Appendix B

Field Data

B-1.0 INTRODUCTION

EPA maintains a website with a partial list of sites that have deployed alternative earthen covers (http://www.clu-in.org/products/altcovers/). The EPA also funded a study that monitored alternative earthen cover deployments at sites across the country referred to as the Alternative Cover Assessment Program (ACAP). The goal of the ACAP was the development of field-scale performance data for landfill final cover systems. Both prescriptive RCRA and alternative cover designs were tested in the project. ACAP is part of the EPA National Risk Management Research Laboratory's Superfund Innovative Technology Evaluation Program established to promote the development of new and innovative technologies used to address hazardous waste problems. Test sections have been installed at landfills in Sacramento County, California; Lake County, Montana; Lewis & Clark County, Montana; Monticello, Utah; Cedar Rapids, Iowa; Omaha, Nebraska; Boardman, Oregon; Altamont, California; Monterey, California; and the Marine Corps Logistics Base in Albany, Georgia. In addition, retrofit monitoring (to study existing alternative covers constructed prior to ACAP) has been established in Cincinnati and Logan, Ohio (http://www.acap.dri.edu/). Although ACAP was relatively short term, it revealed that ET cover types worked well in dry climates.

Perhaps the best applicable data for LANL cover systems is that from a longer-term research project (Dwyer 1997, 2001, 2003) located at Sandia National Laboratories located in Albuquerque, New Mexico, referred to as the Alternative Landfill Cover Demonstration (ALCD). For equivalence determination to meet NMED requirements for deployment of an alternative earthen cover, this ALCD data should be considered. This project showed that a well-designed ET cover or capillary barrier cover system can perform as well or better than a prescriptive cover system, even with a geomembrane within it.

B-2.0 ALTERNATIVE COVER DEPLOYMENTS AND FIELD DEMONSTRATIONS

B-2.1 ACAP Program

There are a number of sites monitored under the ACAP to track the effectiveness of landfill closures across the country. Those most applicable to the LANL site include demonstrations at Polson, MT; Helena, MT; Boardman, OR; Sacramento, CA; and Altamont, CA. Figure B-2.1-1 shows these sites' approximate geographical locations.

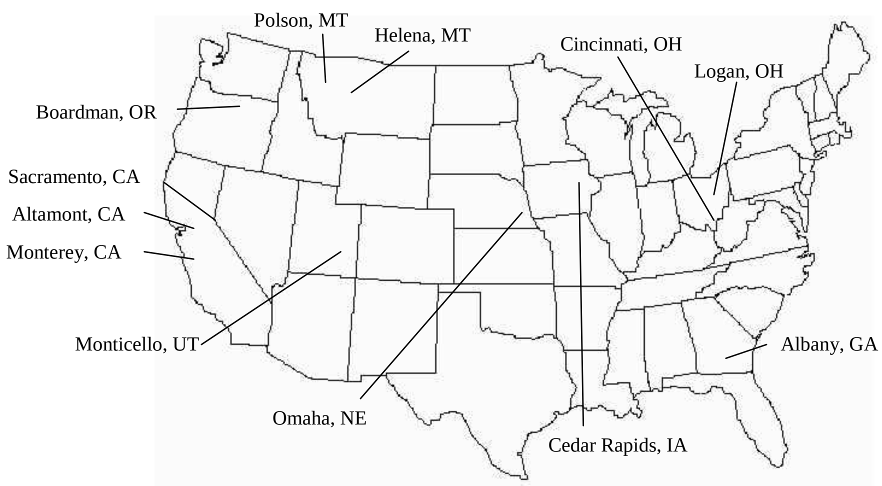

Figure B-2.1-1. ACAP sites

B-2.1.1 Finley Buttes Regional Landfill Oregon (Arid Site)

The Finley Buttes Regional Landfill located in Boardman, Oregon, is an active regional solid waste management facility, which serves the Pacific Northwest. It has a capacity of 500,000 tons/year. Access to the site is by highway, Columbia River barge system, and rail. The landfill is located 10 miles south of Boardman, Oregon, in the vicinity of Finley Buttes, on a 1,802-acre parcel of land.

Regulatory Agency/Contact:
Sacramento County Public Works Agency
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Type of Facility: RCRA D (MSW, industrial, commercial, C&D debris).

Annual Precipitation: 8.7 inches.

Test Covers:

1. Composite/GCL: 1 m of soil over a geomembrane over a GCL.
2. Thin ET cover: 1.2 m of soil.
3. Thick ET cover: 1.8 m of soil.

Figure B-2.1-2. Finley Buttes Regional Landfill test covers installation

Vegetation: A mixture of crested wheat grasses, alfalfa, and clover that are adapted to the semiarid climate.

Soil Properties: Sagehill fine sandy/silt loam used to store incidental precipitation and provide nutrients to the vegetation has an available water storage capacity of between 12.5 and 16.7 percent. The soil material at Finley Buttes consists of a windblown assemblage of sand and silt with a small percentage of clay-size constituents that is classified as ML in the Unified system and silt in the USDA system.

Table B-2.1-1. General Characteristics of Sagehill Fine Sandy/Silt Loam

Slightly plastic	High frost susceptibility
Non-expansive	Low permeability
Mod. low friction angle	High capillary potential
Slight cohesion	Low to moderate corrosion potential

Table B-2.1-2. Summary of Laboratory Test Results for Sagehill Fine Sandy/Silt Loam

SOIL CHARACTERISTIC	AVERAGE OR TYPICAL VALUE
Field Moisture	15% on weight basis 0.21 volumetric basis (m^3/m^3)
Saturation	40%
Dry Density	97 pcf
Moist Density	111.6 pcf
Saturated Density	123.8 pcf
Saturated Moisture	27.2% on weight basis 0.42 volumetric basis (m^3/m^3)
Buoyant Density	61 pcf
Maximum Density	112 pcf
Optimum Moisture	14.5%
Volume of Solids	0.57
Volume of Voids	0.43
Field Capacity	0.33 volumetric basis (m^3/m^3)
Wilting Point	0.09 volumetric basis (m^3/m^3)

Table B-2.1-2. (continued)

SOIL CHARACTERISTIC	AVERAGE OR TYPICAL VALUE
Void Ratio	0.75
Specific Gravity	2.71
Air Entry Potential	-4 kpa
Coefficient of Permeability	5×10^{-6} cm/sec

Table B-2.1-3. Sagehill Fine Sandy/Silt Loam Gradation Requirements

UNIFIED CLASSIFICATION	PERCENT PASSING
Sand – No. 4	100%
No. 10	95–100%
No. 100	85–100%
Silt – No. 200	70–90%
0.05 mm	50–70%
0.01 mm	5–20%
Clay – 0.005 mm	0–15%
0.001 mm	0–5%

Table B-2.1-4. Recommended Amendments to Sagehill Fine Sandy/Silt Loam

TOTAL FERTILITY NEEDS	APPLICATION RATE
Nitrogen	60 lbs. per acre – N
Phosphorus	70 lbs. per acre – P205
Sulfur	15 lbs. per acre – Actual S
Zinc	5 lbs. per acre – Actual Zn

Fertility needs and nutrient requirements are dependent upon the actual soils that are utilized for the construction of the AEC.

Data collection at the Boardman site began December 9, 2000. Water balance summaries for the test sections at the Boardman site are shown in Table B-2.1-5. Total recorded precipitation during the 31-month data collection period was 336 mm. Mean annual precipitation for the site is about 220 mm. Trace amounts of percolation (< 1 mm) were recorded for all three test sections.

Table B-2.1-5. Boardman, Oregon, Test Cover Results

Cover Design	Start Date	Current Data	Avg. Annual Precip (mm)	Cum. Precip (mm)	Cum. Percola-tion (mm)	Cum. Surface Runoff (mm)	Cum. Lateral Flow (mm)	Cum. ET (mm)
			219					
Composite / GCL	12/09/00	07/2/03		336	Trace	0	0	368
ET-thin	12/09/00	07/2/03		336	Trace	0	—	351
ET-thick	12/09/00	07/2/03		336	Trace	0	—	399

B-2.1.2 Lake County Landfill
Polson, Montana (Semiarid Site)

The Lake County Landfill occupies a 51-acre site approximately three miles southwest of Polson, Montana. The landfill is owned and operated by the Lake County Solid Waste Management District, 106 4th Avenue East, Polson, MT 59860. The landfill serves all of Lake County plus two small adjoining communities for a total population of about 28,000. The landfill began accepting waste in 1976. The site is licensed by the Montana Department of Environmental Quality as a Class 2 Municipal Waste Landfill. Under that definition, the landfill can accept municipal solid waste, commercial waste, nonhazardous industrial waste, and construction debris. The post-closure intended use of the site is as non-irrigated open space. In the fall of 1997, the Lake County Solid Waste Management District began the design work for an expansion onto 95 acres of adjoining properties. The expansion area license application was submitted to the Montana Department of Environmental Quality in January of 1999. During the review process, it was recommended by the state agency that the District consider use of an ET cover system. The suggestion was made primarily due to the high seismic rating for Lake County, as the alternative cover would prove more stable. A secondary benefit of the alternative cover would be the on-site use of soils that would have to be removed as excess to the operation with the prescriptive cover design.

Lake County Solid Waste Management District
Mark Nelson
12 Fifth Ave East
Polson, MT 59860
406.883.7325
trashman@compuplus.net
Annual Precipitation: 13.6 inches.

Test Covers:

1. Prescriptive: Composite Clay Cover: 15 cm topsoil over 45 cm silty sand over 60 mil geomembrane over 45 cm compacted silt over 45 cm sandy gravel.
2. ET cover/capillary barrier: 15 cm topsoil over 45 cm silt over 45 cm silty sand over 45 cm sandy gravel.

Vegetation: Thickspike, Bluebunch, Slender and Crested Wheat grasses, Mountain Brome, Idaho Fescue, Prairie Junegrass, Needle-and-Thread, Meadow Brome, Canada and Kentucky Bluegrasses, Yarrow, Fringed Sagewort, Alfalfa, Rubber Rabbit brush, Prickly Rose, Arrowleaf Balsamroot, Dolted Gayfeather, Lewis Flax, Silky Lupine, and Cicer Milkvetch.

Soil Properties:

Table B-2.1-6. Physical Properties of Polson, MT, Lake County Landfill Borrow Soils

Soil Sample	Source 1	Source 2	Source 3
Saturated hydraulic conductivity (cm/sec)	1.3×10^{-4}	8.9×10^{-4}	2.8×10^{-6}
Saturated water content	0.3937	0.4153	0.4134
Residual water content	0.0431	0.0181	0.0200
Calculated unsaturated hydraulic parameters:			
a (cm^{-1})	0.0053	0.0211	0.0015
n	2.0090	1.5650	1.4900
Particle size characteristics: 2µm clay	4	2	4
% fines	46	28	69
d_{10} (mm)	0.014	0.037	0.0043
d_{30} (mm)	0.057	0.08	0.015
d_{50} (mm)	0.083	0.12	0.049
d_{60} (mm)	0.11	0.14	0.061
Cu	7.9	3.8	14
Cc	2.1	1.2	0.86
Summary of Atterberg limits: LL	NA	NA	34.0
PL	NA	NA	26.9
PI	NA	NA	7.1
Classification: USCS	SM	SM	ML
USDA	Loamy sand	Sand	Sandy loam

Table B-2.1-7. Monitoring Results for Polson, MT, Lake County Landfill Test Covers

Cover Design	Start Date	Current Data	Avg. Annual Precip (mm)	Cum. Precip (mm)	Cum. Percolation (mm)	Cum. Surface Runoff (mm)	Cum. Lateral Flow (mm)	Cum. ET (mm)	Cover Design
			382						
Composite / comp. clay	11/19/99	07/2/03		1116	1.5	18	41	1036	Composite / comp. clay
ET / cap. barrier	11/19/99	07/2/03		1116	0.2	18	--	1135	ET / cap. barrier

B-2.1.3 Lewis and Clark County Landfill Helena, MT (Semiarid Site)

The Lewis and Clark County Landfill occupies a 320-acre site in southeastern Lewis and Clark County, approximately 10 miles northeast of Helena. The landfill is owned by Lewis and Clark County and operated by the Lewis and Clark County Public Works Dept. (3402 Cooney Dr., Helena, MT 59602). It serves urban and rural areas near Helena. Currently (1994) permitted operations (Phase I) include an active fill footprint confined to an 80-acre portion of the site. The landfill began accepting waste in 1994. The operational site life for Phase I has been projected to about the year 2045. The Lewis and Clark Landfill is a Class II disposal site and receives municipal solid wastes, commercial wastes, nonhazardous industrial wastes, and construction debris. Post-closure intended use of the site is as non-irrigated open space, consistent with the surrounding land use and zoning. Approximate elevations of the natural grade range from 3800 ft to 3910 ft msl. As of May 1999, an estimated 353,700 cubic yards of disposal volume had been consumed. In accordance with Montana and federal regulations, current plans for final cover at the Lewis and Clark Landfill specify installation of a prescriptive cover. Lewis and Clark County has begun investigation of the use of an alternative final cover design of equivalent performance, largely for long-term stability and economic reasons. The site contains ample sources of fine-textured borrow material appropriate for use in an infiltration-limiting application. The site owner has developed an alternative design that will be evaluated by participation in ACAP. The proposed design is a monofill-type cover utilizing sufficient on-site soils to support a vegetation community based on native grassland-type vegetation to limit deep percolation through the cover.

Regulatory Agency/Contact:
Lewis and Clark County Public Works Dept.
Will Selser
3402 Cooney Dr.
Helena, MT 59602
406.447.1635
selser@co.lewis-clark.mt.us

Type of Facility: RCRA D (MSW, industrial, commercial, C&D debris).

Annual Precipitation: 12 inches.

Test Covers:

ET cover: 15 m topsoil over 120 cm sandy clay over 30 cm sandy gravel.

Vegetation: Bluebunch, Slender, West Wheat grasses, Sandburg Bluegrass, Sheep Fescue, Blue Gamma, Green Needlegrass, and Needle-and-Thread.

Soil Properties: Sandy Clay Loam (Table B-2.1-8).

Table B-2.1-8. Physical Properties of Lewis and Clark County Landfill Borrow Source

Soil Sample		**1**	**2**	**3**	**4**
Saturated hydraulic conductivity (cm/sec)		7.9×10^{-6}	1.6×10^{-6}	8.6×10^{-8}	1.6×10^{-8}
Saturated water content		0.4576	0.4494	0.4874	0.4791
Residual water content		0.00	0.0237	0.00	0.00
Calculated unsaturated hydraulic parameters a (cm^{-1})		0.0031	0.0024	0.0015	0.0017
n		1.2586	1.3034	1.2175	1.2002
Particle size characteristics:	2μ clay	22	20	32	32
	% fines	32.42	30.69	54.96	48.9
	d_{10} (mm) d_{30} (mm)	NA 0.052	NA 0.066	NA NA	NA NA
	d_{50} (mm)	0.39	0.43	0.050	0.092
	d_{60} (mm)	0.58	0.62	0.13	0.22
	Cu Cc	NA NA	NA NA	NA NA	NA NA
Summary of Atterberg limits	LL	64.3	74.7	105.3	88.4
	PL	19.6	17.0	18.7	18.6
	PI	44.6	57.6	86.6	69.8
Classification:	USCS	CH	CH	CH	CH
	USDA	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam

Table B-2.1-9. Monitoring Results of Lewis and Clark County Landfill Test Cover

Cover Design	Start Date	Current Data	Avg. Annual Precip (mm)	Cum. Precip (mm)	Cum. Percolation (mm)	Cum. Surface Runoff (mm)	Cum. Lateral Flow (mm)	Cum. ET (mm)
ET / cap. barrier	10/19/99	07/2/03	305	760	0	50	—	680

B-2.1.4 Kiefer Landfill
Sacramento, CA (Semiarid Site)

The Kiefer Landfill occupies a 1,084-acre site in eastern Sacramento County, approximately 15 miles southeast of the Sacramento, California metropolitan area. The landfill is owned and operated by the Sacramento County Public Works Agency, Waste Management and Recycling Division (9850 Goethe Rd, Sacramento, CA, 95827-3561) and primarily serves rural portions of the county. Currently (1998) permitted operations include 660 acres, with the active fill footprint confined to a 232-acre portion of the site (the 165-acre Module M-1 and Module M-1L [67 acres]). The landfill began accepting waste in 1967. The operational site life has been projected to about the year 2035. Kiefer Landfill is a Class III disposal site and receives municipal solid wastes, commercial wastes, nonhazardous industrial wastes, and construction debris. Post-closure intended use of the site is as non-irrigated open space, consistent with the surrounding land use and zoning.

Regulatory Agency/Contact:
Sacramento County Public Works Agency
Chris Richgels
9850 Goethe Road
Sacramento, CA 95827-3561
916.875.7011
richgelse@saccounty.net

Type of Facility: RCRA D (MSW, industrial, commercial, C&D debris).

Annual Precipitation: 17.2 inches.

Test covers:

1. Thin ET cover: 1.22-m clay loam soil with native grass vegetation.
2. Thick ET cover: 2.44-m clay loam soil with Poplar/Eucalyptus tree vegetation surface.

Vegetation:

1. Thin ET cover: California Brome, Purple Needlegrass, Zorro Fescue, Arroyo Lupin, and Oleander bushes.
2. Thick ET cover: hybrid poplar or eucalyptus trees.

Soil Properties: (Table B-2.1-10).

Table B-2.1-10. Physical Properties of Kiefer Landfill Borrow Soil

Soil Property		Value
Saturated hydraulic conductivity (cm/sec)		1.23×10^{-6}
Calculated unsaturated hydraulic parameters:	a (cm^{-1})	0.00133
	n	1.16864
Particle size characteristics:	2µm clay	9.4%*
	% fines	40.4%*
	d_{10} (mm)	0.0026*
	d_{30} (mm)	0.052*
	d_{50} (mm) d_{60}(mm)	0.17*
0.45*Cu 2.31*Cc172.4*		
Summary of Atterberg limits:	LL	52*
	PL	29*
PI		23*
Classification:	USCS	SM*
USDA		Sandy loam*

Table B-2.1-11. Monitoring Results of Kiefer Landfill Test Covers

Cover Design	Start Date	Current Data	Avg. Annual Precip (mm)	Cum. Precip (mm)	Cum. Percolation (mm)	Cum. Surface Runoff (mm)	Cum. Lateral Flow (mm)	Cum. ET (mm)
thin ET-type	07/29/99	07/2/03	440	1380	102	106	—	1340
thick ET-type	07/29/99	07/2/03	440	1380	10	67	—	1088

B-2.1.5 Altamont Landfill and Resource Recovery Facility
Livermore, California (Semiarid Site)

Regulatory Agency/Contact:
Waste Management, Inc.
Ken Lewis
10840 Altamont Pass Road
Livermore, CA 94550-9745
925.455.7350
klewis@wm.com

Type of Facility: RCRA D (MSW, industrial, commercial, C&D debris).

Annual Precipitation: 13.5 inches.

Test covers:

1. Prescriptive Cover: 30-cm topsoil over a geomembrane over 30 cm of compacted soil.
2. ET cover: 30-cm minimum of intermediate cover foundation layer, 60-cmof compacted support layer, 45-cmof vegetative soil layer.

Vegetation: 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.

Soil Properties: Soil for both the intermediate cover and compacted low-permeability/support layers will be obtained on-site and will generally consist of soils ranging in USCS classification from SC or SM with greater than 30% fines to CH or MH. The vegetative soil layer will be on-site soils, lightly compacted and hydroseeded with native plant species.

Table B-2.1-12. Monitoring Results of Altamont Landfill Test Covers

Cover Design	Start Date	Current Data	Avg. Annual Precip (mm)	Cum. Precip (mm)	Cum. Percolation (mm)	Cum. Surface Runoff (mm)	Cum. Lateral Flow (mm)	Cum. ET (mm)
Composite / comp. clay	11/10/00	07/2/03	368	903	4	59	4	825
ET-type	11/10/00	07/2/03	368	903	4	84	—	818

B-2.2 Solid Waste Facilities with Approved Alternative Landfill Covers

B-2.2.1 Kirtland Air Force Base
Albuquerque, NM (Arid Site)

Kirtland Air Force Base has had three alternative final covers approved using an ET cover to close three separate solid waste facilities. Kirtland Air Force Base is located in the southwest portion of Albuquerque, NM near the Manzano Mountains. The landfills average about 40 acres each in size. The first cover was constructed and completed in 2003 (Figure B-2.2-1).

Figure B-2.2-1. ET cover installation on Kirtland Air Force Base

Regulatory Agency/Contact:
New Mexico Environment Department

Type of Facility: Solid Waste Facility, RCRA Subtitle D.

Annual Precipitation: 8.5 inches.

Test covers:

Used the ALCD, Sandia National Laboratory test covers data – see under Test Covers section.

Vegetation: Native grasses.

Table B-2.2-1. Soil Properties at KAFB

Layer	Thickness (cm)	Dry Density (g/cm^3) @ Specific Gravity	Saturated Hydraulic Cond. (cm/hour)	Porosity	Van Genuchten Parameters			
					θ_s (vol/vol)	θ_r (vol/vol)	α (1/cm)	n
Com-pacted Soil	120	1.6 @ 2.7	1.43856	0.41	0.3951	0.06	0.0508	1.36

B-2.2.2 New ET Cap Technology Covers Landfills at Fort Carson

Fort Carson, Colorado, completed in October 2000: The first of three ET covers relying on the use of native soils and plants as cap material rather than the more typical plastic sheeting and imported clay.

While not compromising performance, savings could reach approximately $100,000 per acre compared to conventional RCRA Title C landfill caps, according to the Fort Carson Directorate of Environmental Compliance and Management.

Figure B-2.2-2. Discing soil prior to seeding

Fifteen of the 20 acres of the World War II-era landfill were covered by an ET cover. The remaining five acres will be capped conventionally, paved over, and then used for the location of an Army Reserve motor pool.

Fort Carson demonstrated to the regulators that the ET cap technology was safer for the environment and less expensive than prescriptive landfill covers.

In addition, Fort Carson is using about 500 tons of biosolids (sewage sludge) from its wastewater treatment plant as a soil amendment on top of the cap. The installation will monitor the cap to make certain it performs as predicted.

B-2.2.3 Other Solid Waste Facilities with Alternative Landfill Covers in Semiarid to Arid Climates from U.S. EPA's Website

<u>Yucaipa Landfill, Yucaipa, CA</u>

Monolithic ET cover approved and monitored consisting of 48 inches of silty sand. LEACHM water balance model used for approval. Initial data for moisture content shows consistency with model.

Twenty Nine Palms MCAGCC, Twenty Nine Palms, CA

Monolithic ET cover approved and monitored consisting of 73 inches of poorly graded sand with silt. Water balance model used for application was HELP (probably accounted for the overly thick cover). No measurable infiltration detected to date.

Coyote Canyon Landfill, Somis, CA

Monolithic ET cover approved with monitoring. Results showed that water migrated downward to 36 inches but had no impact on dry soils at 51 inches that remained dry. Flux showed strong upward suction, which draws stored water up to the surface, where it was evaporated.

Lopez Canyon Landfill, CA

Monolithic ET cover approved with monitoring in Los Angeles area. Design was silt sand/clayey sand layer overlying 2-foot foundation layer. UNSAT-H model predicted no percolation in first year and less than the conventional cover in the next 10 years. First three years of data show a less than 5% change in relative volumetric moisture at bottom compared to 90% near surface. Approval obtained for final cover construction.

Pantex Plant, Amarillo, TX

Monolithic ET cover installed over C&D site consisting of 12–18 inches of topsoil and 18 inches of fill soil. Native grasses and winter wheat used for plants.

Denver Arapahoe Disposal Site, Arapahoe County, CO

Monolithic ET cover approved consisting of 6 inches of topsoil and 30 inches of lightly compacted soil (minimum of 28% fines). Compacted to 80–90% of maximum dry density. Monitored with six leachate sumps for quantity over time. UNSAT-H used for water balance.

Gaffey Street Sanitary Landfill, Wilmington, CA

Capillary barrier ET cover approved and installed. UNSAT-H used for model showing less than 3 cm/year infiltration or 0.2% of total precipitation plus irrigation.

Coyote Canyon Landfill, Somis, CA

Monolithic ET cover approved and operational since 1994. Design was 78 inches local soils with 30 inches of fine-grained soil for barrier layer. Total thickness was due to support of habitat of threatened California gnatcatcher. Monitoring with soil moisture probes showed strong upward flux and uneven infiltration due to microclimates on each side of landfill.

Kirtland AFB, Albuquerque, NM

Monolithic ET cover approved and operational since 2003.

Mr. “M” Landfill, Lewiston, MT

Monolithic ET cover installed and approved consisting of 6 inches of topsoil, 30 inches of soil. Water Balance model was Chemflo.

Norton Air Force Base, CA

Monolithic ET cover approved and installed.

California Valley Landfill, CA

Monolithic ET cover installed.

Del Rio Landfill, Phoenix, AZ

Monolithic ET cover approved.

El Toro Marine Corps, Station, CA

Monolithic ET cover approved for full scale.

Sunshine Canyon Landfill, CA

Monolithic ET cover approved for full scale.

Azusa Landfill, CA

Monolithic ET cover approved for full scale.

Bishops Canyon Landfill, Los Angeles, CA

Monolithic ET cover approved for full scale.

Bradley Landfill, Sun Valley, CA

Monolithic ET cover approved for full scale.

B-2.3 Superfund Sites with Approved Alternative Landfill Covers

B-2.3.1 Rocky Mountain Arsenal
Denver, CO (Semiarid Site)

Multiple landfills and sites to be closed covering hundreds of acres: Former Basin F, Complex & Shell Trenches Basin A, South Plants Central Processing.

RMA is currently closing multiple sites with ET covers and capillary barriers. The RMA was once considered the most contaminated site in the United Sates. It is the site of the military's biological chemical weapons fabrication. Some areas in the site are deemed too hazardous to remove and thus must be closed in place by means of an ET cover.

Type of Facilities: CERCLA (Hazardous).

Annual Precipitation: 19 inches.

Vegetation: Native grasses.

Soil: Silty sand.

B-2.3.2 Operating Industries, Inc. (OII) Superfund Landfill Monterey Park, CA (Semiarid Site)

OII Superfund landfill in southern California closure constitutes the first ET cover approved by the EPA for construction at a Superfund site.

Type of Facility: CERCLA.

Figure B-2.3-1. OII Landfill

Average Precipitation: 14.9 inches per year.

The selected baseline cover was a 1500-mm-thick single soil layer with a saturated hydraulic conductivity of 1027 m/s and moisture retention characteristics typical of silty soils. The average fines content reported for these soils is 54% and the plasticity index is 5% ~USCS designation ranges over CL to ML. Campbell's fitting parameters used for the baseline cover are listed in Table B-2.3-1. Weather data needed for the analyses includes daily precipitation and daily minimum and maximum air temperatures. Weather conditions generated for 30 years using data for southern California led to an average precipitation of 379 mm/year and an average evapotranspiration of 1015 mm/year.

Table B-2.3-1. Properties Used in Baseline Cover Analysis[1]

Property Value	
Soil Campbell parameter *a*	24.89
Campbell parameter *b*	4.215
Weather yearly average precipitation	379 mm
Vegetation rooting depth	300 mm
Data wilting point	1500 kPa
Minimum root potential	3000 kPa
Maximum potential/actual transpiration ratio	1.1
Root resistance ratio	1.05
Crop cover fraction	0.75
Modeling initial volumetric moisture	23%

[1] "Journal of Geotechnical and Geoenvironmental Engineering" © ASCE / May 2003 / 429

B-2.3.3 Lee Acres Superfund Site Farmington, NM (Arid Site)

Point of Contact:
Steve Dwyer of Dwyer Engineering, LLC
DwyerEngineering@yahoo.com

Monitoring over a multiple-year period indicated zero flux. Farmington, NM is located in the northeast corner of New Mexico near the four corners region of New Mexico, Arizona, Utah, and Colorado. The site was originally permitted as a municipal landfill in 1962. However, in 1980 it was expanded to include the disposal of liquid waste. Containment berms were built where liquid waste was dumped. Plumes formed that found their way to the groundwater that was used by a local community. This groundwater was contaminated. The landfill was closed to liquid waste disposal in 1985 and solid waste disposal in 1986. Lee Acres is listed on the EPA's National Superfund Database, identification number NMD980750020. The Record of Decision stated that the site will be covered with a capillary barrier. A test cover was placed and monitored at the site in 1997.

Figure B-2.3-2. Lee Acres Landfill, Farmington, NM

Regulatory Agency/Contact:
Sai Appaji
Remedial Project Manager
USEPA Region 6, Superfund Division
Dallas, TX 75202
214.665.3126

Type of Facility: CERCLA (hazardous waste).

Annual Precipitation: 7 inches.

Test Cover:

Capillary barrier 15 cm soil gravel admixture surface treatment over 76 cm soil layer over 15 cm of pea gravel.

Actual Cover: Same as test cover.

Vegetation: Native grasses.

Soil Properties:

The soil to be used comes from a nearby borrow source composed of silty sand (Denoted SM).

Table B-2.3-2. Lee Acres Landfill Soil Properties

Dry Density (g/cm^3)	Sat. Hydraulic Conductivity (cm/sec)	Porosity	Van Genuchten Parameters			
			θs	θr	α (1/cm)	n
1.70	8.37e-4	0.371	0.333	0.036	0.0444	1.56

B-2.3.4 Idaho National Engineering and Environmental Laboratory (INEEL) Idaho Falls, Idaho (Arid Site)

A number of landfills have been established on the INEEL that contain municipal, hazardous, or radiological waste. Several of these landfills have been closed (or are approved to be closed), with surface covers emplaced over the buried waste. Covers range from simple evapotranspiration designs to protect human health and the environment for existing historical disposal sites at Central Facilities Area (CFA) and Naval Reactor Facility (NRF) to a complex multi-layered surface cover at the ICDF that was developed for an engineered, long-term treatment, storage, and disposal facility. Two sets of research covers have been studied at the INEEL. The alternative covers installed at the site are summarized in Table B-2.3-3. The Protective Cap/Biobarrier Experiment (PCBE) landfill covers mainly focused on the ecological relationship to cover designs, and the Engineered Barrier Test Facility (EBTF) covers examined surface barrier hydrologic performance with high surface infiltration rates.

Precipitation: 8.7 inches per year.

Table B-2.3-3. Summary of INEEL Landfills and Their Covers

LANDFILL					COVER							
Name	Type	Installed (yr)	Waste Disposal Method	Contents	Type	Total Thick-ness m (ft)	Vegetative Cover Thickness m (ft)	Bio-Barrier Thickness m (ft)	Geomem-brane	Surface Slope (%)	Gas Venting	Monitoring System
CFA Landfill I	Municipal	Early 1950s	Trenches	Construction debris, paper, cafeteria garbage, wood, paper, flammable materials	Native soil ET		Yes	N/A	None		None	Cap –TDR, neutron probe Vadose – soil gas Aquifer – monitoring wells
CFA Landfill II	Municipal	1972	Direct disposal	Trash sweepings, cafeteria garbage, wood and scrap lumber, masonry/ concrete, metals, liquid waste	Native soil ET		Yes, with riprap over NE face	N/A	None		None	Cap – TDR, neutron probe Vadose – soil gas Aquifer – monitoring wells
CFA Landfill III	Municipal	1982	Trenches	Trash sweepings, cafeteria garbage, wood and scrap lumber, masonry/ concrete, waste asphalt, paint	Native soil ET		Yes	N/A	None		None	Cap –TDR, neutron probe Vadose – soil gas Aquifer – monitoring wells
NRF landfills	Radio-logical	2004	Leach fields	Soil	ET with bio-barrier	1.75 (5.7)	Grasses and forbs	0.45 (1.5)	None		None	Surface – rad sampling Cap – neutron probe Aquifer – monitoring wells

Table B-2.3-3. (continued)

LANDFILL					COVER							
Name	Type	Installed (yr)	Waste Disposal Method	Contents	Type	Total Thick-ness m (ft)	Vegetative Cover Thickness m (ft)	Bio-Barrier Thickness m (ft)	Geomem-brane	Surface Slope (%)	Gas Venting	Monitoring System
PCBE	8 m × 8 m test plots	1997	N/A	N/A	ET with shallow biobarrier	2.5 (8.2)	1) wheatgrass, 2) 12 native plants	0.5 (1.6)	None	0	None	Cap – soil moisture, changes vegetation, plant rooting depths
PCBE	8 m × 8 m test plots	1997	N/A	N/A	ET with deep biobarrier	2.5 (8.2)	1) wheatgrass, 2) 12 native plants	0.5 (1.6)	None	0	None	Cap – soil moisture, changes vegetation, plant rooting depths
EBTF	4 (??)– 3 m × 3 m cells	1996	N/A	N/A	ET	??	None	0	None	0	None	Cap – tensiometers, TDR's, heat dissipation sensors, thermocouples, neutron probe
EBTF	4 – 3m × 3 m cells	1996	N/A	N/A	Capillary barrier	2.51 (8.2)	None	0.76 (2.5)	Yes	0	None	Cap – tensiometers, TDR's, heat dissipation sensors, thermocouples, neutron probe

**B-2.3.5 Hastings Groundwater Contamination Superfund Site
Hastings, NE**

Monolithic ET cover approved to minimize infiltration and reduce contaminant migration in groundwater. Design is 27 inches native soil. Water balance model is UNSAT-H. Accepted in place of GCL cover. ARARs require an alternative cover design provides “equivalent reduction” in infiltration and “equivalent protection” from wind and water erosion when compared to conventional designs. Cover design agreed to by EPA, state, and PRPs was based on data from ET cover performance from ACAP projects and other sources. Conceptual design approved in September 2002.

B-2.4 Landfill Cover Demonstrations

**B-2.4.1 DOE-Hanford Superfund Site
Richland, WA**

A barrier development program was started in the mid-1980s at the Hanford Site as recommended by the “Final Environmental Impact Statement for the Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes.” The goals of the barrier program were to develop reliable technology for permanent, long-term containment of near-surface radioactive waste or waste/residuals that were too deep, hazardous, and/or expensive to excavate. It was determined that test lysimeters should be constructed and designed for outside experiments to simulate actual climatic conditions at Hanford. A lysimeter can measure quantities of water used by plants, evaporated from soil, and lost by deep percolation. In 1987, the Field Lysimeter Test Facility (FLTF) was constructed and data collected up to 1994 under the Protective Barrier Program. Between the end of 1994 and 2004, the Integrated Disposal Facility project sponsored the tests. The original tests helped to design the Hanford Barrier, which is a full-scale cover system completed in 1994 and monitored to date. Lysimeter tests conducted between 1994 and present also incorporated effects of erosion and dune sand migration. Figure B-2.4-1 shows the original FLTF in 1988.

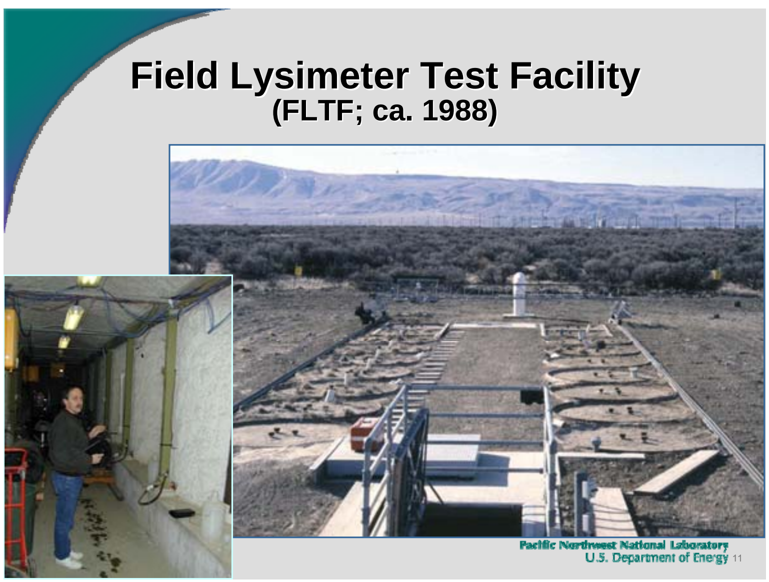

Figure B-2.4-1. Field Lysimeter Test Facility, ca. 1988 (Fayer 2005)

The FLTF contains a total of 24 lysimeters of three types: 14 drainage, 4 weighing, and 8 small-tube lysimeters.

The climate of Hanford typically is hot, dry summers and cool, wet winters. Annual precipitation is 160 mm. November through January typically receive about 45% of average annual precipitation; in July through September, 13% of annual precipitation occurs. Snowfall accounts for about 38% of the precipitation moisture content, accumulating an average of 335 mm.

Small-Tube Lysimeters (five with similar dimensions)

Small-tube lysimeters are 169 cm long and 30.4 cm in diameter. Each tube was fitted with a drain port and could be weighed to determine water storage to within an accuracy of 1.4 mm. Five different cover designs were tested as capillary barrier ET covers:

1. 15 cm of 1–3-cm diameter gravel to control erosion, 135 cm of silt loam over a three-layer sand and gravel filter, tested with and without vegetation as Cheatgrass.
2. 150 cm of silt loam over a 20-cm sand and gravel mixture with and without vegetation as Cheatgrass.
3. 150 cm of silt loam over a 20-cm graded sand filter with and without Cheatgrass.
4. 20 cm of silt loam mixed with 30% gravel (by weight) to control erosion, 130 cm of silt loam over a three-layer sand and gravel filter with and without Cheatgrass.
5. 150 cm of silt loam over a three-layer sand and gravel filter with and without vegetation as Cheatgrass.

The results for all five cover designs that used silt loam as the moisture-holding layer showed no infiltration for the 3–3.5 years of monitoring, even with those with supplemental irrigation representing twice the average monthly precipitation. This was the case regardless if there was a vegetation layer. It was also shown that erosion control can be enhanced with a significant quantity of gravel as an admixture without negatively altering the drainage or water storage characteristics of the cover design. Monitoring with three times precipitation after the original 3.5-year test showed drainage through the barrier, but only for those lysimeters without vegetation. These tests showed that silt loam is the key design element for the full-scale Hanford Barrier.

Small Tube Clear Lysimeter (two with similar dimensions)

The two small tube clear lysimeters are 3 m in depth and 0.3 m in diameter. A drainage port at the bottom allows drainage to be collected and weighed. The cover designs for the two lysimeters are as follows:

1. 1.5 m of screened sand over 1.5 m of gravelly sand with and without Cheatgrass vegetation.
2. 0.15 m of coarse gravel, 1.35 m of screened sand, and 1.5 m of gravelly sand with and without vegetation.

For the first three years, supplemental irrigation was applied at twice the annual average for the first three years and for the next three years, irrigation was increased to three times the annual average. During the six-year study, infiltration was observed, but the cover design with vegetation drained the least for both design cases. The first designs represented the Pitrun Sand taken from the on-site borrow pit to evaluate hydraulic characteristics of this component of the Hanford Barrier. This design had an average of 21.8 mm/year of infiltration under ambient precipitation and 63.5 mm/year under enhanced precipitation. The second design represented the gravel mulch component of the Hanford Barrier full-scale operation and had 89.1 mm/year of infiltration under ambient precipitation and 332 mm/year under enhanced precipitation.

Drainage Lysimeters

There are two different cover designs represented in these test lysimeters. The drainage lysimeter is a steel cylinder 2 m in diameter and 3 m in length. Each lysimeter has drain fittings and access ports allowing installation of thermocouples, psychrometers, tensiometers, and neutron probes for monitoring soil moisture. The two different cover designs tested are described as follows:

1. 1.5 m silt loam and 0.3 m of sand and gravel mixture over 0.1-m diameter rock in a steel with and without Cheatgrass vegetation.
2. 1.0 m silt loam and 0.3 m of a sand and gravel mixture over 0.1-m diameter rock with and without Cheatgrass vegetation.

Comment [MSOffice1]: Correct?

The first lysimeter represented the design thickness of the top layer of silt loam of the Hanford Barrier, and the second lysimeter mimicked an eroded Hanford Barrier by reducing the thickness of silt loam from 1.5 m to 1.0 m. The test results for infiltration show that the first lysimeter with plants performs well below the design specification of 0.5 mm/year to date. Without plants, it functions even at two times normal precipitation. Only at less than three times precipitation did the lysimeter with no plants allow drainage to occur. The second lysimeter with shrub-steppe vegetation only continues to show no drainage, even for the enhanced precipitation regimes.

The following show a summary of the original and additional FLTF and infiltration results, as follows:

Results of Original FLTF Tests

Description	Precip. Trtmt.*	Plant Trtmt.	Reps	Obs. Periods (yr)	Avg. Drainage (mm/yr)
Hanford Barrier (1.5 m silt loam)	Ambient	Shrub-steppe	4	4.3 to 14.8	all **0.0**
	Ambient	No plants	3	8.2 to 11.6	**0.0** to **0.2**
	Enhanced	Shrub-steppe	4	4.0 to 12.8	all **0.0**
	Enhanced	No plants	3	7.9 to 12.0	**6.1** to **16.2**
Hanford Barrier w/Gravel Admix (1.5 m silt loam)	Ambient	Shrub-steppe	2	4.3 to 7.3	both **0.0**
Eroded Hanford Barrier (1.0 m silt loam)	Ambient	Shrub-steppe	2	8.2 to 12.6	both **0.0**

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*Enhanced Precipitation = 32 cm/yr for 3 years, then 48 cm/yr

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Figure B-2.4-2. Results of original FLTF tests (Fayer 2005)

Results of Additional FLTF Tests

Description	Plant Trtmt.	Reps	Avg. Drainage (mm/yr) Ambient Precipitation	Enhanced Precipitation*
Gravel Mulch	No plants	1	89.1	332.0
Pitrun Sand	Shrub-steppe	1	21.3	69.0
Basalt Side Slope	No plants	1	53.9	269.0
Sandy Gravel Side Slope	No plants	1	109.0	365.0
Hanford Barrier: Eroded, then Dune Sand Deposition	Shrub-steppe	2	0.0, 0.0	58.5, 123
Modified RCRA Subtitle C Barrier	Shrub-steppe	1	0.0	0.0

Battelle *Enhanced Precipitation = 32 cm/yr for 3 years, then 48 cm/yr

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Figure B-2.4-3. Results of additional FLTF tests (Fayer 2005)

Other lysimeter tests were conducted for construction materials for the side slopes as seen in Figure B-2.4-3. It is interesting to note that the gravel mulch had significantly more drainage than the basalt side slope, even though the basalt had larger rock size and void space. The Hanford Barrier silt loam also performed well simulating erosion. No infiltration occurred under normal precipitation. At three times precipitation, no significant drainage occurred.

The modified RCRA Subtitle C Barrier uses a 1-m silt loam soil. The first upper half is amended with pea gravel (15% by weight) and the lower half is compacted, to create a low conductivity layer. The sand filter and gravel drainage layer were placed below. This vegetated test lysimeter shows no drainage, even with three times precipitation treatment.

Hanford Barrier Prototype Full-Scale Test Results

After 10 years of research, including the lysimeter testing program, a multi-layered earthen barrier was developed and a prototype barrier constructed in 1994 over an existing waste site. The cover system was highly instrumented to provide a complete water balance, including accurately measured drainage from cover and side slope. Monitoring of the cover system has been ongoing since 1994. Details of the design of the Hanford Barrier are shown in Figure B-2.4-4 for the rip-rap side slope section and the Pitrun gravel side slope section.

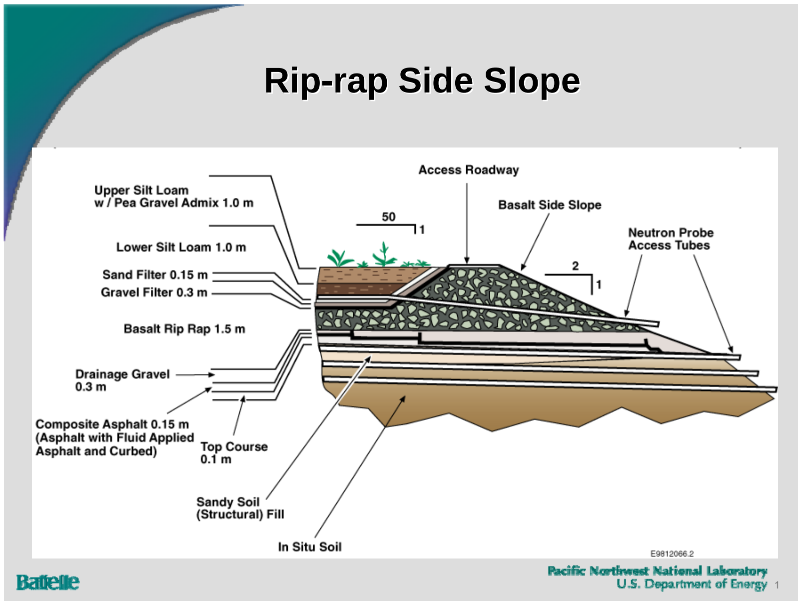

Figure B-2.4-4. Rip-rap side slope (Fayer 2005)

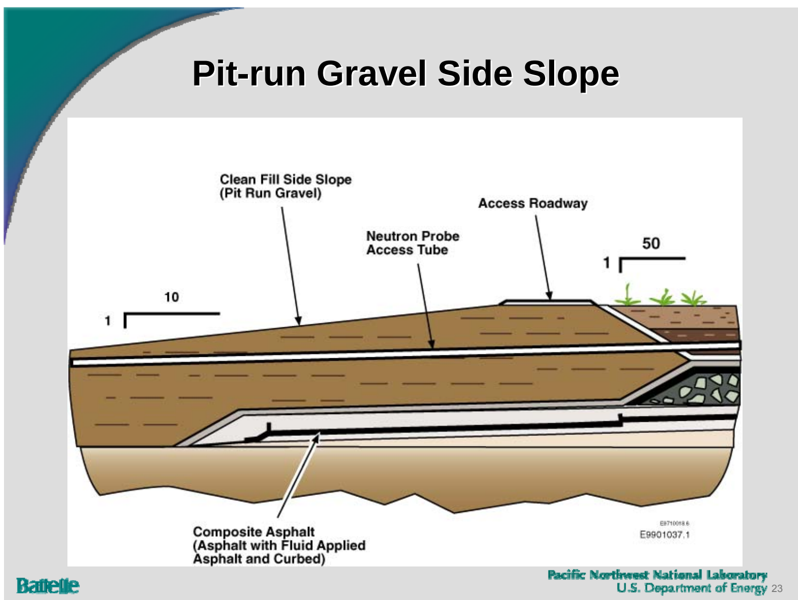

Figure B-2.4-5. Pit-Run gravel side slope (Fayer 2005)

The cover system is instrumented with a 6.5-meter square basin lysimeter beneath the asphalt pad of one of the collection basins to monitor infiltration through the asphalt layer. Fourteen water balance monitoring stations are located throughout the cover and allow use of a neutron probe, capacitance probe, segmented time domain reflectometry, and heat dissipation units for monitoring soil moisture. Drainage from the collection zones is monitored with use of tipping bucket gauges and dosing siphons. Plant community and burrowing animal activities are monitored. Rock creep gauges and differential settlement gauges are surveyed using electronic distance measuring equipment to determine movement with the cover. The area of the cover is 6.9 acres with Cheatgrass vegetation.

Results to date: Of over nine years of monitoring, percolation occurred in only one test plot (less than 2 mm) following the third simulated 1,000-year storm event. Total percolation was less than 5% of the prescribed limit of 5 mm/year. Percolation from the remaining plots has been very small, attributed to condensation in drainage pipes. However, the side slopes, as noted in the above table, have generated significant amounts of drainage. About 23% of the total precipitation was infiltrated on the irrigated gravel slope and 21% for the non-irrigated gravel slope. In contrast, the non-irrigated rip-rap basalt rock slope drained only 15% of precipitation, whereas the irrigated rip-rap basalt rock slope drained about 23%. This discrepancy has been attributed to water loss from wind action on the rock surfaces, which acts to reduce drainage from the rock slopes.

B-2.4.2 ALCD
Sandia National Laboratories
Albuquerque, NM (Arid Site)

PI: Stephen F Dwyer, PhD, PE
505.844.0595

Six large-scale landfill test covers were constructed and monitored for water balance from May 1997 through June 2002 (Figure B-2.4-6). Two of the covers were used as EPA standard baseline prototypes for comparison: one that met minimum requirements set forth for municipal landfills (RCRA Subtitle D Cover) and the other meeting minimum requirements set forth for hazardous waste landfills (RCRA Subtitle C Cover). Four alternative covers were then constructed side-by-side with the baseline covers to enable direct comparison under the same ambient conditions. The first alternative cover featured a GCL designed for low saturated hydraulic conductivity. The remaining three covers were designed specifically for optimal performance in dry environments; specifically, they were designed to take advantage of the storage capacity of the cover and maximize removal of water via evapotranspiration. Two of the dry environment alternative landfill covers featured capillary barriers within their profiles while the last cover consisted of a simple monolithic soil cover, referred to as an ET cover. Details of the project are described in Dwyer (2003).

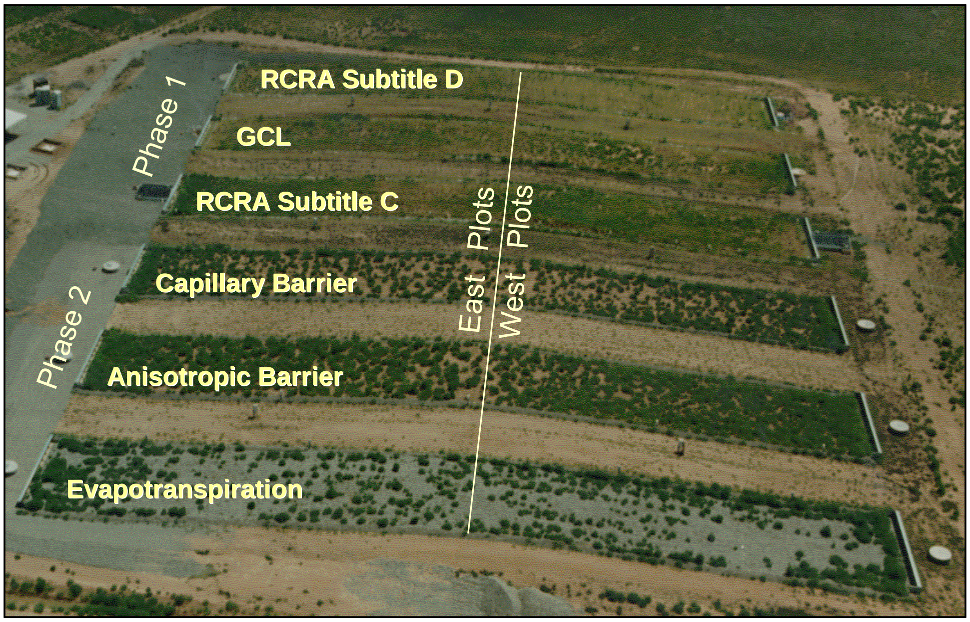

Figure B-2.4-6. ALCD @ Sandia National Laboratories

Table B-2.4.1 Seed Mix for ALCD
Vegetation:

Desired Establishment	Quantity in Mixture(1) (% of total vegetation) (kg/hectare	Seed(2)
Warm Season Grasses:		
Bouteloua gracilis (Blue Grama)	20	1.1
Hilaria jamesii (Galleta)	10	3.4
Sporabolis cyptandrus (Sand Dropseed)	50	0.6
Cool Season Grasses:		
Oryzopsis hymenoides (Indian Ricegrass)	10	3.4
Stipa comata (Needle & Thread)	10	4.5

(1) Approximate percentage of total species present in number of plants per given area.
(2) Note that differences in weight among the various species can result in large differences in the mass ratio (kg/ha) of seed required in the seed mixture.

Table B-2.4-2. Subtitle D Cover in ALCD
Soil Properties:

Layer	Thick-ness (cm)	Dry Density (g/cm^3) @ Specific Gravity	Saturated Hydraulic Cond. (cm/hour)	Porosity	Van Genuchten Parameters				Initial Suction Value (cm)
					θ_s (vol/vol)	θ_r (vol/vol)	α (1/cm)	n	
Topsoil	15	1.5 @ 2.7	3.6374	0.45	0.4328	0.06	0.1057	1.36	700
Barrier Soil	45	1.7 @ 2.7	0.004426	0.37	0.3587	0.06	0.033	1.36	1000
Pea Gravel (1)	23	1.65 @ 2.64	15,912	0.374	0.374	0.017	2.5075	2.47	11

Table B-2.4-3. Capillary Barrier in ALCD

Layer	Thick-ness (cm)	Dry Density (g/cm^3) @ Specific Gravity	Saturated Hydraulic Cond. (cm/hour)	Porosity	Van Genuchten Parameters				Initial Suction Value (cm)
					θ_s (vol/vol)	θ_r (vol/vol)	α (1/cm)	n	
Topsoil	30	1.5 @ 2.7	3.6374	0.45	0.4328	0.06	0.1057	1.36	1000
Sand	15	1.66 @ 2.64	65.52	0.37	0.34	0.026	0.0597	2.81	16
Pea Gravel	23	1.65 @ 2.64	15,912.	0.374	0.374	0.017	2.5075	2.47	11
Compacted Soil	45	1.6 @ 2.7	1.43856	0.41	0.3951	0.06	0.0508	1.36	10,000
Sand	30	1.66 @ 2.64	65.52	0.37	0.34	0.026	0.0597	2.81	16

Table B-2.4-4. Anisotropic Barrier in ALCD

Layer	Thick-ness (cm)	Dry Density (g/cm^3) @ Specific Gravity	Saturated Hydraulic Cond. (cm/hour)	Porosity	Van Genuchten Parameters				Initial Suction Value (cm)
					θ_s (vol/vol)	θ_r (vol/vol)	α (1/cm)	n	
Topsoil	30	1.5 @ 2.7	3.6374	0.45	0.4328	0.06	0.1057	1.36	1000
Compacted Soil	45	1.6 @ 2.7	1.43856	0.41	0.3951	0.06	0.0508	1.36	1000
Sand	30	1.66 @ 2.64	65.52	0.37	0.34	0.026	0.0597	2.81	16
Pea Gravel	23	1.65 @ 2.64	15,912.	0.374	0.374	0.017	2.5075	2.47	11

Table B-2.4-5. ET Cover in ALCD

Layer	Thick-ness (cm)	Dry Density (g/cm^3) @ Specific Gravity	Saturated Hydraulic Cond. (cm/hour)	Porosity	Van Genuchten Parameters				Initial Suction Value (cm)
					θ_s (vol/vol)	θ_r (vol/vol)	α (1/cm)	n	
Topsoil	30	1.5 @ 2.7	3.6374	0.45	0.4328	0.06	0.1057	1.36	2643
Compacted Soil	45	1.7 @ 2.7	0.1563	0.41	0.3587	0.06	0.033	1.36	2643
Pea Gravel (1)	23	1.65 @ 2.64	15,912	0.374	0.374	0.017	2.5075	2.47	11

(1) Modeled to simulate the bottom lysimeter.

Table B-2.4-6. Average Annual Flux Measured Results

Landfill Cover	Average Annual Flux (mm/year)
Subtitle D	1.39
GCL Cover	0.48
Subtitle C	0.04
Capillary Barrier	0.16
Anisotropic Barrier	0.04
ET Cover	0.05

B-2.4.3 Other Demonstration Sites

Uranium Mill Tailings Repository, Monticello, UT

Demonstration project consisting of horizontal lysimeter with instrumentation within soil. Design is 8 inches soil/gravel admixture, 36 inches of fine-grained soil, 12 inches of soil/rock admixture (biointrusion layer), 12 inches of fine-grained soil, geotextile filter, and 14 inches of sand. Results showed less than 0.1 mm/yr percolation relative to precipitation of 350 mm/yr.

Nevada Test Site, NV

Monolithic ET cover approved for full scale operational. Monitored by TDR at 8 depths from 1 to 8 feet. Design is 1 foot topsoil and 10 feet of compacted native alluvium soil. After two years of monitoring, water infiltrated less than 2 feet into cover before being removed via ET.

<u>Milliken Landfill, San Bernardino County, CA</u>

Monolithic ET cover of 60 inches of silty sands and native grasses and shallow rooting shrubs. Lysimeters and soil moisture probes constructed, including prescriptive cover as comparison. Monitoring shows less than 0.04% infiltration compared to rainfall.

<u>Apple Valley Landfill, Apple Valley, CA</u>

Monolithic ET cover over large vertical cylinder of MSW with leachate collection to evaluate cover effects of thickness of landfill. Infiltration will be evaluated based on leachate quantity results over time.

<u>Phelan Landfill, Phelan, CA</u>

Monolithic ET cover demonstration installed in 1998 consisting of four horizontal lysimeters and eight moisture capacitance probes. Design was 1.5 m of gravelly sands with silt and native annual grasses and shrubs. Infiltration varied with aspect and soil depth, with north slopes having more infiltration than east slopes.

Other demonstration projects are summarized below in tabular format.

Table B-2.4-7. Field Data from Landfill Cover Test Plots

Location	Reference	Design	Size	Flux (1)	Comments
Los Alamos National Laboratory, Los Alamos, NM	Nyhan et al., 1990	1. Subtitle D 'type' Cover (20 cm sandy loam, 108 cm crushed tuff)	3 m × 10.7 m	10.6 cm	Precipitation = 173.7 cm
		2. Capillary Barrier (71 cm sandy loam over sand and gravel)		2.6 cm	
Los Alamos National Laboratory, Los Alamos, NM	Nyhan et al., 1997	1. Subtitle C 'type' Cover (61 cm loam, 30 cm sand, 30 cm bentonite amended tuff – no geomembrane)	1 m × 10 m	0 to 0	5% to 25% slope; no vegetation on covers; 1991 to 1995 monitoring period
		2. Capillary Barrier #1 (15 cm topsoil, 76 cm crushed tuff, 30 cm gravel)		17.40 cm to 3.09 cm	
		3. Capillary Barrier #2 (30 cm loam, 76 cm fine sand, 30 cm gravel)		9.64 cm to 0	
		4. Capillary Barrier #3 (30 cm loam and bentonite, 76 cm fine sand, 30 cm gravel)		5.59 cm to 0	
Wenatchee, WA	Khire et al., 1997; Benson et al., 1994	1. Subtitle D Cover (15 cm topsoil, 60 cm silty clay)	18.3 m × 12.2 m	0.5 cm	1992 to 1995 monitoring period
		2. Capillary Barrier (15 cm topsoil, 75 cm sand)		3.2 cm	

Location	Reference	Design	Size	Flux [(1)]	Comments
Hill Air Force Base, Utah	Hakonson et al., 1994	1. Subtitle C ‘type’ Cover (120 cm topsoil, 30 cm sand, 60 cm bentonite amended loam – no geomembrane)	5 m × 10 m	0.01 cm	1990 to 1994 monitoring period; covers vegetated with native grasses –capillary barrier #2 also included shrubs; 4% slope; precipitation = 173 cm
		2. Soil Cover (90 cm sandy loam)		41 cm	
		3. Capillary Barrier #1 (150 cm topsoil, 30 cm gravel)		24 cm	
		4. Capillary Barrier #2 (150 cm topsoil, 30 cm gravel)		30 cm	
Omega Hills Landfill, Milwaukee, Wisconsin	Montgomery and Parsons, 1990	1. Subtitle D ‘type’ Cover (15 cm topsoil, 120 cm clay)	6 m × 12 m	6.11 cm	1986 to 1989 monitoring period; 33% slope
		2. Subtitle D ‘type’ Cover (45 cm topsoil, 120 cm clay)		9.67 cm	
		3. Capillary Barrier (15 cm topsoil 30 cm glacial till, 30 cm sand, 60 cm clay)		10.30 cm	
Grede Foundries, Reedsburg, Wisconsin	Verbicher Associates, 1996	1. Subtitle D Cover (15 cm topsoil, 60 cm clay)	None given	108 mm/yr	1992 to 1996 monitoring period; test located on mine tailings pile
		2. Subtitle D ‘type’ Cover (15 cm topsoil, 90 cm native soil, 60 cm clay)		45 mm/yr	
		3. Capillary #1 (15 cm topsoil, 90 cm sand, 60 cm clay)		1.1 mm/yr	
		4. Capillary Barrier #2 (15 cm topsoil, 90 cm sand, 90 cm bentonite amended sand)		1.3 mm/yr	
		5. Capillary Barrier #2 (15 cm topsoil, 90 cm sand, 150 cm bentonite amended sand)		2 mm/yr	
Nuclear Regulatory Commission, Beltsville, MD	O’Donnell et al., 1994; Schultz et al., 1995	1. Vegetated Soil Cover (400 cm native soil)	13 m × 19 m	127 cm	1990 to 1994 monitoring period
		2. Resistive Barrier with Riprap (riprap, 30 cm gravel, 45–60 cm clay)		0	
		3. Resistive Barrier with Vegetation (20 cm topsoil, 30 cm gravel, 45–60 cm clay		0	

Location	Reference	Design	Size	Flux [1]	Comments
		4. Capillary Barrier with Vegetation (20 cm topsoil, 30 cm gravel, 45–60 cm clay, 20 cm native soil, 20 cm gravel)		0.13 cm	
Geogrswerder, Germany	Melchior, 1997	1. Subtitle C 'type' Cover (75 cm topsoil, 25 cm sand, 60 cm compacted soil – no geomembrane) @ 4% slope	10 m × 50 m	138 mm	1987 to 1993 monitoring period
		2. Subtitle C 'type' Cover (75 cm topsoil, 25 cm sand, geomembrane, 60 cm compacted soil) @ 4% slope		3 mm	
		3. Capillary Barrier (75 cm topsoil, 25 cm sand, 30 cm gravel, 30 cm sand, 40 cm compacted soil) @ 4% slope		10 mm	
		4. Subtitle C 'type' Cover (75 cm topsoil, 25 cm sand, 60 cm compacted soil – no geomembrane) @ 20% slope		75 mm	
		5. Subtitle C 'type' Cover (75 cm topsoil, 25 cm sand, geomembrane, 60 cm compacted soil) @ 20% slope		4 mm	
Little Packington Landfill, Birmingham, England	Rust, 1996	1. 50 cm topsoil, 100 cm compacted (engineered) clay @ 10% slope	2 m × 5 m	7.8 mm	1992 to 1994 monitoring period
		2. 50 cm topsoil, 100 cm compacted (non-engineered) clay @ 10% slope		7.4 mm	
		3. 50 cm topsoil, 100 cm compacted (engineered) clay @ 20% slope		2.4 mm	
		4. 50 cm topsoil, 100 cm compacted (non-engineered) clay @ 20% slope		8.3 mm	

(1) Flux is cumulative over monitoring period unless noted as an annual flux.