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Monitoring the Prototype Hanford Barrier – Fiscal Year 2018 Report

September 2018

ZF Zhang
JN Thomle
RE Clayton
SF Harding
GL Dai

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

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Executive Summary

After a decade of development activities from 1983 to 1993, the 2.5-ha (6.2-acre) Prototype Hanford Barrier (PHB) was constructed between late 1993 and 1994 over the 216-B-57 Crib in the 200 East Area (46°34'01.23"N, 119°32'28.43"W) at the Hanford Site in southeastern Washington State. The PHB construction was part of a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) treatability test of barrier performance for the 200-BP-1 Operable Unit. The CERCLA treatability test was an enhanced precipitation stress test from water year 1995 (WY95) to WY97 to determine barrier response to extreme precipitation events. A controlled fire test was conducted in 2008 to examine the recovery of vegetation under the natural condition and the performance of the barrier with limited vegetation.

The barrier was monitored extensively between November 1994 and September 1998 to evaluate surface-barrier hydrologic, ecological, and structural performance at the field scale. From fiscal year 1998 (FY98) to present (with monitoring gaps), monitoring focused on a more limited set of water balance, stability, and biotic parameters to evaluate the barrier's hydrologic, structural, and ecological performance. The design, test, and performance of the PHB until 2013 are summarized in DOE-RL (2016) and the monitoring in FY17 is summarized in Zhang et al. (2018).

In FY18, the water content in the silt loam was measured on an approximate quarterly basis. The drainage and the runoff monitoring systems were revamped using a double-tipping-bucket system. The surface barrier structural stability (including surface elevation, barrier settlement, and riprap side slope stability) and ecological surveys (including animal activities, plant floristics, plant cover, and shrub canopy) were also completed. The data collected to date continue to demonstrate that the PHB has performed well since its inception. Water content measurements indicate that there was near zero mobile water content in the barrier. Structural measurements show no indication of wind- or water-caused soil erosion, nor any measurable differences in elevation between 2012 and 2018.

Extensive monitoring of the PHB has continued to present day to obtain first-of-its-kind, long-term performance data. Although continued performance monitoring is needed, integration of more autonomous measurement methods is needed to reduce costs associated with long-term monitoring of the PHB and future surface barriers needed for waste site closure. Geophysical methods are recommended for implementation in FY19.

References

DOE-RL. 2016. *Prototype Hanford Barrier 1994 to 2015*, DOE/RL-2016-37, Rev. 0, U.S. Department of Energy, Richland Operations Office. Richland, WA. Available at http://www.hanford.gov/c.cfm/sgrp/DOE-RL-2016-37/DOE-RL-2016-37_R0.pdf and http://www.hanford.gov/c.cfm/sgrp/DOE-RL-2016-37/Appendices.pdf (Accessed on August 30, 2018).

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Acronyms and Abbreviations

AC	asphalt concrete
CB	capillary break
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CG	creep gauge
CV	coefficient of variation
DOE	U.S. Department of Energy
DTB	double-tipping-bucket
EDM	electronic distance measurement
ET	evapotranspiration
ETC	evapotranspiration-capillary
ETR	combined evapotranspiration and runoff/run-on
FY	fiscal year
HEIS	Hanford Electronic Information System
HMS	Hanford Meteorological Station
NQAP	Nuclear Quality Assurance Program
PHB	Prototype Hanford Barrier
PVC	polyvinyl chloride
RMSE	root mean squared error
SPI	standardized precipitation index
TB	tipping bucket
WY	water year

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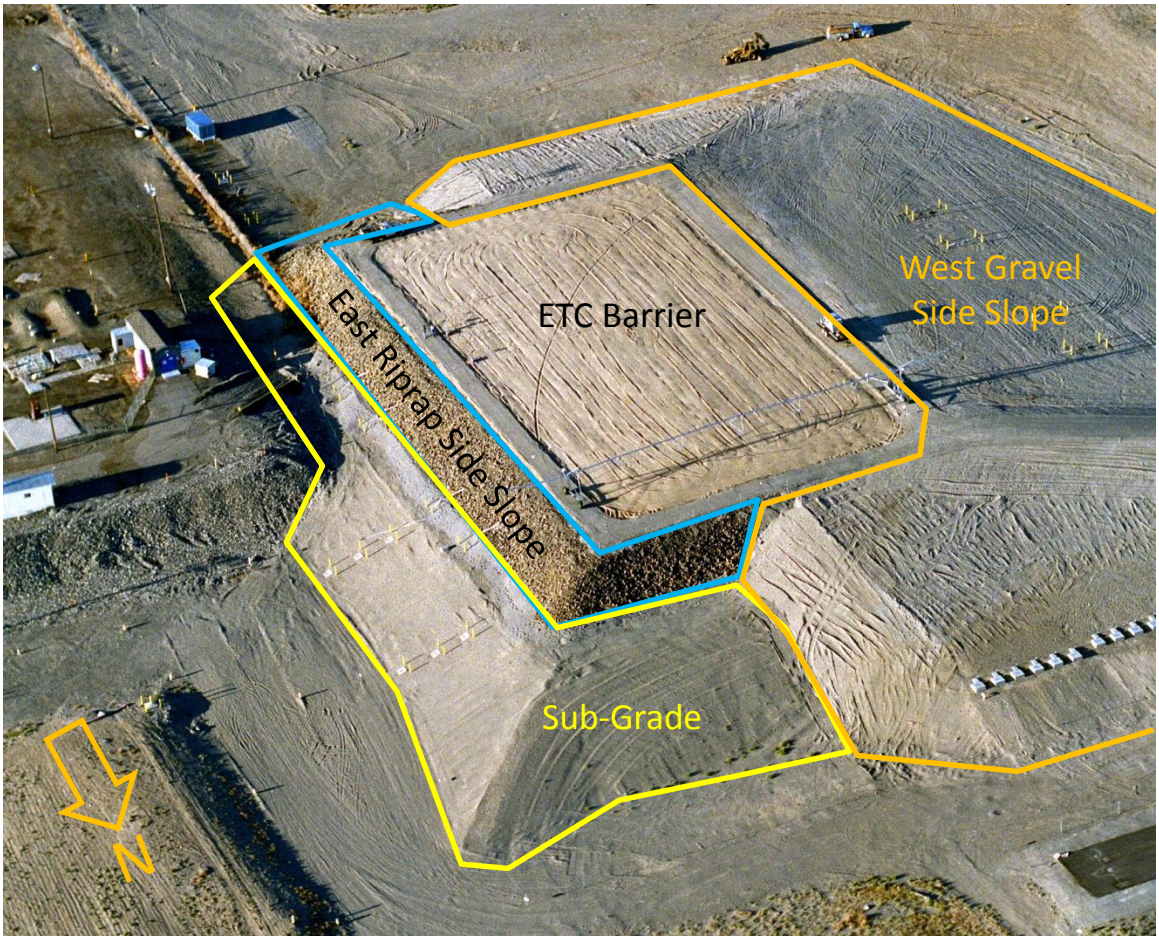
1.0 Introduction

1.1 Background

After a decade of development activities from 1983 to 1993, the 2.5-ha (6.2-acre) Prototype Hanford Barrier (PHB, Figure 1.1) was constructed between late 1993 and 1994 over the 216-B-57 Crib in the 200 East Area (46°34'01.23"N, 119°32'28.43"W) at the Hanford Site in southeastern Washington State as part of a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) treatability test of barrier performance for the 200-BP-1 Operable Unit (DOE-RL 2016). The CERCLA treatability test included an enhanced precipitation stress test during water year 1995 (WY95) to WY97 to determine barrier response to extreme precipitation events and a controlled fire test in 2008 to examine the recovery of vegetation under the natural condition and the performance of the barrier with limited vegetation. The barrier was monitored extensively between November 1994 and September 1998 to evaluate surface-barrier hydrologic, ecological, and structural performance at the field scale. From fiscal year 1998 (FY98) to present (with monitoring gaps), monitoring focused on a more limited set of water balance, stability, and biotic parameters to evaluate the barrier's hydrologic, structural, and ecological performance.



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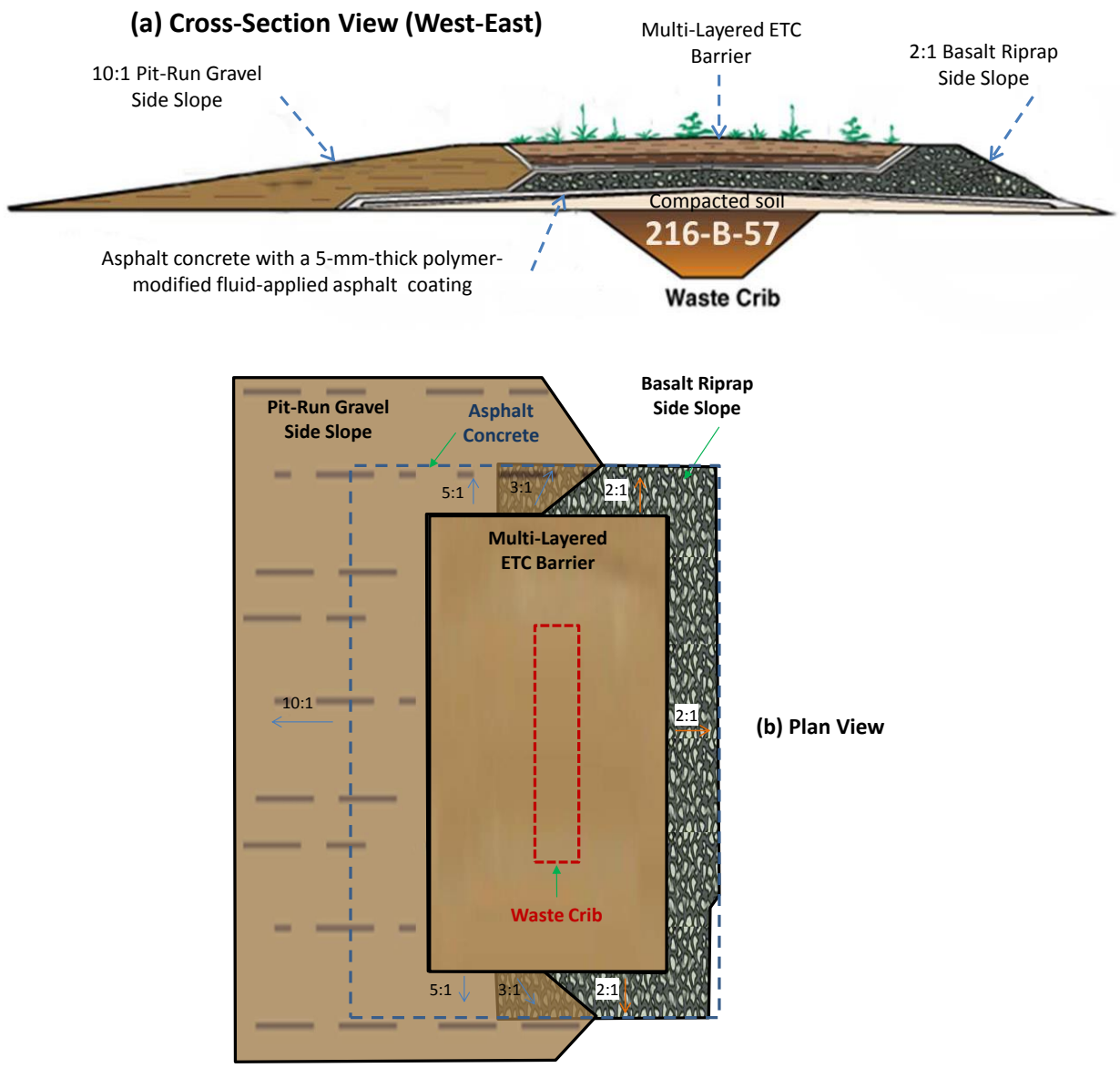


Figure 1.2. Schematic of the PHB: (a) cross-section view (west-east) and (b) plan view (approximate scale).

The PHB consists of four main components (Figure 1.2): (1) An evapotranspiration-capillary (ETC) barrier that consists of a silt loam evapotranspiration (ET) layer and an underlying capillary break (CB) consisting of gravels grading into large basalt, which is intended to prevent intrusion; (2) an asphalt concrete (AC) barrier with a polymer-modified fluid applied asphalt coating and a compacted soil layer beneath it; (3) a gentle pit-run gravel side slope in the west (10:1); and (4) a steep basalt riprap side slope in the east (2:1). The ETC barrier is the portion of the PHB that sits directly above but is larger than the waste zone. The role of the ETC barrier is to store precipitation and release the stored water into the atmosphere and to deter intrusion from the barrier surface by plants, animals, and humans. The AC barrier diverts drainage (if any) and hinders intrusion, and thus acts as a backup to the ETC barrier should the functionality of the latter be compromised. The two side slopes maintain barrier stability so that the ETC barrier remains intact and retains its functionality.

1.2 PHB Performance from 1994 to 2017

The design, test, and performance of the PHB until 2015 are summarized in DOE-RL (2016) based on a comprehensive review and analysis of the data collected at the site and the performance in FY17 in Zhang et al. (2018). The information in DOE-RL (2016) has also been published in several peer-reviewed journal papers. Zhang (2015) analyzed the field water retention of the silt loam layer at four depths and 12 water balance stations using in situ measurements of water content and pressure from 1995 to 2003. In Zhang (2017a), the drainage from the riprap side slope was evaluated with respect to the influence of the side slopes on the effectiveness of a long-term barrier. Zhang et al. (2017) discussed the surface-barrier design and performance of the PHB under conditions of enhanced and natural precipitation and no vegetation. Zhang (2017b) concluded that the count-based calibration of a neutron probe, which was used at the PHB, is appropriate and sometimes even better than ratio-based calibration. The main findings with respect to the performance of the barrier components are as follows:

- The ETC barrier of the PHB performed much better than the drainage design goal of 0.5 mm yr^{-1}.
  - During each winter season, the silt loam layer was recharged by precipitation. The CB considerably enhanced the barrier's storage capacity.
  - During each summer season, all of the summer precipitation and nearly all of the stored water from the winter season was returned to the atmosphere by ET. These seasonal observations were consistent year to year.
  - After the controlled fire test on the northern half of the PHB in September 2008, significantly less vegetation re-established in the burned section of the PHB than in the unburned section. The re-established grasses still removed nearly all the stored water in the burned section, but at a slower rate than in the unburned section, which had fully grown shrubs.
  - No detectable settlement or compression of the ETC barrier occurred.
  - The number and sizes of animal holes on the barrier surface were small and did not discernibly affect barrier function.
- Both side slopes remained stable and well-drained.
- The AC barrier remained stable and allowed negligible water percolation.

In summary, from 1994 to 2017—during which time the barrier experienced 3 years of enhanced precipitation, three 1000-year return, 24-hour simulated rainstorms, and a controlled fire—the monitoring data demonstrate that the barrier satisfied nearly all objectives in the past two decades. The PHB far exceeded the *Resource Conservation and Recovery Act* criteria, functioned in Hanford's semiarid climate, limited drainage to well below the 0.5 mm yr^{-1} performance criterion, limited runoff, and minimized erosion and bio-intrusion.

1.3 Long-Term Barrier Monitoring Strategy

One of the challenges facing deployment of surface barriers is convincing stakeholders that the technology will be effective and long-lasting. A longer period of performance monitoring will help to address this challenge. Hence, DOE-RL (2016) recommended the continuation of the barrier monitoring for several reasons:

- The two-decade monitoring period accounts for only 2% of the 1000-year design life. Extrapolation of past performance into the far future is subject to significant uncertainty, including the possible effects of climate change.

- Extreme events happen very infrequently, perhaps on time scales of decades or longer. Extending the monitoring period increases the likelihood that extreme events will occur and barrier performance will be observed under those conditions.
- The vegetation on the north section of the PHB was still dominated by the shallow-rooted grasses 4 years after the controlled burn. Precipitation levels during this period were normal and were never high enough to stress the barrier. Extending the monitoring period allows for more-complete observation of vegetation recovery and PHB performance.

DOE-RL (2016) recommended structural and ecological monitoring commence as soon as possible because the last structural monitoring was in FY12 and the last ecological monitoring was in 2011. In the future, the frequency of both activities will be approximately once every 5 years. This frequency is less than in the past because, based on past behavior, the barrier structure and ecological state are not expected to change substantially in a few years. Stability and ecological monitoring were conducted in FY18. The monitoring activities conducted in the past, those conducted in FY17 and FY18, and those planned for the future are listed in Table 1.1.

Barrier performance has historically been based on deep drainage. Although this has been an effective measure for verifying barrier performance for the PHB long-term treatability study, the equipment and labor costs are high relative to more autonomous methods that can be used to measure surrogate data as indicators of performance. With the completion of the stability and ecological surveys, barrier monitoring in FY19 will investigate geophysical methods that can be used to monitor barrier performance. Such methods will significantly reduce the costs associated with the PHB monitoring, and will subsequently translate into a cost savings for future barriers as well.

1.4 Scope of the Report

Section 2 describes the monitoring system, including monitoring plots and stations, monitoring methods, and instrument calibration. Section 3 presents the monitoring methods and Section 3 summarizes the monitoring results until July of FY18. The quality reviews for the ecological and drainage data collected in the final quarter of FY18 have not yet been completed and are not included in this report. Once the data qualification is complete, a revision of this report will be issued in FY19. The main findings are summarized in Section 4. Section 5 describes the quality assurance program.

Table 1.1. Past, FY17, and Future Monitoring Components at the Prototype Hanford Barrier

Monitoring Purpose	Monitoring Components	Methods	FY95 to FY13	FY17	FY18	Future[(a)]
Hydrology – Primary	Precipitation	Mini-lysimeters	x			
	Surface runoff and erosion	Runoff flume	x			x
	Water content profile	Neutron probe	x	x	x	x
	Drainage off the asphalt concrete	Drainage vaults	x		x	x
Hydrology – Secondary	Water content at the bottom of the silt loam and beneath the asphalt layer	Neutron probe	x	x	x	x
	Soil water pressure and temperature	Heat dissipation units	x			
	Soil water pressure	Fiberglass blocks	x			
Structural Stability	Barrier settlement	Settlement markers	x		x	x
	Barrier elevation	Elevation markers	x		x	x
	Riprap side slope stability	Creep gauges	x		x	x
	Wind erosion	Wind stations	x			
	Overall barrier conditions	Aerial photos	x			x
Ecological Monitoring	Vegetation characteristics (i.e., floristics composition, plant cover and spatial distribution, plant height, and canopy characteristics)	Field survey	x		x	x
	Gas exchange rate, roots, shrub survivorship, reproduction, and xylem pressure potential	A variety of methods	x			
	Animal activities	Surface inspection, measurement of the counts and dimension of animal burrows, and direct observation using traps	x		x	x

(a) The future monitoring items are subject to change.

2.0 Monitoring Methods and Activities

This section describes the monitoring methods and the results of instrument calibration.

2.1 Hydrological Monitoring

2.1.1 Monitoring Plots and Stations

The PHB was divided into 12 monitoring plots to address the spatial variability of water balance and hydrologic processes when the PHB was constructed in 1994. Figure 2.1 shows the plots, which are denoted as 1W through 6W for those located in the west half and 1E through 6E in the east half. The 12 plots represent three main types of barrier structure:

1. Silt loam plots: 3W, 3E, 6W, and 6E
2. Side slope plots:
    a. 1W and 4W for the west gravel side slope
    b. 1E and 4E for the east riprap side slope
3. Transitional or silt loam boundary plots: 2W, 2E, 5W, and 5E

Not all of the components were monitored in all of the plots, depending on the primary hydrological processes and the function of the components. Each of the 12 curbed zones collected water beneath the plot, which was discharged to a concrete vault. Each collection zone with a vault is equivalent to a drainage lysimeter. The vaults were installed to the north and downgradient from the AC to allow the movement of water by gravity.

2.1.2 Water Content and Storage

<u>Water Content and Storage in the ETC Barrier</u>

For water balance, the focus was on the silt loam, which serves as the media for water storage and vegetation growth. The riprap side slope has very little water storage capacity and the gravel side slope has some water storage capacity. Fourteen monitoring stations, denoted as S1 through S14 (Figure 2.1), were established. Twelve of the fourteen monitoring stations were installed in the four silt loam plots (Figure 2.1)—three stations each in 6W and 6E in the north section and 3W and 3E in the south section—to allow the water processes and balance of these plots to be thoroughly evaluated. Two stations were installed in the two gravel plots, i.e., 1W and 4W, respectively, at the west side slope. There was no water balance monitoring of the east riprap side slope or the four small transition plots because the riprap has little water-holding capacity and the transition plots are less important than others.

Soil water content (θ) was measured using a neutron probe (CPN 503DR Hydroprobe, S/N 50200; Probe 50200). The neutron probe was calibrated in the silt loam for the 2- and 3-inch aluminum access tubes during the period between February and September 2017. The regression relationship between the 16-sec neutron count (N_{16}) and the volumetric water content is:

2-inch Tube $$\theta = -0.0481 + 3.1117 \times 10^{-5} N_{16} \qquad r^2 = 0.9921 \tag{2.1}$$

3-inch Tube $$\theta = -0.0467 + 3.3992 \times 10^{-5} N_{16} \qquad r^2 = 0.9892 \tag{2.2}$$

Neutron loggings were conducted at 13 depths over the 0.15 m to 1.90 m depth interval. The interval between adjacent logging depths was 0.15 m between the 0.15 and 1.80 m depths, and 0.10 m between the 1.80 and 1.90 m depths. Neutron loggings were converted water content using Eq. (2.1). The water storage in the 2-m silt loam (W, in units of mm) is calculated by

$$W = 225\theta_1 + 150\sum_{j=2}^{11}\theta_j + 125\theta_{12} + 150\theta_{13} \tag{2.3}$$

with index j = 1 through 13 corresponding to the 13 logging depths.

Water Content at the Bottom of ETC Barrier and below the Asphalt Layer

Water content of the soil 0.15 m above the bottom of the silt loam storage zone was monitored with eight horizontally oriented neutron probe access tubes (AA1 through AA8 in Figure 2.2) to examine how the side boundaries and the CB at the bottom affected water movement. Water content beneath the AC was monitored with six horizontally oriented neutron probe access tubes (BA1 through BA6 in Figure 2.2) installed at depths of 1, 2, and 3 m below the AC. Neutron loggings were converted water content using Eq. (2.2).

In FY18, neutron probe logging was conducted on an approximate quarterly basis in the silt loam and semi-annually in the sand below the PHB. The functionality of the neutron probe was verified on each logging day before and after the logging.

The logging scheme used in FY18 was the same as that used in FY17. The logging was repeated four times on each logging day. The horizontal neutron loggings were extended to the side slopes so that the edge effect could be revealed more clearly. The logging scheme with four repetitions provides an opportunity to exclude an outlier from the repetitions. A value that differs by about 400 counts (0.012-0.014 m^3m^{-3}) or more for Probe 50200 may be considered as an outlier. Repetitions also provide reassurance when unexpected field conditions occur (e.g., very wet or dry condition at just one location).

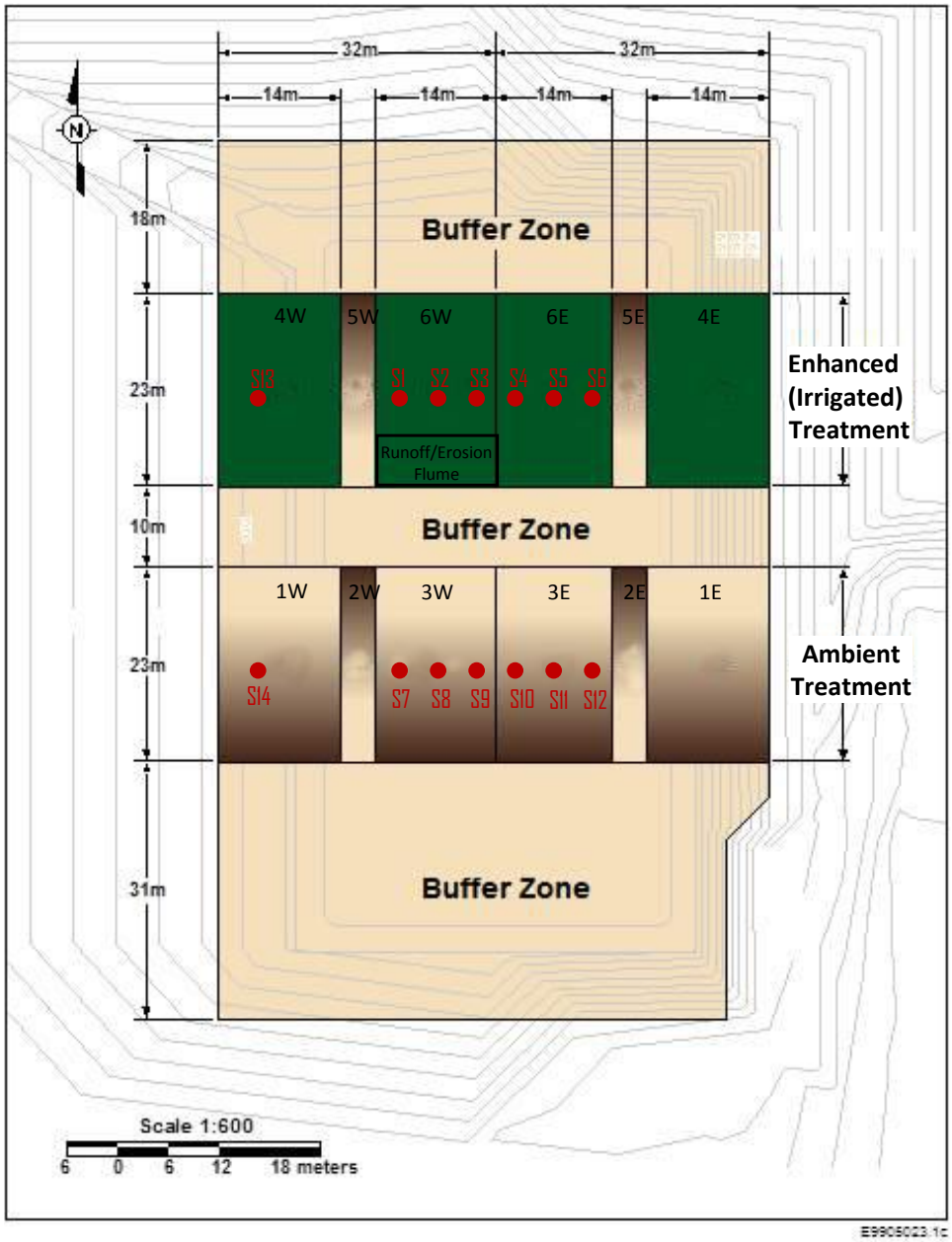


Figure 2.1. Plan view of the Prototype Hanford Barrier showing the 14 water balance monitoring stations (marked as S1 through S14), 12 plots for drainage monitoring (marked as 1W through 6W and 1E through 6E), and the runoff/erosion flume.

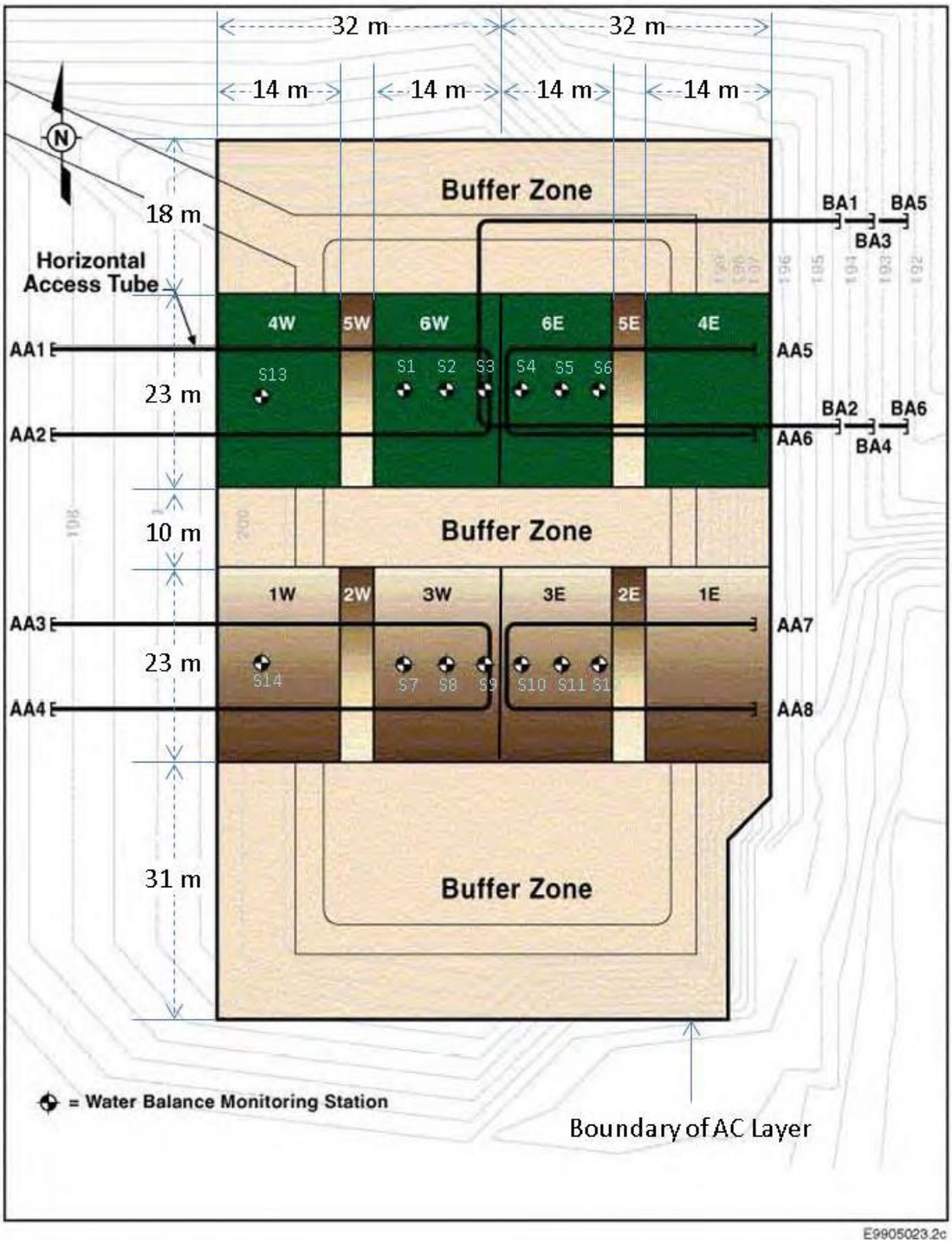


Figure 2.2. The horizontal neutron probe access tubes shown by the U-shaped lines. Tubes AA1 through AA8 are located near the bottom of the silt loam, slightly above the silt-sand interface. Tubes BA1 and BA2 are 1 m below the asphalt concrete, BA3 and BA4 are 2 m below, and BA5 and BA6 are 3 m below.

2.1.3 Drainage Monitoring

Within each of the 12 drainage vaults, the old drainage measurement system [which included a tipping bucket (TB), a pressure transducer, and a dosing siphon] was removed in FY17 (except the bottom portion of the dosing siphon that was partially buried in concrete). This system was replaced with a double-tipping-bucket (DTB) measuring system (Figure 2.3). The DTB system is composed of one small Pronamic Rain-O-Matic Small PCB 9602 TB (Pronamic APS, Ringkobin, Denmark) sitting above a large HS TB6/40 (Hyquest Solutions P/L, Liverpool, NSW, Australia) TB. Drainage from each monitored plot flows first through the small TB and then the large TB and hence is measured twice. The drainage water then flows out of the vault through a hole on the existing pipe of the old siphon system.

The DTB system is used for two reasons. First, the flow rates are highly variable both seasonally and between plots and they range over several orders of magnitude. The maximum flow rate ever recorded at the PHB was 4.4 L min^{-1}, which occurred from the riprap side slope plot 4E on March 28, 1997, after 69.7 mm of water were applied over an 8-hour period 1 day earlier. The maximum flow rate recorded at the PHB during the period without irrigation (FY99-FY13) was 0.5 L min^{-1}, which occurred from the riprap side slope plot 1E on January 30, 2004. Hence, it is expected that the upper bound of flow rate should be close to 0.5 L min^{-1} under the natural precipitation condition. The lower and upper bounds of the flow rates measurable with the small TB are roughly one order of magnitude less than those of the large TB. The maximum flow rate of the small TB is approximately 0.5[1] L min^{-1} (0.09 mm hr^{-1} for the full plots; 0.33 mm hr^{-1} for the transitional plots) and that for the large TB is 3[2] L min^{-1} (0.56 mm hr^{-1} for the full plots; 1.96 mm hr^{-1} for the full plots). Second, both TBs should function normally under natural precipitation conditions. Data from the two TBs in the same drainage vault can serve as a check of the functionality and accuracy of each other. Another advantage of the DTB system is that it can be removed from the vault for testing, repair, or replacement if it should fail. Currently, no irrigation is planned for this test. If irrigation is applied in the future, the DTB will need to be redesigned if the expected drainage rates exceed 3 L/min.

The 12 assembled DTB systems were installed in the 12 existing drainage vaults, respectively (Figure 2.4) in FY18. The total height of the assembled DTB system is about 5 feet (1.5 m). This height can be adjusted as needed. The system started in operation in early July.

[1] According the datasheet of the Rain-O-Matic Small Rain Gauge, it takes about 255 ms to open and 295 ms to close. This translates to a maximum of 109 tips/min. Because each tip is about 5 ml, the maximum flow rate is estimated to be 545 ml/min.
[2] Per the datasheet of the Tipping Bucket Flow Gauge Model TB6/40.

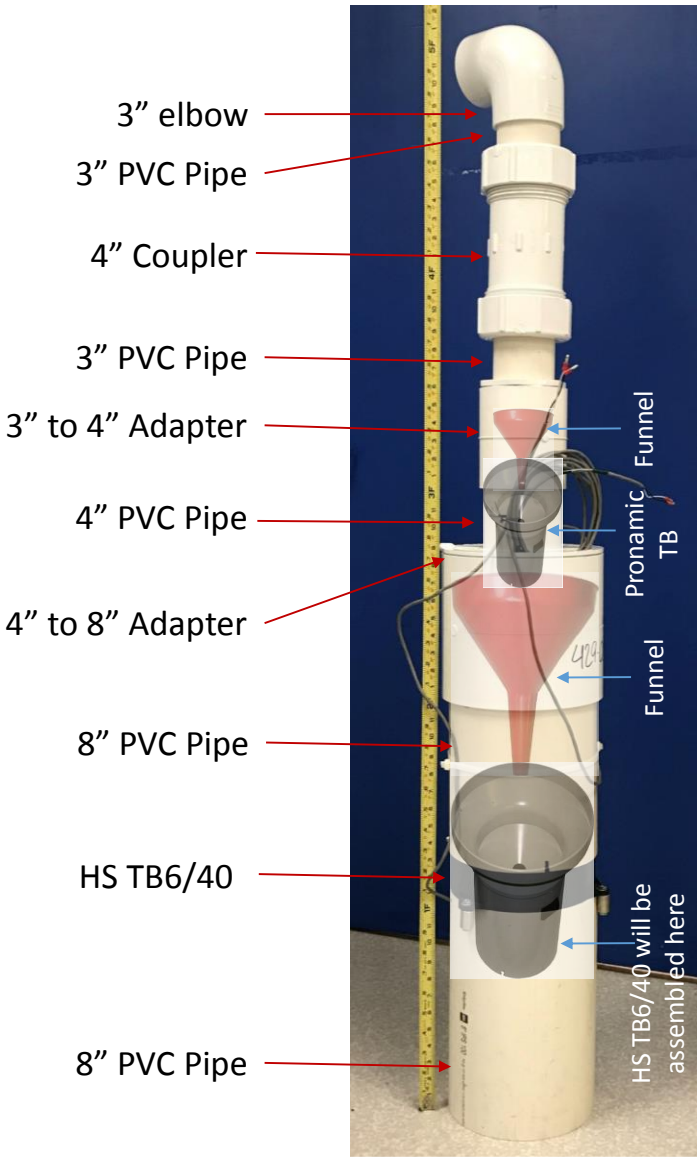


Figure 2.3. The assembled DTB system. The red arrows point to the PVC pipes or adapters. The blue arrows point to the items inside the pipes. The images of the funnels and tipping buckets are not those of the actual items used in the DTB system and are not to scale.

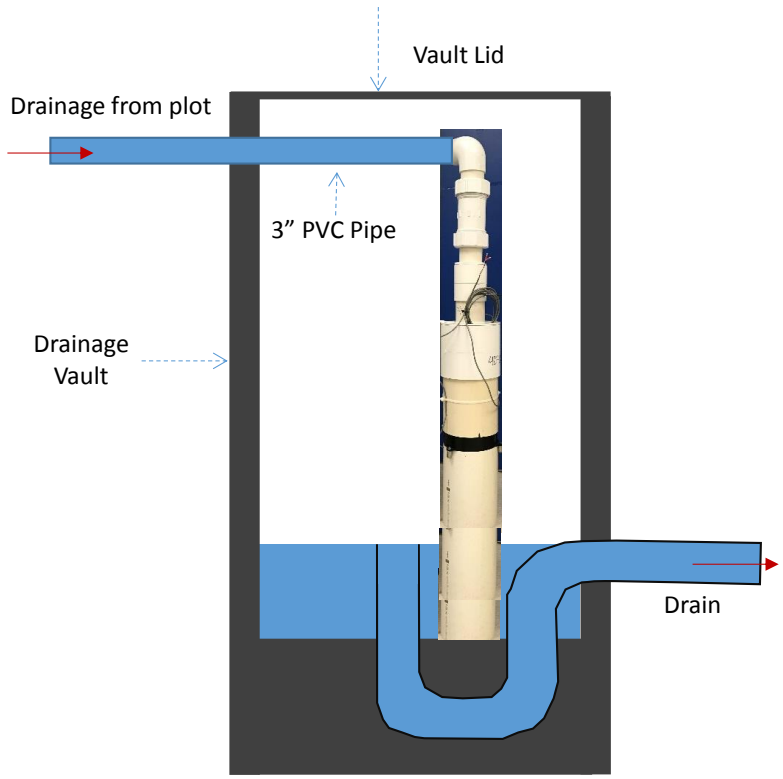


Figure 2.4. Schematic showing the installation of a DTB system in a drainage vault (not to scale).

2.1.4 Runoff

Only one 6-m-wide by 15-m-long runoff plot (Figure 2.1) was established for runoff monitoring because runoff was not expected to be a major component of the water balance, as reported in DOE-RL (2016). If runoff occurred within that plot, it was assumed that the rate would be applicable to the remaining barrier surface. Any short-distance runoff within the ETC barrier can become run-on in a different location within the ETC. This within-the-barrier runoff cannot be detected by the runoff flume.

The runoff monitoring system was revamped in FY18. The old system was replaced by a new system, which consists of a small TB, a large TB, and a 1-gallon plastic vessel (2.5). Two TBs are used so that they can be used to check each other. The plastic container is used to check the occurrence of soil erosion. If soil erosion occurs, the soil particles are expected to be collected in the vessel. Runoff water was allowed to overflow through a hole near the top of the plastic vessel.

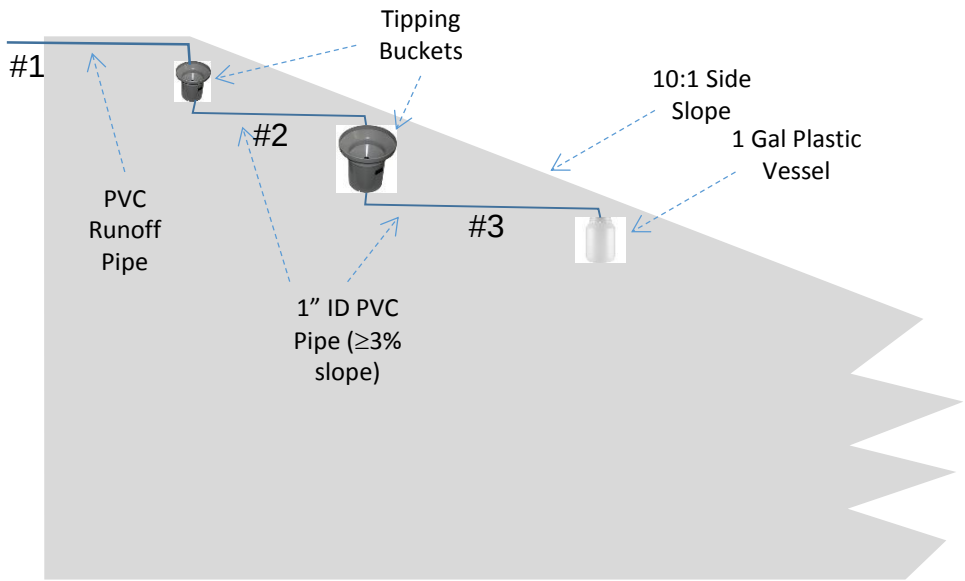


Figure 2.5. Schematic of the runoff measurement system.

2.1.5 Precipitation

Precipitation is not measured on site. The measurement at the nearby Hanford Meteorological Station (HMS) is used in the analysis. The HMS is located near the center of the Hanford Site between the 200 West and 200 East Areas and is about 3 miles west of the PHB.

2.2 Barrier Stability Survey

Structural stability of the PHB was evaluated by measuring the settlement of the subgrade below the AC, elevation change of the barrier surface, and displacement in the riprap side slope.

Subsidence or settling of the AC barrier was quantified by measuring the change in the elevation of settlement markers, DSG1 and DSG2, attached to the AC. These two settlement markers, 14 m apart, were installed at the north end of the barrier during barrier construction (Figure 2.6).

Elevation changes of a barrier surface indicate the inflation or deflation of the barrier as well as subsidence. Elevation surveys were taken at 338 (13 × 26) locations marked by wood stakes, 3 m apart (Figure 2.6).

Because of its steepness (2:1), the riprap slope was considered to have potential for movement. A total of 15 creep gauges (CGs) were installed at 13 locations (Figure 2.6) in the riprap slope during or after barrier construction to monitor slope displacement.

From the start of monitoring in 1994 through 2003, elevation and horizontal locations were measured by an electronic distance measurement (EDM) system. From 2004 to 2018, a real-time-kinematic global positioning system (Trimble Navigation Ltd., Sunnyvale, CA) was used because of a malfunction in the EDM system.

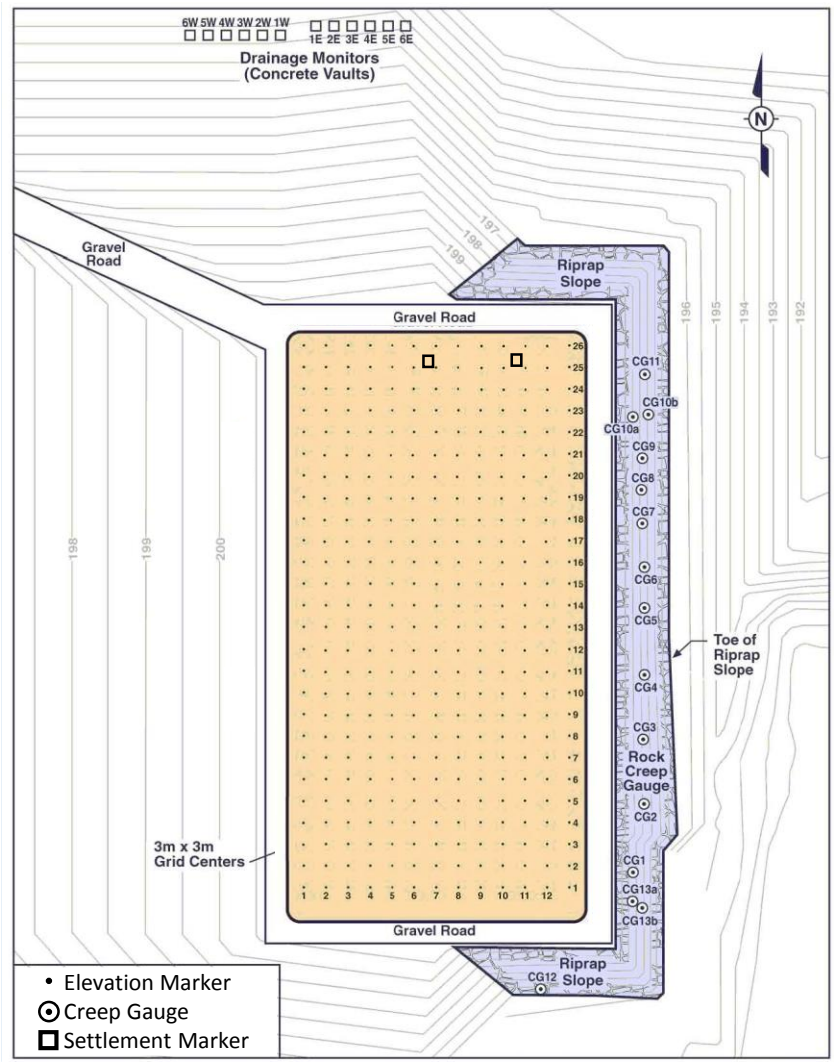


Figure 2.6. Plan view schematic showing the 338 (13×26) elevation markers, 2 settlement markers and 15 creep gauges. The elevation markers also marked the corners of 300 (12×25) quadrats of 3 × 3 m^2.

The brass caps of two boreholes C9549, and C9550 (Figure 2.7) with known coordinates (Table 2.1) were used to verify the accuracy of the GPS system before and after measurements were taken. The elevation at all the points was determined relative to monument 2E-122. All of these brass caps are known locations of borings managed in the Hanford Electronic Information System (HEIS[1]). These points were obtained using the NAD83 horizontal datum and the survey system was verified each logging day before and after the survey by taking observations at known locations (C9549). The error between the pre- and post-survey values within 1 day should be no more than 0.05 m horizontal distance and 0.01 m elevation.

At each of the survey locations, a 2”×2”×0.5” (length × width × height) flat rigid plate with a small hole in the center was placed at the north side of the survey marker. The sharp point of the rover rod was kept in the hole of the flat plate so the rover rod did not penetrate into the ground surface. The size of the hole was optimized so that the tip of the rover rod was flush with the bottom of the plate to keep from adding

[1] https://ehs.hanford.gov/eda/

to the elevation from the thickness of the plate. Four 30-sec GPS measurements were taken at each of the survey point.

Table 2.1. Known Brass Cap locations from HEIS and monument location from previous surveys.

Well ID	E HEIS (m)	N HEIS (m)	Elev. HEIS (m)	Use
C9550	573549.49	137719.05	190.18	Base Station
2E-122	573386.802	137699.717	191.686	Ref Monument
C9549	573663.52	137697.13	189.61	QA Verification

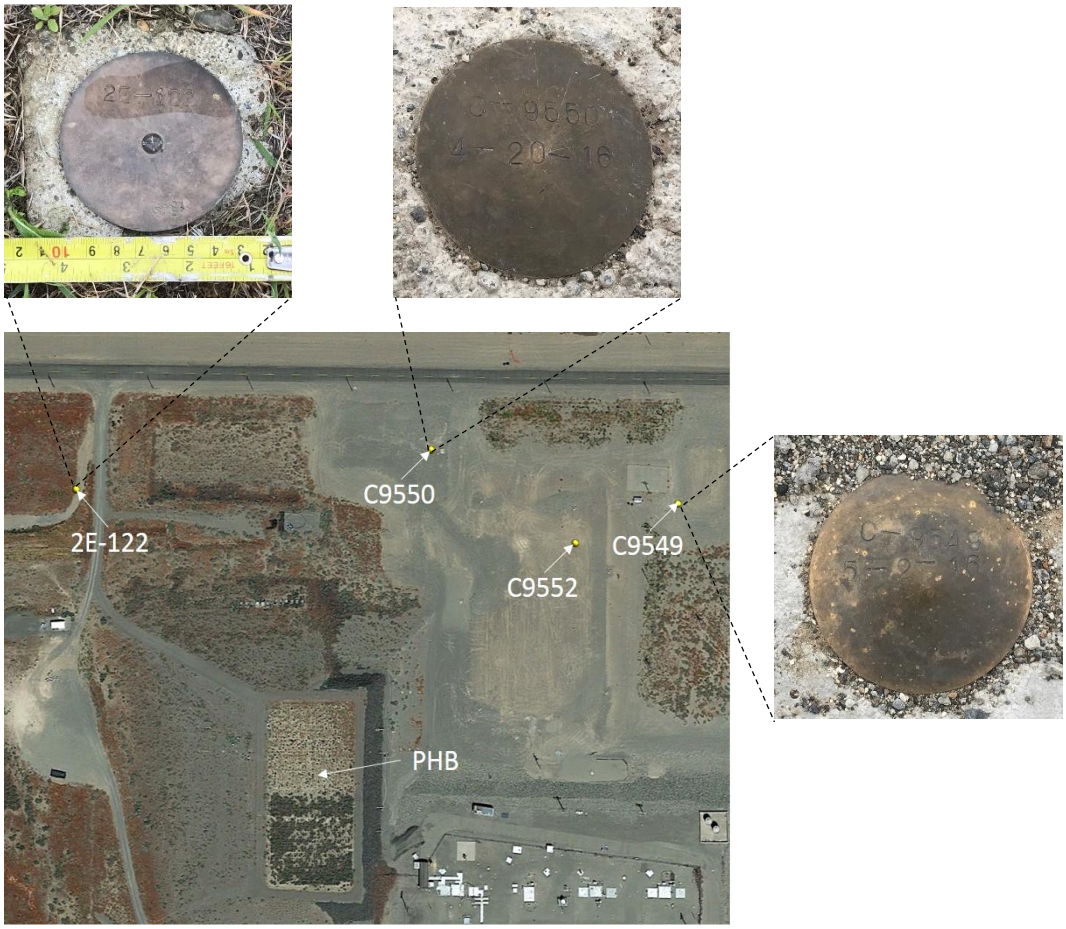


Figure 2.7. Brass cap monuments and their location as provided by the Hanford Environmental Information System (HEIS) and previous surveys.

2.3 Ecological Survey

Ecology monitoring, which consisted of observing and recording the characteristics of vegetation and animal activities, was conducted in FY18.

The primary variables monitored included species composition, canopy dimension, and plan cover. Most of the vegetation characteristics were measured on 300 quadrats of 3×3 m^2 (Figure 2.6) and selected area in the west and north side slopes.

Animal activities were monitored in the 300 quadrats by examining animal evidence on the barrier surface and intrusion (burrowing) by insects and mammals. Evidence of animal use included the presence of droppings, tracks, nests, burrows, resting spots, and gall formation. Animal hole or burrow dimensions were measured manually during ecological surveys.

3.0 Monitoring Results

This section presents the climate conditions, the hydrological monitoring results through June 2018, and the barrier structural stability survey results. The FY17 report (Zhang et al. 2018) presented the monitoring results through September 2017. The PHB hydrology in this report covers the period from September 2017 to June 2018.

3.1 Climate Conditions

Precipitation was categorized with the standardized precipitation index (SPI) developed by McKee et al. (1993). The SPI is a probability index defined as the standard normal random variable (with mean $\mu = 0$ and standard deviation $\sigma = 1$) obtained from the cumulative probability. The nature of the SPI allows the quantification of an anomalously dry or wet event at a particular time (t) scale. According to the SPI values, McKee et al. (1995) categorized the precipitation of a given period into seven classes:

1. extreme wet (SPI > 2)
2. severe wet (1.5 < SPI ≤ 2)
3. moderate wet (1 < SPI ≤ 1.5)
4. near normal (-1 < SPI ≤ 1)
5. moderate dry (-1.5 < SPI ≤ -1)
6. severe dry (-1 < SPI ≤ -1.5) and
7. extreme dry (SPI ≤ -2)

The Hanford Site has a steppe (semi-arid) climate with typical dry hot summers and cool wet winters (Hoitink et al. 2005). Under the Hanford climate, the most likely season for recharge is between November and March (termed the winter season), when ET is low (Gee et al. 1992; Gee et al. 2005). In addition to winter rains, snowmelt can be an important contributor to recharge. To be consistent with the precipitation pattern, a water year (WY) is defined as the 12-month period from November of the previous year to October of the current year. As such, a WY consists of a 5-month winter season and a 7-month summer season.

The WY meteoric precipitation at the Hanford Site has an average, P^{avg}, of 171.9 mm (WY48 to WY17) and varies from 101.3 to 293.6 mm. On average, 58.8% (101.2 mm) of the precipitation falls in the winter season and 41.2% (70.8 mm) falls in the summer season. The average snowfall for the past 62 years (1946-2017) with records is 361 mm. The maximum ever recorded in one winter was 1424.9 mm, which fell in the winter of 1992-1993. The monthly precipitation from September 2017 to June 2018 and the multi-year (WY48-WY17) average are shown in Figure 3.1.

Based on the monitoring data from WY95 to WY13 (DOE-RL 2016), winter-season precipitation has the greatest potential to increase ETC barrier water storage, which could potentially lead to drainage if the soil water storage is above the storage capacity. In WY18, the winter-season (November to March) precipitation was 95.3 mm, which corresponded to an SPI of -0.025 and was categorized as “near normal.”

In WY18, the first snowfall was on November 5, 2017, and the last was on February 23, 2018, for a period of 110 days. During this period, the total snowfall was 173 mm, which is about half of the average snowfall of 361 mm.

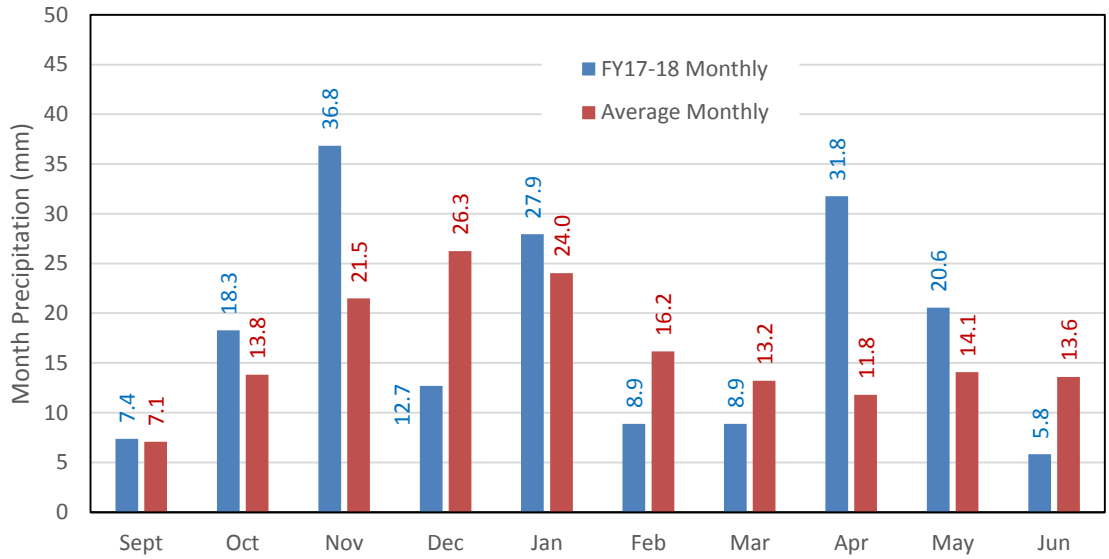


Figure 3.1. Monthly precipitation from September 2017 to June 2018 and multi-year (WY48-WY17) average.

3.2 Barrier Hydrology

3.2.1 Repeatability of Neutron Loggings

Based on the four repetitions of neutron loggings, the root mean squared error (RMSE) of water content measurements and calculated 2-m water storage was calculated. The average value of the RMSE of water content was 0.0014 m^3m^{-3} and the corresponding coefficient of variation (CV) was 2.3%; the RMSE of the 2-m water storage was 0.78 mm and the corresponding CV was 0.6%. These very small RMSE and CV values indicate that the neutron loggings had very high precision in water content loggings.

3.2.2 Soil Water Process in the Silt Loam Storage Layer

Figure 3.2 shows the neutron-probe-measured soil moisture profiles for the 12 monitoring stations in the ETC barrier. Figure 3.3 shows the soil moisture contour of the north (S1 through S6) and south (S7 through S12) cross-sections in the ETC barrier. In September 2017 (Figure 3.2a, Figure 3.3a), the entire soil profile had very low water content (<0.07 m^3m^{-3}), which was slightly (approximately 0.01 m^3m^{-3}) higher than the residual water content. This was because the stored water had been removed by transpiration or evaporation in the previous summer. The soil water content at 0.15-m depth was between 0 and 0.02 m^3m^{-3}, indicating that some residual water was removed from surface soil, probably by evaporation during the hot summer.

The precipitation during the winter season of WY18 recharged the ETC barrier (Figure 3.2b, Figure 3.2c; Figure 3.3b, Figure 3.3c). In late March of 2018, which was about the wettest time of the year, the wetting front depth was approximately 0.8 m among the 12 monitoring stations. Infiltration water had not reached the bottom of the ETC barrier at any of the monitoring stations. By June 2018 (Figure 3.2d, Figure 3.3d), the majority of the stored water in the soil had been released back to the atmosphere by ET. The soil water content was no more than 0.08 m^3m^{-3} for all the stations, which is approximately 0.02 m^3m^{-3} higher than the residual water content.

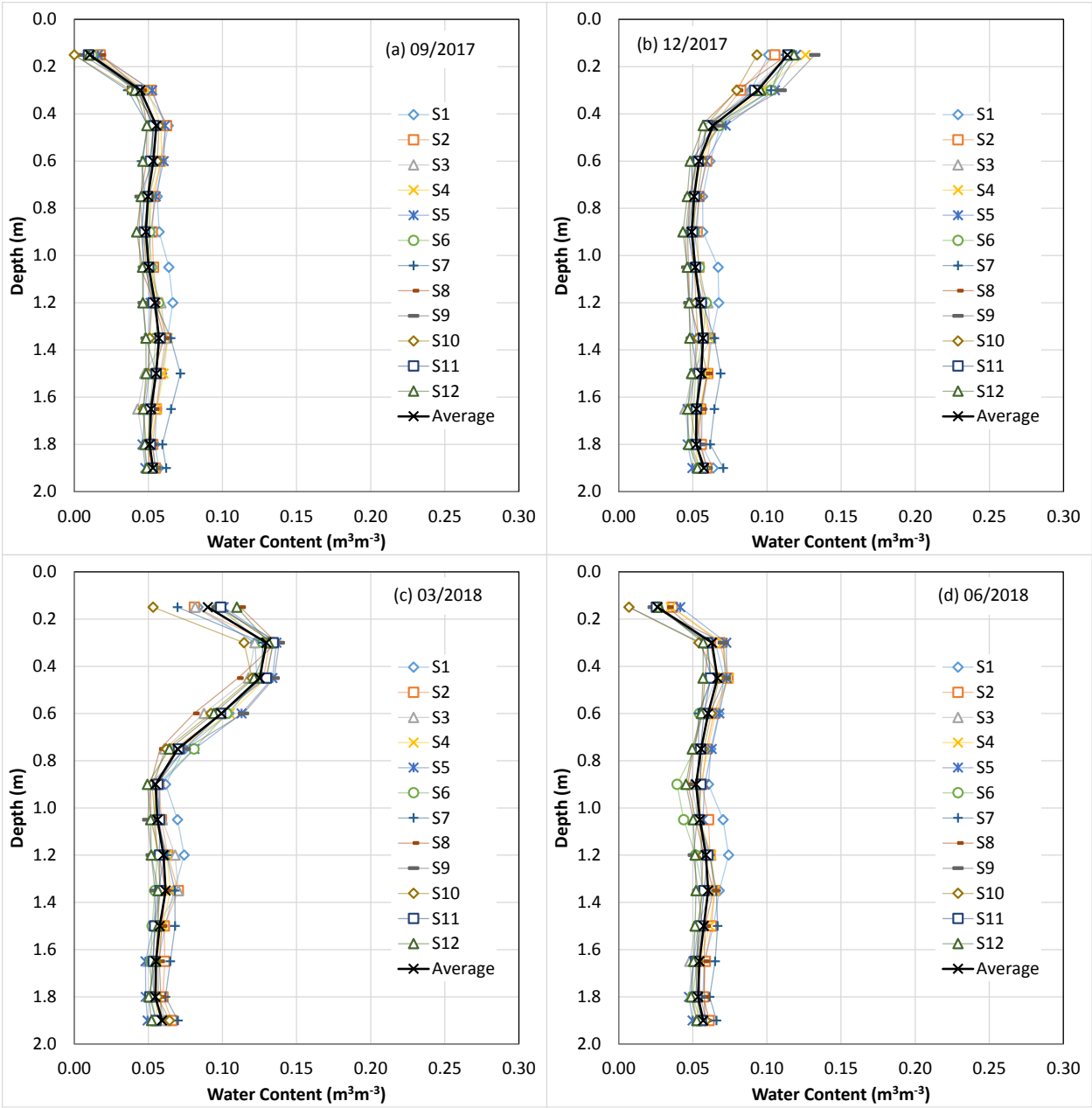
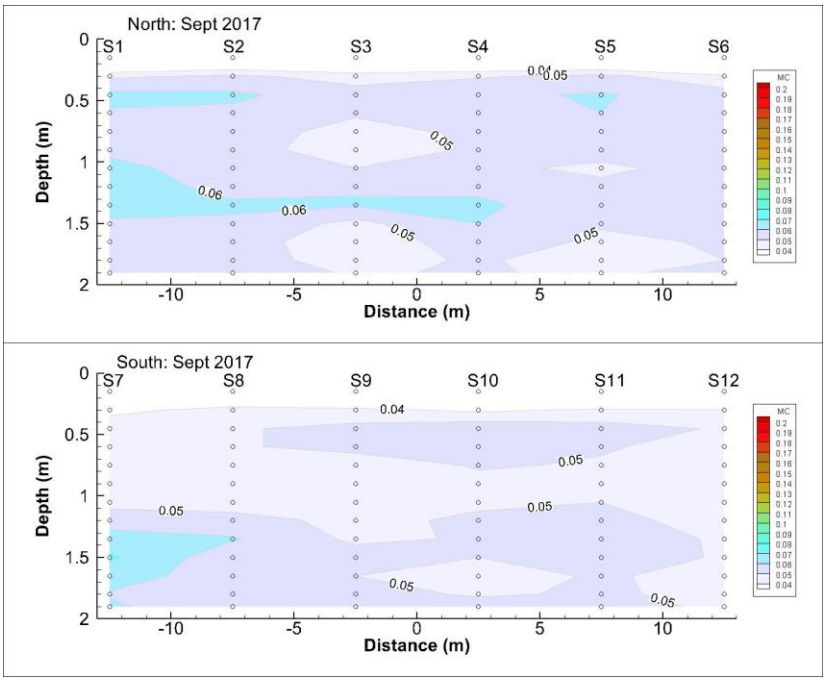
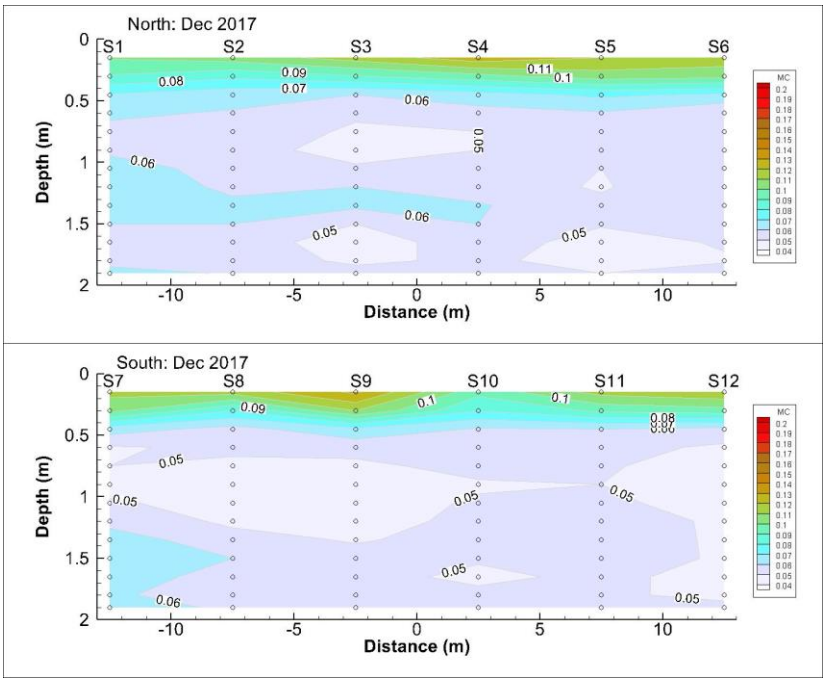


Figure 3.2. Water content profiles in the silt loam of the ETC barrier.

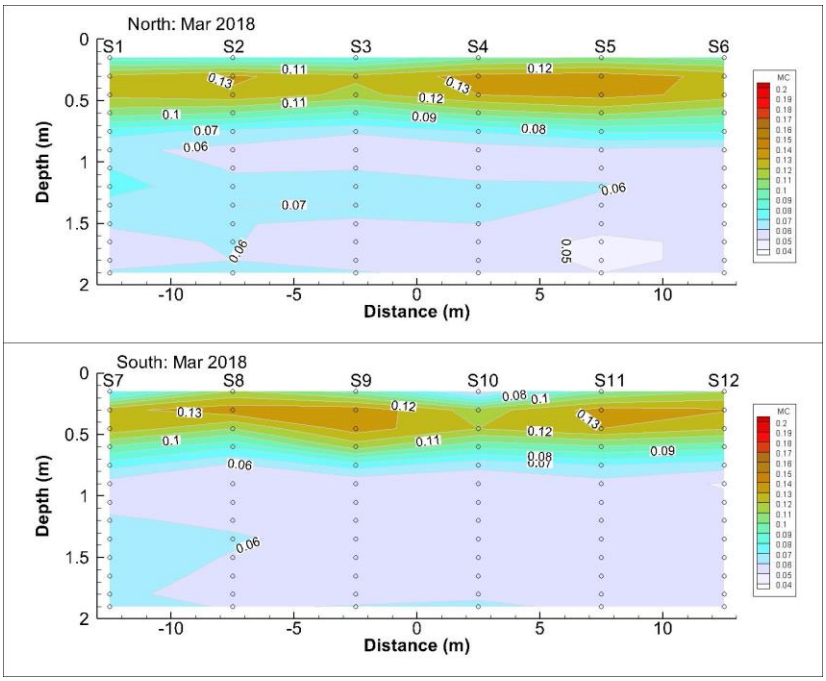


(a)

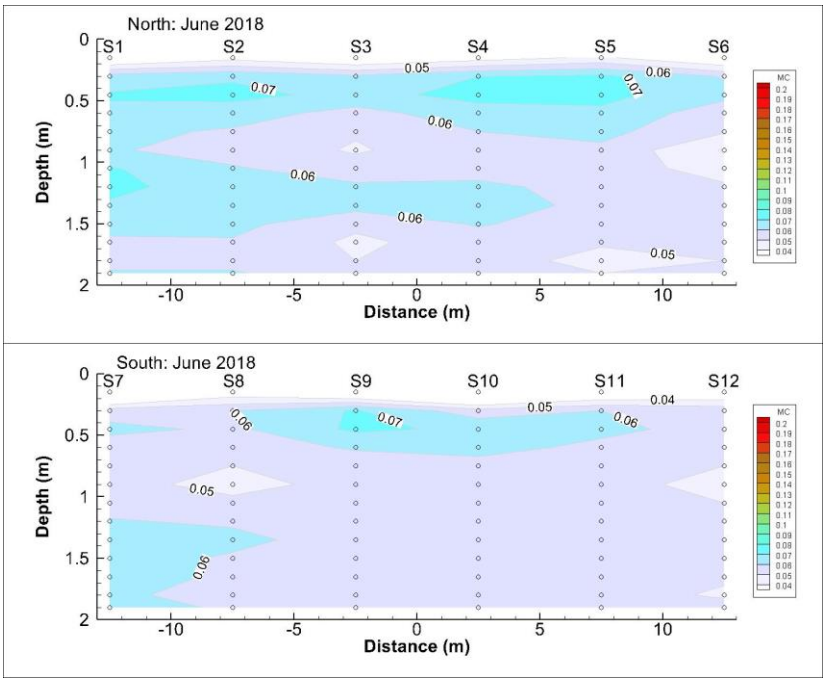


(b)

Figure 3.3. Soil moisture contour of the north and south cross-sections in the silt loam of the ETC barrier at different times.



(c)



(d)

Figure 3.3. Soil moisture contour of the north and south cross-sections in the silt loam of the ETC barrier at different times (cont.)

3.2.3 Water Balance

Four vertical neutron logging campaigns were conducted in FY18. The quality assurance of the results of the logging in September had not completed by the time this report was published and hence these results are not included in this report. They will be included in a future revision once the qualification has been completed.

Water balance was calculated for three periods based on neutron loggings from September 2017 to June 2018. Assuming water flow in the barrier soil is vertical only, ET can be estimated based on the mass balance equation:

$$ET = P - R - D - \Delta W \tag{3.1}$$

where P is precipitation, R is runoff (when positive) or run-on (when negative), D is drainage, and ΔW is change in water storage at each monitoring station.

In FY18, the old drainage monitoring system was replaced by the new DTB system, which started in operation in July 2018; the runoff system is being revamped. Hence, neither drainage nor runoff data had been obtained by June. The soil water dynamics described in the previous section indicated that there was very little chance for drainage to occur from the ETC barrier. Hence, D = 0 was assumed in water balance calculation at the ETC barrier. Based on the runoff data from 1994 to 2013 (DOE-RL 2016; Zhang 2016), runoff on the PHB is usually negligible but could happen when melted snow flows on frozen soil. Some of the snowmelt might flow from one location to another within the ETC barrier before it infiltrates to the subsoil. Calculated ET using Eq. (3.1) would be overestimated when within-the-barrier runoff happened and underestimated when within-the-barrier run-on happened.

At the PHB, R is not monitored for each of the monitoring stations but for only one separate flume (Figure 2.1). Rearranging terms in Eq. (3.1) and assuming D = 0 yields:

$$ETR = ET + R = P - \Delta W \tag{3.2}$$

where ETR is the combined ET and runoff/run. ET can only take non-negative values, but R can be positive (for runoff) or negative (for run-on). Theoretically, when ETR is negative, R must be negative because ET is always non-negative. However, when ETR is positive, the occurrence of runoff or run-on cannot be determined. In reality, measurement error in water storage could also lead to a negative ETR.

<u>The Fall and Winter Seasons</u>

From September 12 to December 31, 2017, precipitation was 75.2 mm, of which an average of 33.5 mm was stored in the ETC barrier and 41.7 mm was lost via ET or runoff (Table 3.1). From December 31, 2017 to March 31, 2018, precipitation was 45.7 mm, of which an average of 23.2 mm was stored in the ETC barrier and 22.5 mm was lost via ET or runoff (Table 3.1). The total amount of stored water from September 12 to March 31 was 56.7 (= 33.5+23.2) mm, which was 14% of the available storage capacity (402 mm), indicating only a small fraction of the available storage capacity of the ETC barrier was filled in the winter of FY18.

<u>The Spring Season</u>

From March 31 to June 13, the soil at all the stations was losing water via ET. The ETC barrier lost an average of 42.7 mm of stored water and 55.6 mm of precipitation during this period (Table 3.1). The total amount of water lost to the atmosphere via ET was 98.3 mm on average (assuming no runoff/run-on

occurred during this period). During the spring period, 75% (= 42.7/56.7) of the stored water was released to the atmosphere. It is expected that more soil water is released to the atmosphere in the rest of the summer.

Table 3.1. Water balance at the monitoring stations.

	9/12 to 12/31			12/31 to 3/31			3/31 to 6/13		
Station	P	ΔW	ETR = P - ΔW	P	ΔW	ETR = P - ΔW	P	ΔW	ETR = P - ΔW
S1	75.2	29.7	45.5	45.7	21.1	24.6	55.6	-36.4	92.0
S2	75.2	26.3	48.9	45.7	25.5	20.2	55.6	-36.2	91.8
S3	75.2	32.7	42.5	45.7	21.7	24.0	55.6	-41.3	96.9
S4	75.2	32.2	43.0	45.7	23.0	22.7	55.6	-39.6	95.2
S5	75.2	32.9	42.3	45.7	27.0	18.7	55.6	-42.0	97.6
S6	75.2	35.4	39.8	45.7	21.0	24.7	55.6	-51.5	107.1
S7	75.2	40.4	34.8	45.7	17.7	28.0	55.6	-46.1	101.7
S8	75.2	30.2	45.0	45.7	27.2	18.5	55.6	-42.2	97.8
S9	75.2	42.3	32.9	45.7	22.7	23.0	55.6	-46.4	102.0
S10	75.2	30.5	44.7	45.7	17.6	28.1	55.6	-34.5	90.1
S11	75.2	34.1	41.1	45.7	25.0	20.7	55.6	-46.3	101.9
S12	75.2	35.3	39.9	45.7	29.0	16.7	55.6	-50.3	105.9
Avg	**75.2**	**33.5**	**41.7**	**45.7**	**23.2**	**22.5**	**55.6**	**-42.7**	**98.3**

3.2.4 Water Storage in the ETC Barrier

Water storage (W) in the 2-m-thick ETC barrier is shown in Figure 3.4 for the 12 monitoring stations located on the ETC barrier. After the hot and dry summer in 2017, the water storage was the lowest in September 2017, with an average of 95 mm (ranging between 84 and 106 mm), which is lower than the residual water storage of 116 mm (Zhang 2015).

The largest observed storage in FY18 was on March 31, 2018, and had an average of 151 mm (ranging between 137 and 157 mm), which was 29% of the storage capacity (518 mm). These results again show that only a very small fraction of the available storage capacity was used in the winter season of FY18, indicating very little chance for drainage to occur from the ETC barrier.

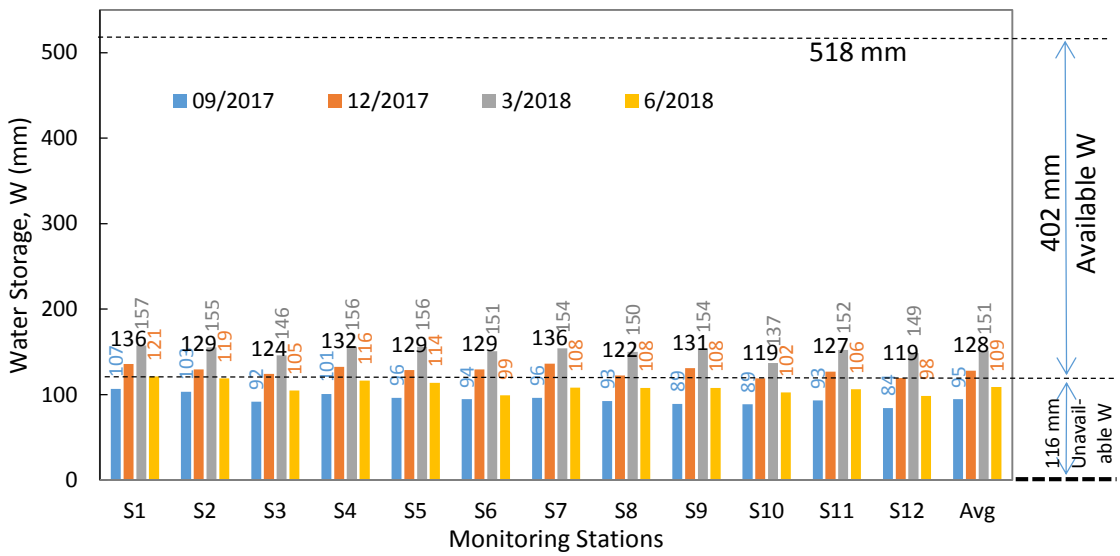


Figure 3.4. The 2-m soil water storage at the 12 monitoring stations in the ETC barrier. The two dashed lines show the storage capacity (518 mm, Section 3.1.2 of DOE-RL 2016) and the residual water storage (116 mm, Zhang 2015) of the silt loam barrier. The labels above the bars are the measured water storage at each station. W: 2-m soil water storage.

3.2.5 Water Content near the Bottom of the Silt Loam Layer

Figure 3.5 shows the observed soil water content along four horizontal lines near the bottom the silt loam layer within the ETC barrier and across the ETC barrier edges (i.e., AA1-AA5 and AA2-AA6 in the north section; AA3-AA7 and AA4-AA8 in the south section; Figure 2.2). The water content at the side slopes stayed low (approximately between 0.01 and 0.02 m^3m^{-3}) all year because of the coarse property of the materials.

Near the bottom of the silt loam layer, between x = -15 and x = 14 m (Figure 3.5), the water content ranged between 0.045 and 0.052 m^3m^{-3} all year with an average of 0.054 m^3m^{-3}. This average is slightly less than the residual water content of 0.058 m^3m^{-3}, indicating that there was near zero available water for plant use and near zero mobile water content.

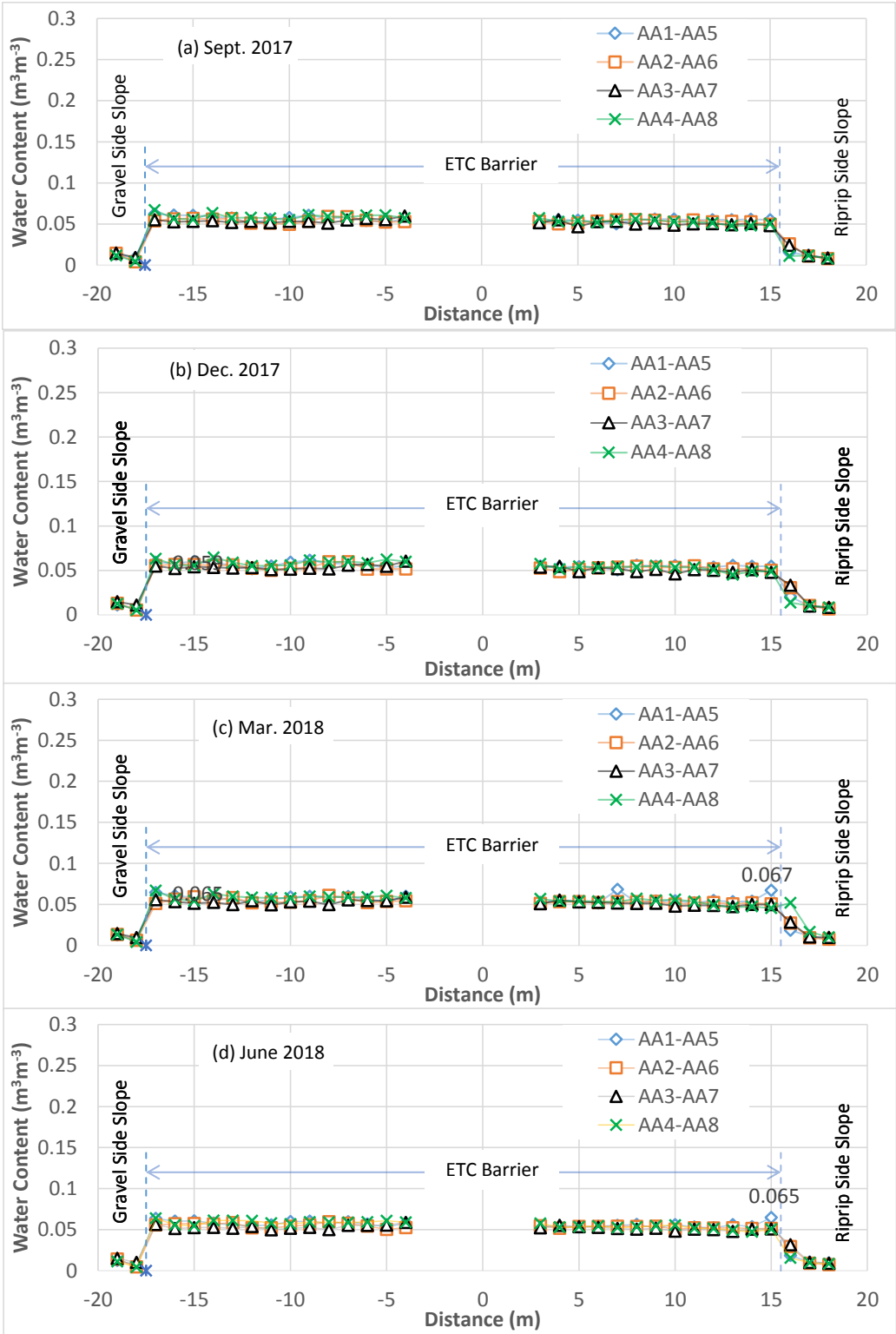


Figure 3.5. Soil water content along four horizontal lines 1.85 m below ground surface (0.15 m above the silt loam/sand capillary break). The approximate locations of the west and east edges of the ETC barrier are marked by vertical dashed lines.

3.3 Barrier Stability

3.3.1 Barrier Surface Elevation

The measured location of reference 2E-122 was slightly different from the historical location (Table 2.1) due to differences in instrument accuracy. Thus, in the analysis, the elevation observations in 2018 were adjusted for this difference in elevation associated with the reference location, which is assumed to be in a fixed location outside the PHB boundary (Figure 2.7). This means any change in 2E-122 is not considered as part of the change in PHB structure. Figure 3.6 shows the contour of the observed elevation of the PHB in 2012 and 2018. The elevation contours for the 2 years are very similar. To better show any changes, the elevation difference between 2018 and 2012 is shown in Figure 3.7. Among all the 338 observations, 316 (93.5%) of them were within ±0.02 m; 18 (5.3%) were between -0.3 m and -0.2 m or between 0.2 m and 0.3 m. Only 4 observations (1.2%) were either above 0.03 m or less than -0.03 m. The differences for these 4 observations are marked in Figure 3.7. The relatively large changes in a few observation could be caused by animal activities. The growth of vegetation and the accumulation of organic material on ground surface could also slightly increase the surface elevation. On average, the elevation of the PHB was 201.857 in July 2018, which is 0.005 m higher than that (201.852) in September 2012. Based on the 4 repetitions at each observation point, the average of the RMSE of the repeated elevation observations was ±0.002 m (ranging between 0 and 0.005 m). These results indicate no measurable difference between the elevation in 2012 and 2018. There is no indication of soil loss due to either wind- or water-caused soil erosion.

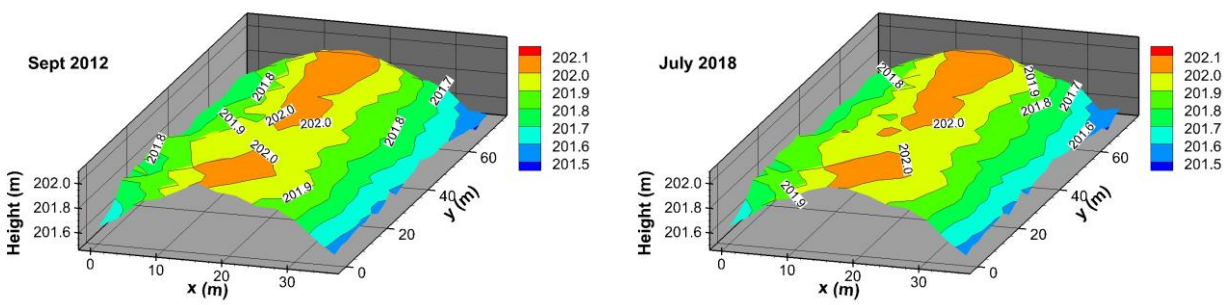


Figure 3.6. Contour of the observed elevation of the Prototype Hanford Barrier in 2012 and 2018.

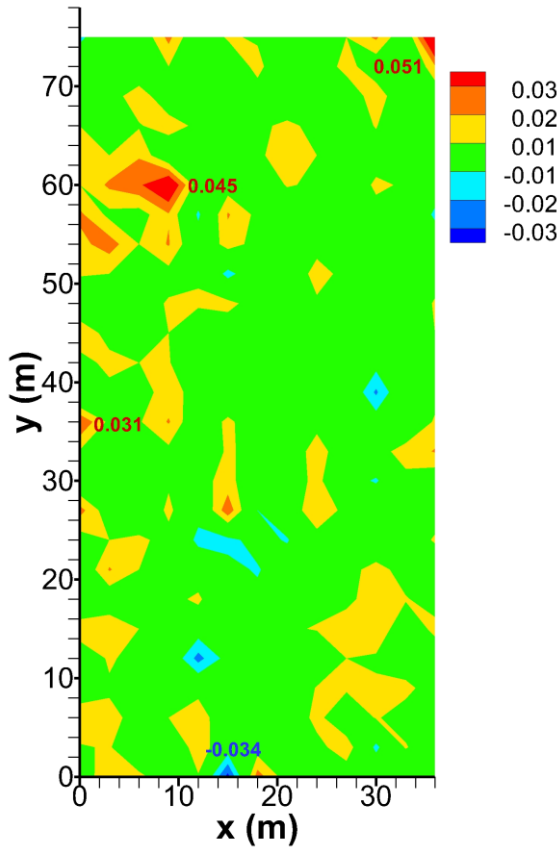


Figure 3.7. Elevation difference between 2012 and 2018.

3.3.2 Barrier Settlement

Table 3.2 lists the elevation values of the two settlement markers measured in 2012 and 2018. The 2018 values were 0.001 and 0.006 m higher than those in 2012, respectively. These differences are close to the observation error of the instrument and hence indicate no difference in the elevation between the two years.

Table 3.2. Elevation (m) of the settlement markers.

Date	SG1	SG2
9/11/2012	201.949	201.684
7/10/2018	201.950	201.689
Difference	0.001	0.006

3.3.3 Riprap Stability

Figure 3.8 shows the positions of the CGs in 2018 relative to their corresponding positions in 2012. Most of the points fall in the lower right quadrant. Of the 13 CGs, 11 had positive changes up to 0.048 m to the outward east, 11 had negative changes down to -0.038 m to the south, and 8 had positive changes up to 0.010 m in the vertical direction. On average, over the 13 CGs, the changes with 1 σ are dx = 0.014±0.014 m, dy = -0.015±0.013 m, and dz = 0.002±0.003 m. The average changes are comparable to the standard deviation, indicating that any changes are beyond detection and the riprap side slope was very stable from 2012 to 2018.

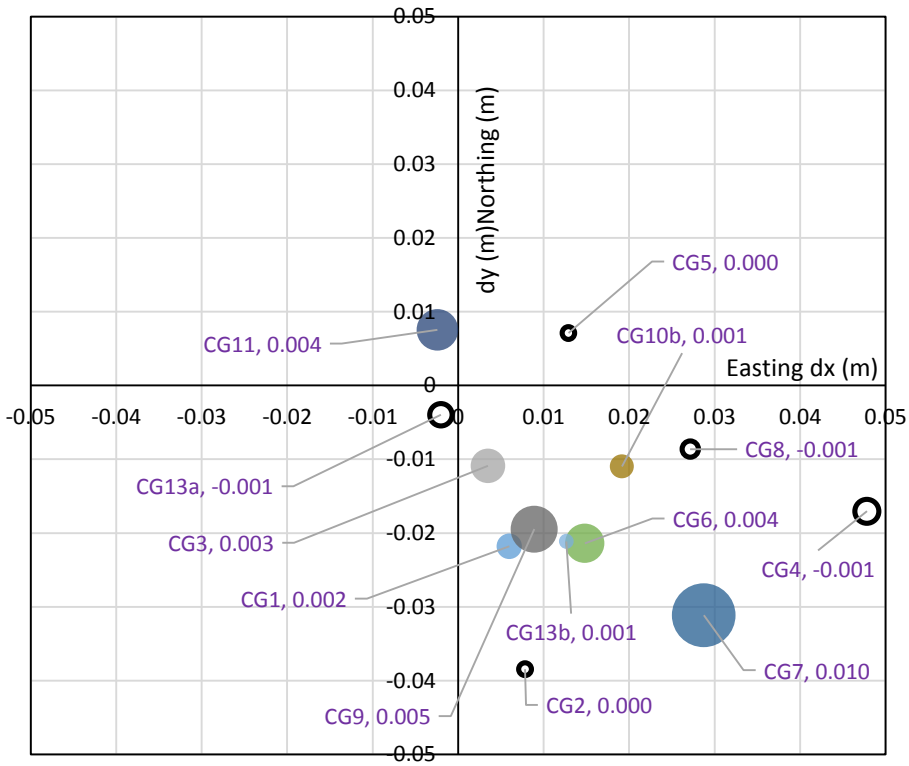


Figure 3.8. Positions of creep gauges in 2018 relative to their corresponding positions in 2012. CG10a and CG12 were not surveyed in 2012 and hence are not included here. A positive dx value indicates lateral movement of the side slope outward. A filled bubble indicates an increase in CG elevation, while an empty bubble indicates a decrease. The area of the bubble indicates the change in elevation as shown by the number nearby.

4.0 Conclusions

In FY18, the water content in the silt loam was measured on an approximate quarterly basis. The surface barrier structural stability (including surface elevation, barrier settlement, and riprap side slope stability) and ecological surveys (including animal activities, plant floristics, plant cover, and shrub canopy) were also completed. The data collected to date continue to demonstrate that the PHB has performed well since its inception. Water content measurements indicate that there was near zero mobile water content in the barrier. Structural measurements show no indication of wind- or water-caused soil erosion, nor any measurable differences in elevation between 2012 and 2018. The ETC barrier of the PHB continues to perform much better than the drainage design goal of 0.5 mm yr^{-1}. The monitoring results of barrier hydrology and structural stability are summarized below. The quality reviews for the ecological and drainage data collected in the final quarter of FY18 have not yet been completed and are not included in this report. Once the data qualification is complete, a revision of this report will be issued in FY19.

4.1 Barrier Hydrology

In WY18, the winter-season (October-March) precipitation was 95.3 mm, which corresponded to an SPI of -0.025 and was categorized as "near normal." The first snowfall was on November 5, 2017, and the last was on February 23, 2018, for a period of 110 days. During this period, the total snowfall was 173 mm, which is about half of the average snowfall of 361 mm.

In September 2017, the entire soil profile had very low water content (<0.07 m^3m^{-3}), which was slightly (approximately 0.01 m^3m^{-3}) higher than the residual water content. In late March of 2018, which was near the wettest time of the year, the wetting front depth was approximately 0.8 m among the 12 monitoring stations. Infiltration water had not reached the bottom of the ETC barrier at any of the monitoring stations. The total amount of stored water during the fall and winter seasons was 56.7 mm, which is only 14% of the available storage capacity (402 mm).

From March 31 to June 13, the soil at all the stations was losing water via ET. In middle June, the soil water content was no more than 0.08 m^3m^{-3} for all the stations, which is approximately 0.02 m^3m^{-3} higher than the residual water content. In additional to the 55.6 mm precipitation, 42.7 mm (75%) of the 56.7 mm stored water in the previous fall-winter season was released to the atmosphere via ET.

The largest observed water storage was on March 31, 2018, with an average of 151 mm (ranging between 137 and 157 mm), which is 29% of the storage capacity (518 mm). These results show that only a small fraction of the available storage capacity was used in the winter season of FY18.

Near the bottom of the silt loam layer, the water content all year round ranged between 0.045 and 0.052 m^3m^{-3} with an average of 0.054 m^3m^{-3}. This average is slightly less than the residual water content of 0.058 m^3m^{-3}, indicating that there was near zero available water for plant use and near zero mobile water content.

The monitoring period extended to 24 years by FY18. The WY18 weather was normal. The barrier response was normal and there was no indication of drainage from the ETC barrier.

4.2 Barrier Structural Stability

On average, the elevation of the PHB was 201.857 m in July 2018, which was 0.005 m higher than that (201.852 m) that in September 2012. The average of the RMSE of the repeated elevation observations

was ±0.002 m. These results indicate no measurable difference between the elevation in 2018 and 2012. There is no indication of soil loss due to either wind- or water-caused soil erosion.

The 2018 elevation values of the settlement markers were 0.001 and 0.006 m higher than those in 2012, respectively. These differences are close to the observation error of the instrument and hence indicate no difference in the elevation between 2018 and 2012.

The changes of the coordinates (horizontal and vertical) of the creep gauges at the riprap side slope were comparable to the observation errors (approximately 0.01 m horizontally and 0.003 m vertically) from 2012 to 2018, indicating that the changes were beyond detection and the riprap side slope was very stable during this period.

5.0 Quality Assurance

The results presented in this report originate from work performed by the Pacific Northwest National Laboratory under the Nuclear Quality Assurance Program (NQAP). The NQAP implements the requirements of U.S. Department of Energy Order 414.1D, *Quality Assurance*, and 10 CFR 830 Subpart A, *Quality Assurance Requirements*. The NQAP uses ASME NQA-1-2012, *Quality Assurance Requirements for Nuclear Facility Applications*, as its consensus standard and NQA-1-2012 Subpart 4.2.1 as the basis for its graded approach to quality.

Two quality grading levels are defined by the NQAP:

Basic Research - The required degree of formality and level of work control is limited. However, sufficient documentation is retained to allow the research to be performed again without recourse to the original researcher(s). The documentation is also reviewed by a technically competent individual other than the originator.

Not Basic Research - The level of work control is greater than basic research. Approved plans and procedures govern the research, software is qualified, calculations are documented and reviewed, externally sourced data is evaluated, and measuring instrumentation is calibrated. Sufficient documentation is retained to allow the research to be performed again without recourse to the original researcher(s). The documentation is also reviewed by a technically competent individual other than the originator.

The work supporting the results presented in this report was performed in accordance with the *Not Basic Research* grading level controls.

6.0 References

DOE-RL. 2016. *Prototype Hanford Barrier 1994 to 2015*, DOE/RL-2016-37, Rev. 0, U.S. Department of Energy Richland Operations Office. Richland, Washington. Available at http://www.hanford.gov/c.cfm/sgrp/DOE-RL-2016-37/DOE-RL-2016-37_R0.pdf and http://www.hanford.gov/c.cfm/sgrp/DOE-RL-2016-37/Appendices.pdf (Accessed on August 30, 2018).

Gee GW, MJ Fayer, ML Rockhold, and MD Campbell. 1992. "Variations in Recharge at the Hanford Site," *Northwest Science*, 66(4):237-250.

Gee GW, JM Keller, and AL Ward. 2005. "Measurement and Prediction of Deep Drainage from Bare Sediments at a Semiarid Site," *Vadose Zone Journal*, 4:32-40.

Hoitink DJ, KW Burk, JV Ramsdell (Jr.), and WJ Shaw. 2005. *Hanford Site Climatological Summary 2004 with Historical Data*, PNNL-15160, Pacific Northwest National Laboratory. Richland, Washington.

McKee TB, NJ Doesken, and J Kleist. 1993. "The Relationship of Drought Frequency and Duration of Time Scales," *Eighth Conference on Applied Climatology, American Meteorological Society*, 179-186 pp.Jan. 17-23, 1993,Anaheim, California.

McKee TB, NJ Doesken, and J Kleist. 1995. "Drought Monitoring with Multiple Time Scales," *9th Conference on Applied Climatology*, Am. Meteorol. Soc., Dallas, Texas.

Zhang ZF. 2015. "Field Soil Water Retention of the Prototype Hanford Barrier and Its Variability with Space and Time," *Vadose Zone Journal*, 14(8):1-10. doi:10.2136/vzj2015.01.0011.

Zhang ZF. 2016. "Evaluating the Long-Term Hydrology of an Evapotranspiration-Capillary Barrier with a 1000 Year Design Life," *Water Resources Research*, 52. doi:10.1002/2015WR018167.

Zhang ZF. 2017a. "Long-Term Drainage from the Riprap Side Slope of a Surface Barrier," *Water*, 8:156-164.

Zhang ZF. 2017b. "Should the Standard Count Be Excluded from Neutron Probe Calibration?," *Soil Sci. Soc. Am. J.*, 81:1036-1044.

Zhang ZF, CE Strickland, and SO Link. 2017. "Design and Performance Evaluation of a 1000-Year Evapotranspiration-Capillary Surface Barrier," *Journal of Environmental Management*, 187:31-42.

Zhang ZF, JN Thomle, and RE Clayton. 2018. *Monitoring the Prototype Hanford Barrier – Fiscal Year 2017 Report*, PNNL-27383 DVZ-RPT-0001 Rev 0, Pacific Northwest National Laboratory. Richland, Washington.

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