1 of 1

FIELD LYSIMETER TEST FACILITY
STATUS REPORT IV: FY 1993

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ABSTRACT

At the U.S. Department of Energy's Hanford Site near Richland, Washington, a unique facility, the Field Lysimeter Test Facility (FLTF) is used to measure drainage from and water storage in soil covers. Drainage has ranged from near zero amounts to more than 50% of the applied water, with the amount depending on vegetative cover and soil type. Drainage occurred from lysimeters with coarse soils and gravel covers, but did not occur from capillary barrier-type lysimeters (1.5 m silt loam soil over coarse sands and gravels) except under the most extreme condition tested. For capillary barriers that were irrigated and kept vegetation-free (bare surface), no drainage occurred in 5 of the past 6 years. However, this past year (1992-1993) a record snowfall of 1425 mm (56.1 in.) occurred and water storage in the irrigated, bare-surfaced capillary barriers exceeded 500 mm resulting in drainage of more than 30 mm from these barriers. In contrast, capillary barriers, covered with native vegetation (i.e., shrubs and grasses) did not drain under any climatic condition (with or without irrigation).

In FY 1994, the FLTF treatments will be increased from 11 to 17 with the addition of materials that will simulate portions of a prototype barrier planned for construction in 1994 at the Hanford Site. The 17 FLTF treatments are designed to test the expected range of surface soil, vegetation, and climatic conditions encountered at the Hanford Site and will assist in evaluating final surface barrier designs.

EXECUTIVE SUMMARY

The Field Lysimeter Test Facility (FLTF), a unique facility for monitoring water balance of surface isolation barriers at the Hanford Site, is completing its sixth year of operation. The facility, located adjacent to the 200 West Area, near the Hanford Meteorological Station (HMS), consists of 24 lysimeters filled with a variety of soil/sediment configurations. Twenty lysimeters were constructed as capillary barriers filled with either a 1-m- or 1.5-m-thick layer of fine soil (silt loam) overlying a coarse-textured subsoil (capillary break) and simulate surface isolation barriers with two different water storage capacities. Four lysimeters were filled with gravel-covered coarse sand and simulate surfaces that lack an isolation barrier. The soil configurations, combined with different vegetation and climate (precipitation) regimes, produce 11 distinct treatments which span the extremes in expected surface water balance for Hanford Site soils and cover systems. Precipitation treatments have ranged from ambient (non-irrigated) precipitation, averaging 169 mm/yr, to accelerated precipitation, which includes ambient plus irrigation, and currently averages 480 mm/yr.

The water storage capacity and drainage characteristics of the capillary-barrier (i.e., silt loam over coarse sand/gravel) lysimeters were determined. In early 1988, shortly after the initiation of lysimeter testing, two lysimeters were saturated with water and then allowed to drain. The water storage limit (i.e., amount of water held before drainage) for these lysimeters (with 1.5-m-thick silt loam layers) was determined to be slightly over 500 mm. Decreasing amounts of drainage from these two lysimeters and from three other bare-surfaced lysimeters were observed to occur only in the summers for several years (1988-1990). Small amounts of drainage (<0.4 mm/yr), attributable to thermal gradients, occurred in five of the bare surface (wettest) lysimeters during 1991 and 1992. No drainage was observed in any of the remaining 15 capillary-barrier lysimeters, and water storage in all lysimeters remained well below 500 mm until February 1993.

Drainage (as much as 30 mm) was observed from five of the six bare, irrigated, capillary barrier-type lysimeters during 1993. The combination of irrigation and snowmelt (after a record winter snowfall of 1425 mm) caused water storage to exceed 500 mm in the bare-surface, irrigated lysimeters. During 1993, no drainage was observed in any of the remaining (15) capillary-barrier lysimeters. The non-draining capillary-barrier treatments included all ambient lysimeters (11 total), as well as all vegetated, irrigated-lysimeters (4 total).

Evapotranspiration rates from a vegetated, fine soil (silt loam) surface have been sufficiently high that all applied water from precipitation has been removed from the soil annually, under both present (ambient) and wetter climate conditions (up to three times the annual average precipitation) including this past 1992-1993 winter which had record snowfall. Optimal soil hydraulic properties (i.e., relatively high water retention/water holding capacities and unsaturated conductivities) sustain high evaporation rates from the silt loam soil. Additional water is removed when vegetation is present. The minimum water storage for vegetated treatments is about half that for non-vegetated (bare) treatments. The fact that no drainage has occurred from silt loam soils (with vegetation) after nearly 6 years of testing suggests that surface isolation barrier designs with vegetated capillary barriers, which include silt loam surfaces, will be successful in preventing recharge at waste sites at Hanford.

In contrast to the vegetated, capillary-barrier treatments, all four coarse soil (non-capillary barrier) treatments drained. Bare, sandy soil covered with gravel drained the most, vegetated sandy soil the least. Ambient precipitation treatments drained an average of 60 mm/yr, while elevated precipitation (480 mm/yr) treatments drained an average of 285 mm/yr. More than 80% of the applied water drained through the bare gravel cover this past year (1992-1993). The vegetated, sandy soil drained during 1991 and again in 1993 even though sagebrush roots had penetrated the entire 3-m depth of the vegetated lysimeters by early summer of 1991. Water storage capacity in the sandy soil was too low to prevent drainage.

Detailed soil water measurements were made at near-surface on selected silt loam-covered (capillary barrier) lysimeters during FY 1992. Soil cores were taken to depths of 35 cm and analyzed for soil water content and matric suction. Soil water contents at the near surface varied according to both treatment and sampling time. Vegetated soils were driest, with highest matric suctions at depth. Matric suctions exceeding 10 Mpa (100 bars) were observed at depths of 35 cm. The data suggest that near-surface monitoring of soil water may be needed to complement the neutron probe estimates of soil water and water storage.

A vegetation survey was made on selected capillary-barrier lysimeters. The survey showed significant increases in vegetation in response to the applied water. Under elevated precipitation treatments there were increases in plant density and leaf area index. Total biomass was correlated with plant density and leaf area index.

The FLTF test results have been used to guide the design, development, and testing program of a large-scale (100 x 60 x 15 m) prototype barrier facility located over a waste disposal facility (200 BP-1) at the Hanford Site. The prototype barrier construction was begun in September of 1993 and is scheduled for completion in April of 1994. Water balance data for both soil and gravel surfaces are available from the FLTF and will continue to guide the water balance tests at the prototype barrier. These tests are expected to show that net water infiltration can be controlled effectively on silt loam soil cover surfaces but that large amounts of water will infiltrate gravel-covered side slopes. Quantification of the actual water infiltration and drainage through the sideslopes will be a key contribution from the prototype barrier testing.

Complementary work to prototype-barrier testing will be conducted at the FLTF. Six drainage-type lysimeters will be exhumed in early FY 1994 and replaced with materials representing the prototype barrier. Two of the lysimeters will be filled with silt-loam soil, amended with pea gravel in the top 1-m depth, to represent the prototype barrier surface, while two lysimeters will be filled with basalt rock-rip/rap to represent the extreme coarse side-slope conditions of the prototype test. An additional two

lysimeters will be filled with clean-fill gravel material used to test the other side-slope condition of the prototype test. The three new barrier configurations (silt loam/pea gravel, basalt rock and clean-fill gravel) will be tested under ambient and irrigated (3X) precipitation conditions over the next 3 years.

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ABBREVIATIONS

Units of Measure

bar	pressure unit
d	day
dia.	diameter
cm	centimeter
cm ³	cubic centimeter
g	gram
h	hour
in.	inch
k	kilo (prefix, 10 ³)
kg	kilogram
kg/m ³	kilogram per cubic meter
kg-wt	kilogram-weight
L	liter
lb	pound
m	meter
m ²	square meter
mg	milligram
ml	milliliter
mm	millimeter
Mpa	mega pascal (pressure unit)
s	second
yr	year
wt	weight

Hanford Site Terms

ALE	Arid Lands Ecology (Reserve)
BWTF	Buried Waste Test Facility
DOE	U.S. Department of Energy
FLTF	Field Lysimeter Test Facility
HMS	Hanford Meteorological Station
PNL	Pacific Northwest Laboratory
EPA	U.S. Environmental Protection Agency
WHC	Westinghouse Hanford Company

CONTENTS

ABSTRACT	iii
EXECUTIVE SUMMARY	v
ACKNOWLEDGMENTS	ix
ABBREVIATIONS	xi
1.0 INTRODUCTION	1
1.1 CAPILLARY BARRIERS	1
1.2 HANFORD SITE TESTS	2
2.0 DESCRIPTION AND OPERATION OF THE FIELD LYSIMETER TEST FACILITY	5
2.1 DRAINAGE LYSIMETERS	5
2.2 WEIGHING LYSIMETERS	5
2.3 CLEAR-TUBE LYSIMETERS	7
2.4 WEATHER STATION AND METEOROLOGICAL DATA	9
2.5 SOIL VARIABLES	9
2.6 EXPERIMENTAL DESIGN AND METHODS OF ANALYSIS	10
2.6.1 Drainage Errors	12
2.6.2 Water Storage Analysis	12
3.0 RESULTS OF LYSIMETER WATER BALANCE STUDIES	17
3.1 DRAINAGE RESULTS	17
3.2 WATER STORAGE	24
3.2.1 Vegetated Lysimeters	25
3.2.2 Bare Lysimeters	27
3.3 VEGETATION EFFECTS ON WATER BALANCE	28
3.3.1 Root Observations	28
3.3.2 Species Composition	29

3.4	SOIL WATER TENSION AND SUCTION VALUES	30
4.0	PLANT BIOMASS ESTIMATES AT THE FIELD LYSIMETER TEST FACILITY	35
4.1	INTRODUCTION	35
4.2	METHODS	35
4.3	RESULTS	37
5.0	CONCLUSIONS	41
6.0	RECOMMENDATIONS	43
7.0	FIELD LYSIMETER TEST FACILITY PUBLICATIONS	45
8.0	REFERENCES	47
	APPENDIX A - TARGET AMOUNTS OF WATER APPLICATION	A.1
	APPENDIX B - NEUTRON PROBE CALIBRATION	B.1
	APPENDIX C - SURFACE WATER CONTENT AND SUCTIONS AT SELECTED TIMES ON SELECTED LYSIMETERS	C.1

FIGURES

2.1	Location of the Field Lysimeter Test Facility on the Hanford Site	6
2.2	Cutaway Drawing of the Field Lysimeter Test Facility Showing the Drainage, Weighing, and Clear-Tube Lysimeters	7
2.3	Instrument Locations in Weighing and Drainage of Lysimeters . . .	8
2.4	Treatment Description of the Field Lysimeter Test Facility . . .	11
2.5	Monthly Precipitation Records at the Hanford Meteorological Station	13
2.6	Hanford Site Monthly Snowfall Record	14
2.7	Precipitation Data for the Field Lysimeter Test Facility and Hanford Meteorological Station	15
3.1	Cumulative Drainage Data for (a) 1988 to 1993 and (b) 1993, for Bare Lysimeters as Specified by Treatment Numbers	23
3.2	Drainage Data for Vegetated Lysimeters	24
3.3	Drainage Data for Clear-Tube Lysimeters	25
3.4	Water Storage for Weighing Lysimeters	26
3.5	Water Storage for Lysimeter Treatments 1 to 7	27
3.6	Tensiometer Data at Two Depths as a Function of Time for Bare, Irrigated Lysimeter	31
3.7	Water Potentials for Bare and Vegetated, Ambient Surfaces of Capillary Barrier Lysimeters, October 1991	33

TABLES

2.1	Field Lysimeter Test Facility Treatments	12
3.1(a)	Water Balance of Drainage Lysimeters at the Field Lysimeter Test Facility	18
3.1(b)	Weighing Lysimeter Water Balance at the Field Lysimeter Test Facility	21
3.1(c)	Clear-Tube Lysimeter Water Balance at the Field Lysimeter Test Facility	22
4.1	Linear Regression Parameter Values for the Leaf Area and Biomass Models Described in Equations 1-3	38
4.2	Estimated Total Plant Biomass and Biomass Index on Each Lysimeter in 1989 and 1992	38
4.3	Treatment Statistics for Biomass Study at the Field Lysimeter Test Facility	39

1.0 INTRODUCTION

Cover systems are used to isolate buried waste from the accessible environment at most, if not all, waste sites throughout the United States (Lutton et al. 1979; EPA 1986, 1987, 1991; Anderson et al. 1989). These covers range from very simple designs, consisting of nothing more than a thin mantle of soil placed over the waste, to complex designs, consisting of multiple layers of soils and geosynthetic materials. Control of water intrusion into the waste is a major feature of the more complex designs.

1.1 CAPILLARY BARRIERS

A proposed surface cover design for the Hanford Site includes a "capillary barrier" (Wing and Gee 1990). The "capillary barrier" is a cover system consisting of layers of fine soil overlying coarse soils. Textural contrast in soils provides a "capillary break," which limits drainage and stores water in the upper (fine) soil until the soil at the interface approaches saturation. The resulting increased water storage increases water availability for evaporation and plant transpiration (Miller 1973).

Capillary barrier systems have been proposed and tested under varied climate and site conditions throughout the world (Rancon 1980; Nyhan et al. 1986; Cartwright et al. 1987; Andersen and Clausen 1988; Healy 1989; Schulz et al. 1989; Melchior et al. 1993). While this concept has been known for many years (Alway and McDole 1917), practical use of the concept for infiltration control at waste sites is a relatively recent innovation (Rancon 1980).

In humid climates, a capillary barrier is less effective than in arid climates because soil is often wetted to near saturation, resulting in periodic drainage into the underlying coarse soil (Melchior et al. 1993). Booth and Price (1989), Healy (1989), and Andersen and Clausen (1988) have shown that significant portions (ranging from 20% to 50%) of the annual precipitation at humid sites can drain through a capillary barrier, which on sloping surfaces in wet climates acts more like an internal drain.

In contrast, Schulz et al. (1989) have demonstrated that a capillary barrier at a humid site (Beltsville, Maryland) when covered with adequate

vegetation, coupled with impermeable surface-runoff structures (designed to divert most of the water off the cover) can limit drainage to insignificant amounts. Nyhan et al. (1986) have demonstrated that a capillary barrier system also can limit drainage under semi-arid conditions, but that total effectiveness is subject to climate variability conditions, as well as soil and plant factors. In arid environments, water stored near the soil surface can readily be removed by evaporation and plant transpiration thus, in dry climates, little or no drainage is expected from a properly designed capillary barrier system (Winograd 1981).

1.2 HANFORD SITE TESTS

At the U.S. Department of Energy's Hanford Site, cover systems containing a capillary barrier have been proposed as a means to isolate low-level radioactive wastes for long periods of time (up to 1,000 years or more). Just how well such a surface barrier system will perform at the Hanford Site is a matter of great interest and has resulted in extensive use of lysimeters to document surface water balance (Gee et al. 1992a) and more recently the development of a large-scale prototype barrier design (KEH 1993).

The Field Lysimeter Test Facility (Kirkham et al. 1987; Gee et al. 1989; Campbell et al. 1990; Campbell and Gee 1990) was designed specifically to test the performance of a capillary barrier system under arid site conditions. A series of simulated cover systems, ranging from 3-m-thick gravel-covered bare soil (to represent soil covers over buried tanks at the Hanford Site) to vegetated silt-loam soil (1.5 m thick) overlying coarse (capillary barrier) layers of sand, gravel, and rock are currently being tested under ambient and elevated precipitation conditions. The tests are conducted in lysimeters of three distinct types: drainage, weighing, and clear-tube, each with differing configurations (as described in the following section) ranging in size from 2 m x 3 m for drainage lysimeters to 0.3 m x 3 m for the clear-tube lysimeters. Previous reports on this facility have documented that testing in the first 3 years and have verified the expected performance of the capillary barrier: fine soil (bare or vegetated silt loams) over coarse soil sequences appeared to be effective in removing both ambient and elevated (twice the

annual average) precipitation via evapotranspiration process. During the first 5 years of testing, no drainage occurred from any of the weighing lysimeters. Small and decreasing amounts of water were collected from 6 of the 14 drainage lysimeters in the summer and early fall (July-October) for the first 3 years of operation (November 1987 - October 1990). No drainage was obtained from any of these lysimeters in winter or spring. The summer water collection was only observed on bare surface treatments (wettest lysimeters). This water was attributed to condensation resulting from thermal gradients, acting on the walls of the wet lysimeters, thus was considered an artifact of the lysimeter design and not counted as drainage (Campbell and Gee 1990). No condensate water was observed from any of the vegetated lysimeters, even under irrigated conditions, presumably because they were considerably drier than the bare soil treatments.

Water balance observations have been made on capillary barriers at the Field Lysimeter Test Facility for nearly six years under a wide range of test conditions (ambient and elevated precipitation; vegetated and non-vegetated surfaces). The following sections describe the present facilities, the ongoing tests, past and present results, and future plans.

2.0 DESCRIPTION AND OPERATION OF THE FIELD LYSIMETER TEST FACILITY

A detailed description of the design and operation of the FLTF (Gee et al. 1989; Campbell et al. 1990; Campbell and Gee 1990) is available in previous reports. A brief summary of the facility follows. The facility is located adjacent to the 200-West Area near the Hanford Meteorological Station (HMS) and consists of 24 lysimeters (14 drainage-type, 4 weighing-type, and 6 clear-tube lysimeters). Figure 2.1 shows location, and Figure 2.2 shows a schematic of the facility.

2.1 DRAINAGE LYSIMETERS

Each drainage lysimeter is 2 m in diameter and 3 m deep. Twelve lysimeters contain about 6,600 kg of silt loam soil (1.5 m deep), two (treatment 6) contain about 4,400 kg (1.0 m deep). Below the silt loam in all lysimeters is a 0.3-m-thick graded filter (consisting of #20-30 sand, grading to #4 sand, pea gravel over 0.1-m-dia. rock). The underlying material is 0.15-m-dia. basalt riprap (washed rock).

The 14 drainage lysimeters are arranged with seven of them on each side of an access/instrument tunnel, as shown in Figure 2.2. Each lysimeter is equipped with a sloping floor and drain spout (allowing catchment of drainage water). Access ports are located in all drainage lysimeters and have allowed placement of thermocouples, thermocouple psychrometers, tensiometers, and neutron probe access tubes as shown in Figure 2.3. All 14 drainage lysimeters were constructed to simulate capillary barriers. The experimental treatments are described in Section 2.6.

2.2 WEIGHING LYSIMETERS

Four weighing lysimeters are located at the FLTF, two on each side of the access/instrument tunnel. Each weighing lysimeter is 1.5 x 1.5 x 1.7 m and contains about 5,900 kg of soil (1.5 m deep) placed on top of about 0.2 m of #20-30 sand. Each weighing lysimeter rests on a 9,000-kg (20,000 lb) capacity, Weigh-Tronix platform scale (Weigh-Tronix, Inc., Fairmont, Minnesota). Scale weights are recorded every 20 s on a CR7X datalogger

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FIGURE 2.1. Location of the Field Lysimeter Test Facility on the Hanford Site

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FIGURE 2.2. Cutaway Drawing of the Field Lysimeter Test Facility Showing the Drainage, Weighing, and Clear-Tube Lysimeters

(Campbell Scientific Instruments, Inc., Logan, Utah). Like the drainage lysimeters, each weighing lysimeter has a sloping bottom and a drain port at the low point. The weighing lysimeters also have instrumentation as shown in Figure 2.3, so that water content and potential can be monitored, along with soil temperature and root distribution. Clear-glass root observation tubes (minirhizotrons) 5 cm in dia. and 1.5 m long are located in vegetated lysimeters. The four weighing lysimeters simulate capillary barriers, and their treatments are described in Section 2.6.

2.3 CLEAR-TUBE LYSIMETERS

The clear-tube lysimeters are made from transparent, cast Acrylic plastic (Port Plastics, 7500 S.W. Tech. Center Dr., Portland, Oregon 97223) and are 0.3 m in dia. and 3 m deep. Three clear-tube lysimeters are located on each side of the access tunnel in the FLTF for a total of six. Drainage is periodically collected at the bottom of each clear-tube lysimeter through a drain spout into a plastic container that is weighed to the nearest 0.001 kg.

FIGURE 2.3. Instrument Locations in Weighing and Drainage of Lysimeters

Two clear-tube lysimeters (designated as C03-1 and C06-3) were installed and filled in November 1988 with basalt riprap, capped by a filterbed in the lower half, and 1.5 m of Warden silt loam soil (Xerollic Camborthid) from McGee Ranch in the top half (identical to 12 of the drainage lysimeters). A small (above-ground height, approximately 0.15 m) *Artemisia tridentata* (sagebrush) was transplanted into each of these lysimeters. Four additional lysimeters were installed in October 1989, each filled with pit-run gravelly sand in the bottom half (1.5 m) and with screened sand in the top 1.5 m. Two of these sand-filled lysimeters (designated as C02-9 and C05-11) were topped with 0.15 m of coarse gravel. The remaining two sand-filled lysimeters (designated as C02-9 and C05-11) were each transplanted with small sagebrush in late 1989.

2.4 WEATHER STATION AND METEOROLOGICAL DATA

The FLTF is located near the Hanford Meteorological Station (HMS) where current and long-term weather records are available. The long-term weather records have been used in modeling water balance of surface (protective) barriers (Fayer et al. 1985; Fayer 1987; Fayer 1990). Recent data (past 6 years) have been used to document the ambient (non-irrigated) climatic variables for the FLTF.

Climatic variables were measured hourly at the HMS. These data (air temperature, solar radiation, wind, humidity, and precipitation) were obtained from the HMS via tape and stored in computer files for use in computing potential evapotranspiration (Fayer et al. 1992) and for documenting precipitation treatments. Precipitation at the FLTF was also measured by monitoring weight change of weighing lysimeters before and after storms.

2.5 SOIL VARIABLES

Soil variables were measured in several ways. Water storage and water content were obtained via recorded weight changes from weighing lysimeters and by neutron probe measurements. Soil water tensions were measured with tensiometers and temperatures were measured with copper-constantan thermocouples. On selected days, surface samples were collected from lysimeters and water contents, and water potentials were measured. For the dry surface soils, the samples were tested for water activity (relative humidity) using a water activity meter. Matric potential (expressed as matric suction) was estimated from water activity as described by Gee et al. (1992b). Evapotranspiration was measured directly by weight changes in weighing lysimeters and indirectly by changes in water content from neutron probe data. Drainage was measured by periodically collecting outflow from lysimeters in plastic storage containers, then weighing the storage container (to nearest gram). Precision of the drainage measurement is estimated to be equivalent to ± 0.001 mm or less.

A water budget was developed for each lysimeter to account for temporal variations in precipitation, evaporation (including transpiration), storage, and drainage. While drainage measurements are emphasized in this report,

water storage data are also used to analyze performance of lysimeter treatments with no drainage.

2.6 EXPERIMENTAL DESIGN AND METHODS OF ANALYSIS

Eleven distinct treatments are currently being tested at the FLTF. Figure 2.4 and Table 2.1 identify these treatments. The various soil, plant and precipitation combination in these treatments represent a range of surface conditions that presently exist at the Hanford Site, plus conditions that reflect elevated precipitation. The elevated precipitation treatment was considered important for projecting barrier performance under potential future climate change.

During the past 6 years, annual precipitation has ranged from 127 mm (in 1987) to >240 mm (in 1993) and average 169 mm/yr. [The long-term (1912-1980) average for the Hanford Site is 160 mm/yr]. Figure 2.5 shows monthly values of the past 6-year average as well as long-term (1912-1980) average reported.

On average, 38% of winter precipitation is snow, and annual snowfall averages 335 mm (13.2 in.). This past winter, 1992-1993, there was a record snowfall of 1425 mm (56.1 in.) which was more than four times the long-term average. Figure 2.6 shows the actual snowfall for 1992-1993 and the long-term average (1912-1980).

Irrigation was used to supplement natural precipitation on some of the lysimeters (see Figure 2.4). Irrigation was applied to lysimeters on the west side, except D08-2. Lysimeters D09-7 and D11-7 (see Figure 2.4) were covered and sealed with plastic from August 1988 through July 1990, when covers and plastic seal were removed. Each irrigated lysimeter had a small, manual plastic precipitation gage next to it. Irrigation was scheduled to remove deficits at the beginning and middle of each month. During the first 3 years (November 1987 - October 1990), the irrigation treatment was designed to create a 2X (twice the annual average) precipitation condition. For the past 3 years (November 1990 to present), irrigation was increased to create a 3X (three times the annual average) precipitation condition. Irrigation was applied at intervals that were dictated in part by weather, equipment, and technician availability. A target amount of supplemental irrigation was

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FIGURE 2.4. Treatment Description of the Field Lysimeter Test Facility

specified, based on the long-term monthly precipitation. Appendix A shows the planned or target water applications. Figure 2.7 shows the cumulative target amount, the actual total water applied (including precipitation), and the actual precipitation for each of the past years (November 1987 through July 1993).

Drainage data were collected approximately every 2 weeks. In 1993 during periods of considerable drainage, drainage was collected weekly. Drainage was determined from water collected in drainage lines (see Figure 2.2) from all lysimeters during site visits. There has been no attempt to measure continuous outflow from any of the lysimeters, thus reported data represent time-averaged drainage values.

TABLE 2.1. Field Lysimeter Test Facility Treatments

Treatment	Precipitation			Surface				Soil Texture	Thickness			Lysimeter #
	A ^(a)	2A ^(b)	B ^(c)	Bare	Veg	Admix	Gravel		1.0 m	1.5 m	3.0 m	
1	X				X			Si L		X		W01-1, D04-1, D07-1, C03-1
2	X			X				Si L		X		W02-2, D01-2, D08-2
3		X			X			Si L		X		W03-3, D13-3, D14-3, C06-3
4		X		X				Si L		X		W04-4, D10-4, D12-4
5	X				X	X		Si L		X		D02-5, D05-5
6	X				X			Si L	X			D03-6, D06-6
7			X	X				Si L		X		D09-7, D11-7
8	X						X	S			X	C01-8
9	X				X			S			X	C02-9
10		X					X	S			X	C04-10
11		X			X			S			X	C05-11

^(a)Ambient precipitation
^(b)2X, 3X annual average
^(c)Breakthrough +2X, 3X annual average

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2.6.1 Drainage Errors

We checked all outflow lines for evaporation losses. Evaporation losses were found to be 5 g in 480 days. This is equivalent to an error in drainage of <0.0025 mm/yr, thus was considered to be insignificant. There was an inadvertent error observed on one of the clear-tube tests. The closed tube on C04-10 (gravel-covered sand, 3X precipitation) was found in early summer (July 14-23) of 1993 to be open for a week, and drainage water was lost during that period of time. As there was measured drainage before and after that time period, the lost data was synthesized by averaging the before and after data and incrementally adding this amount to the drainage data set. All other records represent actual recorded drainage values.

2.6.2 Water Storage Analysis

Neutron probe data were collected manually (recorded in laboratory record books) and electronically. The electronic data were read by computer, stored in FLTF data files, then processed in terms of water content and water storage. Details of the process used to transform neutron probe data from raw contents to water content and water storage are given in Appendix B.

FIGURE 2.5. Monthly Precipitation Records at the Hanford Meteorological Station. Bar graphs represent long-term (1912-1980) record, data points represent past 6-year averages.

Water storage data (from neutron probe) are provided in this report along with weighing lysimeter data. The weighing lysimeter data were collected on 10-minute intervals and averaged on an hourly basis and represent the most complete record of the water balance available. Records dating from November 1987 to present are in FLTF files. In January 1992, WL01 was removed and the electronic scale was replaced under this lysimeter. In addition to the annual calibration (Campbell and Gee 1990), specialized servicing of all the weighing lysimeters was done in summer and fall of 1992. Debris was removed from around the scales of all weighing lysimeters and a mesh screen was placed over the air gap between the inner and outer box of the lysimeter

FIGURE 2.6. Hanford Site Monthly Snowfall Record. Bar graph represents averages (1912-1980), data points represent 1992-1993 winter values.

to minimize further debris accumulation. The weighing lysimeter calibration for WL01 was adjusted to account for the new scale. Because of the scale replacement, all data were checked for proper calibration both in early spring and fall of 1992. By fall of 1992, all scales were working correctly. Weight change data from the weighing lysimeters as well as precipitation, irrigation, temperature, and other key data are plotted and reviewed weekly. Appendix A (Figure A.1) provides an example of these weekly plots.

FIGURE 2.7. Precipitation Data for the Field Lysimeter Test Facility and Hanford Meteorological Station. Solid line represents target amounts of total precipitation (irrigation plus ambient precipitation). Dashed line is actual applied precipitation, dot/dash line is ambient precipitation.

3.0 RESULTS OF LYSIMETER WATER BALANCE STUDIES

A summary of lysimeter water balance data for nearly 6 years (November 1987 - July 1993) is provided in the following subsections. Data from drainage, weighing and clear-tube lysimeters are grouped and analyzed according to treatment.

3.1 DRAINAGE RESULTS

Drainage data from all lysimeters are presented in Table 3.1 and shown in Figures 3.1 to 3.3. Table 3.1 lists the cumulative drainage values for each treatment. Excluded from Table 3.1 are 1988 tests, where excess water was applied to check for leaks and to saturate two lysimeters (D09-7 and D11-7) (Campbell and Gee 1990). All drainage values are rounded to the nearest mm of water. Drainage from all lysimeters is scaled to a unit cross-sectional area (i.e., water volume/area = length, expressed in mm, to conform to conventional S.I. units used for precipitation, recharge, etc.).

The data clearly indicate that all capillary-barrier (silt loam soil) treatments, except those with bare soil, exposed to the highest (3X) precipitation treatment, have had no drainage after nearly 6 years of testing. All other treatments (e.g., sandy soils) exhibited drainage. Drainage is least for vegetated sand under ambient precipitation and greatest for gravel-covered sand under elevated (3X) precipitation. The bare, irrigated (2X) treatment showed no drainage (3-year test). When the irrigation (elevated precipitation) treatment was modified (increased to 3X) the silt loam again showed no drainage for the first 2 years. Evaporation was sufficiently high that all of the applied water was removed from all silt loam soils (except for treatment 7, where excess water was applied and evaporation was purposely prevented).

During the past year (1992-1993) the record snowfall caused precipitation to exceed the 3X target (see Figure 2.6). Because water storage was initially high in irrigated, bare lysimeters, the excess winter precipitation

TABLE 3.1(a). Water Balance of Drainage Lysimeters at the Field Lysimeter Test Facility

Lysimeter	Water Year ^(a)	Precipitation and Irrigation	Storage Change	ET	Drainage
		mm			
D04-1 (Ambient, Vegetated)	1988	127	-188	310	(5) ^(c)
	1989	173	-12	185	0
	1990	144	8	136	0
	1991	144	-7	151	0
	1992	174	5	169	0
	1993 ^(b)	235	2	233	0
D07-1 (Ambient, Vegetated)	1988	127	-192	318	(1)
	1989	173	-15	188	0
	1990	144	9	135	0
	1991	144	-13	157	0
	1992	174	11	163	0
	1993	235	8	227	0
D01-2 (Ambient, Bare)	1988	127	-22	143	(6)
	1989	173	-18	191	0
	1990	144	-4	148	0
	1991	144	-14	158	0
	1992	174	9	165	0
	1993	235	53	182	0
D08-2 (Ambient, Bare)	1988	127	-38	163	(2)
	1989	173	-16	189	0
	1990	144	-6	150	(1)
	1991	144	-16	160	0
	1992	174	10	164	0
	1993	235	51	184	0
D13-3 (2X Precip., Vegetated)	1988	294	-196	488	(2)
	1989	367	27	340	0
	1990	304	-22	326	0
	1991	479	-1	480	0
	1992	487	25	462	0
	1993	406	-24	430	0
D14-3 (2X Precip., Vegetated)	1988	294	-222	513	(3) ^(c)
	1989	367	22	345	0
	1990	304	-21	325	0
	1991	479	4	475	0
	1992	487	23	464	0
	1993 ^(b)	406	-29	435	0

TABLE 3.1. (contd)

Lysimeter	Water Year ^(a)	Precipitation and Irrigation	Storage Change	ET	Drainage
		mm			
D10-4 (2X Precip., Bare)	1988	294	-33	325	(2)
	1989	367	30	337	0
	1990	304	-32	336	0
	1991	479	12	467	0
	1992	487	45	442	0
	1993	406	34	338	34
D12-4 (2X Precip., Bare)	1988	294	-21	313	(2)
	1989	367	34	332	(1)
	1990	304	-25	328	(1)
	1991	479	17	462	0
	1992	487	39	448	0
	1993	406	34	340	32
D02-5 (Ambient, Vegetated, Admix)	1988	127	-138	263	(2)
	1989	173	-27	199	0
	1990	144	16	128	0
	1991	144	-15	159	0
	1992	174	9	165	0
	1993	235	5	230	0
D05-5 (Ambient, Vegetated, Admix)	1988	127	-123	244	(6)
	1989	173	-11	184	0
	1990	144	14	130	0
	1991	144	-12	156	0
	1992	174	9	165	0
	1993	235	4	231	0
D03-6 (Ambient, Vegetated)	1988	127	-157	277	(7)
	1989	173	-7	180	0
	1990	144	12	132	0
	1991	144	-10	154	0
	1992	174	7	167	0
	1993	235	8	227	0
D06-6 (Ambient, Vegetated)	1988	127	-133	259	(1) ^(c)
	1989	173	-6	179	0
	1990	144	8	136	0
	1991	144	-9	153	0
	1992	174	7	167	0
	1993 ^(b)	235	7	228	0
D09-7 (Breakthrough, Bare)	1991	479	-45	524	0
	1992	487	31	456	0
	1993	406	29	375	2

TABLE 3.1. (contd)

Lysimeter	Water Year ^(a)	Precipitation and Irrigation	Storage Change	ET	Drainage
		mm			
D11-7 (Breakthrough, Bare)	1991	479	-45	524	0
	1992	487	29	458	0
	1993	406	33	371	2
(a) Water Year - November 1 of previous year through October 31 of year specified. (b) 1993 Water Year - exception = November 1 1992, through July 31, 1993. (c) Numbers in parenthesis represent summer condensate water.					

TABLE 3.1(b). Weighing Lysimeter Water Balance at the Field Lysimeter Test Facility

Lysimeter	Water Year ^(a)	Precipitation and Irrigation	Storage Change	ET	Drainage
		mm			
W01-1 (Vegetated- Ambient ppt)	1988	127	-201	328	0
	1989	173	-12	185	0
	1990	144	14	130	0
	1991	174	6	168	0
	1992	235	10	225	0
W02-2 (Bare- Ambient ppt)	1988	127	-76	203	0
	1989	173	-16	189	0
	1990	144	-1	145	0
	1991	144	-10	154	0
	1992	174	11	163	0
	1993 ^(b)	235	54	181	0
W03-3 (Bare- Irrigated)	1988	294	-192	486	0
	1989	367	6	361	0
	1990	304	-4	308	0
	1991	479	18	461	0
	1992	487	28	459	0
	1993	406	-27	433	0
W04-4 (Vegetated- Irrigated)	1988	294	-68	362	0
	1989	367	26	341	0
	1990	304	-18	322	0
	1991	479	30	449	0
	1992	487	39	448	0
	1993	406	51	325	30
(a) Water Year - November 1 of previous year through October 31 of year specified.					
(b) 1993 Water Year - exception = November 1, 1992, through July 31, 1993.					

TABLE 3.1(c). Clear-Tube Lysimeter Water Balance at the Field Lysimeter Test Facility

Lysimeter	Water Year ^(a)	Precipitation and Irrigation	Storage Change + ET	Drainage
		mm		
C03-1 (Vegetated-Not Irrigated/ Ambient)	1990	144	144	0
	1991	144	144	0
	1992	174	174	0
	1993 ^(b)	235	235	0
C06-3 (Vegetated- Irrigated)	1990	304	144	0
	1991	479	144	0
	1992	487	174	0
	1993	406	235	0
C01-8 (Gravel-Not Irrigated/ Ambient)	1990	144	104	40
	1991	144	88	56
	1992	174	108	66
	1993	235	93	142
C02-9 (Vegetated-Not Irrigated/ Ambient)	1990	144	120	24
	1991	144	144	0
	1992	174	174	0
	1993	235	235	0
C04-10 (Gravel- Irrigated)	1990	304	192	112
	1991	479	212	267
	1992	487	210	277
	1993	406	70	336
C05-11 (Vegetated- Irrigated)	1990	304	182	122
	1991	479	456	23
	1992	487	487	YY0
	1993	406	329	YY77
(a) Water Year - November 1 of previous year through October 31 of year specified.				
(b) 1993 Water Year - exception = November 1, 1992, through July 31, 1993.

FIGURE 3.1. Cumulative Drainage Data for (a) 1988 to 1993 and (b) 1993, for Bare Lysimeters as Specified by Treatment Numbers (see Figure 2.4 for treatment description)

FIGURE 3.2. Drainage Data for Vegetated Lysimeters

precipitation increased total storage above 500 mm and drainage occurred. During 1993, when drainage was greatest, an amount equal to 58% of the November 1992 through July 1993 precipitation had drained from the ambient, gravel covered lysimeter, while 83% had drained through the irrigated gravel covered lysimeter. These results are consistent with model simulations (Smoot et al. 1990) of gravel-covered sandy soils at Hanford. Significant quantities of precipitation are expected to drain from side-slopes of above-grade covers at Hanford if these side-slopes remain barren (void of vegetation).

3.2 WATER STORAGE

Water storage, as determined from weight change and neutron probe measurements, is shown for all four weighing lysimeters in Figure 3.4. Agreement between weight change and neutron probe is excellent, except in early 1993, when snowcover caused weight change to exceed probe readings. Based on the overall observations, we use neutron probe data to estimate the

FIGURE 3.3. Drainage Data for Clear-Tube Lysimeters

water storage in all drainage lysimeters (treatments 1 through 7). Drainage lysimeter data are shown in Figure 3.5.

3.2.1 Vegetated Lysimeters

Vegetation, coupled with surface evaporation (via evapotranspiration), is able to remove at least 480 mm/yr. The data in Figure 3.5 clearly indicate that vegetated, capillary-barrier lysimeters (treatments 1, 3, 5, and 6) all maintain water storage levels well below their estimated drainage limits. The water storage in all vegetated lysimeters was reduced from between 200 and 300 mm of water to a lower limit of storage (less than 100 mm) for all treatments. The water storage is reduced to a unique lower limit of storage for each treatment by summer of each year. Such an observation coupled with the observation of no drainage from the vegetated treatments (after a record snowfall, and above-normal annual precipitation) provides verification of the performance of capillary barriers for the Hanford Site, even under extreme

FIGURE 3.4. Water Storage for Weighing Lysimeters

FIGURE 3.5. Water Storage for Lysimeter Treatments 1 to 7

conditions. After the first winter, storage in all vegetated treatments averaged less than 200 mm, which is less than half the 500 mm needed to cause drainage. Thus, it is reasonable to conclude that vegetated capillary barriers similar to the lysimeter design will perform extremely well.

3.2.2 Bare Lysimeters

The bare treatments maintained a relatively high storage throughout the course of the 6-year study. During the first 5 years, virtually all applied water (for both ambient and irrigated lysimeters) was removed through evaporation. Six of the lysimeters exhibited some response to summer thermal

gradients such that small amounts of condensation were collected in the outflow lines. Less than 0.4 mm/year was collected from any of the lysimeters during 1991 and 1992.

The ambient lysimeters always remained below the 500-mm limit. The irrigated (2X, 3X) lysimeters remained below the 500-mm limit until February 1993, when the limit was exceeded and drainage occurred. Over 30 mm of water drained from the lysimeters of treatment 4.

Water storage (plus evapotranspiration) in clear-tube lysimeters can be obtained only by a gross water balance ($\text{Precipitation} - \text{Drainage} = \text{ET} + \text{Storage}$) since the clear-tube lysimeters are not monitored for water content. The four non-capillary barrier (sand-filled) lysimeters should provide the best estimate of water storage change, because all of the four sand-filled lysimeters were wetted initially to drainage and all have exhibited drainage over the past 3 years. Table 3.1 shows water storage, precipitation, and evapotranspiration in the sand-filled lysimeters for the time period January 1991 - July 1993.

3.3 VEGETATION EFFECTS ON WATER BALANCE

The ability of vegetation to prevent drainage is clearly demonstrated by the lysimeter data presented in Sections 3.1 and 3.2. Vegetative covers are superior to covers without vegetation. To increase the effectiveness of a barrier in limiting drainage, maximize vegetative growth on the barrier surface. The following sections describe the root and species observations made on the four vegetated, clear-tube lysimeters.

3.3.1 Root Observations

In early 1989, a few months after two capillary barriers (1.5-m-thick silt loam soil overlying layers of sands, gravels, and rock) were constructed in clear-tube lysimeters (C03-1 and C06-3), roots were observed growing in the wettest (irrigated) clear-tube lysimeter (C06-3). As a result of winter rain and irrigation (2X) treatment, a visual wetting front was observed to penetrate about two-thirds (1-m) into the silt loam soil by early spring 1989. In May 1989, roots were found at the 1.5-m depth of the silt loam soil and

over the course of several months a proliferation of roots was observed in the 1.5-m-deep silt loam soil layer. Over the next 3 years, roots were observed to permeate the silt loam but no roots penetrated more than 1 cm into the sand. In late 1991, in spite of an increase in irrigation to a 3X treatment, the sagebrush plant died.

By early February 1993, the entire profile of the irrigated, clear-tube lysimeter (C06-3), was noticeable wet, including the underlying rock materials. However, no drainage water was collected from this lysimeter. In March 1993, a small sagebrush was transplanted on lysimeter C06-3 and by late May sagebrush roots had penetrated more than 1.5 m through the silt loam and sand and had moved into the wetted gravel below the sand. By late July 1993, a few sagebrush roots had moved downward into the rock to a depth of about 2 m. As late as September 1993, there appeared to be no further root penetration and the sand and gravel appeared dry. Continued monitoring of root growth over the next several years is planned for this lysimeter.

These observations suggest two things. First, that wetted gravel and basalt rock fail to create a plant root barrier. Sagebrush roots apparently are not physically restricted in any way by coarse sands, gravels, or rocks. Second, these coarse subsoils have limited storage capacity. As soon as water is extracted from the coarse material-surfaces the roots are limited in their capacity to survive, and if water is not supplied the probability is high that they will die. It is expected that over the next year there will be no further root penetration into the subsoil, since evapotranspiration from the sagebrush should be sufficiently high to remove excess water from the silt loam soil, thus preventing any further drainage into the sand, etc. As long as deep-rooted vegetation persists on this lysimeter, drainage should be prevented.

3.3.2 Species Composition

Sagebrush vegetation was not maintained on the clear-tube, ambient, capillary barrier lysimeter (C03-1). The sagebrush died in 1989 within a year of transplanting. Over the past 4 years, the ambient capillary barrier has not been visibly wetted. Bromus tectorum L. (cheatgrass) has invaded the lysimeter, and in 1993, cheatgrass occupied most of the lysimeter surface. By

July 1993, cheatgrass roots were visible in the clear-tube and were observed to have grown to a depth of about 0.6 m. Below this depth, the soil and underlying sand and gravel have remained dry. These data suggest that under ambient precipitation (even with extreme snowmelt) that cheatgrass-covered capillary barriers (silt loam soils) should be effective in preventing drainage below the silt loam soil layer.

Drainage was observed in irrigated, vegetated sand. Clear-tube lysimeter C05-11, which had roots extending the entire 3-m depth of the lysimeter, drained in early 1993 and also in early 1991, presumably as a result of the extreme winter precipitation. Sagebrush roots, in ambient vegetated lysimeter C02-9, were able to extract water from the entire 3-m depth in the C02-9 lysimeter for nearly 3 years and prevent drainage. In 1992, the sagebrush plant on C02-9 died, and the remaining vegetation was cheatgrass. The cheatgrass was unable to extract water at depth and the soil profile is now visibly wetted. While no drainage was collected in 1993, drainage is imminent. These data suggest that species composition is critical to cover water balance, particularly when soils are coarse (sands, etc.). Furthermore, the ability of vegetation to prevent drainage was shown to be a function of the precipitation regime. As precipitation increased, the potential for drainage increased, even for sagebrush.

3.4 SOIL WATER TENSION AND SUCTION VALUES

Tensiometers were used to monitor soil water tensions in five of six irrigated bare silt loam lysimeters. Tensions at 100-cm and 150-cm depths are shown in Figure 3.6. While there is scatter in data for individual dates, the trends in tensions reflect important responses to summer evaporation and winter precipitation events. Tensions in these wet lysimeters ranged from near zero to over 800 mbars. Tensions beyond this range are beyond the limit of the tensiometer. In early February 1993, when drainage occurred from these lysimeters, all tensions were near saturation. Lysimeters D09 and D11 (the two lysimeters that were saturated and used to determine water storage in 1988) did not initially drain and have drained only slowly since late March 1993 (see Figure 3.1).

FIGURE 3.6. Tensiometer Data (Tensions) at Two Depths (100 cm and 150 cm) as a Function of Time for Bare, Irrigated Lysimeters

The data clearly indicate that tensions can be relatively high, even in bare soils in summer. Since late 1990, the tensions in D09 and D11 have consistently cycled higher than 600 cm in late fall and early winter (in response to summer drying). The differences between tensions in these lysimeters and the other bare, irrigated lysimeters is attributed to hysteretic behavior of soil drying. Only D09 and D11 were wetted to saturation thus they are no longer on the same wetting and drying cycle as the other lysimeters. Possibly the initially wetter soil in D09 and D11 could have caused drying to greater depths than the other lysimeters. In addition, some physical changes (density, etc.) were observed in these lysimeters during saturation (Campbell et al. 1990). These changes may also be responsible for the significant difference in observed tensions.

During October 1991 and June 1992, surface soil samples were taken from lysimeters to evaluate the water suctions that exist near the soil surface. Figure 3.7 shows with and without vegetation tensions that existed in October of 1991 in surface soil. Similar observations were made in June 1992. It appears that vegetative silt loam soil can dry to significant depths. The measured water potentials, expressed as matric suctions, are well above the upper limit (>7.0 Mpa) of potentials needed to maintain turgor in desert plants. These data suggest that vapor flow (evaporation) is occurring at depth in the silt loam soil. Appendix C provides details of these measurements.

FIGURE 3.7. Water Potentials (Suction Profiles) for Bare and Vegetated, Ambient Surfaces of Capillary Barrier Lysimeters, October 1991

4.0 PLANT BIOMASS ESTIMATES AT THE FIELD LYSIMETER TEST FACILITY

4.1 INTRODUCTION

Plant measurements were made on the FLTF in 1989 and 1992 to aid in the interpretation of lysimetry data. We estimated total above- and below-ground biomass on each of ten lysimeters (eight drainage and two weighing lysimeters). Results are provided at the species level. We describe field sampling methods, models developed to estimate canopy leaf area from non-destructive measures, relationships between leaf area and biomass, and root/shoot ratios. The estimates were made by developing correlations between shoot biomass and leaf area index for several of the major plant species. The computer code and raw data are on file in FLTF task records and can be obtained from Steven O. Link, plant intrusion task leader.

4.2 METHODS

All individual plants on each lysimeter were measured to estimate biomass. All estimates were made non-destructively except for Bromus tectorum (cheatgrass). The non-destructive tests required the development of morphological models to relate simple canopy measures to canopy biomass. The location of each individual and groups of Bromus tectorum individuals were also documented, but are not discussed in this report. The species occurring on the lysimeters include Agropyron sibericum (Siberian wheatgrass), Artemisia tridentata (sagebrush), Bromus tectorum, Oryzopsis hymenoides (Indian ricegrass), and Poa sandbergii (Sandberg's bluegrass).

The measurements (cm) taken to predict biomass for all but B. tectorum include the greatest shoot (leaves) height, the greatest floral height, the longest dimension observed while looking straight down over an individual's canopy, and the dimension 90° from the longest dimension. These perpendicular measures were made for the bases of the bunchgrasses. Measurements taken in B. tectorum clumps were the greatest dimension and the dimension 90° to the greatest dimension.

The model for P. sandbergii was developed by double sampling. Fifteen individuals which spanned the range of sizes found on the lysimeters were

located off the lysimeters for harvest. The same dimensional measures were taken on these individuals before harvest. All shoot material was clipped and placed in a plastic bag for later analysis. Single-sided leaf area was measured with a LI-COR 3100 leaf area meter. Shoot material was then dried in a convection oven at 55°C for at least 48 hours for biomass values. A linear regression model was developed to predict shoot leaf area from morphometric measures (cm) as follows:

$$Y = b_0 + b_1w + b_2pw + b_3fht + b_4lht + b_5w^2 + b_6pw^2 + b_7fht^2 + b_8lht^2, \quad (1)$$

where Y is predicted leaf area (cm²), w is the greatest projected basal diameter (cm), pw is the perpendicular width to w, fht is the floral height, lht is leaf height, and b_i are linear regression parameters.

Agropyron sibericum and Oryzopsis hymenoides are uncommon species which precluded the development of a similar model. Both species are related to Pseudoroegneria spicata; therefore, their leaf areas were estimated using a P. spicata model. All measures except leaf height were taken on 15 individuals spanning all sizes above seedlings. Sample processing was as described for P. sandbergii. The model is as follows:

$$Y = b_0 + b_1w + b_2pw + b_3fht + b_4w*pw*fht. \quad (2)$$

Shoot biomass was estimated from predicted leaf area by making use of the biomass to leaf area ratios of 0.0215 for P. sandbergii, and 0.0285 for P. spicata. Biomass for A. tridentata was estimated using the model of Uresk et al. (1977) which is as follows:

$$Z = b_0 + b_1w*pw*lht, \quad (3)$$

where Z is total (leaves, stems, wood) shoot oven dried biomass (g). Shoot biomass for B. tectorum was obtained by harvesting and drying all shoots within a 100-cm² area and assuming that the stand density on the lysimeters was constant and equal to the average of the five harvested values. The

harvests for B. tectorum were done on the lysimeters. Shoot biomass was then obtained by multiplying the biomass per cm² by w and pw.

Root biomass (g) was estimated making use of published root/shoot ratio values. The root/shoot ratio for P. sandbergii was 2.26 and for B. tectorum, 0.5 (Link et al. 1990a). The root/shoot ratio for P. spicata and A. tridentata was 2.35 based on community level data as described in Rickard and Vaughan (1988). Computer coding was done with the SAS Institute (1985) software package.

4.3 RESULTS

The regression model [Equation (1)] developed for P. sandbergii was highly significant with an adjusted R² value of 0.96. Regression parameter estimates are listed in Table 4.1. Table 4.2 shows how plant biomass responded dynamically to changes in precipitation (and irrigation). Lysimeters with ambient precipitation had small increases or decreases in biomass. The main observation on the dynamics of total plant biomass on the lysimeters is that irrigation caused significant increases in overall biomass. The majority of biomass was contributed by A. tridentata. Oryzopsis hymenoides biomass decreased in all lysimeters from 1989 to 1992 suggesting that factors other than water influenced its survival on the lysimeters. Table 4.3 provides treatment statistics for the biomass (vegetation) study. Between the two test years, 1989 and 1992, the irrigation treatment significantly increased biomass. Treatment 5 (gravel admix) had the lowest average biomass (due to one replicate showing a great reduction in biomass). Because of limited replication (2), no firm conclusions were drawn on these observations. The maximum weight change (for the irrigated lysimeters) averaged less than 0.5kg/yr. If such weight changes, due to biomass increase, were to occur on the weighing lysimeters, the error in water storage would be less than 0.5mm/yr. This error in water storage due to biomass changes is negligibly small (less than 1%) compared to overall water storage for any of the lysimeter treatments (see Figure 3.5).

TABLE 4.1. Linear Regression Parameter Values for the Leaf Area and Biomass Models Described in Equations 1-3

Parameters	<i>P. sandbergii</i> Leaf Area (cm ²)	<i>P. spicata</i> Leaf Area (cm ²)	<i>A. tridentata</i> Total Aboveground Biomass (g)
b_0	438	514.7	196
b_1	-50.4	12.46	0.00102
b_2	-78.4	-18.72	
b_3	155.5	-21.73	
b_4	-494	0.01121	
b_5	1.1958		
b_6	6.325		
b_7	-2.016		
b_8	23.99		

TABLE 4.2. Estimated Total Plant Biomass (g) and Biomass Index (g/m²) on Each Lysimeter in 1989 and 1992

Surface Area (m ²)	Lysimeter	Treatment	Biomass			
			Total (g)	Index (g/m ²)	Total (g)	Index (g/m ²)
2.99	D04-1	Ambient, 1.5 m	3442	1150	3455	1160
2.99	D07-1		3417	1140	3291	1100
2.34	W01-1		3803	1620	3337	1430
2.99	D13-3	Irrigated, 1.5 m	5318	1780	10491	3510
2.99	D14-3		6381	2130	9582	3200
2.34	W03-3		3844	1640	7131	3050
2.99	D02-5	Ambient, 1.5 m,	2623	750	1357	450
2.99	D05-5	Gravel Admix	3343	1110	4164	1390
2.99	D03-6	Ambient, 1.0 m	3325	1110	4015	1340
2.99	D06-6		3045	1020	3481	1160

TABLE 4.3. Treatment Statistics for Biomass Study at the Field Lysimeter Test Facility

Treatment	Type	Estimated Total Biomass (g/m ²)	
		Mean SEM ^(a) 1989	Mean SEM ^(a) 1992
1	1.5 m soil, ambient ppt.	1306 ± 159	1227 ± 100
3	1.5 m soil, irrigated	1852 ± 146	3254 ± 135
5	1.5 m soil, admix, ambient	998 ± 120	923 ± 469
6	1.0 m soil, ambient ppt.	1065 ± 47	1253 ± 89
(a) SEM = standard error of mean Tukey's (HSD) test, comparison at 0.05 confidence level (Steel and Torrie 1960).			
Note: In 1989 Treatment 3 > Treatment 5, 6; Treatment 3 n.s. Treatment 1 In 1992 Treatment 3 > Treatment 1, 5, 6.			

5.0 CONCLUSIONS

The FLTF continues to provide important water balance data needed in the design of surface barriers (covers) for the Hanford Site. During FY 1993, a record snowfall occurred, resulting in "above-normal" water storage in all lysimeters. Water storage in bare, irrigated, lysimeters (with 1.5-m-deep silt loam soils) exceeded the 500-mm water storage limit and drainage occurred. No drainage occurred in any other capillary barrier treatment. These data demonstrate the limits of capillary barriers when soil water storage capacities are exceeded. Soil water storage responded to climatic variation and to presence and absence of vegetation. Storage differed dramatically between treatments, being the least under vegetated treatments and greatest under bare, irrigated conditions.

The irrigated, bare soil treatment is an extreme case. Bare surfaces presently exist at the Hanford Site, only at sites with coarse (gravel-covered) surfaces that have received soil sterilants or herbicides. Bare surface conditions, which result from fire or drought, are typically transient conditions, lasting less than one year at the Hanford Site. Since the irrigated bare soil treatment has been maintained for nearly 6 years, water storage in the bare soil lysimeters was abnormally high. High initial water storage, coupled with elevated precipitation, caused the lysimeters to drain.

Under irrigation, where vegetation was present, summer and fall water storage was reduced to values similar to that occurring in vegetated treatments without irrigation. The low water storage in the vegetated treatments allowed the extreme winter snowmelt events in 1993 to be stored without exceeding the storage limit (500 mm) and by July all winter precipitation (including irrigation) was removed via evapotranspiration.

These data support the concept that vegetation can efficiently remove excess water from a surface barrier at the Hanford Site. Should fire or drought remove vegetation on silt loam soils at Hanford, new vegetative growth will most likely be initiated rapidly because of the abundance of seed sources (Rickard and Vaughan 1988).

Species composition may change (e.g., from shrubs to grasses) as a result of fire or drought (Link et al. 1990b). The observations of increased vegetative growth (nearly double the biomass) on irrigated lysimeters is not surprising and supports the concept that additional water will increase vegetation in the water-limited environment at the Hanford Site.

The observations of significant drainage from gravel-covered lysimeters suggest that bare, gravel surfaces at the Hanford Site will readily transmit water and drain much of the annual precipitation. Elevated winter precipitation contributed to increased drainage in 1993. Drainage ranged from 58% to 83% of applied water for ambient and irrigated, gravel-covered lysimeters, respectively.

From our lysimeter results, we can project an expected performance of the prototype barrier, planned for construction in FY 1994. We anticipate that the vegetated soil surfaces will store and release (via evapotranspiration) all of the applied (ambient plus irrigation) water on the cover top surfaces. In contrast, the rip-rap (rock) side slopes are expected to drain most of the applied water, with somewhat less drainage occurring from the clean-fill side slopes. The quantification of this drainage will be important in evaluating total cover performance.

6.0 RECOMMENDATIONS

The past year provided valuable information on the operation of a capillary barrier system at an arid site under extreme precipitation (snowfall) conditions. Continued operation, with imposed supplemental winter snowfall, would test the performance of capillary barrier systems under repeated extreme events. For this reason, we recommend that the FLTF be maintained and tested for a minimum of three additional years.

We also recommend adding six additional treatments to the FLTF. These treatments will consist of pairs of lysimeters filled with 1) basalt rock (prototype barrier side-slope), 2) clean-fill gravel (another prototype barrier side-slope), and 3) vegetated silt loams (prototype barrier cover). Because of cost constraints, we recommend that these treatments be conducted in existing lysimeter containers. We recommend excavating and refilling lysimeters D02-5 and D09-7 (see Figure 2.4) with basalt rock, lysimeters D04-1 and D11-7 with clean-fill soil, and lysimeters D07-1 and D14-3 with vegetated silt loam, 2-m-thick (with 15 wt% pea-gravel admixed into the top 1 m). One of each pair of lysimeters will receive ambient precipitation; the other lysimeter of each pair will receive 3X precipitation.

We recommend that the FLTF, including these new treatments, be monitored for at least 3 more years. Water balance data from the new treatments will be compared with water balance observations in the other eleven FLTF treatments and at the prototype barrier. Comparisons between prototype and FLTF water balance will allow us to evaluate scale-effects (i.e., lysimeter to field scale) and the merit of using lysimeter data to extrapolate in time and space to full-scale barrier situations. If such efforts prove successful, much time and money can be saved by utilizing past lysimeter records to forecast large-scale water balances of waste covers for Hanford, under present and expected future climatic conditions.

7.0 FIELD LYSIMETER TEST FACILITY PUBLICATIONS

1. Kirkham, R. R., G. W. Gee, and J. L. Downs. 1987. Field Lysimeter Test Facility for Protective Barriers: Experimental Plan. PNL-6351, Pacific Northwest Laboratory, Richland, Washington.
2. Gee, G. W., R. R. Kirkham, J. L. Downs, and M. D. Campbell. 1989. The Field Lysimeter Test Facility (FLTF) at the Hanford Site: Installation and Initial Tests. PNL-6810, Pacific Northwest Laboratory, Richland, Washington.
3. Campbell, M. D., G. W. Gee, M. J. Kanyid, and M. L. Rockhold. 1990. Field Lysimeter Test Facility: Second Year (FY 1989) Test Results. PNL-7209, Pacific Northwest Laboratory, Richland, Washington.
4. Campbell, M. D., and G. W. Gee. 1990. Field Lysimeter Test Facility: Protective Barrier Test Results (FY 1990, The Third Year). PNL-7558, Pacific Northwest Laboratory, Richland, Washington.
5. Campbell, M. D., G. W. Gee, R. R. Kirkham, S. J. Phillips, and N. R. Wing. 1991. "Water Balance Lysimetry at a Nuclear Waste Site," In Proceedings of the International Symposium on Lysimetry, ed. R. G. Allen, pp. 125-134. American Society Civil Engineers, New York.
6. Kirkham, R. R., M. L. Rockhold, G. W. Gee, M. J. Fayer, M. D. Campbell, and L. J. Fritschen. 1991. "Lysimeters: Data Acquisition and Analysis," In Proceedings of the International Symposium on Lysimetry, ed. R. G. Allen, pp. 362-370. American Society of Civil Engineers, New York.
7. Phillips, S. J., J. F. Relyea, C. J. Kemp, N. R. Wing, M. D. Campbell, G. W. Gee, M. J. Graham, R. R. Kirkham, and M. S. Rubin. 1991. "Development of Hanford Site Lysimeter Facilities," In Proceedings of the International Symposium on Lysimetry, ed. R. G. Allen, pp. 19-27. American Society of Civil Engineers, New York.
8. Waugh, W. J., M. E. Thiede, L. L. Cadwell, G. W. Gee, H. D. Freeman, M. R. Sackschewsky, and J. F. Relyea. 1991. "Small Lysimeters for Documenting Arid Site Water Balance," In Proceedings of the International Symposium on Lysimetry, ed. R. G. Allen, pp. 151-159. American Society of Civil Engineers, New York.
9. Fayer, M. J., M. L. Rockhold, and M. D. Campbell. 1992. "Hydrologic Modeling of Protective Barriers: Comparison of Field Data and Simulation Results." Soil Sci. Soc. Am. J. 56:690-700.
10. Gee, G. W., P. J. Wierenga, B. J. Andraski, M. H. Young, M. J. Fayer, and M. L. Rockhold. 1994. "Variations in Water Balance and Potential Recharge at Three Western Desert Sites." Soil Sci. Soc. Am. J. 58:Jan/Feb issue (in press).

8.0 REFERENCES

- Alway, F. J., and G. R. McDole. 1917. "Relation of Water-Retaining Capacity of a Soil to Its Hygroscopic Coefficient." J. Agri. Res. 9:27-71.
- Andersen, L. J., and E. V. Clausen. 1988. "The Capillary-Barrier Test Field at Botterup, Denmark," In Hydrology and Safety of Radioactive and Industrial Waste Disposal. International Symposium, Vol. 1, pp. 1-4. Communications International Association of Hydrogeologists, Orleans, France.
- Anderson, D. C., M. J. Lupo, M. C. Anderson, and S. L. Hana. 1989. "Cover Design and Other Closure Considerations for a Low-level Radioactive Waste Site," In Superfund '89. Proceedings of the 10th National Conference, pp. 4-8. Hazardous Material Control Research Institute, Silver Spring, Maryland.
- Booth, C. J., and B. C. Price. 1989. "Infiltration, Soil Moisture and Related Measurements at a Landfill with a Fractured Cover, Illinois." J. Hydrol. 108:175-188.
- Campbell, M. D., and G. W. Gee. 1990. Field Lysimeter Test Facility: Protective Barrier Test Results (FY 1990, the third year). PNL-7558, Pacific Northwest Laboratory, Richland, Washington.
- Campbell, M. D., G. W. Gee, M. J. Kanyid, and M. L. Rockhold. 1990. Field Lysimeter Test Facility: Second Year (FY 1989) Test Results. PNL-7209, Pacific Northwest Laboratory, Richland, Washington.
- Cartwright, K., T. H. Larson, B. L. Herzog, T. M. Johnson, K. A. Albrecht, D. L. Moffett, D. A. Keefer, and C. J. Stohr. 1987. A Study of Trench Covers to Minimize Infiltration at Waste Disposal Sites. NUREG/CR-2478, Vol. 3, U.S. Nuclear Regulatory Commission, Washington, D.C.
- Fayer, M. J., W. Conbere, P. R. Heller, and G. W. Gee. 1985. Model Assessment of Protective Barrier Designs. PNL-5604, Pacific Northwest Laboratory, Richland, Washington.
- Fayer, M. J. 1987. Model Assessment of Protective Barrier Designs: Part II. PNL-6297, Pacific Northwest Laboratory, Richland, Washington.
- Fayer, M. J. 1990. Test Plan for Hydrologic Modeling of Protective Barriers. PNL-7152, Pacific Northwest Laboratory, Richland, Washington.
- Fayer, M. J., M. L. Rockhold, and M. D. Campbell. 1992. "Hydrologic Modeling of Protective Barriers: Comparison of Field Data and Simulation Results." Soil Sci. Am. J. 56:690-700.
- Gee, G. W., R. R. Kirkham, J. L. Downs, and M. D. Campbell. 1989. The Field Lysimeter Test Facility (FLTF) at the Hanford Site: Installation and Initial Results. PNL-6810, Pacific Northwest Laboratory, Richland, Washington.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992a. "Variation in Recharge at the Hanford Site." Northwest Sci. 66:237-250.

Gee, G. W., M. D. Campbell, G. S. Campbell, and J. H. Campbell. 1992b. "Rapid Measurement of Low Soil Water Potentials Using a Water Activity Meter." Soil Sci. Soc. Am. J. 56:1068-1070.

Healy, R. W. 1989. "Seepage Through a Hazardous-waste Trench Cover." J. Hydrol. 108:213-234.

KEH (Kaiser Engineers Hanford). 1993. Engineering Report Prototype Surface Barrier at 200-BP-1 Operable Unit. WHC-SD-EN-T1-142, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Kirkham, R. R., G. W. Gee, and J. L. Downs. 1987. Field Lysimeter Test Facility for Protective Barriers: Experimental Plan. PNL-6351, Pacific Northwest Laboratory, Richland, Washington.

Link, S. O., G. W. Gee, and J. L. Downs. 1990a. "The Effect of Water Stress on Phenological and Ecophysiological Characteristics of Cheatgrass and Sandberg's Bluegrass." J. Range Management 43:506-513.

Link, S. O., G. W. Gee, M. E. Thiede, and P. A. Beedlow. 1990b. "Response of a Shrub-steppe Ecosystem to Fire: Soil Water and Vegetational Change." Arid Soil Research and Rehabilitation 3:163-172.

Lutton, R. J., G. L. Regan, and L. W. Jones. 1979. Design and Construction of Covers for Solid Waste Landfills. EPA 600/2-79/165, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Melchoir, S., K. Berger, B. Vielhaber, G. Miehlich. 1993. "Water Balance and Efficiency of Different Landfill Cover Systems." In Proceedings of the International Symposium on Geology and Confinement of Toxic Wastes. Geoconfine '93, eds. M. Arnould, M. Barres, and B. Come, pp. 325-330. June 8-11, 1993, Montpellier, France.

Miller, D. E. 1973. "Water Retention and Flow in Layered Soil Profiles." In Field Soil Water Regime, ed. R. R. Bruce, pp. 107-117. Soil Science Am. Special Publ. Series #5, Madison Wisconsin.

Nyhan, J. W., W. Abeele, T. Hakonson, and E. A. Lopez. 1986. Technology Development for the Design of Waste Repositories at Arid Sites: Field Studies of Biointrusion and Capillary Barriers. LA-10574-MS, Los Alamos National Laboratory, Los Alamos, New Mexico.

Rancon, D. 1980. "Application of the Capillary Barrier Technique to Storage in Trenches." In Underground Disposal of Radioactive Wastes, Vol. 1, pp. 241-265, (French with English summary). IAEA-SM-243/71, International Atomic Energy Agency, Vienna.

Rickard, W. H., and B. E. Vaughan. 1988. "Plant Community Characteristics and Responses." In Shrub-Steppe, Balance and Change in a Semi-Arid Terrestrial Ecosystem, eds. W. H. Rickard, L. E. Rogers, B. E. Vaughan, and S. F. Liebetrau, pp. 109-179. Elsevier, New York.

SAS Institute Inc. 1985. SAS User's Guide: Statistics, Version 5 Edition. SAS Institute Inc., Cary, North Carolina.

Schulz, R. K., R. W. Ridky, and E. O'Donnell. 1989. Control of Water Infiltration into Near Surface LLW Disposal Units. NUREG/CR-4918, Vol. 3, U.S. Nuclear Regulatory Commission, Washington, D.C.

Smoot, J. L., J. E. Szecsody, B. Sagar, G. W. Gee, and C. T. Kincaid. 1990. Simulations of Infiltration of Meteoric Water and Contaminant Plume Movement in the Vadose Zone at Single Shell Tank 241-T-106 at the Hanford Site. WHC-EP-0332, Westinghouse Hanford Company, Richland, Washington.

Steel, R.G.D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York.

Uresk, D. W., R. O. Gilbert, and W. H. Rickard. 1977. "Sampling Big Sagebrush for Phytomass." J. Range Management 30:311-314.

EPA (U.S. Environmental Protection Agency). 1986. Covers for Uncontrolled Hazardous Waste Sites. EPA/540/2-85/002, U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA (U.S. Environmental Protection Agency). 1987. Minimum Technology Guidance on Final Covers for Landfills and Surface Impoundments. U.S. Environmental Protection Agency, Washington, D.C.

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

Wing, N. R., and G. W. Gee. 1990. "Protective Barrier Development: Overview." In Proceedings of the Twenty-Eighth Hanford Symposium on Health and the Environment, Environmental Monitoring, Restoration, and Assessment: What Have We Learned?, ed. R. H. Gray, pp. 147-151. Pacific Northwest Laboratory, Richland, Washington.

Winograd, I. J. 1981. "Radioactive Waste Storage in Thick Unsaturated Zones." Science 212:1457-1464.

APPENDIX A

TARGET AMOUNTS OF WATER APPLICATION

TABLE A.1. Target Amounts of Water for Irrigated FLTF Treatments

<u>Date</u>	<u>Target 2X Treatment (mm)</u>	<u>Date</u>	<u>Target 3X Treatment(mm)</u>
07-Nov-87	7.8	07-Nov-90	12.0
14-Nov-87	19.2	14-Nov-90	29.2
21-Nov-87	31.2	21-Nov-90	47.2
28-Nov-87	42.8	28-Nov-90	64.5
05-Dec-87	53.9	05-Dec-90	81.2
12-Dec-87	64.7	12-Dec-90	97.3
19-Dec-87	75.0	19-Dec-90	112.8
26-Dec-87	85.0	26-Dec-90	127.7
02-Jan-88	94.5	02-Jan-91	142.0
09-Jan-88	103.7	09-Jan-91	155.8
16-Jan-88	112.5	16-Jan-91	169.0
23-Jan-88	121.0	23-Jan-91	181.8
30-Jan-88	129.2	30-Jan-91	194.0
06-Feb-88	137.0	06-Feb-91	205.8
13-Feb-88	144.6	13-Feb-91	217.1
20-Feb-88	151.8	20-Feb-91	227.9
27-Feb-88	158.7	27-Feb-91	238.3
06-Mar-88	166.3	06-Mar-91	248.4
13-Mar-88	172.7	13-Mar-91	258.0
20-Mar-88	178.8	20-Mar-91	267.2
27-Mar-88	184.7	27-Mar-91	276.1
03-Apr-88	190.4	03-Apr-91	284.7
10-Apr-88	195.8	10-Apr-91	292.9
17-Apr-88	201.1	17-Apr-91	300.9
24-Apr-88	206.1	24-Apr-91	308.5
01-May-88	210.3	01-May-91	315.9
08-May-88	215.1	08-May-91	323.0
15-May-88	219.6	15-May-91	329.9
22-May-88	224.1	22-May-91	336.6
29-May-88	228.4	29-May-91	343.0
05-Jun-88	233.2	05-Jun-91	349.3
12-Jun-88	237.2	12-Jun-91	355.5
19-Jun-88	241.2	19-Jun-91	361.4
26-Jun-88	245.1	26-Jun-91	367.3
03-Jul-88	248.9	03-Jul-91	373.0
10-Jul-88	252.7	10-Jul-91	378.7
17-Jul-88	256.4	17-Jul-91	384.3
24-Jul-88	260.1	24-Jul-91	389.8
31-Jul-88	263.8	31-Jul-91	395.2
07-Aug-88	267.4	07-Aug-91	400.7
14-Aug-88	271.1	14-Aug-91	406.1
21-Aug-88	274.8	21-Aug-91	411.6
28-Aug-88	278.5	28-Aug-91	417.0
04-Sep-88	282.2	04-Sep-91	422.5
11-Sep-88	286.0	11-Sep-91	428.1
18-Sep-88	289.8	18-Sep-91	433.8
25-Sep-88	293.7	25-Sep-91	439.5
02-Oct-88	297.7	02-Oct-91	445.4
09-Oct-88	301.8	09-Oct-91	451.4
16-Oct-88	306.0	16-Oct-91	457.6
23-Oct-88	310.4	23-Oct-91	463.9
31-Oct-88	320.0	31-Oct-91	480.0

Cum. Rain and Irrigation - Week Ending 25-AUG-92
(Rain) = 5.1, (Irr.) = 5.6

Cumulative Rain + Irr. vs Target
01-NOV-91 Thru 25-AUG-92

On 25-AUG-92 (Rain+Irr.)=407.7, (Target)=415.5

FIGURE A.1. Example of Weekly Data from the Field Lysimeter Test Facility Showing Water Storage Changes and Targeted Actual Water Approach

APPENDIX B

NEUTRON PROBE CALIBRATION

APPENDIX B

NEUTRON PROBE CALIBRATION

INTRODUCTION

Water contents in soil can be determined with a neutron probe using a standard linear equation with the two parameters slope and intercept. Determination of these parameters, i.e., calibration of a neutron probe, traditionally involves a significant amount of soil coring that can disturb an experimental site. Further, the coring usually must be done on several dates on which the water contents are different so that a range of water contents can be sampled. We have 18 pairs of soil core-neutron probe counts collected on a single date encompassing a water content range that is less than expected for the duration of the experiment. We were concerned about having insufficient data in the wet range. Rather than resampling to improve our calibration, we elected to use another method whereby lysimeter weight changes were used to determine the equation slope and a small set of soil core data was used to determine the intercept.

MATERIALS AND METHODS

Four 2.25-m² weighing lysimeters were constructed with a 1.5-m-deep layer of silt loam soil (Gee et al. 1989). Two of the lysimeters contain a mixture of annual and perennial vegetation; the other two are non-vegetated. The lysimeters rest on Weigh-Tronix^(a) platform scales that have a weight resolution equivalent to 0.02 cm of water, thus their designation as weighing lysimeters. The weight of each lysimeter was monitored hourly.

A Campbell-Pacific Nuclear Model 503-DR probe^(a) was used to measure water contents in the lysimeters every 15 cm down to a depth of 135 cm.

Sixteen-second counts were converted to water content using

$$\theta = a_0 + a_1 C \quad (1)$$

(a) The use of product names does not signify an endorsement.

where θ = water content (m^3/m^3)

a_0 = intercept

a_1 = slope

C = neutron counts during 16-s reading.

Water storage (S_{np} , cm) in each lysimeter was calculated using Simpson's method as described by Haverkamp et al. (1984):

$$S_{np} = [\theta_1 + (\theta_1 + 4\theta_2 + 2\theta_3 + 4\theta_4 + 2\theta_5 + 4\theta_6 + 2\theta_7 + 4\theta_8 + \theta_9)/3 + \theta_9]\Delta z \quad (2)$$

where Δz is 15 cm. Water storage changes in the sand and gravel layers underlying the silt loam were considered negligible based on their retention properties and the observation of water potentials consistently below -250 cm.

Probe readings were conducted on 47 dates between November 1987 and October 1989. For each date, S_{np} values were calculated and associated with the lysimeter weight at 0600 h. Discrepancies could exist between neutron probe and lysimeter storage values for the following reasons: measurement times, snow cover, irrigation and precipitation, and temperature. Probe measurements occurred during the day rather than at 0600 h. A snow cover is detectable with a weighing lysimeter but not with the probe. Recent irrigation or precipitation that had not infiltrated beyond the top several centimeters would be detected by the weighing lysimeter but would not be adequately detected by the probe. Temperatures below freezing could have affected the equipment. To minimize the possible effects of these factors, the number of dates was reduced by eliminating those dates that did not satisfy the following screening criteria:

- lysimeter weight change between 0600 and 1800 h (the interval during which probe measurements occurred) must be <0.25 cm
- snow must be absent
- average daily air temperature must be $>0^\circ\text{C}$
- irrigation or precipitation must not occur on the measurement date or its preceding date

Of the 47 dates, 24 were eliminated because of recent irrigation or precipitation, two were eliminated because of snow, and one was eliminated because of temperature.

Between measurement dates, ΔS_{np} (the change in storage calculated with the neutron probe) was compared with ΔS_{wl} (the change in storage detected by the weighing lysimeters). Using a least-squares technique, the slope of the neutron probe equation was optimized to produce the best match between ΔS_{np} and ΔS_{wl} . With the optimized slope, the intercept of Equation (1) was calculated using a set of soil water contents and associated neutron probe readings obtained on November 4, 1987. The soil water contents were determined on samples from the depth interval from 0 to 30 cm in each of 18 lysimeters. Water contents ranged from 0.094 to 0.220 m³/m³. The neutron probe readings were conducted in each lysimeter at the depth of 15 cm.

RESULTS AND DISCUSSION

Using the least-squares technique, the optimum slope was determined to be 1.81×10^{-5} . Figure B.1 shows the high correlation between ΔS_{np} and ΔS_{wl} ($r^2 = 0.975$). Using this slope and the least-squares technique, the optimum intercept was determined to be -0.0163. Figure B.2 shows the comparison of predicted and measured water contents. Using the optimized values of slope and intercept, the correlation coefficient (r^2) was .834. Figure B.3 shows the three calibration equations, and Table B.1 summarizes their parameters.

During the period when the lysimeters were monitored, water contents in portions of the lysimeters ranged from 0.03 to 0.30 m³/m³. This range is larger than that for the core data (i.e., 0.09 to 0.22); thus, the lysimeter data should yield a better estimate of the slope than the core data.

FIGURE B.1. Comparison of Storage Changes Determined with the Neutron Probe and Weighing Lysimeters

FIGURE B.2. Comparison of Predicted and Measured Water Contents

FIGURE B.3. Neutron Probe Calibration Equations

TABLE B.1. Parameters for Neutron Probe Calibration Equations

<u>Calibration Equation Number</u>	<u>Slope</u>	<u>Intercept</u>	<u>Source</u>	<u>Description</u>
1	0.0000200	-0.0348	PNL-6810 ^(a)	Slope calculated from core data; intercept calculated by forcing equation to match dry barrel standard.
2	0.0000170	-0.0144	PNL-6810 ^(a)	Slope and intercept calculations from weight changes in lysimeter WL-1.
3	0.0000181	-0.0163	This Report	Slope calculated from lysimeter weight changes; intercept calculated from core data, using optimized slope.

(a) Gee et al. (1989).

APPENDIX C

SURFACE WATER CONTENT AND SUCTIONS AT
SELECTED TIMES ON SELECTED LYSIMETERS

TABLE C.1. Surface Water Content and Matric Suction at Various Times on Selected Lysimeters

<u>SAMPLE</u>	<u>EVENING 10/10/91</u>			<u>MORNING 10/11/91</u>	
	<u>DEPTH(cm)</u>	<u>%H2O(g/g)</u>	<u>SUCTION(Mpa)</u>	<u>%H2O(g/g)</u>	<u>SUCTION(Mpa)</u>
D08-2	0.5	1.22	209.7	1.76	79.6
Dry (Ambient)	1	1.63	174.6	1.64	81.3
bare	5	2.23	57.5	2.25	43.7
	10	4.30	2.3	5.61	1.2
	20	7.56	1.1	8.24	0.4
W02-2	0.5	1.32	183.1	1.82	75.3
Dry (Ambient)	1	1.66	117.6	1.77	82.2
bare	5	2.59	44.1	2.42	40.1
	10	5.89	1.8	6.10	1.2
	20	7.30	1.0	7.99	0.4
W03-3	0.5	1.27	206.6	2.00	58.7
Wet (Irrigated)	1	1.63	139.4	2.11	59.4
Vegetated	5	2.55	35.9	3.38	9.1
	10	4.54	3.1	5.35	1.5
	20	3.50	8.6	3.82	6.5
D14-3	0.5	1.40	134.0	1.68	84.8
Wet (Irrigated)	1	1.77	91.8	1.64	107.1
Vegetated	5	2.57	20.4	2.15	58.1
	10	5.27	1.5	3.51	7.9
	20	3.08	9.4	3.31	14.7
D10-4	0.5	2.46	67.6	2.65	43.1
Wet (Irrigated)	1	5.05	2.8	4.34	13.5
bare	5	7.63	0.8	7.61	0.4
	10	9.01	0.8	9.30	0.1
	20	10.77	0.3	10.50	0.1
D04-1	0.5	--	--	1.65	70.5
Dry (Ambient)	1	--	--	1.44	111.1
Vegetated	5	--	--	1.42	122.7
	10	--	--	1.83	93.3
	20	--	--	2.30	48.8
	35	--	--	3.17	16.4

TABLE C.1. (contd)

MORNING 10/18/91

<u>SAMPLE</u>	<u>DEPTH(cm)</u>	<u>%H2O(g/g)</u>	<u>SUCTION(Mpa)</u>
D08-2	0.5	1.35	132.3
Dry (Ambient)	1	1.48	97.7
bare	5	1.99	50.7
W02-2	0.5	1.26	205.9
Dry (Ambient)	1	1.48	133.7
bare	5	2.70	28.6
W03-3	0.5	1.93	67.0
Wet (Irrigated) 1		4.43	3.4
Vegetated	5	8.61	0.7
D14-3	0.5	2.42	20.1
Wet (Irrigated)	1	6.19	1.4
Vegetated	5	7.98	1.0
D10-4	0.5	2.82	8.1
Wet (Irrigated)	1	7.66	1.1
Vegetated	5	9.47	0.7
D04-1	0.5	1.42	119.6
Dry (Ambient)	1	1.41	116.1
Vegetated	5	1.49	114.5
D04-1	0.5	2.06	92.8
Dry (Ambient)	1	2.58	48.1
Vegetated	5	3.53	17.2

TABLE C.1. (contd)

SAMPLE	EVENING 07/01/92			MORNING 07/02/92	
	DEPTH(cm)	%H2O(g/g)	SUCTION(Mpa)	%H2O(g/g)	SUCTION(Mpa)
W02-2	0.5	1.23	184.2	2.14	32.8
Dry, bare	1	1.55	121.2	2.77	13.8
	5	9.25	1.2	7.15	1.4
	10	9.65	1.0	9.21	1.4
	15	11.57	1.1	9.43	1.1
	20	9.97	1.4	10.25	1.1
W01-1	0.5	1.34	170.3	1.97	47.2
Dry, veg	1	1.79	74.9	2.18	38.8
	5	5.68	1.8	4.47	2.3
	10	5.80	2.2	4.83	2.1
	15	6.02	1.9	4.91	2.1
	20	5.64	1.8	4.80	2.3
W03-3	0.5	1.16	193.5	2.07	50.7
Wet, veg	1	1.44	141.3	1.98	45.7
	5	4.69	3.2	3.71	4.4
	10	4.86	2.4	4.33	3.0
	15	3.45	10.0	3.58	6.6
	20	--	5.9	3.98	5.9
W04-4	0.5	1.08	110.7	2.98	8.2
Wet, bare	1	1.20	12.2	5.31	1.7
	5	1.84	1.1	9.02	1.1
	10	2.98	20.8	11.55	1.1
	15	3.21	11.3	12.76	0.8
	20	3.30	7.2	13.67	1.1
D14-3	0.5	1.14	197.2	1.82	55.6
Wet, veg	1	1.29	180.8	2.08	36.3
	5	1.89	79.7	4.21	3.2
	10	2.86	23.1	4.26	3.0
	15	3.23	11.5	3.53	6.5
	20	3.42	7.8	3.83	5.7
D10-4	0.5	1.39	108.3	2.95	10.4
Wet, bare	1	1.66	8.5	4.80	2.6
	5	7.16	1.1	7.94	1.0
	10	10.38	1.0	9.79	0.8
	15	10.27	1.1	11.79	1.2
	20	12.07	0.8	12.76	1.0

TABLE C.1. (contd)

	<u>EVENING 07/01/92</u>			<u>MORNING 07/02/92</u>	
<u>SAMPLE</u>	<u>DEPTH(cm)</u>	<u>%H2O(g/g)</u>	<u>SUCTION(Mpa)</u>	<u>%H2O(g/g)</u>	<u>SUCTION(Mpa)</u>
D08-2 Dry, bare	0.5	0.56	145.4	1.88	56.1
	1	1.78	96.1	2.44	18.6
	5	4.86	1.8	5.53	1.8
	10	7.53	1.5	8.74	1.2
	15	8.59	1.3	8.73	0.8
	20	7.98	1.4	8.98	1.2
D04-1 Dry, veg	0.5	1.21	122.6	1.80	66.2
	1	1.76	87.3	2.12	42.4
	5	4.92	2.2	4.19	3.2
	10	4.96	2.2	4.53	3.9
	15	4.61	1.9	4.07	3.6
	20	5.67	1.9	4.16	3.6

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