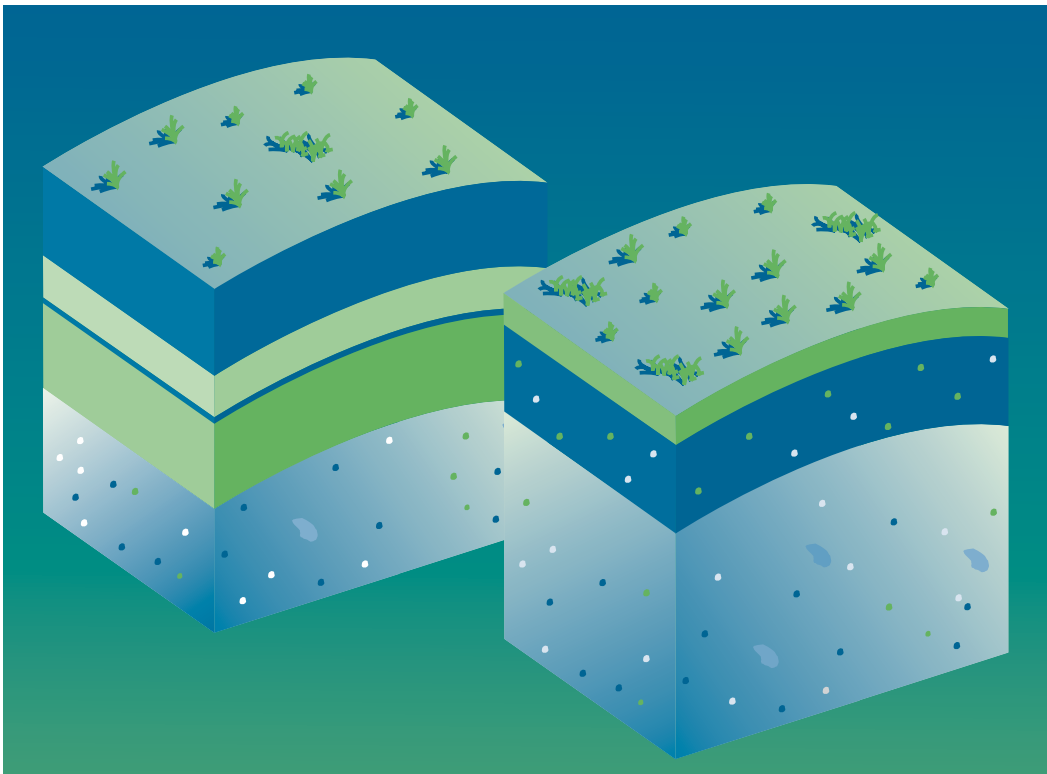




Technology Overview

Technology Overview Using Case Studies of Alternative Landfill Technologies and Associated Regulatory Topics



March 2003

Prepared by
Interstate Technology & Regulatory Council
Alternative Landfill Technologies Team

Copyright 2003 Interstate Technology & Regulatory Council

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at www.itrcweb.org.

DISCLAIMER

This document is designed to help regulators and others develop a consistent approach to their evaluation, regulatory approval, and deployment of specific technologies at specific sites. Although the information in this document is believed to be reliable and accurate, this document and all material set forth herein are provided without warranties of any kind, either express or implied, including but not limited to warranties of the accuracy or completeness of information contained in the document. The technical implications of any information or guidance contained in this document may vary widely based on the specific facts involved and should not be used as a substitute for consultation with professional and competent advisors. Although this document attempts to address what the authors believe to be all relevant points, it is not intended to be an exhaustive treatise on the subject. Interested readers should do their own research, and a list of references may be provided as a starting point. This document does not necessarily address all applicable health and safety risks and precautions with respect to particular materials, conditions, or procedures in specific applications of any technology. Consequently, ITRC recommends also consulting applicable standards, laws, regulations, suppliers of materials, and material safety data sheets for information concerning safety and health risks and precautions and compliance with then-applicable laws and regulations. The use of this document and the materials set forth herein is at the user's own risk. ECOS, ERIS, and ITRC shall not be liable for any direct, indirect, incidental, special, consequential, or punitive damages arising out of the use of any information, apparatus, method, or process discussed in this document. This document may be revised or withdrawn at any time without prior notice.

ECOS, ERIS, and ITRC do not endorse the use of, nor do they attempt to determine the merits of, any specific technology or technology provider through publication of this guidance document or any other ITRC document. The type of work described in this document should be performed by trained professionals, and federal, state, and municipal laws should be consulted. ECOS, ERIS, and ITRC shall not be liable in the event of any conflict between this guidance document and such laws, regulations, and/or ordinances. Mention of trade names or commercial products does not constitute endorsement or recommendation of use by ECOS, ERIS, or ITRC.

**Technology Overview Using Case Studies of
Alternative Landfill Technologies
and Associated Regulatory Topics**

March 2003

**Prepared by
Interstate Technology & Regulatory Council
Alternative Landfill Technologies Team**

Copyright 2003 Interstate Technology & Regulatory Council

ACKNOWLEDGEMENTS

The members of the Interstate Technology & Regulatory Council (ITRC) Alternative Landfill Technologies Team wish to acknowledge the individuals, organizations, and agencies that contributed case studies to this technology overview.

The Alternative Landfill Technologies team effort, as part of the broader ITRC effort, is funded primarily by the United States Department of Energy. Additional funding and support have been provided by the United States Department of Defense, the United States Environmental Protection Agency, and Waste Management, Incorporated. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers.

The work team also wishes to recognize the efforts of

- The Colorado Department of Public Health and Environment—Charles Johnson, team leader, and Ron Forlina
- California Southwest Regional Control Board—Peter Fuller
- California Central Industrial Waste Management Board—Melissa Gunter
- Oklahoma Department of Environmental Quality—David Smit
- Montana Department of Environmental Quality—Ricknold Thompson
- South Carolina Department of Health and Environmental Control—Van Keisler
- Kansas Department of Health and Environment—Paul Graves
- Louisiana Department of Environmental Quality—Narendra Dave
- Pennsylvania Department of Environmental Protection—John Oren

The team also wishes to recognize the efforts of the researchers investigating these technologies and the consultants and businesses striving to deploy these new technologies. These include Waste Management, Incorporated; Desert Research Institute/University of Nevada; University of Wisconsin; Mitretek; Washington Group International; Ecolotree; Air Force Center for Environmental Excellence; University of Colorado; Kosec Engineering; AquAeter; and Geosyntec. With the states represented above, they contributed the latest research, years of experience, and the case studies contained in this document. Thanks also go to the city of San Antonio for its contribution during the scoping of the Alternative Landfill Technologies Project and careful review of the case studies.

We depend on input from all perspectives to give ITRC documents the broadest application practical in the industry. The team members above display that mix of these perspectives and skills necessary to further our understanding of the technologies.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	i
1. INTRODUCTION	1
1.1 Purpose.....	1
1.2 Next Steps	2
2. RCRA-EQUIVALENT COVER DEMONSTRATION PROJECT, ROCKY MOUNTAIN ARSENAL, COMMERCE CITY, COLORADO.....	3
2.1 Site Setting.....	3
2.2 Design Basis	4
2.3 Design/Construction/Construction Monitoring	13
2.4 Operation	13
2.5 Postconstruction/Operation Evaluation	14
2.6 References.....	14
3. THE APPROVAL PROCESS FOR AN ALTERNATIVE FINAL COVER SYSTEM FOR THE DENVER ARAPAHOE DISPOSAL SITE, ARAPAHOE COUNTY, COLORADO..	15
3.1 Site Setting.....	15
3.2 Design Basis	15
3.3 Design/Construction/Construction Monitoring	23
3.4 Operation and Monitoring.....	24
3.5 Postconstruction/Operation Evaluation	25
4. OPERATING INDUSTRIES, INC. SUPERFUND LANDFILL.....	26
4.1 Site Setting.....	26
4.2 Design Basis	26
4.3 Design/Construction/Construction Monitoring	30
4.4 Operation and Monitoring	33
4.5 References.....	33
5. AN ALTERNATIVE FINAL COVER ON THE MCPHERSON COUNTY LANDFILL IN KANSAS	35
5.1 Site Setting.....	35
5.2 Design Basis	36
5.3 Design/Construction/Construction Monitoring	42
5.4 Operation and Monitoring	43
5.5 Postconstruction/Operation Evaluation	44
6. MR. "M" LANDFILL, ALTERNATIVE COVER, FERGUS COUNTY, MONTANA	47
6.1 Site Setting.....	47
6.2 Design Basis	47
6.3 Design/Construction/Construction Monitoring	54
6.4 Operation	56
6.5 Postconstruction/Operation Evaluation	57

6.6	References.....	58
7.	EVAPOTRANSPIRATION LANDFILL COVERS: DEFINITION AND CONCEPT VERIFICATION.....	59
7.1	Definition.....	59
7.2	Concept Verification.....	60
7.3	References with Abstracts	60
7.4	Additional References.....	62
8.	DEVELOPING AND DEMONSTRATING A PERFORMANCE-BASED APPROACH TO POSTCLOSURE CARE.....	63
8.1	Introduction.....	63
8.2	Relevance and Timeliness	64
8.3	Modules of Postclosure Care	65
8.4	Two Case Studies for Leachate Model	67
8.5	Summary	68
8.6	Figures	69
9.	SUMMARY FOR SITES IN THE EPA ALTERNATIVE COVER ASSESSMENT PROGRAM.....	81
9.1	Site Setting.....	81
9.2	Design Basis	81
9.3	Design/Construction/Construction Monitoring	92
9.4	Operation and Monitoring	93
9.5	Postconstruction/Operation Evaluation	94

LIST OF TABLES

Table 2-1.	Test cover specifications.....	10
Table 2-2.	Monthly data summary for testing year 2001	12
Table 3-1.	Results of #200-sieve wash.....	22
Table 3-2.	Components of the approved final cover and the alternative final cover	23
Table 9-1.	ACAP site details.....	82
Table 9-2.	Plant community characteristics of ACAP test sections.....	87
Table 9-3.	ACAP details	88

LIST OF FIGURES

Figure 2-1.	Cross section of RMA RCRA cover.....	4
Figure 2-2.	Cross section of RMA alternative RCRA cover.....	5
Figure 2-3.	RCRA-Equivalent Cover Demonstration Project monitoring instrumentation	11
Figure 3-1.	Soil cover design comparison	18
Figure 4-1.	Typical reinforcement detail for horizontal reinforcement anchored into solid waste	29

Figure 4-2. Schematic view of the evapotranspirative cover system	32
Figure 8-1. Postclosure care logic diagram	69
Figure 8-2. Leachate collection and recovery system logic diagram	69
Figure 8-3. Groundwater monitoring logic diagram	70
Figure 8-4. Landfill gas logic diagram	70
Figure 8-5. Cover system logic diagram.....	71
Figure 8-6. Typical landfill degradation phases of MSW and stability.....	71
Figure 8-7. Typical degradation phases of MSW and risk	72
Figure 8-8. Case Study I—New York landfill.....	72
Figure 8-9. COD leachate point comparisons	73
Figure 8-10. BOD leachate point comparisons	73
Figure 8-11. Arsenic vs. time	74
Figure 8-12. Barium vs. time.....	74
Figure 8-13. Cadmium vs. time	75
Figure 8-14. Chromium vs. time.....	75
Figure 8-15. Selenium vs. time.....	76
Figure 8-16. Mercury vs. time	76
Figure 8-17. VOCs vs. time.....	77
Figure 8-18. New York landfill case study conclusions.....	77
Figure 8-19. Case Study II—Michigan landfill.....	78
Figure 8-20. Comparison of leachate quality and waste age—BOD and COD	78
Figure 8-21. Comparison of leachate quality and waste age—volatile acids.....	78
Figure 8-22. Comparison of leachate quality and waste age—iron	79
Figure 8-23. Comparison of leachate quality and waste age—VOCs.....	79
Figure 8-24. Michigan landfill case study conclusions	80
Figure 9-1. Location of ACAP sites	84
Figure 9-2. ACAP cover design profiles	85
Figure 9-3. Schematic of ACAP drainage lysimeter	91

APPENDICES

APPENDIX A. Acronyms

APPENDIX B. ITRC Contacts

TECHNOLOGY OVERVIEW USING CASE STUDIES OF ALTERNATIVE LANDFILL TECHNOLOGIES AND ASSOCIATED REGULATORY TOPICS

1. INTRODUCTION

The ITRC's Alternative Landfill Technologies team compiled case studies to support the team's technical/regulatory guidance document on alternative landfill covers. The case studies present an overview of alternative covers being used at solid waste and hazardous waste facilities. Solid waste, hazardous waste, and radionuclide waste regulation contain provisions prescribing basic covers to be used on landfills. However, each of these regulations also allows and contains provisions for the design and construction of alternative landfill covers.

The U.S. Environmental Protection Agency (EPA) has a database tracking 35 alternative landfill cover demonstration projects and full-scale operating facilities in 18 different states. Annual rainfall associated with these alternative landfill cover projects ranges from a low of approximately 3.5 to a high of 56 inches per year. Twenty-four of the alternative landfill covers are demonstration projects, and 11 are full-scale covers at operating facilities. There are 20 solid waste/industrial waste/construction debris demonstration projects currently in the database. There are also two hazardous waste and three mixed waste demonstration projects.

Alternative landfill covers are already in use, or the designs are approved and field testing is being conducted, at pre-Subtitle D unlined facilities, Subtitle D lined facilities, Pre-Subtitle C unlined facilities, and Subtitle C lined facilities. There are Subtitle D alternative cover designs in place or approved at industrial, municipal, and debris landfills. Alternative landfill covers have several potential benefits over the current regulatorily prescribed landfill covers, while being equally protective of human health and the environment. Some of the benefits include, but are not limited to, more readily available construction materials, ease of construction, more implementable quality assurance/quality control programs, increased long-term cover integrity and stability.

1.1 Purpose

This case studies document is intended for use by regulators, facility owners and operators, consultants, academics, and stakeholder associated with solid waste, hazardous waste, and mixed waste alternative landfill cover projects.

The purpose of the case studies is to present examples of the flexibility used in the regulatory framework for approving alternative landfill cover designs, current research information about the use of alternative covers, and examples of approved designs and constructed covers. The case studies in this document were not designed specifically to answer all of the possible questions that practitioners might have regarding regulatory flexibility, design, construction techniques, or long-term postclosure care associated with alternative landfill covers. Rather, the case studies are presented as they were developed to satisfy the specific needs of the regulators, facilities, and consultants working on the specific projects presented in the documented cases. This ITRC document will be followed by an Alternative Landfill Covers technical/regulatory guidance

document that will expand on these topics and include a decision tree for use in evaluating the design, construction, and monitoring of alternative landfill covers.

1.2 Next Steps

This document presents several types of case studies related to solid waste, hazardous waste, and mixed waste alternative landfill cover projects. There are three primary types of case studies. One group of cases documents the alternative landfill cover regulatory controls, design, and construction process at solid waste and hazardous waste facilities. A second group, in the Alternative Cover Assessment Program (ACAP), is being conducted by the Desert Research Institute and funded by EPA to document research on types of alternative landfill covers during construction. The ACAP section discusses the cover elements as the test fill was constructed, the associated monitoring, and an evaluation of the alternative landfill cover results. Additional ACAP research information is provided on the compact disk (CD) provided with this case study document. A third group is a compilation of cited research information that was assimilated on behalf of the Air Force Center for Environmental Excellence describing alternative landfill covers, specifically evapotranspiration designs, with a discussion and references containing information verifying the concept. Equally important as the alternative landfill cover discussions provided in these case studies are the references attached to each case study and attached CD.

Each case study or suite of research information contained in this document is presented in its current status, and conclusions are those of its author. This ITRC document does not attempt to establish absolute correctness of each case study, the ACAP project summary, or the research information, but rather presents these so interested parties may learn from the examples. The ITRC Alternative Landfill Covers technical/regulatory guidance document (in progress at this writing) will present guidance for evaluating and making decisions on preferred approaches for regulatory flexibility, landfill design using alternative covers, construction, long-term care, and stakeholder relations associated with the implementation of an alternative cover, given certain governing conditions.

During the compilation of these case studies and based on members' experience, the ITRC Alternative Landfill Technologies team concluded that alternative landfill cover designs have a substantial contribution to the waste management industry and can be as protective and economically feasible as traditional capping technologies. However, experience in the industry is limited, and valid guidance describing the regulatory flexibilities currently available, critical design parameters, construction considerations, monitoring and postclosure care in the context of the landfill itself is necessary. The follow-up guidance from this ITRC team will encourage the proper application of this innovative technique and increase awareness of these new cover designs within the regulatory community, consulting community, and surrounding community.

2. RCRA-EQUIVALENT COVER DEMONSTRATION PROJECT, ROCKY MOUNTAIN ARSENAL, COMMERCE CITY, COLORADO

July 2002

Prepared by

- Carl Mackey, Washington Group International
- Lou Greer, Washington Group International
- D. George Chadwick, Jr., George Chadwick Consulting
- Martin Kosec, Telesto Solutions, Inc.

2.1 Site Setting

2.1.1 Site Description

The Rocky Mountain Arsenal (RMA) encompasses 27 square miles located northeast of Denver in Commerce City, Colorado and just west of the Denver International Airport. Following construction in 1942 to support the World War II effort, certain RMA facilities were leased to private industry for chemical manufacturing. Specific areas of the RMA became contaminated due to years of weapons and chemical production. In 1984, a systematic investigation of site contamination was initiated in accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the RMA was listed as a Superfund site in 1987. The record of decision (ROD), which details the remediation of RMA, was signed in 1996 (FWENC 1996). At the completion of remediation, the RMA will become one of the largest urban wildlife refuges as the Rocky Mountain Arsenal National Wildlife Refuge.

2.1.2 Selected Remedy

The selected remedy outlined in the ROD for the RMA includes constructing Resource Conservation and Recovery Act (RCRA)–equivalent covers over three remediation projects with a surface area of approximately 250 acres. Ensuing agreements with regulatory agencies include construction of RCRA-equivalent covers at two additional remediation projects, increasing the total area covered by RCRA-equivalent covers to approximately 450 acres. These remediation projects include former manufacturing, disposal basin, and disposal trench areas and contain contaminated soils, manufacturing wastes, and munitions debris.

2.1.3 RCRA Demonstration Project

Prior to design and construction of full-scale RCRA-equivalent covers for the remediation projects, it was necessary to meet a ROD requirement to “demonstrate cap performance equivalent to a RCRA landfill cap according to an EPA and State approved demonstration which will include comparative analysis and field demonstration.” In 1995, the Army, Shell/Washington Group, U.S. Fish and Wildlife Service (USFWS), EPA and the Colorado Department of Public Health and Environment (CDPHE) began discussions on how to demonstrate RCRA Subtitle C equivalency. A working group consisting of representatives from each of these parties was formed to implement and oversee a process that would fulfill ROD

requirements. This work was conducted as a preimplementation design study known as the RCRA-Equivalent Cover Demonstration Project (RCRA Demonstration Project) (Washington 1998a, Washington 1998b).

2.2 Design Basis

2.2.1 Regulatory Barriers

The RMA project has not encountered regulatory barriers as such but has received rigorous oversight from the regulatory agencies. Regulatory involvement during ROD development was based on the premise that it was very important to complement the comparative analysis with a reasonably full-scale field demonstration. This high standard of performance required an aggressive investigation and approval by the working group. Agreement was necessary to determine

- how RCRA equivalency would be determined;
- how the comparative analysis would be conducted;
- how the field demonstration would be designed, constructed, and monitored; and
- how the transition from the field demonstration to the full-scale projects would be implemented.

If the RCRA Demonstration Project failed to demonstrate equivalency, a prescriptive RCRA Subtitle C cap would be constructed. A comparison of the two cover systems at RMA is exhibited in Figs. 2-1 and 2-2.

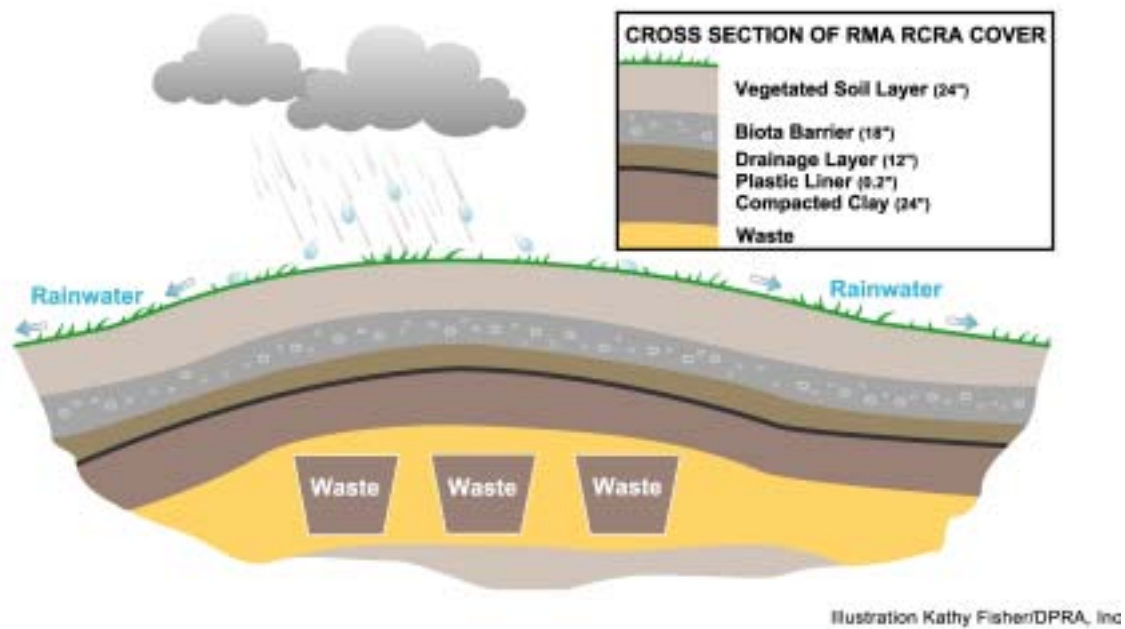


Figure 2-1. Cross section of RMA RCRA cover.

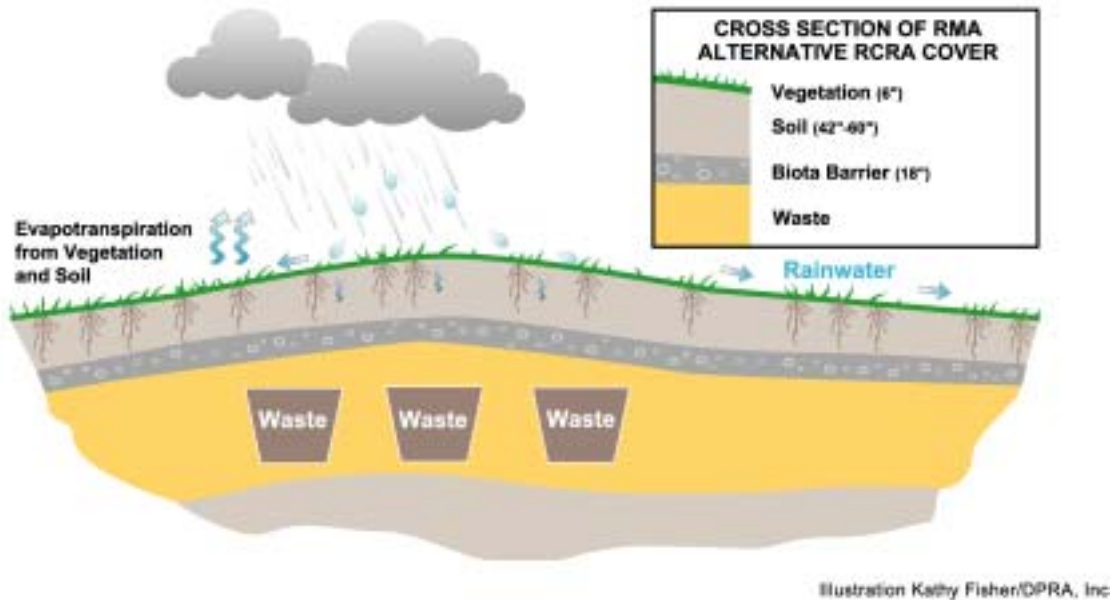


Figure 2-2. Cross section of RMA alternative RCRA cover.

2.2.2 Public Involvement

During the design phase of the field demonstration, RMA personnel participated in a series of RMA-sponsored public meetings to provide information on the RCRA Demonstration Project. Since the project involved an innovative alternative cover design, these presentations involved an explanation of the alternative cover concept, an indication of locations where these alternative covers would be constructed, and a summary of the benefits in using the alternative cover design. Public meetings were also scheduled to update the status of the project and to discuss transition to full-scale project design.

2.2.3 Site Characterization

The primary factors supporting use of an alternative cover at RMA include the following site conditions.

2.2.3.1 Soil Characterization

Excavations made around the RMA provided an indication that over most RMA soils in nonponding areas, water does not percolate deeply into the soil profile. To more completely characterize on-site soils, a field test pit investigation was initiated in 1997 to obtain site-specific field data for use in the ROD-required comparative analysis. Numerous soil samples were collected from test pits excavated in the prospective borrow areas. Samples were analyzed for particle-size gradation testing (wet sieves and hydrometers), saturated hydraulic conductivity, and the moisture characteristic curve to provide the information for subsequent computer simulations of soil moisture movement for various cover designs.

2.2.3.2 *Vegetation Characterization*

The plant species selection process for habitat restoration and revegetation of soil cap/cover sites at RMA was initiated in 1988. Vegetation on the entire site was mapped, and vegetation community types were classified based upon plant species composition. A number of relict areas were identified, as they are relatively undisturbed and contain plant species representative of presettlement conditions. These plant inventories provided an initial list of species for use in restoration of disturbed sites at RMA. A concurrent Order 1 soil-mapping project classified soil types. Once soil types were known, Soil Conservation Service manuals, other revegetation documents, and experts were consulted to determine appropriate plant species for each soil type. The objective of the USFWS *Comprehensive Management Plan* (USFWS 1996) to establish native grassland plant communities also controlled the type of plant species eligible for consideration in the seed mixes.

For alternative soil covers at RMA, the factors influencing species selected for the seed mix include soil type, height at maturity (as a feature to deter prairie dog invasion), persistence (as a component of stable, self-sustaining plant communities), leaf-area index contribution, and seed availability. A mix of cool and warm season grass species was also important to achieve in the final seed mix to insure transpiration activity for as much of the year as possible. A diversity of native forbs was also included.

2.2.3.3 *Climate/Microclimate Characteristics*

The climate at the RMA is semiarid. As measured at the former Stapleton Airport adjacent to RMA, monthly mean temperatures range from a low of 30.1 degrees Fahrenheit (°F) in January to a high of 73.4°F in July. Annual precipitation at the airport averages about 15.6 inches. Annual potential evapotranspiration is much higher, as indicated by the fact that estimated pan evaporation at nearby Cherry Creek Reservoir averages 54.9 inches per year. Of particular relevance to the viability of alternative covers is the fact that most of the precipitation typically occurs during the growing season when it is most readily evaporated or transpired by plants. An average of 75% of the annual precipitation typically falls during the April through October season, and an average of only 11% falls during the December through February winter period when potential evapotranspiration is lowest.

2.2.3.4 *Geology/Hydrology*

The site geology and hydrology conditions were not critical to the project as they were not factors for siting the alternative covers. Sites for which RCRA-equivalent covers are to be constructed are already determined based on soil contamination and former manufacturing and disposal areas.

2.2.3.5 *Surface Water Characteristics*

Surface water conditions are not detrimental to the siting of any of the remediation projects utilizing RCRA-equivalent covers as long as the covers are designed with slopes and drainage controls to prevent significant ponding of water or excessive runoff. Additionally, the design of

drainage swales may require enhancements since these conditions were not tested in the field demonstration (e.g., impermeable liners and/or armoring).

2.2.3.6 *Biota*

RMA currently supports a significant concentration of short grass prairie, shrubland, and riparian associated species. Many prairie dog colonies provide habitat for a diversity of short grass prairie species, including burrowing owls, thirteen-lined and spotted ground squirrels, jack rabbits, and prairie rattlesnakes. Prairie dogs also serve as a prey base for coyotes, badgers, and many raptor species, including ferruginous hawks and bald eagles. Mule and white-tailed deer are the most noticeable mammals on the site, occurring at densities higher than typical for prairie habitats. A diversity of small mammals also occurs in various habitats on the site. Birds found on the site include year-round residents, nesting species, and seasonal migrants. In addition to this nearly complete complement of prairie species, the site provides habitat for several federally listed threatened, endangered, and candidate plant and animal species.

2.2.4 Cover Goals and Standards

The ROD establishes goals and standards for remediation projects utilizing RCRA-equivalent covers to ensure cover performance is equivalent to a RCRA landfill cap. The ROD goals for the covers are to

- serve as effective long-term barriers,
- maximize runoff and minimize ponding,
- minimize erosion by wind and water,
- prevent damage to integrity of cap by biota and humans, and
- maintain cover of locally adapted perennial vegetation.

The remediation standards for the covers are to

- allow no greater range of infiltration through the cover than the range of infiltration that would pass through an EPA-approved RCRA cap,
- prevent contact between hazardous materials and humans/biota by using biota barriers and maintaining institutional controls,
- demonstrate cover performance equivalent to a RCRA landfill cap according to an EPA- and state-approved demonstration that will include comparative analysis and field demonstration, and
- maintain cover percolation less than or equal to the percolation of the underlying native soil.

Other than the working group realizing that “maximizing runoff” was not appropriate for the project, these goals and standards were used as the basis of design for the RCRA Demonstration Project and will be maintained as the basis of design for the future full-scale remediation projects. Specific design criteria from the RCRA Demonstration Project to implement the goals and standards are currently being evaluated to confirm their application or need for revision for the full-scale remediation projects. The evaluation consists of a review of lessons learned from

the RCRA Demonstration Project, along with a postdemonstration geotechnical evaluation of the test covers. Specific goals and design criteria are discussed below.

2.2.4.1 Allowable Infiltration/Flux

RCRA-equivalent covers at RMA are not being utilized as landfill caps but will be constructed over existing remediation sites. As such, no bottom liners or leachate collection systems will be constructed. However, as part of the long-term monitoring plan that is being developed in the design for the full-scale remediation projects, pan lysimeters will be placed at strategic locations in the covers to confirm ongoing successful performance.

Each of four test covers that were constructed for the RCRA Demonstration Project successfully passed the percolation performance criterion of 1.3 mm/year that was established for the field demonstration. This performance criterion was based on technical issues and negotiations with CDPHE and EPA (Washington 1998b). A critical requirement for full-scale RCRA-equivalent covers is to minimize deep percolation into any waste materials, thereby minimizing groundwater contamination. The exact implementation of this goal is yet to be determined and will be established during design. Retaining the 1.3-mm/year percolation standard as the benchmark criterion for assessing full-scale cover performance is currently being considered.

2.2.4.2 Cover Establishment and Integrity

The full-scale RCRA-equivalent covers will include 18 inches of broken concrete to serve as a biota barrier layer to attain the goal of the cover serving as a long-term barrier and the standard of isolating waste materials from humans and extensive burrowing by biota, particularly prairie dogs and badgers. The biota barrier was not used in the RCRA Demonstration Project because its design had not yet been determined and the RMA did not want to risk testing the wrong material. Therefore, the RMA decided to conduct a conservative test, realizing that a successful test would only perform better with the addition of a biota barrier that may serve as a capillary break and/or provide additional water holding capacity and rooting depth.

The soil layer will be placed over the biota barrier at a low slope to provide for runoff and minimize ponding but also to protect against unacceptable soil erosion. Based on the RCRA Demonstration Project design (Washington 1998a) and the minimum cover slope recommended by EPA (EPA 1991), the full-scale covers will be constructed having surface slopes of 3% to alleviate any slope stability concerns. While the field demonstration was not of sufficient size or duration to assess erosion to a great degree, slope length will be evaluated during full-scale design to minimize loss due to water and wind erosion. The design will also include overbuilding the soil layer by 6 inches to account for potential erosion loss over 1000 years. Erosion monuments will be included in the full-scale covers to monitor erosion.

Following placement of the soil layer, the covers will be vegetated and managed to meet the goal of maintaining a cover of locally-adapted perennial vegetation.

2.2.4.3 *Ecological Diversity and Density*

The goal of revegetation on alternative cover areas at RMA is to create stable, self-sustaining, native grassland communities that will provide habitat to a diverse, but limited, number of prairie biota while providing the transpiration and erosion control requirements of the alternative cover design. Prairie dogs, deep-taproot shrub and tree species, and noxious weeds will be excluded. All other prairie biota, including large grazing herbivores, will be managed to maintain the as-built conditions of the alternative cover areas.

2.2.5 Design Basis Evaluation

Before starting any designs for full-scale RCRA-equivalent cover projects, the RCRA Demonstration Project was conducted to demonstrate the equivalency of alternative covers at RMA. The following sections describe how the RCRA Demonstration Project was successful in meeting the ROD demonstration requirements for RCRA equivalency and in providing a means to evaluate the design basis for full-scale projects.

2.2.5.1 *Comparative Analysis Modeling*

The comparative analyses required by the ROD were performed using the UNSAT-H model to simulate one-dimensional unsaturated flow through potential alternative covers. The simulations assumed a unit gradient lower boundary condition located at the bottom of the proposed covers. Soil parameters were estimated from the laboratory testing described under Section 2.3.1. Local university experts estimated additional modeling input values for the seasonal distributions of leaf area index and the root density function. Meteorological data from the weather station at the nearby former Stapleton Airport were also utilized for model input. The working group decided to simulate the historic conditions that appeared to be most likely to produce drainage from the alternative covers. From the 48-year precipitation record then available from the Stapleton Airport, the 1982–83 period was chosen because it had more precipitation during the winter and early spring than any other period of record. The 1965–69 period was also chosen because it included the wettest 1-year, 3-year, and 5-year periods of record.

For each of the modeled soils, an estimate was made for the cover thickness required to limit drainage from the cover bottom to a maximum of 1.3 mm/year. In every case, results indicated that of the years being simulated, the 1982–83 period required more cover thickness than did the 1965–69 period. Results indicated that the required cover thickness ranged from 1.17 feet for the clay soil up to 3.67 feet for one of the sandy loam soils, the average being 2.17 feet.

2.2.5.2 *Field Demonstration Test Plots*

Based on the favorable results of the comparative analysis modeling, a field demonstration was designed including four test cover sections. The test covers were constructed in the spring of 1998 with two different soil types and three different cover thicknesses ranging 42–60 inches. Although the comparative analysis indicated that thinner covers would meet the performance criterion, the minimum cover thickness was set at 42 inches due to a desire to keep future biota

barriers below the frost zone to protect them from frost heave. The test covers were constructed as indicated in Table 2-1.

Table 2-1. Test cover specifications

Designation	Percent fines (passing #200 sieve)	Cover thickness (inches)
Test Cover A	35%–50%	42
Test Cover B	≥50%	48
Test Cover C	≥50%	60
Test Cover D	≥50%	42

Each test cover was sloped diagonally at 3% and placed over a 30 × 50 foot pan lysimeter, consisting of a very flexible polyethylene liner under a geocomposite drainage layer to collect any percolation.

2.2.5.3 Field Demonstration Monitoring/Evaluation

After construction of the field demonstration, vegetation was allowed to establish over a three-year period. Beginning September 1, 2000, a one-year test period was conducted to determine if the test covers could meet the performance criterion of having no more than 1.3 mm of percolation during the test year. Natural precipitation was supplemented with irrigation to achieve wet conditions during the test year. Weekly inspections were conducted throughout the vegetation establishment period and the test year to check the condition of the field demonstration, as well as to collect and evaluate monitoring data. The monitored items include those displayed in Fig. 2-3 and described below:

- **Percolation**—Each test cover was constructed over a pan lysimeter that drains to a collection point for measurement. Any percolation collected from the test covers first drains into a tipping bucket precipitation gage from which data can be remotely accessed. Additionally, a collection pan was placed underneath the tipping bucket gage to allow direct measurement of total percolation.
- **Soil Moisture Data**—Soil moisture probes were placed in the test cover profile to monitor soil moisture conditions. A set of eight probes was placed on each of three covers, while three sets were placed on the fourth cover for a total of 48 soil moisture probes. The probes were wired to a data collector allowing data to be accessed remotely.
- **Surface Water Runoff Data**—The design of the field demonstration included a series of berms and swales around each test cover to isolate surface water runoff. Runoff from each test cover was drained to a collection tank where it can be measured.
- **Precipitation Data**—A weighing bucket precipitation gage was installed near the test covers to provide measurement of natural precipitation. Data can be accessed remotely, or obtained from direct readings of the gage chart paper.
- **Irrigation Data**—During the test year period, six plastic rain gages were placed on each test cover to allow manual measurement of irrigation.

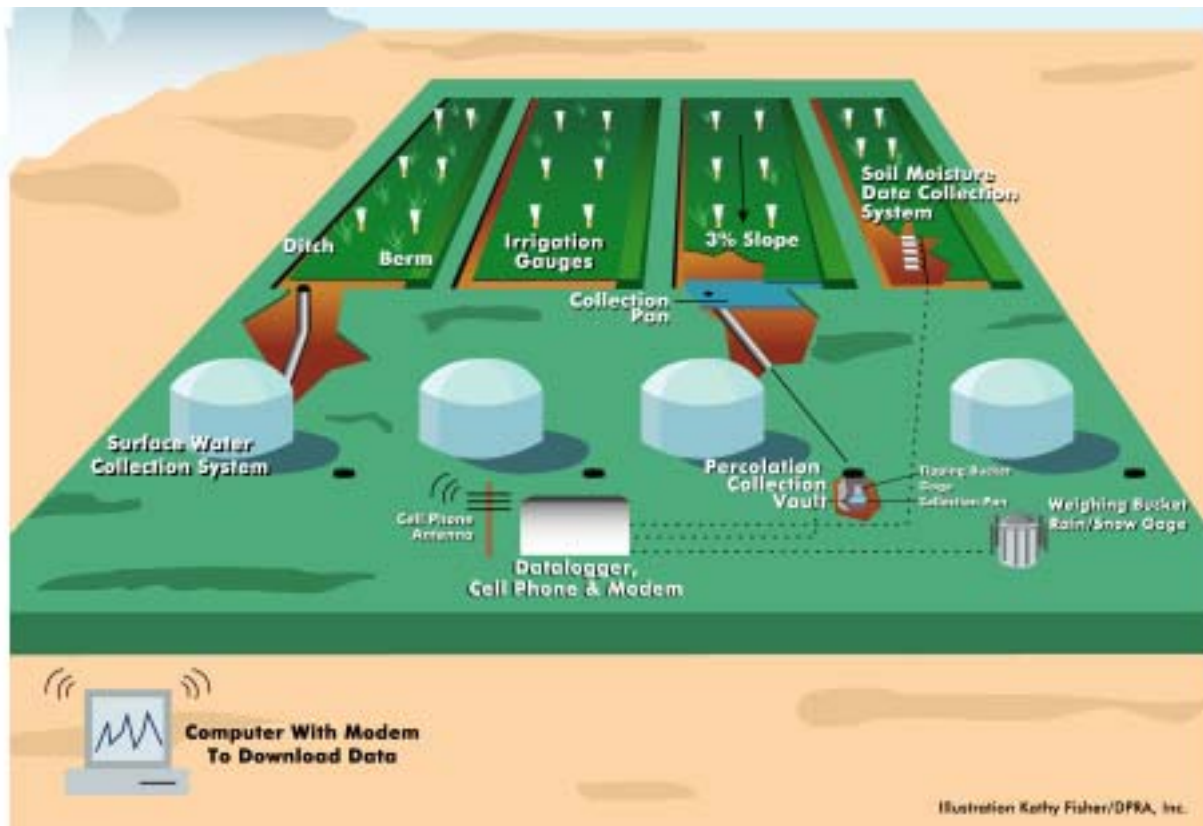


Figure 2-3. RCRA-Equivalent Cover Demonstration Project monitoring instrumentation.

Table 2-2 summarizes monitoring data collected during the test year.

As indicated under the “Deep Percolation” heading, all four test covers were successful in passing the performance criterion of no more than 1.3 mm/year. Although still an order of magnitude lower than the criterion, the relatively higher amount of percolation measured in Test Cover D was likely due to a surficial depression that developed over a backfilled pit in which soil moisture probes were installed. These results are very favorable in light of the fact that the covers received about 6 inches more water during the test year than the average annual precipitation.

In addition to the monitoring and data evaluation described above, assessments were conducted to evaluate the cover vegetation, root density, and wildlife impacts. Results of these assessments indicated excellent establishment of the seeded native species. After three growing seasons, the plant community developed cover values consistent with other seeded sites and the surrounding established prairie, although root density remained well below that measured in native prairie indicating that the plant community was continuing to develop. As expected, wildlife activity at the site increased as the plant community developed and was considered normal.

Table 2-2. Monthly data summary for testing year 2001

Month	Average temperature at RMA (deg. F)	Natural Precipitation (inches)	Irrigation (inches)				Precipitation plus irrigation (inches)				Surface runoff (inches)				Deep percolation ^a (millimeters)			
			Test Cover A	Test Cover B	Test Cover C	Test Cover D	Test Cover A	Test Cover B	Test Cover C	Test Cover D	Test Cover A	Test Cover B	Test Cover C	Test Cover D	Test Cover A	Test Cover B	Test Cover C	Test Cover D
Sep	63.0	1.34	1.07	1.13	0.97	1.16	2.41	2.47	2.31	2.50	0.03	0.02	0.04	0.02	0	0	0	0.0056
Oct	50	0.49	0.49	0.53	0.52	0.54	0.98	1.02	1.01	1.03	0.01	0.02	0.02	0.01	0	0	0	0
Nov	29.6	0.86	0.26	0.24	0.32	0.24	1.12	1.10	1.18	1.10	0	0	0	0	0	0	0	0
Dec	28.4	0.11	0	0	0	0	0.11	0.11	0.11	0.11	0	0	0	0	0	0	0	0
Jan	30.4	0.72	0.73	0.78	0.76	0.74	1.45	1.50	1.48	1.46	0	0	0	0	0	0	0	0
Feb	28.6	0.40	0	0	0	0	0.40	0.40	0.40	0.40	0	0	0	0	0	0	0	0
Mar	39.8	1.00	0.93	0.90	0.90	0.91	1.93	1.90	1.90	1.91	0	0	0	0	0	0	0	0
Apr	49.1	1.56	0.94	0.92	0.94	0.93	2.50	2.48	2.50	2.49	0.12	0.11	0.11	0.11	0	0.0022	0	0.0043
May	56.2	4.22	0	0	0	0	4.22	4.22	4.22	4.22	0.07	0.08	0.07	0.06	0	0.0043	0	0.0301
Jun	68.8	1.48	0.20	0.21	0.20	0.20	1.68	1.69	1.68	1.68	0.01	0.03	0.03	0.06	0	0	0	0.0468
Jul	76.6	2.39	0	0	0	0	2.39	2.39	2.39	2.39	0.03	0.07	0.07	0.11	0	0.0024	0	0.0338
Aug	73.3	0.99	1.26	1.31	1.25	1.27	2.25	2.30	2.24	2.26	0	0	0	0	0	0.0005	0	0.0120
Annual	49.6	15.56	5.88	6.02	5.86	5.99	21.44	21.58	21.42	21.55	0.27	0.33	0.34	0.37	0	0.0094	0	0.1326

^aThe deep percolation values listed are those reported from the tipping bucket precipitation gages, not from manual volumetric measurements of collected deep percolation (which were somewhat less).

2.2.5.4 Design Concept Evaluation

Some of the initial interest in alternative covers at RMA was based on the potential for cost savings, which were estimated at greater than \$100,000 per acre, compared to a prescriptive RCRA Subtitle C cap. Also appealing was the belief that an alternative cover was naturally sustainable and a good fit for the RMA future as a wildlife refuge. Additionally, field evidence existed that supported an alternative cover design. Research indicated other field demonstrations in similar climates were producing favorable results, especially the Pawnee National Grasslands in northern Colorado where a 4-foot soil layer had not produced any measurable percolation during the two decades of monitoring. At the RMA, excavations made in low slope areas indicated water does not percolate very deeply. Such evidence indicates that relatively low-cost, sustainable RCRA-equivalent covers would be protective of human health and the environment and meet project requirements.

2.3 Design/Construction/Construction Monitoring

2.3.1 Design

With the success of the RCRA Demonstration Project, the field demonstration design will be used as the basis of design for the full-scale remediation projects. However, the RMA has agreed to a request from the regulatory agencies to conduct a postdemonstration investigation of the test covers that will evaluate percent clay as an index parameter (in addition to percent fines) and the sensitivity of soil density to percolation performance. The RCRA Demonstration Project working group is continuing to meet to review lessons learned and the results of the postdemonstration assessment. The working group will use this information to establish design criteria and sitewide guidance for such issues as the cover soil specification and placement densities, borrow soil characterization, quality assurance/quality control, low-slope swale design, erosion/settlement, institutional controls, and long-term monitoring.

2.3.2 Construction

The RCRA Demonstration Project field demonstration was constructed in spring 1998, successfully passed a test year period on August 31, 2001 and continues to be monitored. Following grade fill placement, the first full-scale RCRA-equivalent cover is scheduled for construction in early 2004, with the remaining covers scheduled for construction beginning in 2006.

2.4 Operation

Lessons learned from the RCRA Demonstration Project, along with goals and standards identified in the ROD, will be used during design to prepare appropriate plans establishing operational requirements. The plans will address such issues as percolation performance monitoring, cover integrity monitoring, and ecological succession.

2.4.1 Percolation/Flux Monitoring

The long-term operations and maintenance (O&M) plan that will be developed during the design phase for full-scale remediation projects will address monitoring procedures and performance requirements. Pan lysimeters will be installed under the cover system at strategic locations to monitor any deep percolation. The working group will establish appropriate criteria for monitoring both performance and compliance aspects of the covers and will establish requirements for responding to monitoring data.

2.4.2 Cover Integrity Monitoring

In addition to providing for deep percolation monitoring, the O&M plan will establish inspection and corrective action requirements for monitoring vegetation, cover soils, erosion, settlement, institutional controls, wildlife, and groundwater.

2.4.3 Ecological Succession

As mentioned previously, the goal of revegetation and habitat restoration is establishment of stable, self-sustaining grassland communities. Revegetation techniques and seed mixes are developed to accelerate the process of plant community succession so that early stages of community development are skipped and the process begins at a midseral stage. After initial establishment, further natural refinement is expected as individual plant species and populations sort into niches for which they are best adapted. However, certain aspects of plant community development, such as invasion by undesirable plant species, will be discouraged with management practices. The goal of managing these sites is to preserve the as-built nature with the flexibility of allowing plant community and habitat development to the extent compatible with the cover maintenance goal.

2.5 Postconstruction/Operation Evaluation

Once constructed, remediation projects utilizing a RCRA-equivalent cover will be evaluated every five years during the RMA's standard CERCLA five-year review process.

2.6 References

EPA (U.S. Environmental Protection Agency). 1991 (May). *Design and Construction of RCRA/CERCLA Final Covers*, EPA/625/4-91/025.

FWENC (Foster Wheeler Environmental Corporation). 1996 (June). *Record of Decision for the On-Post Operable Unit, Version 3.1*.

USFWS (U.S. Fish and Wildlife Service). 1996 (March). *Rocky Mountain Arsenal National Wildlife Refuge Comprehensive Management Plan*.

Washington (Washington Group International). 1998a (January). *RCRA-Equivalent Cover Demonstration Project Final Design Package*.

Washington. 1998b (July). *RCRA-Equivalent Cover Demonstration Project Comparative Analysis and Field Demonstration Design Scope of Work*.

3. THE APPROVAL PROCESS FOR AN ALTERNATIVE FINAL COVER SYSTEM FOR THE DENVER ARAPAHOE DISPOSAL SITE, ARAPAHOE COUNTY, COLORADO

Prepared by Ron Forlina, Colorado Department of Public Health

This case study is written to add to the knowledge base of the ITRC Alternative Landfill Technologies Team. It describes the methodology used by the Colorado Department of Public Health and Environment (CDPHE) to evaluate and ultimately approve an alternative final cover system for the eighth largest municipal solid waste landfill in the United States.

The landfill is owned by the city and county of Denver, Colorado. In the most succinct terms, unsaturated modeling was used to compare the currently approved cover system, which is a traditional barrier layer and topsoil system, to an evapotranspiration cover system. This study follows the ITRC outline to document the various steps used along the way. The procedures used worked for this project; however, it is worth noting that other methods could and should be used to achieve the same conclusions and regulatory approval at other sites.

3.1 Site Setting

3.1.1 Denver Arapahoe Disposal Site

Located in Section 31, Township 4 South, Range 65 West 6th Principle Meridian and the North ½ and the North ½ of the South ½ of Section 32, Township 4 South, Range 65 West, 6th Principle Meridian, Arapahoe County, Colorado. It is important to note that the site is approximately 11 miles southeast of the Rocky Mountain Arsenal (RMA), where comprehensive evaluations of alternative final cover systems have been on going for the last six years. Much of the knowledge gained from these test plots was applied to this project.

3.1.2 Surface Area

87 acres in Section 31; 477 acres in Section 32.

3.1.3 Type of Waste in Landfill

Municipal solid waste.

3.1.4 Future Land Use

Open space.

3.2 Design Basis

3.2.1 Regulatory Barriers

- Lack of time for staff to develop the expertise needed to evaluate a project of this type.

- Lack of detailed knowledge of the underlying scientific principles involved.
- Lack of any municipal or commercial facilities willing to invest in the research that is required to demonstrate the effectiveness of an alternative cover system.

3.2.2 Public Involvement

In Colorado, solid waste is a matter of dual jurisdiction. The state provides technical opinions regarding landfill designs and modifications to the local governing body, i.e., the county or municipality where the landfill is located. If the state determines that a proposed plan cannot meet the requirements of the regulations, the project is denied. Conversely, if the state determines that the facility can comply with the regulations, a recommendation to approve the project is made to the local governing body. The amount of public involvement is then decided by the local governing body. The local governing body then makes a decision either to grant approval. The modifications to the engineering design and operations plan, for this project, were determined by the local governing body to be administrative modifications, which do not require public involvement in this case.

3.2.3 Site Characterization

3.2.3.1 Soil Characterization and Volume

The characterization of the soil, in particular, the methods employed to approximate the soil water characteristic curve (SWCC) is perhaps the most significant departure from the work done at the RMA. At RMA samples were submitted for laboratory analysis to develop the SWCC. The following tests were performed to develop moisture redetection characteristics:

- Hanging column method by ASA¹, Chapter 26
- Pressure plate method by ASTM D2325-68 (94)/ASA¹, Chapter 26
- Submerged pressure outflow cell by ASA¹, Chapter 24
- Psychrometer method by SSSAJ², 1982
- Vapor equilibrium method pressure membrane by ASTM D 3152

These tests are not commonly performed in soil laboratories. They are expensive and time-consuming, and—because they are not commonly performed—they have a relatively higher degree of uncertainty associated when compared to other soil characterization tests.

To resolve this dilemma, the SWCC was developed using an established physicoempirical technique (Arya & Paris).³ The Arya & Paris technique uses bulk density, grain size distribution and particle density to develop the relationship between water content and soil matric potential or SWCC. The validity of using this approach is discussed below in the section describing the modeling used for this project.

¹ *Methods of Soil Analysis*, Part 1. 1986. A. Klute, ed. ASA No. 9, American Society of Agronomy, 2nd ed., Madison, Wisc.

² *Soil Science Society of America Journal* (1984) 48:7–10.

³ “A Physicoempirical Model to Predict the Soil Moisture Characteristic from Particle-Size Distribution and Bulk Density Data,” Lalit M. Arya and Jack F. Paris, *Soil Science Society of America Journal* (1981) 45:1024–30.

3.2.3.2 *Plant Characterization*

A report titled *Leaf Area Indices and Root Density Functions for the Denver Arapahoe Disposal Site* was prepared by Edward F. Rodente, Ph.D. for the project. Dr. Rodente is a professor at the Colorado State University in Fort Collins, Colorado and does consulting work for Shepard Miller also in Fort Collins. Dr. Rodente developed the vegetative cover species. The seed mix was designed to include 50% warm season grasses and 50% cool season grasses. The plant species was developed to replicate true native vegetation. The vast majority of plants present near the facility and generally all along the Front Range did not grow here until the first pioneers settled here.

3.2.3.3 *Climate/Microclimate Characteristics*

Daily meteorological data from Stapleton International Airport for 1982 and 1983 were used for the modeling. Daily meteorological data include maximum, minimum air temperatures and dew point temperature, solar radiation, average wind speed, average cloud cover and precipitation. Potential evapotranspiration data was developed using the Penman equation in the UNSAT-H model. The UNSAT-H model requires not only the daily meteorological data but also the data such as surface albedo, site altitude, height of wind measurement and the average annual atmospheric pressure.

3.2.3.4 *Geology*

The site is located in the Denver Basin. The basin was formed in late Cretaceous and early Tertiary time. The uppermost formation is the Dawson Formation. It is approximately 150 feet thick beneath the site. Site borings show the formation to be comprised of interbedded claystones and sandstones. This heterogeneous mix is likely the result of multiple fluvial depositional and erosional cycles. Colluvial and alluvial soils overlay the Dawson formation at the site.

3.2.3.5 *Hydrology*

NA

3.2.3.6 *Surface water Characteristics*

NA

3.2.3.7 *Biota*

The flora at the facility is described above in Sect. 3.2.3.2. A detailed study of the fauna was not conducted for this project. However, it is likely that a typical assortment of small mammals, birds, deer, and antelope commonly found along the Front Range inhabit the area.

3.2.4 Cover Goals

3.2.4.1 Allowable Infiltration /flux

The objective for this project was to compare the performance of the approved cover and an alternative cover design using the UNSAT-H model. The allowable infiltration for approval, without additional modeling, was +10% of what UNSAT-H predicted for the approved cover system.

The alternative cover system is known variously as an “evapotranspiration (ET) cover,” a “monolithic cover,” or a “sponge cap.” Fig. 3-1 depicts the two systems considered in this project.

Leachate Management. Leachate is going to be used as the primary evaluation of the performance of the cover system. There are six leachate sumps in Section 31, the immediate area of the project. Testing with lysimeters or other devices designed to detect moisture infiltration was discussed. The results of these discussions brought us to the conclusion that using such methods would turn the project into another science project. There are numerous research

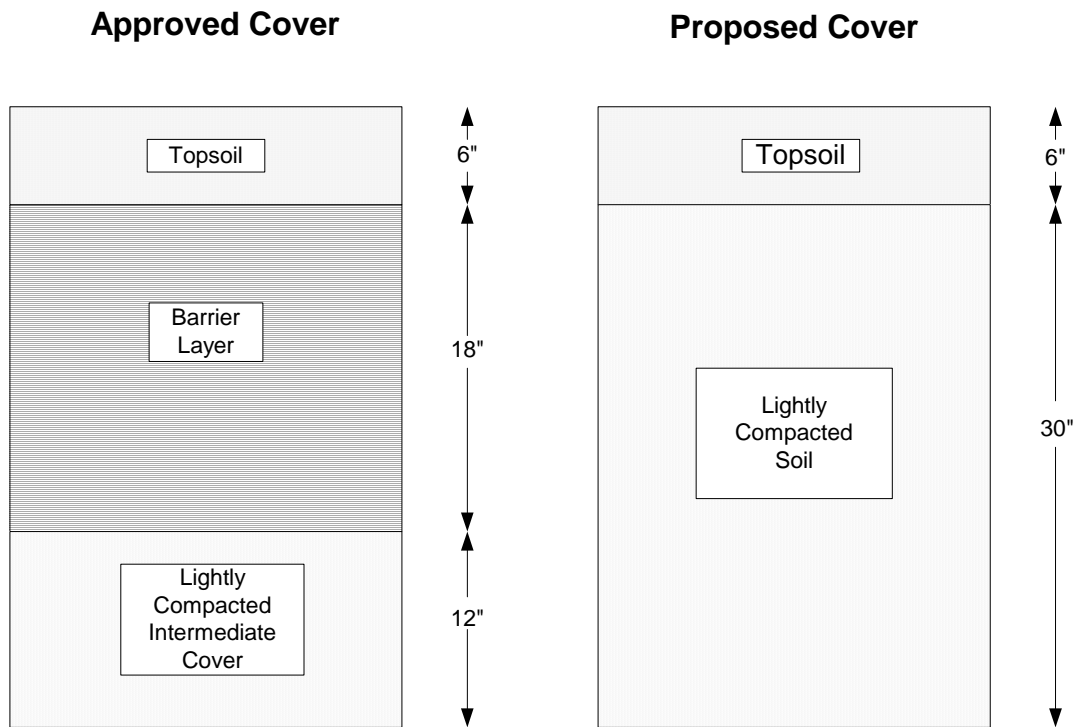


Figure 3-1. Soil cover design comparison.

projects under way throughout our nation, and the team felt that it was time to use the information garnered at those sites and actually build a nonresearch cover system. As the landfill has been filled, asymptotic leachate generation rates have been observed. What leachate has been collected has exhibited chemical characteristics more representative of storm water than leachate. The sumps will continue to be monitored through the 30-year postclosure period.

There are six permanent leachate collection sumps in Section 31. The performance evaluation of the alternative cover design will be the monitoring of fluid levels in the sumps. When Section 31 begins postclosure, quarterly monitoring of fluid levels in the sumps will be conducted. The results of these measurements will be compared to a baseline established during the eight quarterly monitoring events conducted in 2000 and 2001. Every five years during postclosure, barring a catastrophic failure, a trend analysis of the leachate levels will be conducted. The results of the trend analysis and the data will be submitted to CDPHE and Arapahoe County. If there are no significant increases in leachate levels, the alternative cover system will be considered to be functioning properly. As very little leachate is currently being generated, an increase in leachate levels in the sumps will be interpreted as a potential failure of the system.

This conclusion would trigger an investigation of the cover system to determine the cause of the increase in leachate levels. Long-term monitoring of the cover and repair of any erosional features are incorporated into the existing design and operation plan for the facility to ensure the viability of the cover system.

3.2.4.2 Allowable Erosion

As stated in the previous section, long-term postclosure monitoring of the facility will continue for a minimum of 30 years. Any erosional features that develop will be repaired as they are discovered. Therefore, zero erosion will be allowed.

Maximum Slope Length and Angle. NA

Ecological Diversity and Density. These topics were addressed in Sects. 3.2.3.2 and 3.2.3.7.

3.2.4.3 Cover Integrity

Cover integrity and maintenance throughout the life of the site, including postclosure, will provide a ready means to systematically evaluate the performance of the cover system. As stated in Sect. 3.2.3.2, a vegetative species mix was developed specifically for the site by Dr. Edward F. Rodente. This plant mix will be a major element in the stabilization of the final cover.

3.2.5 Design Basis Evaluation

3.2.5.1 Protection of Human Health and the Environment

This protection will be measured and maintained as defined by Sect. 2.1.15 of the Colorado Regulations Pertaining to Solid Waste Disposal Sites and Facilities (6 C.C.R. 1007-2), which states, "Solid waste disposal sites and facilities shall comply with the groundwater protection standards at the relevant point of compliance as defined in Section 1.2, and the owner/operator shall make a demonstration of compliance."

3.2.5.2 Modeling

The models used for this project are all in the public domain. Descriptions of the models and online resources are listed below.

- UNSAT-H—This model was selected by the team to be the primary basis for decision making as to the adequacy of the proposed alternative cover system.

“UNSAT-H is a FORTRAN computer code used to simulate the one-dimensional flow of water, vapor, and heat in soils. The code addresses the processes of precipitation, evaporation, plant transpiration, storage, and deep drainage.” Provided by the Hydrology Group, Pacific Northwest National Laboratory.

http://terrassa.pnl.gov:2080/~mj_fayer/unsath.htm

- VS2DI—This model is included for reference as it addresses the same questions as UNSAT-H, is in the public domain, and can be used as a check on UNSAT-H results.

“A graphical software package for simulating fluid flow and solute or energy transport in variably saturated porous media.” Provided by the U.S. Geological Survey (USGS).

<http://water.usgs.gov/software/vs2di.html>

- RETC—This model was integral to the design process, as it was used to generate the van Genuchten parameters used for input to UNSAT-H.

“RETC is a program for analyzing the hydraulic conductivity properties of unsaturated soils. The parametric models of Brooks-Corey and van Genuchten are used to represent the soil water retention curve, and the theoretical pore-size distribution models of Mualem and Burdine predict the unsaturated hydraulic conductivity function. The simulation can be generated from observed soil water retention data, assuming that one observed conductivity value (not necessarily at saturation) is available. The program also permits users to fit analytical functions simultaneously to observed water retention and hydraulic conductivity data.”

The manual for this model provides comparisons of observed phenomena and theoretical conclusions. Provided by the EPA Office of Research and Development, National Risk Management Research Laboratory, Subsurface Protection and Remediation Division.

<http://www.epa.gov/ada/csmos/models/retc.html>

- MULTIMED—The team chose this model to use in the event that the UNSAT-H modeling showed a large enough flux through the proposed cover vs. the approved cover to cause concern about meeting the requirements of the regulations at the relevant point of compliance.

“The Multimedia Exposure Assessment Model (MULTIMED) for exposure assessment simulates the movement of contaminants leaching from a waste disposal facility. The model consists of a number of modules that predict concentrations at a receptor due to transport in

the subsurface, surface air, or air. To enhance the user-friendly nature of the model, separate interactive pre- (PREMED) and postprocessing (POSTMED) programs allow the user to create and edit input and plot model output.” Provided by EPA Center for Exposure Assessment Modeling.

<http://www.epa.gov/ceampubl/multimed.htm>

Implementation of the Arya and Paris Physicoempirical Model. The relationship of soil moisture content and the pressure head on the soil is fundamental in the application of UNSAT-H, as well as in understanding unsaturated flow in general. This relationship is also known as the “soil water characteristic curve” (SWCC). The Arya and Paris method utilizes grain size distribution, bulk density, and particle density to generate the SWCC by conducting routine geotechnical tests that are inexpensive and can be done in a timely manner with a high degree of accuracy. Once the SWCC is developed, it is input to a public-domain computer model known as RETC⁴. RETC produces the van Genuchten parameters, which are then input to the UNSAT-H model.

Validation of the Arya and Paris Physicoempirical Model.⁵ The physicoempirical approach was validated for this project by applying the method to data developed for the RMA. The physicoempirical technique was applied to the data and then compared to the results obtained using the data obtained from the more costly, time-consuming tests listed in Sect. 3.2.3.1. The results validated the use of the physicoempirical method to develop the SWCC. Additionally, Refs. 4 and 5 below contain numerous examples comparing observed data to estimated data.

From a regulatory perspective, this approach has the advantage of using common geotechnical soil characteristic tests, i.e., grain size analysis and bulk density, whereas the tests conducted for the RMA are very specialized and can be performed at a limited number of laboratories. The approach the team chose has the potential to use routine, commonly available, reproducible, and inexpensive tests to justify and design alternative final covers.

For this project, ten samples from random soil stockpiles at the facility and three samples from topsoil stockpiles at the facility were collected. The samples were subjected to a #200-sieve wash to determine the percent fines in them. The #200-sieve wash was used to bracket the soil types at the site. The coarsest sample and the median sample from the on-site stockpiles were selected for additional testing, as was the median topsoil sample. The three samples were then tested for grain size distribution, Standard Proctor, and saturated hydraulic conductivity. The lab test also included hydrometer analysis, which is essential to generate a complete SWCC. Table 3-1 presents the results of the #200-sieve wash.

⁴ *The RETC Code for Quantifying the Hydraulic Functions of Unsaturated Soils*, M. Th. Van Genuchten, F. J. Leij, and S. R. Yates, U.S. Salinity Laboratory, U. S. Department of Agriculture, Agricultural Research Service, Riverside, California 92501, IAG-DW12933934.

⁵ “A Physicoempirical Model to Predict the Soil Moisture Characteristic from Particle-Size Distribution and Bulk Density Data,” Lalit M. Arya and Jack F. Paris, *Soil Science Society of America Journal* (1981) 45:1024–30.

Table 3-1. Results of #200-sieve wash

Sample	Passing #200 Sieve (%)	Moisture content
ACS 1	34	23.3
ACS 2	64	12.5
ACS 3	52	13.4
ACS 4	28	9.1
ACS 5	74	20.3
ACS 6	68	19.1
ACS 7	29.3	19.8
ACS 8	81	13.5
ACS 9	75	11.7
ACS 10	78	12.1
<i>Topsoil samples</i>		
ACST 1	69	13.2
ACST 2	80	11.6
ACST 3	82	11.1

3.2.5.3 Test Plots

This project benefited from its proximity to the RMA, where comprehensive studies have been going on for the last six years. The use of this information is presented in Sect. 3.2.3.1. Specifically, the data was used to evaluate the effectiveness of the physicoempirical model. If the results hold up over the test of time, this will be a case where tangible benefits to the general public, aside from the obvious, will be realized from Superfund dollars.

3.2.5.4 Natural Analogues

At this site, desert conditions exist. By designing a system that mimics the natural environment in using low precipitation; high evaporation; soil moisture balance; and hearty, native plant species, very little moisture will infiltrate the cover system, and a minimal amount of effort will be required to keep the system working for the long term.

3.2.5.5 Cost Savings

Cost savings of 15% have been estimated for this project. According to Colorado’s most current financial assurance calculations, the first phase of this project should result in a savings of approximately \$750,000. As the concept and its constructability evolve, the cost savings should become even larger. The current mindset of equipment operators who build landfill covers needs to be modified. Currently, heavy compaction is used to build the barrier layers; also water is added to the barrier layers. At the Denver Arapahoe Disposal Site, soils from a construction project were being disposed of on top of the landfill during a site visit prior to approval of the project. The landfill managers were reporting that simply disposing the soils and the associated

placement were resulting in compactations greater than 90% of Standard Proctor, which exceeds the specification of 85% of Standard Proctor approved for the project. As equipment operators become familiar with a less aggressive approach to compaction, the projects will likely be completed faster, consequently reducing the cost of construction even further.

3.3 Design/Construction/Construction Monitoring

3.3.1 Design

3.3.1.1 Criteria

NA

3.3.1.2 Specifications

The approved plan allows the flexibility of using of the existing, approved cover as well as the proposed alternative final cover. The components of the approved cover and the alternative final cover are depicted graphically in Fig. 3-1 and listed in Table 3-2.

Table 3-2. Components of the approved final cover and the alternative final cover

Approved cover	Alternative final cover
6" topsoil	6" topsoil
18" barrier layer $K < 1 \times 10^{-7}$ cm/sec	30" lightly compacted soil
12" lightly compacted soil	

In the approved cover, the refuse is covered with a six to 12-inch-thick layer of daily or intermediate cover, which will act as a base for the overlying barrier layer. The barrier layer will be compacted to 95% of the standard Proctor maximum dry density at moisture between 4% below and 2% above the optimum moisture content. The permeability coefficient is targeted at 1×10^{-7} cm/sec. A 6-inch-thick topsoil layer will be on top of the barrier layer.

The alternative final cover will consist of 36 inches of material, with a minimum of 28% of fine-grained material (i.e., material passing the #200 sieve), will be compacted between 80% and 90% of the Standard Proctor maximum dry density, and will have less than the optimum moisture content, as determined by the Standard Proctor test. The grain size specification is used to ensure that the cover system will perform as designed.

3.3.1.3 Regulatory Barriers

NA

3.3.2 Construction

3.3.2.1 Criteria

A 36-inch soil cover as described above.

3.3.2.2 Specifications

- Minimum of 28% fines (i.e., material passing the #200 sieve).
- Compaction between 80% and 90% of maximum dry density.
- Dry of optimum moisture content.

3.3.2.3 Monitoring QA/QC

- Grain size distribution test once every 5,000 cubic yards of material placed.
- A Standard Proctor test every 10,000 cubic yards placed.
- In situ density test using a nuclear gauge every 1,000 cubic yards placed.
- Oven-dry moisture content tests at a frequency of one every 1,000 cubic yards placed.
- Verification of proper thickness on a 100-foot grid system.

3.3.2.4 Constructability

To be determined upon full-scale implementation.

3.3.2.5 Regulatory Barriers

NA

3.3.2.6 Field Methods

See Sect. 3.3.2.3.

3.4 Operation and Monitoring

3.4.1 Flux Monitoring

NA

3.4.2 Leachate Management

See Sect. 3.2.4.1.

3.4.3 Cover Integrity Monitoring

3.4.3.1 Allowable Movement

NA

3.4.3.2 Erosion

A long-term postclosure monitoring program detailed in Sects. 3.2.4.1 and 3.2.4.2 will be implemented.

3.4.3.3 Corrective Action/Forensic Study

NA

3.4.3.4 Field Methods

NA

3.4.3.5 Groundwater Monitoring

The approved groundwater monitoring program will continue through the active life and postclosure period.

3.4.3.6 Ecological Succession

NA

3.5 Postconstruction/Operation Evaluation

3.5.1 Design Selection Process Evaluation

3.5.2 Goals Evaluation

3.5.3 Criteria Evaluation

3.5.4 Specifications Evaluation

3.5.5 Comparison to Design Goals

3.5.6 Cost Savings

3.5.7 Ability to Overcome Regulatory Barriers

3.5.8 Groundwater Monitoring

4. OPERATING INDUSTRIES, INC. SUPERFUND LANDFILL

Prepared by Jorge G. Zornberg, University of Colorado at Boulder

4.1 Site Setting

4.1.1 Name

Operating Industries, Inc. (OII) Superfund landfill.

4.1.2 Location

Monterey Park, California, approximately 16 km east of downtown Los Angeles.

4.1.3 Surface Area

The site includes approximately 60 hectares of the “South Parcel,” where the refuse prism rises approximately 35–65 meters above the surrounding terrain. A relatively flat top deck of about 15 hectares is surrounded by slopes of varying steepness. Slopes on the west side and most of the south side are generally the flattest and are typically about 3:1 (horizontal to vertical). Slopes on the north and east sides are generally the steepest, and considerable portions of the north slope were as steep as 1.3:1 before implementation of the final cover system. Land use adjacent to the South Parcel, in addition to the Pomona Freeway, includes commercial development to the east, residential developments to the south, and an industrial parcel to the west.

4.1.4 Type of Waste in Landfill

The 60-hectare South Parcel of the OII landfill was operated from 1948 to 1984, receiving approximately 30 million cubic meters of municipal, industrial, liquid, and hazardous wastes.

4.1.5 Future Land Use

Undecided.

4.2 Design Basis

4.2.1 Regulatory Barriers

The cover design criteria mandated by EPA were derived from both federal and state regulations. In 1986, the landfill was placed on the National Priorities List of Superfund sites.

The prescriptive cover, defined by a consent decree, consisted of a 1200-millimeter-thick system, which included a 300-millimeter-thick vegetative layer, a 300-millimeter-thick clay layer, and a 600-millimeter-thick foundation layer.

4.2.2 Public Involvement

Public participated heavily in the final selection of the system. Participation involves public meetings, newsletters, and fact sheets.

4.2.3 Site Characterization

4.2.3.1 Soil Characterization and Volume

Before implementation of the final closure system at the site, the refuse mass reached over 76 meters above grade, with slopes as steep as 1.3H:1V.

The landfill, a former sand and gravel quarry pit excavated up to 60 meters deep in places, was filled with solid and liquid wastes over a 40-year period. There is no evidence indicating that subgrade preparation or installation of a liner system took place prior to the placement of solid waste in the quarry. The maximum vertical thickness of the solid waste in the landfill is approximately 100 meters. The landfill received waste until 1984, which is when an interim soil cover of variable thickness (1–5 meters), consisting of silty clay to silty sand, was placed on top of the landfill. The site has been undergoing final closure under the EPA Superfund program since 1986.

A variety of site characterization and seismic studies were undertaken as part of predesign analyses for final closure of the site (e.g., Matasovic and Kavazanjian 1998). Selection of the final cover system at the site was driven by stability concerns, which led to the identification of alternative covers such as exposed geomembrane and evapotranspirative (ET) cover systems. One of the reasons for considering alternative covers for final closure was the difficulty in demonstrating adequate stability of conventional covers under static and seismic conditions. Although an exposed geomembrane cover would be stable under both static and seismic conditions, evaluation of the uplift by wind of the geomembrane becomes a key design consideration (Zornberg and Giroud 1997). Finally, an ET cover system was selected because of aesthetic, economical, and technical considerations. Selection of this system allowed use of geogrid reinforcements on steep portions of the landfill to satisfy static and seismic stability design criteria.

4.2.3.2 Geology

The native foundation material that underlies the landfill is geologically characterized as the Tertiary age Pico unit of the Fernando formation. The Pico unit includes conglomerate, sandstone, and siltstone/claystone subunits. The conglomerate consists of gravels and cobbles in a silt to coarse-grained sand matrix, the sandstone contains fine- to medium-grained sand with periodic calcareous concretions, and the siltstone/claystone subunit is interlayered with fine-grained silty sandstone beds.

4.2.4 Cover Goals

4.2.4.1 Allowable Infiltration/Flux

The key design criteria at the site deal with the percolation performance of the cover and static and seismic stability of the steep side slopes of the landfill. The percolation design criteria established by the applicable or relevant and appropriate requirements (ARARs) required that the performance of the final cover system be hydrologically equivalent to or better than a layered regulatory cover (prescriptive cover) that includes a 300-millimeter-thick barrier layer with a saturated hydraulic conductivity of 1×10^{-8} m/sec or less.

4.2.4.2 Allowable Erosion

The 30-year soil loss should be less than 300 millimeters. Also, the calculated gully depth should be less than 910 millimeters in this period of time. Additional design criteria include the following:

- The topsoil layer should be graded to resist erosion from precipitation of probable maximum precipitation (PMP)(ARAR).
- Structures which control erosion should be designed to withstand maximum credible earthquake (MCE) without damage (ARAR).
- Final cover should be designed and constructed to prevent erosion by water and wind (ARAR).
- The topsoil layer should be at least 6 inches thick (functional requirement).
- The topsoil layer should promote vegetation that is self-sustaining (design consideration).
- Temporary erosion control of the topsoil layer should be achieved using temporary erosion control matting, if needed, or other suitable methods (design consideration).
- Long-term erosion control of the topsoil layer should be achieved through combination of flat slopes, smooth slope transitions, and use of appropriate soil types and seed/fertilizer mixes that preclude gully initiation (design consideration).
- Topsoil and vegetation should resist gully initiation under the tractive forces of surface-water runoff from the cover (design consideration).

4.2.4.3 Cover Integrity

The stability criteria were a static factor of safety of 1.5 and acceptable permanent seismically induced deformations less than 150 millimeters under the MCE. The basis of the seismic stability criteria is that some limited deformation or damage may result from the design earthquake and that interim and permanent repair would be affected within a defined period after the seismic event.

One of the most challenging design and construction features of the project was related to the north slope of the landfill, which is located immediately adjacent to the heavily traveled Pomona freeway (over a distance of about 1400 meters), rises up to 65 meters above the freeway, and consists of slope segments as steep as 1.5:1 (H:V) and up to 30 meters high, separated by narrow benches. The toe of the north slope and the edge of refuse extend all the way up to the freeway.

After evaluating various alternatives, geogrid reinforcement were used for veneer stability of the north slope. Stability analyses showed that for most available cover materials, compacted to practically achievable levels of relative compaction on a 1.5:1 slope, the minimum static and seismic stability criteria were not met. Veneer geogrid reinforcement with horizontally placed geogrids was then selected as the most appropriate and cost-effective method for stabilizing the north slope cover (Zornberg et al. 2001). The veneer reinforcement consisted of polypropylene uniaxial geogrids, installed at 1.5-meter vertical intervals for slopes steeper than 1.8:1 and at 3-meter vertical intervals for slopes between 2:1 and 1.8:1. The geogrid panels were embedded a minimum of 0.75 meters into the exposed refuse slope face from which the preexisting cover had been stripped. The geogrid panels were curtailed approximately 0.3–0.6 meters away from the finished surface of the slope cover to permit surface construction, operation, and maintenance activities on the slope face without the risk of exposing or snagging the geogrid. Fig. 4-1 shows the typical veneer reinforcement detail selected based on the shear strength of the soils used in construction.

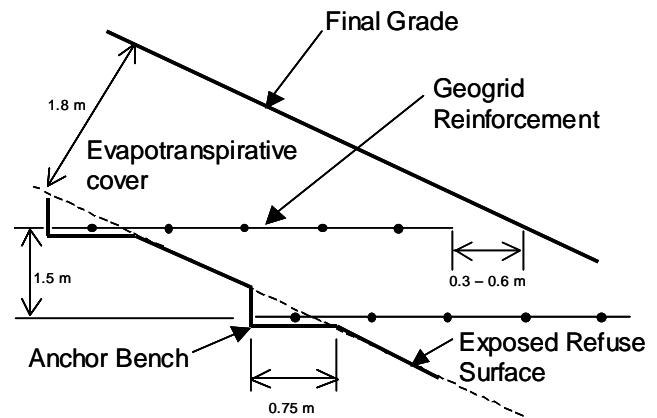


Figure 4-1. Typical reinforcement detail for horizontal reinforcement anchored into solid waste (from Zornberg et al. 2001).

4.2.5 Design Basis Evaluation

4.2.5.1 Protection of Human Health and the Environment

Selection of the final cover system at the site was driven by stability concerns, which led to the identification of alternative covers such as exposed geomembrane and ET cover systems. One of the reasons for considering alternative covers for final closure of the landfill was the difficulty in satisfying stability of conventional resistive covers under static and seismic conditions. Although an exposed geomembrane cover would be stable under both static and seismic conditions, evaluation of the uplift by wind of the geomembrane becomes a key design. Finally, an ET cover system was selected because of aesthetic, economical, and technical considerations. Selection of this system allowed use of geogrid reinforcements on steep portions of the landfill to satisfy static and seismic stability design criteria.

4.2.5.2 Modeling

The analysis and design of the ET cover at the OII Superfund site involved unsaturated flow simulations conducted using the computer program LEACHM (Hutson and Wagenet 1992). LEACHM is a one-dimensional, finite-difference water balance model that uses Richards' equation to simulate unsaturated water flow. The model has algorithms to predict evaporation from the soil surface and transpiration by plants. The soil surface is considered horizontal, and precipitation in excess of the infiltration capacity of the profile is considered to be shed as

overland flow. The program has fitting routines to compute moisture-retention parameters from experimental data. Moisture retention is described by Campbell's equation (Campbell 1974).

LEACHM was selected for the infiltration analysis at the OII Superfund site because (a) the code was particularly suitable for parametric evaluations, which was a significant component of this study; (b) local experience was available involving comparison of measured pan evaporation data with predicted values for the arid climate of southern California; and (c) it had received acceptance by local regulatory agencies for projects in California. LEACHM has been used and tested to simulate unsaturated flow processes in projects involving comparison between lysimeter measurements and numerical results. The original version of the LEACHM code was modified as part of this investigation to accommodate analyses involving longer periods of time and moisture-retention functions other than those implemented in the original version of the code. The general approach followed in the analysis of the ET cover at the OII Superfund site involves five phases undertaken to define the cover configuration, evaluate its performance, and demonstrate regulatory compliance:

- Evaluation of the hydraulic performance of a baseline ET cover. This phase provides understanding of the general mechanisms of water transfer within an ET cover under site-specific weather conditions.
- Equivalence demonstration of the baseline cover system. This phase evaluates regulatory compliance of the baseline cover by comparing percolations estimated through the ET cover and the regulatory-mandated (prescriptive) cover.
- Sensitivity evaluation of parameters governing the hydraulic performance of ET covers. This evaluation quantifies the sensitivity of parameters governing the design of an ET cover (e.g., rooting depth, cover thickness) and provides a site-specific basis for the final cover design. Some results on this sensitivity evaluation are reported by Zornberg and Caldwell (1998).
- Compilation of the ET cover design at the OII Superfund site. This phase includes final selection of the cover design parameters based on results obtained in the previous three phases using site-specific, though generic, soil information.
- Equivalence demonstration of the selected cover layout performed using site-specific and soil-specific hydraulic properties measured for each candidate borrow soil. This final phase accounts for the moisture-retention properties of the actual soils used for construction.

4.3 Design/Construction/Construction Monitoring

4.3.1 Design

The design criterion for the cover system at the OII Superfund site required that the percolation through the proposed ET cover be less than or equal to that through the prescriptive cover. The prescriptive cover at the site was defined by a consent decree as the state of California-mandated prescriptive cover. The approach adopted for evaluating equivalence between the proposed ET cover and the prescriptive cover was to compare percolations estimated numerically through both covers when exposed to identical climatic conditions. The prescriptive cover consists of a horizontal, 1200-millimeter-thick system that includes a 300-millimeter-thick protection layer, a 300-millimeter-thick clay layer having a saturated hydraulic conductivity of 10^{-8} m/s, and a 600-

millimeter-thick foundation layer. The protection layer and the foundation layer were both assumed to have a saturated hydraulic conductivity of 10^{-6} m/s.

4.3.2 Construction

4.3.2.1 Cover Characteristics and Specifications

The use of site-specific weather conditions for southern California provided a basis for the design of an ET cover at the OII Superfund site. The prescriptive cover used as a basis of comparison with an alternative cover system was defined by a consent decree. The rationale for selection of the cover design parameters at the site is as follows:

- Rooting Depth. The analyses indicated that rooting depths larger than that selected for the baseline case (300 millimeters) would not significantly enhance the performance of the ET cover system. Consequently, native vegetation, which typically exceeds 300 millimeters in rooting depth, was selected for the cover.
- Saturated Hydraulic Conductivity. Although the saturated hydraulic conductivity is only one of the parameters governing the hydraulic performance of an unsaturated cover system, it is probably the only hydraulic parameter feasible of being incorporated into construction specifications. Based on the results of parametric evaluations, the ET cover was specified to have a saturated hydraulic conductivity not exceeding 5×10^{-7} m/s. This requirement was usually achieved for identified borrow soils by specifying a minimum density of 90% of the maximum Standard Proctor density and placement moisture ranging from optimum to $\pm 2\%$. In addition to saturated hydraulic conductivity, moisture-retention properties had to be defined for each borrow source for use in soil-specific equivalence demonstrations, as discussed in the next section.
- Cover Thickness. Based on the evaluation of the performance of the baseline cover system and on the sensitivity of the cover thickness, a 1200-millimeter-thick engineered ET cover was selected for the site. Although the analyses indicated that a thinner ET layer was feasible, erosion and maintenance considerations governed the final selection of the minimum cover thickness. In addition, a 600-millimeter-thick soil foundation layer was adopted for construction underneath the engineered ET cover layer.
- Placement Moisture Content. Sensitivity analyses indicated no major influence of placement moisture content on long-term percolations. Nonetheless, placement moisture content was usually specified as the optimum moisture content $\pm 2\%$ to achieve the target saturated hydraulic conductivity and control the desiccation potential of cover soils.
- Irrigation. The analyses suggested that ET cover systems in arid and semiarid climates rely on periods of relative dryness to remove moisture stored in the system during previous precipitation events. Also, parametric evaluations showed that permanent irrigation schemes adversely affect this process, resulting in increases in percolation. Consequently, no permanent irrigation scheme was considered for the cover system at the site.

Fig. 4-2 shows a schematic view of the cover cross section. The design of the final cover system at the OII Superfund site was also constrained by requirements involving shear strength, resistance to erosion, shrinkage potential, and ability to sustain vegetation. Erosion calculations

were

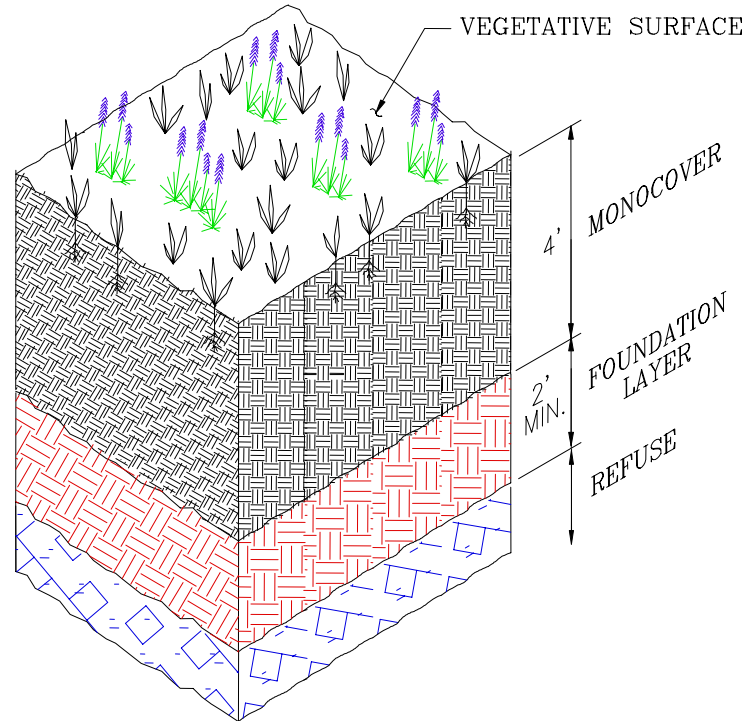


Figure 4-2. Schematic view of the evapotranspirative cover system.

performed to evaluate both sheet erosion and gully erosion on the landfill slopes. These evaluations led to the use of erosion control products, in addition to vegetation, in steeper landfill slopes. Agronomic properties of the soils (salinity, pH, sulfate content, organic content) were also measured in borrow soils design the appropriate seed mix and assess the potential need of soil enhancements to facilitate vegetation growth. Besides specifying the maximum saturated hydraulic conductivity of the cover soils and requiring soil-specific equivalence demonstrations, construction specifications also limited the soil types to be used for construction (CL, ML, SC, and SM), plasticity index (8%–30%), and fines content (>35%). The range of moisture-retention properties of the cover soils was not explicitly specified because of the difficulty in translating moisture-retention properties into construction specifications. Instead, the suitability of each candidate borrow soil was evaluated by implementing a soil testing program and compiling soil-specific equivalence demonstrations.

4.3.2.2 Constructability

The cover has to satisfy multiple requirements: unsaturated hydraulic characteristics, shear strength, shrinkage (desiccation cracking) potential, resistance to erosion, and ability to sustain vegetation. The optimum cover placement conditions required to achieve each of these diverse requirements are not always compatible with each other. For example, stability and erosion control are enhanced by a high degree of compaction; however, a high degree of compaction may inhibit vegetation growth. Accordingly, laboratory testing on remolded samples of potential cover materials were used to define specifications compatible with the different requirements.

Design of the final cover system was completed in 1998. Construction of the evapotranspirative cover was completed in April 2000. In particular, construction of the north slope was accomplished in 12 months. In this particularly challenging portion of the cover, approximately 500,000 cubic meters of soil and 170,000 square meters of geogrid were placed. Total area of geogrid placement exceeded 9.3 hectares. The maximum height of reinforced portion of the landfill slopes was 55 meters (the maximum height of the total landfill slope was 65 meters).

4.4 Operation and Monitoring

4.4.1 Flux Monitoring

Performance monitoring of the cover, consisting of a series of time domain reflectometry probes, will be implemented during three years following construction to monitor moisture variations and the cover performance. The analyses presented in this paper document the procedures that led to the selection of the parameters governing the design of the final cover system.

4.4.2 Leachate Management

Approximately 300 million gallons of liquid industrial wastes were disposed of in the landfill. Leachate forms from these liquids as they mix with water at the site. If this leachate is not controlled, it may contaminate the soil, surface water, or groundwater. Initially, leachate was collected and stored in temporary on-site tanks and then removed by trucks for off-site treatment and disposal. In 1991, construction of an on-site leachate treatment plant began on the North Parcel away from homes. The Leachate Treatment Plant is now operating and treats only liquids from the site. Under EPA's preferred alternative for final remedy, the Leachate Treatment Plant would be used to treat additional liquids collected around the landfill perimeter.

4.5 References

- Campbell, G. (1974). "A simple method for determining unsaturated conductivity from moisture retention data." *Soil Science*, 117(6): 311–14.
- Hutson, J. L., and R. J. Wagenet (1992). *Leaching Estimation and Chemistry Model, LEACHM*. New York State College of Agriculture and Life Sciences, Cornell University.
- Matasovic, N., and E. Kavazanjian (1998). "Cyclic characterization of OII landfill solid waste." *J. Geotech. and Geoenv. Engrg.*, 124(3): 197–210.
- Zornberg, J. G., and J. A. Caldwell (1998). "Design of monocovers for landfills in arid locations." *Third Intl. Conf. on Envir. Geotechnics, Lisbon*, A. A. Balkema, 169–74.
- Zornberg, J. G., and J. P. Giroud (1997). "Uplift of geomembranes by wind—Extension of equations." *Geosynthetics Intl.*, 4(2): 187–207.

Zornberg, J. G., S. Somasundaram, and L. LaFountain (2001). "Design of geosynthetic-reinforced veneer slopes." *Proc. of the International Symposium on Earth Reinforcement (IS Kyushu 2001), Fukuoka, Japan*, A. A. Balkema, Tokyo, 1: 305–10.

5. CASE STUDY OF AN ALTERNATIVE FINAL COVER ON THE McPHERSON COUNTY LANDFILL IN KANSAS

Prepared by Paul Graves, MS, PE, Chief, Solid Waste Landfills Unit, Bureau of Waste Management, Kansas Department of Health and Environment, 1000 SW Jackson, Suite 320, Topeka, Kansas 66612-1366

This case study was prepared as part of an initiative by the Interstate Technology and Regulatory Council, Alternative Landfill Technologies Team and follows a standard outline they developed. The objective is to use a number of such case studies as a basis for developing a technical guidance manual on landfill alternative final covers. The alternative final cover profiled in this case study is a hybrid evapotranspiration/capillary barrier/clay barrier design. The coarse sand in the capillary barrier also serves as a drainage layer.

The author acknowledges the work done by the design consultant, Engineering Solutions and Design of Overland Park, Kansas, and the vision of the landfill owner, McPherson Area Solid Waste Utility. Their partnering on this project and willingness to perform extensive analyses to support the alternative final cover design was integral to the state's approval.

5.1 Site Setting

5.1.1 Name

The facility is known as the McPherson Area Solid Waste Utility (MASWU) Landfill or the McPherson County Landfill.

5.1.2 Location

The city of McPherson (the county seat) is situated at the center of McPherson County, which is located near the center of Kansas, about 150 miles west-southwest from Topeka. The McPherson County Landfill is located about 6 miles north of the city limits at 1481 Pueblo Road, McPherson, Kansas 67460. This location is midway between the cities of McPherson and Lindsborg and about 1½ miles west of Interstate 135/U.S. Highway 81. The landfill is in the southeast quarter of the southeast quarter of Section 16, Township 18 South, Range 3 West. The coordinates are 38° 28' 48" N, 97° 39' 02" W.

5.1.3 Surface Area

The landfill property comprises approximately 81 acres; waste disposal was permitted on approximately 31 acres. The alternative final cover was constructed on approximately 15 acres of a vertical expansion area in which waste disposal ceased on October 9, 2001.

5.1.4 Type of Waste in Landfill

The alternative final cover was constructed over a municipal solid waste disposal area.

5.1.5 Future Land Use

The owner filed a restrictive covenant for the landfill property, in accordance with state regulations. The restrictive covenant specifies that after closure the property shall be used only for “pasture land.”

5.2 Design Basis

5.2.1 Regulatory Barriers

State regulations would ordinarily have required a final cover for the subject area of the McPherson County Landfill to consist of (in order of placement) a minimum of 18 inches of low-permeability soil (hydraulic conductivity $\leq 1 \times 10^{-5}$ cm/sec), a geomembrane (typically 40-mil low-density polyethylene), a drainage layer, protective soil at least as thick as the frost penetration depth (approximately 30 inches), and native grass. This design would also have necessitated a passive or active landfill gas collection system. The state regulations do not include a provision for alternative final covers; however, a variance procedure has been established, including the option of variances “granted to facilitate experimental operations intended to develop new methods or technology...where significant health, safety, environmental hazards, or nuisances will not be created, and when a detailed proposal is submitted and accepted which sets forth the objectives, procedures, controls, monitoring, reporting, time frame, and other data”⁶. The state approved the alternative final cover for the McPherson County Landfill under the variance authority.

5.2.2 Public Involvement

State regulations stipulate that a public notice must be issued for “significant” modifications to a permit and that a public hearing must be conducted when a proposed action may generate “significant” local interest. The Kansas Department of Health and Environment has developed a policy to define “significant” permit modifications. Based on that policy and consistent with past practices relative to minor modifications, substituting an alternative final cover for the regulatory cover was deemed “not significant,” so a public notice was not issued. Given that the facility is located in a relatively rural and remote area and based on the type of modification and past experience in McPherson County, local interest was anticipated to be minimal, and therefore a public hearing was not conducted.

5.2.3 Site Characterization

A permit was first issued by the state of Kansas for the McPherson County Landfill in 1976. The permit was amended in 1994 to incorporate Subtitle D standards, in 1996 to allow the vertical expansion of a pre-Subtitle D municipal solid waste landfill (MSWLF), and in 1998 to further address the vertical expansion. The MSWLF ceased active operation on October 9, 2001 (a

⁶ Kansas Department of Health and Environment. *Kansas Administrative Regulations, Article 29—Solid Waste Management*. August 2001.

transfer station operated by MASWU at a different location handles all the municipal solid waste streams that used to go to the McPherson County Landfill), and since then MASWU has continued operation of a construction and demolition landfill at the facility while constructing the final cover on the MSWLF vertical expansion unit. The landfill property includes approximately 81 acres in a square parcel of land, on which waste disposal has occurred primarily on the southeast quadrant. The facility includes a gated entrance and scale house, two storm-water detention ponds, groundwater monitoring wells, soil borrow areas, and undisturbed areas. The surrounding land use is primarily agricultural.

5.2.3.1 Soil Characterization

The *Soil Survey of McPherson County, Kansas*⁷ indicates that there are four soil units on the McPherson County Landfill property. Listed in descending order of area covered, these are Longford silty clay loam, 3%–6% slopes; Lancaster-Hedville loams, 6%–12% slopes; Longford silty clay loam, 2%–6% slopes, eroded; and Crete silt loam, 1%–3% slopes. This composition corresponds with soil investigations that characterized the on-site soils primarily as silty clay. A laboratory analysis concluded that subsurface soils from the site exhibited permeability rates on the order of 1×10^{-8} cm/sec.

5.2.3.2 Plant Characterization

Most of the site has been cleared due to the landfill operations. Native grasses will be established on the disturbed areas upon closure. Undisturbed areas of the site and areas where volunteer vegetation has occurred exhibit characteristic rangeland plants as described in the previously cited soil survey of McPherson County. These can include grasses, forbs, shrubs, and trees such as big bluestem, little bluestem, switchgrass, sideoats grama, Indiangrass, western wheatgrass, tall dropseed, eastern cottonwood, green ash, black willow, hackberry, Russian mulberry, boxelder, black walnut, American elm, red elm, osageorange, and American plum.

5.2.3.3 Climate/Microclimate Characteristics

The following information was excerpted from the previously cited soil survey of McPherson County: In winter the average temperature is 32.9 degrees F, and the average daily minimum temperature is 22 degrees. The lowest temperature on record, which occurred at McPherson on February 12, 1899, is -27 degrees. In summer the average temperature is 78.5 degrees, and the average daily maximum temperature is 91.4 degrees. The highest recorded temperature, which occurred at McPherson on several dates, the last being August 12, 1936, is 117 degrees. The total annual precipitation is 28.93 inches (recorded at McPherson 1951–1976). Of this, 21.33 inches, or 74%, usually falls in April through September, which includes the growing season for most crops. In 2 years out of 10, the rainfall April through September is less than 14.93 inches. The heaviest one-day rainfall was 11.39 inches at Lindsborg on October 20, 1941. Average seasonal snowfall is 19.1 inches. The greatest snowfall, 57.3 inches, occurred at Lindsborg during the winter of 1959–1960. On an average of 17 days at least 1 inch of snow is on the ground. The

⁷ U.S. Department of Agriculture, Soil Conservation Service. *Soil Survey of McPherson County Kansas*. April 1983.

number of such days varies greatly from year to year. Sun shines 75% of the time possible in summer and 63% in winter. The prevailing wind is from the south. Average wind speed is highest, 13.5 miles per hour, in April.

5.2.3.4 *Geology*

The following information was excerpted from a hydrogeologic site investigation⁸ required for the 1994 permit modification: The subject site lies within the McPherson Lowlands Section of the Great Plains Physiographic Province. The region is characterized by rolling hills and steep stream valleys. According to the USGS report 85-4336 "Ground Water Flow & Solute Transport in the Equus Beds Area, South Central Kansas, 1940-79," subsidence has occurred in the area since the Cretaceous geologic time resulting from dissolution of salt beds within the underlying Wellington Formation. Collapse within the Wellington Formation caused subsequent erosion of overlying beds and influenced the depositional patterns of the Pleistocene streams in the area. The McPherson Channel, which trends southward from near Lindsborg and includes the subject site, was a major drainage created from the salt bed subsidence that was subsequently filled with Pleistocene deposits. The subsurface soils encountered in this investigation consisted of silty and sandy clays with zones of caliche. The cohesive soils were relatively consistent laterally throughout the area of this investigation and to the maximum depth of the exploratory borings (55 feet below the ground surface). Based on information obtained through exploratory borings made at the existing landfill site by Hydraulic Drilling Company in 1974, the subsurface soils were logged as cohesive silty/sandy clays to the depth of the underlying shale bedrock, which was encountered at 103 feet in the 1974 borings.

5.2.3.5 *Hydrology*

Groundwater flow is generally to the north. Depth to groundwater varies approximately 15–25 feet below the ground surface. The uppermost aquifer is approximately 30 feet thick. Hydraulic conductivity in the aquifer is approximately 3.3×10^{-6} cm/sec.

5.2.3.6 *Surface Water Characteristics*

The site is not within the 100-year flood plain. Site drainage is designed to accommodate the 25-year, 24-hour storm, which has a total rainfall of about 5.5 inches and a peak intensity of 8.4 inches per hour. Runoff from the site is collected in perimeter channels and controlled in two storm-water detention basins which discharge to tributaries of Indian Creek.

5.2.3.7 *Biota*

Plants were described in Sect. 5.2.3.2. Access to the site is limited by perimeter fencing and an active construction and demolition landfill that is directly adjacent to the closed MSWLF. Therefore, livestock will be prevented from entering until operations at this facility cease. The

⁸ Allied Environmental Consultants, Inc. *Hydrogeologic Site Investigation, McPherson County Landfill, McPherson County, Kansas*. Revised October 20, 1994.

restrictive covenant for this property limits postclosure uses to “pasture land”; however, given the prevalence of rangeland in McPherson County, it is unlikely that grazing will actually occur on this site during the postclosure period. Whether or not grazing does occur during postclosure, the permittee will be required to perform inspections and repair any damage to the final cover. The alternative final cover design for this facility did not include any special measures to prevent damage to the final cover due to livestock or wildlife; nevertheless, the depth of soil cover (over 7 feet total thickness) should be sufficient to prevent animal access to the waste. The presence of wildlife on the site is minimal and is currently limited primarily to insects, worms, birds, and small mammals. In the long term, the site is expected to revert to rangeland and may become habitat for such open-land native species as bobwhite quail, mourning dove, pheasant, meadowlark, field sparrow, and cottontail rabbit.

5.2.4 Cover Goals

The designer expressed the following rationale in applying for state approval of the alternative final cover: it would simplify the construction, reduce the potential for slope failures, avoid the risk of geomembrane failure, and reduce the maintenance requirements. Implicit in this rationale is the fact that the alternative final cover would be less expensive to construct and maintain than the prescriptive cover. These savings are discussed in Sect 5.2.5.5.

5.2.4.1 Allowable Infiltration/Flux

The criterion for approval of the alternative final cover was qualitatively established as hydraulic performance equivalent to the prescriptive final cover. Essentially, this meant that the modeling had to show zero infiltration through the alternative final cover when subjected to 30 years of recorded precipitation.

Leachate Management. This alternative final cover was constructed over a vertical expansion of a pre-Subtitle D MSWLF. The subject MSWLF does not have a leachate collection system. Therefore, leachate is not collected and managed in the contemporary sense. Instead, leachate migration is controlled by the hydrogeologic conditions underlying the site. A network of groundwater monitoring wells is located around the MSWLF and is regularly sampled to detect any contaminants exceeding the regulatory levels. To date, such exceedances have not been detected at this facility.

5.2.4.2 Allowable Erosion

This parameter was not established as a design criterion. Nonetheless, state regulations require stabilization of the landfill final cover with vegetation and other erosion control measures as necessary. The state’s rules also require routine inspection and repair of erosion during the active and postclosure (minimum of 30 years) periods.

Maximum Slope Length and Angle. The alternative final cover at this facility was constructed at slopes ranging from 5:1 to 20:1 horizontal to vertical, with associated slope lengths varying from 100 to 500 feet. The northern edge of the subject landfill occurs at a 2.5:1 slope with a slope length of up to 100 feet. However, the final cover on this northern slope consists of the

intermediate soil and clay barrier layers only as a temporary measure until the adjacent construction and demolition landfill extends against and stabilizes this slope.

Ecological Diversity and Density. These parameters were not established as design criteria. However, vegetation on landfill final covers in Kansas typically consists of a blend of native grasses recommended by the County Extension Agent. In this way, an appropriate diversity and density is generally achieved (although the diversity is limited to grasses so as not to result in root damage of the final cover). For the subject final cover, the following seed mix was specified: western wheatgrass at 3.5 pounds/acre, native Indian grass at 4.0 pounds/acre, native Blackwell switchgrass at 5.0 pounds/acre, and brome grass at 10.0 pounds/acre.

5.2.4.3 Cover Integrity

The state regulations require stability analyses to demonstrate acceptable safety factors for landfill final covers under static and seismic conditions. This alternative final cover was determined to have adequate factors of safety (≥ 1.5 for static conditions and ≥ 1.3 for seismic conditions).

5.2.4.4 Landfill Gas

Numerous MSWLFs in Kansas have been capped with a compacted clay layer similar to the one included in this alternative design. Significant problems associated with landfill gas have not been identified with the use of these compacted clay covers. Therefore a landfill gas collection layer was not included or required in the subject design. With the relatively low generation rates anticipated, the landfill gas is expected to diffuse through the compacted clay cover. However, vents may be required if significant accumulation or migration of landfill gas is identified in the future.

5.2.5 Design Basis Evaluation

As an alternative final landfill cover of this design had not previously been implemented in Kansas, the evaluation of the design relied primarily on modeling and the underlying principles of evapotranspiration, capillary barrier, and low-permeability barrier.

5.2.5.1 Modeling

The design engineer used the Hydrologic Evaluation of Landfill Performance (HELP) model by EPA and the VS2DI model (“A Graphical Software Package for Simulating Fluid Flow and Solute or Energy Transport in Variably Saturated Porous Media”) by USGS to develop the proposed alternative final cover. In addition to actual rainfall data, several potential failure scenarios were modeled, including increasing the confidence interval for annual precipitation until failure occurred, running the model with half the initially assumed time between storm events, and running the highest historical wet year repeatedly until failure occurred. This methodology helped identify weaknesses in the originally proposed alternative final cover, and so the engineer amended the design to address these issues. Design modifications included adjusting the thickness of the capillary barrier and adding a French drain at the toe of slope.

Changes were also made in the design to substitute readily available material in the coarse sand layer. The analyses for the final design showed no significant infiltration through the alternative final cover subjected to 30 years of recorded precipitation for the region.

5.2.5.2 Test Plots

A pilot-scale version of this alternative final cover was not constructed. However, in addition to literature from several published case studies, the design team performed laboratory testing on the proposed cover materials as necessary to support modeling. These laboratory tests included characterization of the materials (initial moisture content, bulk density, porosity, percent saturation, and sieve analysis) as well as determining saturated hydraulic conductivity and moisture-retention data.

5.2.5.3 Evaluation

The design was evaluated on the basis of the modeling results and the documented success of similar applications. Evaluating the model results was facilitated by the graphical output provided by the VS2DI model.

5.2.5.4 Natural Analogues

This methodology was not explicitly used in the design of this alternative final cover. However, an understanding of the behavior of natural soil systems under hydrologic cycles is fundamental to grasping the principles involved in this design.

5.2.5.5 Cost Savings

A cost estimate prepared by the design consultant showed construction costs of \$1.165M for the prescriptive cover and \$1.146M for the alternative cover, thus indicating a slight savings for constructing the latter. The estimated costs for the prescriptive cover geomembrane and geonet, \$520,000 and \$280,000, respectively, were offset by additional costs for soil materials in the alternative cover. The low bid for the alternative cover construction was \$0.905M, and this bid was awarded. In addition to the modest construction savings, the design consultant and the landfill owner had decided to pursue an alternative final cover primarily due to the anticipated maintenance savings. These savings are expected to accrue due to the avoided costs of landfill gas venting and reduced cover repair as compared with a prescriptive cover. Over the minimum 30-year postclosure care period, these avoided/reduced costs may potentially amount to \$40,000–80,000, representing an estimated 5%–10% savings.

5.2.5.6 Protection of Human Health and the Environment

Based on the model results showing that the alternative final cover would result in negligible infiltration under design conditions, the state determined that the alternative final cover would not significantly increase the risks of adverse impacts on human health and the environment. Therefore, the alternative final cover was approved under the variance procedure established in the regulations.

5.3 Design/Construction/Construction Monitoring

5.3.1 Design

The alternative final cover was designed during the period from the summer of 2000 through the fall of 2001, when it was conditionally approved by the state. One of the key conditions was improving drainage of infiltration water from the cover toe of slope.

5.3.1.1 *Criteria*

The state required hydraulic performance equivalent to the prescriptive cover. The designer selected and modified the alternative final cover parameters until modeling software indicated negligible percolation through the cover under design conditions (30 years of recorded precipitation).

5.3.1.2 *Specifications*

The alternative final cover consists of the following layers, in order of construction: 24 inches compacted clay (hydraulic conductivity less than or equal to 1×10^{-7} cm/sec), 14 inches coarse sand (hydraulic conductivity $\pm 6.0 \times 10^{-2}$ cm/sec), 12 inches fine sand (hydraulic conductivity $\pm 2.4 \times 10^{-3}$ cm/sec), and 36–45 inches of loam with native grasses established on top.

5.3.1.3 *Regulatory Barriers*

To obtain state approval, extensive modeling was required. Refer to Sects. 5.2.1 and 5.2.5.1 of this case study for more information.

5.3.2 Construction

The alternative final cover was constructed during the fall of 2001 and the spring of 2002.

5.3.2.1 *Criteria*

The construction requirements were established in the engineering drawings, technical specifications, closure report, and construction quality assurance plan.

5.3.2.2 *Construction Methodology*

The clay layer was compacted in 6-inch lifts, at 5% above the modified Proctor optimum moisture content, and at adequate compaction to achieve a hydraulic conductivity less than 1×10^{-7} cm/sec (although the state requirement is generally 1×10^{-5} cm/sec). Course sand was then spread over the clay in a manner such that equipment did not travel directly on the clay layer. The coarse sand surface was rolled prior to installation of the fine sand layer. The fine sand and topsoil were installed in a similar manner, except that the loam was installed without significant compaction so as to promote root growth.

5.3.2.3 *Monitoring QA/QC*

A construction quality assurance (CQA) plan, required by the state, established testing and reporting requirements. A test pad was used to determine the hydraulic conductivity achieved with the available construction equipment, proposed compaction procedures, and moisture/density parameters. Verification testing was also conducted on the clay layer during construction. Thicknesses of all soil layers were measured at set intervals. Characteristics of the clay and sand layers were established in laboratory tests prior to construction and source controls were considered effective for maintaining consistency.

5.3.2.4 *Constructability*

One of the primary considerations in designing the alternative final cover was to facilitate construction. The materials in the cover are commonly used in a variety of public works and land development projects, and no significant construction problems were encountered. A local construction company was awarded the contract and successfully completed the project on time and within budget.

5.3.2.5 *Regulatory Barriers*

As noted in Sect. 5.3.2.3, the state required CQA procedures to ensure proper construction techniques and verify that specifications were met. A final CQA report and certification is pending to document the inspections and testing performed during construction. This is not considered a “barrier” to alternative final covers, as any landfill cover would be subject to these requirements.

5.4 Operation and Monitoring

5.4.1 Flux Monitoring

To evaluate the performance of the alternative final cover, the state required a pan-type lysimeter to be constructed under the cover. This is consistent with an EPA Demonstration Bulletin dated April 2000, titled “Alternative Cover Assessment Program.” The landfill owner and its consultant opted to construct two lysimeters.

5.4.1.1 Field Methods

The lysimeters each slope to a drainage sump that drains via pipe to a collection beaker. Liquid levels in the collection beakers will be monitored on a periodic basis, primarily after significant precipitation. The monitoring results will be recorded and maintained for future correlation with rainfall data and cover performance evaluation.

5.4.2 Leachate Management

As noted in Sect. 5.2.4.1, this landfill does not have a leachate collection system.

5.4.3 Cover Integrity Monitoring

The landfill owner is required to conduct regular inspections during the postclosure period (minimum of 30 years). One of the key parameters checked in those inspections will be the cover integrity. Any damage such as erosion or animal burrows must be repaired as soon as practicable. Any slope or stability failures must be reported to the state along with a plan for repairing the damage.

5.4.3.1 Allowable Movement

The state does not have specific rules on allowable movement of the final cover. Only insignificant movement would be allowed, in other words, that which does not substantially reduce the function of the cover or result in potential or actual adverse impacts to human health and the environment.

5.4.3.2 Erosion

As noted in Sect. 5.4.3, the landfill final cover must be inspected and any significant erosion repaired.

5.4.3.3 Corrective Action/Forensic Study

As noted in Sect. 5.4.3, the landfill final cover must be inspected and any damage corrected. Significant failures would be subject to a determination of cause and evaluation of remedial measures.

5.4.3.4 Field Methods

Survey controls are required to be maintained at the landfill site. Significant failures would be surveyed, if possible, to facilitate the corrective design. Minor damage to the final cover, such as surface erosion and animal burrows, will be located during visual inspections.

5.4.4 Ecological Succession

This topic is addressed in Sects. 5.2.3.2 and 5.2.3.7.

5.5 Postconstruction/Operation Evaluation

5.5.1 Design Selection Process Evaluation

This type of evaluation is not required by the state, and it is unlikely that the landfill owner will have an incentive to perform such an evaluation. The design consultant or other interested parties may opt to evaluate the selection process to incorporate data gathered and lessons learned into future designs; however, this evaluation has not been performed to date.

5.5.2 Goals Evaluation

The goals expressed by the design consultant were to simplify the final cover construction, reduce the potential for slope failures, avoid the risk of geomembrane failure, and reduce the maintenance requirements. Based on feedback from the landfill owner, the first of these goals was accomplished in that construction difficulties were not encountered. The second of these goals may have already been accomplished (i.e., the “potential” for failures may be reduced due to the nature of the cover materials used); however, long-term monitoring will better assess whether this objective has been met. The third goal was obviously satisfied as geomembrane was not included in the design. The fourth goal, reduction of the maintenance requirements, is another that can be evaluated only with long-term observations.

5.5.3 Criteria Evaluation

The field data collected with regard to this alternative final cover will be considered in future similar applications. If this alternative final cover is determined to perform as intended, then the criteria will likely be considered appropriate.

5.5.4 Specifications Evaluation

Similar to the criteria evaluation, a determination of the relative success of the specifications will depend in large part upon the long-term performance of the alternative final cover. At present, the specifications appear to be appropriate based on the modeling results and construction experience.

5.5.5 Comparison to Design Goals

The primary design goal was to provide hydraulic performance equivalent to the prescriptive final cover. As the alternative final cover has only recently been completed, it is too early to make this determination. Other design goals included slope stability and erosion control. To date there have been no indications of slope stability problems. The vegetative cover has not been established yet, so it is too early to make a determination on erosion control. (Temporary erosion control measures employed during construction have been successful.)

5.5.6 Cost Savings

A postclosure evaluation of cost savings has not been prepared, primarily because construction was just recently completed and sufficient time has not transpired for a proper accounting of maintenance costs and savings. Construction savings associated with the alternative final cover and anticipated maintenance savings were addressed in Sect 5.2.5.5.

5.5.7 Ability to Overcome Regulatory Barriers

The landfill owner, its consultant, and state staff successfully worked together to overcome the regulatory barriers for approval of this alternative final cover. The regulatory barriers were reduced by the fact that the state has an established regulatory variance procedure. The design

consultant and the landfill owner further overcame regulatory barriers with their understanding and willingness to perform the required modeling to demonstrate the acceptability of this alternative final cover.

5.5.8 Groundwater Monitoring

This facility has a system of groundwater monitoring wells that are sampled on a regular basis to determine the concentration of contaminants in the underlying aquifer due to landfill leachate. To date, concentrations of contaminants have not been detected above regulatory levels. If exceedances occur in the future, the landfill owner will be required to perform assessment monitoring. This will involve testing for an expanded list of constituents, with an increased frequency, and perhaps with additional wells. If it is determined that constituents above regulatory levels have migrated off site, a release impact plan would be required to assess the proximity of potential receptors and the need for corrective action.

6. MR. "M" LANDFILL, ALTERNATIVE COVER, FERGUS COUNTY, MONTANA

Prepared by Rick Thompson, Solid Waste Management Section Supervisor, Montana Department of Environmental Quality

6.1 Site Setting

6.1.1 Name

Mr. "M" Lewiston Class II Landfill (Mr. "M" Landfill). (Class II Landfills are facilities licensed to accept municipal solid wastes.)

6.1.2 Location

The Mr. "M" Landfill is located approximately three miles east of Lewistown, in the SW ¼ of Section 8, T15N, R19E, Fergus County, Montana.

6.1.3 Surface Area

Based on site surveying, the entire footprint that contains waste is 9.85 acres.

6.1.4 Type of Waste in Landfill

The landfill has been in operation since 1958. The landfill received household wastes; although evidence of white goods (refrigerators, freezers, washers, dryers, and similar appliances), demolition wastes, and metals can be seen on site. The landfill stopped receiving waste on September 15, 1998. The volume of solid waste on site at the time of closure was estimated to be approximately 486,000 cubic yards, based on conservative estimates of the original topography before initiating placement of solid waste.

6.2 Design Basis

6.2.1 Regulatory Barriers

- Administrative Rules of Montana 17.50.506(17) requires that landfill units and lateral expansions must be designed, constructed, and operated in a manner to "prevent harm" to human health and the environment.

This is a broad performance standard intended to prevent all forms of harm and would depend at least on the amount of precipitation, the type and concentrations of specific contaminants present in the leachate, the permeability of the liner barrier, the subgrade permeability, depth to groundwater, groundwater quality, proximity and hydraulic connection to drinking-water supply aquifers and wells, and other factors that limit the ability of water percolating through the cap to reach pathways that pose a reasonable risk to human or environmental health.

- Montana solid waste regulations require that landfill units be constructed in a manner that maximum contaminant levels (MCLs) established in Montana groundwater regulations will not be exceeded in the uppermost aquifer at the relevant-point-of-compliance groundwater monitoring wells.

This specific performance standard requires the adequate location of a sufficient number of wells within the proper saturated zone, so the observations strongly depend on the aquifer characteristics and the nature of the pathway leachate or contaminated gas would follow to reach the aquifer. Alternative cover designs must minimize percolation to avoid production of gas and leachate that can contaminate groundwater.

- Montana solid waste regulations require that the performance standard for the infiltration layer of a closed landfill unit be a minimum of 18 inches of earthen material that has a permeability less than or equal to the permeability of any bottom liner, barrier layer, or natural subsoils present or a permeability no greater than 1×10^{-5} cm/sec, whichever is less.

Infiltration is not the same as percolation, although limitation of the former also restricts the latter. If the rule is strictly adhered to as it is written, a well-developed shallow-rooted vegetative cap must limit infiltration without the help of moderate to deep-rooted plants that would limit downward percolation. Plant root depths are also restricted to the top 6 inches. As such, this language provides a significant legal barrier to alternative design, because percolation will occur when the shallow-rooted plants are dormant during the winter, thus the alternative cap must provide at least the same permeability throughout the upper 18 inches of the infiltration layer, but permeability may vary below that depth.

On the other hand, if percolation is substituted for infiltration in that rule language, the concept of equivalence requires the amount of free drainage at the base of both layers to be equal, assuming the same distribution in space and time of precipitation and freezing.

6.2.2 Public Involvement

There was no public involvement in the selection of the alternative cover design for the facility. Montana law requires public involvement during the licensing phase of solid waste management facilities in the form of a published National Environmental Policy Act of 1969/Montana Environmental Policy Act 1971 document. Written comments are allowed within a 30-day comment period on the design, operation, monitoring, and closure designs for a proposed facility. Any modifications to the plans after the facility is licensed are typically reviewed by the Montana Department of Environmental Quality Solid Waste Program without public involvement.

6.2.3 Site Characterization

6.2.3.1 Soil Characterization

The *Soil Survey of Fergus County, Montana* (NRCS 1988) describes the on-site soils as follows:

Timberg-Castner Complex:

The Timberg soil moderate to deep and well drained. It formed in residuum derived dominantly from semi-consolidated shale inter-bedded with sandstone. Typically, the surface layer is a reddish brown clay loam about 6 inches thick. The subsoil is reddish brown and brown silty clay about 19 inches thick. The substratum is dark yellowish brown silty clay about 12 inches thick. Dark yellowish brown shale is at a depth of about 37 inches. Depth to shale ranges from 20 to 40 inches.

Permeability of the Timberg soil is slow. Available water capacity is low to moderate. Effective rooting depth is 20 to 40 inches. The average annual wetting depth where soil is under natural vegetation is 20 to 26 inches.

The Castner soil is shallow and well drained. It formed in residuum derived dominantly from fractured hard sandstone. Typically, the surface layer is grayish brown stony loam about 7 inches thick. The underlying material is pale brown very channeled loam about 7 inches thick. Light gray sandstone is at a depth of about 14 inches. Depth to sandstone ranges from 10 to 20 inches.

Permeability of Castner soil is moderate. Available water capacity is very low. Effective rooting depth is 10 to 20 inches. The average annual wetting depth where the soil is under native vegetation is 10 to 20 inches.

Based on field observations and test pit logs, the predominant soil both underlying the in-place solid waste and for the closure design is the Timberg soils, as described above.

There was a need for general fill materials, clayey soils, and topsoil for use in closing the Mr. "M" Landfill. Two borrow areas were identified during the field studies. Five test pits were excavated in the proposed borrow areas. Representative soil samples were collected and analyzed for geotechnical and hydraulic properties pertinent to the landfill cap design.

6.2.3.2 *Plant Characterization*

There was no native vegetation within the landfill boundary. Due the disturbance from landfilling activities the site had become inhabited with noxious weeds such as knapweed. Typical vegetation in surrounding vicinity consists primarily of range grasses, including western wheatgrass and green needle grass, as well as native legumes, such as yellow blossom sweet clover.

6.2.3.3 *Climate Characteristics*

The climate for Fergus County is described as usually warm in the summer and is characterized by frequent hot days. In winter, periods of very cold weather are caused by arctic air moving in from the north or northeast. Cold periods alternate with milder periods that often occur when westerly winds are warmed as they move down slope. Most precipitation falls as rain during the

warmer part of the year and is usually heaviest in late spring or early summer. Winter snowfalls are frequent, but the snow cover usually disappears during mild periods (NRCS 1988).

Weather data used for the design of the cover system was collected from the National Atmospheric and Oceanic Administration (NOAA) weather station located at the Lewistown Airport and summarized at the National Climatic Data Center (NCDC). Precipitation data was summarized monthly 1959–1989; temperature data was summarized 1959–1986. Based on available data, the average annual precipitation is 17.98 inches (NOAA/NCDC), the average annual air temperature is 43 degrees F, and the average frost-free period is 120 days (NRCS 1988). The 25-year, 24-hour storm for the area is 3.0 inches (NOAA Atlas 2, Volume 1). The heaviest one-day rainfall for Fergus County during the period of record was 2.9 inches at Winifred, approximately 40 miles north of Lewistown (NRCS 1988). The average annual free water surface evaporation is 30 inches (NOAA 1982).

6.2.3.4 *Geology*

The Mr. “M” Landfill is located within Fergus County in the central portion of Montana. Fergus County has a wide range of topography that is characterized by rolling plains in the northern part of the county, the North and South Moccasin Mountains and the Judith Mountains in the central part, and the Big Snowy and Little Snowy Mountains in the southern part (NRCS 1988).

The Lewistown quadrangle is topographically dominated by the Judith Mountains and the Moccasin Mountains. These large Tertiary intrusive centers are cored by a variety of porphyritic rocks occurring in faulted domal structures in which Paleozoic and Mesozoic rocks are exposed. Smaller domes in the area expose Paleozoic and Mesozoic rocks and may be cored by intrusives at depth. A thick Cretaceous section forms the outer flanks of these domes and underlies the extensive Quaternary gravel deposits that cover a large portion of the map area (Porter 1991).

The Mr. “M” landfill is located at the contact of the Cretaceous Fall River Sandstone and the Cretaceous Kootenai Formation. The Kootenai is an interbedded mixture of shales, siltstones, and sandstones. Most of the developed facility is in the Kootenai. Because of the porosity of the Fall River Sandstone, a liner would have been required for units developed over the sandstone.

6.2.3.5 *Hydrology*

Groundwater is found beneath the facility in the interbedded sandstones at a depth of 17–104 feet. The primary source of drinking water is the Third Cat Creek Sandstone at the base of the Kootenai. This is about 150 feet deep at the landfill office. Groundwater flow is generally to the west, following the direction of local drainages.

6.2.3.6 *Surface Water Characteristics*

The facility is located on the south side of a westerly trending ridge and is about ½ mile from the nearest surface water, Boyd Creek.

6.2.3.7 *Biota*

The flora for the site was described in Section 2.3.2. Animal access to the facility is limited by a perimeter fence, and no grazing is allowed on site. Wildlife that can access the site include small rodents and birds. An occasional deer will leap over the fence; however, access to more open rangeland land is available, and the site is not particularly attractive to larger game animals.

6.2.4 Cover Goals

The closure design for the Mr. “M” Landfill is an alternative final cover that includes an infiltration layer designed to reduce infiltration to at least equivalent to the “standard” infiltration layer and an erosion layer designed to provide protection from wind and water erosion equivalent to the “standard” erosion layer. The proposed cap was designed to provide reduction in infiltration and erosion based on the “water balance” approach. The moisture contained within the cover will be removed via evaporation and transpiration.

Designing a landfill cover using the water balance approach has several advantages which include:

- Reduction of construction quality assurance and quality control (QA/QC) as compared to the “standard” cap design. The most intensive QA/QC work for a “standard” cap infiltration layer construction is monitoring in-place density and moisture content. Infiltration layer soils are typically placed at 95% of maximum dry density at or slightly above optimum moisture content to obtain the desired reduction in hydraulic conductivity. Using the water balance approach, the cap soils are placed at or near their natural density and moisture content to maximize the soil void space and facilitate plant growth.
- The water balance approach eliminates the need for a protective layer directly over the infiltration layer. In a “standard” cap design, a protective layer is required to reduce desiccation and frost effects on the infiltration layer, but not considered in establishing the performance standard for the infiltration layer. Using the water balance approach, desiccation and frost effects are eliminated because the soils are placed at or near their natural moisture and density. All soils placed above the intermediate cover are considered in evaluating the performance of the landfill cap.
- The water balance approach allows for both shallow- and deep-rooting plant species, while the “standard” cap design only allows for shallow-rooting plant species. This difference is important at the Mr. “M” Landfill site because yellow blossom sweet clover is a native legume that thrives in the area. With the “standard” cap design, the sweet clover would be removed from the area to protect the infiltration layer from the taproot, even though the nitrogen-fixing action of legumes is desirable. With the water balance approach, the taproot is beneficial because it will aid in removing moisture from the lower sections of the cap via transpiration.

6.2.4.1 Allowable Infiltration/Flux

As stated in state solid waste regulations, the performance standard for the infiltration layer of a closed landfill unit is a minimum of 18 inches of earthen material that has a permeability less than or equal to the permeability of any bottom liner, barrier layer, or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less. The Mr. "M" Landfill has no bottom liner or barrier layer; therefore, the permeability of the infiltration layer must be equal to or less than the permeability of the native subsoils. A conservative estimate for the in-place permeability of the native soils was determined to be 5.0×10^{-7} cm/sec. This estimate was used to establish the performance standard for the infiltration layer.

Leachate Management. Currently, no leachate collection activities are performed or necessary for the Mr. "M" Landfill.

6.2.4.2 Allowable Erosion

Erosion due to storm-water run-on and runoff during the construction and vegetation growth period (one year) and the postconstruction period was kept to a minimum. Prior to the construction of the cap, a surface water management system was constructed. Site run-on was controlled by a series of perimeter ditches and swales which diverted any run-on around the landfill site. A permanent erosion control slope break was constructed on the west-facing slope of the landfill and temporary dikes consisting of straw bales were placed every 50 feet along the flow line of the permanent slope break during construction and reseeding.

Maximum Slope Length and Angle. The final cover was contoured so that all surfaces have a minimum slope of 6%. The slope of any portion receiving final cover never exceed 33% (3:1).

Ecological Diversity and Density. This element was not specified in the design submitted for review as it not a design requirement under Montana solid waste regulations.

6.2.4.3 Cover Integrity

A seismic and slope stability analysis was not performed for the facility.

6.2.5 Design Basis Evaluation

6.2.5.1 Modeling

HELP Modeling. A 30-year weather simulation was generated from regional weather patterns, using the HELP model. The program used weather trends and patterns from Great Falls, Montana, since it is the nearest city recognized within the model database. To create a more realistic simulation, site-specific data were input for latitude, normal mean monthly air temperatures, normal mean monthly precipitation, and average wind speed. Site-specific weather data was based on information discussed in Sect. 6.2.3.3.

Laboratory tests were reviewed and on-site soils were identified per the U.S. Department of Agriculture soil classification system. Default soil parameters for the soil type were input into the model. Field measurements from the site investigation and design specifications corresponding to the modeled scenario were used to input the maximum leaf area index and evaporative zone depth. Initial soil moisture conditions were steady state values calculated by the HELP model.

A one-acre area have a minimum (settled) grade of 2% and maximum slope length of 220 feet was used for modeling. The 30-year annual surface infiltration (net flux) is given by:

$$\text{Net Flux} = \text{Annual Average Precipitation} - \text{Runoff} - \text{Evapotranspiration}$$

For the scenario modeled, the net flux was computed as 0.69 inches/year (2.0×10^{-4} cm/hour) at the interface between the soil and the waste. This value was used for the CHEMFLO modeling and comparison of alternatives.

CHEMFLO Modeling. Samples collected from on-site soils proposed as an alternative landfill cap material to the clay performance standard were analyzed for physical and hydraulic properties. These laboratory results were utilized in a numerical modeling study to determine the thickness of soil cap that is equivalent to an 18-inch clay cap having a performance standard hydraulic conductivity of 5.0×10^{-7} cm/sec. The equivalent thickness of the soil was evaluated based on water movement into a landfill cap. That is, for a given thickness of a clay cover, modeling was conducted to determine the equivalent thickness of the on-site soil having the same water content as clay.

Modeling was performed with the EPA-approved CHEMFLO computer code and was used in this analysis. CHEMFLO models one-dimensional vertical flow in unsaturated soils and requires input data from laboratory analyses and infiltration rate data computed using the HELP model. CHEMFLO simulations were conducted assuming vertical flow in a finite soil column with a constant surface infiltration boundary condition with an initial moisture content of 9.5%. Soil moisture characteristics computed from laboratory data were fit to the van Genuchten/Mualem analytical equation that relates the water content and hydraulic conductivity to the matrix potential. In the modeling simulations, it was assumed that the moisture characteristics of the on-site soil were the same as the clay moisture characteristics. Also, three hydraulic conductivities were utilized in the CHEMFLO runs: 5.0×10^{-7} cm/sec (clay), 1.7×10^{-6} cm/sec, (geometric mean for the on-site soil K_{sat}), and 4.6×10^{-6} cm/sec (arithmetic mean for the on-site soil K_{sat}).

6.2.5.2 Test Plots

No test plots were constructed and evaluated prior to the construction of the alternative cap.

6.2.5.3 Evaluation

Results from the CHEMFLO modeling provided an equivalent clay cap thickness factor of 1.13–1.31 for the on-site soil, which corresponds to 20.3–23.6 inches of on-site soil performing the same as an 18-inch clay cap with a 5.0×10^{-7} cm/sec hydraulic conductivity. Sensitivity analyses

were conducted and revealed that CHEMFLO results are reasonable with the most sensitive input parameter to the water movement being infiltration rate. However, in CHEMFLO simulations with an increased infiltration rate, the equivalent clay cap thickness factor for the on-site soil decreased.

6.3 Design/Construction/ Construction Monitoring

6.3.1 Design

6.3.1.1 Criteria

Based on the computer modeling, a 24-inch-thick on-site soil final cover was found to be equivalent to the performance standard of 18 inches of clay with a hydraulic conductivity of 5.0×10^{-7} . As an added safety factor, the design engineer proposed to place a final cover of 36 inches minimum of soil as an alternative cover to the prescribed standard cover.

6.3.1.2 Specifications

The alternative final cover design chosen for the site consisted of the following layers from bottom to top:

- On the side slopes (3:1 maximum slope):
 - Intermediate cover: 8–24 inches of fill material
 - Final cover: 30-inch moisture-retention layer (permeability = 5.0×10^{-7} cm/sec) and 6 inches of top soil
- On the top slopes (6% minimum grade)
 - Intermediate cover: 14–22 inches of fill material; capillary break (1 inches of ½ - minus poorly graded, rounded, washed gravel); geotextile (8 oz/yd² nonwoven geotextile fabric)
 - Final cover: 30-inch moisture-retention layer (permeability = 5.0×10^{-7} cm/sec) and 6 inches of top soil

6.3.1.3 Regulatory Barriers

To gain approval to construct the alternative cover at the Mr. “M” Landfill, the facility owner demonstrated that the selected cover design would perform similarly to the prescribed Subtitle “D” cap. With limited time allowed for the completion of the cover, extensive modeling had to be done to gain approval from the Solid Waste Program.

6.3.2 Construction

The alternative final cover at the Mr. “M” Landfill was constructed during the fall of 1999 and seeding completed in the spring of 2000.

6.3.2.1 *Criteria*

The final cover construction criteria were based on the design criteria outlined in Sect. 6.3.1.1. State solid waste regulations require that detailed preconstruction engineering drawings and a construction quality control and quality assurance plan be approved by the department prior to the commencement of construction.

6.3.2.2 *Specifications*

Based on the design specifications in Sect. 6.3.1.2, intermediate cover consisting of fill material was placed 14–22 inches thick over the waste areas to prepare an even subgrade for the capillary and moisture-retention layers.

A passive landfill gas venting system was constructed along the northern border of the landfill. The gas venting system consists of a series of perforated pipes placed in trenches that breach the in-place intermediate cover. The trenches were filled with a poorly graded gravel to provide a highly conductive media. The western portion of the landfill gas venting system was covered by the capillary break material. The area along the northern boarder of the landfill was covered with a minimum of 12 inches of poorly-graded gravel which will act as a capillary break.

The moisture-retention layer was placed in 6-inch lifts and wheel-rolled with a compactor to achieve the desired compaction. The moisture-retention layer was placed to a minimum depth of 30 inches and a compaction of approximately 118 pounds per cubic foot achieved. Depth of the moisture-retention layer was measured normal to the slope, and bulk density samples were taken to verify that the desired compaction was achieved.

All areas receiving the moisture-retention layer also received a minimum 6 inches of topsoil. The topsoil was a mixture of on-site soils and 10% by volume agricultural wastes. The agricultural wastes consisted of a mixture of sawdust, manure, and straw generated at the Fergus County Fairgrounds.

All areas receiving final cover, disturbed during construction activities, or not containing a mature stand of vegetation were seeded. All seeded areas received temporary erosion control as described in Sect. 6.2.4.2. The seed mixture applied to the site did not contain native legumes because the site was inhabited by noxious weeds such as spotted knapweed. The Natural Resources Conservation Service (NRCS) recommended that the site be seeded with a grass mixture for the first few years of postclosure. During this time period, the site will be sprayed to remove the noxious weeds. When the weeds are under control, the site will be seeded with natural legumes, such as yellow blossom sweet clover.

Fertilizer was broadcast over all areas that were seeded. Fertilizer shall be applied the following rates: nitrogen 40 pounds/acre, phosphorus (P_2O_5) 40 pounds/acre, potassium (K_2O) 60 pounds/acre.

6.3.2.3 *Monitoring QA/QC*

All construction activities were subject to inspections by the design engineer. Inspections of the construction work included, but were not limited to, the following:

- measuring grades and inspection of base preparation;
- placing grade stakes over areas that received cover soil;
- measuring thickness and placement methods for individual earth material layers, with increased frequency for the moisture-retention layer;
- field classification of earth materials used for the individual cover layers;
- inspection of layout and construction of the capillary break;
- inspection of layout and construction of the passive gas venting system; and
- inspection of erosion control devices.

The engineer made routine site inspections on a weekly basis. During inspections, the engineer kept detailed notes of all construction and inspection activities. All notes taken during the inspections were included in the final construction quality assurance report were submitted to the department.

Quality assurance testing for the moisture-retention layer soils included field classification and limited laboratory classification. The moisture-retention layer soils were field classified by the design engineer while measuring the depth of the moisture-retention layer soils. Any area within the moisture-retention layer that was found to have the wrong soil type or deleterious substances (i.e., rocks, large clods of clay, trash, etc.) was marked and repaired appropriately.

During the construction activities, a minimum of four samples were taken of the moisture-retention layer and analyzed for particle size distribution. Additional samples were taken and analyzed as necessary when a material change was noted based either on field observations or laboratory results.

All other soil types listed in the construction specifications were visually classified.

At the conclusion of closure construction activities, the design engineer submitted a construction quality assurance report to department.

6.4 Operation

6.4.1 Flux Monitoring

This final cover for the Mr. "M" Landfill was not designed or built with instrumentation to determine flux through the cap.

6.4.2 Leachate Management

N/A

6.4.2.1 Quantity Characterization

N/A

6.4.3 Cover Integrity Monitoring

As required in the postclosure care plan for the facility, the integrity of the alternative cover will be monitored and an annual report of postclosure activities submitted to the department. Careful attention will be given to vegetation growth and any erosion of the cap, and any damage repaired immediately. Settled areas of cover must also be repaired and brought back to grade.

6.4.3.1 Allowable Movement

N/A

6.4.3.2 Erosion

See Sects. 6.2.4.2 and 6.4.3 for the discussions on erosion controls at the facility.

6.4.3.3 Corrective Action/Forensic Study

As stated in Sect. 6.4.3, the final cover will be inspected for damage or failure. As part of the postclosure requirements, corrective actions will be under taken immediately to repair the damage. The owner operator must also determine the cause of the damage or failure of the cover and submit a mitigation plan to the department for review and approval.

6.5 Postconstruction/Operation Evaluation

6.5.1 Design Selection Process Evaluation

The design engineer may choose to evaluate the selection process for use in the future design and construction of alternative caps. The state solid waste regulation does not require this type of evaluation, and the owner has no interest or funds to perform the evaluation.

6.5.2 Goals Evaluation

The goals established by the owner and the design engineer and outlined above in Sect. 6.2.4 were all met. The only negative aspect was the lengthy time period (three months) that it took to complete the construction due to the owner's doing all of the construction activities with his own equipment and minimal labor instead of hiring a third-party construction firm as recommended by the design engineer. Some of the cost savings estimated by choosing the alternative cap design to close the facility were negated by losses incurred from delays in completing construction.

6.5.3 Criteria Evaluation

The success of the alternative cover design at the facility will be determined by the groundwater monitoring system currently in place. The design engineer may choose to evaluate the methodology used in the selection of the final infiltration criteria for the alternative cover at the Mr. "M" Landfill if there is groundwater contamination and gas migration at the site in the future.

6.5.4 Specifications Evaluation

In the short term, the specifications for the alternative cover designed for the facility appear successful. The cap was constructed with relative ease by the owner, and the construction quality report submitted to the department indicated that all the specifications were met. The long-term performance of the cap (i.e., preventing groundwater contamination and gas migration) will determine whether the specifications selected were adequate.

6.5.5 Comparison to Design Goals

Refer to Sect. 6.5.2.

6.5.6 Cost Savings

A cost comparison between the alternative cover design and the prescribed Subtitle "D" cover was not made by the design engineer. It was decided that the alternative cover design would be more cost-effective, as all of the cover material was located on site or within the local area and the construction would be done by the owner using his own equipment and labor.

6.5.7 Ability to Overcome Regulatory Barriers

The alternative cover design and construction was completed with little or no regulatory barrier. The department cooperated with the owner and the design engineer and accepted the design criteria based on the parameters determined by the modeling conducted using on-site soils.

6.6 References

Final Closure for the Mister M Landfill, Lewistown, Montana, September 1998, prepared by Ray Schwaller, P.E. and Gary Jones, Portage Environmental, Inc., 2024 9th Ave., Helena, MT 59601.

"Mister M Landfill Closure Summary and Certification," January 2000, letter report prepared by Gary Jones, E.I., Portage Environmental, Inc., 2024 9th Ave. Helena, MT 59601.

7. EVAPOTRANSPIRATION LANDFILL COVERS: DEFINITION AND CONCEPT VERIFICATION

Prepared by Victor L. Hauser, Ph.D., P.E.⁹

Conventional landfill covers rely on barriers to control movement of precipitation into landfills; in effect, the barriers oppose natural forces. Evapotranspiration (ET) covers are a new alternative landfill cover designed to work with the forces of nature rather than against them; they stop water movement without conventional barrier layers. ET landfill covers are unique because they use technology that has rarely been used to design waste covers even though the concepts are well known and proven. This discussion identifies papers containing proof of the concept and references to the extensive, pertinent literature. Comprehensive understanding of the concept requires study of the papers referenced.

A primary function of all modern landfill covers is to control the amount of precipitation moving through the cover and into the waste stored below the cover. The ET cover must meet this requirement, as well as all other landfill cover requirements.

7.1 Definition

ET landfill covers employ a layer of soil covered by native grasses. Water that infiltrates through the surface is held in the soil layer by capillary forces until the plant cover removes the water. The soil provides a water reservoir to temporarily store water, and the plants empty the reservoir by their natural “pumping” action. An ET landfill cover must be able to hold the largest amount of water produced by a critical-event storm (Hauser et al., 2001). Four essential requirements must be met:

- soil with adequate plant-available water-holding capacity,
- adequate soil thickness to store the water derived from a “critical-event” storm,
- low soil density to permit adequate root growth (less than 94 pounds/ft³ [1.5 g/cm³]), and
- robust, healthy plant cover.

ET covers are vegetated; however, they are different from and should not be confused with “vegetated” landfill covers that fail to meet essential requirements. Any of the following factors may cause a vegetated cover to fail: (a) inadequate soil depth, (b) reduction of soil water-holding capacity by soil compaction, or (c) poor root growth resulting from soil compaction and the associated high soil strength (Hauser et al., 2001). Many vegetated landfill covers lack one or more essential properties of an ET cover; they are subject to failure as a landfill cover.

⁹ Principal Engineer, Mitretek Systems, 13526 George Road, San Antonio, TX 78230. Note: This paper was prepared at the request of and with the support of the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT), Brooks AFB, Texas.

7.2 Concept Verification

From near the 96th meridian (Tulsa and Omaha) and continuing west to the Rocky Mountains, water supply limits plant production from one of the largest bodies of fertile soil in the world. While water limits plant growth in the Great Plains, years of high rainfall (e.g., greater than 40 inches at Amarillo) are common. These facts prompted hydrologic studies summarized by Hauser et al. (2001). Beginning in 1907 and continuing to modern times, scientists, engineers, and hydrologists studied the movement and availability of soil water for plant production in the Great Plains. This body of knowledge—combined with principles of soil physics and results of other concurrent studies—provides proof of the ET landfill cover concept (Hauser et al., 2001).

The water-balance studies of the past century demonstrated that plants and soil control the downward movement of water. Technology developed concurrently revealed the mechanisms that control water movement in soil. Hauser and Shaw (1994) first defined the principles of the ET cover in 1994. The following references contain discussions of the concept and its verification and, in turn, reference the large body of literature providing proof of concept.

7.3 References with Abstracts

Hauser, V. L. and M. A. Shaw. 1994. "Climate effects on water movement through soil vegetative landfill covers." *Proc. 17th International Madison Waste Conference*, Sept. 21–22, Dep. Engr. Professional Development, Univ. of Wisconsin, Madison, Wisc.

This paper defined the ET landfill cover concept. The ET cover contains no "impermeable" materials, but it requires adequate soil water-holding capacity to store precipitation until ET can remove the water from storage. The paper discussed the effectiveness of the ET cover for much of the United States.

Hauser, V. L., B. L. Weand, and M. D. Gill. 2001. "Natural covers for landfills and buried waste." *Am. Soc. Civil Engineers, J. Environ. Engineering* 127(9) 768–75.

Nearly all currently used landfill covers (caps) employ barrier-type systems to stop the downward flow of water in soil. The ET landfill cover does not use barriers. It consists of a layer of soil covered by native grasses to control infiltrating precipitation: the soil stores infiltrating water, and natural ET empties the soil's water reservoir. The ET landfill cover concept has been extensively verified by field studies. Where applicable, ET landfill covers meet the requirements for landfill covers for decades or centuries; in addition, construction and maintenance costs are low. The paper discusses conventional covers; vegetated covers; long- and short-term proof of the ET landfill cover concept; reasons for failure of vegetative covers; and the design, application, and benefits of an ET landfill cover.

The following technical reports and papers were prepared with the support of the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT), Brooks AFB, Tex. Most of them are available from AFCEE/ERT at (210) 536-4331, or <http://www.afcee.brooks.af.mil/er/ert/landfill.htm>:

Weand, B. L., J. D. Horin, V. L. Hauser, D. M. Gimon, M. D. Gill, M. Mehata, and D. J. Casagrande. 1999. *Landfill covers for use at Air Force installations*. 92 pp.

This paper describes the technology of landfill cover options that are available for use by the Air Force. It includes discussion of regulations, technology, design, performance of various covers, as well as eight appendices that provide pertinent regulations, information sources and an extensive bibliography.

Hauser, V. L., D. M. Gimon, D. E. Hadden, and B. L. Weand. 1999. *Survey of Air Force landfills, their characteristics, and remediation strategies*. 45 pp.

This paper contains a survey of 40% of Air Force landfills and discusses their properties and relevant remediation strategies.

Boyer, I., V. Hauser, D. Gimon, and M. Gill. 1999. *Decision tool for landfill remediation*. 42 pp.

This document contains a summary of federal regulations regarding landfill covers and 15 decision tree diagrams designed to assist the landfill manager in determining the most appropriate method for landfill remediation. It is sufficiently general to be of use to any landfill owner. An important feature is the explanation of options presented in the decision trees to assist the user with correct interpretation of landfill cover regulations and selection of appropriate landfill covers.

Gill, M. D., V. L. Hauser, J. D. Horin, B. L. Weand, and D. J. Casagrande. 1999. *Landfill remediation project manager's handbook*. 147 pp.

While the intended audience for this paper was Air Force landfill remediation managers, it is equally useful to other landfill managers. It provides information regarding landfill cover options and their use.

Hauser, V. L., D. M. Gimon, and D. R. Jackson. 2000. *Golf courses on Air Force landfills*. 14 pp.

Landfill reuse should be a part of landfill cover planning. This paper discusses the possible effects of golf courses placed on top of landfill covers. It is useful to any landfill manager considering reuse options for landfill surfaces.

Hauser, V. L. and D. M. Gimon. 2001. *Vegetated landfill covers and phytostabilization—The potential for Evapotranspiration-based remediation at Air Force bases*. 26 pp (also includes 109 base-specific sheets).

Landfill managers need a quantitative method to make an initial evaluation of the potential usefulness of an ET cover at a site. This paper provides estimates of potential effectiveness of ET landfill covers at 109 Air Force sites within the continental United States. It covers the nation and can provide general guidance to any landfill manager.

Hauser, V. L., B. L. Weand, and M. D. Gill. (2001). *Alternative Landfill Covers*. Interstate Technology Regulatory Council (ITRC), Alternative Landfill Covers Summit, Sept. 2001, Austin, Tex.

This is a white paper prepared at the request of the ITRC to present the benefits and opportunities—as well as the potential problems—associated with the use of alternative vegetated landfill covers. It provided a common point of departure for a one-day discussion of alternative landfill covers, including differing views of the technology and its application. It is not intended to be an exhaustive review of alternative landfill covers. It contains discussion of landfill cover requirements and characteristics, technology, regulatory limitations, innovative covers—what we know and what we do not know, plant requirements, soil strength, physics of soil water, vegetated cover failure, ET cover definition, concept verification, the critical design event, safety factor, and area of application for the concept.

7.4 Additional References

Hauser, V. L. and B. L. Weand. 1994. “Effectiveness of soil-vegetative covers for waste sites.” *Proc. Superfund XV*, Nov. 29–Dec. 1.

Hauser, V. L., M. A. Shaw, and B. L. Weand. 1995. “A natural cover for buried waste.” *Proc. Am. Defense Preparedness Association*, San Diego, Calif.

Hauser, V. L., B. L. Weand, M. A. Shaw, and A. R. Wusterbarth. 1996. “Natural covers for landfills—A closer look.” *Proc. Am. Defense Preparedness Association*, Orlando, Fla.

Weand, B. L. and V. L. Hauser. 1997. “The evapotranspiration cover.” *Environmental Protection*, Nov.: 40–42.

Hauser, V. L. and B. L. Weand. 1998. “Natural landfill covers.” *Proc. Third Tri-Service Environmental Technology Workshop*, San Diego, Calif.

Hauser, V. L. 1998. “Evapotranspiration (ET) landfill covers.” Presentation to U.S. EPA Technical Support Project Meeting, Nov. 1998, San Antonio, Tex.

8. DEVELOPING AND DEMONSTRATING A PERFORMANCE-BASED APPROACH TO POSTCLOSURE CARE

REFORMING THE 30-YEAR TIME-BASED SYSTEM OF RCRA SUBTITLE D

8.1 Introduction

Waste Management (WM) has developed a conceptual approach to evaluate postclosure care monitoring and maintenance data for landfills to determine when some or all of the major elements of postclosure care are complete. This approach was originally intended to be applicable to Subtitle D–regulated solid waste landfills but could apply to any type of landfill or contaminant source. There are similar questions for determining when corrective action under RCRA is completed (see EPA’s “Final Guidance on Completion of Corrective Action Activities at RCRA Facilities,” currently available via the Internet at http://www.epa.gov/epaoswer/hazwaste/ca/resource/guidance/gen_ca/compfedr.pdf). When existing corrective action methods cannot meet agreed-to standards, then a risk assessment and/or monitored natural attenuation can be considered as demonstrating that there are no further risks to human health and the environment. There are similarities to both approaches.

Waste Management is cofunding a research project with the Environmental Research and Education Foundation (EREF) of the Environmental Industry Association (EIA) to evaluate the use of this model on several different landfills. WM also is cofunding a leachate study to review the long-term affects of age and degradation of waste under different landfill cover and cap designs, climates, liners, waste characteristics, and different operations of landfills.

There are three major goals of this white paper:

- develop a detailed and regulatory-consistent approach to ending postclosure care (PCC) at municipal solid waste (MSW) landfills,
- apply the approach to several real-world landfills for testing and further refinement, and
- make significant progress toward consensus for the approach among major stakeholders.

A key benefit of the approach to the environmental industry will be the ability to accurately focus existing PCC funds on those elements that are most critical to protection of human health and the environment. WM has built a significant level of consensus among key regulatory, research, and industry groups that have identified this subject as a focus of their ongoing efforts. These organizations include the following:

- the United States Environmental Protection Agency, Office of Solid Waste (USEPA–OSW),
- the Applied Research Foundation (ARF) of the Solid Waste Association of North America (SWANA),
- the University of Central Florida (Dr. Debra Reinhart),
- North Carolina State University (NCSU, Dr. Mort Barlaz),
- Interstate Technology and Regulatory Council (ITRC),
- the National Solid Waste Management Association (NSWMA), and
- Waste Management, Inc. (WM).

The conceptual approach described in this paper has been presented to each of these groups, and the approach has received nearly universal support. To our knowledge, the concept is the first comprehensive attempt to address the issue of the duration of PCC at MSW landfills. As shown in this white paper, the approach is completely consistent with applicable federal regulations and their intent (i.e., using risk-based evaluations in a modular, straightforward method to produce a performance-based approach to protecting the environment). This performance-based approach will address the risks associated with source media (e.g. leachate, landfill gas, groundwater, and surface water), specific pathways, and receptors to ensure protection of the environment.

8.2 Relevance and Timeliness

Defining the end of PCC is currently of high interest to the solid waste community and, to be effective, must be resolved in the near future. Currently, no clear direction is provided in federal regulation or guidance on managing the end of PCC. The following background is provided to demonstrate the relevance of this topic.

- Subtitle D, which was promulgated on October 9, 1991 (Title 40 of the Code of Federal Regulations, Parts 257 and 258), imposes a 30-year PCC period on all MSW landfills and allows the director of an approved state program to lengthen or shorten the period based on risks to human health and the environment.
- The preamble to the rule (FR Vol. 56, No. 196, 50978) indicates that the prescribed period was not based on evidence that MSW landfills pose a significant risk to human health or the environment after closure.
- It is clear, based on data and experience accumulated since Subtitle D was promulgated, that the potential threat of each landfill site on the environment is extremely variable and dependent upon climate, location, operational practices, design, etc. PCC periods should therefore vary from site to site and should be performance based.
- The duration of PCC is currently one of three strategic priorities for the USEPA, as described in its document entitled *Draft Strategy for Updating the Federal Criteria for Municipal Solid Waste Landfills* (July 2001).
- The end of PCC was a topic at the recent Association of State and Territorial Solid Waste Management Officials (ASTSWMO) meeting, July 23–25, 2001. The current general position of state regulators, as described at that meeting, is that without clear direction PCC should continue indefinitely, essentially transforming the 30-year postclosure period into a *perpetual care* program.
- The topic was presented in a plenary session on February 27, 2002 at the WasteTech Landfill Conference in Coral Springs, Florida.
- During a keynote address at the WasteTech 2002 conference, the approach presented in this proposal was specifically called out and supported by the acting head of the USEPA Office of Solid Waste (Thea McManus).
- Innovative and complementary research is currently being conducted at North Carolina State University, Florida State University, University of Central Florida, SWANA, and others.

It is vital to address this subject now for the following reasons:

- Postclosure funding mechanisms currently in place (i.e., 30 years) do not consider the potential for longer-term postclosure periods.
- Effective fiscal management of existing PCC funds is therefore critical for proper protection of the environment and the financial health of landfill owners. This process will help prevent unfunded postclosure periods that extend beyond 30 years.
- Early evaluation of actual PCC needs helps identify effective operating practices at an active landfill that could reduce the potential threat of landfills on the environment during PCC.
- A large number of pre-Subtitle D landfills are approaching or have passed the end of shorter stipulated PCC periods.

Further, it is important to understand the long-term maintenance implications of sites with a flexible membrane liner and final cap which minimize infiltration to protect groundwater.

8.3 Modules of Postclosure Care

The conceptual approach for defining the end of postclosure care PCC is illustrated on Fig. 8-1 and is described in more detail on Figs. 8-2 through 8-5. As indicated in Fig. 8-1, it is recommended that the end of PCC be established based on an evaluation of compliance within end-of-postclosure-care (EOPCC) standards for the four PCC components of 40 CFR Part 258.61(a) (i.e., leachate collection, landfill gas, cover or final cap, and groundwater monitoring systems, which are referred to as “modules” in Figs. 8-2 through 8-5). The evaluation would be performed in these four modules, one for each of the required components of PCC. The EOPCC module standards will be based on both prescriptive regulatory standards (i.e., design or operating standards, such as designing and maintaining leachate collection systems to have <1 foot of head of leachate on the liner) and site-specific performance criteria (e.g., risk of future contamination of groundwater from a stabilized leachate). The specific steps for evaluating compliance with the EOPCC standard are illustrated on Figs. 8-2 through 8-5. As shown in the figures, the process is site specific and allows a modular application of the approach to each major function (as defined by Subtitle D) of the closed landfill. Each module will identify the media/source-specific risk-based criteria or standards.

If a facility met the EOPCC standard for a given module then the PCC period for that module would enter “Surveillance” monitoring. Fig. 8-1 shows surveillance monitoring requirements would be site specific, correlated to the potential for future environmental impact. For example, a facility where leachate management is no longer needed may direct available PCC funds to longer-term cap and/or gas system maintenance and monitoring, thereby increasing the efficiency of PCC activities without presenting an additional threat to human health and the environment. More efficient utilization of postclosure costs will ensure that any longer-term needs are provided for with available funds. This approach also could provide the owner/operator and regulatory agencies with a roadmap on how to best manage the PCC period from a financial and an environmental protection perspective.

There are many site-specific variables that need to be considered in evaluating data for the end of PCC for each module. These variables may include the following, at a minimum:

- gas generation and quality;

- subsurface gas migration;
- air quality considerations (not required in Subtitle D);
- potential gas impacts to groundwater;
- odor control (not required in Subtitle D);
- cover system integrity;
- geotechnical considerations (i.e., settlement);
- breakouts and seeps;
- liner leakage rates;
- liner stability;
- rainfall/infiltration rates;
- leachate quality and generation with time, climate, and operational practice;
- groundwater monitoring and standards;
- groundwater fate and transport;
- contaminant attenuation and standards; and
- risk assessment best practices.

One method to use in evaluating the data for each module are statistical procedures for evaluating trends and parameter-specific behavior in existing data and using the trends to predict the potential for future impacts to the environment from the landfill. It is well known that MSW degrades with time and that leachate and gas data may follow first-order decay models as shown in Fig. 8-6. However, from a statistical perspective, the analysis of postclosure data is complex and involves levels of uncertainty for at least three reasons. First, the true concentration of a sample at a given sampling location and a given point in time is needed, not simply the measured concentration (which is an estimate of the true concentration). To find the true concentration from the measured concentrations, statistical methods must be applied. Second, the analysis must allow comparisons to regulatory standards and/or background; because these comparisons require different statistical methods, the EOPCC evaluation must incorporate a broad range of statistical comparisons. The third and most unique complication is that standards must be compared to predicted future concentrations to allow an evaluation of potential future risk (see Fig. 8-7). To perform this comparison, a regression analysis approach is needed that can predict, for example, the 95% upper confidence interval for the predicted mean concentration at a specific future date. This analysis approach has not yet been developed. Because the ability to predict potential future risk is such a fundamental component of the EOPCC approach, the proposed scope of work includes development of original statistical research on this subject. In addition to these complications, the EOPCC approach must consider complications related to the statistical identification of trends (both increasing and decreasing), the treatment of nondetects, tests of distributional form, and outlier detection. Many of these topics are covered in the texts of Gibbons' *Statistical Methods for Groundwater Monitoring* (Wiley, 1994) and Gibbons and Coleman's *Statistical Methods for Detection and Quantification of Environmental Contamination* (Wiley, 2001). Based on studies that WM is now implementing, new statistical methodologies will be used for analyzing data for the project.

8.4 Two Case Studies for Leachate Module

8.4.1 Case Study I

This site is a closed landfill opened in the early '70s in the northeast region of the United States. Most of the waste is municipal and light industrial refuse. The site is located within a glaciated lowland and was excavated into the side of a slope and ravine down to unweathered glacial tills of dark gray silt and clay. There is a saturated unweathered till with a hydraulic conductivity of 1×10^{-6} cm/sec. The overlying weathered till is the top of the unconfined water table, and this unit has a hydraulic conductivity of 1×10^{-5} cm/sec.

Closed in 1992, the landfill is within a 28-acre area with a maximum depth of refuse of about 150 feet. A slurry wall was installed just downgradient of the landfill with a collection trench to control seeps from the downgradient side slope of the landfill. About 2600 gallons/day of leachate are collected. The result of groundwater flowing through the bottom of the landfill on top of the unweathered till created a mound of leachate inside the landfill, enhancing the moisture in the landfill and continuing in spite of the 4 feet of recompacted clay (1×10^{-7} cm/sec) cap with topsoil and grass. Fig. 8-8 shows the landfill cells and Figs. 8-9 through 8-17 show the leachate quality over time. Figs. 8-9 and 8-10 show (on log scale) the biological oxygen demand (BOD) and chemical oxygen demand (COD), which increased and then dramatically declined over time. When the downward trends approach the x axis, the ratio of BOD/COD is <0.1 , considered to represent a “stable” leachate in which organic concentrations will not change. Coincident with this degradation of general organic indicators in the leachate, the hazardous metals and VOCs (Figs. 8-11 through 8-17) also showed a “treatment” effect, where they increase at first and then are present below drinking water standards when the organic indicators are stable (see Fig. 8-18, “Conclusions”).

There is no groundwater contamination at downgradient wells. The nearest receptor is a large river, and—since the source (leachate) should pass a risk assessment—it is logical to assume that the leachate would not have to be managed, but could be released into the groundwater. If pumping of the trench were to stop, the leachate would mix with groundwater and move around the ends of the slurry wall. The downgradient well could be monitored to ensure the risk model is working for a few years, and then the groundwater module could be discontinued as well. If the state requires additional parameters to be sampled in the leachate and some constituents are found to be above state standards, then a dilution attenuation factor (DAF) model could be run. This model is used in Subtitle D for evaluation of alternative liners. The model assumes a 3- × 3-foot hole in the liner, but in this case we would assume no liner or slurry wall. If a well is located 500 feet downgradient (which in this case is the river) and if drinking water or receiving water standards are violated, then the risk assessment would continue.

8.4.2 Case Study II

This site was selected to study leachate quality from sumps that collected leachate from the oldest to newest portions of the landfill. As shown on Fig. 8-19, each sump collects leachate only from individual areas of the landfill. Since no historical leachate data are available beyond a few years, the known age of waste in each cell was used to evaluate the data on a time-based basis.

Cell 1, Phase 1 contained waste disposed of '85-'89 and had a PVC liner. The landfill is located in the Midwest on dune sand deposits. Sand was used as daily cover and side slopes, and consequently the site generated large quantities of leachate. Cell 1, Phase 2 was operated '89-'92, and at the end of '92, the entire cell was capped with a GCL/HDPE with topsoil and grass. A gas collection system is actively operated in Cell 1. Cell 2 was built on a Subtitle D liner, received waste '92-'98, and has a cap with sand and grass. Leachate recirculation on the working face was practiced. Cell 3 is active on a Subtitle D liner with no final cap on top or side slopes. The site receives about 500-700 tons per day and generates about 30,000 gallons of leachate per day from the entire landfill. Cell 3 actively recirculates leachate on the working face. In spite of recirculation, the site, especially during wet seasons, has to truck leachate off site to a POTW as there is not enough incoming waste to absorb all of the leachate associated with rainfall infiltration.

The leachate data vs. age of MSW are shown in Figs. 8-20 to 8-23. Instead of historical data from individual sumps, data are displayed from newest MSW to oldest and show trends similar to historical data in that degradation of organics (BOD/COD) shows behavior similar to leachate quality over time. It appears that after 9-12 years, the leachate is trending to an asymptote where BOD/COD ratios are <0.1 . The metals and VOCs all meet drinking water standards (see Fig. 8-24, "Conclusions"). Since the site is located in a thick vadose zone over a very permeable aquifer, a discharge to spray fields or leach fields should pose no risk to the environment since the hazardous constituents in leachate are below MCLs, especially in Cell 1. For this active site, an option exists from following the flow chart that part of the closed units does not need to manage leachate from Cell 1 because the leachate would meet the state-based risk criteria for alternative discharge options. In this case, the low volume of waste receipts and the permeable daily cover may have degraded the waste sufficiently in the seven years it was open to precipitation and the geomembrane cap served only to reduce the quantity of leachate that needs to be collected. Cell 1 produces only 5000-7000 gallons/day and would be manageable with alternative on-site methods.

8.5 Summary

The conceptual model or flow diagram presented in this white paper is an evolving document and will be modified as the studies and research cofunded by WM and EREF move forward. The process would enable the owner/operator to identify early in the life of the landfill the operational practices that can best mitigate environmental risk (such as additional infiltration, or low-flux covers). The process would also identify and allow consideration for certain practices at closed sites (e.g., leachate recirculation) that may help reduce long-term risk to the environment.

EPA will be invited to review data at certain periods, and SWANA's Applied Research Foundation may also contribute sites for the studies. It is also hoped that ITRC members participate with site data or propose sites (open or closed) where this conceptual model can be applied. For WM's closed sites, portions of this model already have been used for establishing that modules like leachate management and groundwater remediation and/or monitoring can be modified or eliminated.

8.6 Figures:

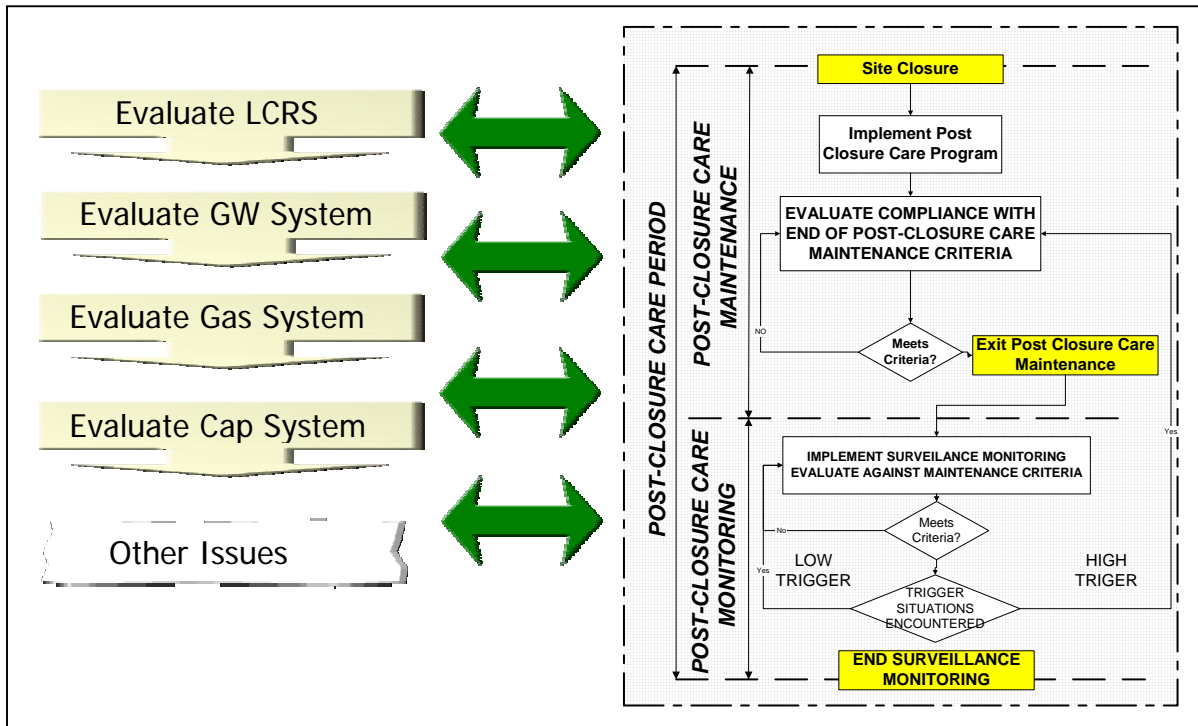


Figure 8-1. Postclosure care logic diagram.

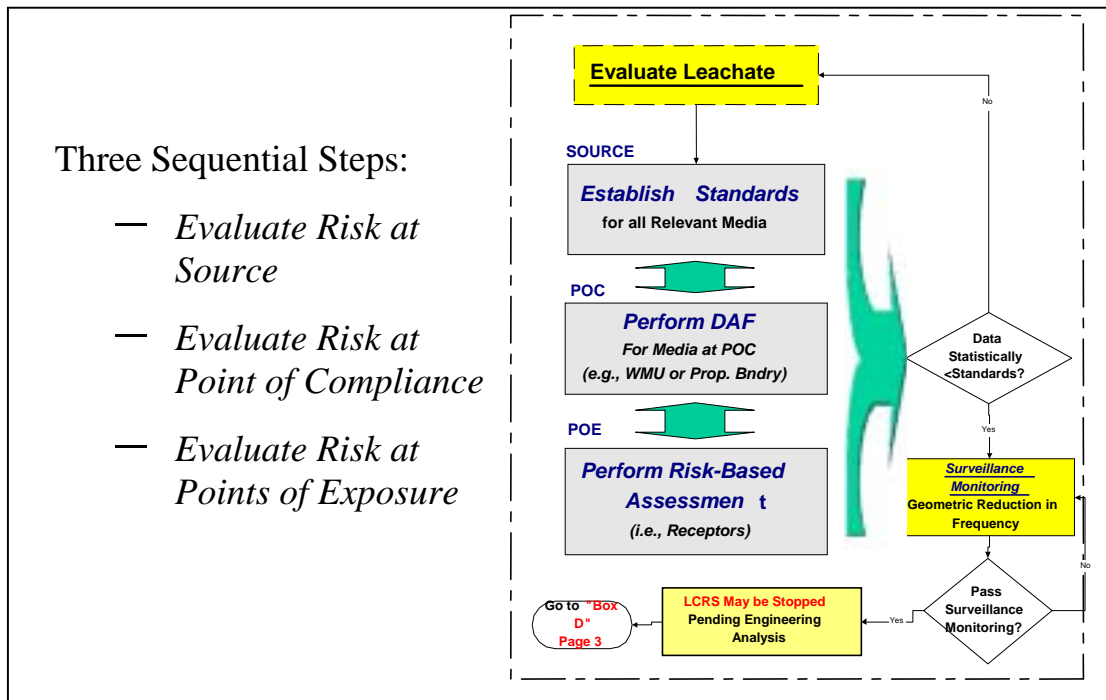


Figure 8-2. Leachate collection and recovery system logic diagram.

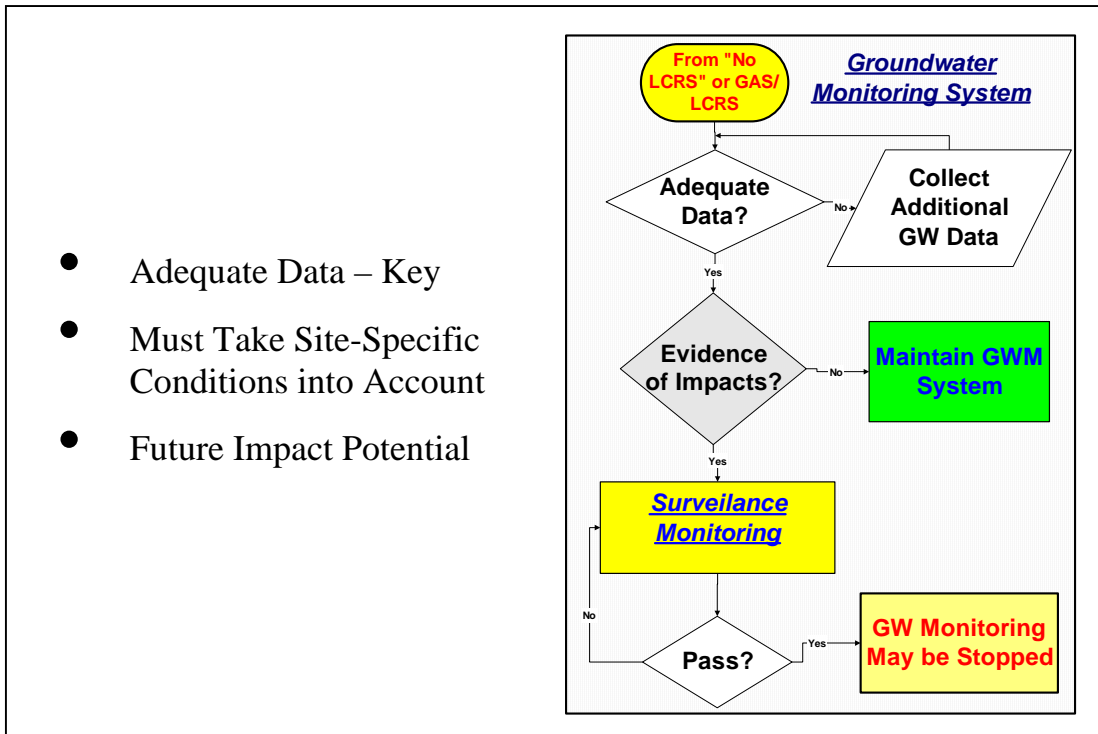


Figure 8-3. Groundwater monitoring logic diagram.

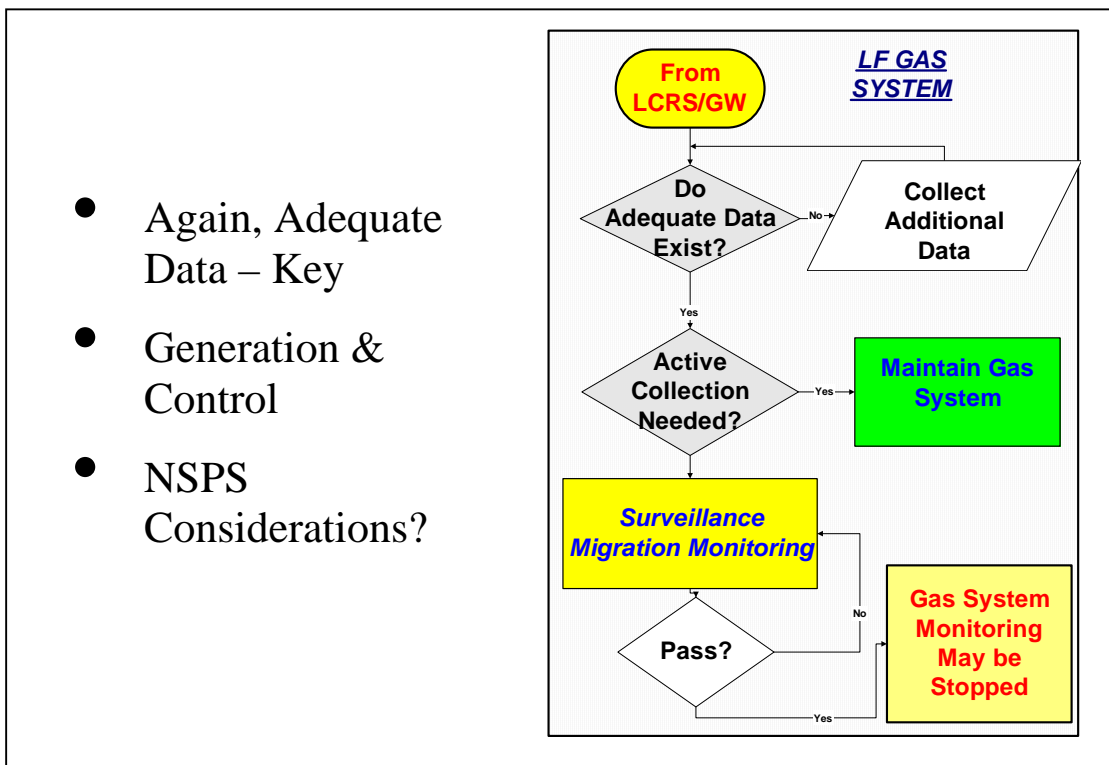


Figure 8-4. Landfill gas logic diagram.

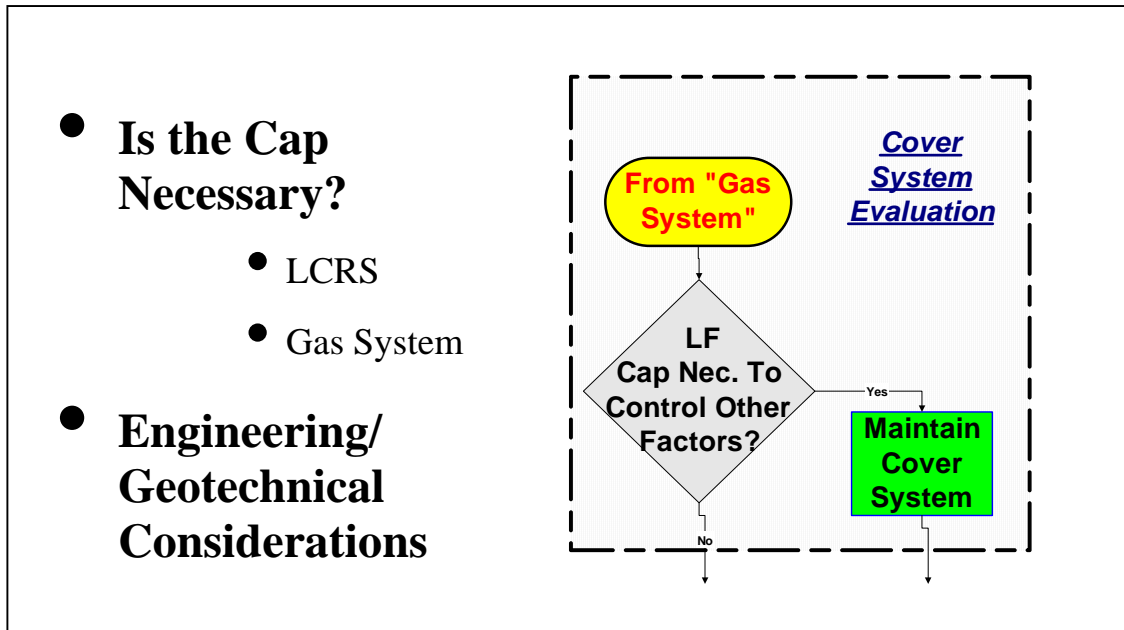


Figure 8-5. Cover system logic diagram.

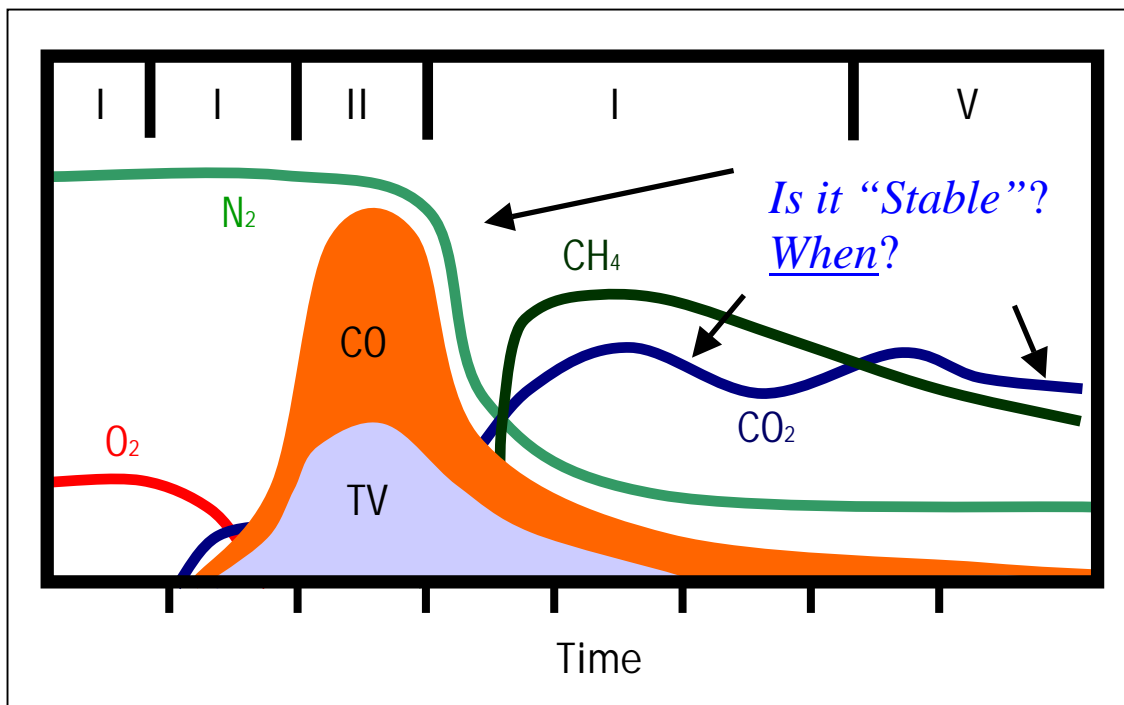


Figure 8-6. Typical landfill degradation phases of MSW and stability.

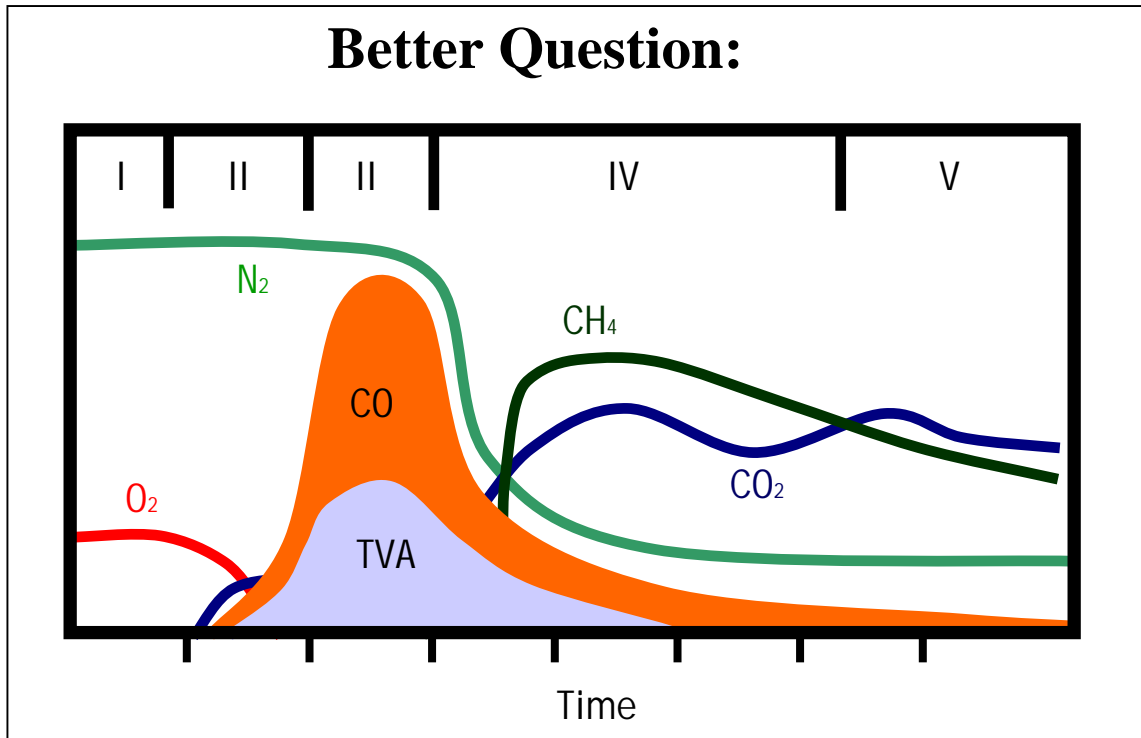


Figure 8-7. Typical degradation phases of MSW and risk.

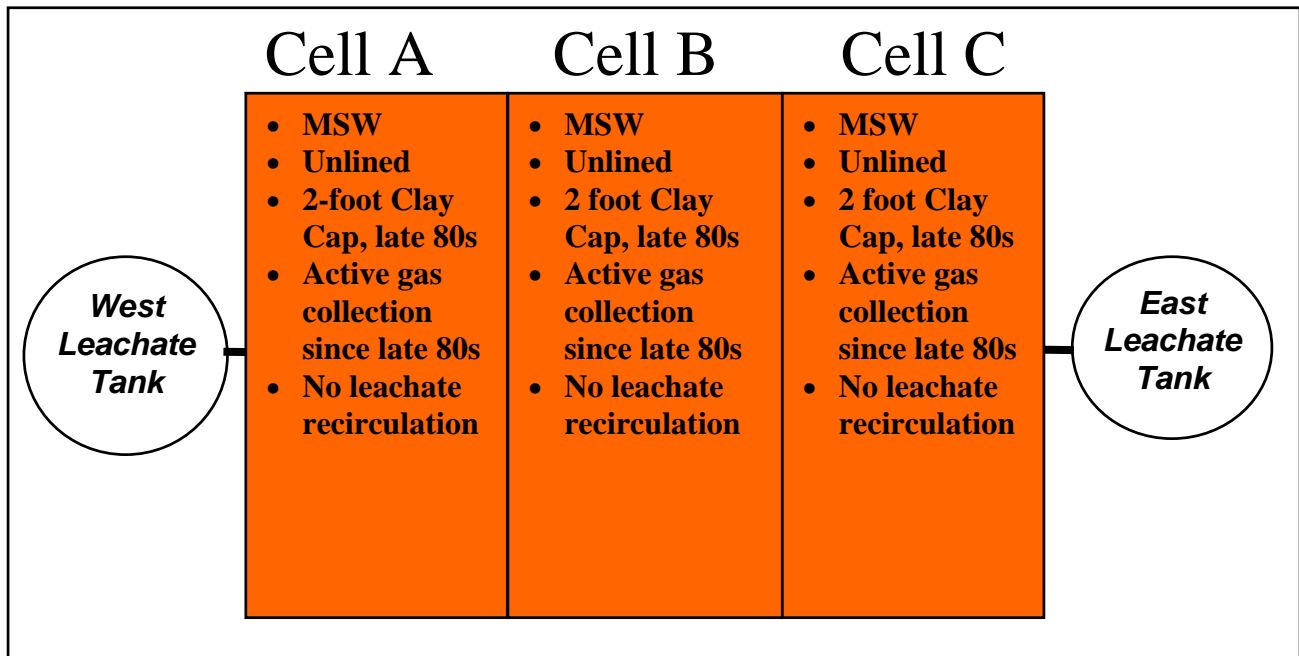


Figure 8-8. Case Study I—New York landfill.

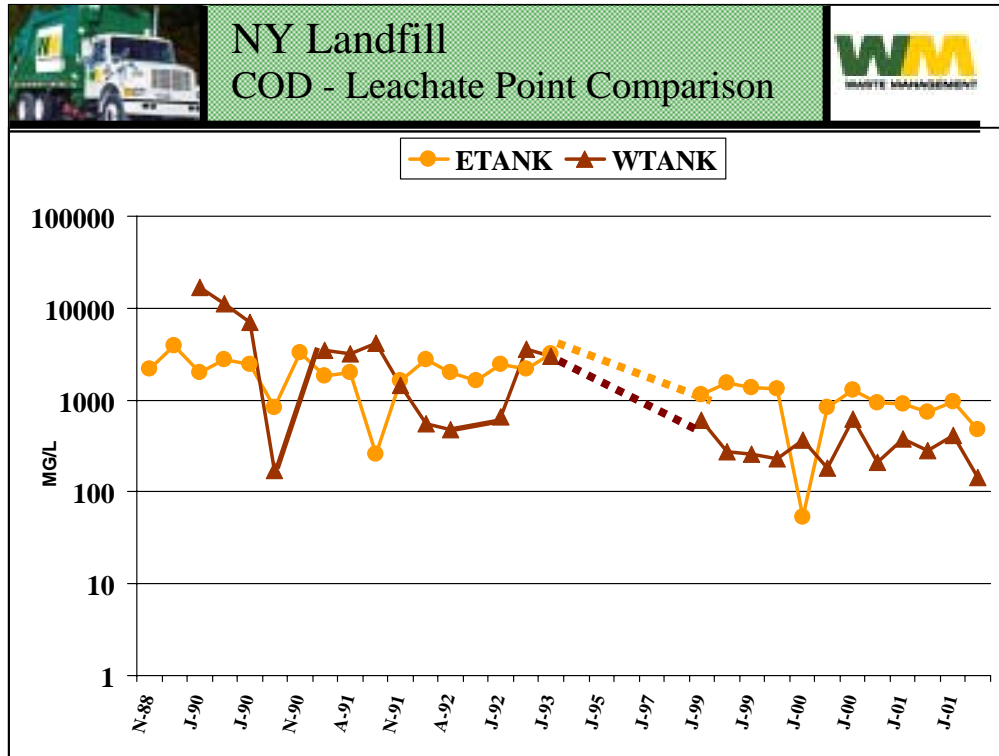


Figure 8-9. COD leachate point comparisons.

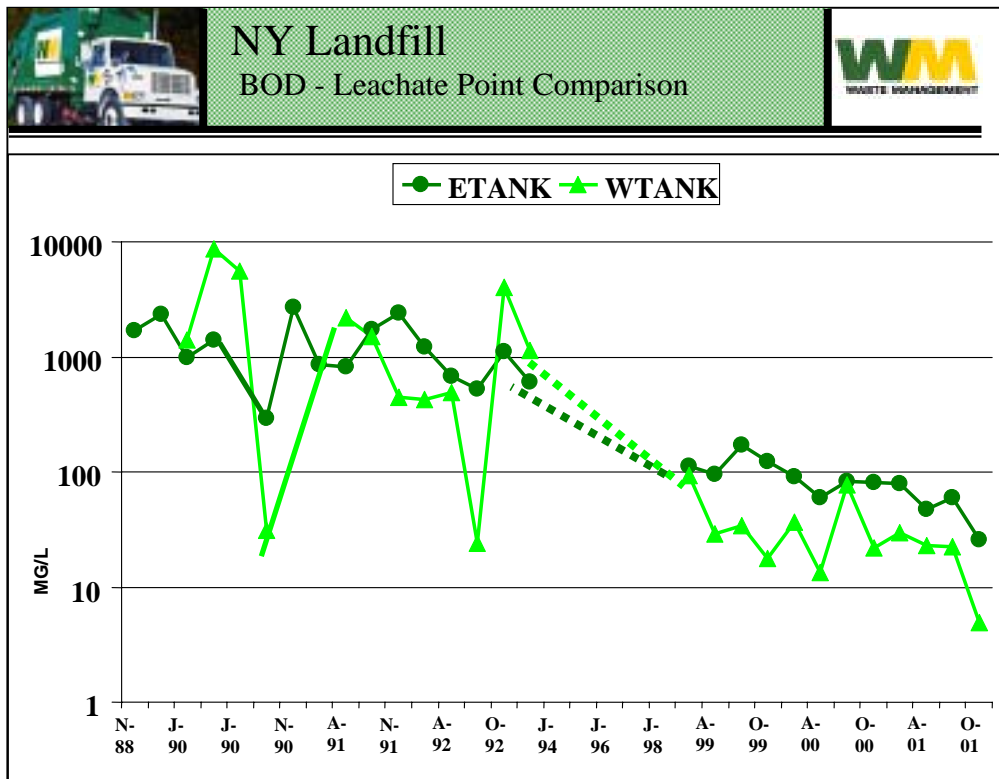


Figure 8-10. BOD leachate point comparisons.

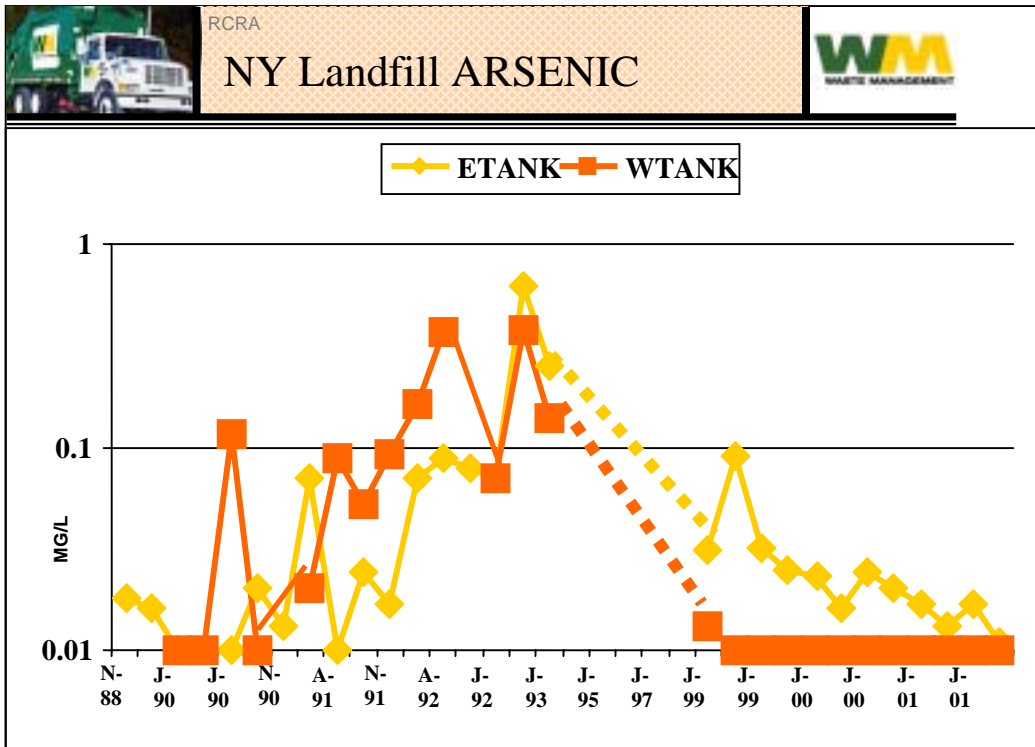


Figure 8-11. Arsenic vs. time.

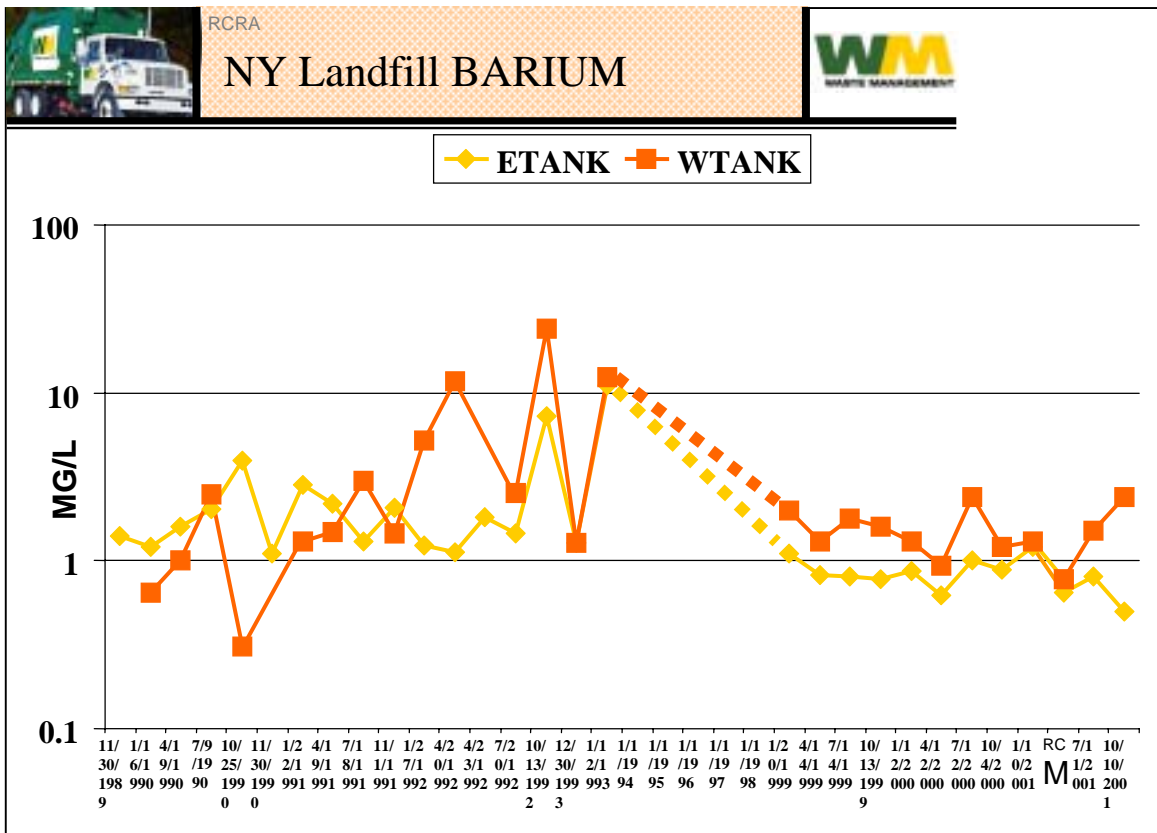


Figure 8-12. Barium vs. time.

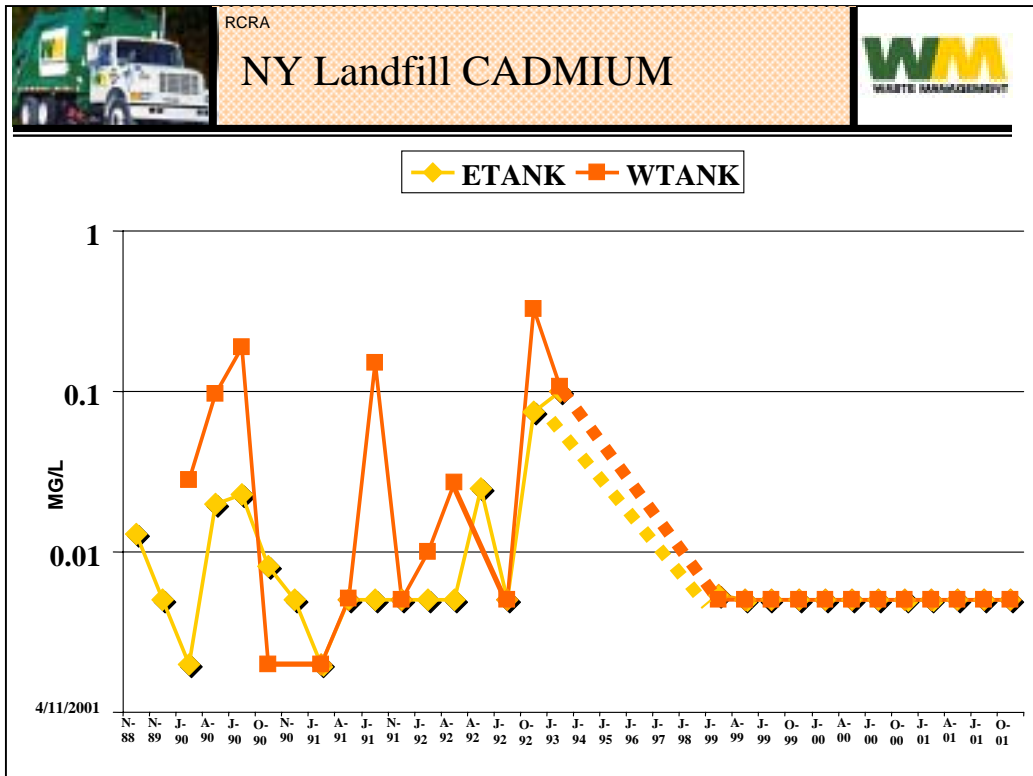


Figure 8-13. Cadmium vs. time.

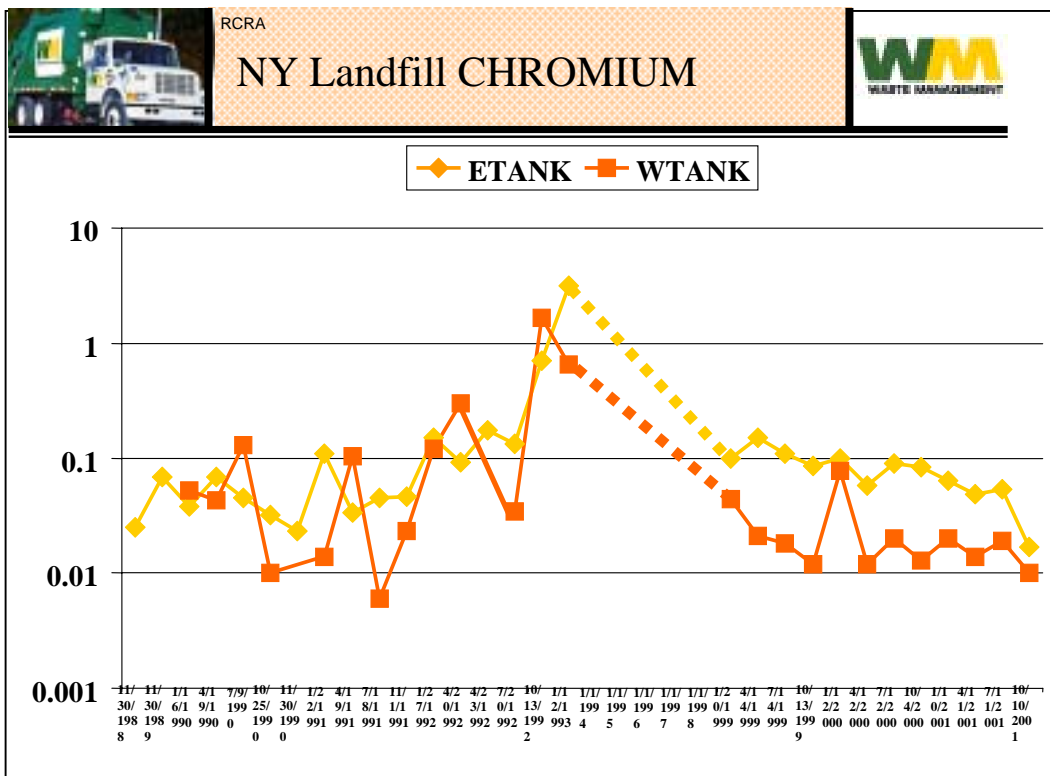


Figure 8-14. Chromium vs. time.

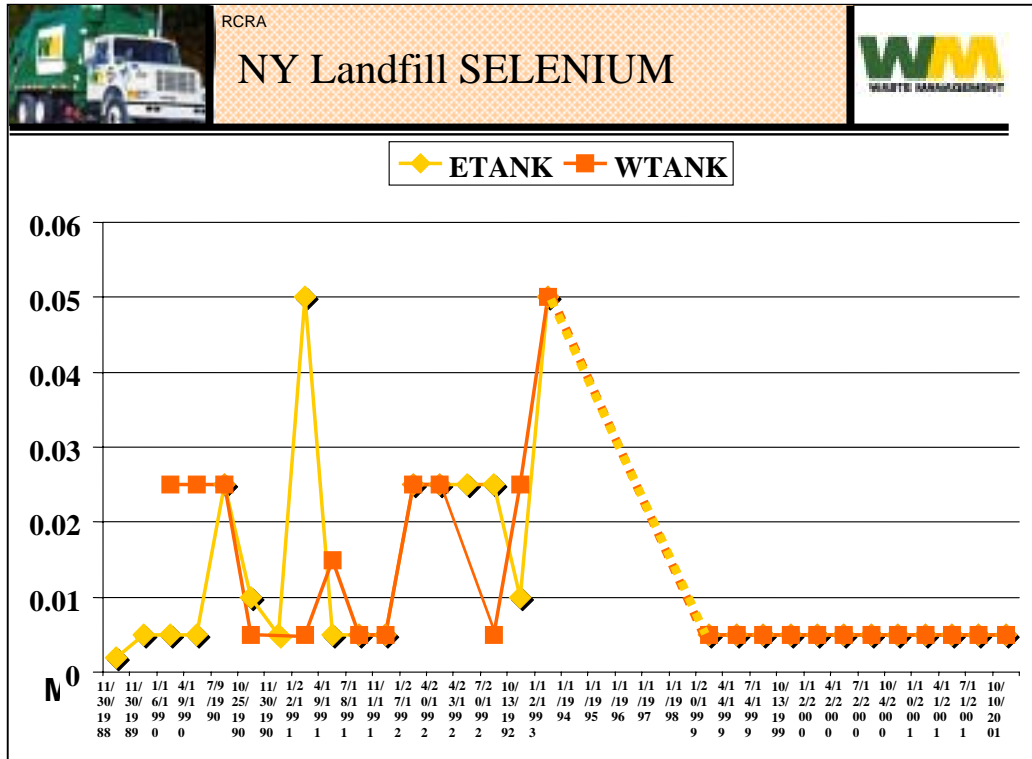


Figure 8-15. Selenium vs. time.

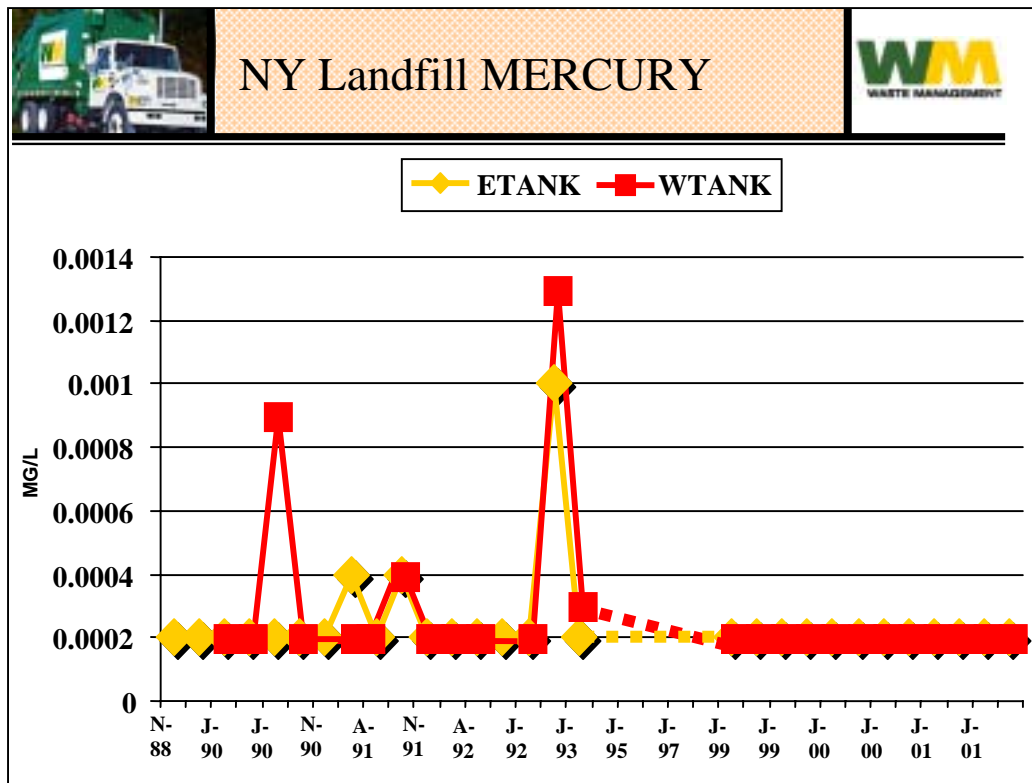


Figure 8-16. Mercury vs. time.

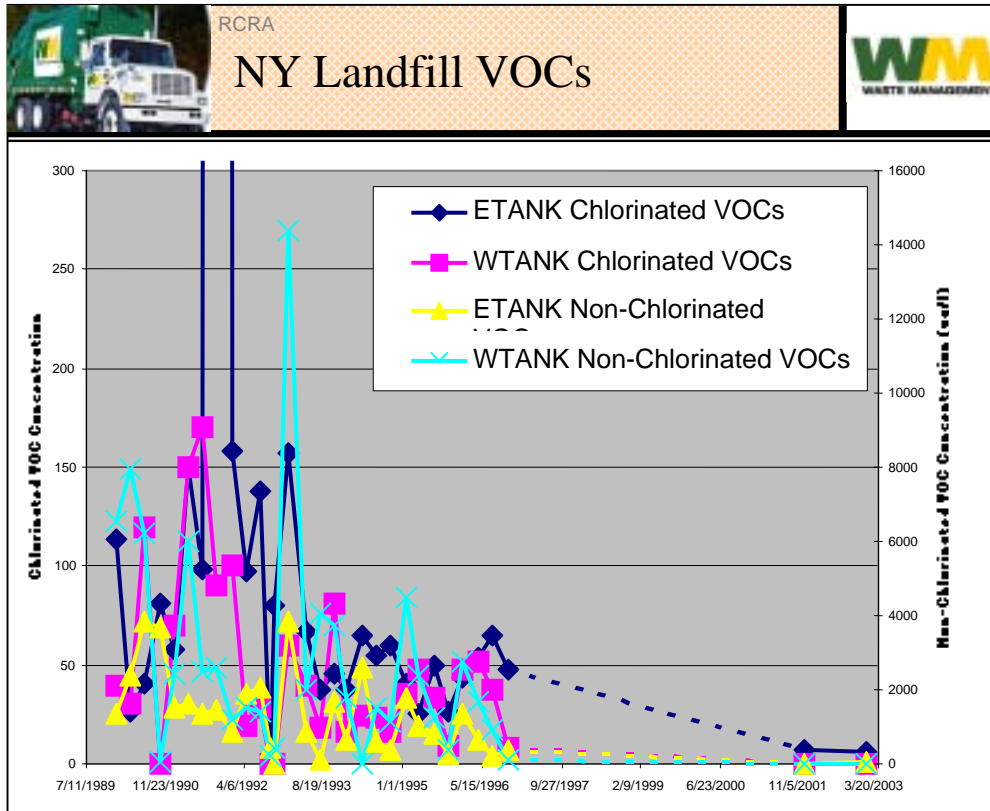


Figure 8-17. VOCs vs. time.

- Profile closed MSW landfill leachate with time
 - BOD/COD < 0.1
 - VOCs have data gaps, but last two sampling events detected only a few VOCs but below their respective MCLs
 - Flat or decreasing trends for indicators
 - Metals below MCLs
- Evaluate Leachate Characteristics by Time Series Plots*

Figure 8-18. New York landfill case study conclusions.

Cell 1, Phase 1	Cell 1, Phase 2	Cell 2	Cell 3,
<ul style="list-style-type: none"> •MSW: 85-89 •PVC Liner •GCL/HDPE Cap <p><i>16 year old MSW</i></p>	<ul style="list-style-type: none"> •MSW: 89-92 •PVC Liner •GCL/HDPE Cap <p><i>12 year old MSW</i></p>	<ul style="list-style-type: none"> •MSW: 92-98 •Sub D Liner •Interim Caps •Leachte Recirc <p><i>9 year old MSW</i></p>	<ul style="list-style-type: none"> •MSW: 98→ •Sub D Liner •No Cap •Leachte Recirc <p><i>3 year old MSW</i></p>

Figure 8-19. Case Study II—Michigan landfill.

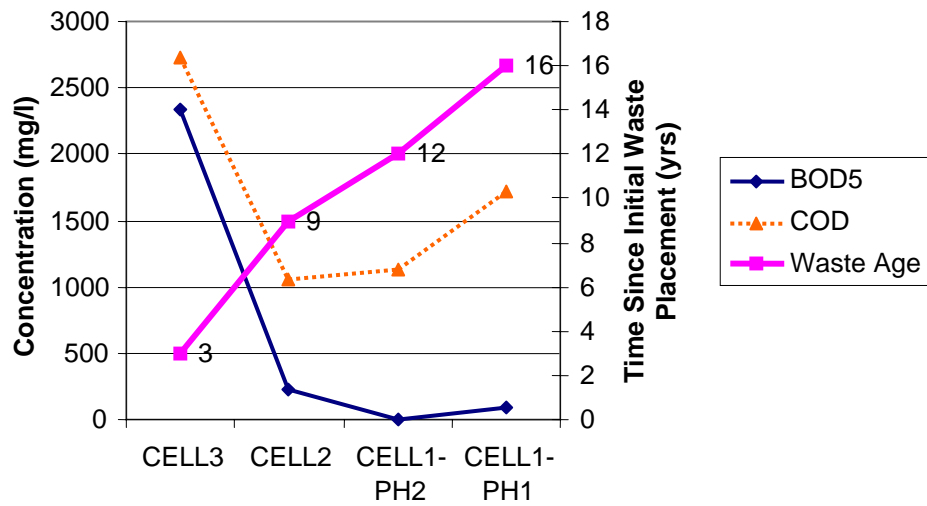


Figure 8-20. Comparison of leachate quality and waste age—BOD/COD.

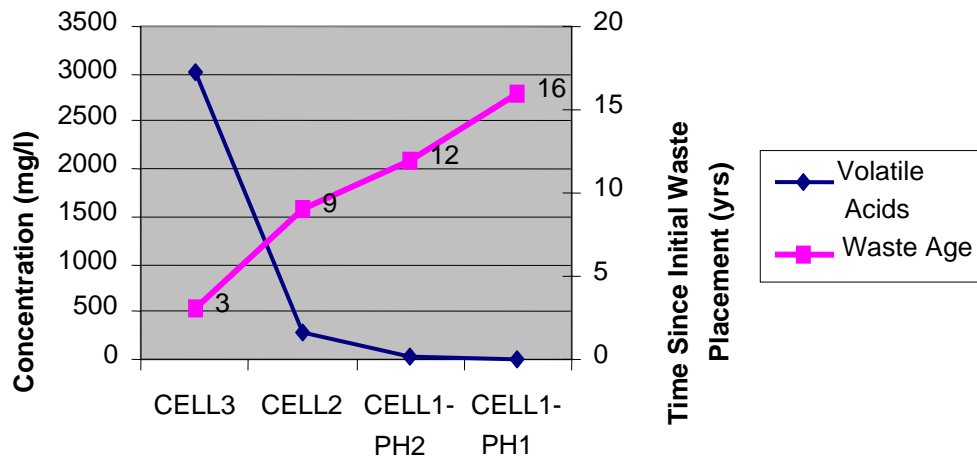


Figure 8-21. Comparison of leachate quality and waste age—volatile acids.

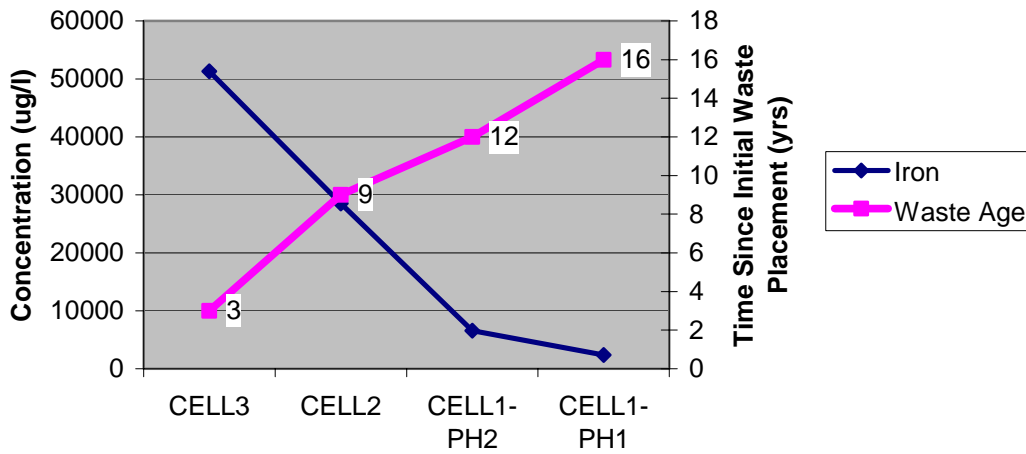


Figure 8-22. Comparison of leachate quality and waste age—iron.

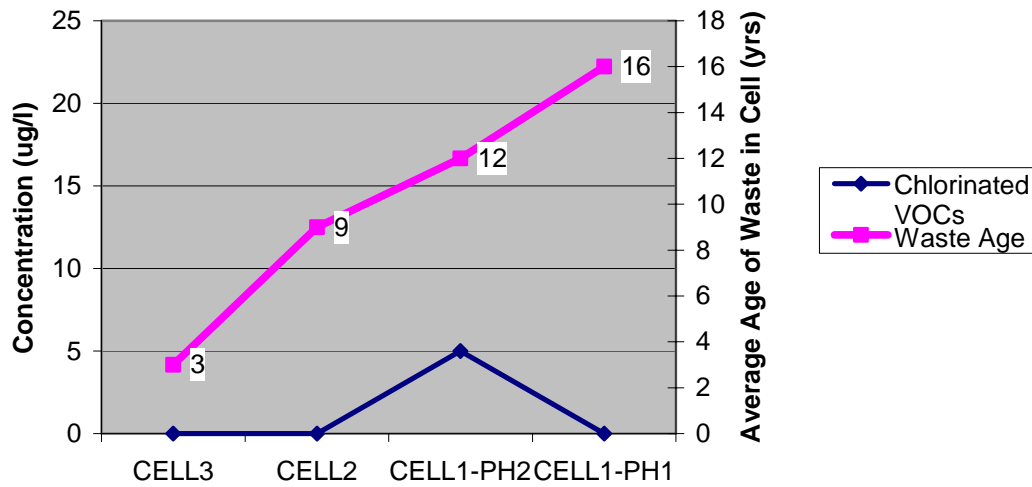


Figure 8-23. Comparison of leachate quality and waste age—VOCs.

Case Study – MI Landfill

- Profile Active & Closed MSW Cells
- BOD/COD < 0.1
- Flat or Decreasing Trends for Indicators
- VOCs Decreasing/ND

Evaluate Leachate Characteristics by Cell

Figure 8-24. Michigan landfill case study conclusions.

9. SUMMARY FOR SITES IN THE EPA ALTERNATIVE COVER ASSESSMENT PROGRAM

This report summarizes site characteristics and information regarding study sites involved in the EPA's Alternative Cover Assessment Program (ACAP) and is intended to serve as case studies for the Interstate Technology Regulatory Council's (ITRC) Alternative Landfill Technologies Team.

The format of this report is the outline chosen by ITRC. Use of this format results in an incomplete set of information due to lack of knowledge by the ACAP team of much of the information sought by ITRC. Many of the items in this outline are common to landfill covers in general and are not specific to alternative designs and thus were not of interest to the ACAP team. The information presented in this report is, however, quite relevant to design and evaluation of alternative earthen final covers and should be of considerable use to those design engineers and regulatory analysts seeking guidance.

Since ACAP involves several sites, much of the information presented here is in the form of tables and figures.

9.1 Site Setting

9.1.1 Name, Location, Surface Area, and Type of Waste in Landfill

See Table 9-1 and Fig. 9-1.

9.1.2 Future Land Use

All ACAP sites are intended to be unirrigated open space.

9.2 Design Basis

9.2.1 Regulatory Barriers

Alternative designs are specifically allowed under federal regulations. At all ACAP sites, the field activities serve to address the requirement for demonstration of equivalent performance as specified in regulations. There are no specific regulatory barriers to deployment of these alternative designs.

9.2.2 Public Involvement

Public involvement was not sought prior to construction of the ACAP facilities as they are test plots.

Table 9-1. ACAP site details

Facility/location	Owner/contact	Landfill type	Active/ inactive	Activity/ total capacity	Estimated closure date
Kiefer Landfill 12701 Kiefer Blvd. Sloughhouse CA 95683	Sacramento County Public Works Agency Chris Richgels 9850 Goethe Road Sacramento, CA 95827-3561 916.875.7011, richgelse@saccounty.net	RCRA D (MSW, industrial, commercial, C&D debris	Active	500,000 tons/year	2035
Altamont Landfill and Resource Recovery Facility 10840 Altamont Pass Road Livermore, CA 94550-9745	Waste Management, Inc. Ken Lewis 10840 Altamont Pass Road Livermore, CA 94550-9745 925.455.7350, klewis@wm.com	RCRA D (MSW, industrial, commercial, C&D debris	Active	2,000,000 tons/year	2010
Monterey Peninsula Landfill 14201 Del Monte Blvd. Marina CA 93933	Monterey Regional Waste Management District Rick Shedden P.O. Box 1670 Marina, CA 93933-1670 831.384.5313, rshedden@mrwmd.org	RCRA D (MSW, industrial, commercial, C&D debris	Active	220,000 tons/year	2090
Monticello Uranium Mill Tailings Repository 731 Highway 191 Monticello UT 84535	U.S. Department of Energy Jody Waugh 2597 B ¾ Road Grand Junction, Co 81503 970.248.6431, Jody.Waugh@gjo.doe.gov	Hazardous waste, mill tailings, asbestos	Inactive	2,600,000 cubic yards	1975
Finley Buttes Regional Landfill 73221 Bombing Range Road Boardman, OR 97818	Waste Connections, Inc. Dan Swanson 611 SE Kaiser; P.O. Box 61726 Vancouver, WA 98666 360.695.4858, dansw@wcnx.org	MSW	Active	500,000 tons/year	2004
Lake County Landfill 3500 Kerr Dam Rd. Polson MT 59860	Lake County Solid Waste Management District Mark Nelson 12 5 th Ave East Polson, MT 59860 406.883.7325, trashman@compuplus.net	MSW	Active	28,000 tons/year	2001

Table 9-1. ACAP site details (continued)

Facility/location	Owner/contact	Landfill type	Active/ inactive	Activity/ total capacity	Estimated closure date
Lewis and Clark County Landfill 4075 Deal Rd. Helena MT 59602	Lewis and Clark County Public Works Dept. Will Selser 3402 Cooney Dr. Helena, MT 59602 406.447.1635, selser@co.lewis-clark.mt.us	RCRA D (MSW, industrial, commercial, C&D debris	Active	353,700 cubic yards	2045
Bluestem Solid Waste Agency 1954 County Home Rd. Marion IA 52302	Bluestem Solid Waste Agency Dave Hogan 6301 Kirkwood Blvd. SW P.O. Box 2068 Cedar Rapids, IA 52406 319.398.1278, 1.888.398.1278 (toll free) dhogan@bluestem.org	RCRA D (MSW, industrial, commercial, C&D debris	Active	825,000 tons to date (40-45K tons/year)	2002
Douglas County Recycling and Disposal Facility 14320 N. 216 th St. Bennington NE 68007	Waste Management of Nebraska Ken Mertl 14320 N. 216 th Street Bennington, NE 68007 402.478.5196, kmertl@wm.com	MSW	Active	600,000 tons/year	2003
Center Hill Landfill Center Hill Rd. and Este Ave. Cincinnati OH 45224	City of Cincinnati Steve Rock (USEPA) 5995 Center Hill Avenue Cincinnati, OH 45224 513.569.7149, Rock.Steven@epamail.epa.gov	MSW, commercial, industrial, residential	Inactive	NA	1977
Green II Landfill 34581 Clay Hill Rd. Logan OH 43138	Goodyear Tire and Rubber Co., Inc. and PPG Industries Shannon Lloyd Sharp and Associates 982 Crupper Avenue Columbus, OH 43229 614.841.4650, sdllloyd@sharptech.net	MSW and hazardous waste	Inactive	NA	1978
U.S. Marine Corps Logistics Base Radford Blvd. Albany GA 31704	U.S. Marine Corps Brian Ventura / Mike Pearson 814 Radford Blvd., STE 20315 Albany, GA 31704-0315 229.639.6261 venturabj@matcom.usmc.mil pearsonms@matcom.usmc.mil	No official classification	Inactive	175,000 tons	1988

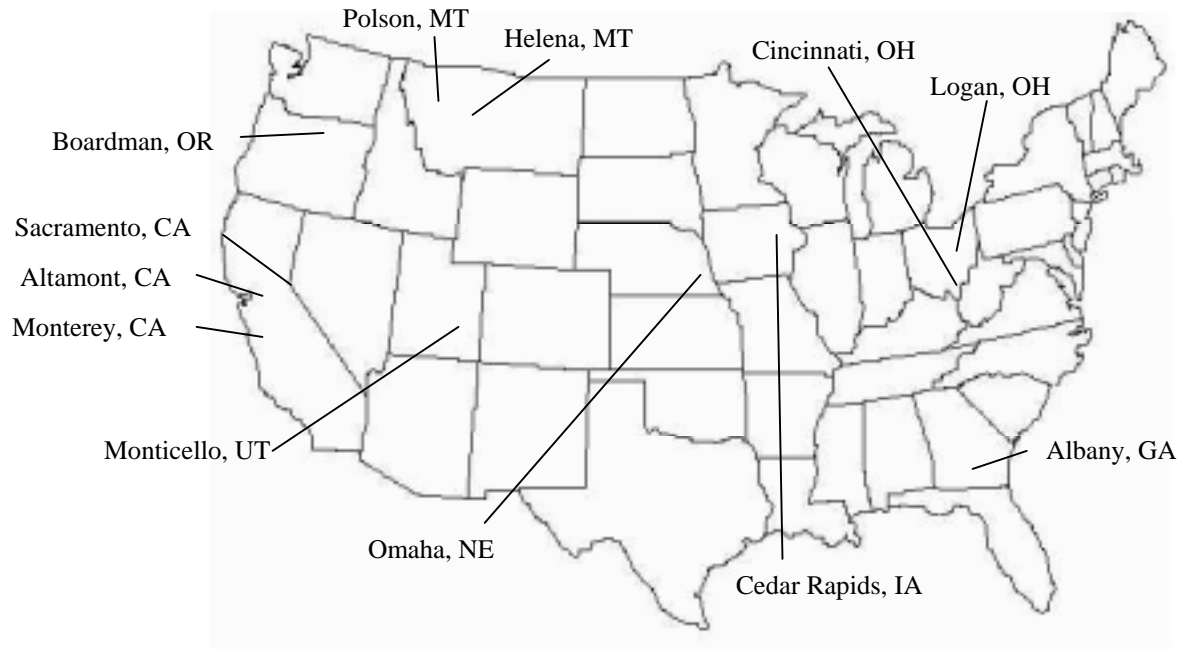


Figure 9-1. Location of ACAP sites.

9.2.3 Site Characterization

9.2.3.1 Soil Characterization and Volume

All soils used in construction were characterized prior to construction of the ACAP sites. Initial soil characterization data are contained in the Site Specific Design Plans for each site are available on the ACAP Web site at www.acap.dri.edu. General soil characteristics for all ACAP covers are shown in Fig. 9-2.

9.2.3.2 Plant Characterization

All plants used in construction were characterized with local input prior to construction of the ACAP sites. Plant community data are contained in the site-specific design plans for each site that are available on the ACAP Web site at www.acap.dri.edu. General plant community characteristics for all ACAP covers are shown in Fig. 9-2 and are listed in Table 9-2.

9.2.3.3 Climate/Microclimate Characteristics

Relevant climate characteristics for ACAP sites were characterized prior to construction. Climate data are contained in the Site Specific Design Plans for each site that are available on the ACAP Web site at www.acap.dri.edu. Mean precipitation data for all ACAP covers are shown in Table 9-3.

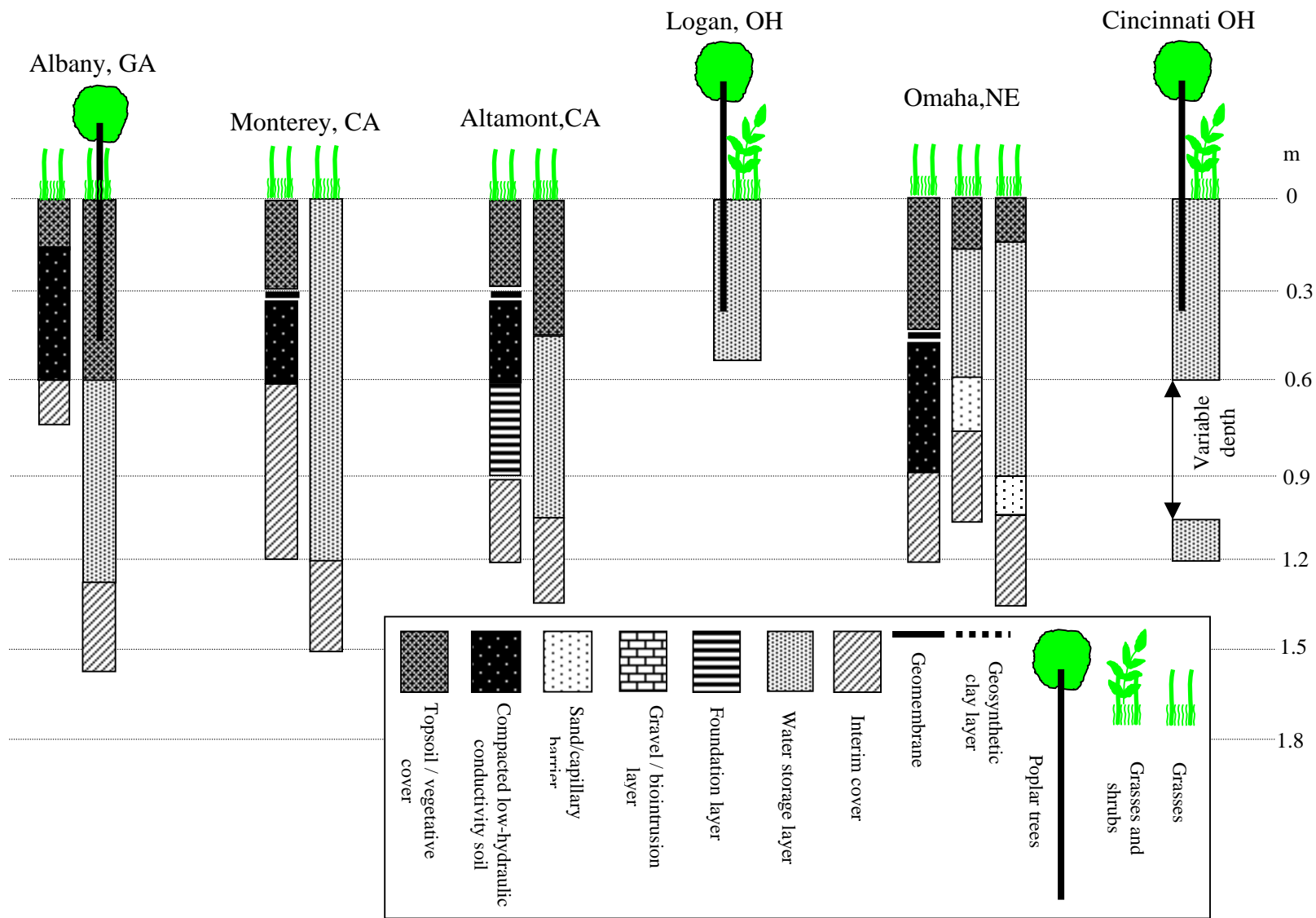


Figure 9-2. ACAP cover design profiles.

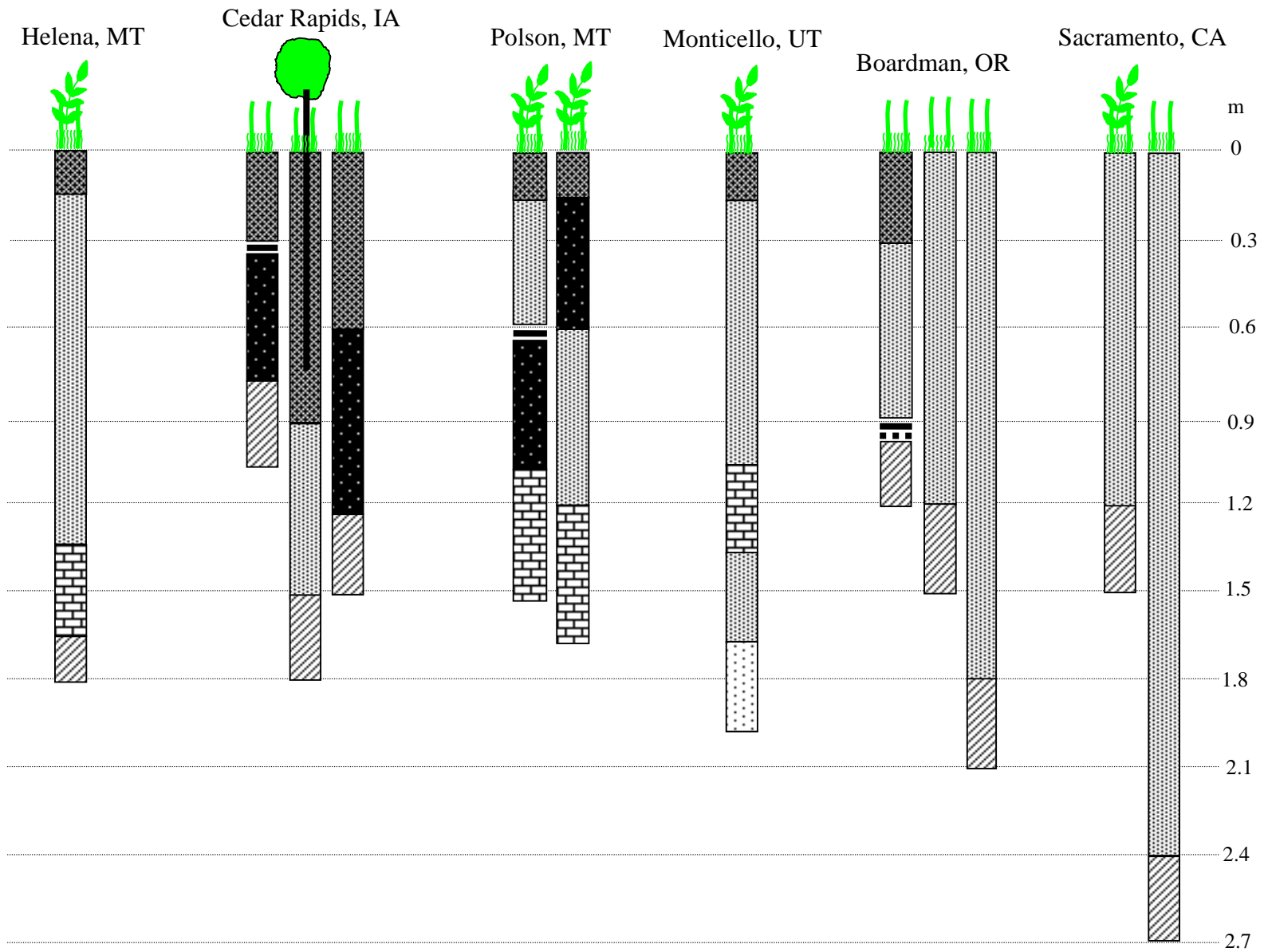


Figure 9-2. ACAP cover design profiles (continued).

Table 9-2. Plant community characteristics of ACAP test sections

Site	Site Seed Mixture
Omaha	Cool season grasses: Brome and switchgrasses
Albany	Bermuda grass, perennial rye, and eastern cottonwood and black poplar, Imperial Carolina DN-34 (Ecap only)
Altamont	Soft chess, slender oats, foxtail chess, Italian ryegrass, red-stemmed filaree, black mustard, yellow star-thistle, prickly lettuce, bull thistle, prickly sow-thistle, blue dicks, California poppy, purple owl's-clover, and miniature lupine
Cedar Rapids	Indian grass, little bluestem, big bluestem, side oats, and switchgrass, tall fescue lawn mix, and crown vetch
Boardman	Siberian, bluebunch, and thickspike wheatgrasses, alfalfa, and yellow blossom sweetclover
Helena	Bluebunch, slender, and west wheatgrasses, Sandburg bluegrass, sheep fescue, blue gamma, green needlegrass, and needle-and-thread
Sacramento	California brome, purple needlegrass, Zorro fescue, arroyo lupin, and oleander bushes
Marina	Blue wild rye, California brome, creeping wild rye, and Pacific hairgrass
Polson	Thickspike, bluebunch, slender, and crested wheatgrasses, mountain brome, Idaho fescue, prairie junegrass, needle-and-thread, meadow brome, Canada and Kentucky bluegrasses, yarrow, fringed sagewort, alfalfa, rubber rabbitbrush, prickly rose, arrowleaf balsamroot, and dolted gayfeather, Lewis flax, and silky lupine, and Cicer milkvetch
Monticello	Western and crested wheatgrasses, gray rabbitbrush, sagebrush, pinyon, and juniper

Table 9-3. ACAP details

Facility location	# Test pads	RCRA minimum design	Alternative design	Performance criterion	Date construction completed	Date vegetation applied	Precipitation (inches/year)
Sacramento	2	NA	ET-type	3mm/year	July 25, 1999	Grasses: November 1999 Shrubs: March 2000	17.2
Altamont	2	Composite	ET-type	3mm/year or equivalent*	Nov. 9, 2000	December 2000	13.5
Marina	2	Composite	ET-type imported soil	Equivalent to RCRA minimum	May 25, 2000	October 2000	16.2
Monticello	1 7.5-acre lysimeter and 2 Caisson lysimeters			3mm/year	June 23, 2000	Spring 2000	15
Boardman	3	Composite	ET-type	3mm/year or equivalent*	Nov. 17, 2000	Early February 2001	8.7
Polson	2	Composite	ET-type with capillary barrier	3mm/year	Oct. 19, 1999	March 31, 2000 reseeded April 10, 2000	13.6

Table 9-3. ACAP program details (continued)

Facility location	# Test pads	RCRA minimum design	Alternative design	Performance criterion	Date construction completed	Date vegetation applied	Precipitation (inches/year)
Helena	1	NA	ET-type	3mm/year	Oct. 18, 1999	Final week of November 1999	12
Cedar Rapids	3	Composite	ET-type	3mm/year or equivalent*	Oct. 2, 2000	Grasses: Sept. 29-Oct. 11, 2000 Trees: Late March 2001	36.4
Omaha	3	Composite	ET-type	3mm/year or equivalent*	Aug. 11, 2000	October 2000	28
Cincinnati	Leachate collection system	NA	ET-type	NA	Feb. 15, 2000	May-June 1999, replanted portions in Fall 1999 and Spring 2000	36-38
Logan	Leachate collection system	NA	ET-type	NA	March 2, 2000	May-June 1999 (20% replanting in Spring 2001)	36-39
Albany	2	Compacted clay	ET-type	Equivalent to RCRA minimum	March 18, 2000	March 15-17, 2000	50.4

9.2.3.4 *Geology*

General question for all covers, not specific to alternatives. Some site-specific information is contained in the site-specific design plans.

9.2.3.5 *Hydrology*

General question for all covers, not specific to alternatives. Some site-specific information is contained in the site-specific design plans.

9.2.3.6 *Surface Water Characteristics*

General question for all covers, not specific to alternatives. Some site-specific information is contained in the site-specific design plans.

9.2.3.7 *Biota*

General question for all covers, not specific to alternatives.

9.2.4 Cover Goals

The performance goal for all ACAP sites is minimization of percolation. In some cases the percolation goal is specified, in others it is equivalency to the RCRA minimum design.

9.2.4.1 *Allowable Infiltration/Flux*

See Table 9-3.

Leachate Management. General question for all covers, not specific to alternatives.

9.2.4.2 *Allowable Erosion*

General question for all covers, not specific to alternatives.

Maximum Slope Length and Angle. General question for all covers, not specific to alternatives.

Ecological Diversity and Density. General question for all covers, not specific to alternatives.

9.2.4.3 *Cover Integrity*

General question for all covers, not specific to alternatives.

9.2.5 Design Basis Evaluation

9.2.5.1 Protection of Human Health and the Environment

General question for all covers, not specific to alternatives.

9.2.5.2 Modeling

All alternative cover designs tested by ACAP were evaluated for predicted performance by numerical methods prior to construction. Methods ranged from Richards' equation-based codes to simple spreadsheet water balance routines. Details of modeling exercises are to be found in the site-specific design plans available on the ACAP Web site (www.acap.dri.edu).

9.2.5.3 Test Plots

The primary feature of ACAP is the evaluation of cover designs in large (10 × 20 m) drainage lysimeters (Fig. 9-3). These field facilities offer excellent ability to quantify the components of the near-surface water budget and are described in the Test Section Installation Instructions (Benson et al. 1999) and the ACAP Construction Summary (Phase II Report) both available on the ACAP Web site (www.acap.dri.edu). Construction of the ACAP test facilities was completed in the fall of 2000. Flux monitoring is scheduled to proceed for 5 years. Data are collected daily for all sites.

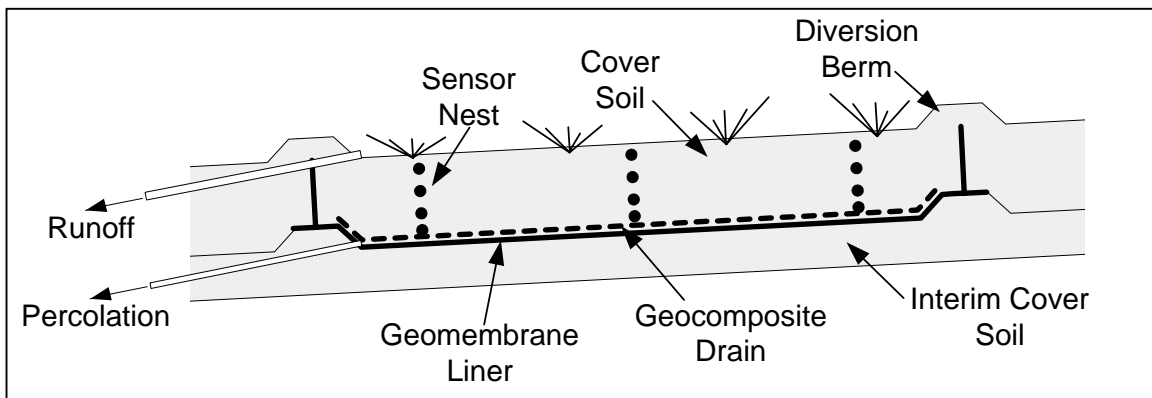


Figure 9-3. Schematic of ACAP drainage lysimeter.

9.2.5.4 Evaluation

Evaluation of ACAP sites is proceeding. A comprehensive summary of data from the first two years of operation is found in “Field Hydrology and Model Predictions for Final Covers in the Alternative Assessment Program—2002” by Roesler et al. This document can be found on the ACAP Web page.

9.2.5.5 *Natural Analogues*

The concept of evaluating natural analogs for ideas for innovative cover designs is an excellent idea. It was not included in the design process for the alternative covers being evaluated by ACAP.

9.2.5.6 *Cost Savings*

Good question. ACAP has not collected cost data.

9.3 Design/Construction/Construction Monitoring

9.3.1 Design

9.3.1.1 *Criteria*

Design criteria for the alternative covers tested by ACAP was allowable flux. Material parameter value was the primary criterion for design of the conventional covers.

9.3.1.2 *Specifications*

Description of all the ACAP test section designs are found in Fig. 9-2 and are described in detail in the Phase II Report (www.acap.dri.edu).

9.3.1.3 *Regulatory Barriers*

Alternative designs are specifically allowed under federal regulations. At all ACAP sites, the field activities serve to address the requirement for demonstration of equivalent performance. There are no specific regulatory barriers to deployment of these alternative designs.

9.3.2 Construction

ACAP is evaluating the performance of test section, not full-scale covers. Notes here refer to the construction of the test sections.

9.3.2.1 *Criteria*

Construction criteria for the ACAP test sections were typically lift thickness and soil density. Saturated hydraulic conductivity was an important criterion when a compacted clay layer was included in a design. A summary of construction criteria is found in the Phase II Report.

9.3.2.2 *Specifications*

Specifications for construction of the ACAP test sections are found in the Phase II Report.

9.3.2.3 *Monitoring QA/QC*

Construction of the ACAP test sections was monitored for lift thickness, soil density, saturated hydraulic conductivity (in the case of compacted clay layers).

9.3.2.4 *Constructability*

Constructability was not specifically evaluated by ACAP.

9.3.2.5 *Regulatory Barriers*

No significant regulatory barriers to cover construction were identified during field activities.

9.3.2.6 *Field Methods*

Field methods for construction of ACAP test sections are described in the Phase II Report.

9.4 Operation and Monitoring

All ACAP sites are in the evaluation phase.

9.4.1 Flux Monitoring

A summary of performance data to date has been compiled in “Field Hydrology and Model Predictions for Final Covers in the Alternative Assessment Program—2002” by Roesler et al.

9.4.1.1 *Field Methods*

Field methods for operation of the ACAP test sections are found in the Phase II Report and the 2002 Annual Report, both at www.acap.dri.edu

9.4.2 Leachate Management

ACAP monitors just the performance of the cover, not the landfill.

9.4.2.1 *Quantity Characterization*

ACAP monitors just the test section, not the landfill.

9.4.2.2 *Quality Characterization*

ACAP monitors just the test section, not the landfill.

9.4.3 Cover Integrity Monitoring

General question for all covers, not specific to alternatives.

9.4.3.1 Allowable Movement

Don't have this information for full-scale covers at all ACAP sites.

9.4.3.2 Erosion

Annual visual inspection for erosion and other problems.

9.4.3.3 Corrective Action/Forensic Study

Obvious problems such as erosion problems have been corrected on ACAP test sections. No forensic evaluation is planned but would be very useful.

9.4.3.4 Field Methods

Visual inspection.

9.4.3.5 Groundwater Monitoring

General question for all covers, not specific to alternatives.

9.4.4 Ecological Succession

Not evaluated by ACAP. Interesting question, though.

9.5 Postconstruction/Operation Evaluation

ACAP is evaluating the performance of test section, not full-scale covers. At this point (November 2002) all ACAP sites have been operational for 2 years. Data collection and analysis is proceeding and is expected to continue for another 2–3 years. A summary of results to date is available on the ACAP Web site (www.acap.dri.edu) and is called “Field Hydrology and Model Predictions for Final Covers in the Alternative Assessment Program—2002.”

9.5.1 Design Selection Process Evaluation

Not planned.

9.5.2 Goals Evaluation

In progress. See summary of results mentioned above.

9.5.3 Criteria Evaluation

ACAP evaluation is still in progress.

9.5.4 Specifications Evaluation

ACAP evaluation is still in progress.

9.5.5 Comparison to Design Goals

In progress. See summary of results mentioned above.

9.5.6 Cost Savings

ACAP has not collected cost data. Might be a good idea.

9.5.7 Ability to Overcome Regulatory Barriers

ACAP has not collected regulatory barrier information. Might be a good idea.

9.5.8 Groundwater Monitoring

General question for all covers, not specific to alternatives.

ACRONYMS

ACAP	Alternative Cover Assessment Program
APC	air pollution control
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society of Testing and Materials
BNA	base/neutral/acid
BOD	biochemical oxygen demand
CAMU	corrective action management unit
CEM	continuous emissions monitor
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
CO	carbon monoxide
COD	chemical oxygen demand
DAF	dilution attenuation factor
DCA	dichloroethane
DCE	dichloroethene
EPA	Environmental Protection Agency
ET	evapotranspiration
GC/ECD	gas chromatograph/electron capture detector
GC/MS	gas chromatograph/mass spectrometer
HDPE	high-density polyethylene
ITRC	Interstate Technology and Regulatory Council
LEL	lower explosive limit
LTTD	low temperature thermal desorption
MASWU	McPherson Area Solid Waste Utility
MCE	maximum credible earthquake
MCL	maximum contaminant level
MSW	municipal solid waste
MSWLF	municipal solid waste landfill
NCDC	National Climatic Data Center
NOAA	National Atmospheric and Oceanic Administration
NPL	National Priority List
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCC	postclosure care
PCE	perchloroethylene
PIC	products of incomplete combustion
PMP	Probable Maximum Precipitation
POC	point of contact
POP	proof of process
POTW	publicly owned treatment works
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act

ROD	record of decision
TCE	trichloroethylene
TDU	thermal desorption unit
TPHC	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TSCA	Toxic Substances Control Act
TSD	treatment, storage and disposal
VO	volatile organic
VOC	volatile organic compound

Work Group Contacts

Charles Johnson
Colorado Department of Public Health
and Environment
4300 Cherry Creek Drive South
Glendale, CO 80246
T 303-692-3348
F 303-759-5355
charles.johnson@state.co.us

David Smit
OK DEQ Land Preservation Division
707 N. Robinson, PO Box 1677
Oklahoma City, OK 73101
T 405-702-5185
F 405-702-5101
dave.smit@deq.state.ok.us

Paul Graves
Chief, Solid Waste Landfills Unit
Bureau of Waste Management
Kansas Department of Health and
Environment
100 SW Jackson, Suite 320
Topeka, KS 66612-1366
T 785-296-1596
F 785-296-1592
pgraves@kdhe.state.ks.us

Bill Abright
Desert Research Institute
University of Nevada-Reno
Reno, NV
T 775-673-7314
Bill@dri.edu

Craig Benson
University of Wisconsin-Madison
1415 Engineering Drive # 2214
Madison, WI 53706
T 608-262-7242
F 608-263-2453
benson@engr.wisc.edu

Steve R. Hill
RegTech, Inc/ITRC
2026 N. Meyers Dr.
Pine, ID 83647
T 208-653-2512
F 208-653-2511
srhill1@mindspring.com

Peter Fuller
California State Water Resource Board
10011 Street
P.O. Box 944212
Sacramento, CA 95814
T 916-341-5675
F 916-341-5709
fullerp@cwpswrcb.ca.gov

Melissa Gunter
California Integrated Waste
Management Board
10011 Street
P.O. Box 4025
Sacramento, CA 95812-4025
T 916-341-6355
F 916-319-7306
mgunter@ciwmb.ca.gov

Victor Hauser
Mitretek
13526 George Road
Suite 200
San Antonio, TX 78230
T 210-479-0479
F 210-479-0482
vhauser@mitretek.org

Rafael Vasquez
Air Force Center for Environmental
Excellence
HQ AFCEE/ERT
3207 North Road
Brooks Air Force Base, TX 78235-5363
210-536-1431
210-536-4330
rafael.vazquez@hqafcee.brooks.af.mil

John Baker
Director, New Technologies
Waste Management, Inc
720 Butterfield Road
Lombard, IL 60148
T 630-572-8679
F 630-218-1596
jbaker1@wm.com

Claire Alrahwan
COSA
San Antonio, TX 78283-3966
T (home) 210-213-7387
scalrahwan@sbcglobal.net

Martin Kosec
Kosec Engineering
4248 McMurray
Fort Collins, CO 80525
T 303-748-2838
F 970-229-1535
kosec_eng@yahoo.com

Mark Ankeny
D. B. Stephens and Associates
6020 Academy NE, Suite 100
Albuquerque NM 87109
T 505-822-8877
F 505 822 8877
mankeny@dbstephens.com

Steve Rock
US EPA5995 Center Hill Av
Cincinnati, OH
T 513-569-7149
F 513-569-7879
rock.steven@epa.gov

Ricknold Thompson
Montano Department of Environmental
Quality
P.O. Box 200901
Helena, MT 59620
T 406-444-5345
F 406-444-1374
rithompson@state.mt.us

Van Keisler
South Carolina Dept of Health and
Environmental Control
2600 Bull St.
Columbia, SC 29201
T 803-896-4014
F 803-896-4292
keislecv@dhec.state.sc.us

Jorge Zornberg
University of Colorado
P.O. Box 428
Boulder, CO 80309
T 303-492-4699
F 303-492-7317
Jorge.zornberg@colorado.edu

Steve Wampler
AquaAeter
7340 E. Caley Ave, #200
Centennial, CO 80111
T 303-771-9150
F 303-771-8776
swampler@aquaeter.com

Narendra Dave
Louisiana Department of Environmental
Quality, New Technology Division
P.O. Box 82178
Baton Rouge, LA 70884-2178
T 225-765-0489
F 225 765-0602
narendra_d@ldeq.org

Stephen Dwyer
Sandia National Lab
P.O. Box 5800 M.S. 0719
Albuquerque, NM 87185
T 505-844-0595
F (505) 844-0244
sfdwyer@sandia.gov

Peter Strauss
PM Strauss & Associates
317 Rutledge St.
San Francisco, CA 94110
T 415-647-4404
F 415-647-4404
petestrauss1@home.com

Anne Callison
Barbour Communications
437 S. Pontiac Way
Denver, CO 80224-1337
T 303-331-0704
F 303.331.0704
awbarbour@aol.com

Lou Greer
Washington Group, International
P.O. Box 1717
Commerce City, CO 80037
T 303-853-3951
F 303-853-3946
Lou.greer@wgint.com

Carl Mackey
Washington Group International
P.O. Box 1717
Commerce City, CO 80037
T 303-286-3951
Carl.mackey@wgint.com

Eric Aitchison
Ecolotree
3017 Valley View Lane
North Liberty, IA
T 319-665-3547
Eric-aitchison@ecolotree.com

Mike Houlihan
Geosyntec
T 410-381-4333
mhoulihan@geosyntec.com

Jeremy Morris
Geosyntec
410-381-4333
jmorris@geosyntec.com

Siew Kour
Nebraska Department of Environmental
Quality
1200 N. Street, Box 98922
Lincoln, NE 68509-8922
T 402-471-3386
Seiw.kour@ndeq.state.ne.us

Kelly Madalinski
USEPA, Technology Innovation Office
Office of Solid Waste and Emergency
Response
1200 Pennsylvania Avenue, NW 5202G
Washington, DC 20460
T 703-603-9901
Madalinski.kelly@epamail.epa.gov