U.S. DEPARTMENT OF
ENERGY

PNNL-17841

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates

WE Nichols ML Rockhold
JL Downs

September 2008

Pacific Northwest
NATIONAL LABORATORY

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UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Summary

This report is a compendium of recharge data collected in Fiscal Years 2004 through 2008 at various soil and surface covers found and planned in the 200 West and 200 East Areas of the U.S. Department of Energy's Hanford Site in southeast Washington State. The addition of these new data to previously published recharge data will support improved estimates of recharge with respect to location and soil cover helpful to evaluations and risk assessments of radioactive and chemical wastes at this site. Also presented are evaluations of the associated uncertainties, limitations, and data gaps in the existing knowledge base for recharge at the Hanford Site.

Acknowledgments

We heartily acknowledge the prior work of JM Keller, CE Strickland, DL Saunders and RE Clayton in their unpublished FY 2007 letter report on recharge that provided substantial portions of the work reported in this compendium and the data collection efforts of those individuals that are the technical bases of the data presented here. The continued field support work of DL Saunders, RE Clayton, and CE Strickland is also acknowledged and commended.

We also gratefully acknowledge the work of AM Playter, SA McKee, S Easterday, and JL Allen who worked with JL Downs to provide the vegetation characterization for the Hanford Solid Waste Landfill site in FY 2008.

Symbols, Abbreviations, and Acronyms

bgs	below ground surface
DOE	U.S. Department of Energy
FH	Fluor Hanford, Inc.
FFTF	Fast Flux Test Facility
FLTF	Field Lysimeter Test Facility
FY	Fiscal Year (October 1 to September 30)
HMS	Hanford Meteorological Station
IDF	Integrated Disposal Facility
LAI	leaf area index
ORHY	*Oryzopsis hymenoides*
PNNL	Pacific Northwest National Laboratory
RACS	Remediation And Closure Science (Project)
RDS	Remediation Decision Support (Project)
STCO	*Stipa comata*
SWL	solid waste landfill
WFM	water flux meter

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Accompanying CD/ROM: Recharge Data Presented in Compendium of Fiscal Year 2004 – 2008 Recharge Data for 200 Area Recharge Estimates

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1 Introduction

Recharge constitutes a boundary condition for vadose zone and groundwater models and therefore is an important quantity to characterize for studies, simulations, and evaluations of waste disposal practices at the Hanford Site. The basis for estimating recharge includes substantial fieldwork and data collection from monitoring sites at Hanford.

Pacific Northwest National Laboratory (PNNL) assembled this compendium for Fluor Hanford, Inc. (FH) as part of the Remediation Decision Support (RDS) function of the Soil and Groundwater Remediation Project. RDS provides scientific and technical support for waste management and cleanup efforts at the U.S. Department of Energy's (DOE) Hanford Site. The purpose of the compendium is to gather and document previously unpublished recharge data for the 200 Areas collected from monitoring activities in Fiscal Years (FY) 2004 through 2008, and use these data to update estimates of recharge for soil types found in the 200 Areas at the Hanford Site. Data collection activities in FY 2008 were supported by FH under the Remediation and Closure Science (RACS) Project.

The most robust estimates of Hanford recharge rates are those that are derived from water balance measurements under Hanford Site soil and climatic conditions. Water balance measurements include direct measurements of drainage and measurements of related variables such as soil water content and soil matric potential. Previously published recharge data packages provide reasonable estimates of site-wide recharge for some soil conditions, but continued monitoring of drainage over a wider range of climate variables (i.e., more extremes in precipitation and temperatures), soil/surface barrier conditions, and over longer time periods serves to refine and improve the defensibility of recharge estimates. For low-drainage conditions, such as those typical of Hanford conditions, these measurements may be required over time scales of decades, or longer, in order to obtain reliable measurements. Significant interruptions in data continuity or site maintenance in these conditions adversely impacts data integrity and thereby reduces the defensibility of recharge estimates derived from those data. This compendium is produced specifically to document additional data collected in recent years in a citable form, and use those data to refine recharge estimates.

The scope of this compendium is limited in the following respects:

- Emphasis is on the 200 East and 200 West Areas of the Hanford Site
- Presents recharge data collected in FY 2004 through FY 2008

This compendium includes an overview of the parameterization of recharge (Section 2), identification of previously published recharge data (Section 3), presentation of previously unpublished data (Section 4), discussion of knowledge gaps (Section 0), and conclusions (Section 6).

To increase the utility of this recharge compendium, the data discussed in this document and other associated information is electronically available in a compact disc (CD/ROM) accompanying this report including site photographs, raw and processed recharge data, and the graphics files used to generate most of the figures depicting recharge data presented in this report.

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2 Parameterization of Recharge

Recharge is defined as the flux of water transmitted across the water table from the vadose zone to the saturated zone. Direct measurement of recharge at the water table is typically impractical due to the inaccessibility, especially at Hanford where the water table is commonly located at depths below ground surface (bgs) of 80 meters or more. The influence of aquifer-influencing operations, such as artificial discharges or remediation pump and treat systems, would further complicate efforts at making a direct measurement for a deep water table. Instead, measurements and analyses in the unsaturated zone at shallow depths are used to characterize deep drainage, that is, the water flux leaving the depth below which the processes of evaporation and transpiration can return water from the unsaturated soil to the atmosphere. This deep drainage, with sufficient time, will be manifest as the recharge flux. The time required will depend on the thickness and hydraulic properties of the vadose zone and the deep drainage rate itself. Changes in the deep drainage rate, such as would result from changes in surface vegetative conditions that increase or decrease the evapotranspiration rate, can take many years to be reflected in the recharge rate for a thick vadose zone in arid conditions such as at the Hanford Site and can be an important consideration in characterizing recharge as well (Nichols et al. 2007).

2.1 Importance

Recharge is the primary mechanism for transporting contaminants from the vadose zone to groundwater. Bacon and McGrail (2002) demonstrated this by showing the sensitivity of buried immobilized low-activity waste (ILAW) glass release and transport to recharge. Their evaluation of the release of technetium-99 from the ILAW glass for five recharge rates revealed that the technetium-99 flux beneath the ILAW disposal zone is more sensitive to the recharge rate than to any other parameter for recharge rates below 10 mm/yr. Recharge rates in this range are common for natural vegetation and soil conditions at Hanford. Such a high sensitivity of waste disposal performance to recharge rate underscores the need to characterize this parameter as accurately as possible.

2.2 Influencing Factors

Important physical properties and processes that influence recharge include climate, soil hydraulic properties and stratigraphy, vegetative cover, land use, and topography. Climate determines the driving forces for recharge, namely the quantity of precipitation available for the land surface water balance, and the energy fluxes that are determinant in the partitioning of precipitation into evaporation, transpiration, and recharge. Soil hydraulic properties and stratigraphy determine the rate at which water is transmitted through the vadose zone, and hence it's resident time for processes of evaporation and transpiration. Vegetative cover determines the strength of the transpiration portion of the land surface water balance. Land use will change the influencing factors including the vegetative cover and surface soils, and hence the hydraulic properties and soil stratigraphy of a site, and hence transpiration rates. Topography is the primary determinant for the portion of precipitation that is subject to overland flow, either "run-on" or "run-off", for a given site. Knowledge of all of the influences is important to the estimation of recharge at a given location.

2.3 Estimation Methods

Recharge rates at the Hanford Site can range from near zero to more than 100 mm/yr (Gee et al. 1992). Measuring a parameter that varies over such a large range requires use of complementary methods. An excellent overview of recharge estimation techniques is provided in Scanlon et al. (2002). The methods in use at the Hanford Site include physical techniques (water balance, lysimetry), tracer techniques (chloride, isotopes), and numerical techniques (computer simulation). These and other methods are discussed at length relative to arid climates such as that at Hanford in the January-February 1994 issue of the *Soil Science Society of American Journal*, which contains a series of papers that were presented at a symposium titled "Recharge in Arid and Semiarid Regions." A brief overview of each technique in use at the Hanford Site is provided here for reference purposes.

2.3.1 Physical

Physical methods attempt to calculate recharge as a residual after measuring other terms (precipitation, evaporation, transpiration, runoff, storage) in the land surface water budget (water balance technique) or directly measure recharge in using an apparatus (lysimeter, water flux meters).

2.3.1.1 Water balance

Water balance methods rely on measurement of several terms in the land surface water balance equation to derive recharge as a residual:

$$D = P - ET - R + \Delta S$$

Where D is drainage (taken to represent recharge) calculated as total precipitation (P) less water returned to the atmosphere through evapotranspiration (ET), less water that runs on or off the control surface (R), plus the net change in storage of water in the soil zone to the depth that evapotranspiration processes affect (ΔS). Precipitation is easily and directly measured. Runon/runoff is often not a parameter of importance for the soils of concern at Hanford, except locally along roadways, parking lots, and other low permeability areas and when snow melt or other large storm events exceed surface infiltration rates. Runon/runoff may also be important along bedrock outcrops and/or flashflood events along the western edge of the Hanford Site near Rattlesnake Mountain or the Gable Mountain/Gable Butte structures. Soil moisture must be measured over the depth range that is affected by evapotranspiration and at frequent time intervals to complete the calculation of recharge (drainage) as a residual.

2.3.1.2 Lysimetry

A lysimeter (as used for drainage measurements at the Hanford Site) is a soil-filled container or field-scale pad that is used to collect water that has flowed through and below the reach of the evapotranspiration process to become deep drainage, and eventually, recharge. The objective of lysimetry is to collect both performance data and model testing data for specific combinations of soil, vegetation, and precipitation. Lysimetry is one of only two methods available (the other being drainage flux meters) to directly measure deep drainage and thereby recharge. A primary strength of a lysimeter is that it can provide a control volume in which a number of water balance components can be integrated and measured directly. This control volume provides the data necessary to calibrate numerical models, that can in turn be used to predict recharge.

While lysimeters provide a direct measure of recharge, they possess some disadvantages. Lysimeters are usually fixed in space, limiting their ability to quantify the effects of spatial variability. The soil filling the lysimeter may not represent the natural stratification or layering that may be present. The length of a lysimeter record is usually much shorter than time periods of interest, although the longer the lysimeter is operated the more this drawback is alleviated. The lysimeter walls and base alter the natural gradients of temperature, air flow, and vapor flow that could be of importance in measuring recharge rates less than 1 mm/yr. Lysimeter walls restrict lateral root growth and artificially promote downward growth. When an irrigation treatment is used, lysimeter tests are subject to an “oasis effect,” a scale effect where heat from un-irrigated surroundings increases the evapotranspiration rate above what it would have been if the entire area surrounding the lysimeter had been irrigated. Finally, it is critical to verify that no leaks of drainage water occur in the lysimeter before the data collected are used.

Lysimeters have long been used at the Hanford Site for several purposes (Hsieh et al. 1973, Gee and Jones 1985, Freeman and Gee 1989, Wittreich and Wilson 1991, Gee et al. 1993, Ward et al. 1997). Lysimeters used to provide data reported in this compendium include containers that isolate the soil from its surroundings and field-scale pads that collect drainage but do not isolate the soil.

2.3.1.3 Water Flux Meters (WFMs)

The function and design of a vadose zone water flux meter (WFM) for direct, in situ measurement of recharge is described in Gee et al. (2002). The design, illustrated in Gee et al. (2002) and shown here as Figure 2.1, concentrates flow into a narrow sensing region filled with a fiberglass wick. The wick applies suction, proportional to its length, and passively drains the meter. Such a meter can be installed in an augured borehole at almost any depth below the root zone. Water flux through the meter is measured with a self-calibrating tipping bucket. Further enhancement to this design are discussed in Gee et al. (2003b).

2.3.2 Tracers

Tracer methods estimate past recharge by means of measuring the vertical distribution of a tracer in soil and sediments of the vadose zone. Several tracers are available that enable estimates of recharge rates: the ones used at Hanford have included chloride and chlorine-36 (Fayer et al. 1999, Fayer and Szecsody 2004) and the stable isotopes deuterium and oxygen-18 (DePaolo et al. 2004, Fayer and Szecsody 2004, Singleton et al. 2006). Isotopes of strontium were also used (Singleton et al. 2006).

2.3.2.1 Chloride and Chloride-36

Chloride originates from seawater, is deposited naturally, and can provide recharge estimates spanning hundreds to thousands of years. In contrast, the isotope chlorine-36 originates from two sources: cosmic irradiation of atmospheric chloride and surface and atmospheric nuclear weapons testing. The quantities of chlorine-36 created through nuclear weapons testing far exceeds natural production rates from cosmic irradiation and therefore furnishes a distinctive marker in the subsurface environment, particularly for

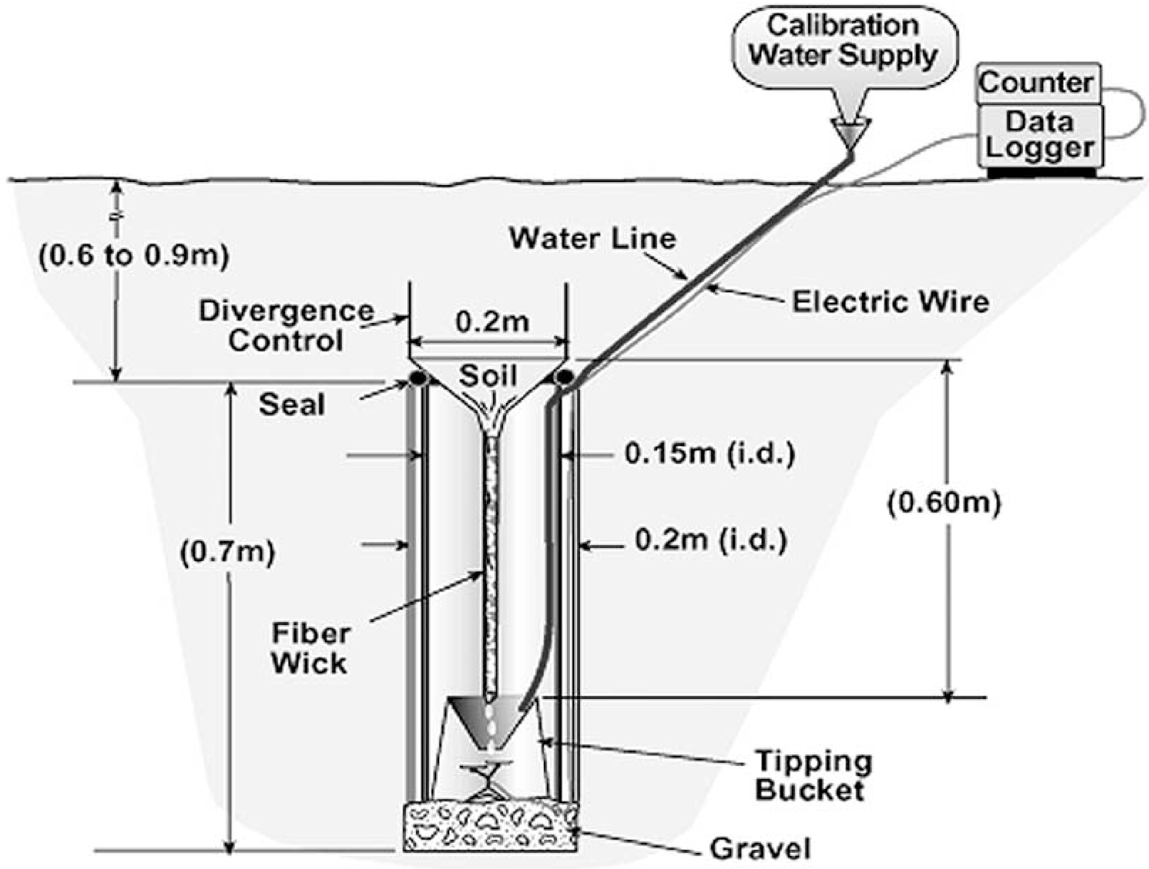

Figure 2.1 Schematic of installed vadose zone water fluxmeter with diversion control (Gee et al. 2002)

arid regions with low recharge rates where this "bomb pulse" is still in transit through the vadose zone. Chlorine-36 data are used to estimate the average recharge rate over the last 50 years for such environments.

Both chloride and chlorine-36 are conservative, nonvolatile, and almost completely retained in the soil when water evaporates or is transpired by plants (Phillips 1994). Some chloride is subject to plant uptake; examples of this shown in Rikard and Vaughn (1988) and in Sheppard et al. (1998). Over hundreds to thousands of years, plant cycling is expected to have a minimal impact on the evolution of the chloride distribution in the soil profile beneath plants. Recharge rates determined using chloride as a tracer reflect conditions that existed hundreds to thousands of years ago and are sometimes called paleorecharge or paleofluxes. When using such paleofluxes to represent current or future conditions, the assumption is that the climate, soil, and vegetation conditions remain similar. In contrast, bomb-pulse chlorine-36 has been present in the environment for only about 50 years. In soils with high pH and high adsorption of other anions, anion exclusion can result in faster movement of chloride. Previous studies strongly suggest a relationship between soil surface area, which is primarily determined by clay content, and anion exclusion, for example Thomas and Swoboda (1970). Most of the sandy soil found at the Hanford Site has a relatively low percentage of clay, so the effects of anion exclusion in this soil would be relatively minor. Two other issues that affect chloride-based estimates of recharge are mineral dissolution and the chloride dilution that is part of the measurement technique. Both issues can be significant when recharge rates exceed a few millimeters per year (Tyler et al. 1999).

Phillips (1994) suggested that systematic uncertainties in estimated chloride deposition rates can be as great as 20% if the chloride mass balance technique is extended to estimate recharge rates prior to the Holocene epoch (approximately 10,000 years ago). Scanlon (2000) suggested the uncertainty was as high as 38%. Because the Hanford Site was flooded by glacial melt water about 13,000 years ago, the interpretation is not extended beyond that time. Therefore, the uncertainty in chloride deposition rates at the Hanford Site is expected to be less than 38%.

There is some uncertainty about the local influence that Hanford Site operations may have had on the time-dependent concentrations of both chloride and chlorine-36 deposited at Hanford (Fayer et al. 1999). Murphy et al. (1991) examined the issue relative to chlorine-36 and concluded there was no nearby source that would confuse the chlorine-36 signal in the sediment.

2.3.2.2 Deuterium and Oxygen-18

Deuterium and oxygen-18 are inert isotopes of hydrogen and oxygen, respectively, that are naturally occurring. Their concentration increases as the lighter components evaporate disproportionately. The increased concentration can be used to delineate seasonal variations in water flux, identify the depth of evaporative enrichment, and roughly estimate recharge.

The recharge rate is determined largely by the magnitude of transpiration and evaporation relative to precipitation and overland flow that has infiltrated the soil. Because water consists of several isotopes of hydrogen and oxygen, each with slightly different atomic weights, evaporation tends to remove the lighter isotopes preferentially. The net result is that the residual water contains a higher proportion of the heavier isotopes. There is a progressive decrease in the proportion of heavy stable isotopes with soil depth because evaporation decreases with depth and because of mixing with infiltrating water. At some depth, the isotopic profile becomes somewhat uniform; this depth represents the vertical extent of significant water vapor flux. The amount of enrichment (relative to the isotopic signature in precipitation) is indicative of the recharge rate.

Oxygen-18 and deuterium are the two isotopes that constitute useful tracers because they are stable (and benign) and occur in measurable quantities. The oxygen-18 and deuterium ratios ($R = {}^{18}O/{}^{16}O$; $R = {}^{2}H/{}^{1}H$) are used to express isotopic composition in delta (δ) units relative to a standard material as follows:

$$\delta = \left[\frac{R_{sample}}{R_{standard}} - 1 \right] \times 1000$$

where δ is reported in permil units (‰; a δ value of 10‰ is equivalent to 1%). Typical values for winter precipitation (the primary source of recharge water for the climate at the Hanford Site) are --19 to -16‰ for $\delta\ {}^{18}O$ and -142 to -120‰ for $\delta\ {}^{2}H$ (Singleton et al. 2006). The actual depth of enrichment will depend on factors that include recharge rate, soil properties, meteorological conditions, and average annual temperature. Murphy et al. (1991) described how deuterium and oxygen-18 could be used to understand recharge rates at the Hanford Site.

2.3.3 Numerical Modeling

Numerical modeling of unsaturated flow in the vadose zone can be used to estimate recharge rates, but because this method introduces the highest uncertainty it is usually reserved for situations where there are little or no data, or to leverage limited short-term data to estimate long-term recharge.

Simulations of recharge at Hanford have been successful at highlighting the important factors that affect recharge and predicting recharge rates for specific cases. Modeling is the primary tool for forecasting recharge rates for future climate and land use scenarios. The simulations also allow the results of the lysimetry and tracer methods to be merged on a consistent basis.

3 Previous Recharge Investigations

Recharge at Hanford Site locations has been studied for decades because of its importance to evaluation of waste transport in the vadose zone and unconfined aquifer. Examples of early attention to natural recharge included the studies of the 200 East Area deep well by Enfield and Hsieh (1971) and Enfield et al. (1973).

With the transition of the Hanford Site's mission from nuclear materials production to environmental cleanup, more resources and effort were brought to bear on measuring and estimating natural recharge at the site. Long-term lysimeter facilities were constructed, maintained, and monitored to measure recharge for several soil and vegetation covers (Gee 1987, Gee et al. 1989). This included the 200 East Lysimeters (Hsieh et al. 1973, Routson et al. 1988, Gee et al. 1994) and later a lysimeter facility that was installed north of the 300 Area (Gee et al. 2005).

In the mid-1990s A site-wide natural recharge map was constructed by using numerical simulation along with soil and vegetation cover maps to extrapolate available point measurements (Fayer and Walters 1995). Site-specific recharge measurements for areas of special interest were undertaken such as at the prototype Hanford Barrier to measure the effectiveness of proposed infiltration barriers (Ward et al. 2005). Data packages were prepared to support compliance assessments including the Solid Waste Landfill (SWL) (Gee et al. 2005), the Integrated Disposal Facility (IDF) (Rockhold et al. 1995, Fayer et al. 1999, Fayer and Szecsody 2004) and the recharge data package for the RCRA Facility Investigation (Fayer and Keller 2007).

By the late 1990s tracer-based methods began to be employed in addition to water balance measurement based methods to estimate recharge (Murphy et al. 1996, Prych 1998, Fayer et al. 1999, Maher et al. 2003, DePaolo et al. 2004, Fayer and Szecsody 2004, Gee et al. 2005, Maher et al. 2006, Singleton et al. 2006, Keller et al. 2007).

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4 Recharge Data Collected in FY 2004-2008

Monitoring of water flux and related properties (e.g. water content, matric potential) has been conducted at various locations for different periods at the Hanford Site. Active monitoring locations are shown in the site map in Figure 4.1 for geographic reference. The monitoring sites, activities, and periods of operation for each site are listed in Table 4.1. Monitoring data are presented and examined on a site-by-site basis in this section.

4.1 Grass Site

The Grass Site is located approximately 4.5 km northwest of the 300 Area in a location dominated by stabilized sand dunes. Layered soil conditions exist at the site with a sandy loam to loamy sand soil present from the surface to a depth of approximately 40 cm followed by a sandy soil. Vegetation at the Grass Site is predominately annual and perennial grass. In 2005 a recharge monitoring station consisting of duplicate WFMs and two water content sensors was installed at this location. WFMs were installed keeping the layered soil column intact. Additional information about the Grass Site and the installation of monitoring equipment can be found in Keller and Gee (2005)[1]. Figure 4.2 shows photographs of the grass-covered surface of the two WFMs at this site in the autumn of 2006.

Table 4.1 Monitoring Sites, Activities, and Periods

Monitoring Site	Monitoring Activities	Monitoring Periods
Grass Site	Water flux, water content	1-Feb-2005 to present
300N Lysimeter	Water flux, water content, matric potential	1981 – December 2006 (Wind damage outage) February 2007 - present
Solid Waste Landfill [a]	Water flux, water content	December 2004 to present
Integrated Disposal Facility (IDF)	Environmental tracer methods, water content	2000-present
200 East Lysimeter	Water content	1991 to present [neutron probe measured water content data extends back to early 1970s (Hsieh et al. 1973)]
Field Lysimeter Test Facility (FLTF)	Water flux, water content, matric potential	1987 to present
Field Lysimeter Test Facility (FLTF) Pit	Water flux	2001 to present
Tank Farms (B, SX, TX)	B: Water flux, water content SX: Water flux, water content TX: matric potential	B: From 2001 to ~2003 SX: From January 2003 to Sept. 2007 TX: October 2002 to September 2007

[a] Leachate data from the SWL has been collected since 1996.

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[1] Keller JM and GW Gee. 2005. *Remediation Decision Support / Characterization of Systems Fiscal Year 2005 Recharge Task Status Report*, Letter Report to George Last, PNNL, September 10, 2005.

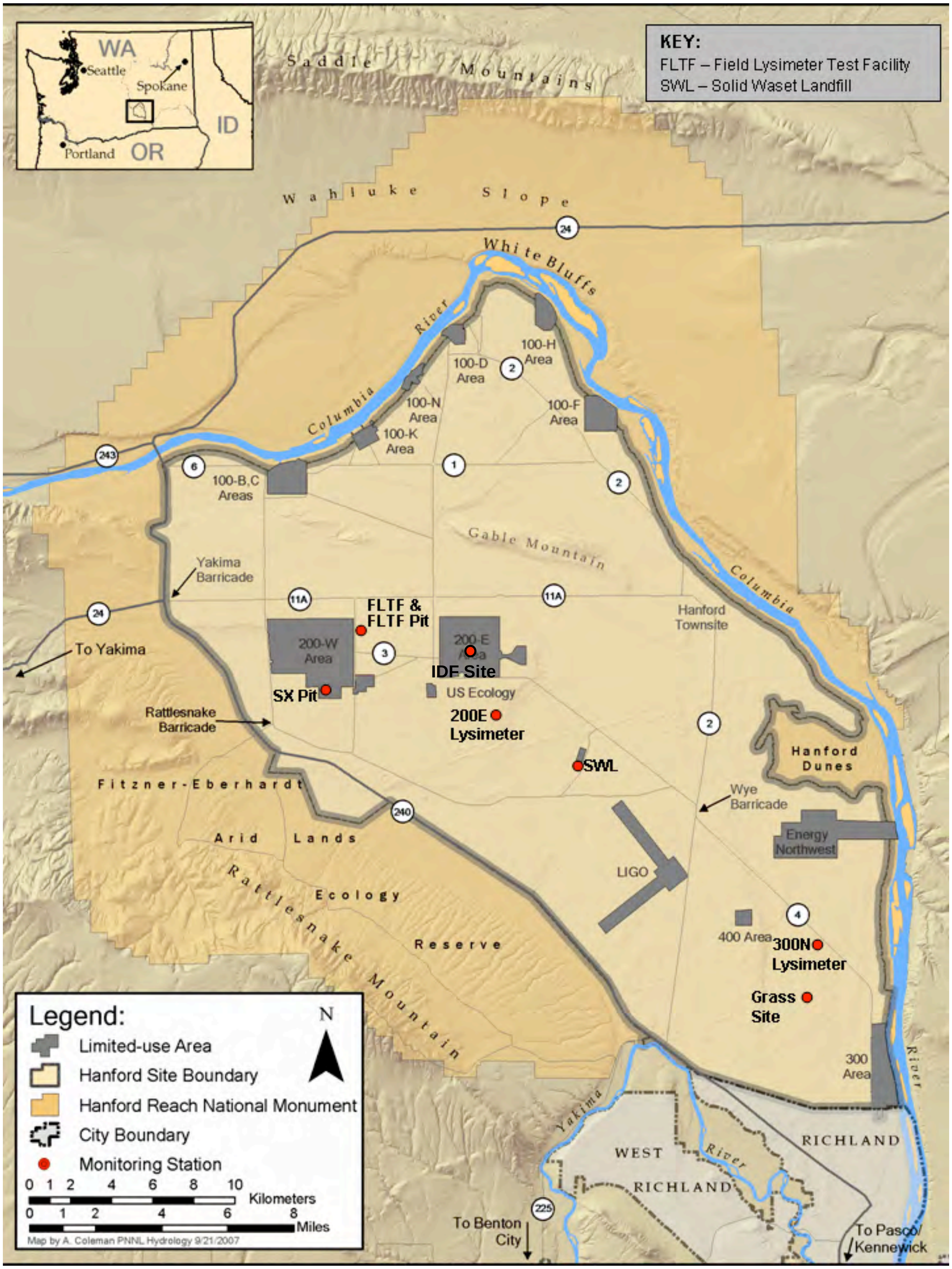

Figure 4.1 Approximate Location of Recharge Monitoring Stations

Figure 4.2 Surface Conditions of the Grass Site WFMs in Autumn 2006 (exposed tops of these WFMs are the identically sized at 20-cm diameter, but appear different sizes because of camera distance)

The water content and cumulative drainage since instrument installation are presented in Figure 4.3 and Figure 4.4. Changes in water content are consistent with seasonal precipitation trends (i.e. wet winters and dry summers). Increased water content is observed in the sand layer (60 cm bgs sensor) underlying the sandy loam layer. This signifies that the soil profile wets up enough to overcome the capillary break formed by this layering. Drainage amounts to date are markedly different between both flux meters (2.4 mm vs. 0.64 mm), possibly reflecting the variability in soil properties. This may be natural variation or variations brought about during installation of the WFMs. The WFMs did not measure drainage in 2007 or 2008. This lack of drainage is not a direct function of precipitation quantity: the HMS measured winter (that is, sum over the months of November through March) precipitation quantities were:

- Winter 2005-2006: 106 mm
- Winter 2006-2007: 109 mm
- Winter 2007-2008: 104 mm

The long-term average winter precipitation at HMS to date is 107 mm. On September 21, 2007, 40 mL of water were added to the calibration lines of each WFM to check their operation. No tips were recorded by the datalogger in response to these water additions, indicating that these sensors are not operating correctly. No attempt has yet been made to excavate and repair or replace these sensors.

4.2 300N Lysimeter

The 300-N Lysimeter site is located about 10 km north of Richland, Washington, just south of the Fast Flux Test Facility (FFTF), and within 300 m of the 300 Area Burial Grounds (618-10). A series of lysimeters designed for water-balance studies and to simulate waste-burial-grounds with bare, coarse-

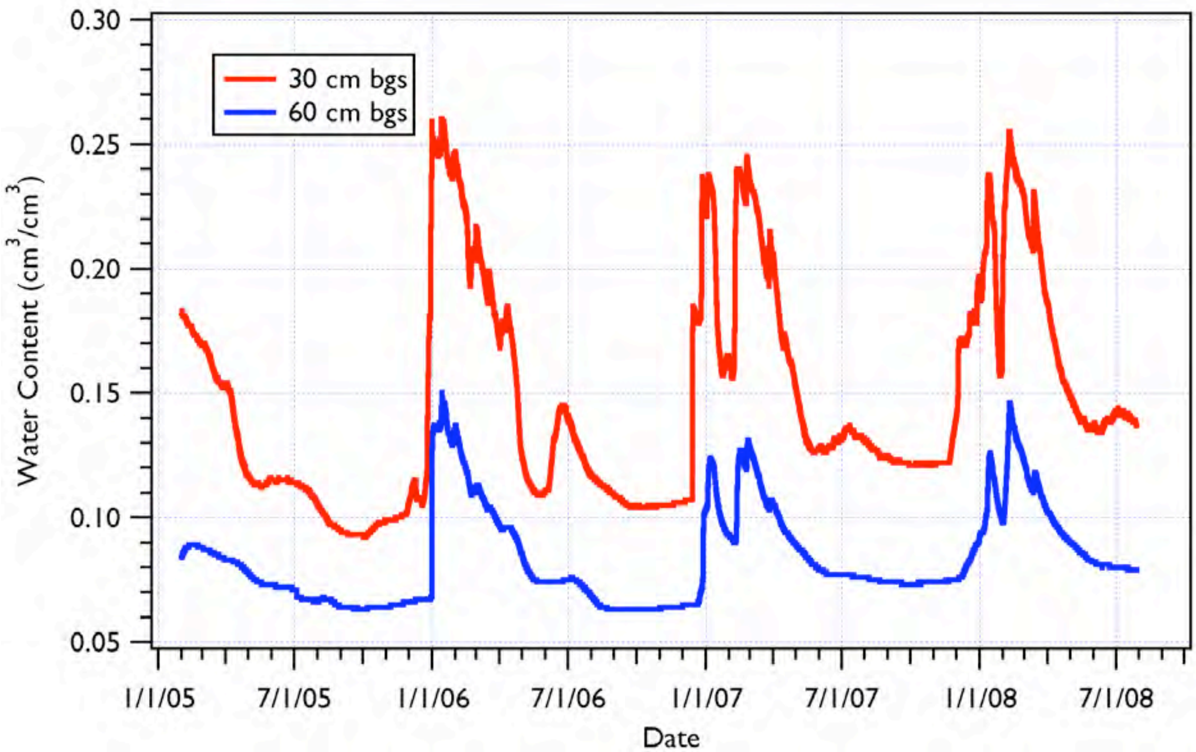

Figure 4.3 Water Content Measured at 30 and 60 cm bgs at the Grass Site

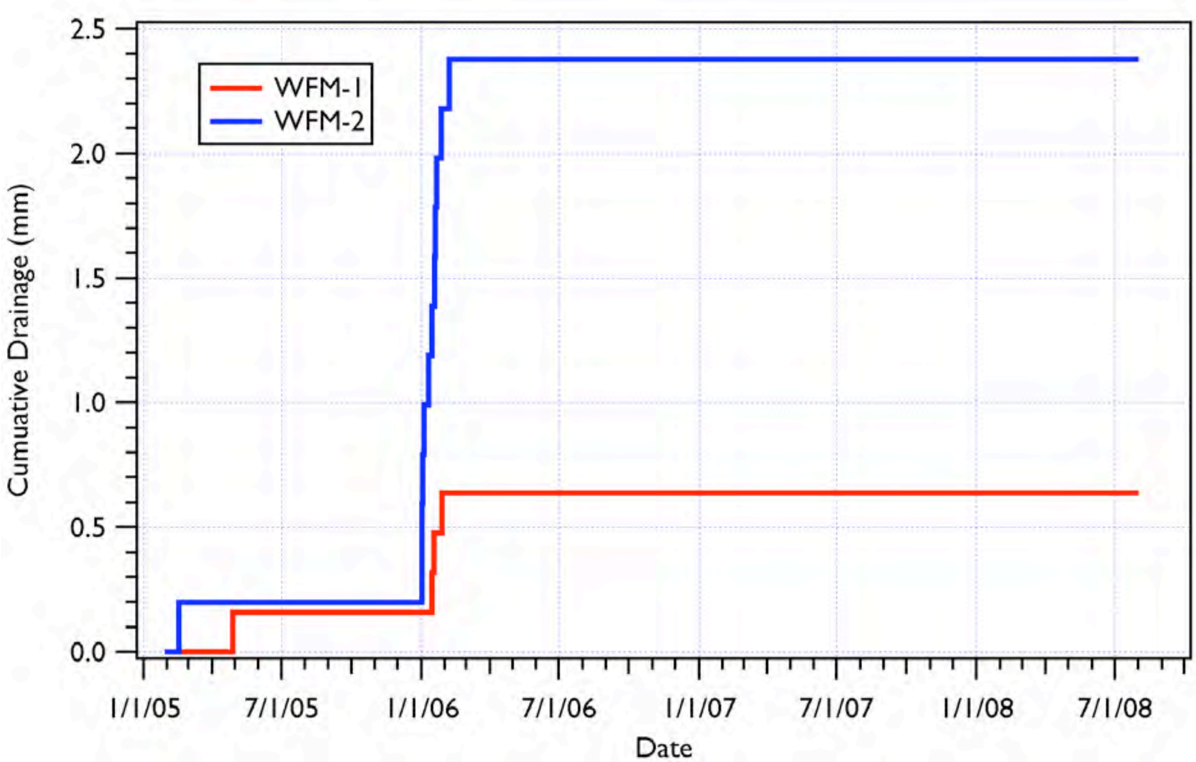

Figure 4.4 WFM Measured Cumulative Drainage at the Grass Site

grained surfaces was constructed at this site in 1978. Detailed descriptions of the site are provided by Gee and Jones (1985), Gee et al. (1992), and Sisson et al. (2002). Other instrumentation includes a Pronamic rain gage installed at the drainage outlet in the bottom of the lysimeter in August 2000. This rain gage was connected electronically to a datalogger to measure drainage on a continuous basis. In April 2002, two WFMs were also installed in the south lysimeter and connected to the datalogger.

Presently the 300-N Lysimeter site consists of two 2.7 m diameter, 7.6 m deep caissons. Monitoring at this site is restricted to one of these, the south caisson. Constructed in 1978, the south caisson lysimeter is filled with Hanford formation sediment screened to contain less than one percent gravel (material > 2 mm). The lysimeter has remained essentially void of vegetation over its lifetime. Automated measurement of drainage from the bottom of the lysimeter is accomplished using a tipping spoon gauge. In addition to this water flux measurement, two WFMs are installed within the lysimeter near the soil surface. Water content and matric potential profiles within the south caisson lysimeter are also monitored, as is matric potential outside the lysimeter at the 7.5 m depth. Additional information about the 300N Lysimeter Site and instrumentation can be found in Phillips et al. (1979) and Sisson et al. (2002).

In December 2006 a windstorm produced a peak gust of 74 mph (a record for the month of December) at the Hanford Meteorological Station (HMS). This windstorm blew over the 300N Lysimeter tripod that housed the datalogger and other measurement control devices. The resulting damage to the datalogger and power supply as well as to the associated wiring was substantial. Soon after the damage at the site was identified, efforts were made to repair and reconnect wiring as well as to better secure the tripod at this location. By February of 2007 the site was again operational, except for the datalogger switch ports controlling the WFMs. In the process of reconstructing the site it was recognized that many undocumented and unused instruments were at the site and that the datalogger program was outdated. An evaluation of instrumentation and the datalogger was performed and a decision made to overhaul the site. This effort included removing unnecessary code from the datalogger program, removing unused sensors from the site, checking functionality of equipment, and encasing all wiring. Because the datalogger switch ports no longer functioned and with consideration given to the age of the dataloggers and the fact that technical support for this model was being phased out by the manufacturer, a new datalogger was purchased for this site. In August of 2007 the new datalogger was installed. By the end of August 2007 the overhaul of the 300N Lysimeter Site was complete. This effort has significantly streamlined operation of the site and extended the operation of this critical facility. Figure 4.5 shows the surface of the 300N Lysimeter Site after completion of the overhaul.

The key measurement at this site is drainage from the bottom of the south caisson lysimeter. Figure 4.6 depicts cumulative drainage from this lysimeter for the period ending August 31, 2007. From the onset of drainage in 1981 to July 30, 2008 the drainage rate has averaged 62.1 mm/yr. During the time that the monitoring system was down in December 2006 and January 2007 due to the wind damage outage, drainage from the base of the lysimeter was not measured. Given the length of the drainage record at this site, the absence of these data does not significantly affect the reported average drainage rate. Measured water content at this site for FY 2007 is shown in Figure 4.7 and for FY 2008 in Figure 4.8.

The water content data display increases in water content in response to the onset of winter precipitation and drying of the profile into the drier spring and summer months in each year. Note that the datalogger at the 300N lysimeter site began to record periodic “NAN” (“not a number”) values from the water content sensors in February 2008 with associated noise evident in Figure 4.8 starting in April. Later in 2008 periodic NAN values also began to be recorded for some of the matric potential sensors. Inspection of the wiring and datalogger connections at this field site did not reveal any obvious problems with the

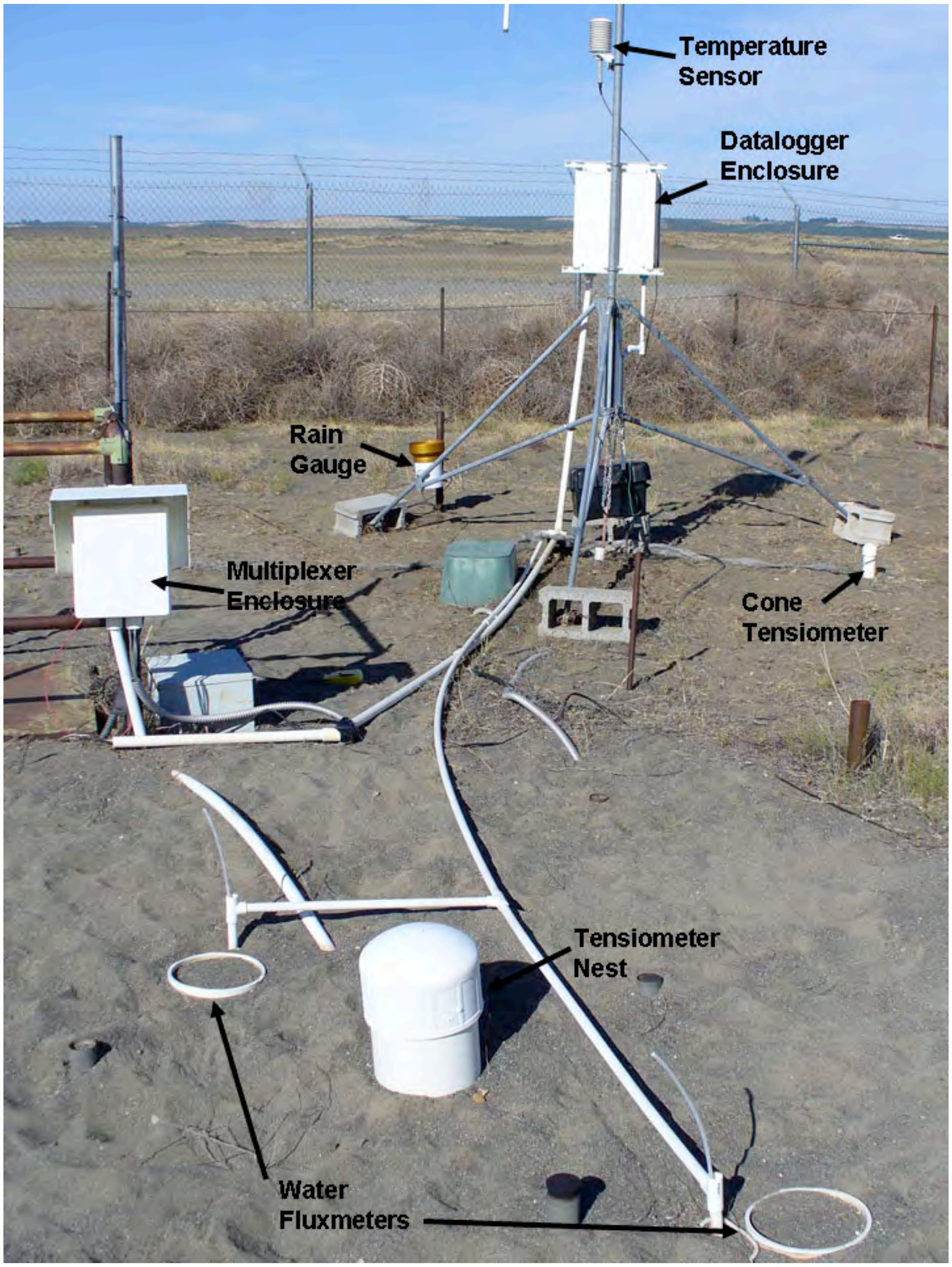

Figure 4.5 Surface Conditions of 300N Lysimeter Site Shortly After Completion of Site Overhaul (photograph taken September 13, 2007). The coarse textured sand in the foreground is the approximate location of the south caisson.

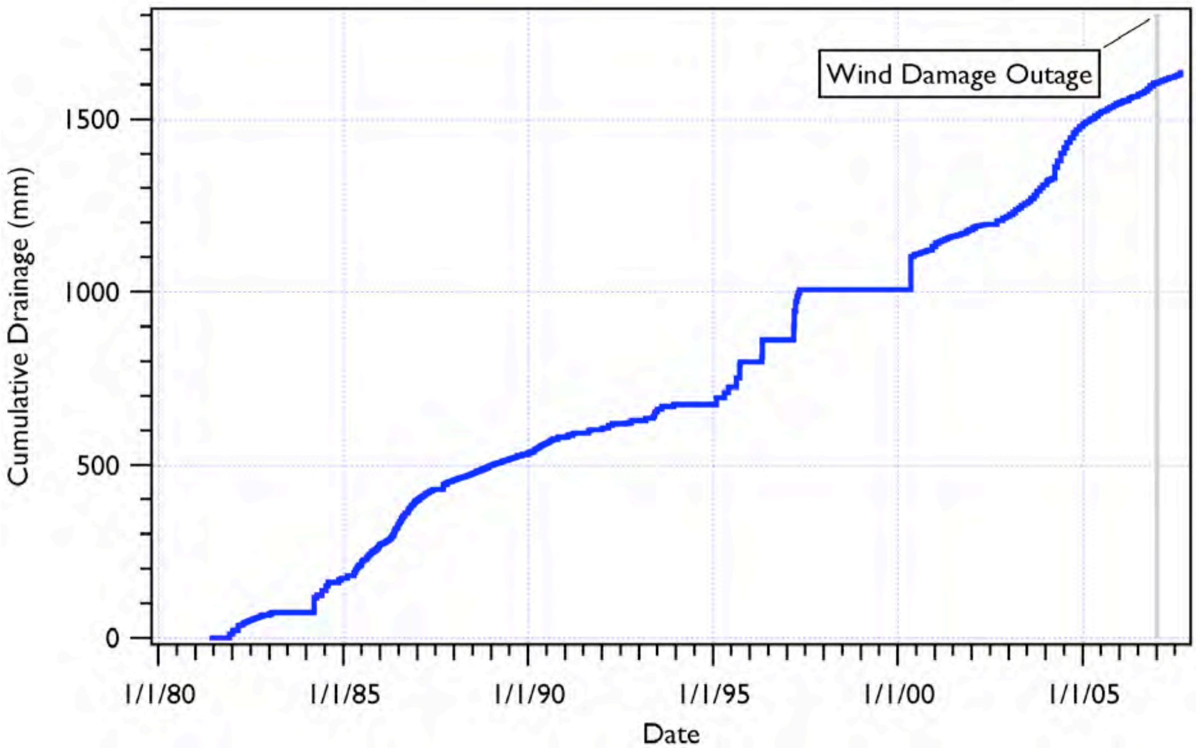

Figure 4.6 300N Lysimeter Measured Cumulative Drainage Since Drainage Onset in 1981

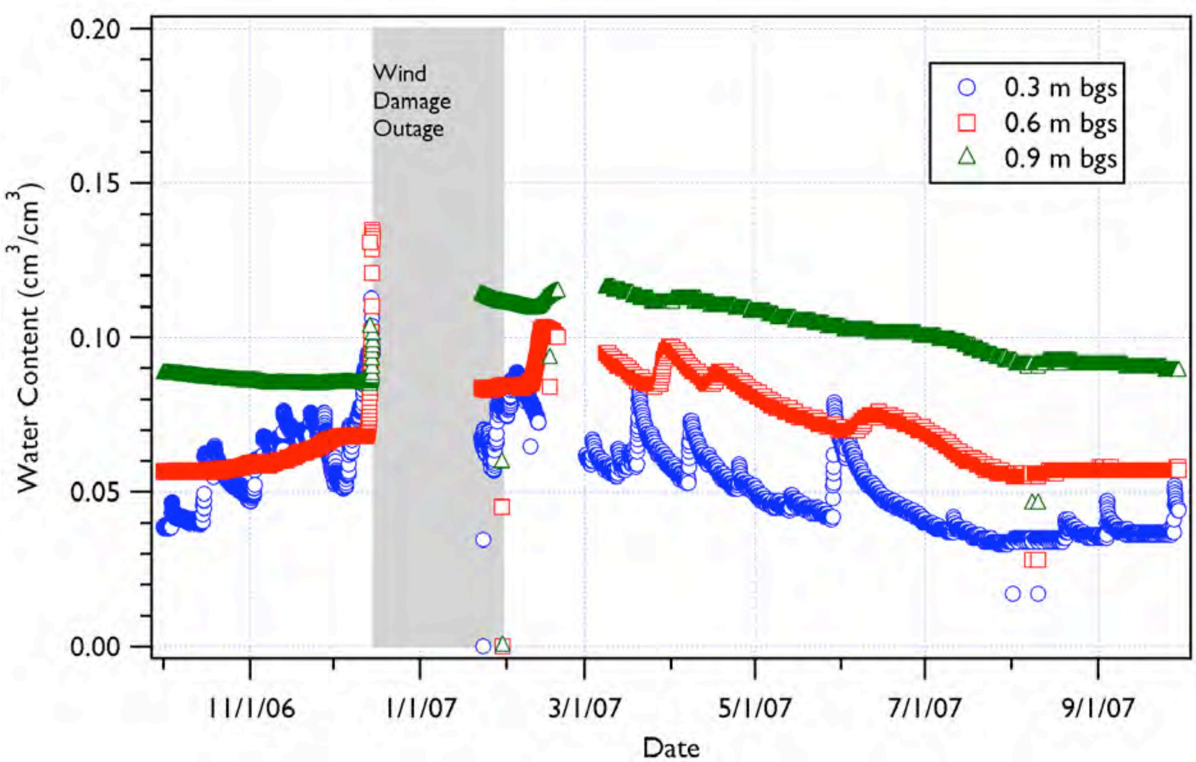

Figure 4.7 300N Lysimeter Water Content Measured at 0.3, 0.6, and 0.9 m bgs for FY 2007

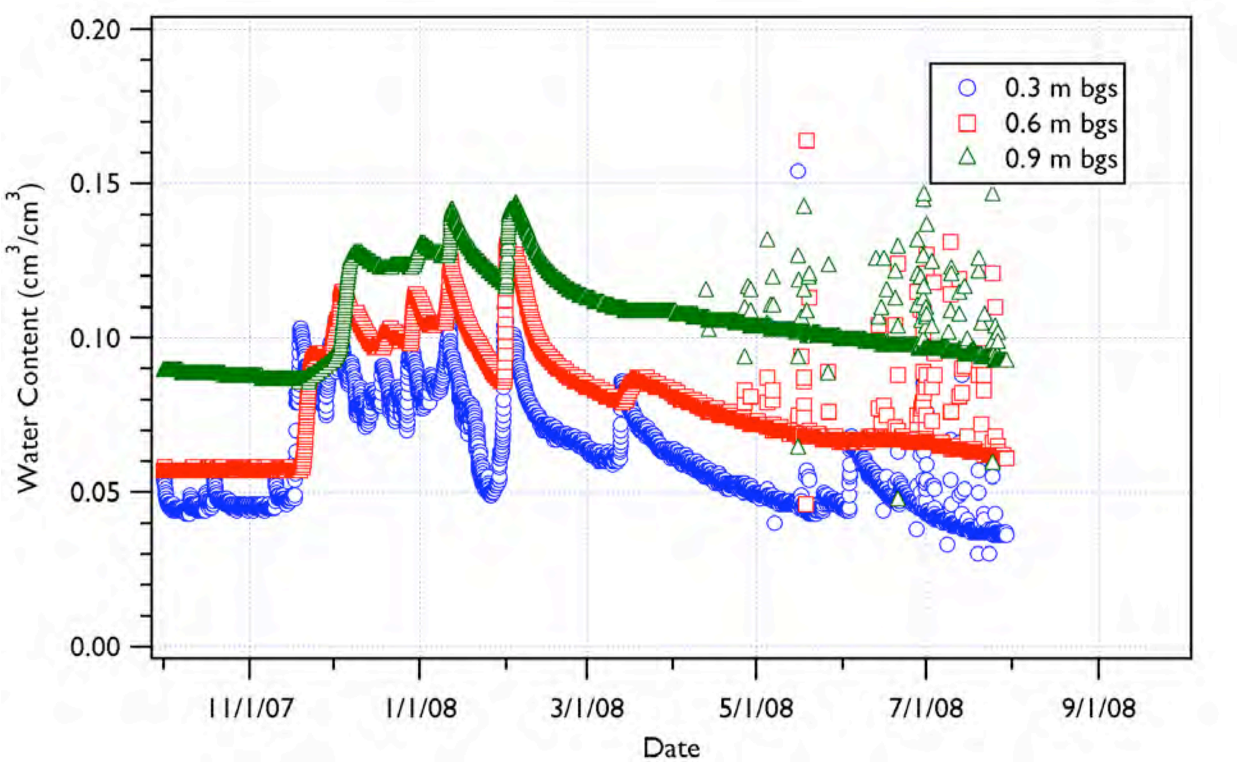

Figure 4.8 300N Lysimeter Water Content Measured at 0.3, 0.6, and 0.9 m bgs for FY 2008

equipment. The periodic NAN values generally are recorded between the hours of 8:00 p.m. and 4:00 a.m., a period each day when air temperatures are typically are declining. Based on this observation, it was suspected that this problem might be the result of condensation forming on the datalogger and/or sensor leads inside the datalogger enclosure. To mitigate such a possibility, desiccant was placed inside the datalogger enclosure. The data record for this site will be monitored to determine if this remedy resolves the problem.

The matric potential data measured by tensiometers within the lysimeter are presented in Figure 4.9, Figure 4.10, Figure 4.11, Figure 4.12, and Figure 4.13 for FY 2004, FY 2005, FY 2006, FY 2007, and FY 2008, respectively. These data exhibit relatively typical response with the near surface sensors indicating a drying profile into the spring and summer. The 0.9 m depth sensor prior to the December 2006 wind damage recorded uncharacteristic matric potential data, as does the 1.5 m depth sensor just after the system was repaired in early February 2007. We cannot say for certain why these sensors were behaving this way, but both appear to be functioning correctly now. In FY 2007 the matric potential at the 7.5 m depth outside the lysimeter (Figure 4.14) varied between 23 and 34 cm. These values are consistent with that measured within the lysimeter at the 7.3 m depth, which remained stable at approximately 25 cm.

A last point about the dataset presented is that the data remain consistent both before and after overhauling the site. This provides important assurance of continuity for these data collected before and after the equipment overhaul.

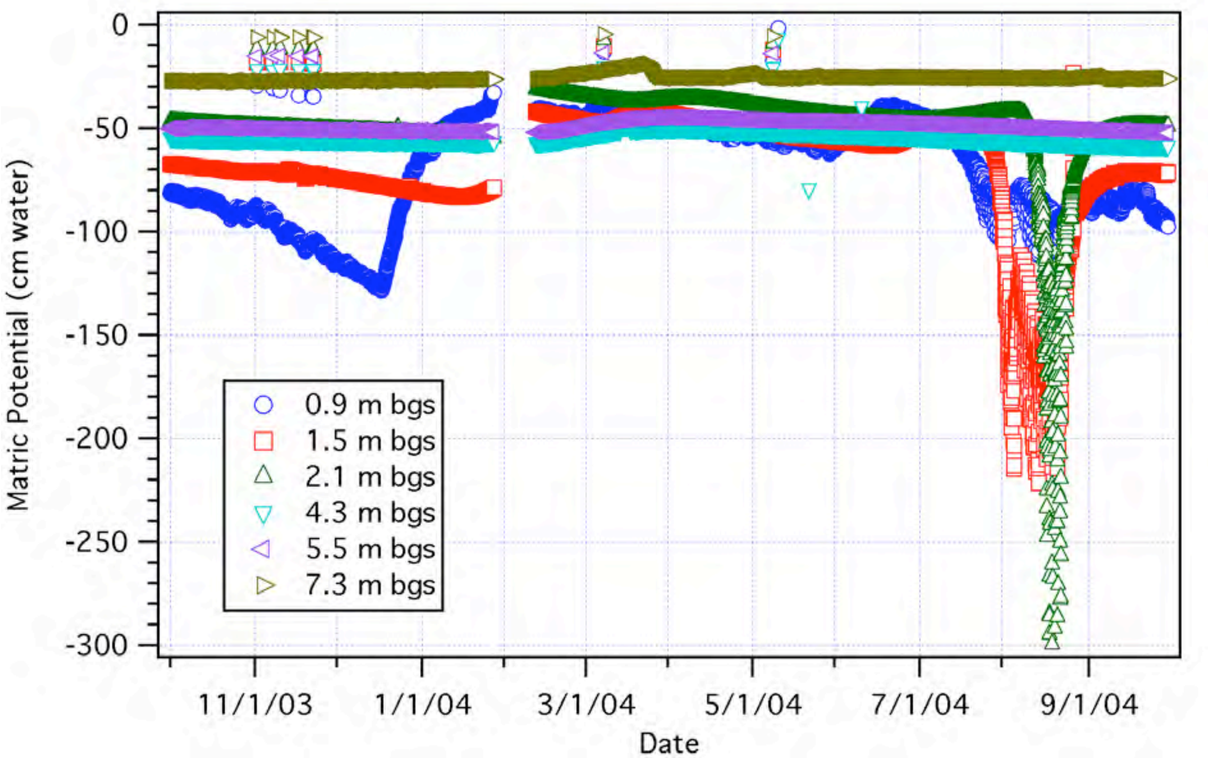

Figure 4.9 300N Lysimeter Matric Potentials Measured at Six Depths for FY 2004 (unfiltered data)

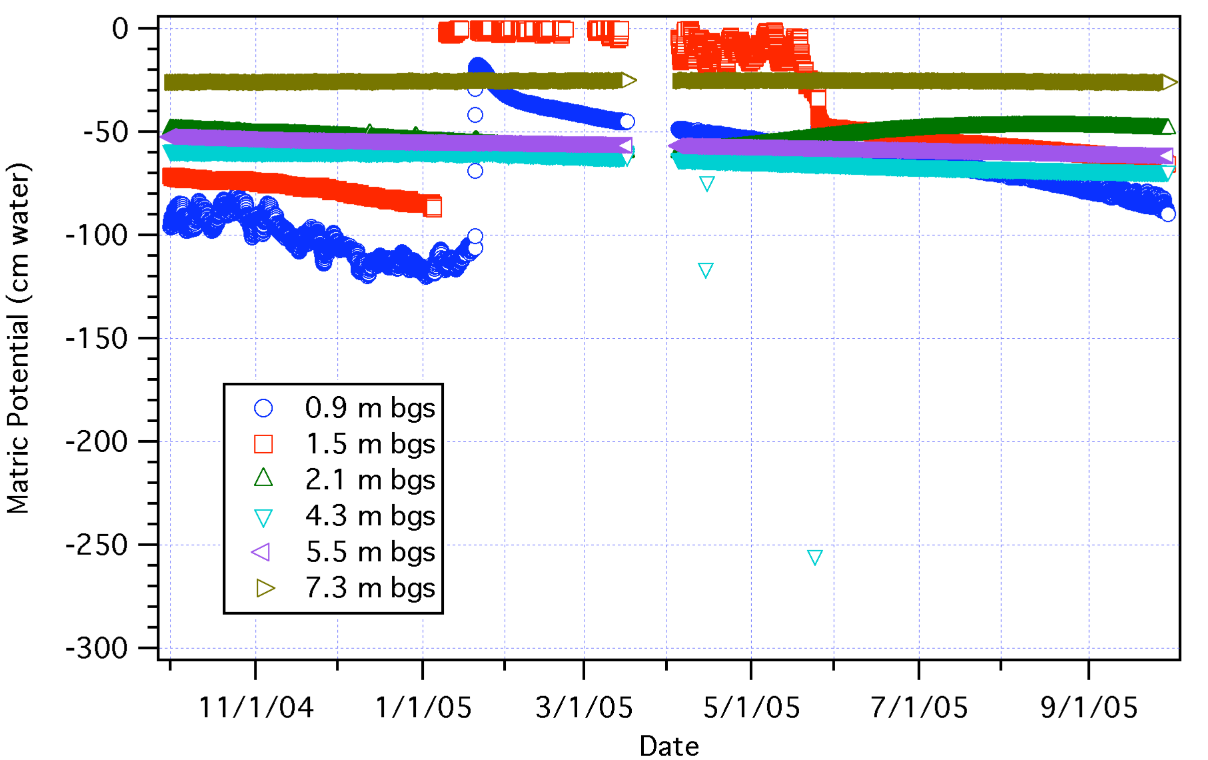

Figure 4.10 300N Lysimeter Matric Potentials Measured at Six Depth for FY 2005 (unfiltered data)

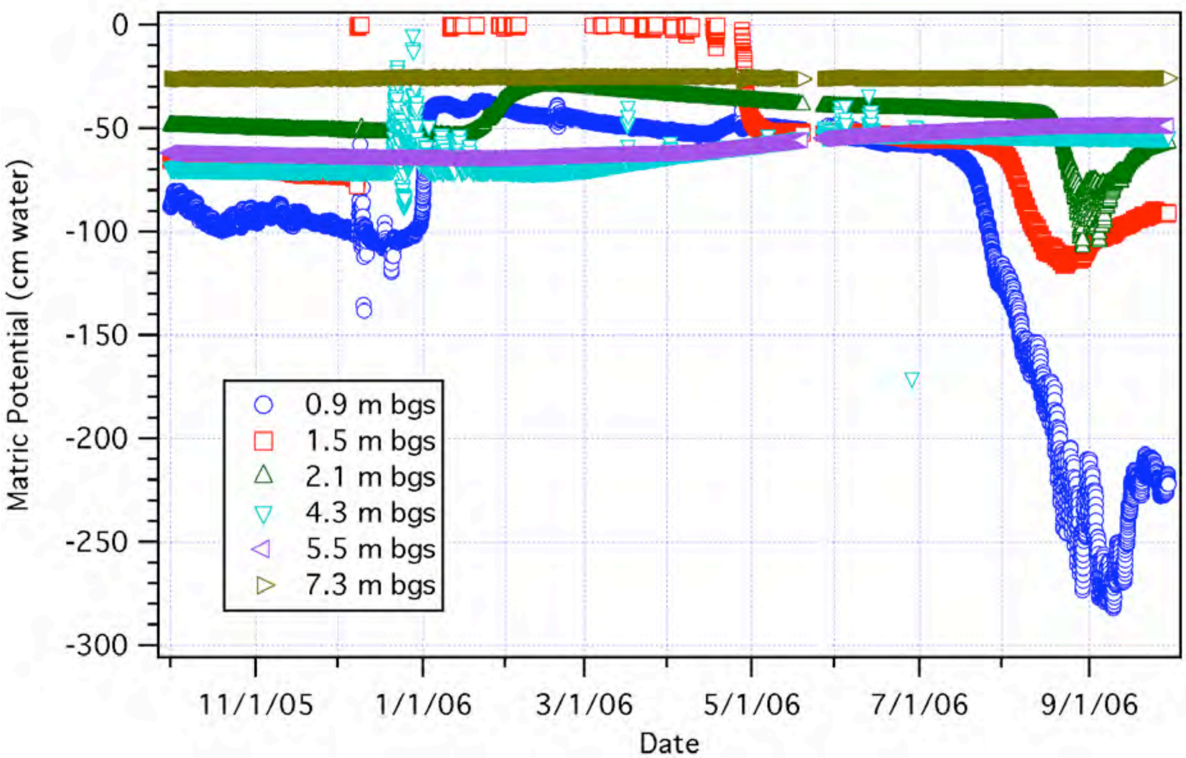

Figure 4.11 300N Lysimeter Matric Potentials Measured at Six Depths for FY 2006 (unfiltered data)

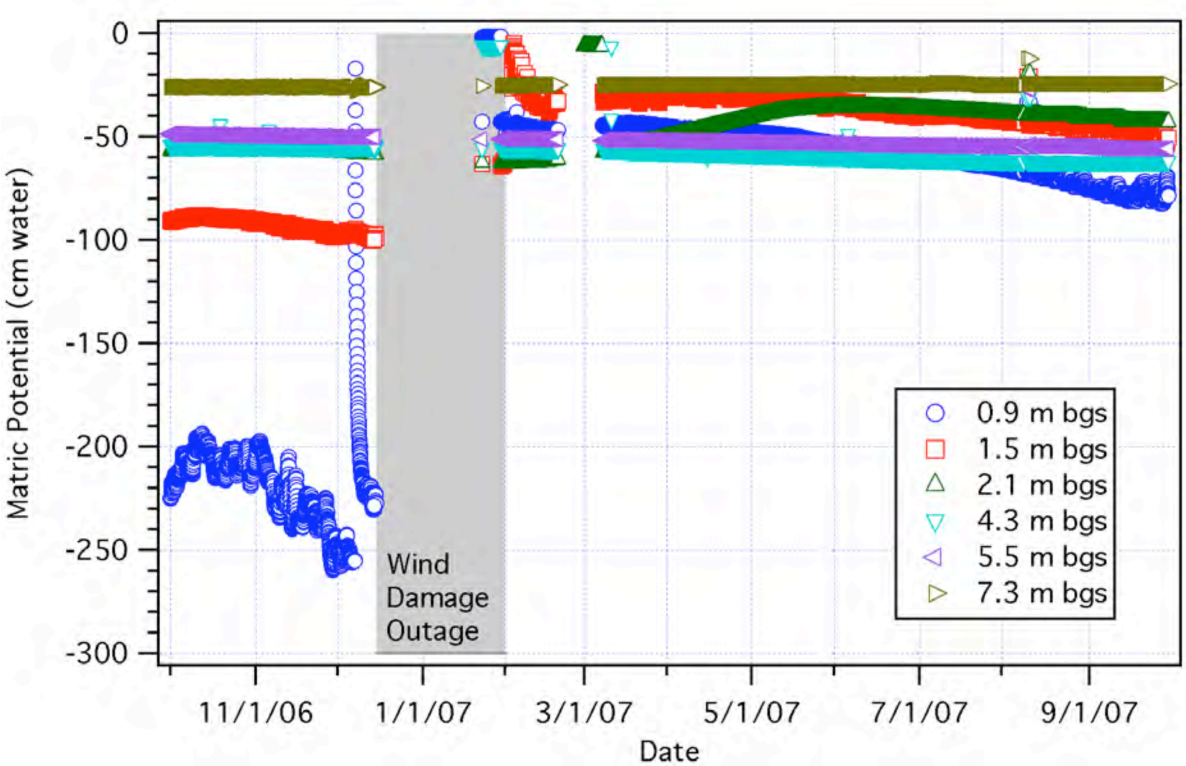

Figure 4.12 300N Lysimeter Matric Potentials Measured at Six Depths for FY 2007 (unfiltered data)

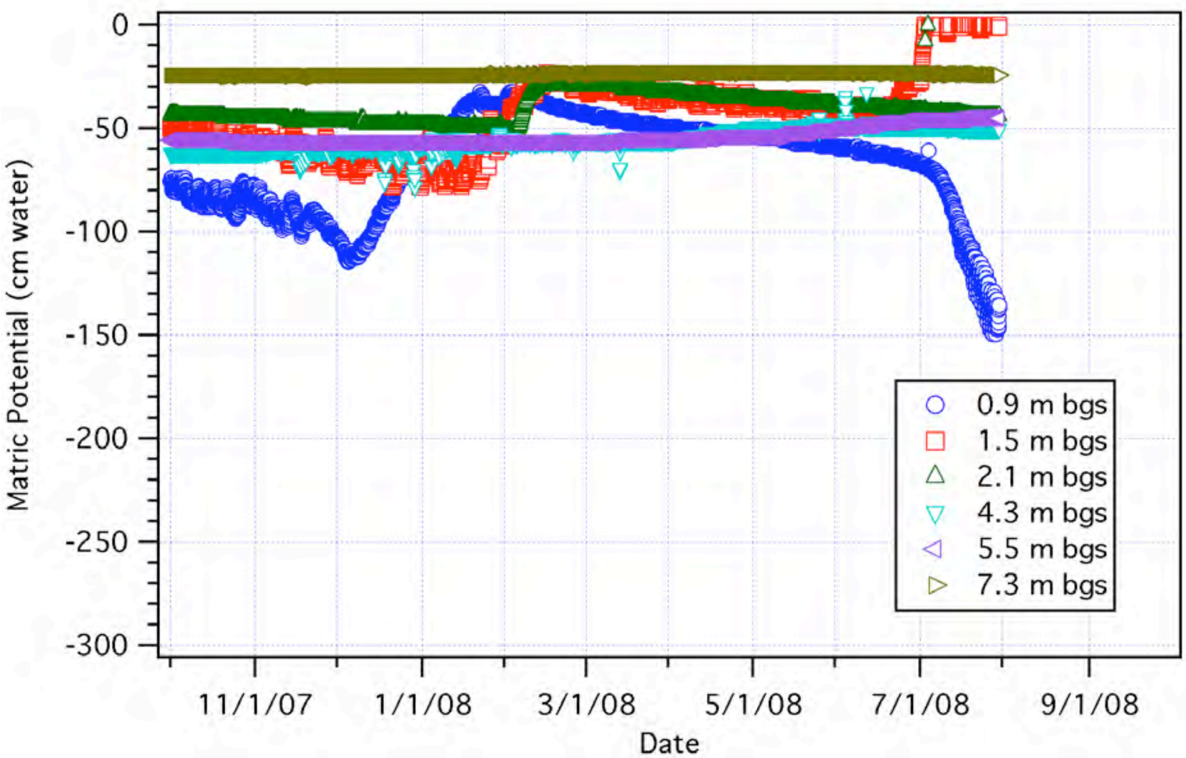

Figure 4.13 300N Lysimeter Matric Potentials Measured at Six Depths for FY 2008 (unfiltered data)

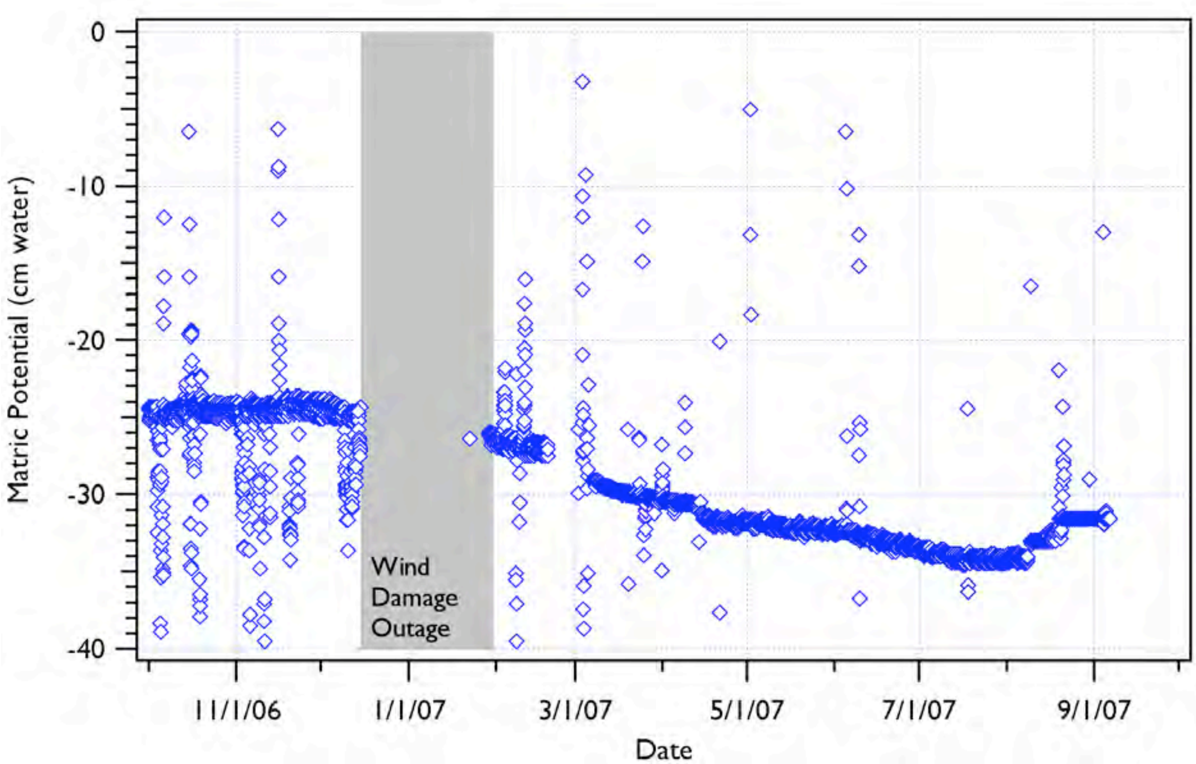

Figure 4.14 300N Lysimeter Cone Penetrometer Tensiometer Matric Potentials at 7.5 m bgs for FY 2007 (unfiltered data)

4.3 Solid Waste Landfill (SWL)

The Hanford SWL site is located in the 600 Area about 6.5 km (4 mi) northwest of the Wye Barricade (refer back to Figure 4.1). Installed at this location is a pair of duplicate WFMs and three water content sensors. The WFMs are filled with gravelly sand material that includes large cobbles, as shown in Figure 4.15. The surfaces of these WFMs are devoid of vegetation. The three water content sensors are placed in similar soil adjacent to the WFMs. Additional information is found in Keller and Gee (2005)[2].

Also at this site is a large (capture area of 85 m^2) basin lysimeter placed at the bottom of the landfill trench and filled with nonorganic waste thoroughly mixed with Hanford formation sediments (Wittreich and Wilson 1991). The surface material above the basin lysimeter is not as cobbly as the WFMs but is still very coarse. In addition, the basin lysimeter surface is vegetated with a sparse population of Indian Ricegrass (Figure 4.16). Measurement of the basin lysimeter drainage is carried out by a separate project, but the RDS project does maintain the data record for the basin lysimeter. Obviously, the differences in soils and vegetation between the basin lysimeter and the WFMs suggest that these are not replicate measurements, and results would not be expected to match.

Figure 4.17 shows the sensor-measured water content from December 2004 through September 2007. As expected, the water content at all depths display seasonal variation in accordance with the wet winter months and dry summer months. Figure 4.18 shows the WFM-measured drainage at this location. Beginning in March of 2007 the second WFM (WFM 2) measured significantly less drainage than the first WFM (WFM 1). During a site visit, it was discovered that a plant had established itself next to the WFM 2, but outside of the divergence control tube, and the plant canopy was intercepting precipitation. At least part of the difference in drainage measured by the two WFMs in FY 2007 can be attributed to this interception (WFM 2 measured nearly 75 mm less drainage than did WFM 1 in this time). The plant near WFM 2 was subsequently removed. While the plant interception may explain nearly all of the difference in the two WFM measurements of drainage, an alternative explanation may be that there was some plant element growing within WFM 2 that was extracting water and thereby lowering drainage as well.

The WFM data collected for two days in FY 2008 (January 31, 2008 and Feb 1, 2008) showed an excessive number of "tips" were recorded for WFM-2 in particular, but also for WFM-1. Although this could possibly be attributed in part to snowmelt and run-on, it is also possible that a “spill event” may have occurred. A similar spill event was noted on January 19, 2005. Data shown in Figure 4.18 include corrections for these events. Although the evidence for spills is inconclusive, such spills could occur when the carboy located in an instrument caisson at this site that is used to store leachate is hauled to the surface to take away for emptying. If this carbuoy is accidentally tipped during transfer, the WFMs, which are installed very near the top of the caisson, could detect the additional water. These spill events are speculative. However, given these issues we consider the drainage measured by the basin lysimeter to be much more reliable that the WFMs for estimating long-term recharge rates at this site.

Using WFM 1 drainage measurements for a three-year period from May 14, 2005 through May 14, 2008, the average calculated drainage was 90.8 mm/yr while for the more problematical WFM 2 the value was 66.4 mm/yr. The long-term drainage measurement intercepted by the SWL basin lysimeter is depicted in Figure 4.19 along with HMS measured precipitation for the same period. From July 1996 through June of 2008, the average recharge calculated based on the basin lysimeter data was 48.1 mm/yr.

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[2] Keller JM and GW Gee. 2005. *Remediation Decision Support / Characterization of Systems Fiscal Year 2005 Recharge Task Status Report*, Letter Report to George Last, PNNL, September 10, 2005.

Figure 4.15 WFM Material at the Hanford SWL

Figure 4.16 SWL Basin Lysimeter (orange dots represent approximate corners of the basin lysimeter)

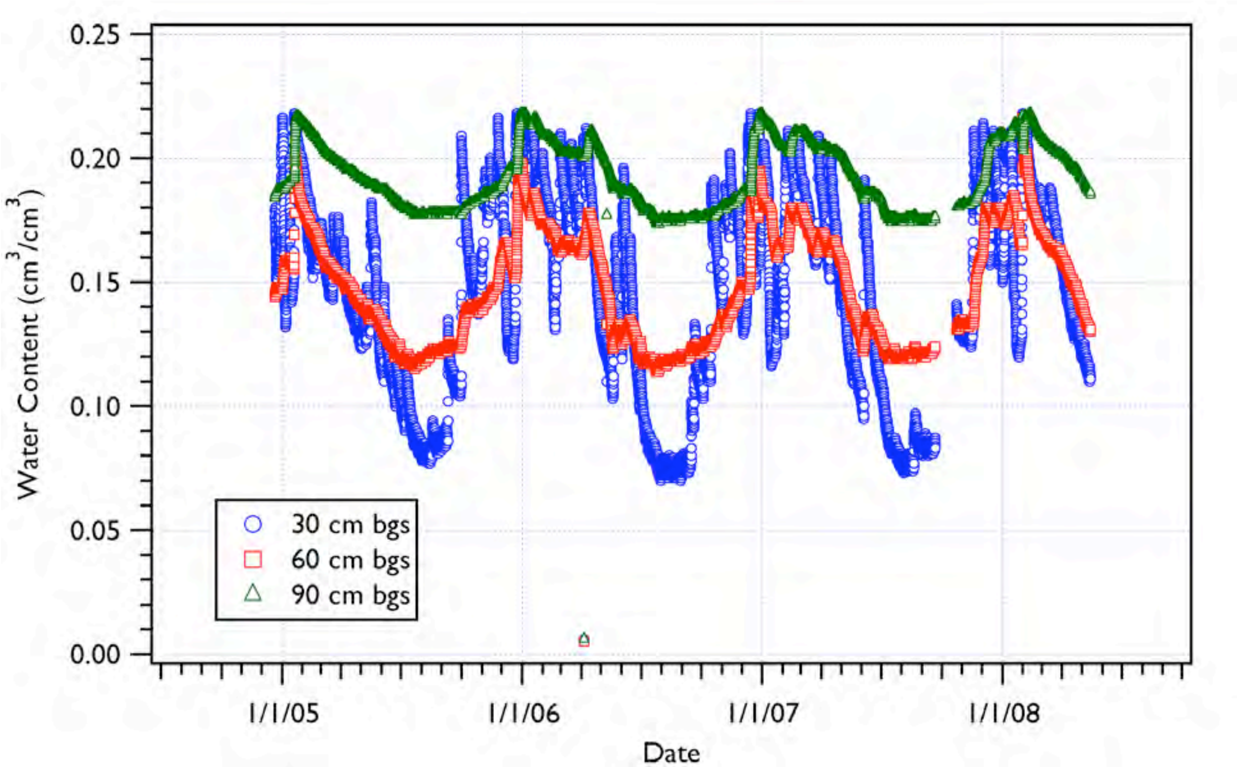

Figure 4.17 SWL Water Content at 30, 60, and 90 cm bgs

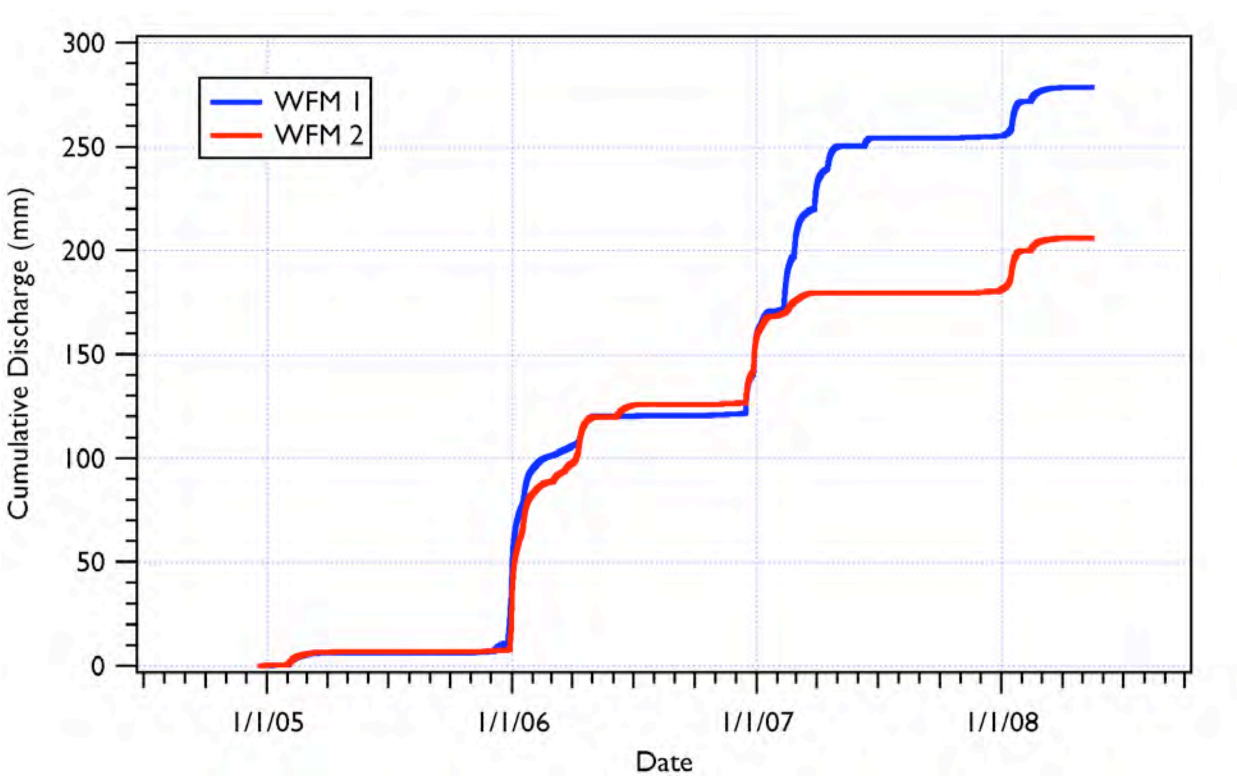

Figure 4.18 SWL Basin WFM Measured Cumulative Drainage

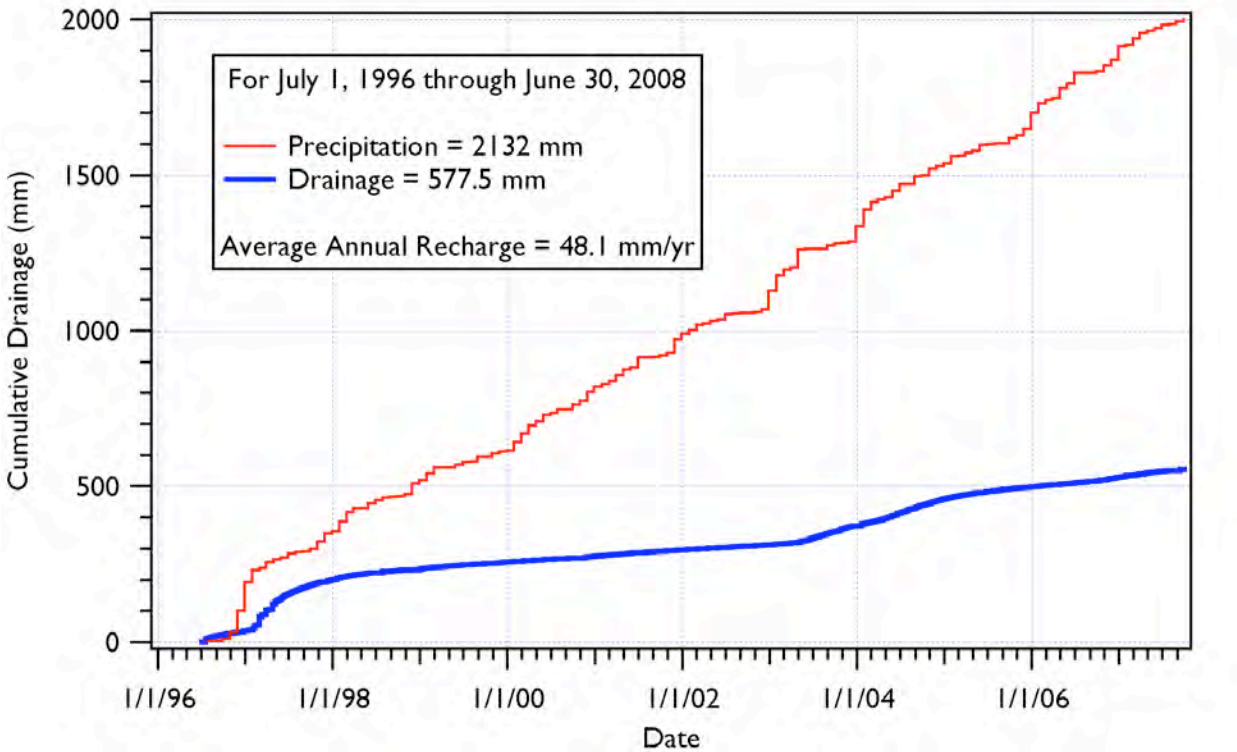

Figure 4.19 SWL Basin Lysimeter Measured Cumulative Drainage

4.3.1 Vegetation Characterization

On August 5, 2008, staff surveyed vegetation on the SWL Basin Lysimeter site off Army Loop Road (refer to Figure 4.20). The objectives of the survey were to 1) determine the density and types of plants occupying the surface of the lysimeter, 2) provide estimates of canopy cover for dominant species and bare soils, and 3) provide an estimate of the leaf area index (LAI) for dominant bunchgrasses growing on the lysimeter surface. The method and result for this characterization are presented here.

4.3.1.1 Method

A survey plot was set up at the SWL site to measure the characteristics of seeded vegetation above the lysimeter. Using architectural drawings as a reference, the western end of the lysimeter was determined to be approximately 16.15 m (53 feet) from the center of the existing SWL caisson entrance, and continue perpendicular to the gravel road entering the site. The gravel roadway runs in a northerly direction, but is not aligned with cardinal directions. The outside dimensions of the lysimeter are identified on architectural drawings as being approximately 4.6 m (15 ft) in width at the western edge, and less than approximately 21.3 m (70 ft) in length. A point was located 16.15 m (53 ft) from the caisson at a bearing of approximately 15 degrees off true north. This identified the center of the western edge of the vegetation survey plot. The plot was constructed to include 12 m on either side of the center point on the western edge to outline the width of the measurement area plot. To adequately overlap the dimension of

Figure 4.20 Vegetation Survey Sample Plot at SWL Location Relative to Location of Caisson

the lysimeter and associated side-slope areas of the below surface drainage basin, the plot length was measured to 25 m, to provide a total survey area of 24 m by 25 m in size (see Figure 4.21).

To determine density of the bunchgrasses within the area, we divided the survey plot into smaller grids to count the bunchgrasses within known areas and to determine species densities. The species encountered were Indian ricegrass [*Achnatherum hymenoides=Oryzopsis hymenoides* (ORHY)], needle-and-thread grass [*Hesperostipa comata=Stipa comata* (STCO)] and seedlings, which were bunchgrasses too small to accurately identify as to species. The first grid cell was set up from 0 – 5 m (length) by 24 meters (width) and included a small portion of the roadway and was sparsely populated with plants. To accurately enumerate the bunchgrasses in this sparsely vegetated area, a smaller grid cell size (2.5 m by 24 m) was used to divide the rest of the plot (see Figure 4.21, Figure 4.22, and Figure 4.23).

On August 7, 2008, staff surveyed the SWL sampling plot to visually estimate percent canopy cover, litter and bare soil cover. This was accomplished using randomly placed quadrats along 4 of the grid transects (refer to Figure 4.21). At transects initiated at 5, 10, 15, and 20 m along the northern side of the measurement plot, six, 0.5-m^2 quadrats were located randomly along each transect across the width of the measurement plot (refer to Figure 4.21). In each 0.5-m^2 quadrat, the percent bare soil, rock, litter, cheatgrass [*Bromus tectorum*, (BRTE)], and bunchgrass canopy was determined. For each bunchgrass within the quadrat, the basal circumference was also recorded (31 bunchgrass plants were sampled in this manner for basal circumference). In addition to measuring basal circumference of plants in the sample quadrats, a random walk sampling of the basal circumference of large bunchgrasses was also conducted. This sampled an additional 47 individual bunchgrasses.

To provide an estimate of leaf area, we selected individual bunchgrasses of representative sizes (small, medium, large) outside of the measurement plot area. These were destructively harvested to measure leaf area. We selected three bunchgrasses for each of three size classes (small, medium and large) for both species as well as representatives for the seedling size class. The basal circumference was measured for each plant that was selected. Each sample was given a unique sample ID (e.g. ORHY-L-1, STCO-M-1) for tracking purposes.

The plants were destructively harvested by clipping the leaf material and gathering all of the current year's growth as well as the standing dead matter, to be separated at a later time, and placed in a paper bag which had the unique sample ID written on it. Once back at the lab, each sample was sorted in order to separate the current year's growth, the standing dead and the seed heads, all of which were placed in separate, labeled bags. Each sample was further sorted and the leaf area of the current year's growth was measured using LiCor 3100 Area Meter instrument. The measurements were recorded cumulatively for each individual bunchgrass and the LiCor was repetitively calibrated to a known 50-cm^2 area after every 50 to 100 cm^2 of plant material measured. Some measurement problems or errors appeared to occur with several of the larger bunchgrass samples as a result of the measurement method. The equipment is sensitive to clumping of the sample and can overestimate leaf area when clumps are not separated or when debris occludes the reflection and shadow seen by the recording system. Therefore, two samples corresponding the large STCO and one sample corresponding to large ORHY were left out of final analyses, because leaf area measurements for these samples were questionable. The individual bunchgrass samples were placed in an oven and dried at 50˚ C for at least 48 hours to determine dry biomass.

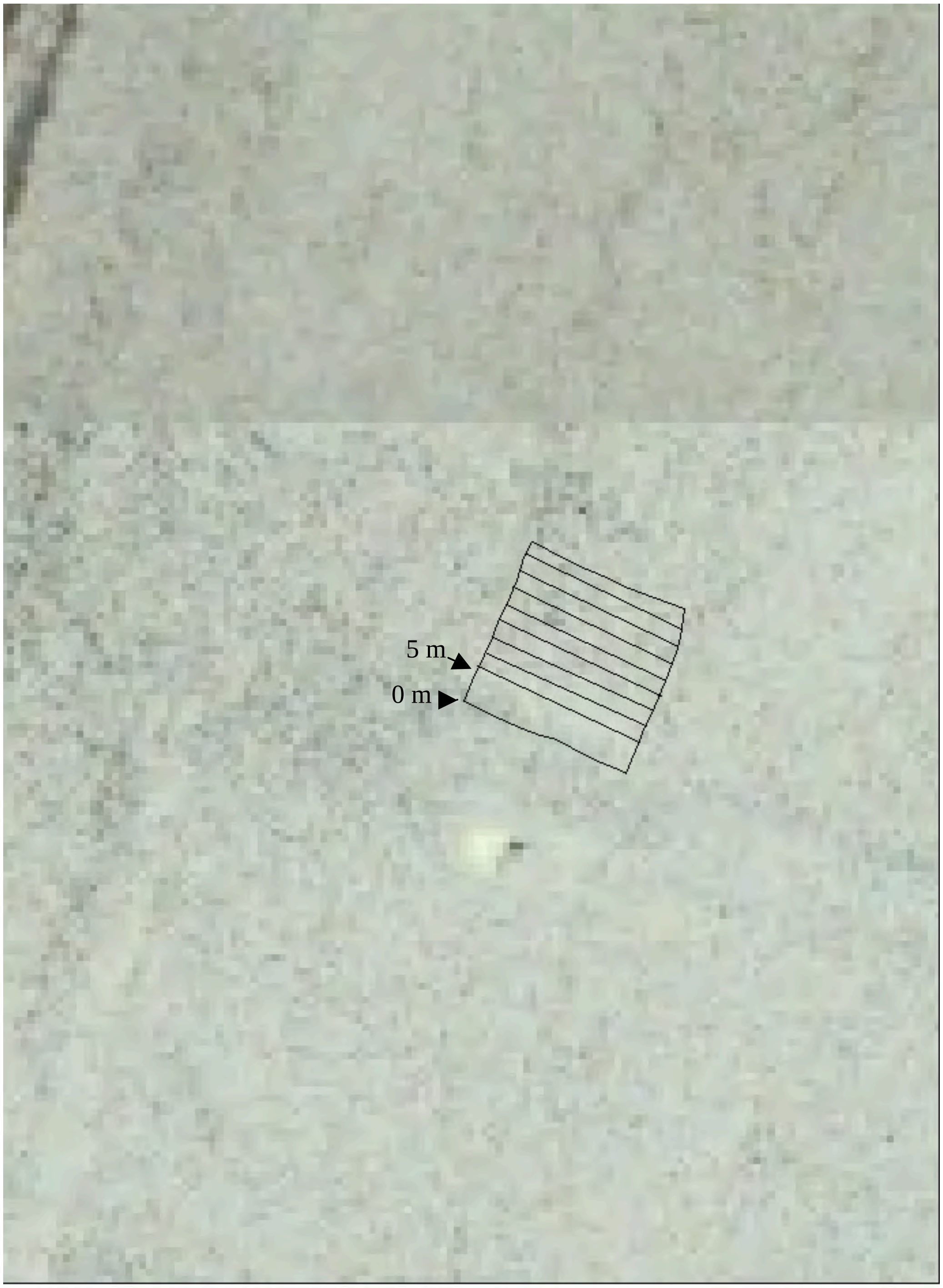

Figure 4.21 Approximate Locations of Transects and Grid Locations within SWL Vegetation Survey Plot

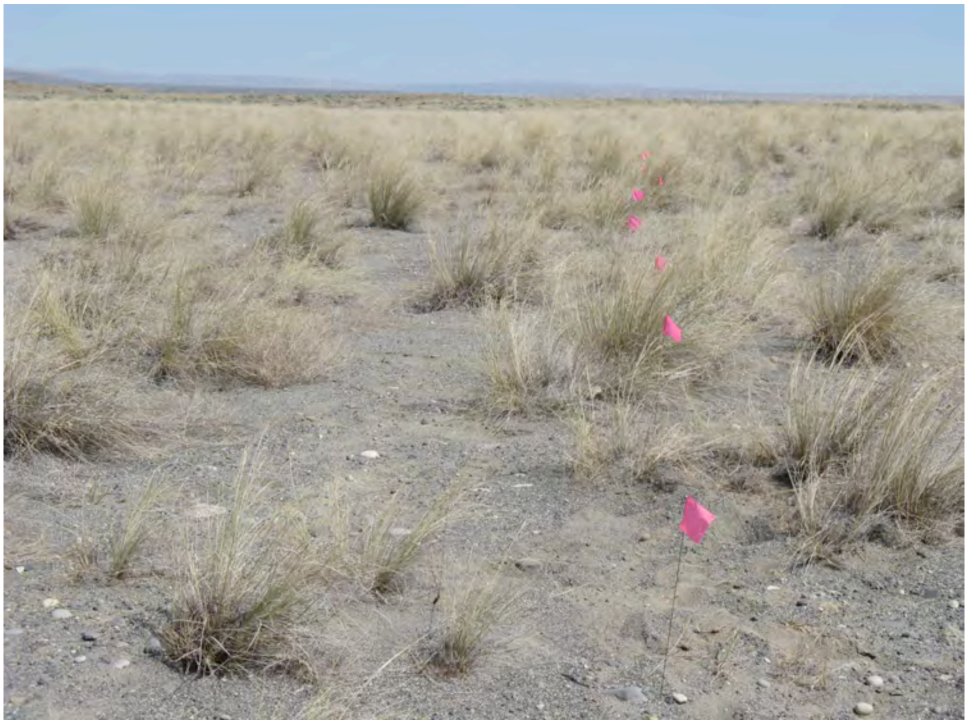

Figure 4.22 Photograph Showing the Transect Flags for SWL Vegetation Sampling Plot

Figure 4.23 Photograph Showing Representative Vegetation Cover at the SWL Site

4.3.1.2 Results

The surface of the SWL is dominated by bare ground (Figure 4.22, Figure 4.23, and Figure 4.24), with an average live plant cover of about 24%. Total herbaceous plant canopy cover in measured in native communities on long-term monitoring plots in similar soils ranges from approximately 30% to 65% (Poston et al. 2006). The plant cover is predominately large bunchgrasses with a minor component of cheatgrass scattered between bunchgrass clumps. Bunchgrass density on the SWL survey area is just slightly less than 1 plant per square meter. Table 4.2 provides information on the total density and variability of bunchgrass density across the area surveyed. The average density of bunchgrass species was 0.93/m^2 (± 0.1 standard error), and 90% of the plants counted on the 600-m^2-survey area were Indian ricegrass.

The basal circumference of the plants is used to represent the relative size of the bunchgrasses on the vegetation survey plot. These ranged from 0.3 cm (seedling) to 135 cm (Indian ricegrass). Seedlings represented about 6% of the plants counted within the survey area and were not considered further in the analysis of size classes and contribution to leaf area.

Average leaf area measured for the different size classes are listed in Table 4.3. A least-squares regression was calculated to describe the relationship between bunchgrass basal circumference and measured leaf area for Indian ricegrass. The data and regression line are shown in Figure 4.25.

Leaf area for the entire vegetation survey area was calculated based on the sampled distribution of bunchgrass basal circumference and the linear regression developed to describe the relationship between basal circumference and leaf area. The sampled distribution of basal circumference size classes (10-cm increments) is assumed to represent the distribution of size classes across the survey plot. The upper limit of each size class in Figure 4.26 is used as the *x* value. The percentage of the sampled bunchgrass in each basal circumference size class is used to determine the number of individuals out of the total 499 plants that would be expected to fall in that basal circumference size class. These are summed to provide a total leaf area estimate of 96,919 cm^2 for the 600-m^2-survey area (Table 4.4). This value may be low because sampling was done at the end of the growing season when plants had begun to senesce. However, all plants still maintained green leaves at the time of sampling, and all leaves that represented the current years growth were measured (both green and senescent leaves).

Using the frequency and regression relationships described here, the calculated total leaf area represents a LAI of approximately 0.02 for the survey plot. Given that the average plant density is nearly 1 plant per square meter, the range of measured leaf areas for various bunchgrass sizes can represent the range of LAI values. LAI values across the survey plot would be expected to range from 0.0004 for small size plants to 0.03 to 0.05 for areas with large bunchgrasses. Because significant bare soil covers the SWL, these LAI estimates may be within expected values. LAI values for shrub-steppe communities are lower than those found in agricultural or forest ecosystems. LAI values for natural native bunchgrass communities found in finer soils on the Hanford site are roughly twice [0.11 to 0.13 LAI for communities that consist of small and large bunchgrasses and numerous forb species: see Link et al. (1990)] the highest values represented here.

4.4 Integrated Disposal Facility (IDF)

The IDF site is located on the south side of the Cold Creek bar, a depositional bar left in the lee of the

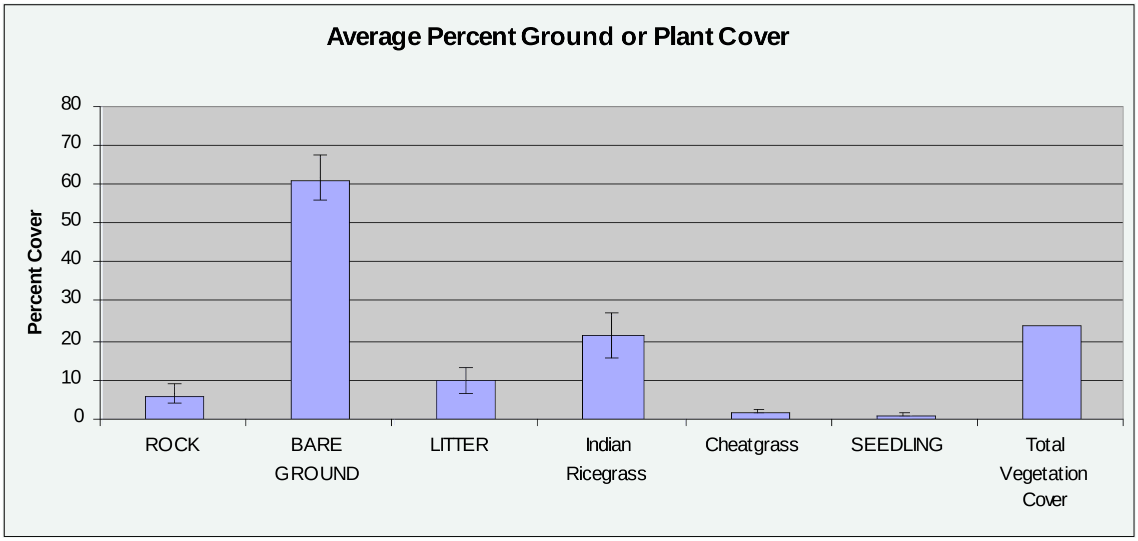

Figure 4.24 Percent Canopy Cover and Ground Cover Measured on the SWL Lysimeter Facility in August 2008

Table 4.2 Measured Density of Bunchgrasses in the Survey Area on the SWL Lysimeter

Measurement Area (m)	STCO	ORHY	Seedling	Totals	Density (#/m^2)
0 – 5	7	22	15	44	0.366667
5 - 7.5	5	32	2	39	0.65
7.5 – 10	4	55		59	0.983333
10 - 12.5	3	40		43	0.716667
12.5 – 15	1	49	3	53	0.883333
15 - 17.5	0	57		57	0.95
17.5 – 20	0	47	1	48	0.8
20 - 22.5	0	65	8	73	1.216667
22.5 - 25	0	81	2	83	1.383333
Total Area	**20**	**448**	**31**	**499**	**0.831667**

Table 4.3 Average Leaf Area (LA) for Replicate Representative Bunchgrass Samples Collected at SWL (N=3 to 4 Samples per Category)

Size	ORHY** LA (cm^2)	STCO* LA (cm^2)
Small	4.18	1.88
Medium	50.97	52.91
Large	289.30	331.95

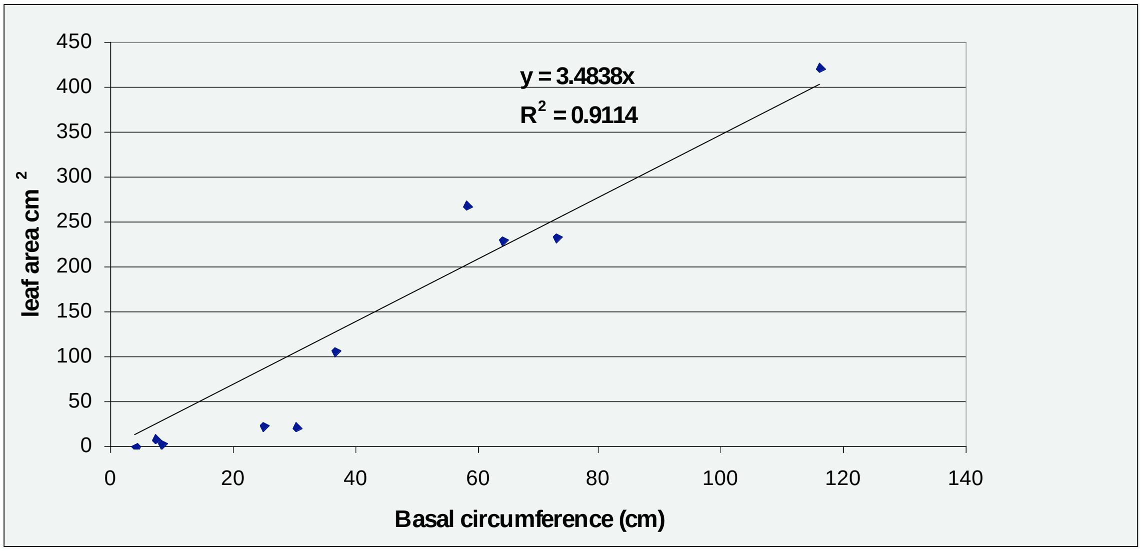

Figure 4.25 Least-squares Regression for Basal Circumference of Bunchgrasses versus Measured Leaf Area on the SWL Vegetation Survey Plot

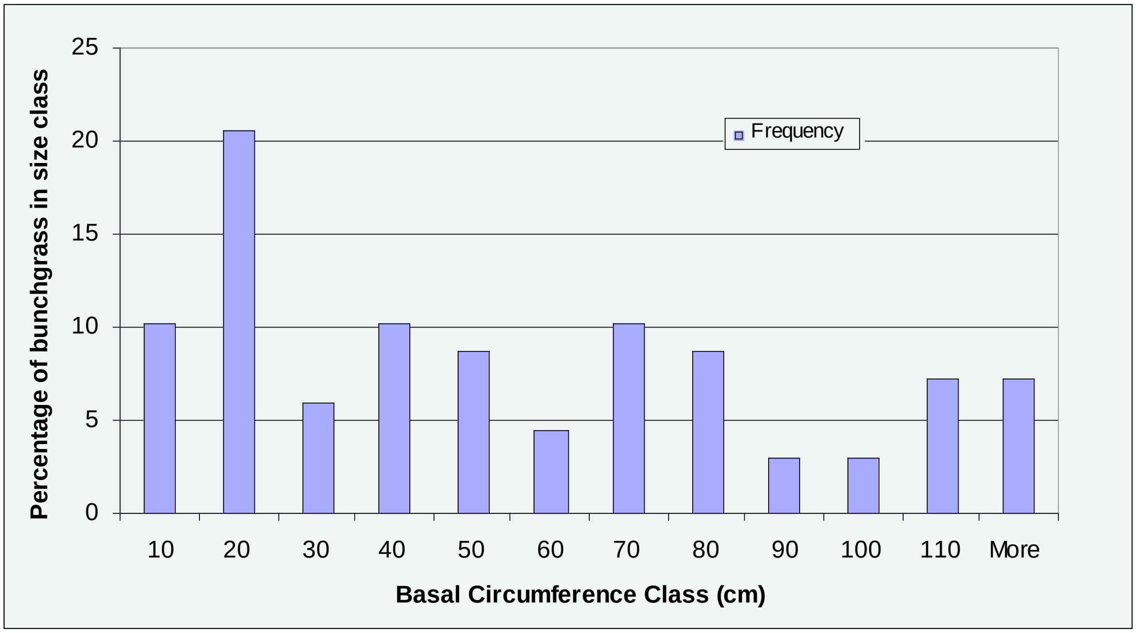

Figure 4.26 Histogram Showing Distribution of Size Classes of Large Bunchgrasses on the SWL Vegetation Survey Plot

Table 4.4 Cumulative Calculated Leaf Area for the SWL Vegetation Survey Area

Basal Circumference Class (cm)	Calculated Leaf Area for Class Size 3.4838*x (cm^2)	Percentage of Individuals in Class	Number in Survey Area (499 Total)	Cumulative Leaf Area (cm^2)
10	34.838	10.3	51	1776.738
20	69.676	20.6	103	7176.628
30	104.514	5.9	29	3030.906
40	139.352	10.3	51	7106.952
50	174.19	8.8	44	7664.36
60	209.028	4.4	22	4598.616
70	243.866	10.3	51	12,437.17
80	278.704	8.8	44	12,262.98
90	313.542	2.9	15	4703.13
100	348.38	2.9	15	5225.7
110	383.218	7.4	37	14,179.07
More	452.894	7.4	37	16,757.08
Total				**96,919.32**

Umtanum Ridge during Pleistocene cataclysmic flooding. This bar is dominated by gravel on the north side (closest to the main flood channels) grading to fine sand on the south side. A long, stabilized dune occupies the southern end of the IDF site. The presence of the dune at the IDF site indicates a history of sand dune activity in this area following the last cataclysmic flood (~13,000 years ago). The dune represents the northern fringe of a large dune field that exists below and south of the Central Plateau. The dune is stabilized by a very healthy stand of shrub-steppe vegetation and is not actively growing or migrating (the dune will eventually be removed during construction of the IDF). The nearest active dune to the IDF site is approximately 3 km south of this area (Gaylord and Stetler 1994).

Recharge for the IDF site has been estimated using environmental tracers. For the immobilized low-activity waste (ILAW) 2001 Performance Assessment, Fayer et al. (1999) used the chloride and chlorine-36 tracer techniques to estimate recharge rates. For the 2005 IDF PA, two tracer techniques were used: chloride mass balance (CMB) and deuterium and oxygen-18 (Fayer and Szecsody 2004). A description of these two techniques can be found in Appendix B of Fayer and Szecsody (2004).

Since March 2000, neutron probe measurements of soil moisture have been collected at this site from a series of 16 access tubes located in different vegetation regimes. These measurements were collected in FY 2008 for the Remediation and Closure Science Project. These data were not ready for inclusion at the time of this report, but will be summarized and published in a future report or journal article.

4.5 200 East Lysimeter

The 200 East Lysimeter Site is approximately 2 km south of the 200 East Area. This site includes an 18.5 m deep, 3 m diameter closed-bottom lysimeter with vertical neutron probe access tubes. In addition, two access tubes are also installed outside of the lysimeter, one in a sagebrush setting and another in grass coverage. The site as it appeared prior to the soil subsidence discovered in 2005 (discussed below) is shown in the photograph provided in Figure 4.27, and as it appeared after the soil subsidence in Figure 4.28. This site was constructed in 1971-1972 and past monitoring activities are described in Gee et al. (1994). Since 1991, neutron logging of the 200 East Lysimeter Site has been performed four times to monitor the moisture profile in the lysimeter and beneath the two vegetation covers: August 1991, March 2005, January 2006, and most recently October 2006.

Figure 4.29 shows normalized neutron counts for a neutron logging conducted in August 1991 and neutron logging conducted in 2005 and 2006. The counts are normalized by their respective standard count taken prior to logging. Higher normalized counts represent wetter soil conditions. During the 1991 measurement the surface of the lysimeter was free of vegetation. After this, vegetation on the surface of the lysimeter was allowed to become established and has remained vegetated since. The counts in March 2005 and January 2006 are elevated near the surface compared to counts from the August 1991 and October 2006 loggings. This is attributed to winter precipitation having increased the near surface moisture content. The March 2005 and January 2006 probing also reveals elevated counts for all three boreholes at a depth of approximately 4 m to about 12 m. By the October 2006 logging, this area of elevated counts appears to have shifted upward to approximately 1 m to 9 m bgs. The elevated counts at depth within the lysimeter are unexpected based on monitoring studies at this site in the 1980s and early 1990s. Figure 4.30 shows the normalized counts from neutron loggings in the vegetated areas. The counts from all periods generally track one another, except for the near surface readings in which response to winter rains and summer drying is observed.

Figure 4.27 200 East Lysimeter (photograph taken prior to 2005)

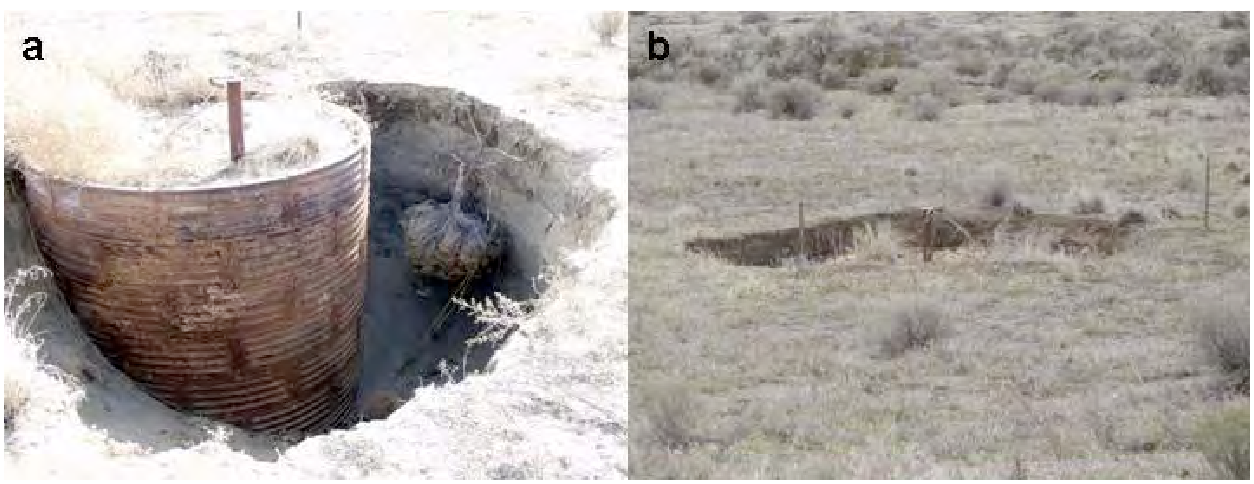

Figure 4.28 200 East Lysimeter Subsidence; Image b Shows the Subsidence From a Distance (photograph taken after discovery of soil subsidence in 2005)

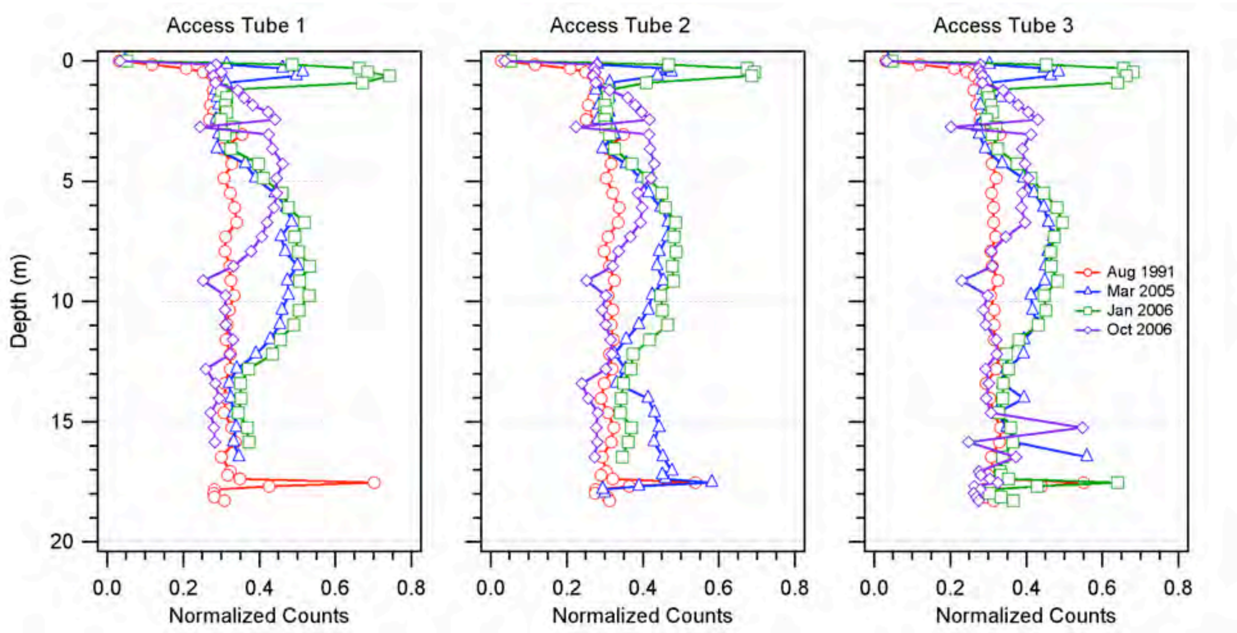

Figure 4.29 200 East Lysimeter Normalized Neutron Probe Counts

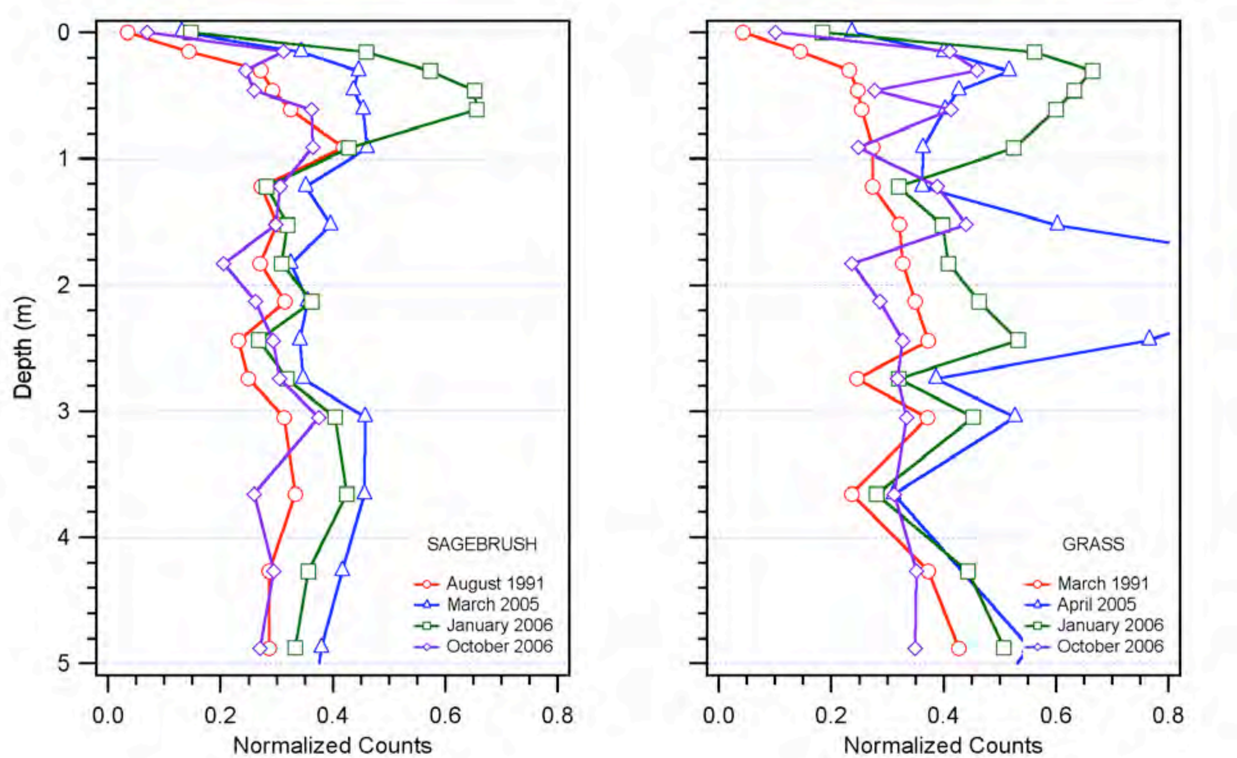

Figure 4.30 200 East Lysimeter Normalized Neutron Probe Counts Taken Under Grass and Sagebrush Vegetative Covers

In March 2005 a large hole was first observed to have developed adjacent to the lysimeter (Figure 4.28). It is not known how the large hole developed but our speculation is that it was the result of a run-on and/or a series of snowmelt events over time. Unfortunately, the extensive and dangerous settling of the soil around the lysimeter has likely seriously compromised the value of neutron logging data collected within this lysimeter. The nearby access tubes in the grass and sagebrush still have potential to provide valuable water balance information under the two predominant plant communities on the plateau. However, access this site has become increasingly restrictive as a result of restrictions imposed due to it being classified as a surface contamination area. It was recommended in 2007 that consideration be given to decommissioning this site, or at least the lysimeter.

4.6 Field Lysimeter Test Facility (FLTF)

The Field Lysimeter Test Facility (FLTF) was originally constructed from November 1986 through June 1987 (Gee et al. 1989, Campbell et al. 1990) and is located adjacent to the HMS. There are three different lysimeter types at the FLTF: fourteen 3 m deep by 2 m diameter drainage lysimeters; six 3 m deep by 0.3 m diameter small-tube lysimeters; and four 1.5 m by 1.5 m by 1.7 m deep weighing lysimeters.

Figure 4.31 shows the layout of the facility. Additional information about the facility and data collection prior to 2004 can be found in Fayer and Szecsody (2004). Under the Recharge Measurement task, drainage is measured from twelve of the drainage lysimeters, four of the small-tube lysimeters, and one of the weighing lysimeters. Automated hourly measurements of mass are made on all four weighing lysimeters. Additionally, tensions are measured in seven lysimeters at various depths. Temperatures within the lysimeters are also measured at over 50 locations, but these data are not summarized here. Of the 21 lysimeters being monitored, nine of them are regularly irrigated to mimic precipitation conditions that are three times greater than the long-term average ambient precipitation. Table 4.5 summarizes the test treatments for the monitored lysimeters. A brief description of each test is provided in Table 4.6.

The enhanced precipitation treatment is attained through irrigation that is applied to attain a target precipitation plus irrigation rate. Figure 4.32 illustrates the cumulative application rate and cumulative target rate for the FLTF water year[3] 2004 (November 1, 2003 through October 31, 2004). Figure 4.33 shows the same for FLTF water year 2005, Figure 4.34 for FLTF water year 2006, Figure 4.35 for FLTF water year 2007, and Figure 4.36 for water year 2008, respectively. The enhanced precipitation treatment does not necessarily represent climatic conditions three times wetter than current climatic conditions. This is because a larger fraction of the enhanced precipitation is applied during spring and summer months when the atmosphere is relatively dry and warm than would be expected for a wetter climate. Consequently, the portion of the enhanced precipitation that is lost to evapotranspiration is likely greater than would be expected with an actual wetter climate with greater precipitation occurring in cooler months.

Figure 4.37 shows the change in water storage since October 1, 2004 for W1 and W3, as calculated from the weighing lysimeter mass. As to be expected, water storage increases during the winter and decreases to a minimum in late summer, with a greater change in water storage under enhanced precipitation

[3] A *water year* is a twelve-month period, usually selected to begin and end during a relative dry season, used as a basis for processing stream flow and other hydrologic data. The period from October 1 to September 30 is widely used in the United States, but other periods are also used depending on local climate conditions. The FLTF water year is designated to begin November 1 and end October 31; this period was selected based on considerations of local soil moisture and climatic patterns encountered at this facility.

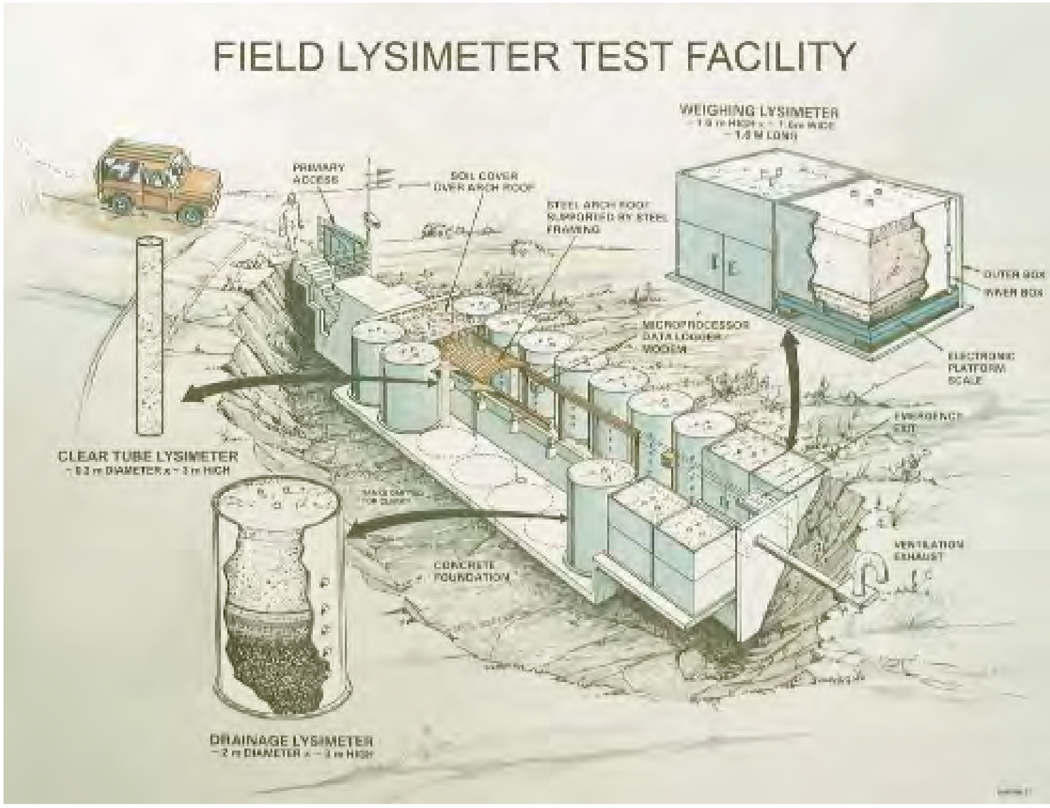

Figure 4.31 Artist rendering of the FLTF at the Hanford Site (Fayer and Gee 2006)

conditions. During FY 2007 weighing lysimeters W2 and W4 responded uncharacteristically and may not represent true values. The W4 scale was replaced in September 2006 and a new calibration obtained. It is suspected that this calibration is incorrect and may be the cause for the odd response. The weighing lysimeter scales were calibrated in September 2008. The scale readings for W4 were hysteretic, leading the technician who calibrated the scales to speculate that the scale for W4 has a bad load cell. A decision will be made in FY 2009 with regard to the future use of this scale.

Figure 4.38 shows the cumulative drainage from the Hanford Barrier Erosion/Dune Sand Deposition treatment. Drainage is measured at a rate of 135.0 mm/yr under the 3X precipitation conditions. The same treatment under ambient precipitation conditions began draining in 2002 and has drained a total of 2.2 mm for an average drainage rate of 0.2 mm/yr calculated since installation (0.4 mm/yr if calculated since drainage onset). Figure 4.39 shows the cumulative drainage from the sand dune migration test. Under enhanced precipitation this treatment produces significant drainage, with a measured drainage rate of 200.8 mm/yr. The D6 lysimeter (ambient precipitation) did not begin draining until 2004, but has drained steadily since that time for an average drainage rate of 14.4 mm/yr calculated since installation (33.8 mm/yr if calculated since drainage onset). Figure 4.40 shows the cumulative drainage for the sandy gravel and basalt side slope treatments under ambient precipitation conditions. Both lysimeters have consistently drained at significant rates since monitoring of these treatments began, with drainage rates of 46.9 mm/yr for the basalt treatment and 100.8 mm/yr for the sand gravel treatment. Figure 4.41 shows the cumulative drainage for the eroded Hanford Barrier treatment. Drainage from this lysimeter didn’t begin until 2003, but has continually drained since, although at decreasing rates every year. Figure 4.42

Table 4.5 Summary of FLTF Treatments and Monitoring Periods

Test Description	ID Treatment	Precipitation Ambient	Precipitation Enhanced	Vegetation [a] NV	Vegetation [a] SRV	Vegetation [a] DRV	ID Lysimeter	Monitoring Period Start	Monitoring Period End
Hanford Barrier	1	✓				✓	W1	4 Nov 87	present
		✓				✓	C3	9 Nov 88	present
	2	✓		✓			D1	4 Nov 87	present
	3		✓			✓	W3	4 Nov 87	present
			✓			✓	C6	9 Nov 87	present
Eroded Hanford Barrier	6	✓				✓	D3	4 Nov 87	present
	18		✓			✓	D13	27 May 98	present
Gravel Mulch	8	✓		✓			C1	17 Nov 89	present
	10		✓	✓			C4	17 Nov 89	present
Pitrun Sand	9	✓				✓	C2	17 Nov 89	present
	11		✓			✓	C5	17 Nov 89	present
Basalt Side Slope	12	✓		✓			D2	1 Nov 94	present
Sandy Gravel Side Slope	14	✓		✓			D4	1 Nov 94	present
Hanford Barrier Erosion / Dune Sand Deposition	19	✓			✓		D5	17 Nov 97	present
		✓			✓		W2	17 Nov 97	present
	20		✓		✓		D12	17 Nov 97	present
			✓		✓		W4	17 Nov 97	present
Sand Dune Migration	21	✓			✓		D6	22 Jul 98	present
	22		✓		✓		D8	22 Jul 98	present
Modified RCRA Subtitle C Barrier	23	✓				✓	D7	23 Feb 99	present
	24		✓			✓	D9	23 Feb 99	present

[a] Vegetation Symbols: NV = no vegetation, SRV = shallow rooted vegetation, and DRV = deep rooted vegetation.

shows cumulative drainage from the gravel mulch and pit run sand treatments under ambient and enhanced precipitation. Both treatments continued to have significant drainage in 2007. A summary of average drainage rates for each treatment as of September 14, 2007 is presented in Table 4.7. The drainage rate is calculated for two bases: first calculating the average annual drainage rate on the basis of time since installation, and second calculating the average annual drainage rate on the basis of time since drainage onset. A newly installed lysimeter requires some time to stabilize and begin to drain at a long-term average rate, so including the time required to reach a long-term moisture profile may not provide the best basis for estimating an annual average drainage rate; hence the reason for the second basis. A lysimeter experiencing higher precipitation (such as for the enhanced precipitation treatments) will stabilize faster, so in those cases the drainage rates calculated under both bases do not differ much or at all. For ambient conditions in less conductive soils, stabilization of the moisture profile takes longer and the difference can be substantial.

Matric potential data for the D12 and W4 lysimeters at 100 cm and 150 cm depths (Figure 4.43 and Figure 4.44, respectively) suggest typical seasonal variation, with drying in the summer (more negative matric potentials) and wetting in the winter (less negative matric potentials). At times the matric potential

Table 4.6 FLTF Treatment Descriptions

Treatment Name	Treatment Description	Lysimeter ID
Hanford Barrier	1.5 m of silt loam that rests on a sequence of materials grading from sand to gravel filter layers and finally to basalt riprap.	W1, C3, D1, W3, C6
Eroded Hanford Barrier	Similar to the Hanford Barrier test, with the exception that the silt loam layer thickness is reduced from 1.5 to 1.0 m.	D3, D13
Gravel Mulch	0.15 m of coarse gravel above 1.35 m of screened (to remove gravel) Pitrun sand, on top of unscreened Pitrun sand.	C1, C4
Pitrun Sand	1.5 m of screened (to remove gravel) Pitrun sand on top of unscreened Pitrun sand.	C2, C5
Basalt Side Slope	1.5 m of unscreened basalt riprap. Beneath the basalt layer is a 0.15-m thick asphaltic concrete layer underlain by gravel and more basalt riprap. Resting on top of the asphaltic concrete is about 2 to 3 cm of silt loam.	D2
Sandy Gravel Side Slope	1.5 m of sandy gravel resting on an asphaltic concrete layer in a manner similar to the basalt side slope test.	D4
Hanford Barrier Erosion / Dune Sand Deposition	Similar to the Hanford Barrier test, with the exception that the top 20 cm of silt loam is removed and replaced with dune sand.	D5, W2, D12, W4
Sand Dune Migration	3 m of dune sand.	D6, D8
Modified RCRA Subtitle C Barrier	A barrier design with only 1 m of silt loam. In addition, the silt layer has two modifications: 1) the upper 0.5 m of silt loam is amended with pea gravel at the rate of 15% by weight, and 2) the lower 0.5 m of silt is compacted to create a low-conductivity layer.	D7, D9

measurements in the W4 lysimeter is positive, likely because saturated conditions in the lysimeter occurred between drainage measurements. Matric potentials within the sand dune migration treatment lysimeters also display typical season variation (Figure 4.45 for 100 cm depth, Figure 4.46 for 150 cm depth, and Figure 4.47 for 210 cm depth). Potentials between the ambient D6 lysimeter and enhanced precipitation D8 lysimeter are generally comparable.

Efforts were begun in FY 2007 to use chloride concentrations in drainage water from select FLTF lysimeters to capture the modern atmospheric chloride deposition rate. The atmospheric chloride deposition rate is important because it is a critical parameter in the calculation of recharge using the chloride mass balance method. The first round of measurements was made in July 2007. Drainage water was collected from lysimeters C1, C2, D4, and D6 in high-density polyethylene bottles and taken to the Applied Geology and Geochemistry lab for analysis using ion chromatography. Table 4.8 presents the chloride concentration results and the calculated chloride deposition rate q_{cl} using the relationship

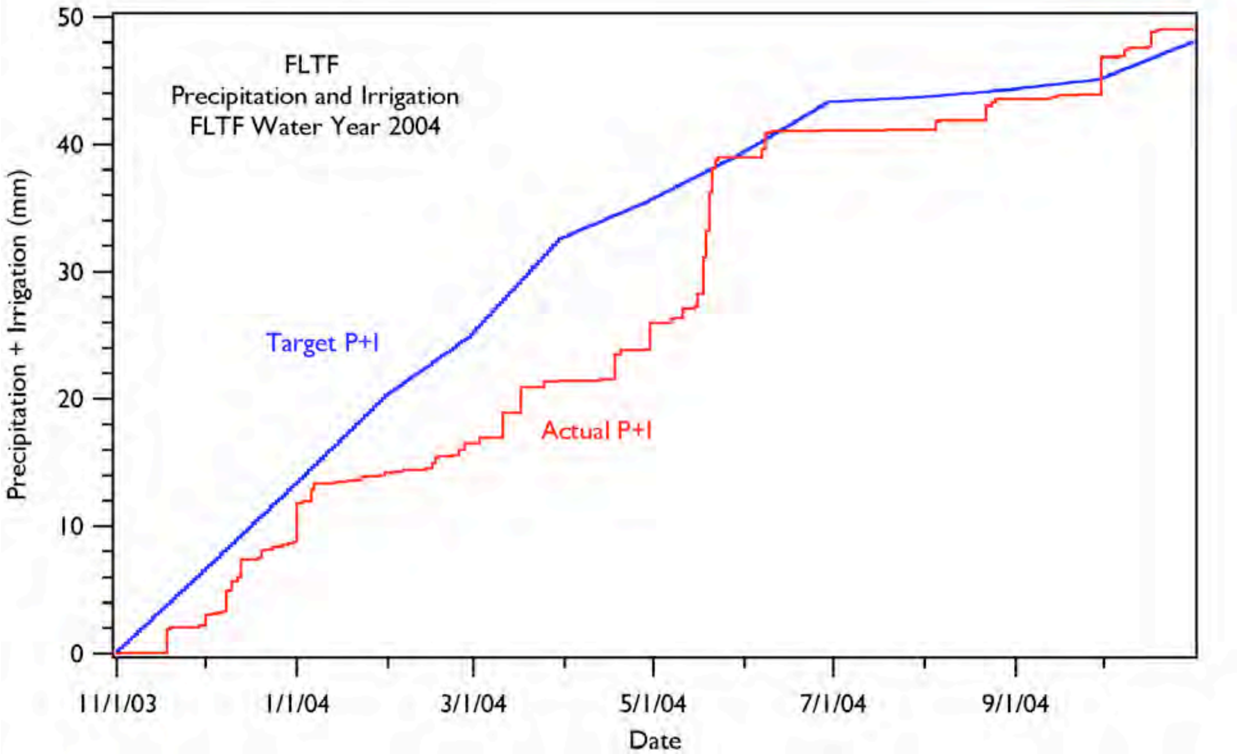

Figure 4.32 FLTF Precipitation Plus Irrigation FY 2004 Water Year (11/1/2003 - 10/31/2004)

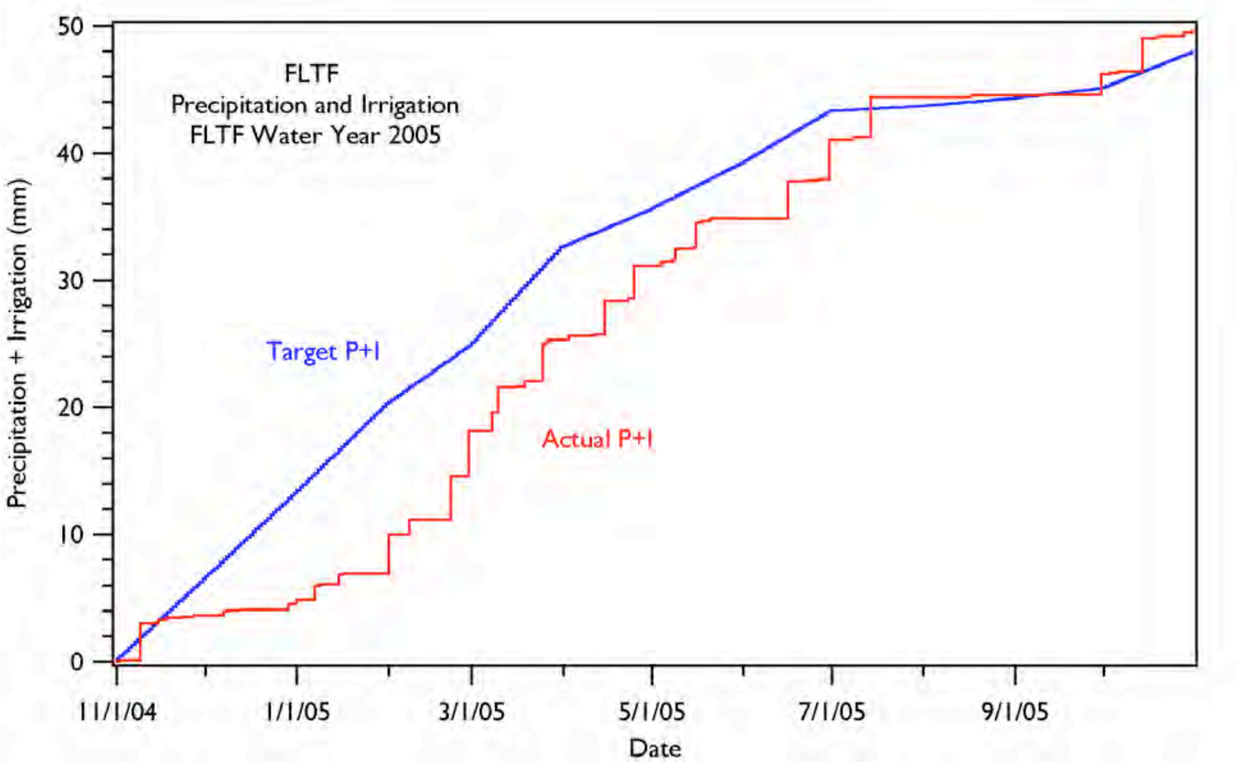

Figure 4.33 FLTF Precipitation Plus Irrigation FY 2005 Water Year (11/1/2004 - 10/31/2005)

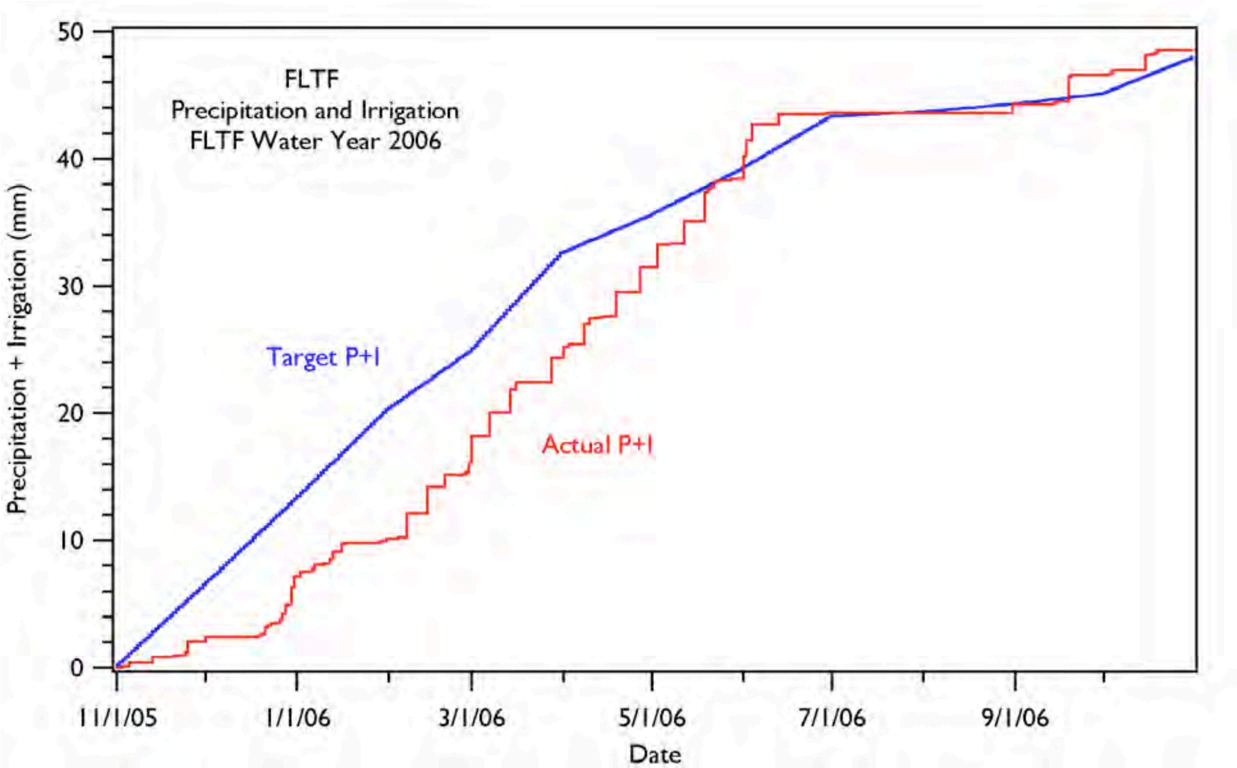

Figure 4.34 FLTF Precipitation Plus Irrigation FY 2006 Water Year (11/1/2005 - 10/31/2006)

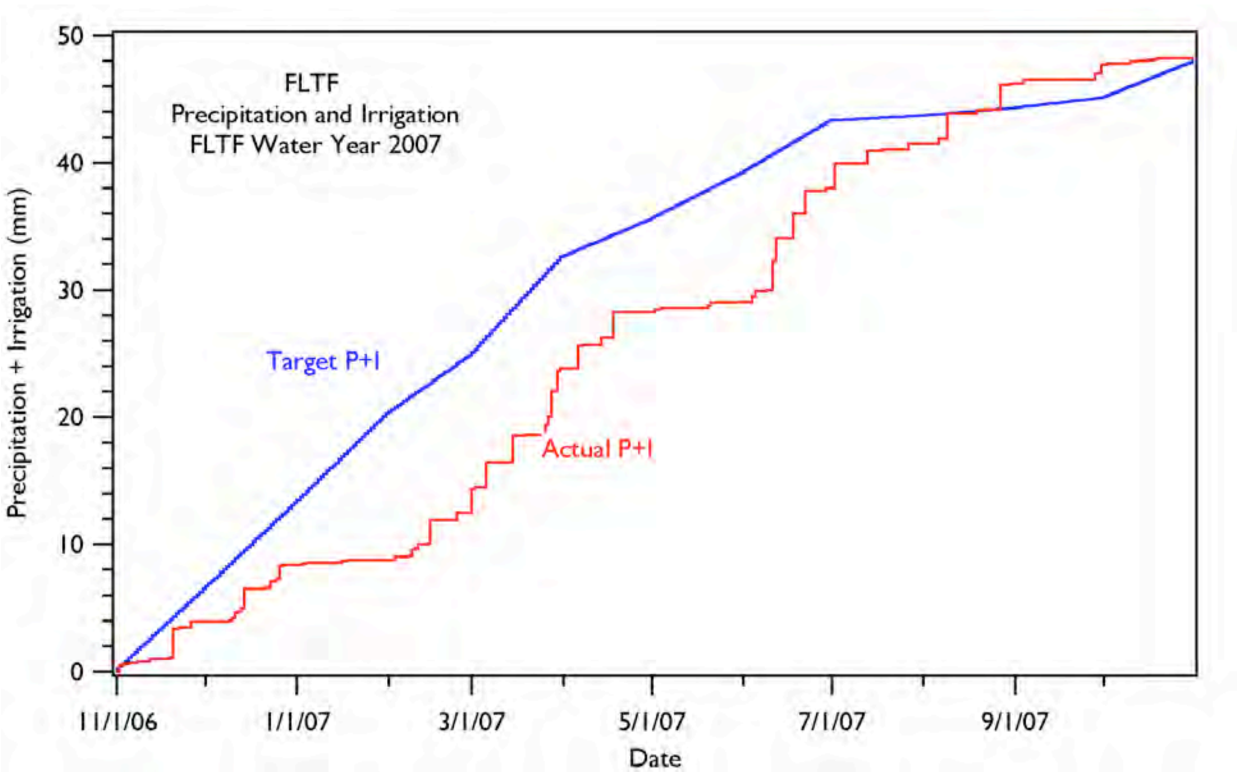

Figure 4.35 FLTF Precipitation Plus Irrigation FY 2007 Water Year (11/1/2006 - 10/31/2007)

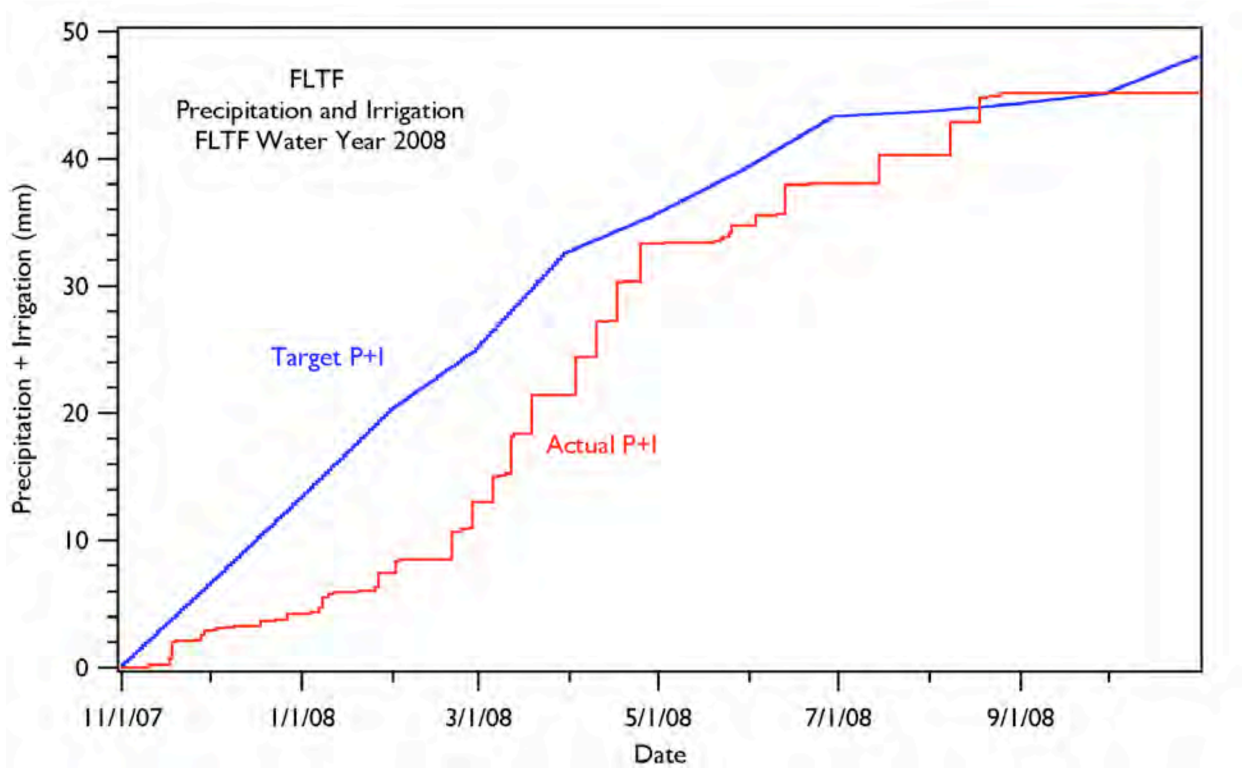

Figure 4.36 FLTF Precipitation Plus Irrigation FY 2008 Water Year (11/1/2007 - 10/31/2008)

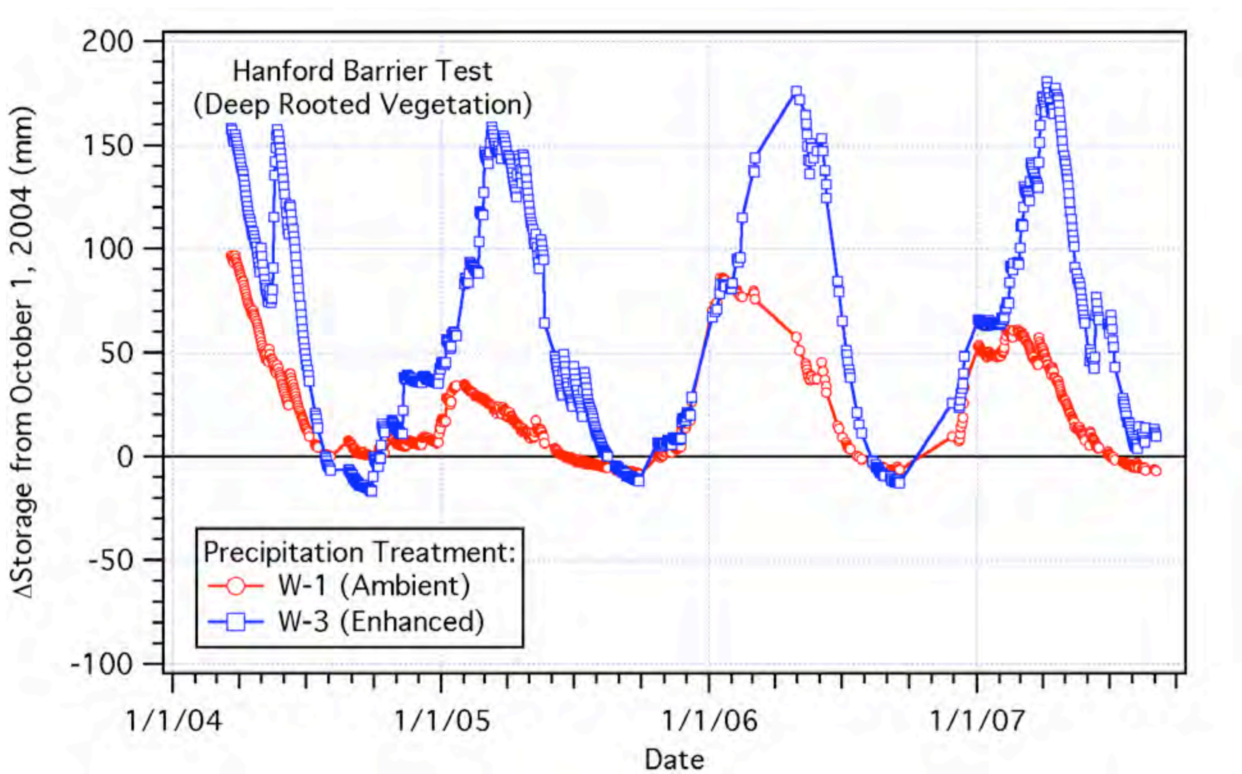

Figure 4.37 FLTF Weighing Lysimeter Treatments W1 and W3 Water Storage Change

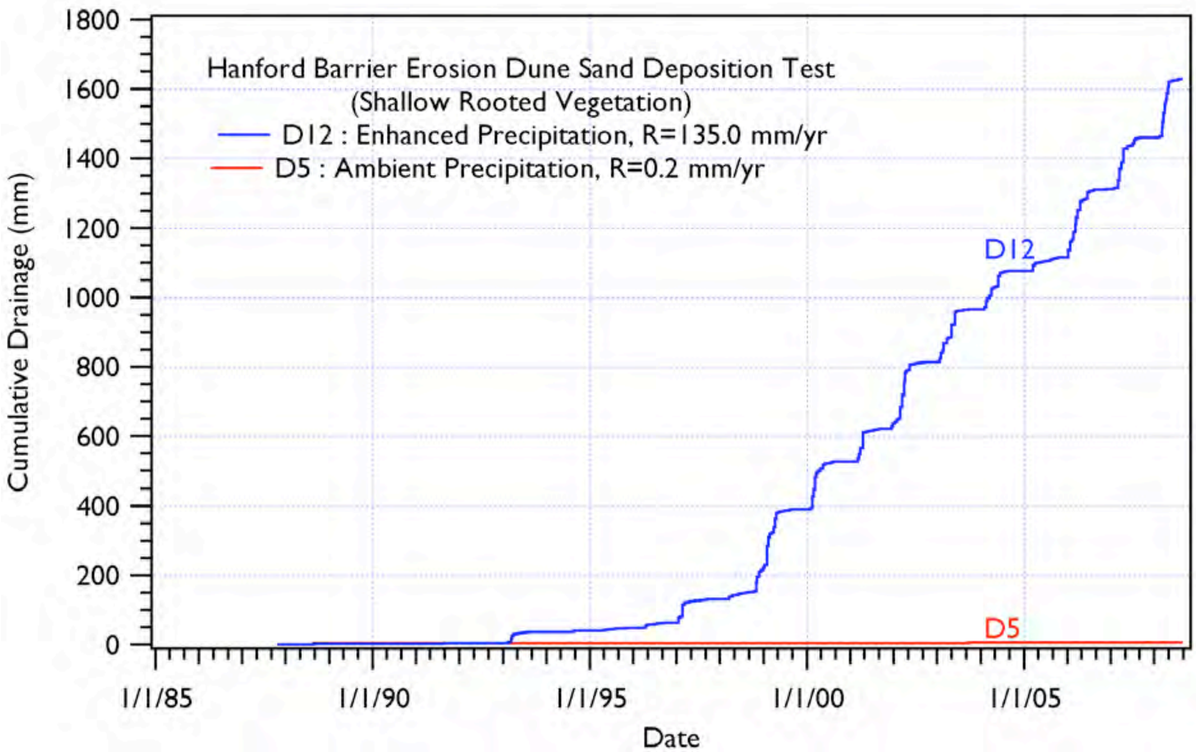

Figure 4.38 FLTF Cumulative Drainage for Treatments D5 and D12 (R is mean annual drainage rate)

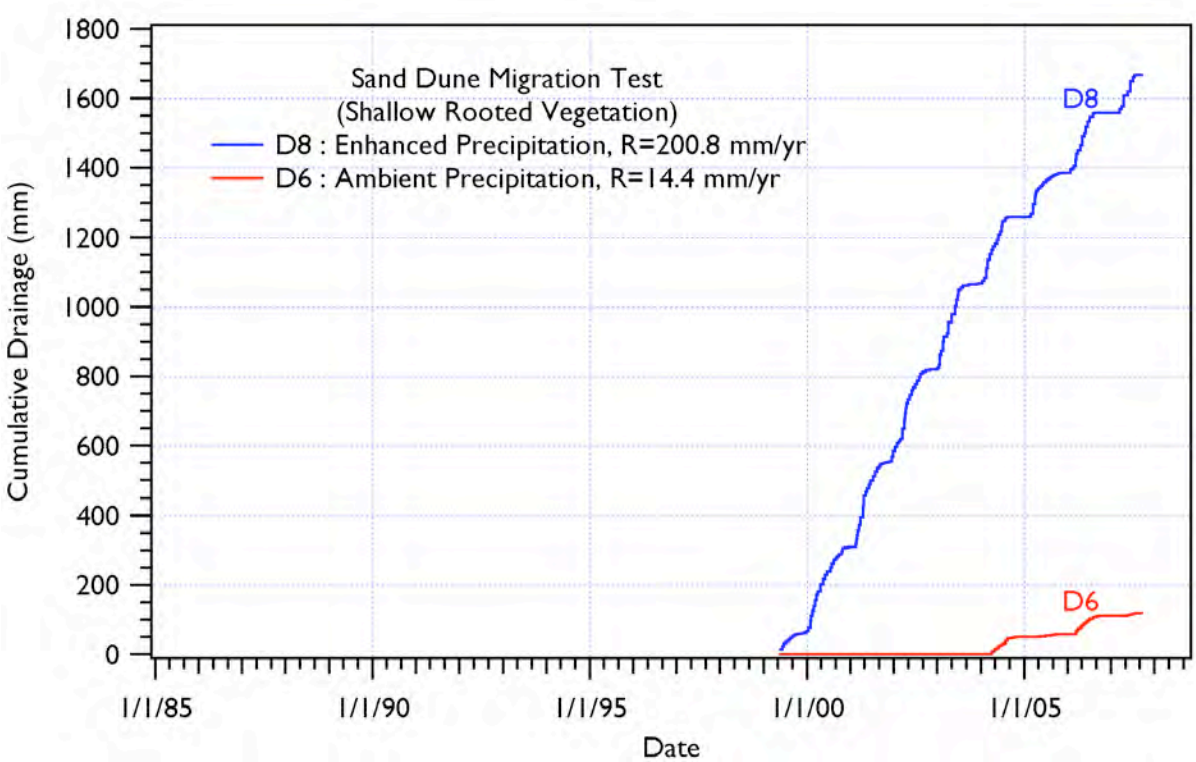

Figure 4.39 FLTF Cumulative Drainage for Treatments D6 and D8 (R is mean annual drainage rate)

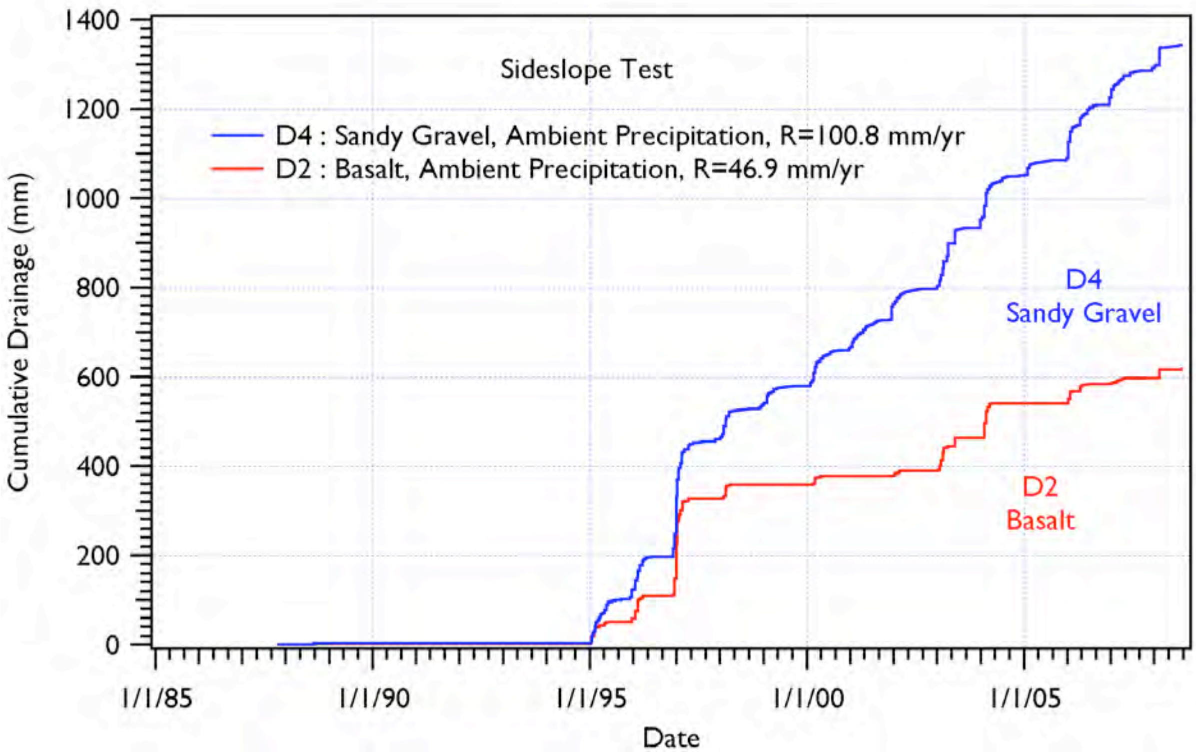

Figure 4.40 FLTF Cumulative Drainage for Treatments D2 and D4 (R is mean annual drainage rate)

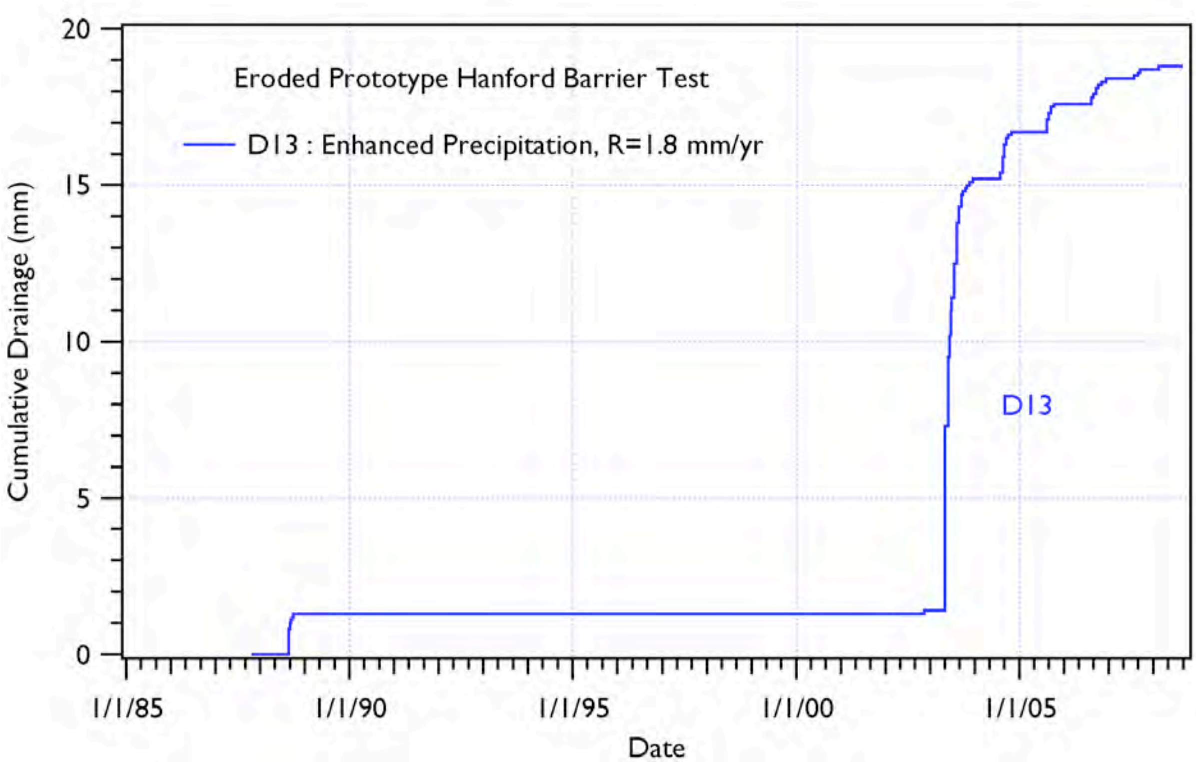

Figure 4.41 FLTF Cumulative Drainage for Treatment D13 (R is mean annual drainage rate)

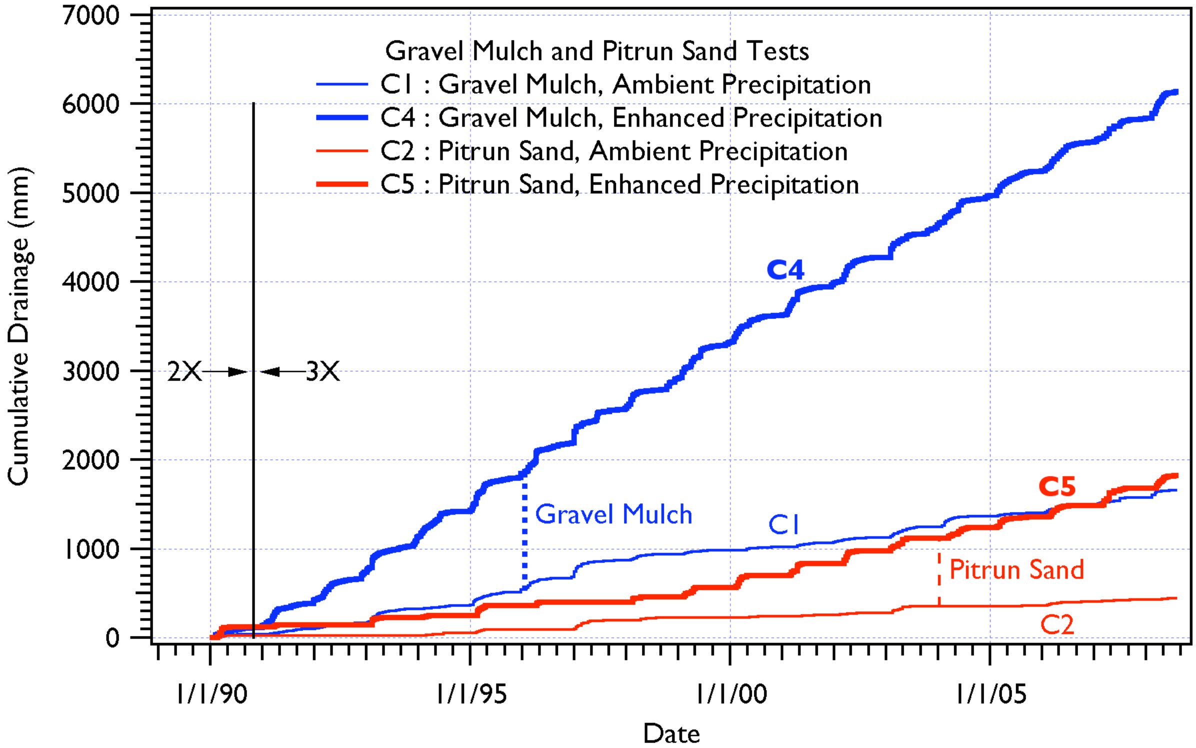

Figure 4.42 FLTF Cumulative Drainage for Treatments C1, C2, C4, and C5

Table 4.7 Summary of FLTF Drainage Rates Through August 1, 2008

Test Description	Lysimeter ID	Precipitation Treatment	Monitoring Period Start	Drainage Rate (mm/yr) [a] Installation Basis	Drainage Rate (mm/yr) [a] Drainage Onset Basis
Hanford Barrier	D1	Ambient	4-Nov-1987	0.00	
Eroded Hanford Barrier	D3	Ambient	4-Nov-1987	0.00	
	D13	Ambient	27-May-1998	1.70	1.70
Gravel Mulch	C1	Ambient	17-Nov-1989	89.0	89.0
	C4	Enhanced	17-Nov-1989	332.8	332.8
Pitrun Sand	C2	Ambient	17-Nov-1989	25.1	25.1
	C5	Enhanced	17-Nov-1989	79.9	79.9
Basalt Side Slope	D2	Ambient	1-Nov-1994	45.2	45.2
Sandy Gravel Side Slope	D4	Ambient	1-Nov-1994	98.4	98.4
Hanford Barrier Erosion / Dune Sand Deposition	D5	Ambient	17-Nov-1997	0.20	0.20
	D12	Enhanced	17-Nov-1997	139.5	139.5
	W4	Enhanced	17-Nov-1997	63.2	63.2
Sand Dune Migration	D6	Ambient	22-Jul-1998	19.1	39.8
	D8	Enhanced	22-Jul-1998	201.	201.
Modified RCRA Subtitle C Barrier	D7	Ambient	23-Feb-1999	0.00	
	D9	Enhanced	23-Feb-1999	0.00	

[a] All drainage rates reported to three significant figures.

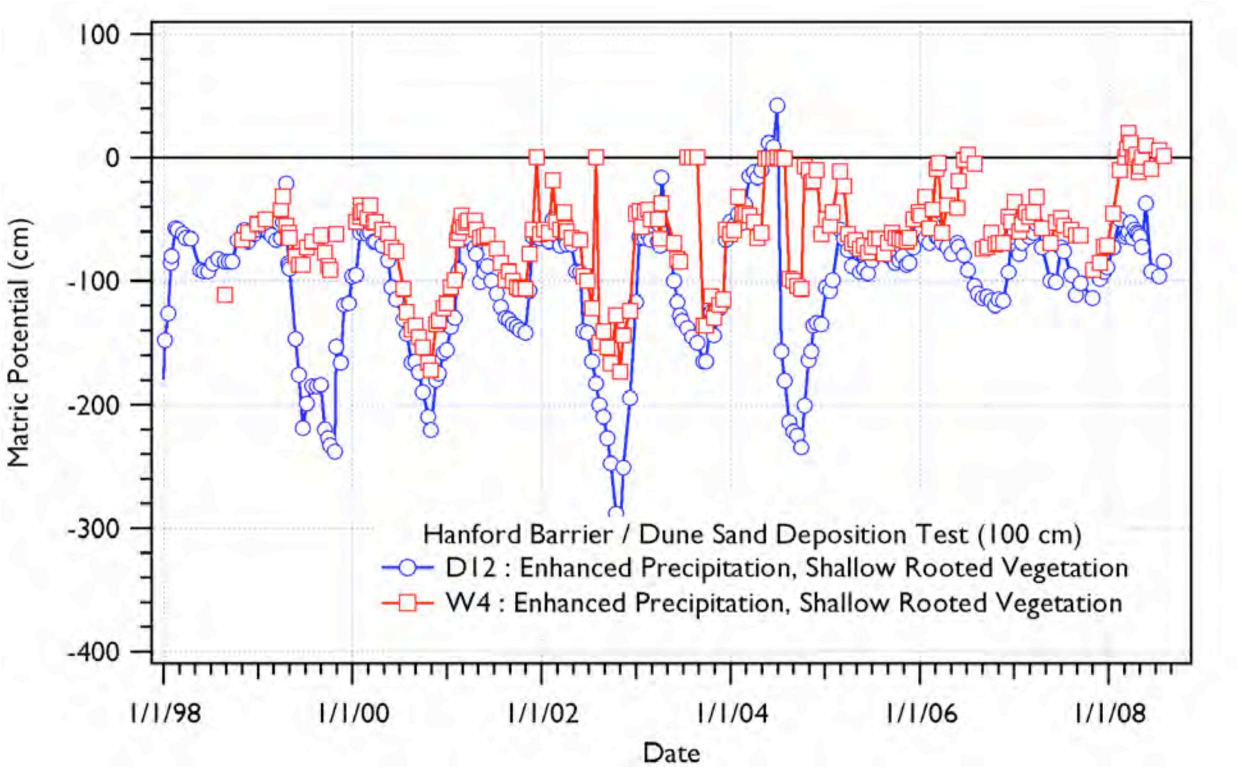

Figure 4.43 FLTF Matric Potentials for Hanford Barrier Dune Sand Deposition Test at Depth 100 cm

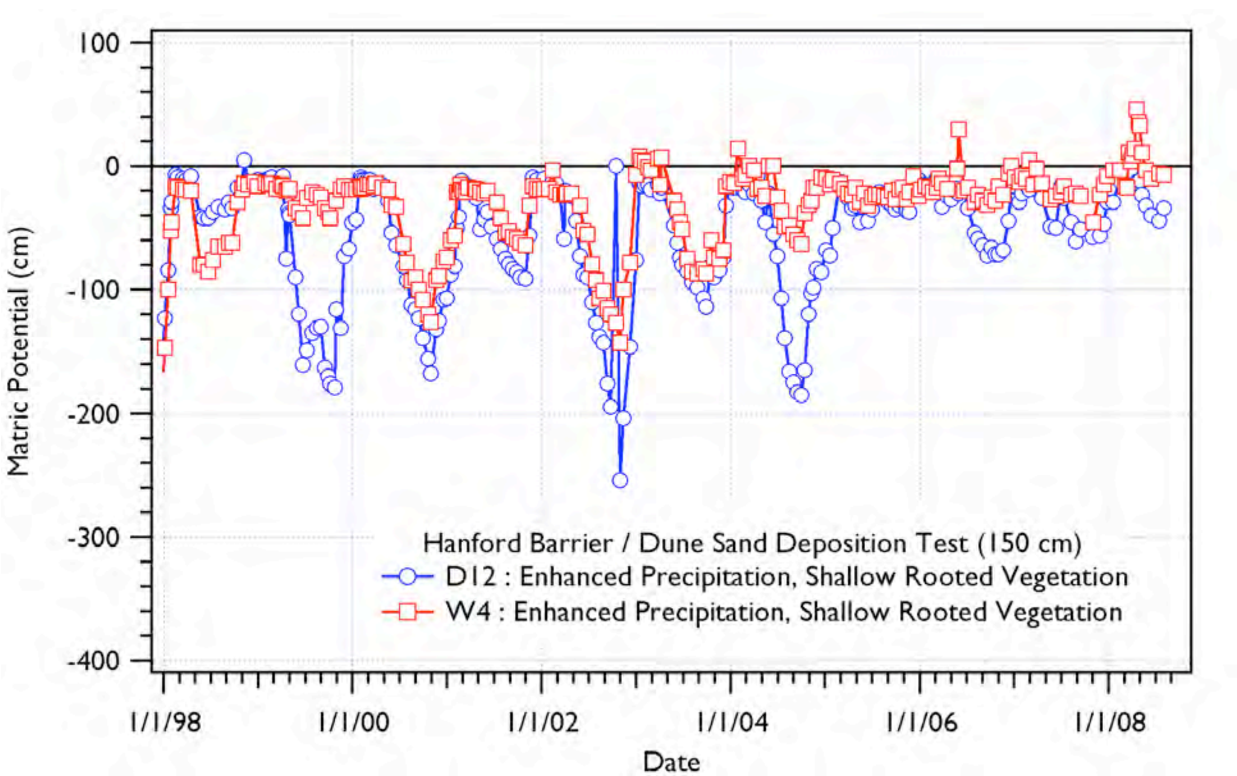

Figure 4.44 FLTF Matric Potentials for Hanford Barrier Dune Sand Deposition Test at Depth 150 cm

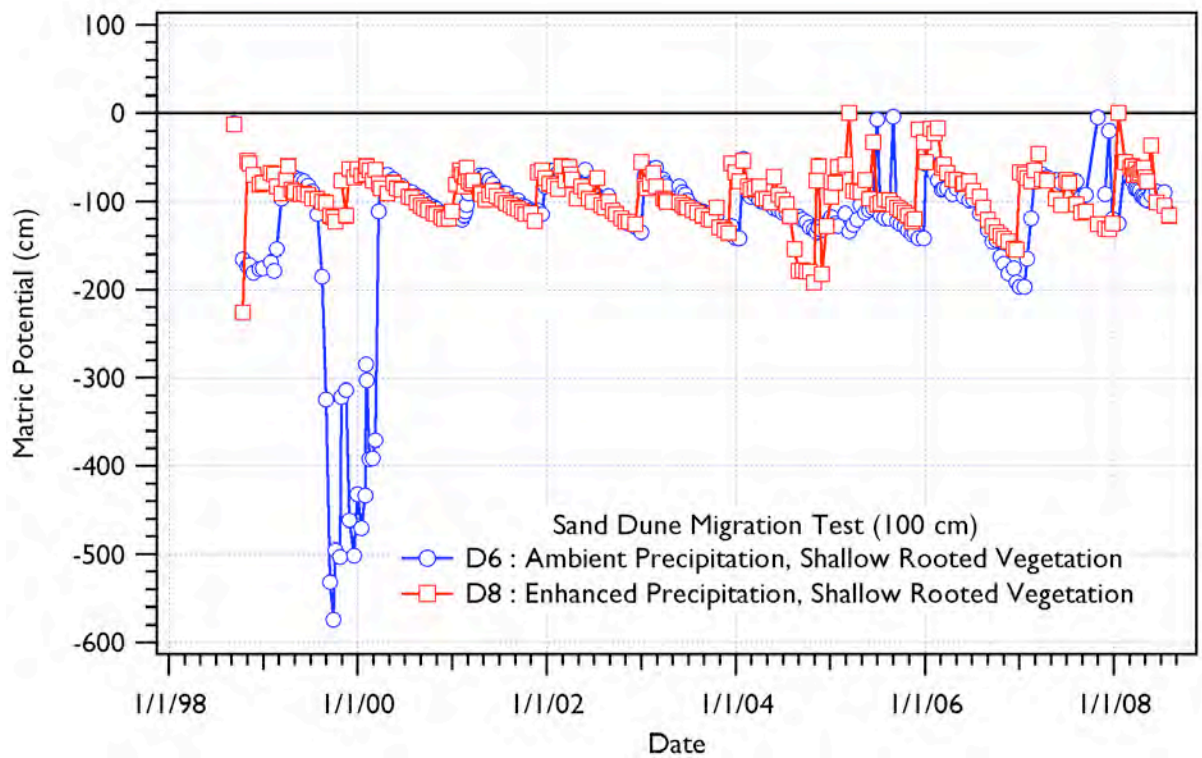

Figure 4.45 FLTF Matric Potentials for Sand Dune Migration Test at Depth 100 cm

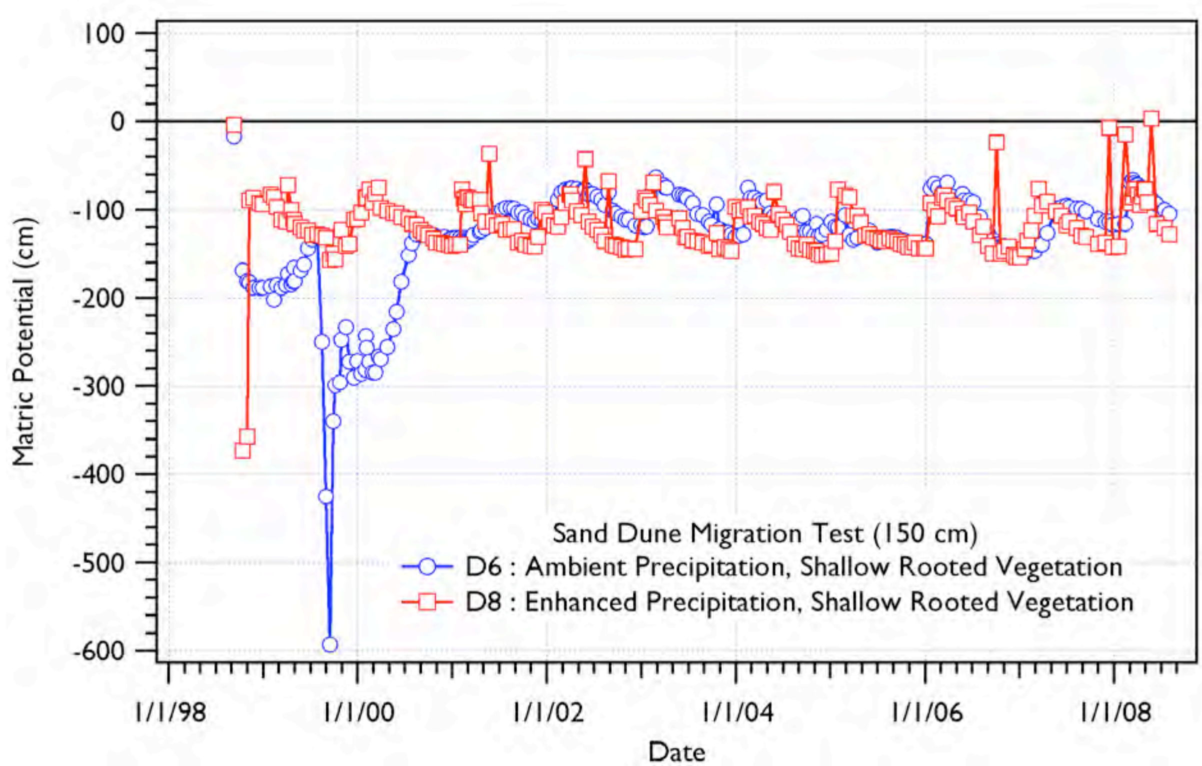

Figure 4.46 FLTF Matric Potentials for Sand Dune Migration Test at Depth 150 cm

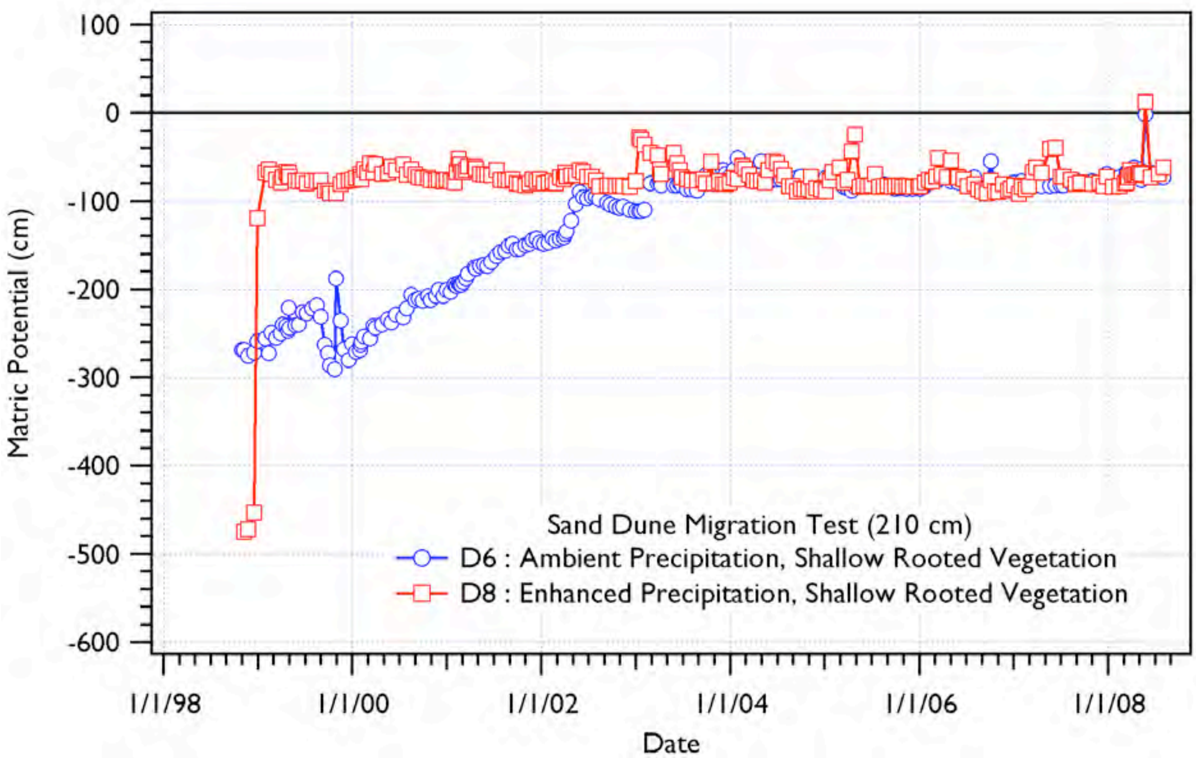

Figure 4.47 FLTF Matric Potentials for Sand Dune Migration Test at Depth 210 cm

$$q_{Cl} = R \times Cl_s$$

where R is the average lysimeter drainage rate and Cl_s is the drainage water chloride concentration. The results suggest a range of modern chloride deposition rates ranging from 130 to 8400 mg/m^2/yr for the 2007 data, for instance. Such a wide range strongly implies that assumptions underlying the calculation should be examined further.

Previous studies using ^{36}Cl/Cl ratios measurements in the soil (Murphy et al. 1996, Prych 1998, Fayer et al. 1999) have estimated Hanford chloride deposition rates ranging from 33 to 40 mg/m^2/yr. One possible explanation for the discrepancy is that geochemical conditions within the lysimeters may not be in equilibrium (as assumed). In particular, the high chloride from D6 may reflect residual chloride being flushed from the sediment. Interestingly, at the 300N Lysimeter Site (Gee et al. 2005) also measured drainage water chloride concentrations that were greater than expected given the documented drainage rate of the lysimeter. In that instance, a 22 percent increase in q_{cl} was required in order for the CMB estimated drainage to match the lysimeter drainage record. The analysis of chloride in drainage water from the FLTF is preliminary and thus inconclusive. Additional drainage water samples were collected for chloride analysis in FY 2008 and periodic sampling will also be performed in FY 2009.

The scale for W4 was replaced in late 2006. Just after it was installed and calibrated (mid-January 2007), it appeared to experience a bind. This apparently went noticed this until late in 2007, when intervention in the form of prying on the scale between the sediment-filled lysimeter box and its enclosure appeared to alleviate the problem. The CR7 datalogger has been working intermittently resulting in numerous periods without data. This datalogger was slated for replacement in FY 2008 but numerous issues were identified

Table 4.8 FLTF Lysimeter Measured Drainage and Measured Chloride Concentrations

Lysimeter ID	Average Annual Lysimeter Drainage (mm/yr)	Chloride Concentration (mg/L)	
		Sept 14 2007	Sept 2 2008
C1	90.7	2.87	2.43
C2	34.7	5.39	7.82
D4	105.4	1.23	1.36
D6	33.3	254.06	88.9

with using the replacement datalogger, a CR1000 model: the CR7 was determined to be better suited for use with the scales at FLTF. The CR1000 would appear to require voltage amplifiers be built in order to achieve the same precision as the CR7 (a difficult proposition). The lack of wiring diagrams for this old system that includes several numerous thermocouples connected to the CR7 datalogger also hinders such an upgrade. Before commencing such an upgrade, the use and value of the data collected needs to be reviewed. During FY 2008 the control module of the CR7 datalogger at FLTF was replaced with one from another CR7 datalogger that was no longer in use. Since this replacement was made, the datalogger appears to be functioning properly.

4.7 Field Lysimeter Test Facility (FLTF) Pit

The FLTF Pit site is a collection of four cement caissons containing WFMs packed with different soil types adjacent to the FLTF (Figure 4.48) and maintained vegetation free. The FLTF Pit flux meters, their treatments, and monitoring periods are presented in Table 4.9. The gravel soil is similar to the gravel material in the FLTF D4 lysimeter (Sandy Gravel Side Slope Test). The silt loam soil is from the same source as that used in the FLTF Hanford Barrier treatments. The sand soil is similar to the FLTF Dune Sand Migration test (D6 and D8 lysimeters) soil. The 5/8-inch minus material is similar to the commercial road base material existing on the surfaces of many Hanford tank farms. All WFMs have the divergence columns at the soil surface, with the exception of one silt loam WFM that has the divergence column at 1 m below the soil surface.

A plot of WFM measured drainage for the sand and sandy gravel material and silt loam at two depths is shown in Figure 4.49. Both silt loam WFMs continue to experience no measurable drainage since 2003. The sand and sandy gravel WFMs readily drain, although the sandy gravel filled WFM has stopped functioning, as displayed by its lack of drainage response when the sand WFM is draining. This issue is currently being explored. The road base WFMs and sand/silt loam WFM drainage are presented in Figure 4.50. Data collected in the first quarter of 2005 are a bit suspect, with greater drainage expected from the road base only material relative to the sand/silt loam material. Trouble encountered with data collection and functionality of these three WFMs upon installation and into the first quarter of 2005 may have led to this discrepancy. From January of 2006 to present all three of these WFMs appear to be working properly, with measurable drainage in 2006 and 2007. As expected, based on material properties, the road base material WFM has the greatest drainage of the three WFMs. Addition of silt loam to both the

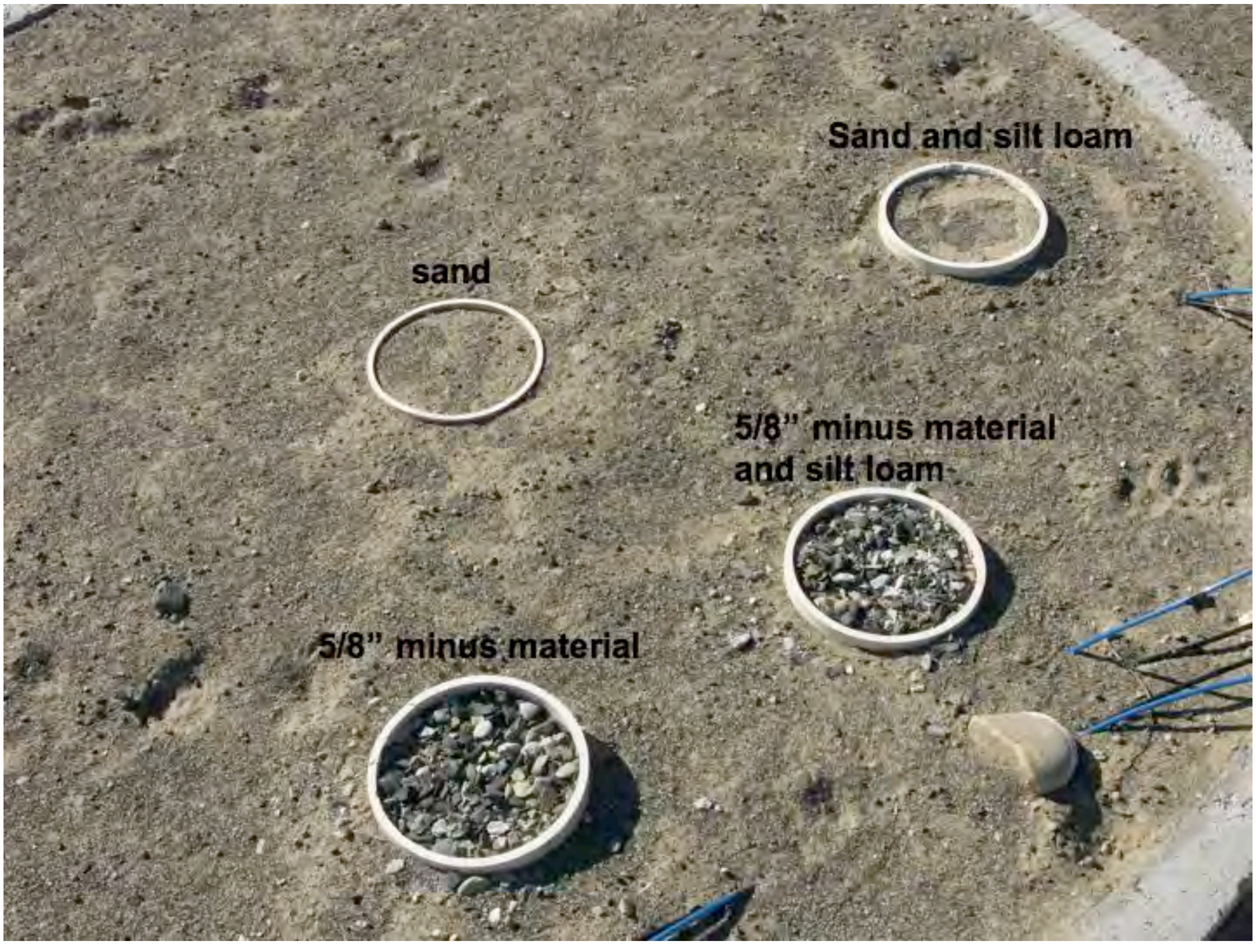

Figure 4.48 Photograph of One of the Four Cement Caissons at the FLTF Pit Showing WFMs Packed with Different Materials

Table 4.9 FLTF Pit WFM Treatments and Monitoring Periods (Al treatments are unvegetated)

Water Flux Meter ID	Soil Description	Monitoring Period
1	Sandy Gravel	Nov 2001 – Sep 2007
2	Silt Loam	Nov 2001 – Sep. 2007
3	Silt Loam (1 m)	Nov 2001 – Sep 2007
4	Sand	Nov 2001 – Sep 2007
5	80% Sand 20% Silt Loam (wt %)	Jun 2004 – Sep 2007
6	5/8-inch minus material	Jun 2004 – Sep 2007
7	80% 5/8-inch minus material 20% Silt Loam (wt %)	Jun 2004 – Sep 2007

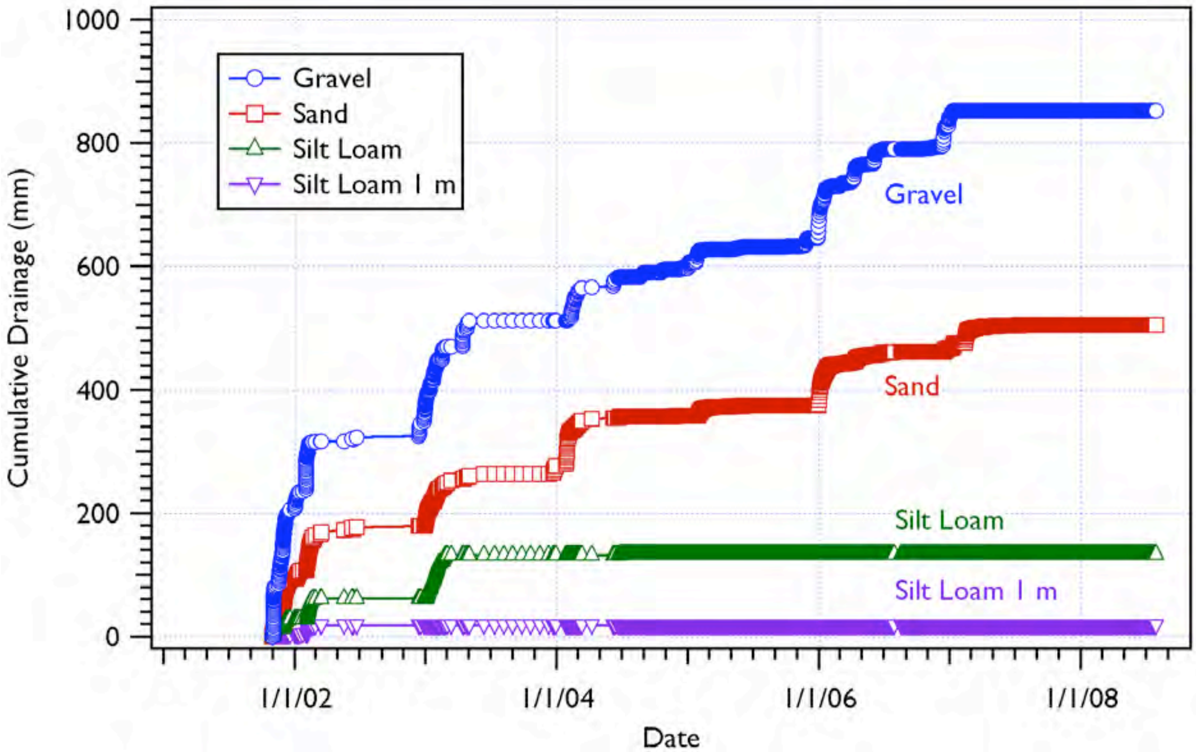

Figure 4.49 FLTF Pit WFM Measured Drainage for Sand, Silt Loam, and Gravel Treatments

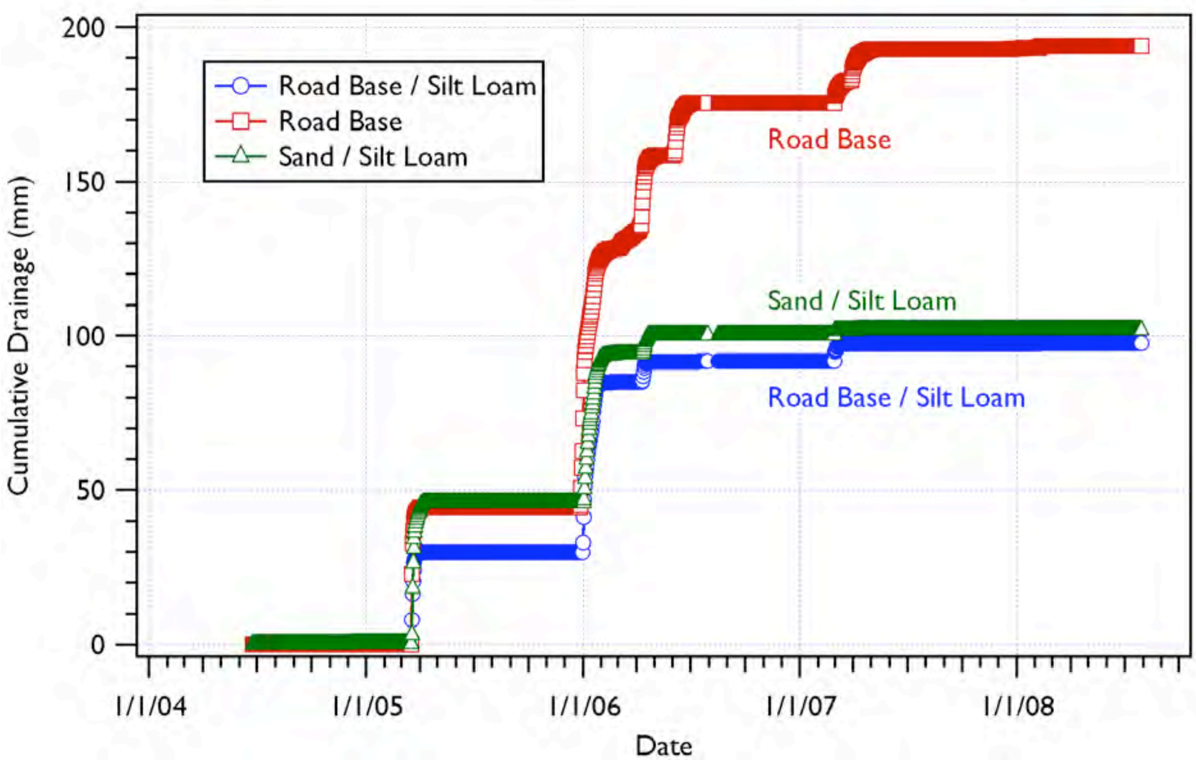

Figure 4.50 FLTF Pit WFM Measured Drainage for Road Base/Silt Loam, Road Base, and Sand/Silt Loam Treatments

sand and road base material results in an increase in the storage capacity of the soil and reduced drainage. In the case of the road base material, the addition of silt loam provides a nearly 50 percent decrease in the drainage rate (60.1 mm/yr versus 30.3 mm/yr for the road base and road base / silt loam, respectively), whereas the addition of silt loam to the sand material produces over a 30 percent reduction in the drainage rate over the same monitoring period (31.7 mm/yr versus 46.6 mm/yr for the sand/silt loam and sand, respectively).

4.8 Tank Farms (B, SX, TX)

Single- and double-shell tanks used for radioactive waste storage pose special concerns at the Hanford Site. Characterization of recharge for the surface conditions of these sites has been a subject of interest, and several monitoring sites were established in efforts to measure this important parameter at these locations. Recharge monitoring is reviewed for the sites at B, SX, and TX tank farms.

4.8.1 B Tank Farm

In FY 2001 eight sensor nests, ranging in depth from 67 m (220 ft) bgs to 0.9 m (3 ft) bgs were placed in contact with vadose-zone sediments inside an uncased borehole (C3360) located adjacent to Tank B-110 (Gee et al. 2003a). The sensor sets were deployed as part of the Vadose Zone Monitoring System (VZMS) for the Hanford Tank Farms and included advanced tensiometers, heat dissipation units, water content reflectometers, thermal probes, and solution samplers. Within the top meter of the surface, a WFM was deployed to directly measure net infiltration from meteoric water (rain and snowmelt) sources. In addition, a rain gage was located within the Tank Farm to document on-site precipitation events. All sensor units, with the exception of the solution samplers, were connected to a solar-powered datalogger located within the B Tank Farm. Data collected with by sensors were accessed by modem and cell phone. The gravel surfaces and lack of vegetation on the Tank Farm promoted accumulation of water in the surface that enhanced drainage. Using early tensiometer data it was confirmed that water flow was vertical and that drainage occurred, but those data did not provide a direct measure of drainage rates because those can only be estimated if the unsaturated hydraulic conductivity of the sediments were known. The WFM provided a direct measure of drainage from meteoric water sources (or surface water spills that might have occurred directly over the fluxmeter). The WFM was calibrated in late March 2002 and results indicated that it was responding properly to water inputs.

The B Tank Farm site was abandoned in early 2004. Most of the sensors had failed by the time monitoring ceased. The above ground equipment was retrieved for other uses, while the in-ground sensors were left in place. Hence there are no recharge data available for this site, but the closure of this site is documented here for historical purposes.

4.8.2 SX Tank Farm

The SX Pit monitoring site is located directly south of SX Tank Farm in excavated Hanford formation sediment. The area immediately surrounding the instrumentation is devoid of vegetation. This site was instrumented with two WFMs, one near the surface and the other 4.7 m bgs, as well as moisture content sensors and tensiometers. The pits were filled around 1999 or earlier and fluxmeter testing began in 2002. Data collection began at this site in January 2003 and ended in FY 2007.

Figure 4.51 shows the water content data collected at this site. These data exhibit reasonable responses to winter precipitation with dampening response with depth. The tensiometer data that are depicted in Figure 4.52, however, are suspect in that 1) the deep tensiometers show much more seasonal modulation than did the tensiometers near the surface and 2) the 3.4 m sensor at times provided readings that were greater than 0 cm, which should not have occurred under expected conditions at this location. At first glance, it appears that the reversal in modulation with depth may have been due to the incorrect assignment of data and corresponding depth, but the matric potential maximums and minimums did not coincide with the appropriate time of the season. In other words, the matric potential data did not exhibit the typical behavior of reaching their maximum value (less negative) in the winter and minimum values (more negative) in the summer. WFM measured drainage data are presented in Figure 4.53. The lack of surface WFM response since August 2005 and the lack of response from the 4.7 m bgs WFM suggest that both units were functioning incorrectly. The coarse sediment at this location is similar to that found at the SWL, where WFMs did measure drainage in 2006 and 2007 (refer back to Figure 4.18). Unfortunately, both SX Pit WFMs lacked a calibration line for testing and troubleshooting. Thus, it can only be assumed that both units had failed.

The SX Pit monitoring site was an existing site prior to the RDS project assuming responsibility for it in FY 2005. An account of instrument installation at this site did not exist, nor were calibration derivations documented, making review of the validity of the data from this site difficult. Complicating matters further was the fact that the internal clock on the datalogger for this site often reset, resulting in incorrect date and time stamps in the data records that were corrected during post processing activities. It was determined that investment in repairing or replacing the datalogger would not improve overall site data quality or instrument performance because of the poor performance of the majority of the instruments, including the key WFM drainage measurement. For these reasons, a recommendation was made in FY 2007 to cease monitoring at this location and to decommission this site.

4.8.3 TX Tank Farm

Vadose-zone hydrologic sensors were deployed in the TX Tank Farm in FY 2002, when four sensor nests ranging in depth from 30.1 m (98 feet) to 1.5 m (5 feet) bgs were placed in an uncased borehole (C3830) located between Tank TX 101 and TX 105 in the TX Tank Farm (Gee et al. 2003a). Because of the reduced size of the borehole (0.18 m for the TX borehole vs. 0.26 m for the B borehole discussed earlier), the sensor sets were limited to advanced tensiometers and thermocouples placed at each of four depths. Also, due to drilling restrictions, WFMs were placed outside the Tank Farm. Two WFMs were placed under coarse gravel surfaces, directly south of the TX borehole C3830 just outside the fenced perimeter of the Tank Farm. Data collected from the sensor nests and flux meters are currently accessed remotely. Early tensiometer data collected from the TX Tank Farm are similar to those at the B Tank Farm and indicate that unit-gradient conditions exist and the Tank Farm was draining.

Matric potentials measured with advanced tensiometers through FY 2007. These data are shown in Figure 4.54. The TX Tank Farm is no longer being monitored. Most of the above ground equipment was retrieved for other uses, while the in-ground sensors were left in place. Hence there are no recharge data available after FY 2007 for this site, but the end of monitoring of this site is documented here for historical purposes.

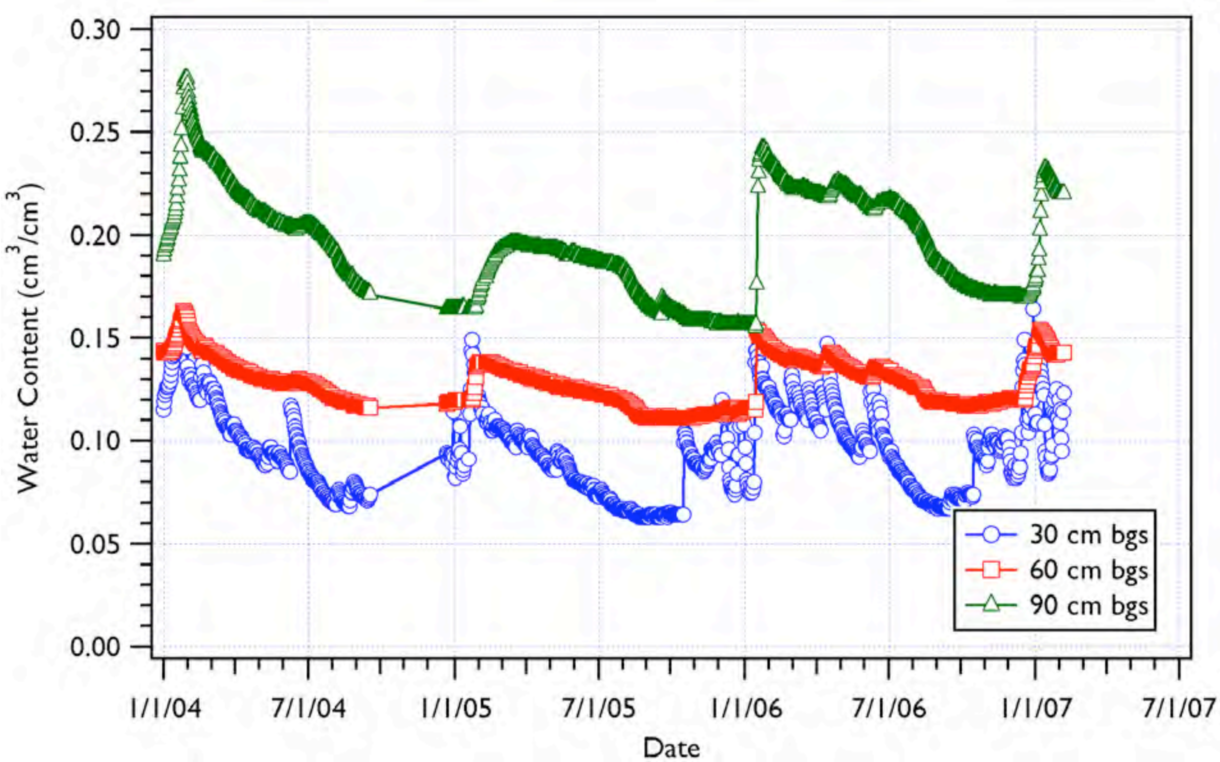

Figure 4.51 SX Pit Measured Water Content at 30, 60, and 90 cm bgs

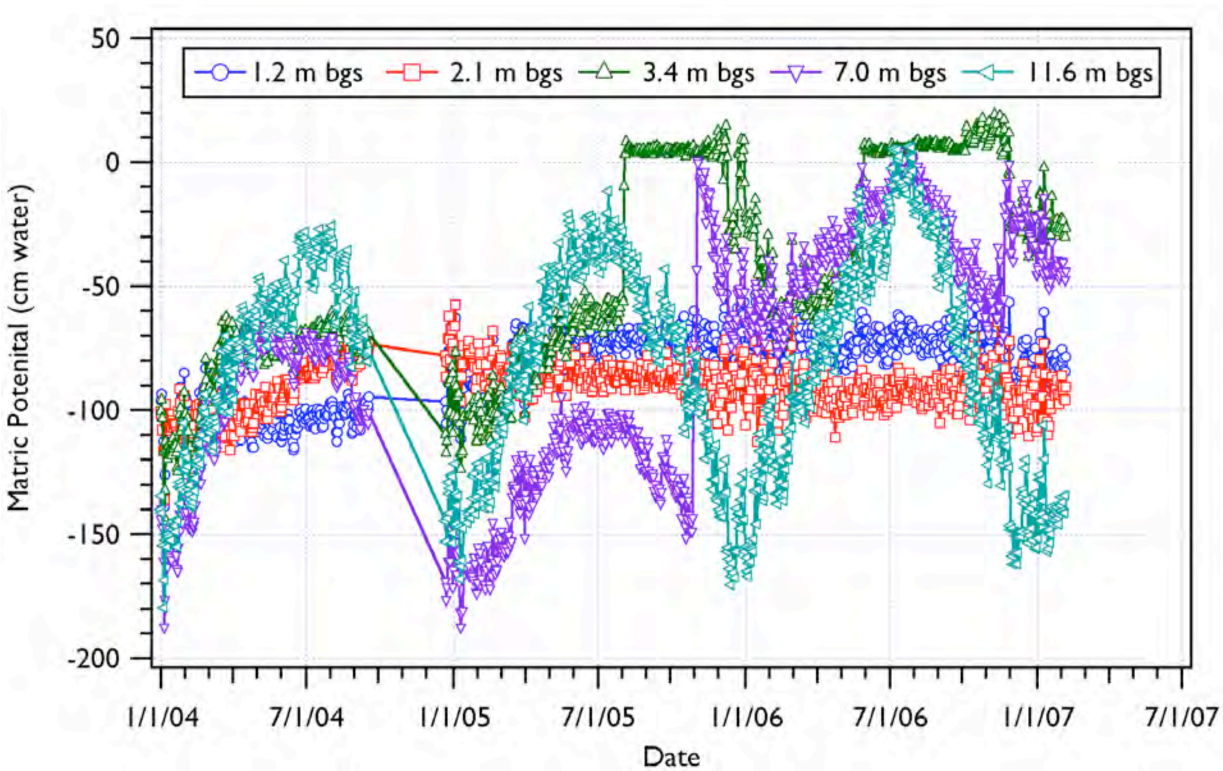

Figure 4.52 SX Pit Measured Matric Potential

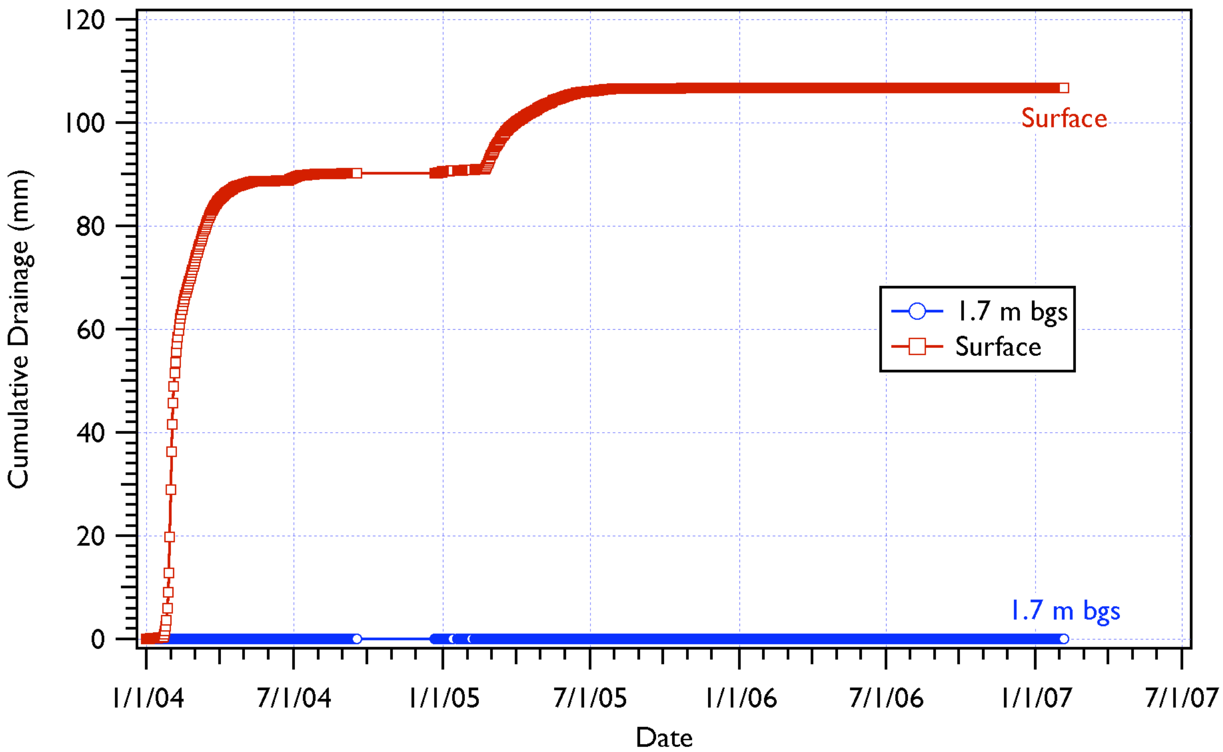

Figure 4.53 SX Pit WFM Measured Cumulative Drainage

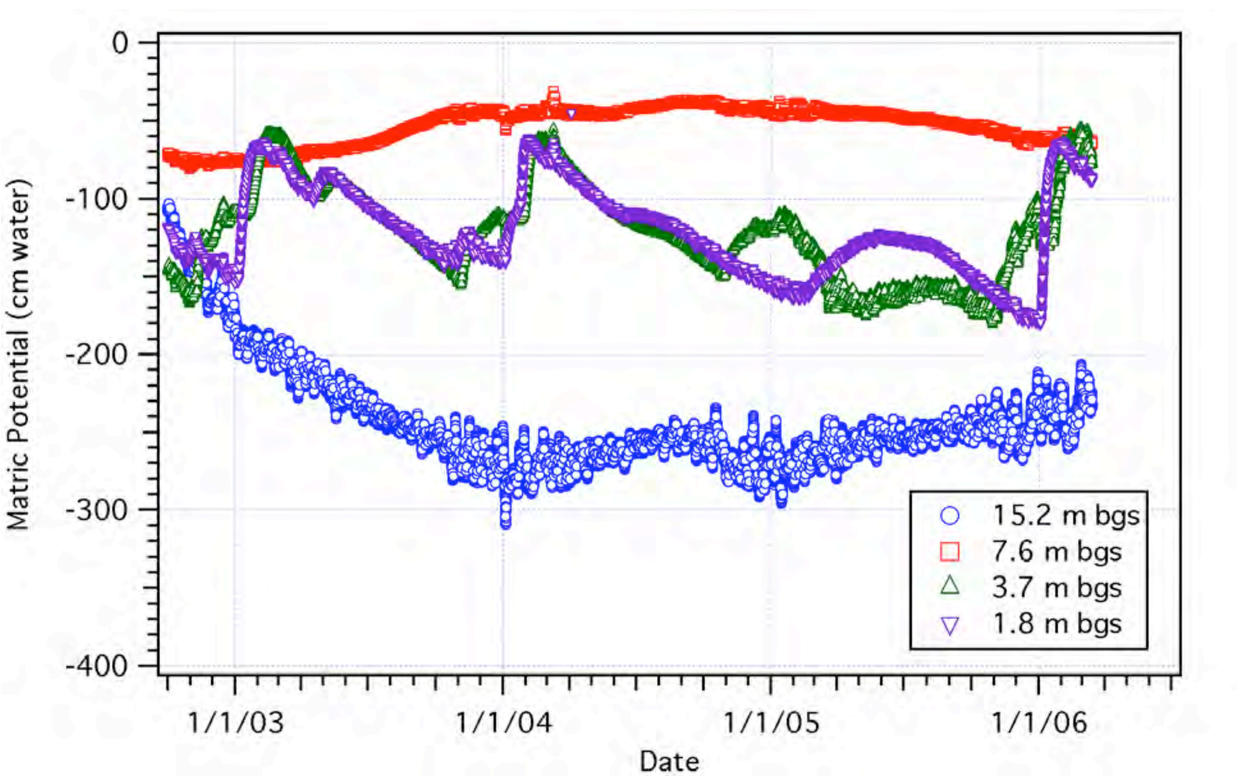

Figure 4.54 TX Tank Farm Matric Potentials at Four Depths Since Installation

5 Knowledge Gaps

This section identifies several gaps in the state of knowledge regarding recharge at the Hanford Site that hamper development of more defensible recharge estimates for specific site conditions. Some of these gaps are currently being addressed by ongoing projects including the RDS Recharge Measurement Task, while other gaps have yet to be formally addressed. Recommendations for addressing these knowledge gaps are discussed as well.

5.1 Existing Knowledge Gaps

Knowledge gaps evolve over time, as needs are identified and previously identified gaps are resolved. The information in this section is taken from a draft recharge roadmap developed by Jason Keller and Mike Fayer of PNNL.

5.1.1 Basalt Outcrops

The higher elevations and unique surface conditions (deep, thin, or no soil) of basalt outcrops on the Hanford Site may produce recharge rates higher than that of the surrounding terrain. Recharge associated with basalt outcrops is not understood. Fayer and Walters (1995) utilized measured recharge for a gravel surface lysimeter to produce their recharge estimate for basalt features such as outcrops, scarps and scree slopes. Preliminary efforts have been made to measure the thickness of soil at selected locations on Gable Mountain, but this information has not been published and remains sparse. Characterization of soil thickness variability on Gable Mountain will aid greatly in estimating the soil-water storage capabilities of that, and similar, areas.

5.1.2 Soil, Vegetation, and Land Use Maps

Current maps of soils, vegetation, and land use at Hanford are either outdated or lack desired accuracy due to limited ground truth data and changing surface conditions related to Hanford operations. The last full-scale soil survey that included the present day Hanford Site was conducted in 1919 (Kocher and Strahorn 1919). Since then, classification schemes have changed and identification methods have improved. The 1919 survey did not consider recharge potential. Hajek (1966) produced a soil map and descriptive report of Hanford Site soils for the portion of the Hanford Site in Benton County using the 1919 survey as a base map and updating the soil classification scheme (Baldwin et al. 1938, SCS 1951, SCS 1960). Downs et al. (1993) used aerial photos acquired in 1987 and 1992 to create plant and wildlife species distribution maps of the Hanford Site.

Note that Fayer and Walters (1995) developed their distributed recharge estimates for the Hanford Site using Hajek's (1966) soil map and Downs et al.'s (1993) vegetation maps.

Recharge estimates from tracer methods presume one-dimensional, vertical downward flow. However, sedimentary layering at Hanford is known to dominate vadose zone flow processes in many instances. The result of neglecting the influence of subsurface heterogeneities can result in overestimation of recharge rates (McCord et al. 1997). The same can be said about measurements of drainage far above the water table in which it is assumed that near surface drainage measurements are directly linked to water reaching the saturated zone without lateral migration. In instances where a layered soil profile acts as a capillary break within the evapotranspiration zone, transmission of downward migrating soil water may be impeded sufficiently to allow evapotranspiration processes to effectively decrease the drainage rate. Finally, subsurface heterogeneities result in recharge being highly spatially variable; in these cases, a single measurement of recharge may not be representative of recharge for the extent of an entire management area. A modern soil survey that is tailored to identify soil types based on their recharge potential (e.g., layering features within ~5m of the surface) is needed.

5.1.3 Structures

Roadways, parking lots, and buildings make up a small fraction of the entire surface area of the Hanford Site, but have the potential to contribute disproportionately to recharge through focused infiltration resulting from runoff from these surfaces. To date, enhanced recharge from such structures has not been estimated or factored into assessments.

5.1.4 Climate and Ecological Change

Recharge is in large part a direct function of climatic conditions, especially of precipitation, wind, and air temperature. The Hanford Site recharge estimates reported in Last et al. (2006) are for the current climate conditions at Hanford. The paleoclimate of the area is known to have been different some 10,000 years ago (Chatters and Hoover 1992, Wing et al. 1995) and is likely be different 10,000 years from now. Further, climate changes induce ecological changes. We need to know what changes to expect, how to quantify these changes, and how to establish reasonable uncertainty bounds on the expected changes. These changes drive our conceptual model of the plant and animal community, erosion potential, and hence the recharge that might occur in the future. Consideration of climate change needs to include both near-term global warming effects and longer-term ice age, or glacial period, effects. The old Barrier Development Program (Wing and Gee 1994) and the Recharge Data Package for the IDF project (Fayer and Szecsody 2004) considered climate and vegetation change, but such considerations are not universal at Hanford. A coherent and consistent framework is needed that describes the climate, vegetation, and animal changes expected at the Hanford Site for as long as the Site is considered a risk.

5.1.5 Time Transformation of Gravel Surfaces

Gravel surfaces such as those covering current waste management areas or comprising side slopes of surface protective barriers will, if left alone, transform due to soil and ecological processes. The manner and rate at which gravel surfaces change are not known and deserve further investigation given the proposed use of gravel surfaces for barrier side slopes and the possibility that some gravel sites may receive no remedial action.

5.1.6 Gravel Covered Waste Management Areas

An improved estimate of recharge underneath Hanford waste management areas is needed. Waste management areas are generally kept bare and covered with gravel to facilitate operations and reduce dust and biotic intrusion. Such a surface condition may result in a disproportionate fraction of recharge at the Hanford Site being related to waste management areas given the small fraction of the entire Hanford Site they make up. The current recharge estimate for gravel surfaces is based on drainage measured beneath unvegetated gravel mulch lysimeters (Fayer and Gee 2006). The gravel mulch contains very few particles less than 2-mm compared to those found in waste management area settings where upwards of 50% or more of the particles are <2-mm (Smoot et al. 1989).

5.1.7 Natural Systems

Other than tracer studies and some testing at the IDF Site, there are few recharge data for natural soils. Tests with lysimeters typically involve repacked soils, which is reasonable for engineered barriers but inadequate for representing most natural soil types. The reason is that such tests do not replicate the intricate near-surface sediment layers that can act as impediments to vertical water movement via hydraulic and capillary barrier effects. Such phenomena are thought to contribute to the low recharge rates observed at the IDF site. The most importance recharge rates to measure are those in the dominant soil types: Rupert sand, Ephrata sandy loam, and Burbank loamy sand.

5.1.8 Vegetated Disturbed Areas

Operations around the Hanford Site significantly disturbed the local soil such that it no longer resembles the original soil type in operational areas. After the Hanford Site is cleaned and closed, these disturbed soils will revegetate. While the Hanford SWL basin lysimeter serves as a good test of a vegetated disturbed area; beyond this, only limited data exist for revegetated disturbed conditions though such conditions will be the norm following closure. This gap could be significant if large portions of the Site receive no action and are allowed to revert to their natural state.

5.1.9 Surface Barriers

Surface barriers are integral to safe and effective closure of many waste sites at the Hanford Site, but there are still several data gaps associated with surface barriers that need to be addressed. First, the functional lifetime of surface barriers is not well defined or supported. A number of processes and events could occur that have either reinforcing or deleterious impacts. A set of designs has been tested in the FLTF since 1987 and one design has been tested in the field since 1994. To date, the designs tested show promise, but the length of the performance record (< 20 years) is short relative to the barrier design life (500 years), and relative to the time scale of long-term performance assessments (thousands of years). Second, new designs are being prepared in an effort to reduce cost, but there are no performance data to support the new designs. Third, regardless of design, no agreed-upon set of degradation/evolution scenarios exists. Several studies have examined specific scenarios (e.g., erosion; dune sand), but some external reviewers have not been satisfied. In particular, some have an expectation that performance ought to degrade as a natural consequence of maturing; others disagree. Finally, questions persist about barrier edge effects and barrier side slope performance.

5.1.10 Subsurface Ecology

The ecology of the subsurface refers to the impacts of plant roots and animal burrowing on recharge. Such impacts arise from changes in hydraulic properties caused by soil mixing, the creation of preferred pathways for water migration, and the damage to important design features such as an HDPE liner or a capillary break. The issue becomes more acute as the thickness of barriers is reduced to reduce costs.

5.1.11 Sensitivity to Duration of Measurement Record

Obtaining a useful estimate of the long-term mean recharge rate requires measuring for a period long enough to encompass the infrequent events (e.g., hundred year storms) that control recharge in the arid environment at the Hanford Site where rates are less than a few millimeters per year. Although necessary, monitoring for decades is expensive and time-consuming. To minimize the cost and duration, a single measurement (if one even exists) is often used to represent the rate for very large areas with no understanding of how closely it resembles the mean long-term rate for that area.

5.1.12 Uncertainty

Performance assessment models that use stochastic analyses require knowledge of the statistical distribution of recharge for a given surface condition. The limited recharge data that exists for each surface condition complicates the calculation of the stochastic distribution of recharge. The method proposed by Last et al. (2006) is to rely on the mean and standard deviation of the winter precipitation and a three-point triangular probability distribution to quantify uncertainty in recharge rates. Improved understanding of the stochastic distribution of recharge as related to surface condition is needed.

5.1.13 Modern Chloride Deposition

Modern chloride deposition rates are assumed to be equivalent to rates estimated using deep chlorine-36 data. Facilities such as coal plants and water purification plants have been suggested as possible local sources of atmospheric chloride. If such emissions occurred and deposition was significant, recharge estimation methods that use soil chloride concentrations would have to account for the modern chloride.

5.1.14 Upland Area Recharge

Diffuse recharge through the vadose zone at elevations above the Central Plateau does not affect waste movement to the groundwater because there are no waste sites at higher elevations, but it does influence groundwater movement and thereby transport of groundwater contaminants to the river. In addition, the Greater Cold Creek watershed, which includes Cold and Dry Creeks, has experienced periods of significant stream flow due to large runoff events. Waichler et al. (2004) estimated that recharge from the Greater Cold Creek watershed ranged from 0.47 Mm^3/yr to 13.3 Mm^3/yr. How such events contribute to groundwater movement is not well understood. Measurements of upland fluxes recharging the groundwater are severely limited; to date, groundwater assessments rely on a groundwater inverse calibration procedure to estimate the incoming fluxes.

5.1.15 Lysimetry

Lysimeters directly measure drainage precisely and accurately. However, the representativeness of this measurement is limited to the extent that these devices experience different soil water dynamics by altering temperature, airflow, and boundary conditions compared to an undisturbed and unrestricted soil column. If a lysimeter test is not carefully designed, the test results could be affected. For example, shallow lysimeters and WFMs create boundary conditions within the evapotranspiration zone that increase evaporation above what occurs in undisturbed soil, and thus reduce recharge in comparison. Deep lysimeters are preferred to shallow lysimeters for this reason. Another example is the effect that lysimeters have on airflow and temperature inside the lysimeter (compared to outside the lysimeter). This effect is likely not noticeable at high recharge rates but could be significant when rates are very low (e.g., less than 1 mm/yr).

5.1.16 Spatial Extrapolation of Recharge Dependence on Hydraulic Property Data

In the recharge map prepared by Fayer and Walters (1995), recharge rates for nearly 60% of the Hanford Site area were represented using simulation results. The hydraulic properties used in those simulations were derived from data based on borehole samples and re-packed samples because *in situ* measurements of soil hydraulic properties for each soil type were not (and still are not) available.

5.1.17 Temperature Effects

Recharge rates within and around tank farms will be spatially dependent on the proximity of a tank, the tank temperature history, and the depth and makeup of the surface cover. Temperature effects are most important to estimating recharge rates during the operation period. Very little has been done to quantify the impact of elevated temperatures on recharge in tank farms.

5.1.18 Anomalous Groundwater Mound North of Gable Mountain

The unusual and persistent groundwater mound on the north side of Gable Mountain is perplexing. Several causes have been proposed, one of which is enhanced recharge, either directly or from upslope. Further characterization of recharge in this area, together with characterization of recharge on basalt outcrops as discussed earlier, is needed to explain this groundwater anomaly.

5.2 Recommendations for Addressing Knowledge Gaps

Clearly, continued field measurement at instrumented sites, such as presented in Section 4 of this compendium, are central to resolving many of the knowledge gaps discussed above. Particularly because recharge is highly episodic in arid climates such as that found at Hanford, a long-term record at well instrumented field investigation sites is crucial to characterizing recharge at time scales of interest for issues concerning radioactive and chemical waste fate and transport at the Hanford Site.

Beyond continued measurement at these instrumented sites, several obvious recommendations flow from the discussion of knowledge gaps above, including:

- Characterization of soil thickness variability on Gable Mountain should be undertaken to reduce the knowledge gap with respect to recharge over basalt outcrops at the Hanford Site
- Effort would be wisely expended to update maps of soils, vegetation, and land use at Hanford, which would be an important basis for spatial extrapolation of point recharge measurements and estimates to other Hanford locations
- Study of recharge for roadways, parking lots, and buildings would be valuable to characterize these spatially limited, but potentially high-recharge and thus important land covers
- A coherent and consistent framework is needed that describes the climate, vegetation, and animal changes expected at the Hanford Site for as long as the Site is considered a risk
- Improved characterization of gravel surface covers, and their expected transformation with time, would be very useful
- More in situ and other measurement of recharge in natural, undisturbed soils is needed especially for Rupert sand, Ephrata sandy loam, and Burbank loamy sand
- More data need to be collected on recharge in revegetated, disturbed conditions
- Consensus has not been reached on how surface infiltration barriers will degrade/evolve over time; additional research is needed to narrow concerns in this area
- All recharge questions would be served by additional understanding of sensitivity and uncertainty aspects
- To improve groundwater flow modeling at the Hanford Site, additional investigation of recharge in upland areas (rather than focus only on waste discharge and disposal locations) is needed
- Investigation of recharge in the area of the anomalous groundwater mound north of Gable Mountain would be immensely useful to ascertaining the cause of this anomaly and thereby improving groundwater flow and transport models for the Hanford Site

There remain many opportunities to improve measurement and estimation of this important parameter that need to be pursued wherever possible.

6 Conclusions

The importance of recharge and available measurement techniques were presented. Data collected at several recharge measurement sites in FY 2004 through 2008 are presented and discussed. These data are available for use in refining and improving recharge rate estimates for soils of the Hanford Site, with emphasis on the soils of the Central Plateau. Critical gaps in the knowledge of recharge at the Hanford Site were presented. These listed gaps serve as a guide to assist in prioritizing future Hanford recharge work towards developing more defensible recharge estimates.

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