillary barrier and (2) a more sophisticated design, with a layer of clay, asphalt, and concrete in the middle.

18. Twenty-nine Palms, California: Marine Corps Air and Ground Combat Center

Precipitation (average annual): 10 centimeters
Temperature (low minimum and maximum monthly means): 9-32°C

A monofill cover design, consisting of 1.85 meters of silty sand, has been installed.

19. Wenatchee, Washington

Precipitation (average annual): 23 centimeters/snow
Temperature (low minimum and maximum monthly means): -2-23°C

Two covers have been installed at this site:

Capillary barrier. This cover consists of vegetated topsoil, underlain by sand.
Resistive barrier. This cover consists of vegetated topsoil, underlain by compacted silty clay.

12. Oahu, Hawaii: Marine Corps Base Hawaii

Precipitation (average annual): 193 centimeters
Temperature (low minimum and maximum monthly means): 22-25°C

Before a water containment system was put in place, water pooled in this area and traveled upward through waste layers. An impermeable barrier, much like a rain gutter, has been installed and plants have been established between the gutters. The impermeable barrier is underlain by compacted soil. To date, results indicate that the plants successfully dewatered the area and that they effectively capture water that escapes the rain gutters.

13. Reedsburg, Wisconsin: Grede Foundries

Precipitation (average annual): 79 centimeters/snow
Temperature (low minimum and maximum monthly means): -8-22°C

This site is using an alternative material, foundry sands. Investigators are testing the material's performance by using it in a variety of covers and at different depths. The sands are compacted in some of the test covers and uncompacted in others.

14. San Bernardino County, California

Precipitation (average annual): 14 centimeters (Milliken site) and 44 cm (Phelan site)
Temperature (low minimum and maximum monthly means): 7-26°C (Milliken site) and 11-24°C (Phelan site)

Two lysimeter-based facilities are located in San Bernardino County. Both sites have covers composed of locally derived soil. At the Milliken site, the cover consists of silty sands. A the Phelan site, the materials are gravelly sands with silt.

15. Savannah River, South Carolina: DOE

Precipitation (average annual): 120 centimeters
Temperature (low minimum and maximum monthly means): 8-28°C

Investigations at this site have focused on subsidence impacts.

8. Los Alamos National Laboratory, New Mexico

Precipitation (average annual): 47 centimeters/snow
Temperature (low minimum and maximum monthly means): 2-20°C
Four covers have been installed at this site:

Conventional cover: This cover consists of topsoil, underlain by crushed tuff.
Loam capillary barrier: This cover consists of loam topsoil, underlain by fine sand.
Clay loam capillary barrier: This cover consists of clay loam, underlain by fine sand.
EPA-recommended design: This cover consists of (1) topsoil, (2) geotextile, (3) medium sand, and (4) compacted soil.

Some interesting plant and animal intrusion experiments have been conducted at this site Researchers have tried to quantify how much gravel and cobble is needed to resis penetration by plant roots and burrowing animals.

9. Milwaukee, Wisconsin: Omega Hills Landfill

Precipitation (average annual): 81 centimeters/snow
Temperature (low minimum and maximum monthly means): -7-22°C

Three covers are being evaluated. Two of the covers have topsoil underlain with compacted till; each of these covers differs in its layer depths. The third cover has fou layers (1) topsoil, (2) compacted till, (3) sand, and (4) compacted till.

10. Monticello: U.S. Department of Energy (DOE)

Precipitation (average annual): 38 centimeters/snow
Temperature (low minimum and maximum monthly means): -4-20°C

Several types of capillary barrier configurations are being tested at this site.

11. Nevada Test Site

Precipitation (average annual): 17 centimeters
Temperature (low minimum and maximum monthly means): 3-30°C

A cover with 2 meters of native soil has been installed at this site.

5. Hill AFB, Utah

Precipitation (average annual): 44 centimeters/snow
Temperature (low minimum and maximum monthly means): -3-24°C
Four covers have been installed at this site:

Control (ET) Cover: This cover consists of a sandy loam and natural grasses.
Capillary barrier cover: This cover consists of (1) sandy loam with grasses and shrubs (2) geotextile, and (3) gravel.
Hanford-type cover: This cover consists of (1) silt loam/pea gravel, (2) silt loam, (3 geotextile, and (4) sand/gravel.
Modified RCRA cover: This cover has the following layers: (1) sandy loam with grasses, (2) geotextile, and (3) clay. Collecting prescriptive cover performance data is important because very few lysimeter-based tests have been conducted for RCRA C and RCRA D covers. Scientists need more information to establish baseline performance standards.

6. Idaho National Engineering and Environmental Lab

Precipitation (average annual): 23 centimeters/snow
Temperature (low minimum and maximum monthly means): -9-20°C
Four covers have been installed at this site:

RCRA-type design cover: This cover consists of (1) loess, (2) geomembrane, and (3 compacted clay.
Thick monolayer: This cover consists of loess.
Biobarrier designs: Two barrier design covers have been installed, each consisting of (1) loess, (2) capillary barrier, and (3) loess. The depth of the bottom loess layer differs between the two covers.

7. Kalamazoo, Michigan: National Council for Air and Stream Improvement

Precipitation (average annual): 89 centimeters/snow
Temperature (low minimum and maximum monthly means): -5-23°C
This site is testing an alternative low-permeability material, paper sludge. Investigators are comparing the performance of paper mill sludge with that of compacted clay. Tw covers have been established, each with a vegetated topsoil that is underlain by native soil. Under the native soil, one cover has a compacted clay, while the other has a compacted paper mill sludge. For both covers, the bottom layer consists of compacted sand.

1. Atlanta, Georgia: Live Oak Landfill

Precipitation (average annual): 125 centimeters
Temperature (low minimum and maximum monthly means): 6-26°C
A resistive barrier-vegetated cover has been installed at this site. The cover consists of two layers: (1) vegetated silt and (2) compacted clay.

2. Beltsville, Maryland: National Research Council (NRC)

Precipitation (average annual): 100 centimeters
Temperature (low minimum and maximum monthly means): 2-26°C
Four covers have been installed at this site:

Bioengineering barrier: Before a water-containment system was put in place, water pooled in this area and traveled upward through waste layers. An impermeable barrier, much like a rain gutter, has been installed and shrubs have been established between the gutters. The impermeable barrier is underlain by an uncharacterized fill. To date, results indicate that the shrubs successfully dewatered the area and that they effectively capture water that escapes the rain gutters. Resistive barrier-vegetated: This cover consists of (1) vegetated topsoil, (2) pea gravel, and (3) compacted clay. Resistive barrier-armored: This cover acts much like a one-way valve (i.e., water goes in, but does not come out). It consists of the following layers: (1) rock armor, (2) pea gravel, and (3) compacted clay. Conductive layer barrier: This cover is effective for small cells, where the aim is to move water laterally around wastes. It consists of the following layers: (1) vegetated topsoil, (2) pea gravel, (3) compacted clay, (4) diatomaceous earth, (5) geotextile, and (6) compacted clay.

3. Denver, Colorado: Rocky Mountain Arsenal

Precipitation (average annual): 39 centimeters/snow
Temperature (low minimum and maximum monthly means): -1B23 EC
Four ET-type barriers have been installed:

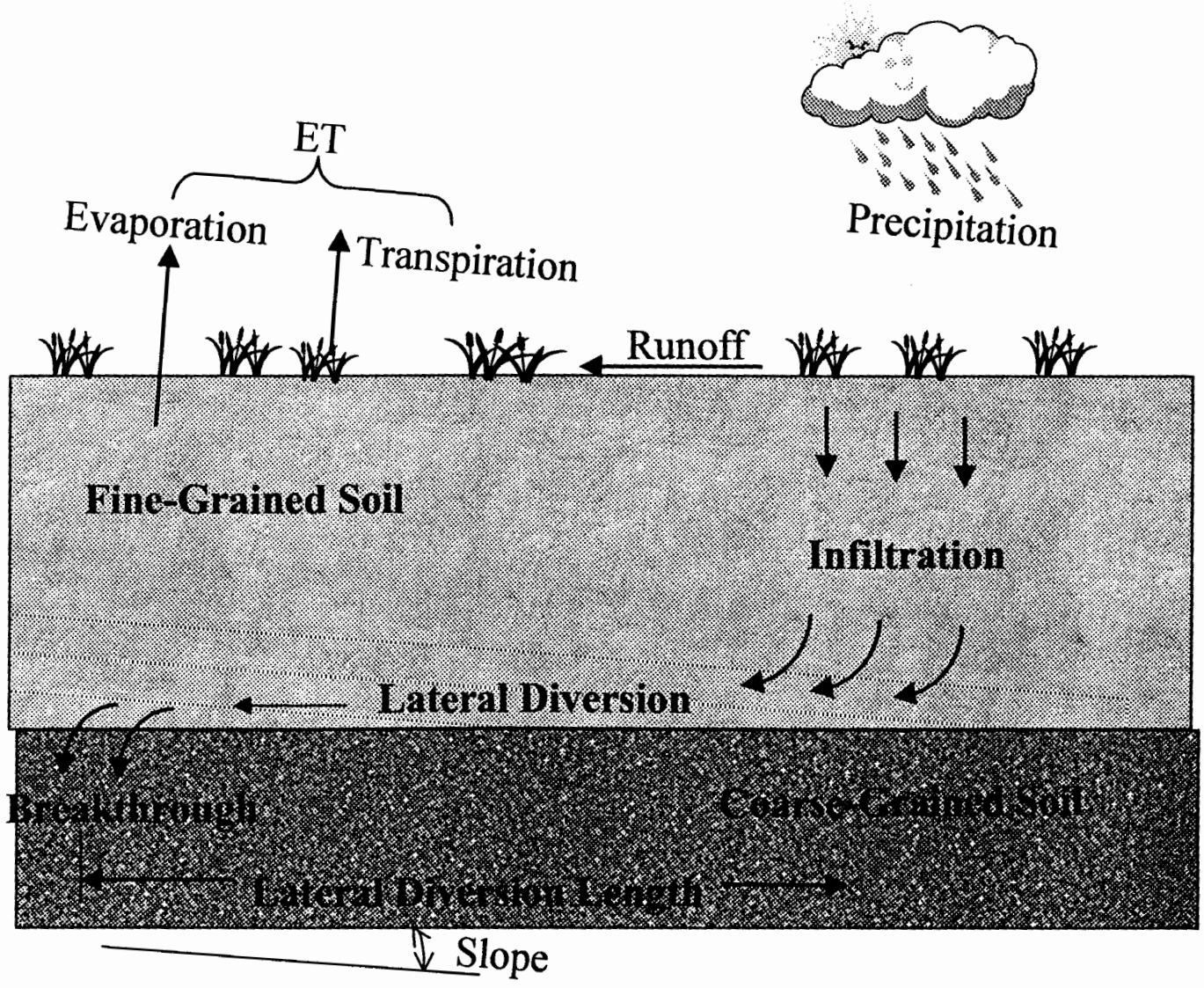
Three covers consist of >50% silt and clay, with each cover using a different depth (i.e., ranging from 1.1 to 1.5 meters).
One cover consists of 1.1 meters of >35% and <50% silt and clay.

4. Hanford, Washington: Pacific Northwest National Laboratory

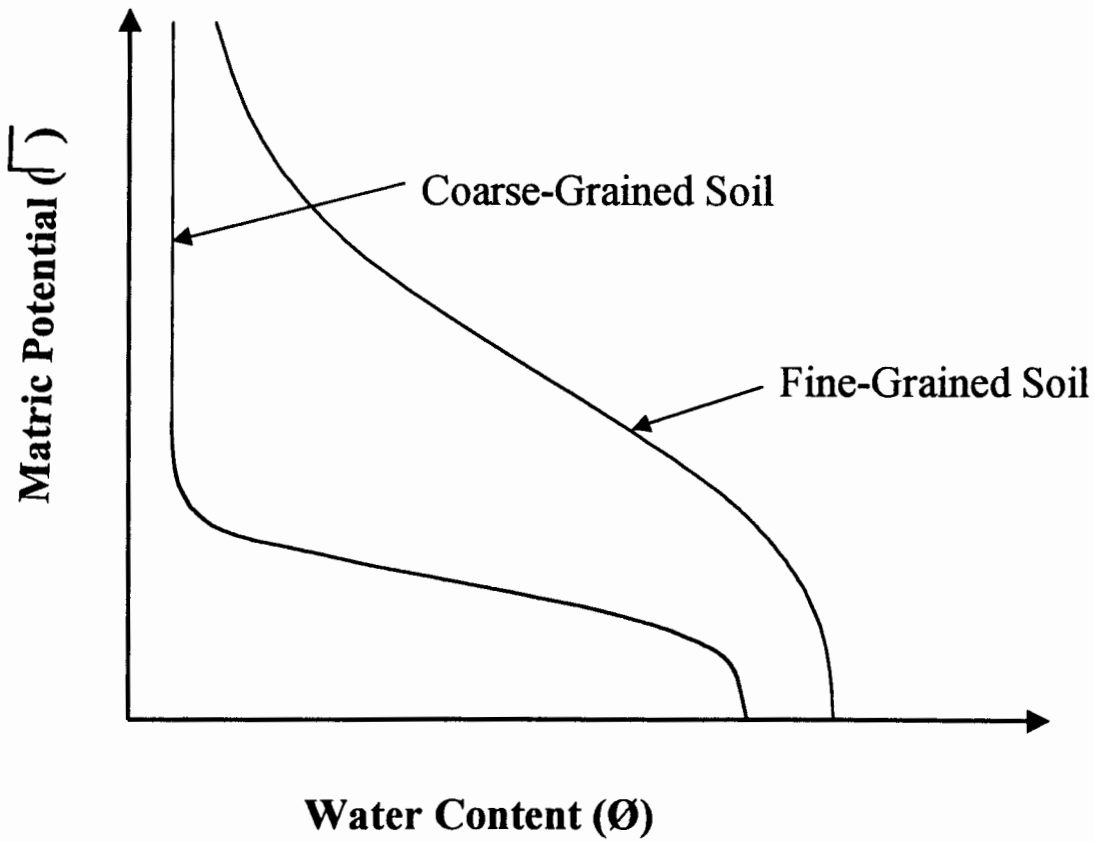
Precipitation (average annual): 16 centimeters/snow
Temperature (low minimum and maximum monthly means): -1-26°C

An ET capillary barrier has been installed. It consists of the following layers: (1) silt loam/pea gravel, (2) silt loam, (3) sand/gravel filter, (4) basalt riprap, (5) drainage gravel, (6) composite asphalt, and (7) structural fill.

Revised EPA Landfill Closure Guidance

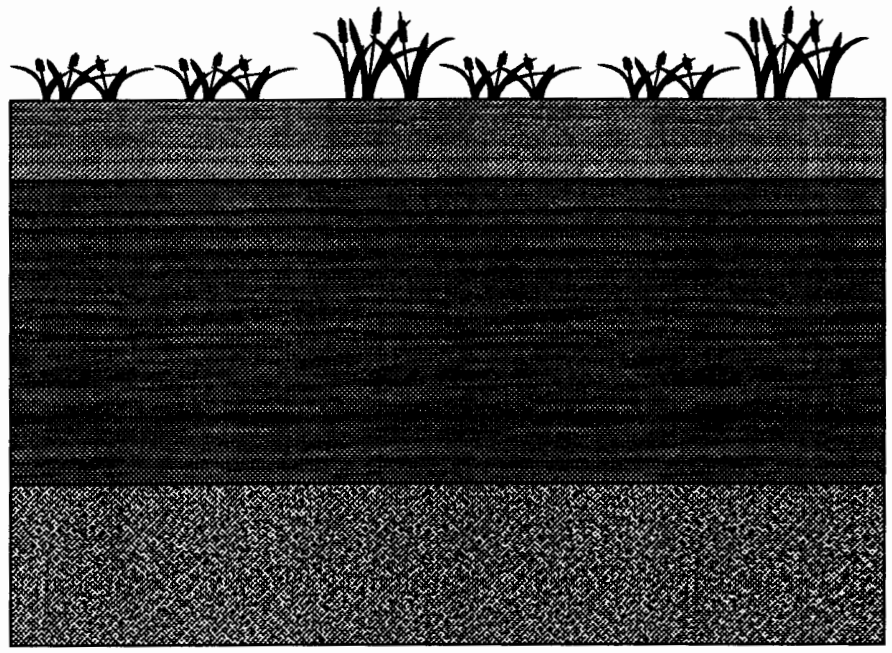


Revised EPA Landfill Closure Guidance



Typical Soil Moisture Characteristic Curves for Fine- and Coarse Grained Soils

Revised EPA Landfill Closure Guidance

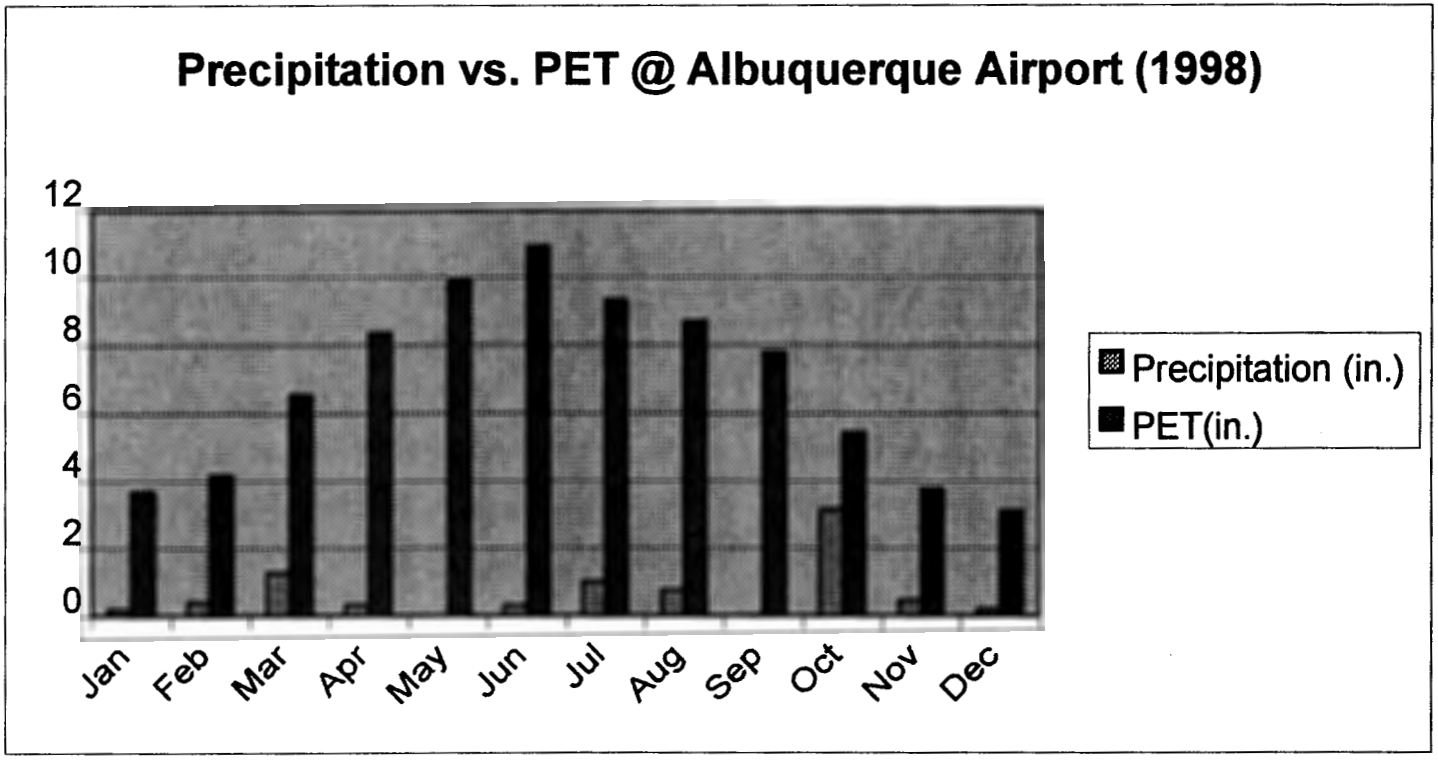


Revised EPA Landfill Closure Guidance

ET Cover Design Concept Summary:

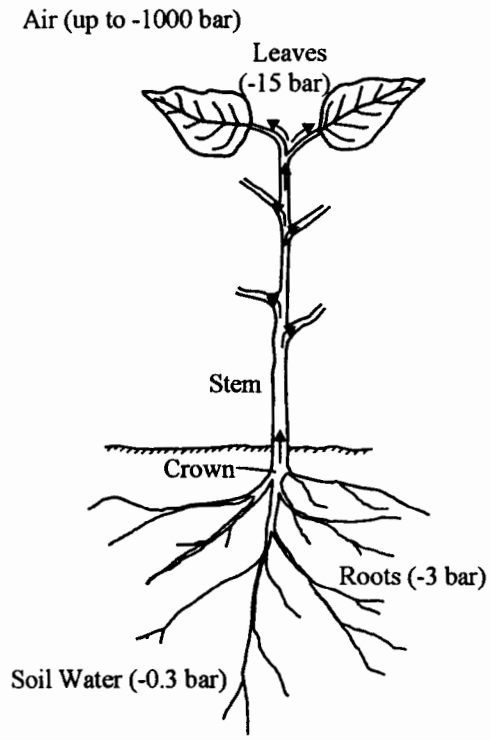
1) Identify the critical infiltration event(s). This generally involves identifying the design precipitation event or series of events.
2) Determine the minimum required soil water storage capacity based on the design infiltration event(s).
3) Determine the minimum soil thickness required.
4) Determine the vegetation (seed mix) to be used and any surface treatment (i.e. gravel veneer, gravel admixture, soil nutrient supplements) to be employed.
5) Determine optional layers (i.e., gas vent layer, biointrusion layer) to be deployed. These layers are to be installed similarly to that described elsewhere in this document. An important point to remember is that a landfill cover must be designed as a system rather than as a composite of individual layers.
6) Verify this design based on:
   a) Predictive computer modeling,
   b) Field data to predict short term performance, and
   c) Natural analogs to predict long-term performance.

Revised EPA Landfill Closure Guidance



Actual Precipitation vs. PET in Albuquerque, NM for 1998

Revised EPA Landfill Closure Guidance



Typical Soil-Plant-Atmosphere Water Potential Variation (Hillel 1998)

Revised EPA Landfill Closure Guidance

False assumption: *C*oncerning the performance of traditional landfill covers (both RCRA Subtitles 'C' and Subtitle 'D' closures) is that water movement will occur only under saturated conditions. Saturated flow in the near surface, when it does occur is primarily downward as the hydraulic gradient is largely due to gravity. Water movemen however, generally occurs under unsaturated conditions. This is particularly the case in dry environments. For water movement in an unsaturated soil, the hydraulic gradient is comprised of both gravity (acting downward) and matric potential differences (which can act either upward or downward). Consequently, both upward and downward wate movement is possible in unsaturated soil.

Darcy's Law can be used to represent the fundamental equation of flow for both scenarios:

For saturated systems:

$Q = K_{sat}\, i\, A$

where: Q = flow rate
K_{sat} = saturated hydraulic conductivity
i = hydraulic gradient; *f*(gravity and pressure potential)
A = area

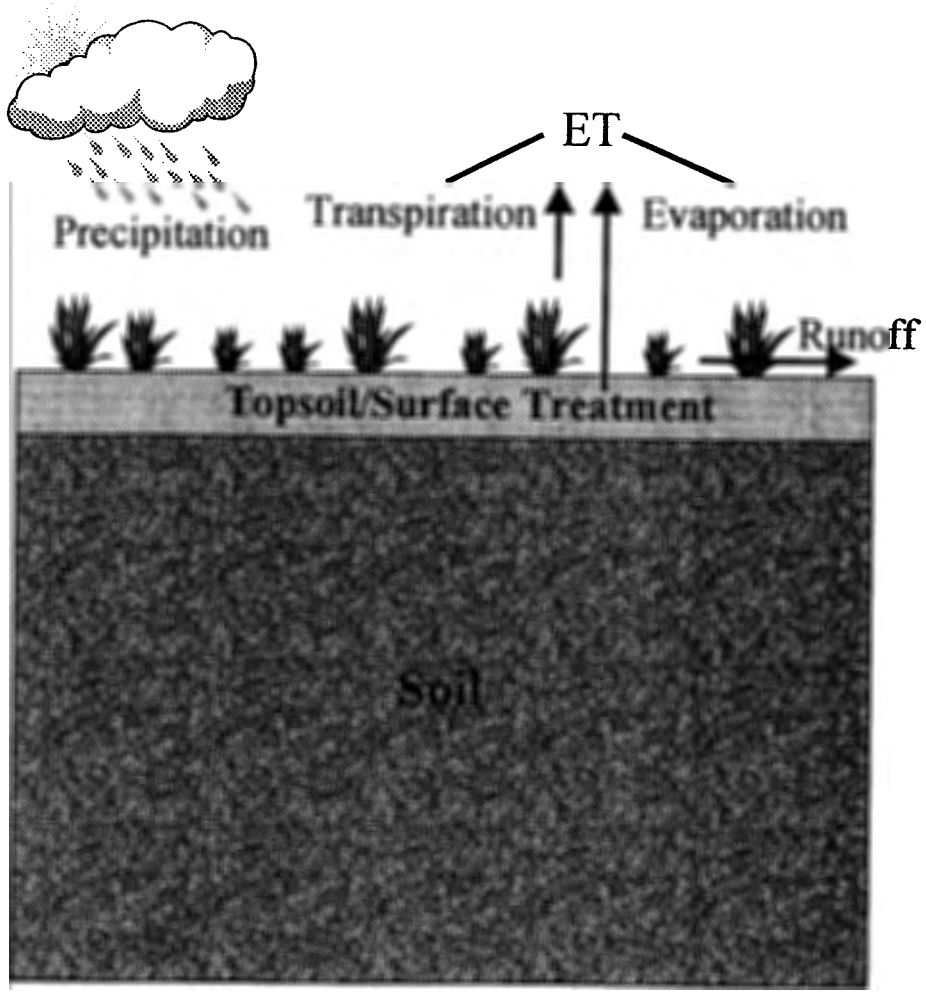
For unsaturated systems:

$Q = K_{unsat}\, i\, A$

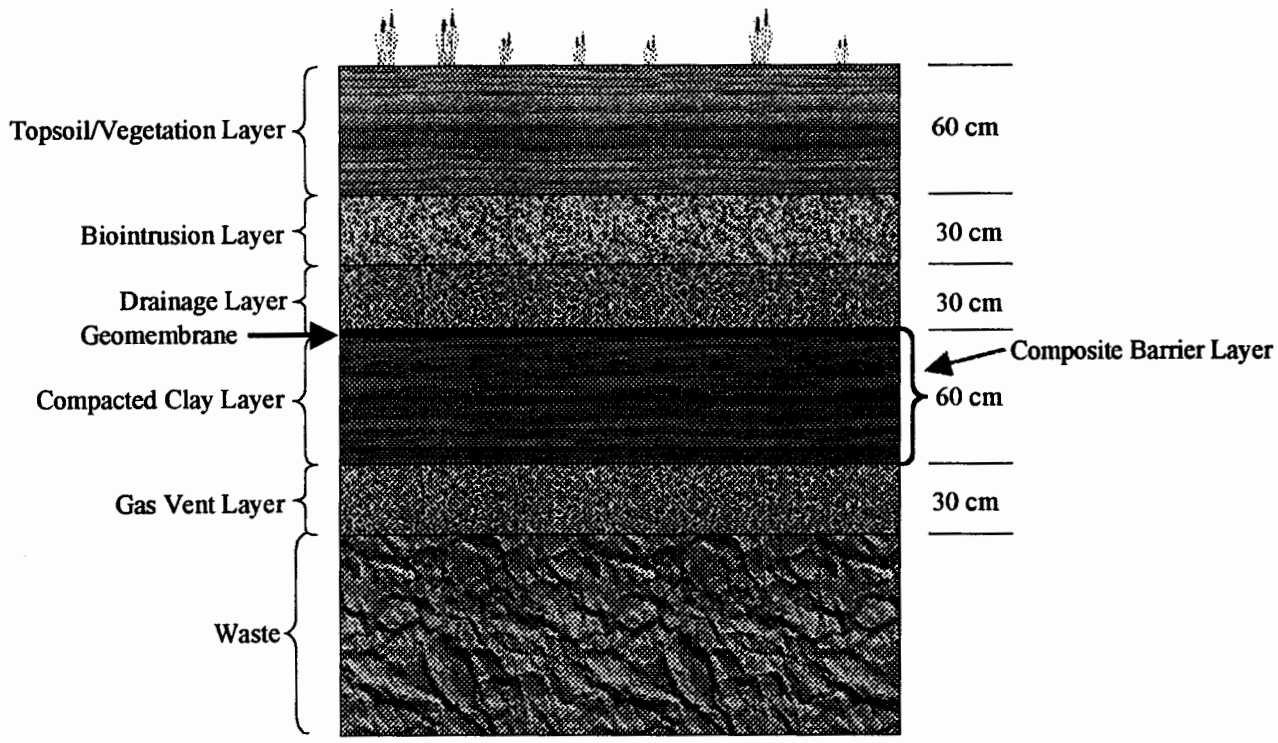
where: Q = flow rate
K_{unsat} = unsaturated hydraulic conductivity
i = hydraulic gradient; *f*(gravity and matric potential)
A = area

Water moves toward regions of higher water potential and is consequently governed by gravity *and* matric potential equilibrium for unsaturated flow. Under saturated conditions, the soil's matric potential is zero.

ET Cover Concept

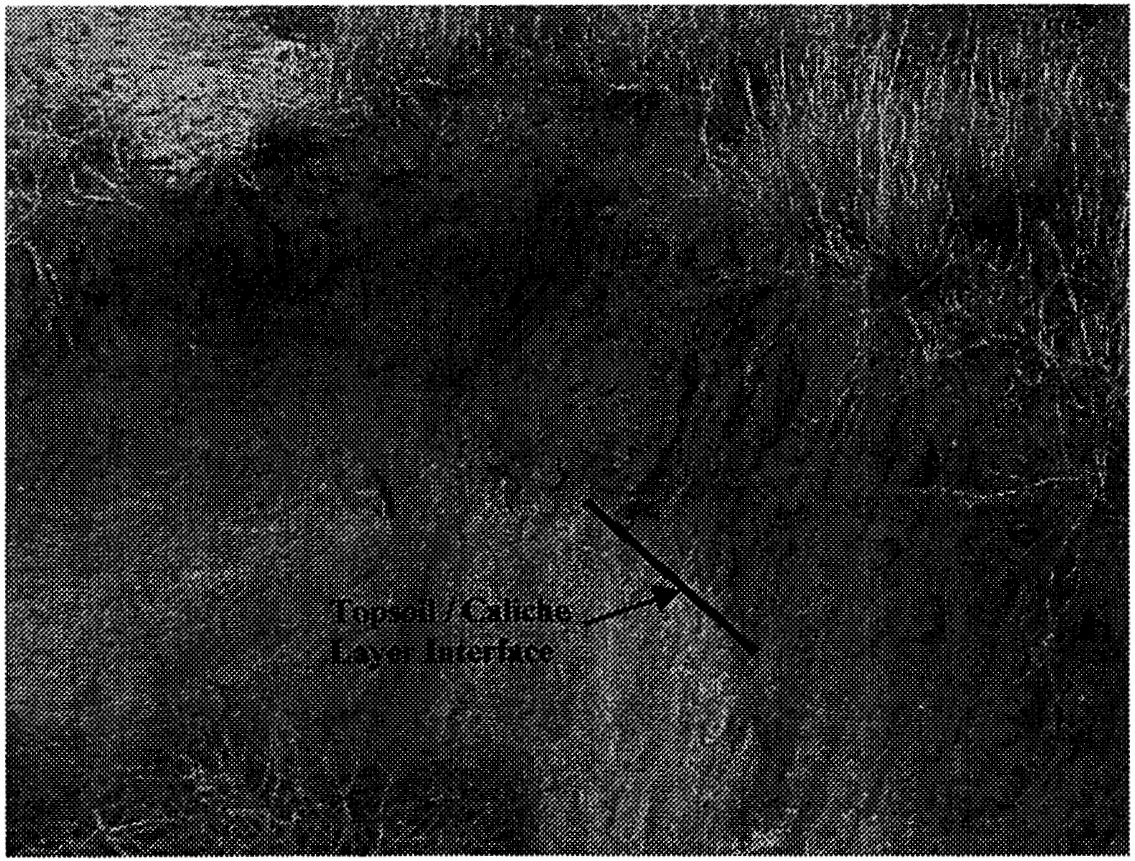


Revised EPA Landfill Closure Guidance



Traditional Subtitle 'C' Compacted Clay Cover (EPA 1991)

Revised EPA Landfill Closure Guidance



$CaCO_3$/Soil Interface at Shallow Depth

Revised EPA Landfill Closure Guidance Document

Key Note: A *very important point involves the review of alternative cover systems. It is highly recommended that a subject expert or panel of experts be retained to review alternative cover systems submitted for permit approval. There are many areas in the design inputs that are subjective or generally out of the expertise of many design civil engineers and should be reviewed for reasonableness. In addition, since few alternative cover systems are installed to date, those that are put forth early will serve as precedences for others to follow. Ensuring early successes should translate to subsequent successes.*

Monticello Mill Tailings (US DOE)

Current Monitoring Efforts:

1991: Undisturbed Samples / weighing lysimeters were installed

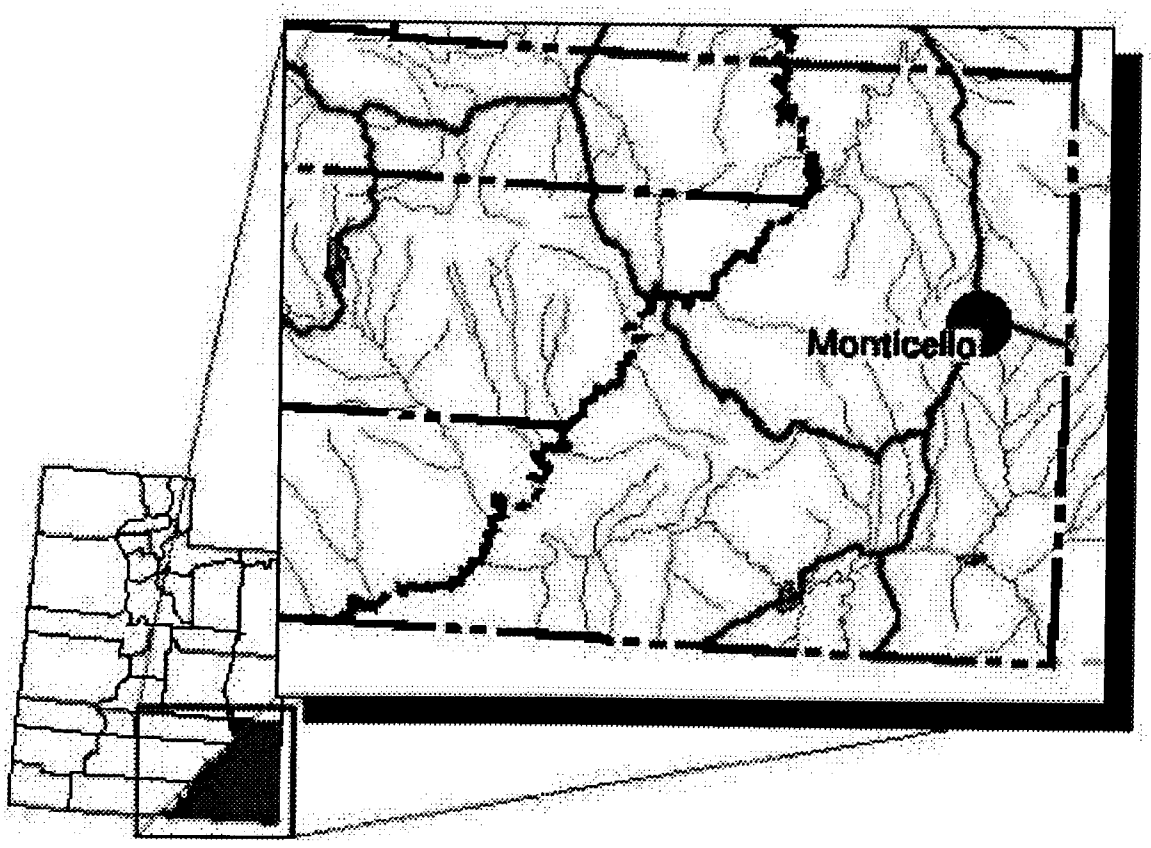
- Measure vegetation characteristic difference in disturbed vs. undisturbed areas.

1993: 30 weighing lysimeters installed to test ET Cover concept.

- Water Balance measurements to be made.
- Funding cut prior to start of monitoring due to change in DOE direction - tailings were to be hauled away and buried elsewhere.
- DOE policy change once again decided to bury the tailings in Monticello.
- Gave DOE Grand Junction office 4 months to finalize a landfill design.
- Consequently, prescriptive cover concept was relied upon in design of cover with a standard double liner system.
- EPA agreed that no monitoring wells were warranted, instead monitoring of the site would depend on the leak detection system installed in the liner.
- EPA Region 8 funded the monitoring of the weighing Lysimeters for the first year (started last year), with DOE agreeing to fund them for another 4 years.
-

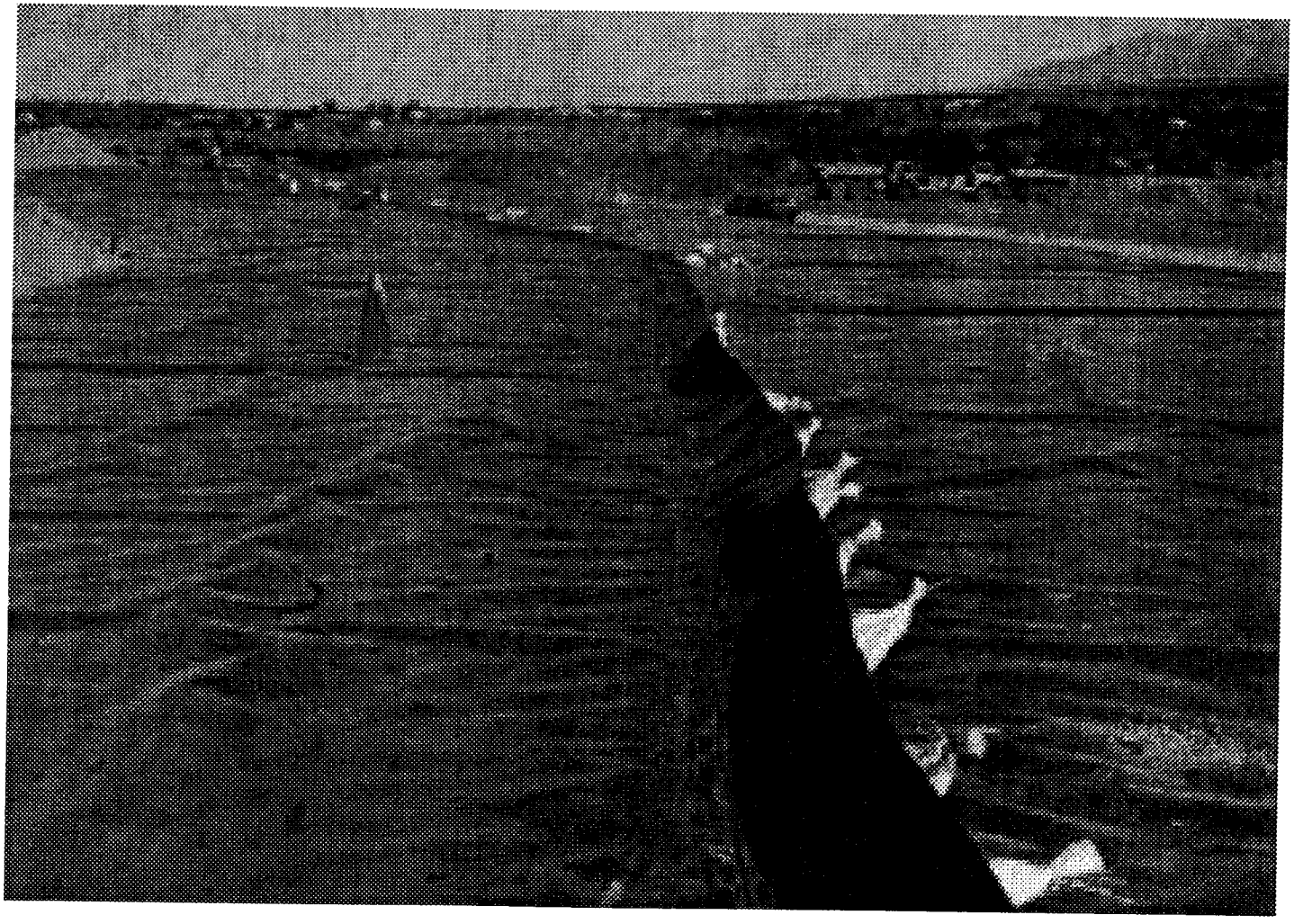
1999: EPA funded monitoring.

- EPA ACAP funded monitoring system; lysimeter installation on East Side of Monticello cell for percolation measurements through upper earthen portion of cover design. The geomembrane in the cover design serves as the base of the lysimeter. Total lysimeter plan area is 7.5 acres.
- EPA Region 8 funded the installation of 2 caisson lysimeters to measure water balance of the cover design. CS615 probes (moisture content), heat dissipation units (matric potential), and tipping bucket collection system for percolation volume collection.



Monticello Mill Tailings Site

Monticello Cover Profile



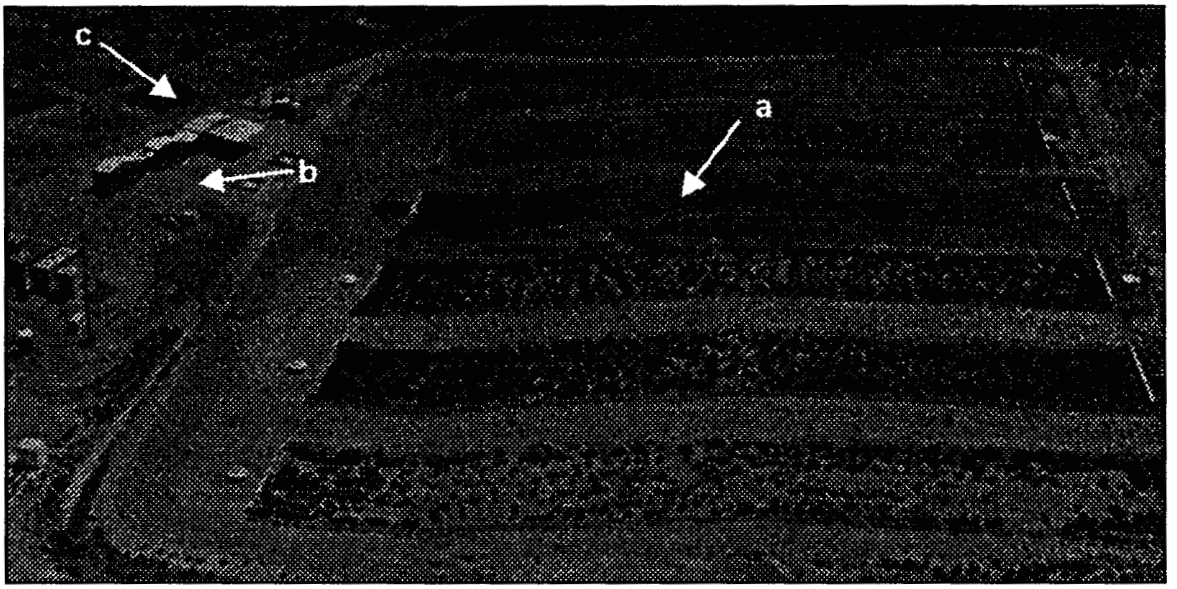


Figure 1. **Locations of the ALCD areas affected by the lightning strike include a) CR7 station which took the initial strike, b) main power supply to landfill stations, and c) field office computer area.**

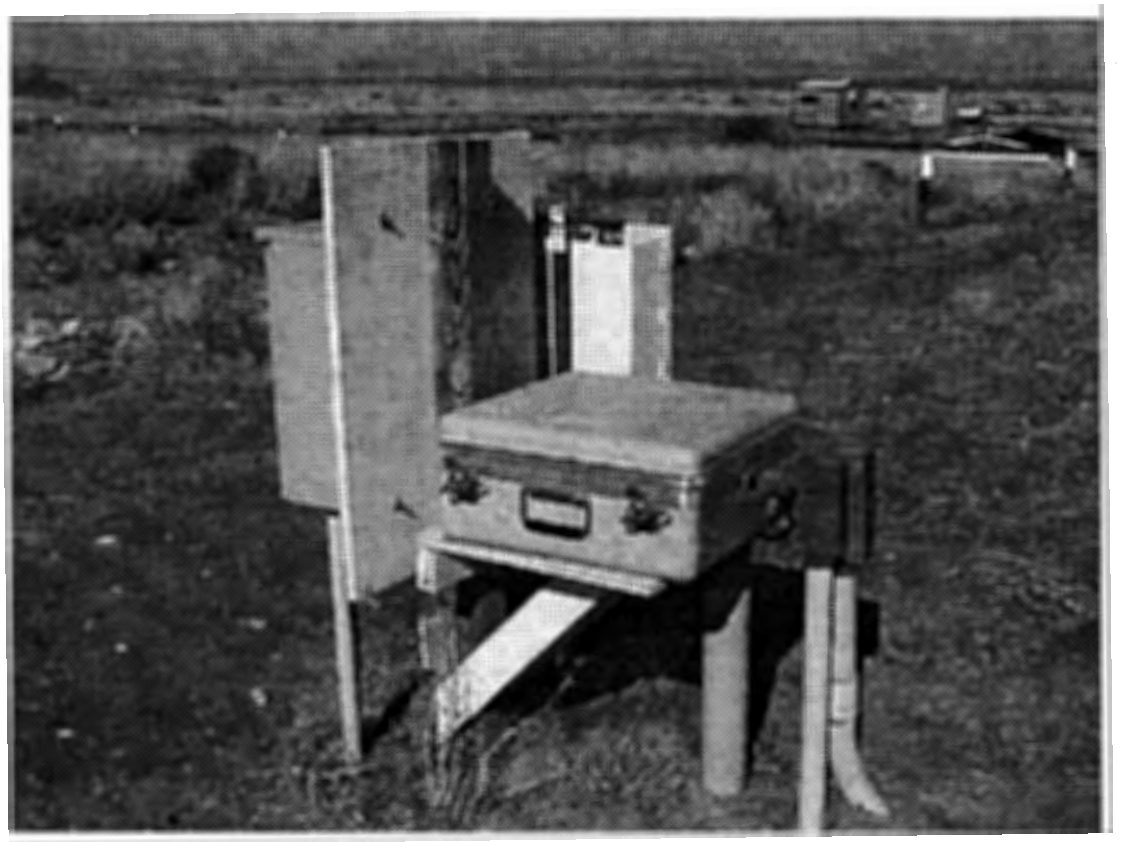


Figure 2. Lightning strike hit this Station CR7.

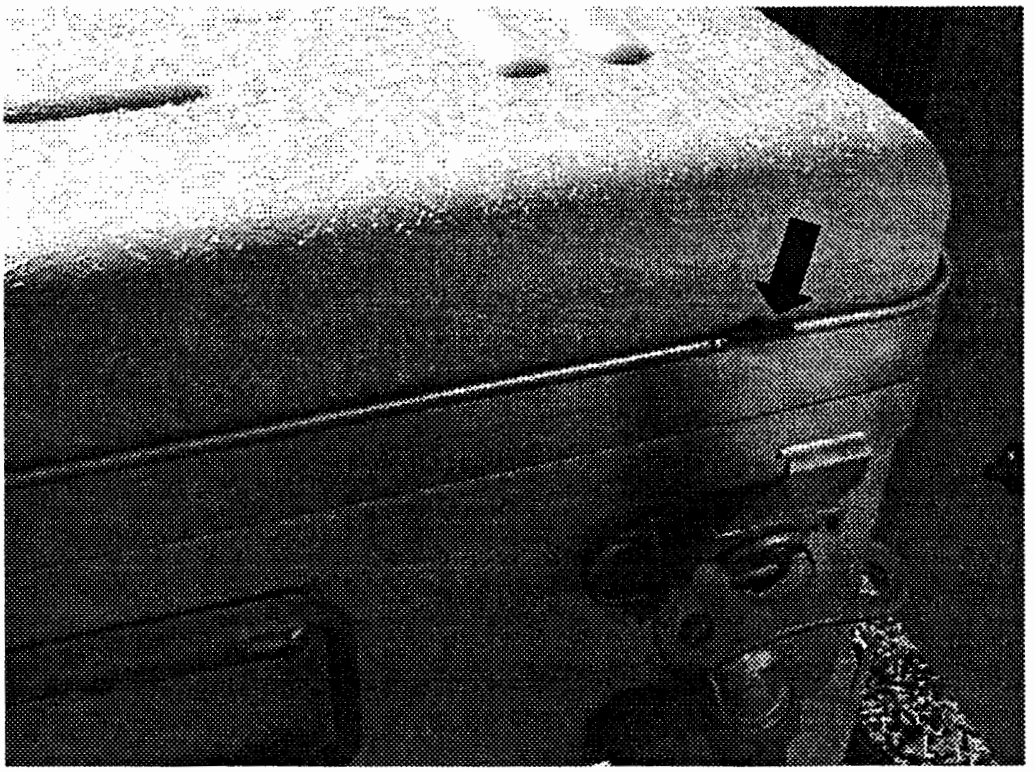


Figure 3. Close up of burned area where lightning strike hit CR7 box.

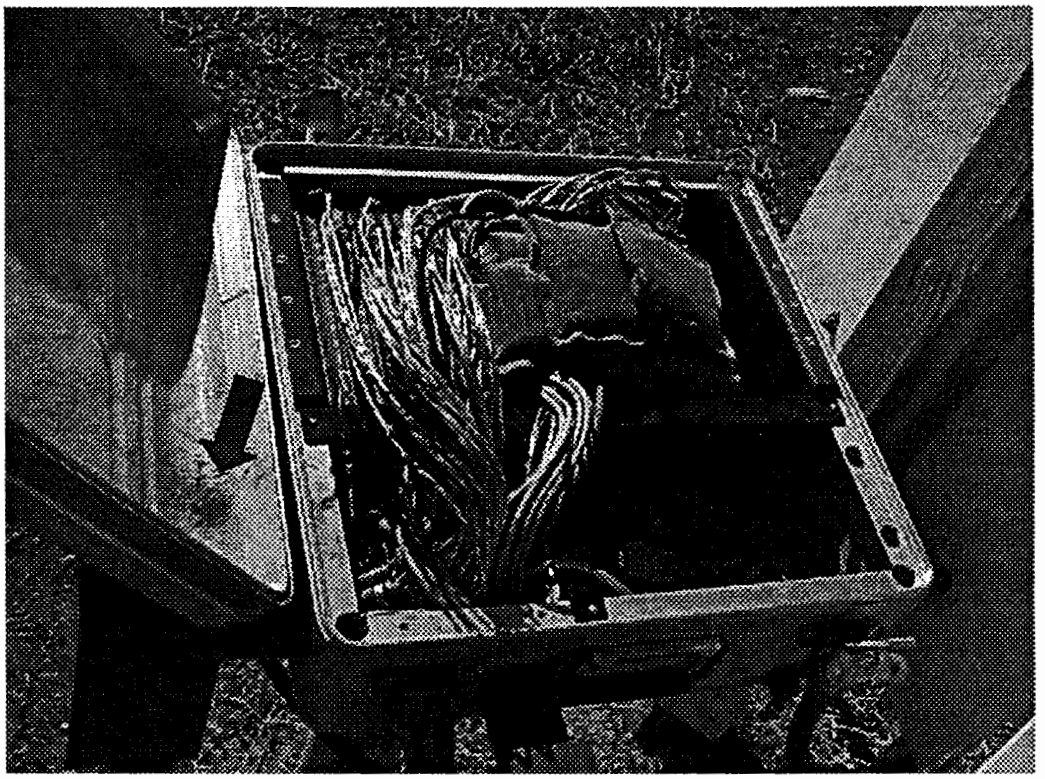


Figure 4. Close up of CR7 box with burned areas on lid of box (CR7 removed for photo)

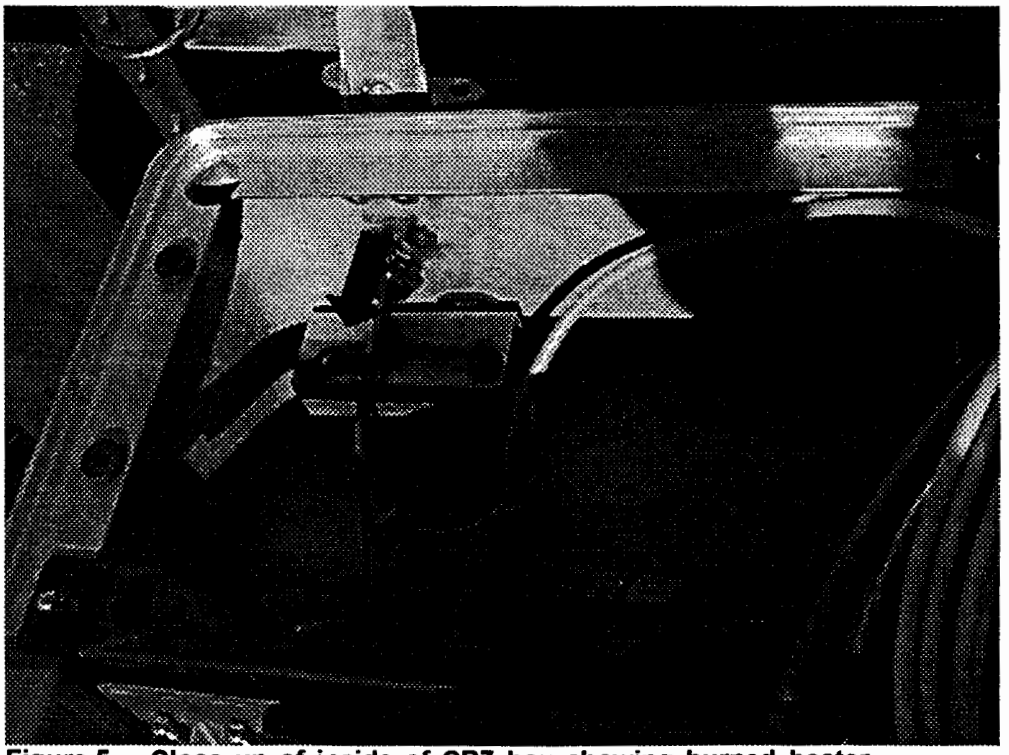


Figure 5. Close up of inside of CR7 box showing burned heater wires (CR7 was removed for photo)

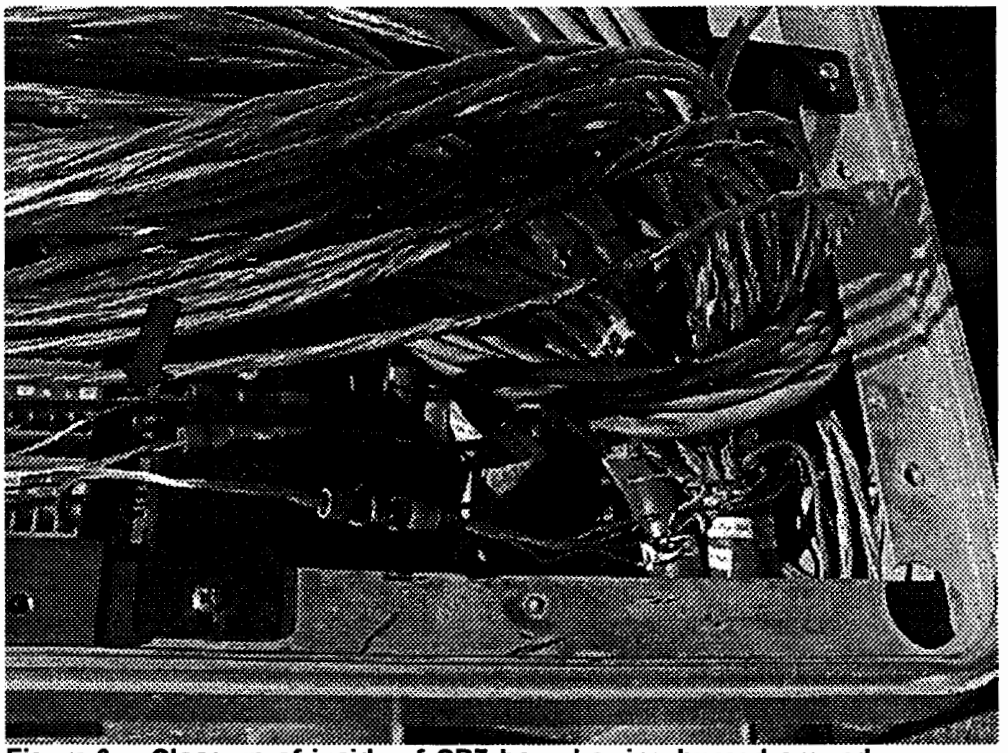


Figure 6. Close-up of inside of CR7 box showing burned ground wires. Approximately 15 wires have been repaired. Arrow points to a few of the repaired. Note burned marks on the blue encased wires and box frame.

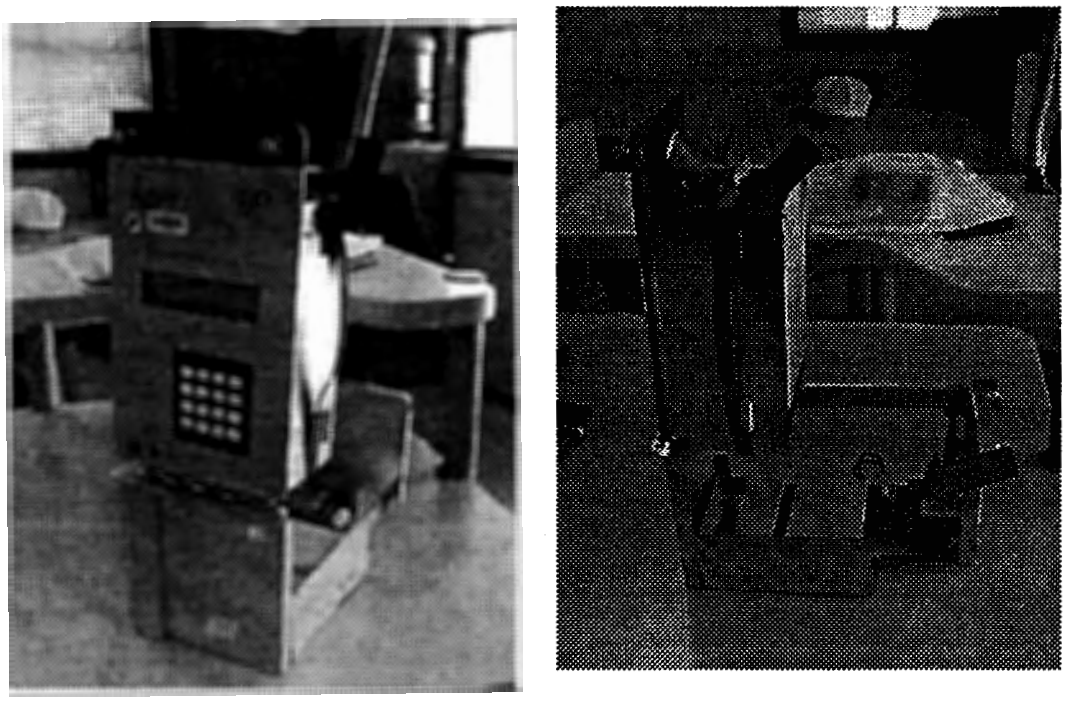


Figure 7. Close ups of CR7 showing burned areas

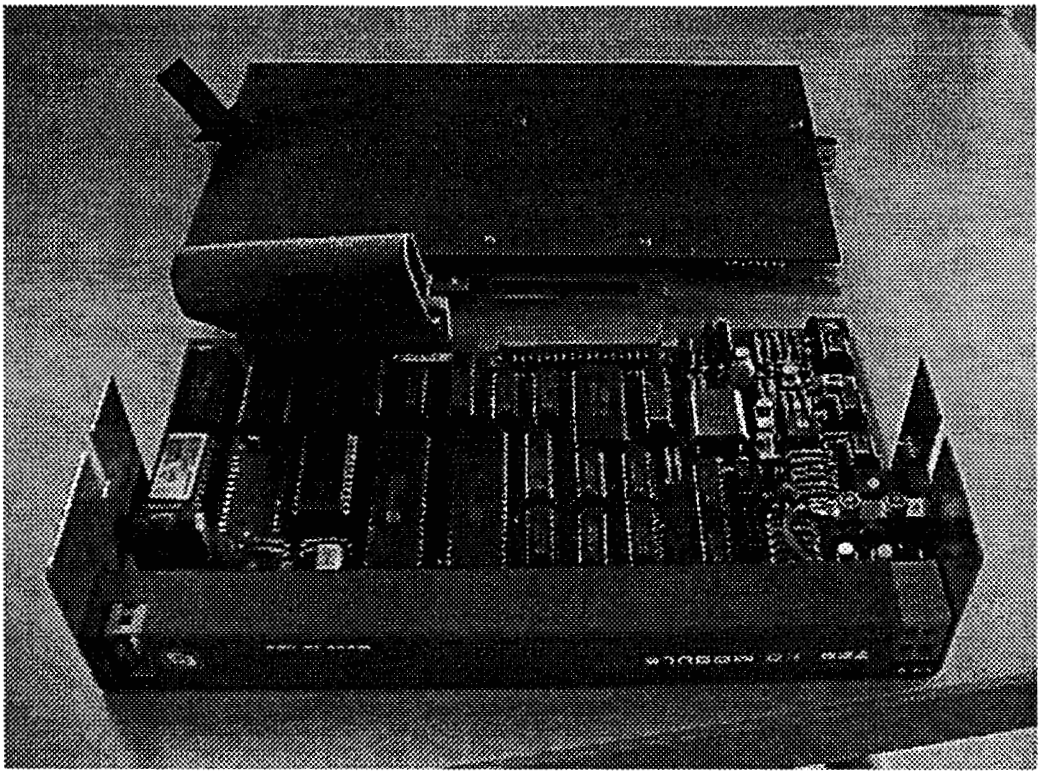


Figure 8. CSI I/O module for the CR7.

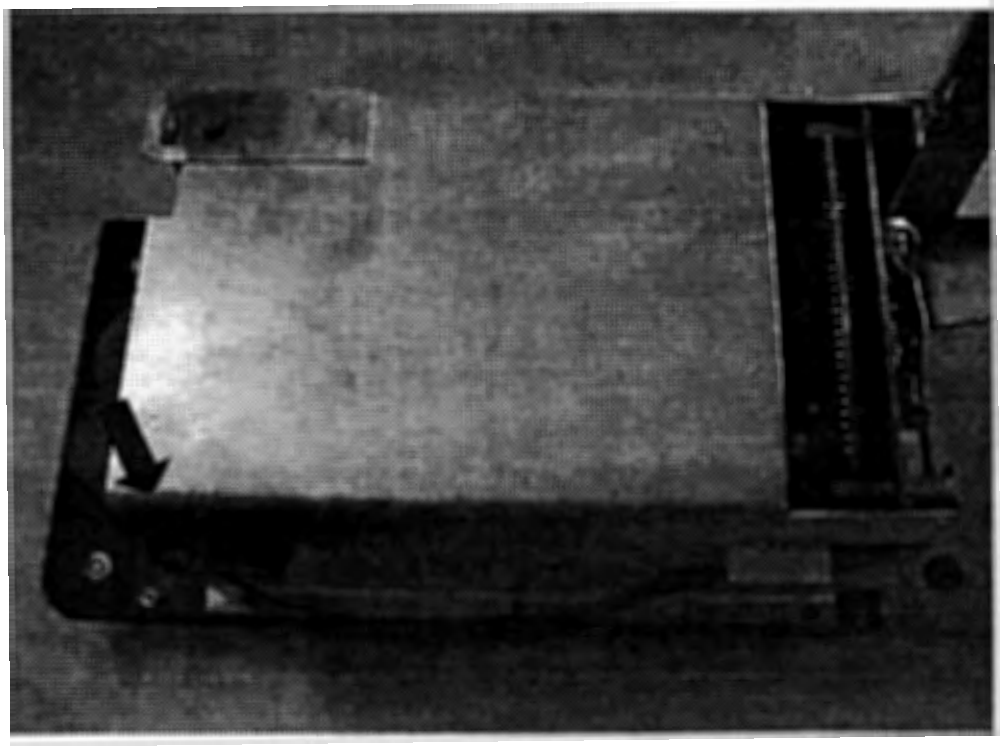


Figure 9. CSI analog input module housed on the bottom of the CR7 datalogger.

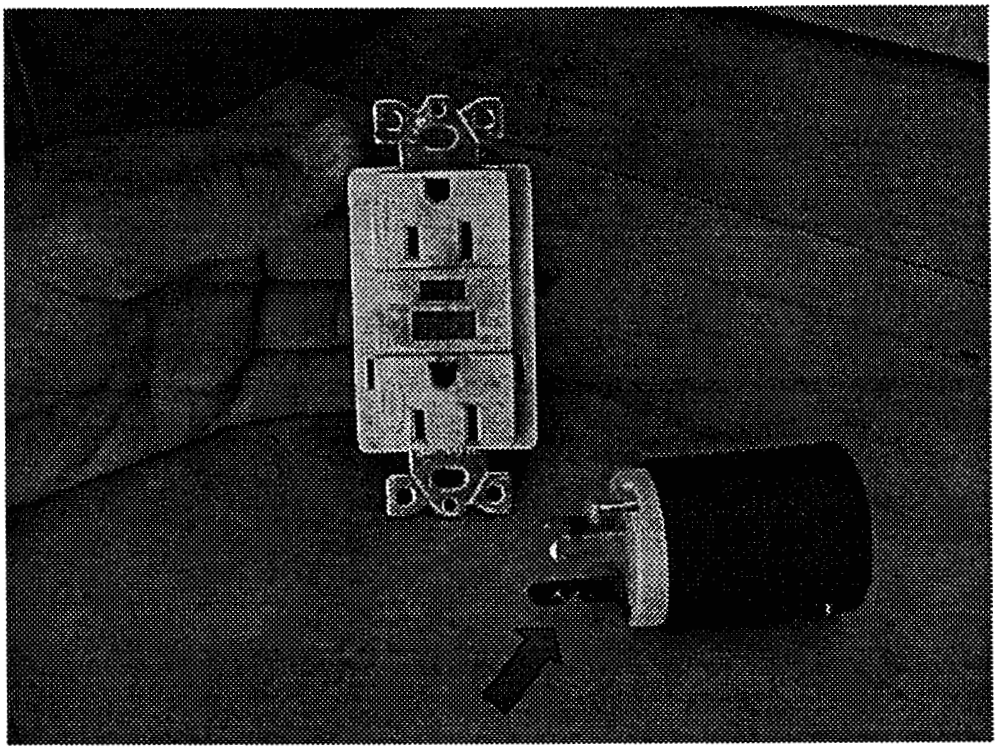


Figure 10. GFI receptacle and plug-in showing fire damage in lightning strike. This power supply ran all the ALCD field stations with the exception of the weather station which was unaffected by the strike. Note burned ground terminal.

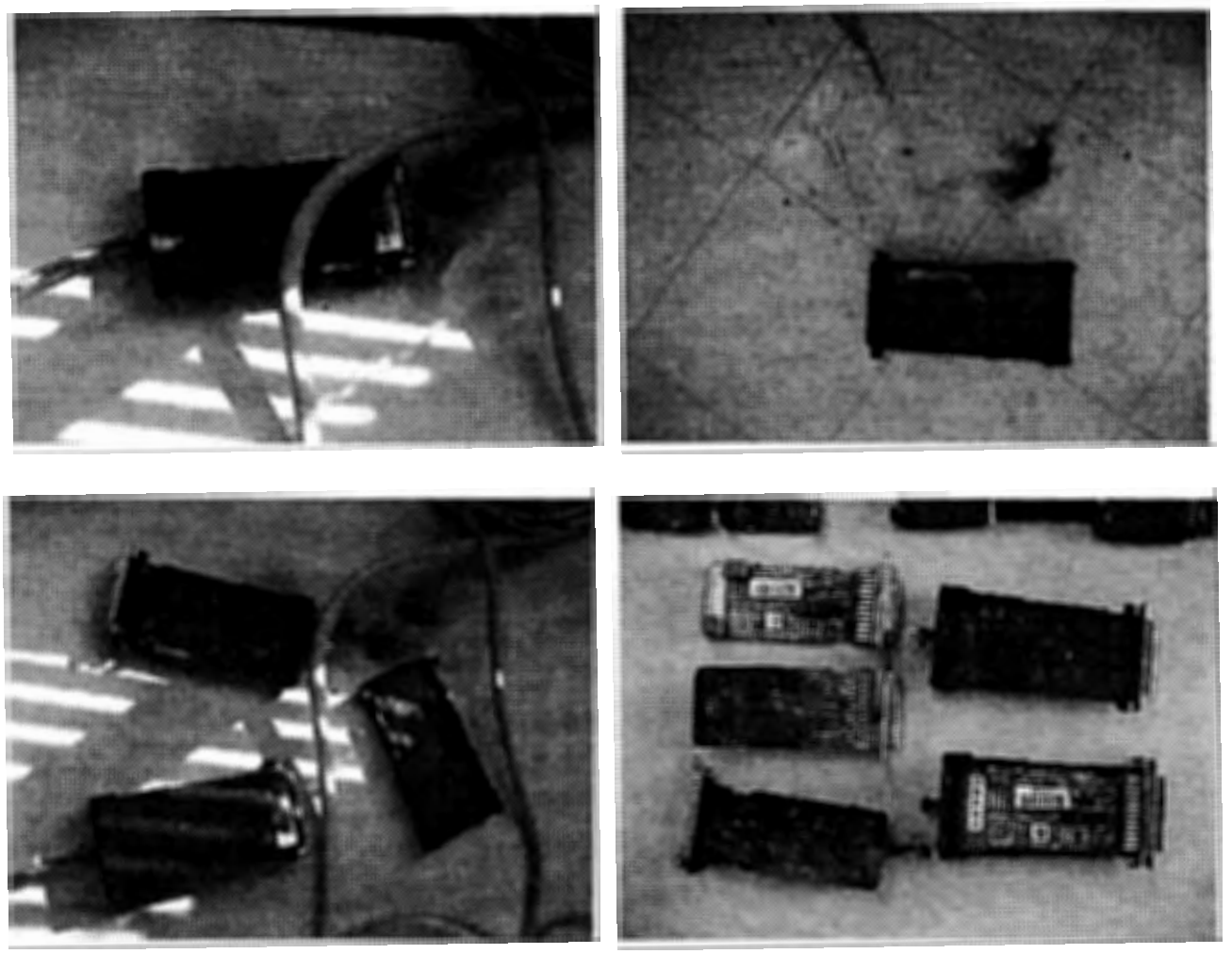


Figure 11. Short haul modems located near the computer that was burned in strike. Most of these modem's covers were blown off.

Figure 12. **CSI's CR10 dataloggers that were effected by the lightning strike. Connections to the dataloggers were not possible after the strike with the exception of the datalogger at the bottom of the photo. This datalogger had a good connection but the program could not be sent (disk attached to datalogger in photo).**

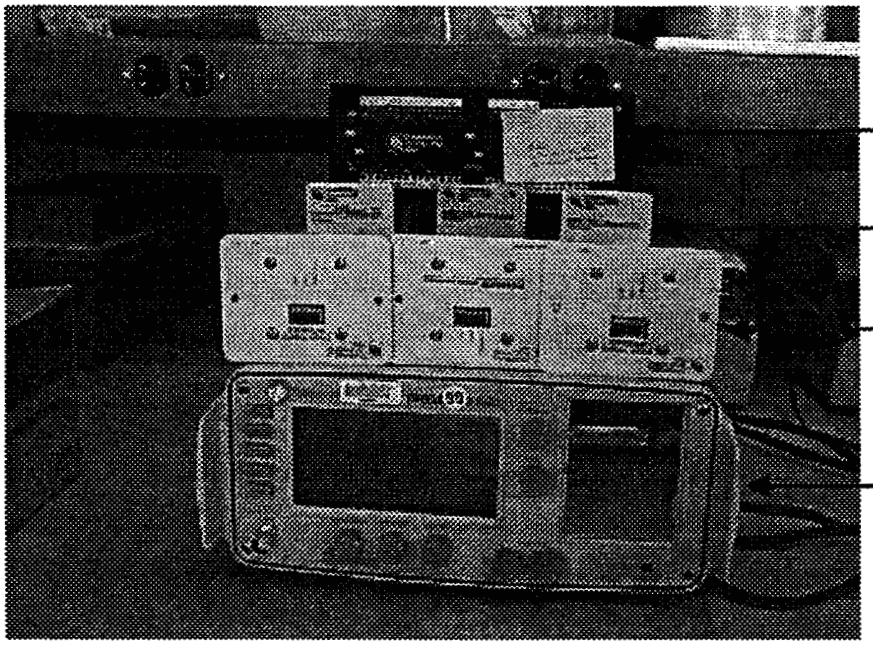


Figure 13. Tektronix 1502B cable testing unit, CSI modules and CR10 wiring panel that were affected by the lightning strike.

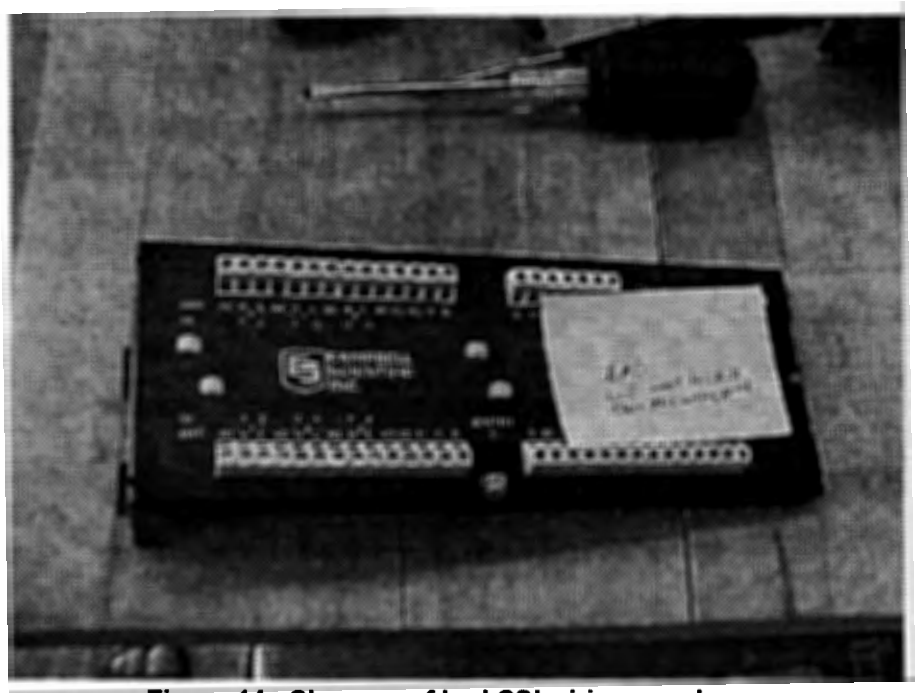


Figure 14. Close-up of bad CSI wiring panel.

Conventional vs. Alternative Landfill Cover Designs: Which is Best for Arid Climates?

Stephen F. Dwyer[1]

Abstract

A large-scale field demonstration comparing final landfill cover designs has been constructed and is currently being monitored. Four alternative cover designs and two conventional designs (a RCRA Subtitle 'D' Soil Cover and a RCRA Subtitle 'C' Compacted Clay Cover) were constructed side-by-side for direct comparison. The demonstration is intended to evaluate the various cover designs based on their respective water balance performance, ease of construction, and cost. This paper provides an overview of the construction of the covers and their respective costs as well as a summary of the first year's performance data.

[1] Principal Investigator, Sandia National Laboratories, MS 0719, P.O. Box 5800, Albuquerque, NM, USA 87185, fax 505-844-0543, phone 505-844-0595, email: sfdwyer@sandia.gov.

Conventional vs. Alternative Landfill Cover Designs: Which is Best for Arid Climates?

Summary

A large-scale field demonstration comparing final landfill cover designs has been constructed and is currently being monitored. Four alternative cover designs and two conventional designs (a RCRA Subtitle 'D' Soil Cover and a RCRA Subtitle 'C' Compacted Clay Cover) were constructed side-by-side for direct comparison. The demonstration is intended to evaluate the various cover designs based on their respective water balance performance, ease of construction, and cost. This paper provides an overview of the construction of the covers and their respective costs as well as a summary of the first year's performance data.

Background

The US Environmental Protection Agency (EPA) recommended landfill cover designs for Resource Conservation and Recovery Act (RCRA) Subtitle 'C' and 'D' regulated facilities are used throughout the US with little regard for regional conditions. Experience in the western United States has shown these designs to be vulnerable to such things as desiccation cracking when installed in arid environments. An EPA design guideline for final landfill covers states: "In arid regions, a barrier layer composed of clay (natural soil) and a geomembrane is not very effective. Since the soil is compacted 'wet of optimum', the layer will dry and crack". The basic soil cover used with Subtitle 'D' covers has a barrier layer that is also subject to deterioration due to freeze/thaw cycles, among other problems.

A study by the EPA of randomly selected landfills revealed that the vast majorities are leaking. Many have serious problems including groundwater contamination and serious ecological impacts such as killing flora and fauna. Virtually all parts of the nation have experienced water contamination due to leachate leaking from landfills in some degree. A more recent study, the California Solid Waste Assessment Test Report found that 72 to 86% of existing landfills with compacted clay barrier layers are failing. It also concluded that these clay barriers leak regardless of climate or site-specific geology. These traditional covers such as the Subtitle 'C' Cover are not only inherently problematic but are very expensive and difficult to construct.

The Alternative Landfill Cover Demonstration (ALCD) is a large-scale field test at Sandia National Laboratories, located on Kirtland Air Force Base

in Albuquerque, New Mexico. Its intent is to compare and document the performance of alternative landfill cover technologies of various costs and complexities for interim stabilization and/or final closure of landfills in arid and semi-arid environments. The test covers are constructed side-by-side for direct comparison based on their performance, cost, and ease of construction. The ALCD is not intended to showcase any one particular cover system. The focus of this project is to provide the necessary tools; i.e., cost, construction and performance data, to the public and regulatory agencies so that design engineers will have less expensive, regulatory acceptable alternatives to the conventional cover designs.

Traditional designs were installed at the ALCD site to serve as baseline covers to compare alternative cover designs against. The baseline covers were installed to meet the minimum regulatory requirements set forth under the RCRA Subtitles 'C' and 'D', which set forth performance standards but do not require the use of a specific cover design to comply with these standards. These regulations allow the governing regulatory agency to consider and approve an alternative final cover design as long as it meets the general performance standards.

Figure 1. Aerial View of Alternative Landfill Cover Demonstration

The covers built include two baseline covers: a conventional RCRA Subtitle 'D' Soil Cover, a conventional RCRA Subtitle 'C' Compacted Clay Cover, and four alternative covers: the Geosynthetic Clay Liner (GCL) Cover, Capillary Barrier, Anisotropic Barrier, and Evapotranspiration (ET) Cover. The test covers are each 13-m wide by 100 m long. The 100 m dimension was chosen because it is representative of hazardous and mixed waste landfills found throughout the Department of Energy complex (approximately 2 acres in surface area). All covers were constructed with a 5% slope in all layers. The slope lengths are 50 m each (100-m length crowned at the middle with half of the length - 50 m - sloping to the east and the other half toward the west). The western slope is monitored under ambient conditions (passive monitoring). A sprinkler system was installed in the eastern slope of each cover to facilitate stress testing of the covers (active monitoring).

Construction and Costs of Test Covers

Each cover was independently designed while the construction was competitively bid with the low bidder receiving a firm fixed price contract. Costs for each cover design were developed as follows: (1) common costs such as mobilizing, demobilizing, and subgrade preparation were evenly assessed to each cover; (2) all other costs such as materials and labor were carefully allocated to each cover design. A summary of the cost per surface square meter for each cover is presented in Figure 8.

Conventional Test Cover 1 (Figure 2) is a basic Soil Cover that is typically installed over municipal solid waste landfills (MSWLF) that meets minimum federal requirements (40CFR258). The cover is 60 cm thick. It is constructed of essentially two layers. The bottom layer is a 45-cm thick compacted soil barrier layer. The soil was compacted wet of the optimum moisture content so as to remold the soil thus lowering its initial permeability to meet the maximum 1×10^{-5} cm/sec saturated hydraulic conductivity requirement. The top vegetation layer is 15 cm of topsoil loosely laid. This layer provides for vegetation growth and erosion protection.

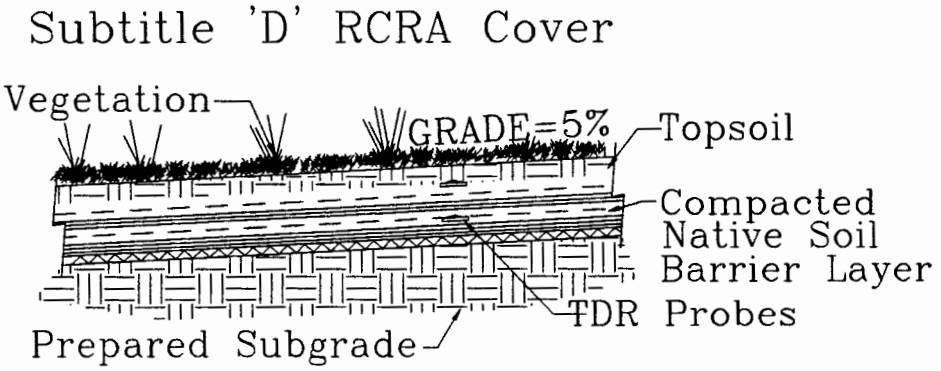


Figure 2 - Conventional Test Cover 1 – Soil Cover

The Soil Cover was the simplest and least expensive ($51.40/m²) of all of the covers installed.

Conventional Test Cover 2 (Figure 3) is a Compacted Clay Cover that is typically installed over hazardous waste landfills. This cover was designed and installed to meet minimum requirements set forth for RCRA Subtitle 'C' regulated landfills (40CFR264). It is 1.5 m thick and consists of three layers. The bottom layer is a 60-cm thick barrier layer. The barrier layer's primary purpose is to prevent the downward movement of water into underlying waste. It was constructed of native soil mixed with 6% bentonite by weight to meet the saturated hydraulic conductivity requirement (maximum of 1×10^{-7} cm/sec). The combination of the compaction requirements, soil amendment, and placement ('wet of optimum') was necessary to yield a maximum hydraulic conductivity of 1×10^{-7} cm/sec. Constructing the barrier layer was very difficult. The purchase and mixing of this bentonite into the soil increased the cost of the cover by 14% versus using unamended soil.

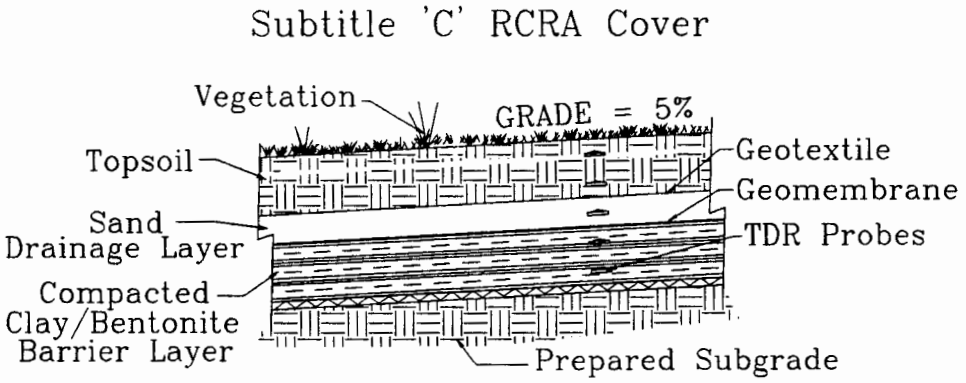


Figure 3 - Conventional Test Cover 2 – Compacted Clay Cover

A 40-mil linear low-density polyethylene geomembrane was placed on top of and in intimate contact with the clay barrier layer creating a composite barrier layer. The total installed cost for the geomembrane was about $10.12 per square meter ($0.94 per square foot).

The middle layer is a 30-cm thick drainage layer. The primary purpose of the drainage layer is to quickly route water that has passed through the vegetation layer laterally to collection drains normally located at the perimeter of the landfill. This layer was constructed of sand placed directly on the geomembrane. Its cost from the supplier was about $7.70 per ton.

A geotextile was placed on top of the sand drainage layer that serves as a filter between the drainage layer material and top layer. This geotextile was installed at a cost of about $3 per square meter ($0.28 per square foot).

The top layer is a 60-cm thick vegetation layer comprised of loosely laid soil. This layer's primary purpose is to provide for vegetation growth, erosion protection, and protect the underlying layers from such events as harmful freeze/thaw cycles. It allows for storage of infiltrated water that can later be evaporated. It is 45 cm of native soil covered by 15 cm of topsoil.

The Compacted Clay Cover was by far the most difficult and expensive test cover to install costing $157.54 per square meter.

Any and all compaction of soil in the alternative designs was compacted 'dry of optimum' rather than 'wet of optimum' as currently recommended with the conventional covers. This was done in an effort to mitigate the potential for desiccation cracking and allow for more initial water storage capacity.

Alternative Test Cover 1 (Figure 4) is a Geosynthetic Clay Cover identical to the conventional Compacted Clay Cover with the exception that the expensive and problematic clay barrier layer was replaced with a manufactured sheet, a geosynthetic clay liner (GCL), installed in its place.

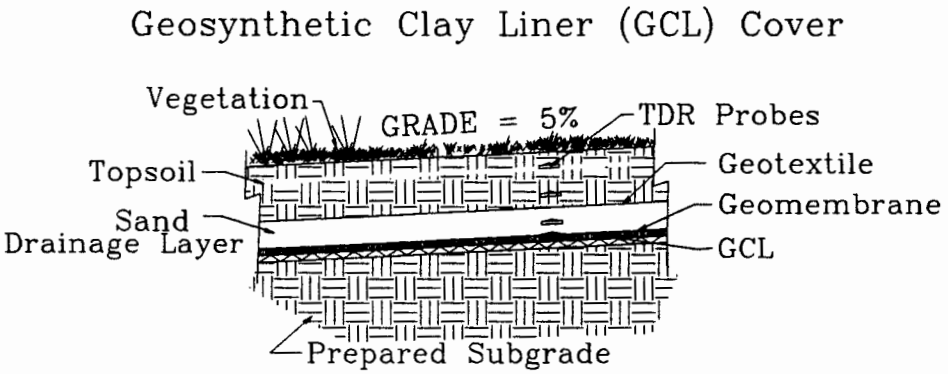


Figure 4 - Alternative Test Cover 1

The GCL is the bottom barrier layer covered with a geomembrane, drainage layer and vegetation layer, respectively. The GCL is a composite of two nonwoven fabrics sandwiching a layer of bentonite. The hydraulic conductivity of the GCL is 5×10^{-9} cm/sec.

Replacing the 60-cm thick clay (amended soil) barrier layer with a GCL substantially reduced the cost and difficulty of construction. The construction cost of this cover design was $89.99 per square meter.

Alternative Test Cover 2 (Figure 5) is a Capillary Barrier. The Capillary Barrier, comprised of a fine-grained layer of soil placed over a coarse-grained layer emphasizes a sufficient contrast between the hydraulic conductivities of the fine-grained layer versus the coarse-grained layer. This contrast lends to the effect that flow through the cover is greatly slowed under unsaturated conditions.

This cover system consists of 4 primary layers: (1) a surface or topsoil layer; (2) an upper drainage layer; (3) a barrier soil layer; and (4) a lower drainage layer. The topsoil layer is 30 cm thick. This surface layer enhances evapotranspiration, protects against desiccation of the barrier soil layer, and provides a medium for growth of vegetation. The vegetation increases evapotranspiration and protects against surface erosion. The upper lateral drainage layer is 22 cm of gravel overlain by 8 cm of sand. The sand serves as a graded filter to prevent topsoil from clogging the drainage layer. The gravel allows for lateral drainage of any water that has percolated through the topsoil. The barrier soil layer and lower drainage layer comprise the capillary barrier. The barrier soil layer is compacted soil 45 cm thick. The lower drainage layer is 30 cm of sand.

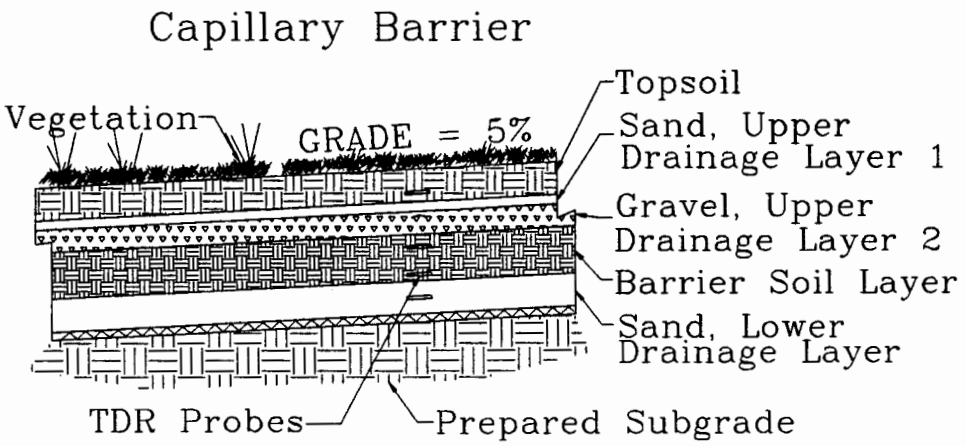


Figure 5 - Alternative Test Cover 2

The Capillary Barrier was installed without any geosynthetic materials. Special care was utilized when placing a lift of material on top of a layer of uncompacted material such as soil on sand or sand on pea gravel. This was done to maintain a smooth, uniform transition between the soil and sand or sand and pea gravel. The construction cost of this cover design was $92.64 per square meter.

Alternative Test Cover 3 (Figure 6) is referred to as the Anisotropic Barrier. The design of the Anisotropic Barrier attempts to limit downward movement of water while encouraging lateral movement of water. This cover is composed of a layering of capillary barriers. The various layers are enhanced by varying soil properties and compaction techniques that lead to the anisotropic properties of the cover.

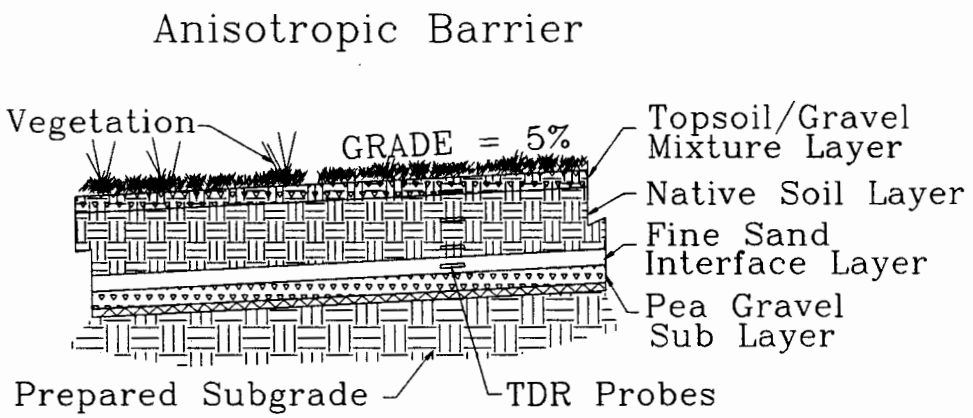


Figure 6 - Alternative Test Cover 3

This cover system consists of 4 layers: (1) a top vegetation layer; (2) a cover soil layer; (3) an interface layer; and (4) a sublayer. The vegetation

layer is 15 cm thick. It is comprised of a mixture of local topsoil and pea gravel. The gravel to soil mixture by weight was 25%. This layer encourages evapotranspiration, allows for vegetation growth, and reduces surface erosion. The cover soil layer is 60 cm of native soil. Its function is to allow for water storage and eventual evapotranspiration and it serves as a rooting medium. The interface layer is 15 cm of fine sand that serves as a filter between the overlying soil and the underlying gravel. It also serves as a drainage layer to laterally divert water that has percolated through the cover soil. The sublayer is 15 cm of pea gravel. It serves as a capillary break. The interface layer and sublayer combined also serve a dual purpose as bio-barriers.

The Anisotropic Barrier was installed without any geosynthetic materials. The construction cost of this cover design was $75.26 per square meter.

Alternative Test Cover 4 (Figure 7) is referred to as an Evapotranspiration (ET) Cover. The ET Cover is a soil cover with an engineered vegetative covering. This cover encourages water storage and enhances ET. It is 90 cm thick. The bottom 75-cm layer was compacted while the top 15-cm layer of topsoil was loosely placed. The soil allows for water storage which, when combined with the vegetation, will increase evapotranspiration. A thin layer of gravel was then spread on the surface. This layer is about an inch thick and serves to reduce surface erosion and provide for better vegetation establishment.

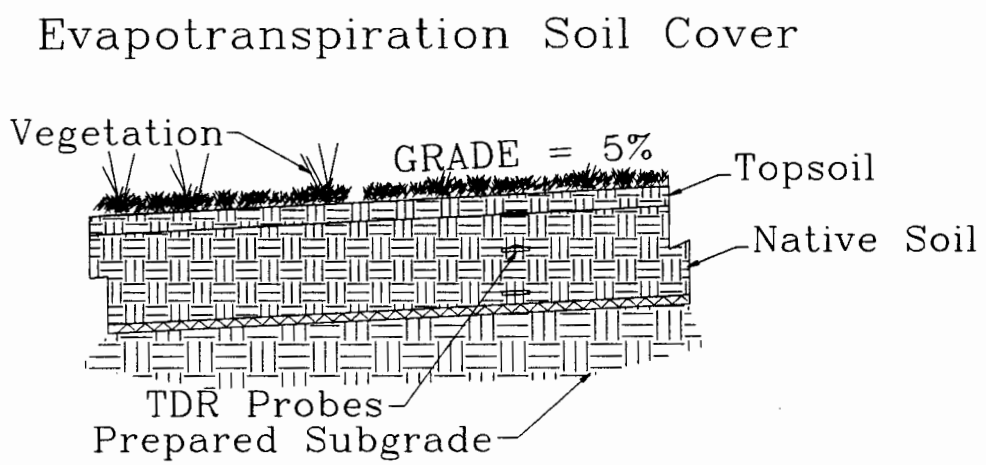


Figure 7 - Alternative Cover 4

The ET Cover was constructed similarly to the RCRA Subtitle 'D' Soil Cover. The RCRA Subtitle 'D' Soil Cover's shallow depth is one of the primary reasons for its inadequacy. Computer modeling revealed that if the depth were increased to 90 cm in the Albuquerque climate, this

would essentially eliminate water infiltration into underlying waste. The construction cost of this cover was $73.89 per square meter.

Water Balance Performance

While a cost saving is the predominant reason owners/operators might prefer to close a landfill with an alternative design, it is the comparable performance of the cover system that will enable it to have a chance to be approved by the governing regulatory entity for deployment. The side-by-side arrangement of this demonstration allows for 'direct' comparison of the water balance performance between the six cover designs.

Continuous water balance and meteorological data is currently being collected. It will be actively collected for a minimum five-year post construction period. In addition, periodic measurements of vegetation cover, biomass, leaf area index, and species composition are being taken.

The demonstration is instrumented to yield water balance data for each cover. Precipitation at the site is measured. Water balance variables (surface runoff, lateral drainage, soil water storage, and percolation) are being obtained with the monitoring systems. All measurements are made with automated monitoring systems to provide continuous data. Manual backup systems are available in case of failure in one or more of the automated measurements systems and/or to verify accuracy of the automated systems.

By current standards, the comparable percolation rates of covers determine their equivalence. The cover system must be able to isolate the underlying waste for the length of time it takes for the waste to be deemed harmless to the surrounding community. The data obtained from demonstrations such as this and others like it provide excellent short-term results of cover systems.

The accumulated percolation for each cover is presented in Figure 8. These data were obtained from May 1997 to March 1998. It is the first year of a planned minimum 5-year study. As expected, the Subtitle 'D' Soil Cover performed poorly. Its percolation rate is increasing as well. Desiccation cracking and detrimental effects from freeze/thaw cycles have led to its decreased ability to minimize percolation. Other factors such as root penetration, earthworm activity, insect activity, etc. are also contributing to its decreased impermeability and will continue to have negative impacts.

The other baseline cover, the Subtitle 'C' Compacted Clay Cover, had little percolation for most of the year. However, in the past few months

percolation is evident. The soil moisture content in the barrier layer has been exhibiting an accumulating effect partly because of the added bentonite but primarily because it is covered by a geomembrane. As moisture moves through the geomembrane by diffusion or a defect in the membrane, it infiltrates the barrier layer. The geomembrane hampers the ability of the barrier layer to dry by evaporation, consequently as additional moisture infiltrates the barrier layer it eventually creates percolation. This trend is expected to continue with the percolation rate increasing slightly with time.

The GCL Cover is not performing as well as expected. There are eight 1-cm^2 defects in the geomembrane. It is hypothesized that as moisture moves through the geomembrane via defects or diffusion, that it runs through the seams of the GCL prior to the seams hydrating, swelling and thus closing. The GCL could also have been damaged during construction but this is not believed to have happened since the quality control on the project was very tight. This type of problem, however is a definite possibility given the loss in transmissivity going from a 2-foot thick clay layer to a manufactured sheet less than ¼-inch thick. The GCL could be experiencing leaching of the bentonite from the membrane or possibly could have sustained damage from root intrusion.

For the Capillary Barrier, the percolation rate for the first year was also higher than expected but is slowing significantly. The divergence capacity at this point may be the problem at the given 5% slope. The unsaturated flow is two-dimensional, with vertical and lateral movement. As the moisture moves laterally downhill in the fine layer, it accumulates to a point where it finally breaks through into the coarse layer. The percolation rate is slowing as the vegetation on the surface thickens with the growth of native grasses and shrubs which are replacing the initial growth of tumbleweeds (these weeds unfortunately are inevitable in the first year or two after the area has been disturbed in arid environments). The vegetation is removing moisture from the surface soil layer, increasing the ET rate.

The Anisotropic Barrier and ET Cover are both performing very well. Their percolation rates have decreased similar to the Capillary Barrier as a result of increased transpiration from the vegetation growth. Recently, the percolation rates of both of these covers have decreased below the rate of the Compacted Clay Cover. As these covers are less than half the cost of the Compacted Clay Cover and their performance is about equivalent (long-term performance is expected to be better than the Compacted Clay Cover), these are probably the two best covers for either a MSWLF or hazardous waste landfill. However, it should be kept in mind that this is only the first year of monitoring and we have already

witnessed changes in percolation trends. Longer-term data are needed to make more definitive decisions. For more information contact Steve Dwyer @ sfdwyer@sandia.gov or 505-844-0595.

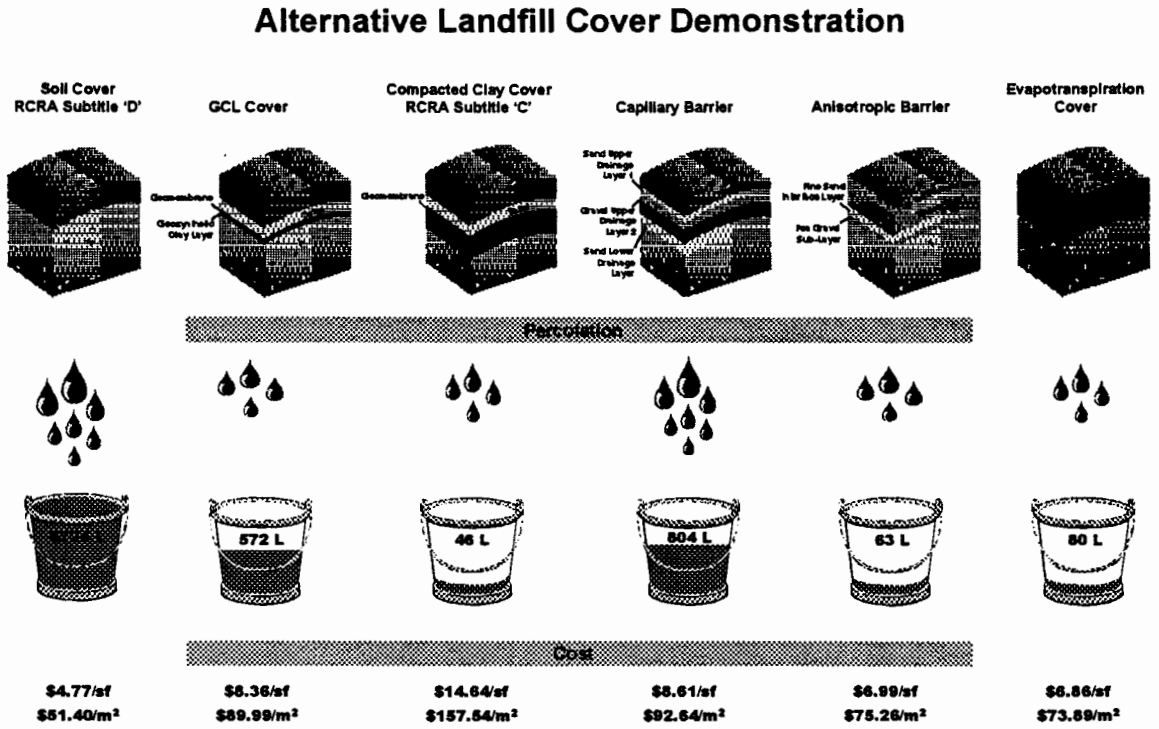


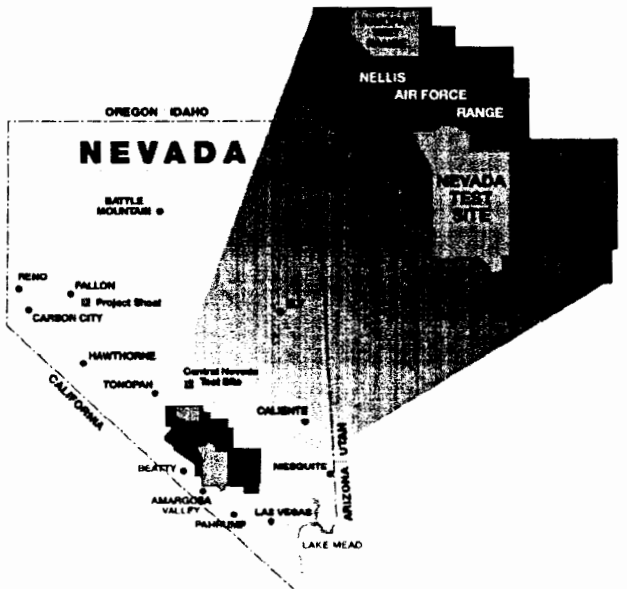
Figure 8 - Summary of Construction Costs & First Year Water Balance Performance

Long-term Monitoring at the Radioactive Waste Management Sites at the Nevada Test Site

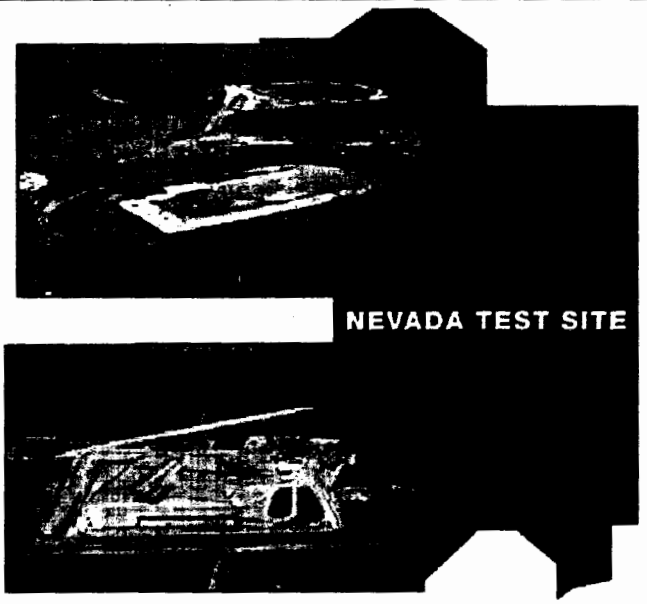
Long Term Monitoring Strategy Meeting
for the Material Disposal Areas, LANL
August 9, 2000

Dan Levitt, Bechtel Nevada

Bechtel Nevada



Bechtel Nevada

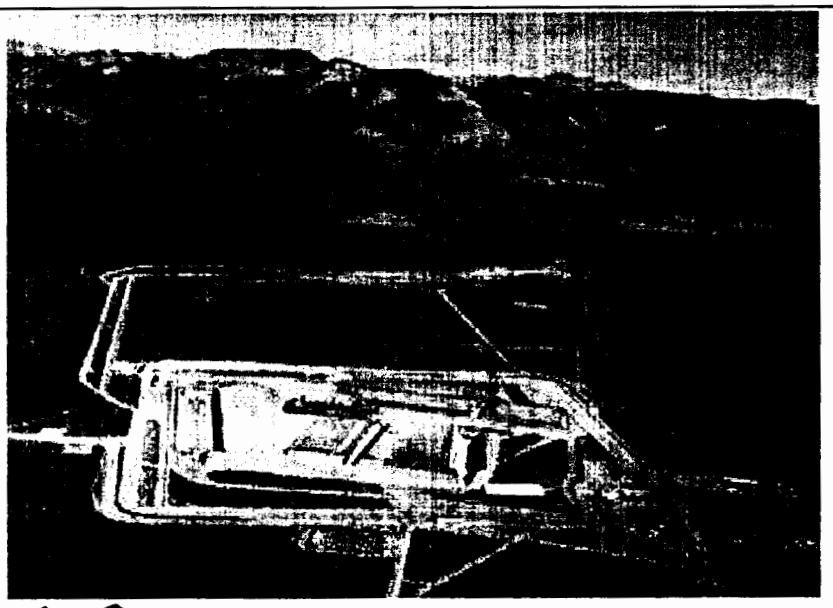


Bechtel Nevada

Area 5 Radioactive Waste Management Site (RWMS)

- Elevation = 975 m (3200 ft)
- Northern edge of Mohave Desert
- Average annual precipitation = 127 mm (5.0 in)
- Groundwater depth = 235 m (771')

Bechtel Nevada



Bechtel Nevada

Area 3 Radioactive Waste Management Site (RWMS)

- Elevation = 1225 m (4020 ft)
- Southern edge of Great Basin Desert
- Average annual precipitation = 171 mm (6.7 in)
- Groundwater depth = 490 m (1608 ft)

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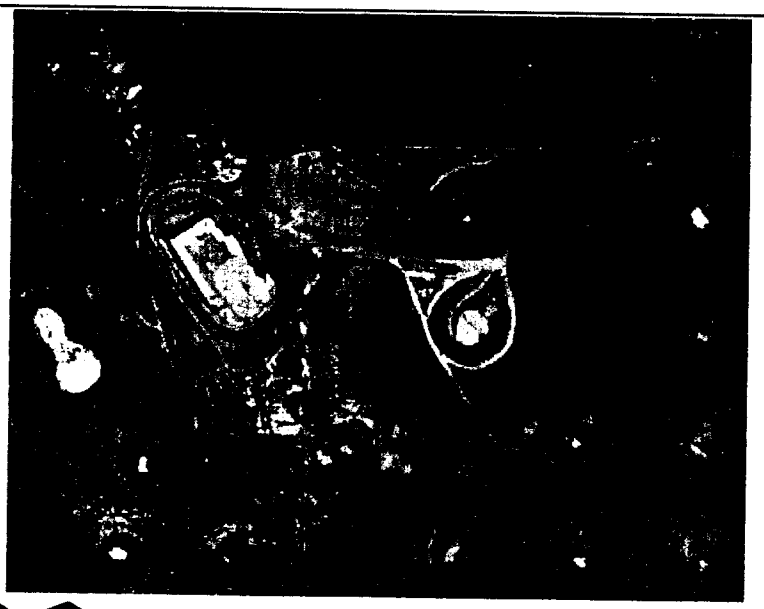

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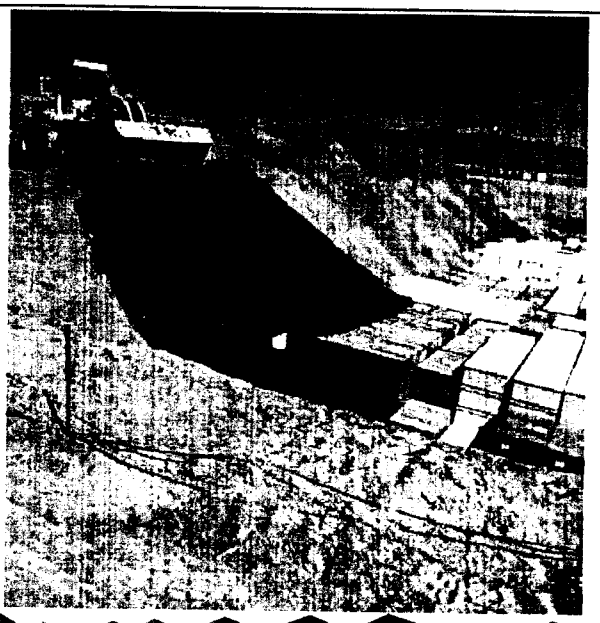

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CIVIL ENGINEERING/SEPTEMBER 1998

ALTERNATIVE LANDFILL COVERS PASS THE TEST

Less expensive landfill covers are performing as well as or better than conventional covers in the first year of a large-scale field demonstration.

STEPHEN F. DWYER

When municipal solid waste and hazardous waste landfills reach their capacities, they're capped with a final cover that keeps out rainfall and prevents leachate generation and possible environmental contamination. These final covers combine layers of clay, sand, vegetated topsoil and, sometimes, synthetic liners.

A 1983 study by the EPA of randomly selected landfills revealed that the vast

fornia "Solid Waste Assessment Test Report," which studied 544 California landfills located in a wide variety of climates, found that 72% to 86% of landfills with compacted clay barrier layers are failing. Though landfills in arid climates are particularly vulnerable to clay layer cracking, this study found that all landfills, regardless of climate or geology, are subject to this problem.

The need for more effective landfill cover designs has compelled Sandia National Laboratories to initiate the Alternative Landfill Cover Demonstration

arid and semiarid environments. Six landfill test covers have been constructed side by side for direct comparison of their performance, cost and ease of construction. Two of the covers are conventional designs that act as baseline covers, and four are alternative designs. The purpose of this project is to provide comparative performance and cost data to the public and to regulatory agencies to help them weigh the merits of alternative, lower-cost landfill covers.

CURRENT COVERS

Most landfill covers in the U.S. are

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RWMS Environmental Monitoring

- Radiation exposure (DOE O 435.1)
- Air Quality (NESHAP, DOE O 435.1)
  - Radon (DOE O 435.1)
- Meteorology (NESHAP, DOE O 5400)
- Biota
  - Vegetation (DOE O 435.1)
  - Animals (DOE O 435.1)
- Subsidence (40 CFR 265.310, DOE O 435.1)
- Groundwater (40 CFR 265)
- Vadose zone
  - Water in vadose zone (DOE O 435.1)
  - Tritium in soil gas (DOE O 435.1)

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Vadose Zone Monitoring Objectives

- Monitor water movement in the vadose zone
- Monitor tritium migration via soil gas in the vadose zone
- Performance Assessment (PA) Maintenance
  - Provide data to confirm assumptions within PAs
    - No downward pathway under natural conditions
- Evaluate performance of monolayer waste covers
  - Bare vs. vegetated waste covers
  - Compacted waste covers vs. natural soil conditions
- Hydrological characterization of the vadose zone

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RWMS Vadose Zone Monitoring Strategy

- Direct measurement of tritium migration (Area 5 RWMS)
  - Soil gas sampling at 4 locations surrounding Area 5 RWMS, and
  - Soil gas sampling at 1 location in the center of Area 5 RWMS
- Direct measurement of water movement (Area 3 and 5 RWMSs)
  - Indirect indicator of radionuclide migration using:
    - Weighing lysimeter facility
    - Automated VZ monitoring systems with buried sensors
    - Neutron probe measurements at selected access tubes

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Weighing Lysimeter Facility at Area 5 RWMS

- Two large weighing lysimeters (2m x 4m x 2m)
- A box of soil on a sensitive scale
- One is vegetated with native plants at approx. natural density
- One has a bare soil surface
- Instrumented with soil water sensors
- Directly measure components of the water balance
- Dataset is continuous since March 1994
- Dataset is tied to PAs and basis for many studies
- Ideal facility for calibration of flow and transport models

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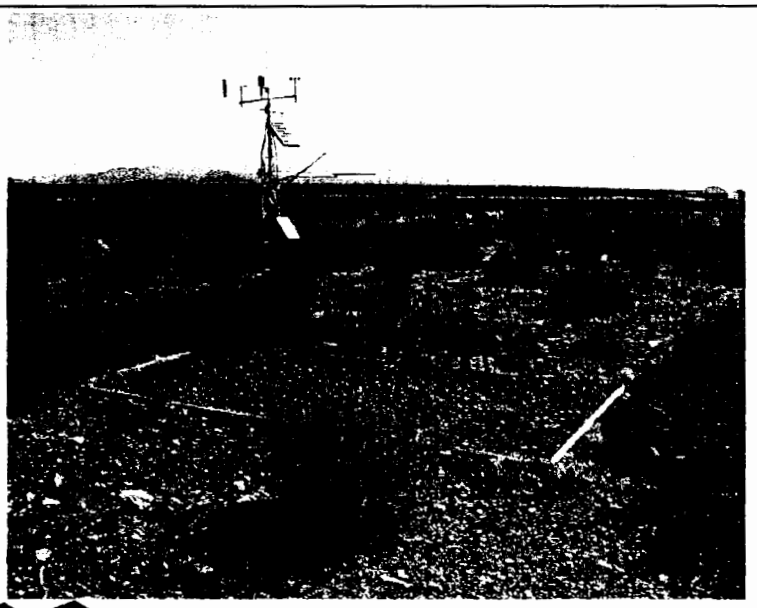

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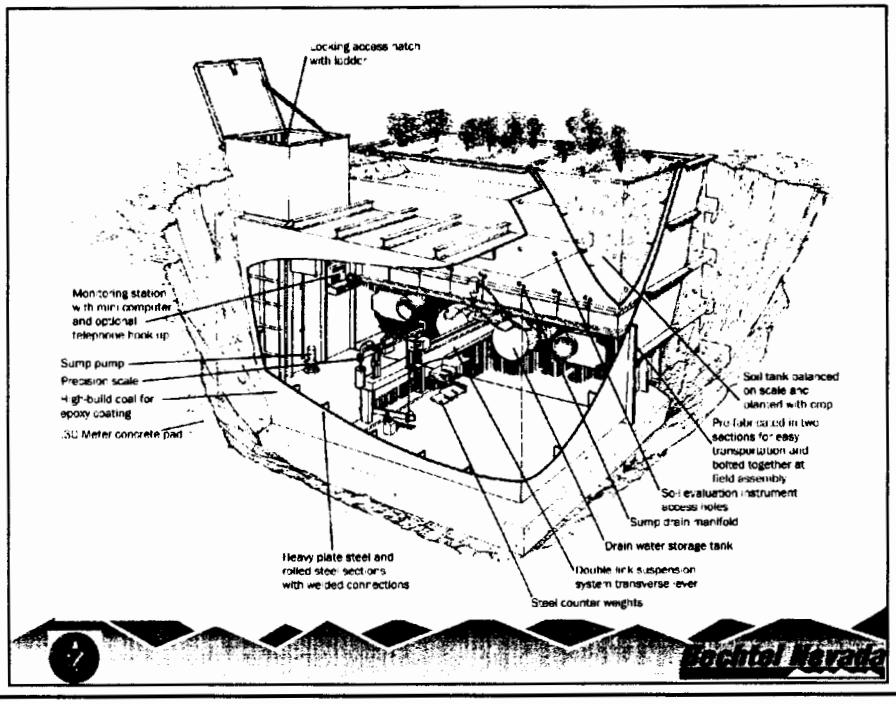
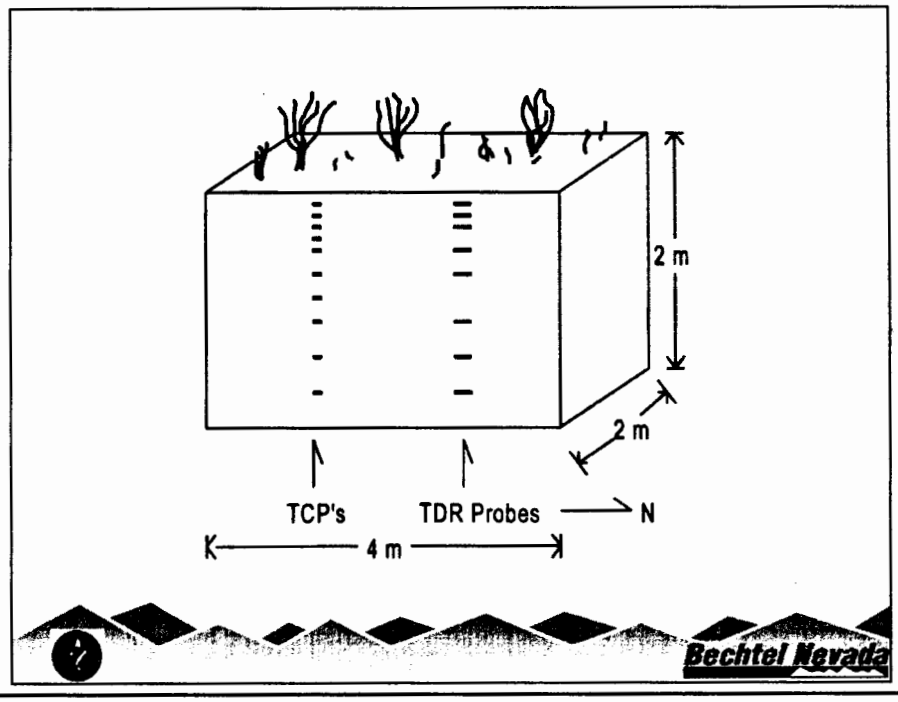

Locking access hatch with ladder
Monitoring station with mini computer and optional telephone hook up
Sump pump
Precision scale
High-build coal for epoxy coating
.30 Meter concrete pad
Soil tank balanced on scale and planted with crop
Pre-fabricated in two sections for easy transportation and bolted together at field assembly
Soil evaluation instrument access holes
Sump drain manifold
Drain water storage tank
Heavy plate steel and rolled steel sections with welded connections
Double link suspension system transverse lever
Steel counter weights
Bechtel Nevada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TCP's
TDR Probes
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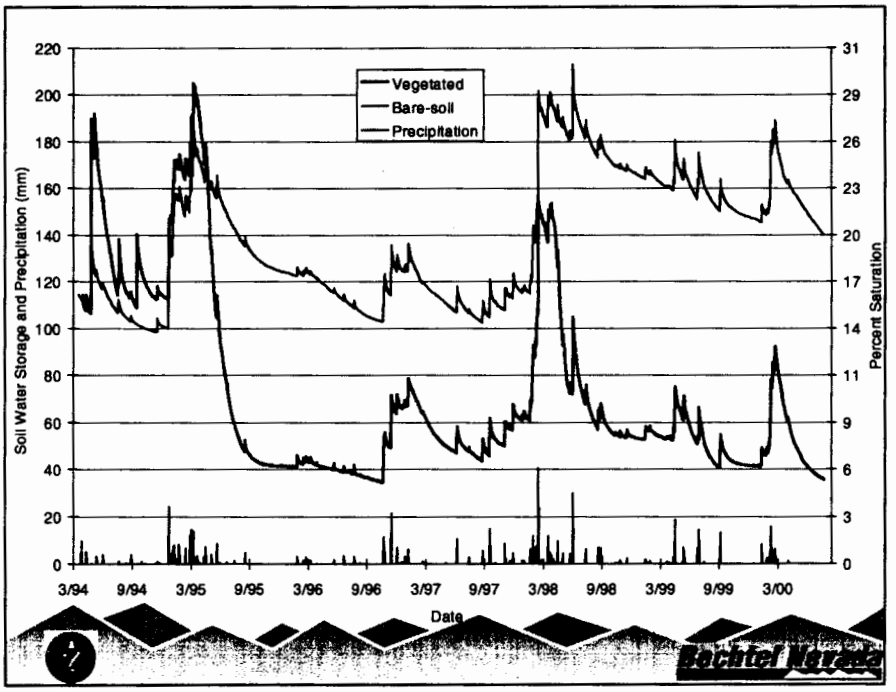
Bechtel Nevada


Vegetated
Bare-soil
Precipitation
Soil Water Storage and Precipitation (mm)
Percent Saturation
Date
3/94
9/94
3/95
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3/97
9/97
3/98
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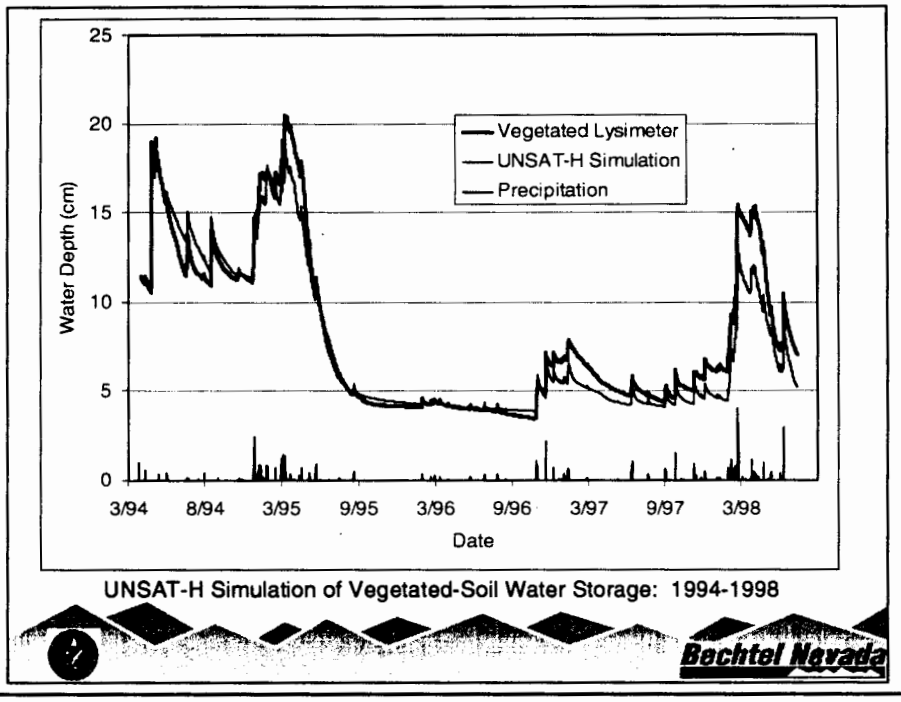
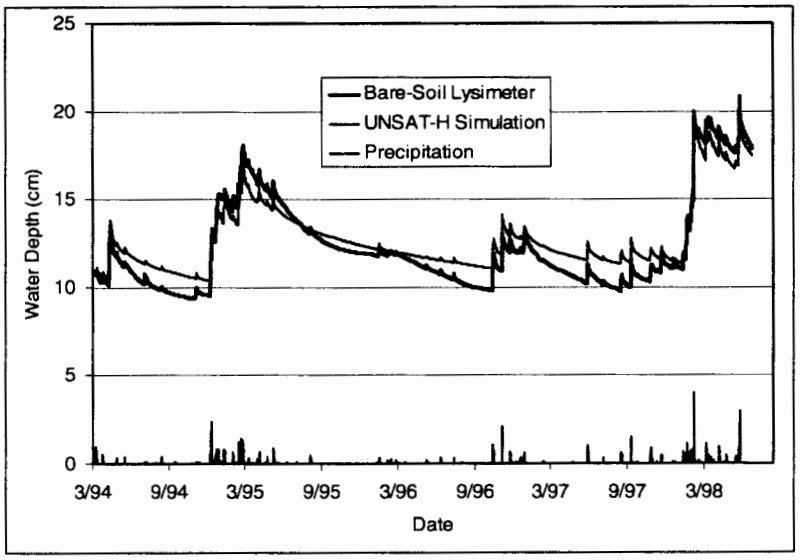
3/00
Bechtel Nevada


Vegetated Lysimeter
UNSAT-H Simulation
Precipitation
Water Depth (cm)
Date
3/94
8/94
3/95
9/95
3/96
9/96
3/97
9/97
3/98
UNSAT-H Simulation of Vegetated-Soil Water Storage: 1994-1998
Bechtel Nevada



UNSAT-H Simulation of Bare-Soil Water Storage: 1994-1998

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Automated VZ Monitoring Systems

- Locations (Area 5 RWMS only)
  - Weighing lysimeter facility
  - Pit 3 waste cover and floor
  - Pit 5 waste floor
  - Neutron probe calibration facility
- Primarily Campbell Scientific Inc. Equipment consisting of:
  - TDR probes: soil water content sensors
  - Heat dissipation probes: (temperature and water potential sensors)
  - Thermistors: temperature sensors
  - Suction lysimeters: liquid sampling devices
  - Soil gas sampling ports: primarily for tritium sampling

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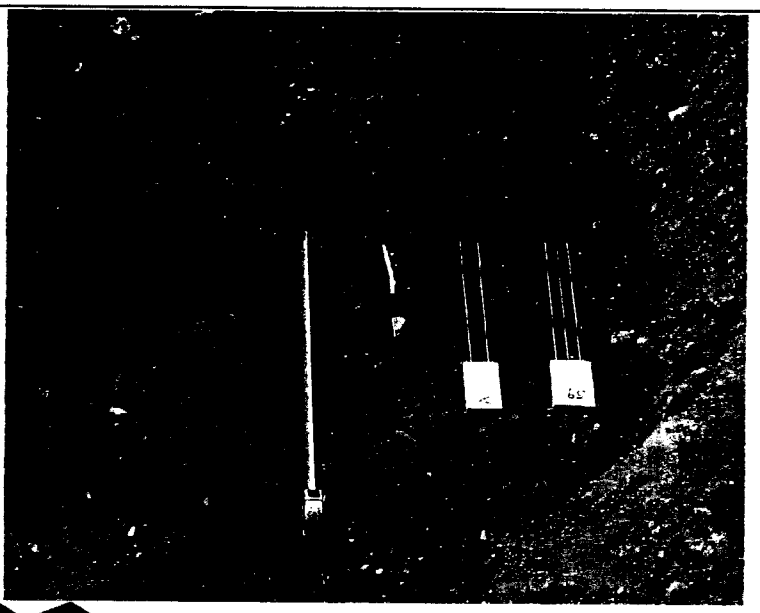
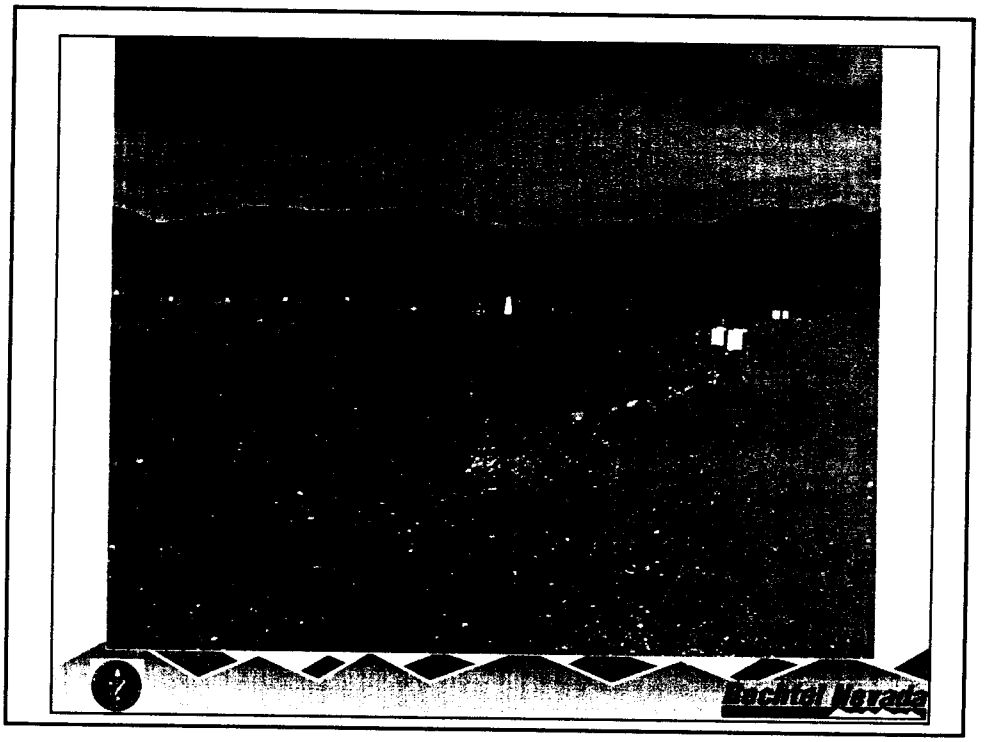
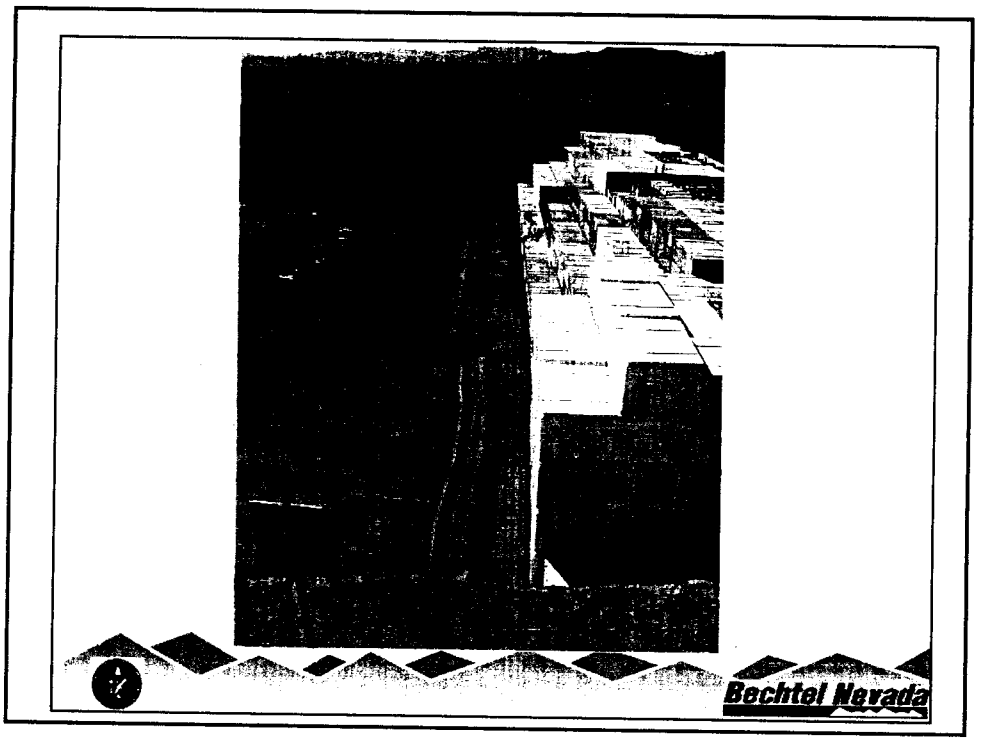



Bechtel Nevada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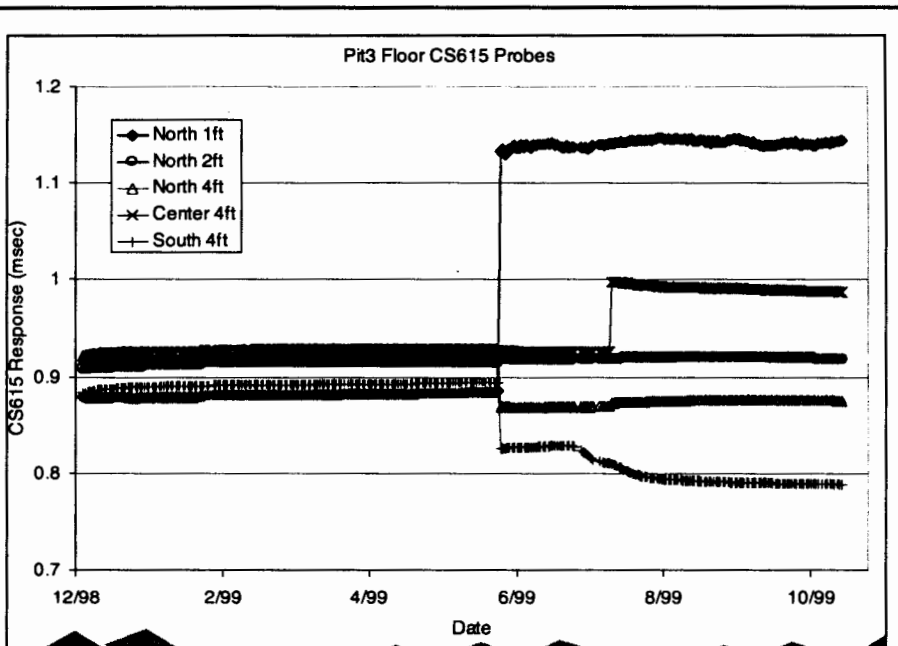
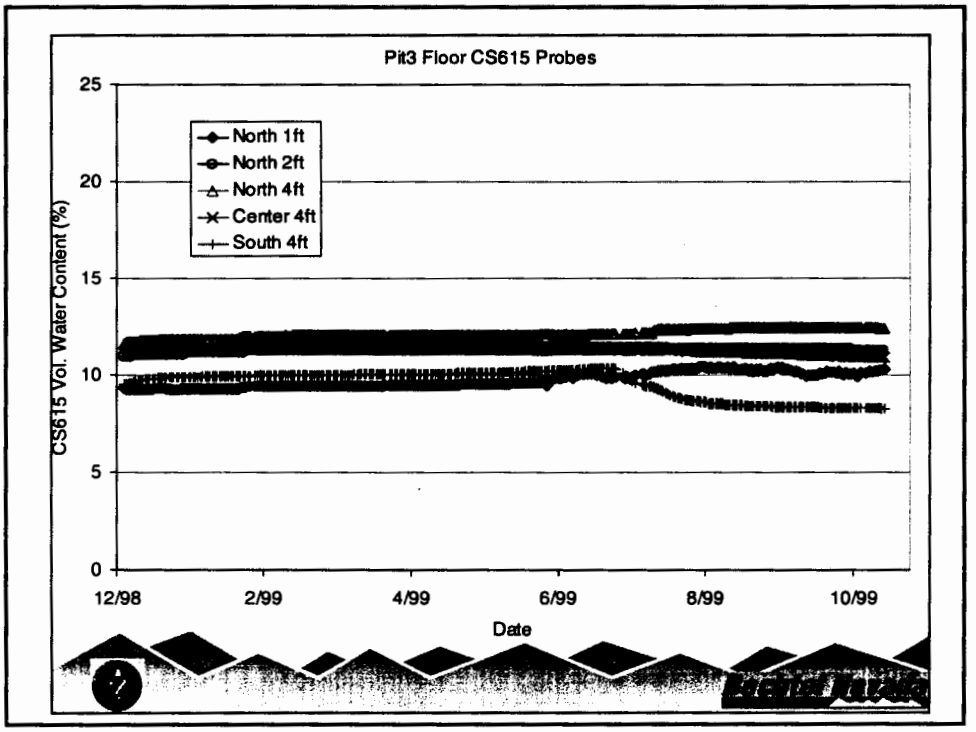
Automated TDR Systems

- TDR systems using CS610 probes
  - Require a Tektronix cable tester to read TDR traces
  - Robust and tested technology
- TDR systems using CS615 reflectometer probes
  - Does not require a cable tester to read TDR traces
  - Untested technology
  - Lightning strike shifted offset of CS615 probes at Pit 3 floor location (did not affect CS610 probes)




Pit3 Floor CS615 Probes
North 1ft
North 2ft
North 4ft
Center 4ft
South 4ft
CS615 Vol. Water Content (%)
25
20
15
10
5
0
12/98
2/99
4/99
6/99
8/99
10/99
Date
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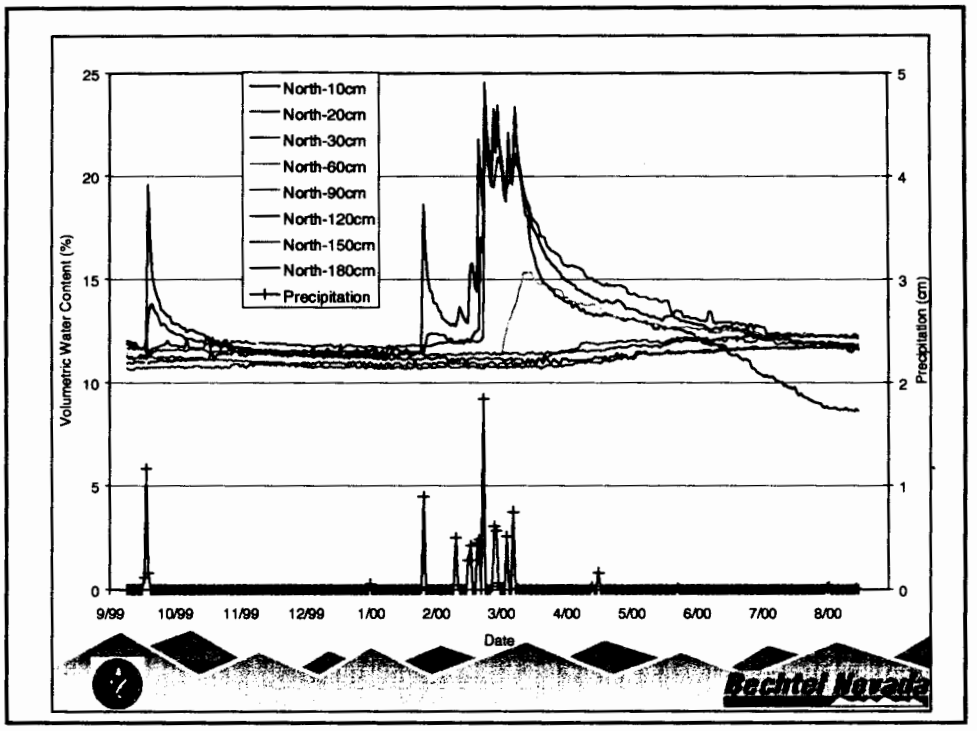
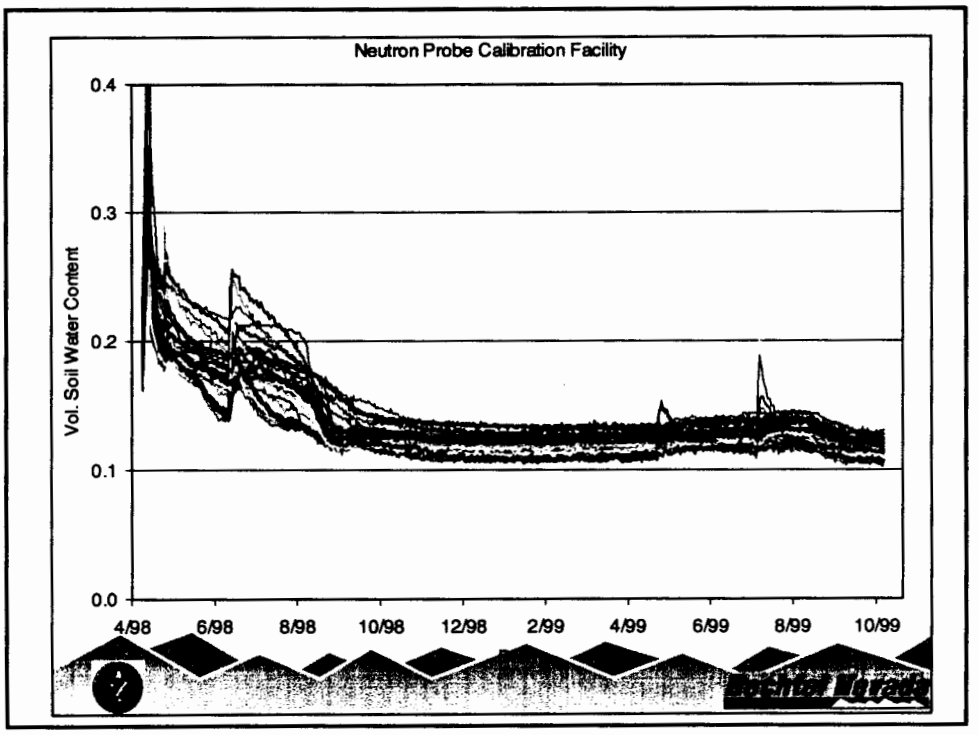
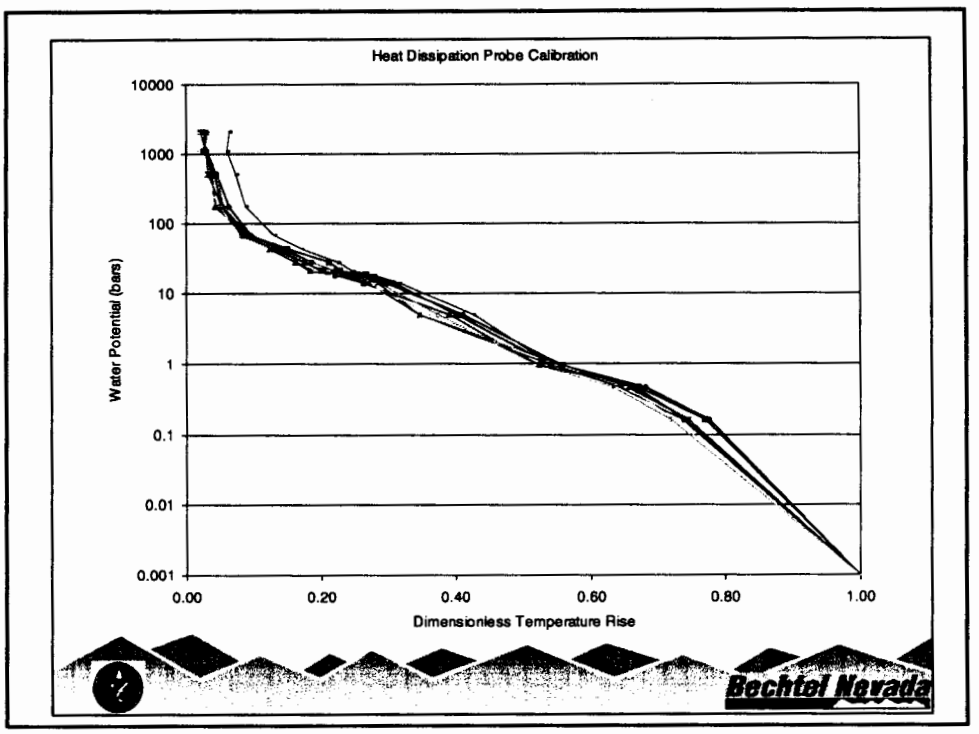
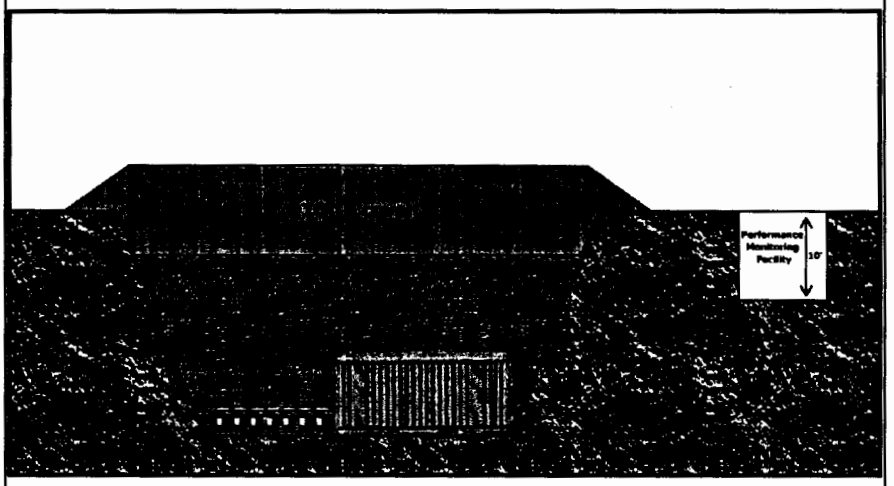

North-10cm
North-20cm
North-30cm
North-60cm
North-90cm
North-120cm
North-150cm
North-180cm
Precipitation
Volumetric Water Content (%)
Precipitation (cm)
25
20
15
10
5
0
5
4
3
2
1
0
9/99
10/99
11/99
12/99
1/00
2/00
3/00
4/00
5/00
6/00
7/00
8/00
Date
Bechtel Nevada


Neutron Probe Calibration Facility
Vol. Soil Water Content
0.4
0.3
0.2
0.1
0.0
4/98
6/98
8/98
10/98
12/98
2/99
4/99
6/99
8/99
10/99
Bechtel Nevada


Heat Dissipation Probe Calibration
Water Potential (bars)
10000
1000
100
10
1
0.1
0.01
0.001
0.00
0.20
0.40
0.60
0.80
1.00
Dimensionless Temperature Rise
Bechtel Nevada

ASTD Cover Instrumentation

- Will be installed in deployed cover and in performance monitoring cells
- TDR probes for measurement of soil water content
- Heat dissipation probes for measurement of soil water potential and temperature
- Sensors will be installed at eight depths
- Instrumentation provides measurements to calculate drainage through waste cover
- Monitoring facility will directly measure drainage through performance monitoring cells

Proposed Closure Cover Design