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Pacific Northwest National Laboratory
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Water Monitoring Report for the 200 W Area Tree Windbreak, Hanford Site, Richland, Washington

G. W. Gee
J. S. Carr
J. O. Goreham
C. E. Strickland

September 2002

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Summary

Water inputs to the vadose zone from irrigation of a tree windbreak in the 200 W Area of the Hanford Site were monitored during the summer of 2002. Water flux and soil-water contents were measured within the windbreak and at two locations just east of the windbreak to assess the impact of the irrigation on the vadose zone and to assist in optimizing the irrigation applications. In May 2002, instrumentation was placed in auger holes and backfilled with local soil. Sensors were connected to a data acquisition system (DAS), and the data were telemetered to the laboratory via digital modem in late June 2002. Data files and graphics were made web accessible for instantaneous retrieval. Precipitation, drip irrigation, deep-water flux, soil-water content, and soil-water pressures have been monitored on a nearly continuous basis from the tree-line site since June 26, 2002.

There has been little rain (6 mm) since early July 2002, so water applied to the soil has been almost exclusively from irrigation. During the first 65 days of monitoring (26 June through 30 Aug), the measured application rate averaged 751 L per day, i.e., 198 gallons per day (gpd) per tree, over 13 times the design rate of 57 L per day (15 gpd) per tree. Feedback from the monitoring data has resulted in subsequent reductions in both application and drainage rates within the tree line. Recent adjustments have reduced the application rate to 159 L per day (42 gpd). Drainage within the tree line from irrigation has exceeded 3100 mm (>10 ft) of water for the 80-day monitoring period. The drainage rate has been reduced more than half, from 36 mm/day for the first 65 days to 17 mm/day for the past 7 days, i.e., through September 24, 2002. In spite of these improvements, the irrigation and drainage rates are still not optimized, with irrigation exceeding the design rate by almost a factor of three. Monitoring of two adjacent sites found no drainage during the 80-day monitoring period. Continued monitoring within and adjacent to the tree line will provide an evaluation of the overall efficiency of the irrigation system, assist in irrigation control, and help assess the impact of drainage on adjacent areas, such as solid-waste burial grounds.

Acronyms and Abbreviations

ET	evapotranspiration
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
ha	hectares
IIS	Internet Information Server
INEEL	Idaho National Engineering and Environmental Laboratory
OWC	Office Web Components
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory

Acknowledgements

This document was prepared for the U.S. Department of Energy under Contract DE-AC06-76RL01830. The work reported is part of the 200 West Area Moisture Monitoring task (Project 43921) under the direction of CH2MHILL Hanford and the tank farm vadose zone project. We wish to thank Tony Knepp (CH2MHILL) for supporting this work. Thanks are also expressed to Dave Skoglie (Duratek Federal Services) for conducting the drilling operations in a timely fashion and to Buck Sisson (Idaho National Engineering and Environmental Laboratory) for providing advice and tensiometers for deployment at the windbreak site.

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1.0 Introduction

Over 1460 trees were planted in the spring of 2001 in the 200-W Area, about 0.5 km (1640 ft) west of the Plutonium Finishing Plant (PFP) on the west side of Dayton Ave. and just south and west of Building MO-281. Figure 1.1 shows the location of the windbreak. The trees act as a windbreak to suppress blowing sand and dust.

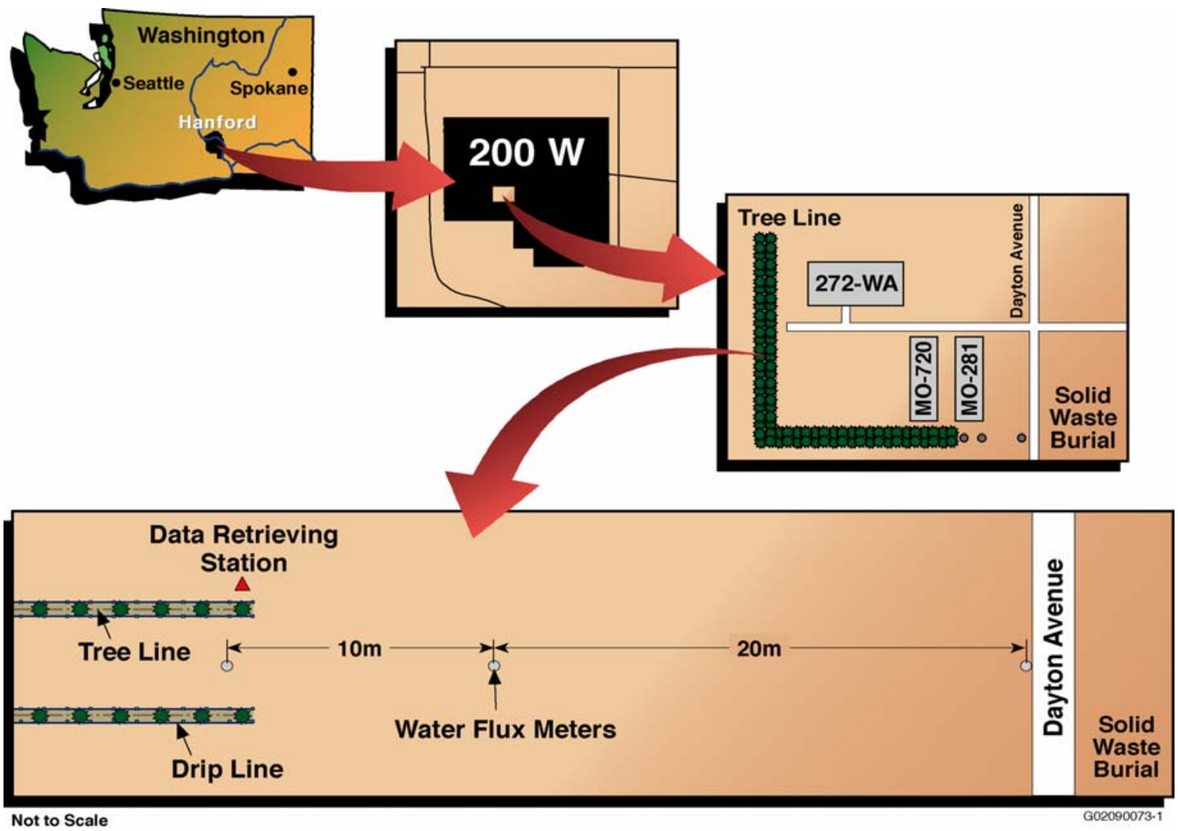

Figure 1.1. Location of the Tree Windbreak in the 200 W Area of the Hanford Site

The trees (Australian willows) were planted in double rows in an L shape, spanning a distance of 1.1 km (3660 feet). Figure 1.2 shows the trees as they appeared in August 2001. Supplemental irrigation for trees is required in the Hanford arid climate in order to maintain the living windbreak since the water demand for the trees is high while meteoric sources are limited and groundwater sources are too deep to provide the needed water. The trees are irrigated by a drip system, capable of supplying enough water to satisfy evaporative demand in the hot summer at Hanford and to keep the soil at or near field capacity. The estimated tree requirement for the Hanford Site is 57 L (15 gal) per tree. The irrigation system is not 100% efficient, so drainage occurs. Drainage water from the irrigation can potentially move laterally, along sloping fine sediments, impacting contaminant plumes that may exist in adjacent solid-waste landfills. The purpose of this study was to measure drainage rates in and adjacent to the tree line in the 200 W Area of the Hanford Site and to provide some guidance on what water application rates might be required to successfully irrigate the trees, yet provide minimal drainage to the subsurface. The following discussion describes the sources of all waters assumed to impact the sold waste landfills and a vadose-zone monitoring system that could be used to detect drainage produced by irrigating the trees.

Figure 1.2. Tree Windbreak in 200 West Area as it Appeared in August 2001

2.0 Irrigation and Drainage Issues

The need for vadose-zone monitoring and irrigation control stems from issues related to potential groundwater contamination. Contaminants have been shown to move from waste-burial grounds and tank farms at Hanford when assisted by excess water such as direct liquid discharges, water line leaks, or meteoric sources (winter rain and snowmelt). There is a concern that irrigation water, used to keep trees alive and establish vegetation in sand-blowing areas, could potentially provide excess water to the subsurface, impacting adjacent solid-waste burial- grounds in the 200-W Area. Subsurface monitoring can be used to assess the impact of the drainage water on the burial grounds. A brief discussion of all expected sources for drainage water is provided, followed by the recommended vadose zone monitoring strategies to assess drainage-water impacts.

2.1 All Expected Sources for Drainage Water

2.1.1 Meteoric Sources

Drainage to groundwater can occur from winter rains and snowmelt at the Hanford Site (Gee et al. 1992). Precipitation from November to March (defined here as winter precipitation) ranges from less than 60 mm (2.4 in.) to more than 200 mm (8 in.), averaging slightly more than 100 mm (4 in.) per year. Under normal conditions, winter precipitation is utilized by native (shrub-steppe) vegetation, and there is virtually no drainage from non-irrigated Hanford soils. However, after fires or mechanical disturbances, significant drainage occurs. Bare gravels and sandy soils can drain in excess of 50 mm per year (more than half of the winter precipitation). When these same soils are revegetated with shallow-rooted grasses, e.g., cheatgrass, they are also susceptible to drainage (Gee et al. 1992). Because of the wild fire in June 2000, extensive acreages of barren soils or soils with only a sparse cover of shallow-rooted grasses surrounded much of the 200-W Area during the fall of 2000. During the winter of 2000/2001 precipitation infiltrated these soils, and in some areas may have contributed to recharge (drainage). In early 2001, vegetation (primarily weeds) invaded the burned areas, and since that time, wind erosion has diminished and the vegetation has utilized some, if not most, of the excess water from precipitation. While the vegetation recovery has been quite rapid and has persisted, there has been no direct measure of the drainage rates in these soils, so actual drainage in the soils between 200 W facilities and Highway 240 can only be estimated. An estimate of expected drainage from meteoric and other water sources in the vicinity of the trees during the Fiscal Year 2001 of irrigation is shown in Table 2.1. The drainage calculation is based on a 105 ha (260-acre) area adjacent to the trees and close to solid waste burial grounds.

2.1.2 Irrigation Source

Irrigation systems are not 100% efficient. That is, the amount of water applied generally is not fully used by the irrigated crop, and drainage occurs. Drainage can be less than 10% or as much as 50% of the applied water over an irrigated area. During a growing season, irrigation water for agricultural crops, e.g., potatoes, corn, etc., is generally applied at the rate of 6 to 12 mm (0.25 to 0.5 in.) per day, particularly in late spring and summer when the crop is established and exposed to sun, heat, and wind. For irrigating trees in a tree line, it is possible that the water requirement per unit area will be greater than that for a typical agricultural crop growing on the same soil because the growing season is longer for trees, and the evaporation demand is equal or greater than a typical crop such as corn or potatoes. Drainage is likely, even under reduced water-application rates. For comparative purposes, a center-pivot system, covering 105 ha (260 acres) and irrigating at a rate of 1100 gallons per minute (gpm), will apply approximately 6 mm (0.24 in.) of water per day, about half that required to sustain a potato crop or an actively growing windbreak. Table 2.1 shows the expected drainage from a center pivot that is 85% efficient in delivering 1100 gpm or 1,580,000 gallons per day (gpd) to 260 acres over a 120-day irrigation period. The total drainage volume expected is more than 2 times that from meteoric sources, i.e., winter precipitation, for the same 260 acres. It should be noted that even if the irrigation efficiency were improved to over 90%, the total drainage from the center pivot would remain the highest source of recharge water for the area surrounding the tree windbreak. For these and other reasons, a center pivot system was not deployed in the 200 W Area.

Improved efficiencies in water application are expected with drip irrigation. Greater than 90% efficiencies can be achieved using drip irrigation. Using a drip-irrigation system, the total water required to irrigate 1460 trees is computed to be 22,000 gpd for 180 days each year. At 90% efficiency, the amount of water drained below the windbreak is estimated to be 396,000 gal per year (Table 2.1). With improved efficiencies as the trees mature, the annual drainage is expected to decrease over time. We estimate that the drip system would be 95% efficient for the remaining 19 years in a 20-year life cycle.

2.1.3 Localized Discharges

Localized discharges are known to occur near the trees from three septic drain fields from the adjacent modular offices. Table 2.1 shows that the total drainage expected from the drain fields (2607 W-10, W-11, W-12) located near the windbreak is less than the estimated drainage from any of the irrigation schemes for the first year. However, the drainage over 20 years exceeds that expected from the tree irrigation (Table 2.2). Unknown amounts of local discharge may occur now or in the future from water-line leaks from the irrigation system and possibly from existing water lines used for raw water and drinking purposes. We estimate these water-line leaks to be less than 1000 gpd. Table 2.1 shows the relative impacts of meteoric, irrigation, septic, and water line leaks in the area near the trees.

Table 2.1. Estimated First-Year Drainage Volumes from Potential Water Sources in the 200-W Area near the Tree Windbreak Ranking is from Highest to Lowest Drainage Volumes

Rank	Source	Applied Amount	Drainage (% applied)	Drainage (gal/yr)
1	Irrigation (Center Pivot)	1,580,000 gpd (120 days)	10	19,000,000 gal (Per 260 acres)
2	Meteoric (rain/snowmelt)	170 (mm/yr)	15	7,100,000 gal (Per 260 acres)
3	Septic Field	1250 gpd	100	456,000 gal
4	Drip Irrigation	22,000 gpd (180 days)	10	396,000 gal
5	Water-Line Leaks	<1000 gpd	100	<365,000 gal

Based solely on Table 2.1, the amount of water potentially impacting groundwater near the tree line in one year is greatest from the center pivot system (not deployed). Meteoric sources of drainage are about a factor 3 less than those from the center pivot system. Drip irrigation should have only a minor impact on groundwater. The expected drainage from drip irrigation of the trees is nearly two orders of magnitude less than that from the center-pivot system, a factor of 18 less than that from meteoric sources, and less than that from existing septic systems.

2.1.4 Timing and Duration

Timing and duration of the potential water applications must also be considered. If the soil is relatively dry before water application, drainage will only occur after the soil is filled to an upper limit of available water, or the so-called "field capacity." While the field capacity of the soils surrounding the trees has not been measured directly, it can be estimated from soil-survey data (Sackshewsky and Becker 2001). Assuming that the soil within the 260 acres surrounding the trees is Quincy sand, the estimated field capacity is 90 mm/m. This means that for every meter of soil depth, the soil will hold 90 mm (3.5 in.) before it drains to any appreciable extent. If the initial water content (before irrigation) is assumed to be 4% by volume, i.e., 40 mm/m, then the available storage capacity of the soil is 50 mm/m. Thus, for a 2-m (6.7-ft) root zone, the total expected storage is 100 mm (4 in.). Any drainage water in excess of this amount is expected to drain to the water table, while the stored 100 mm is available for plant uptake and surface evaporation. Table 2.2 shows a comparison of estimated 20-yr drainage volumes from various sources

Table 2.2. Estimated Total Net Drainage for a 20-Year Period from Various Water Sources in the 200-W Area near the Tree Windbreak. Ranking is from Highest to Lowest Drainage Volumes

Rank	Source	Applied Amount	Net Drainage (% applied)	Net Drainage (gal/ 20 yrs)
1	Meteoric (rain/snowmelt)	170 (mm/yr)	15-1st yr 5-19 years	52,000,000 gal (Per 260 acres)
2	Irrigation (Center Pivot)	1,580,000 gpd (120 days)	10-1st yr	19,000,000 gal (Per 260 acres)
3	Septic Fields	1250 gpd	100	9,130,000 gal
4	Water-Line Leaks	<1000 gpd	100	<7,200,000 gal
5	Irrigation (Drip)	22,000 gpd (180 days)	10-1st yr 5-19 years	4,200,000 gal

Based on the 20-year drainage estimates reported in Table 2.2, meteoric water from the area (260 acres) surrounding the trees is the largest contributor to groundwater, followed by drainage from the center-pivot irrigation system. The drip irrigation system is expected to drain less than either the septic fields or water-line leaks during the 20-yr operational period if irrigation water is applied correctly. While Table 2.1 and Table 2.2 provide estimates of drainage to the water table, these estimates do not directly describe impacts to the adjacent burial grounds. Either a detailed transport analysis, using a two-dimensional hydrologic model, is needed, or direct measurements must be made. For this study, direct measurements were made, and results of the Summer 2000 irrigation are reported.

2.2 Recommended Vadose Zone Monitoring Strategies

2.2.1 Trees and Irrigation System

The trees (Australian willows) were planted ~1.5 m (~5 ft) apart in two rows, separated a distance of ~4.2 m (Figure 1.1). The trees are expected to grow in height to between 18 to 21 m (60 to 70 ft), and the active root zone will extend to a depth of at least 3 m (10 ft). It is expected that 4 to 5 years will be required to achieve full tree height and root extension. A drip-irrigation system delivers water to the base of the trees (Figure 1.1 and Figure 1.2). Two drip-irrigation lines, spaced 0.5 m (1.6 ft) apart, run in parallel on either side of each tree. The drip lines have emitters that are spaced 0.8 m (2.6 ft) apart. The emitters have the capacity for discharging up to 3 gph. The area around each tree affected by the irrigation is estimated to be about 4.2 m^2 (Figure 2.1).

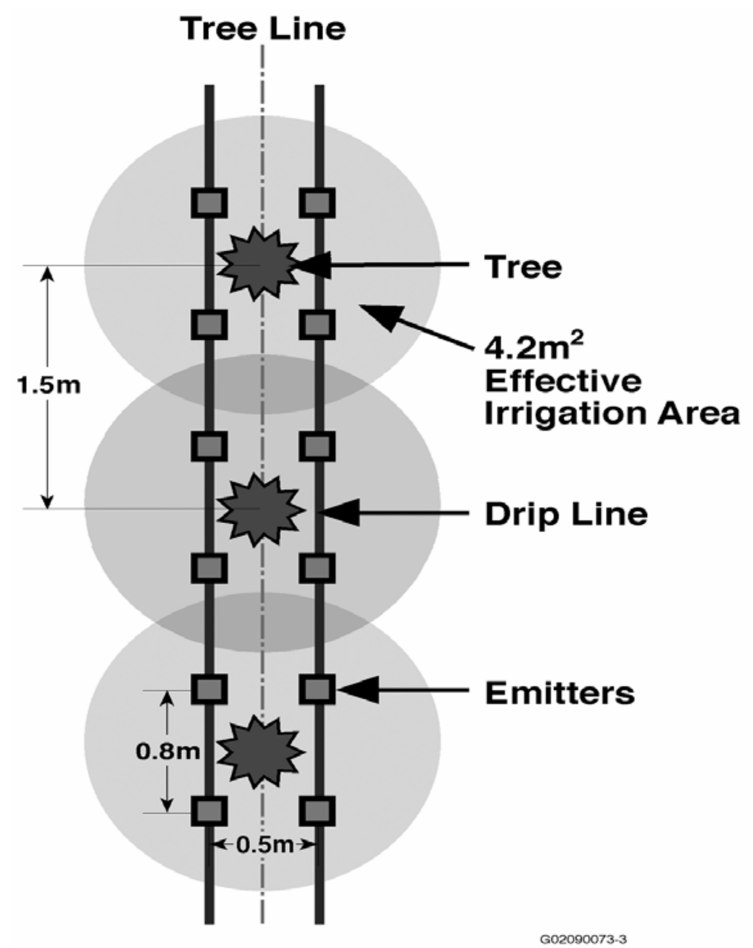

Figure 2.1. Schematic of Drip-Irrigation Lines and the Estimated Area of Coverage Near Each Tree

2.2.2 Sensors

The following sensors are part of the monitoring system for the tree windbreak:

1. Raingage. Precipitation is monitored using a small plastic raingage (Rain-O-Matic, Pronamic Co. Ltd, Sikeborg, Denmark) placed at a 2-m (6.6-ft) height on an instrument tripod just outside the east end of the treeline. The Pronamic raingage has a least count of 1 mm (0.04 in.), i.e., sensitive to 1 mm of precipitation.

2. Drip Emitter Sensors. Drip irrigation is monitored using Pronamic raingages, placed just below ground level and fastened to the drip line directly below the emitter. A gravel base is placed below the raingage to minimize the chance for ponding. Two drip emitters are used in the tree row and are located within 10 m (33 ft) of the data-collection system. The drip sensors have a sensitivity of about 5 mL/tip. Figure 2.2 shows the cross section of the sensor placement. Drip collectors (not shown) are placed directly below the emitters.

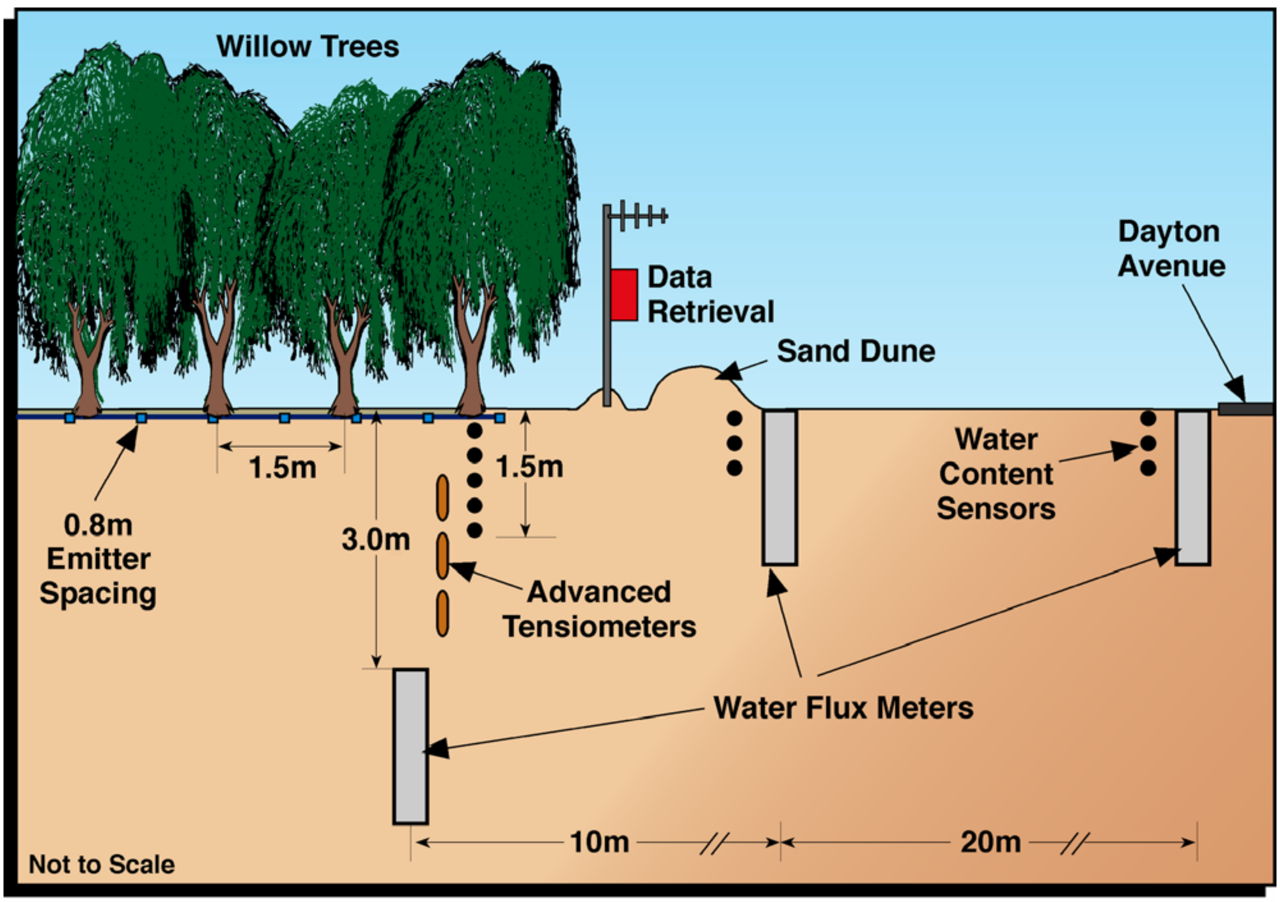

Figure 2.2. Schematic Cross Section of 200 West Tree Windbreak Site Showing Sensor Locations Within and Adjacent to the Tree Line

3. Water Fluxmeters: Pacific Northwest National Laboratory (PNNL) has developed a vadose zone water-fluxmeter (Gee et al. 2002). This unit is basically a miniaturized drainage-lysimeter that can be placed at depth in the soil and directly measures the water flow using a tipping bucket (much like an automated rain gauge). Figure 2.3 show a schematic of a water fluxmeter similar to those deployed at the tree windbreak.

   Three water fluxmeters were installed in May 2002. One flux meter was placed directly in the tree line. A second unit was placed about 10 m (33 ft) directly east of the tree line, at the lee side of an existing sand dune (created by a wind fence adjacent to the tree line). The third unit was placed about 30 m (98 ft) east of the tree line at the western edge of the paved road (Dayton Ave.) separating the tree line from the adjacent solid-waste burial grounds. The placement of the water fluxmeters provides a comparison of the drainage within the tree line and in areas adjacent to the tree line where drainage is expected to be the greatest.

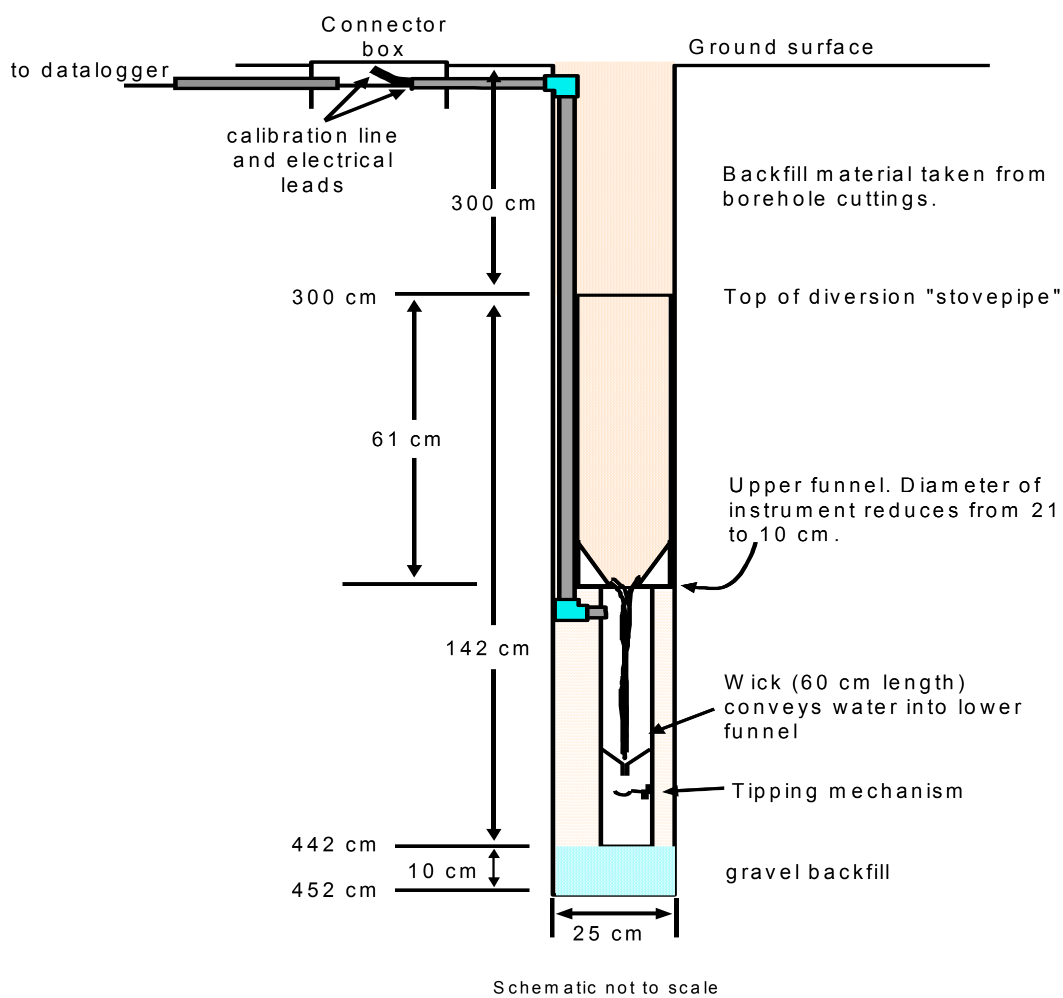

Figure 2.3. Schematic of Water Fluxmeter Similar to Those Used to Measure Drainage at Tree Line and Adjacent Sites

4. Advanced Tensiometers. Tensiometers are water-filled porous cups placed in contact with subsurface sediments. They measure capillary pressures (matrix water potentials). In the Advanced Tensiometer (custom built from the Idaho National Engineering and Environmental Laboratory [INEEL]), an electronic pressure transducer is placed directly within the water-filled cup, and the unit is sealed to create a vacuum or negative pressure (Hubbell and Sisson 1998). As soils wet, the capillary pressure decreases (becomes less negative). The range of operation is from 0 pressure to about -600 mbars. Beyond that range, the cup typically drains—water is lost, and the pressure readings become meaningless. For draining soils, this is not a problem. The tensiometer is calibrated directly in terms of pressure or vacuum applied to the cup. Changes in voltage from the pressure transducer reflect changes in capillary pressure in the soil in contact with the porous cup. As in groundwater flow, pressure-head differences determine flow direction, so in the vadose zone, measurements of capillary-pressure differences between sets of tensiometers can help determine flow direction. In the monitoring scheme, three Advanced Tensiometers (INEEL design) were placed near the water-flux meter at depths of 0.9 m, 1.7 m, and 2.7 m (3 ft, 5.6 ft, and 8.9 ft) below ground surface (bgs). Figure 2.4 shows a schematic of an advanced tensiometer similar to those deployed at the treeline. One modification made to the tensiometers at the treeline site was to increase the water reservoir and seal the pressure sensor into a hole drilled in the side of the water-reservoir tube. Based on previous studies with tensiometers at Hanford, e.g., see http://vadose.pnl.gov, it is anticipated that the tensiometer will operate almost indefinitely without requiring any water refill as long as drainage occurs near the cup. Failure will indicate water removal in excess of the bubbling pressure of the cup, which is not expected in the irrigated tree line.

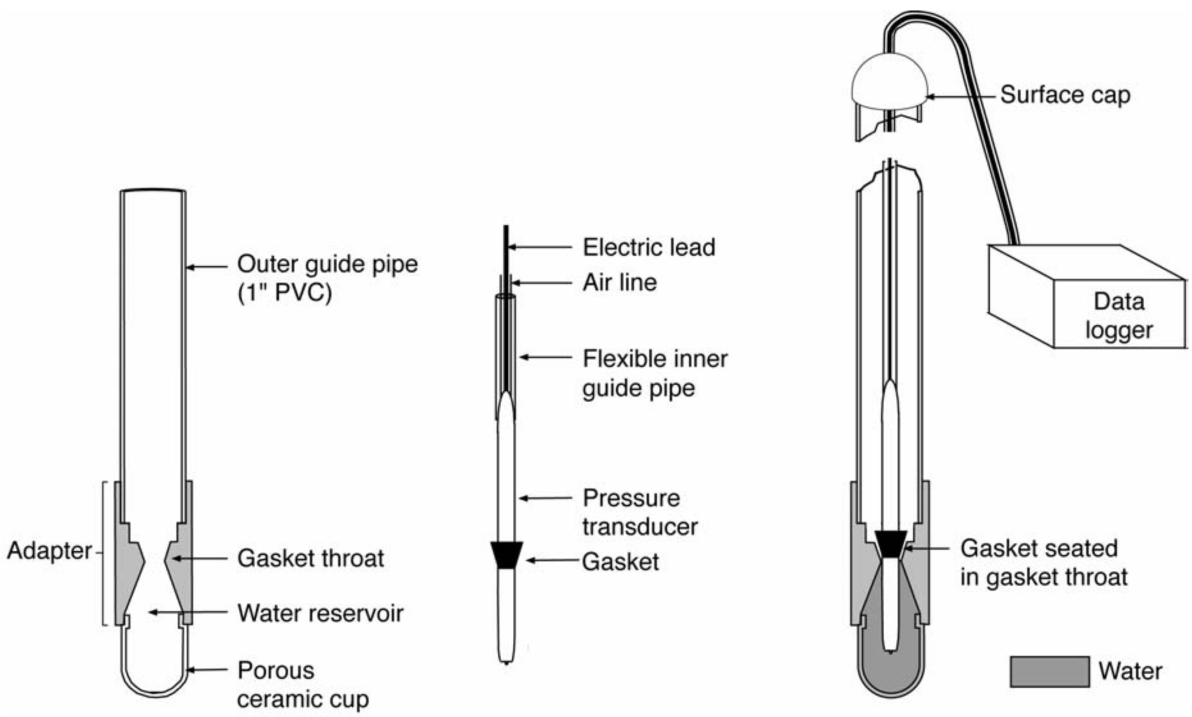

Figure 2.4. Schematic of Advanced Tensiometer Similar to that Deployed at the Tree Line Site in 200 W Area

2.2.3 Data Analysis

Data are retrieved by a CR-23X (Campbell Scientific Inc., Logan, Utah) data logger. A 20-W solar panel is used to charge a small 12V battery for data logger power. A CDPD digital modem is used for radio transmission of data to the laboratory computer where the data are stored and subsequently analyzed for graphical display on a web page. The following provides a summary of the data processing steps for the treeline data sets.

Figure 2.5 shows the data stream and processing pathway for the treeline data sets. The tools used to process the graphs for Vadose are Microsoft Access 2000, Windows 2000 Server, Internet Information Server (IIS), and Microsoft Office Web Components. The languages used are Visual Basic for Applications, Visual Basic Script, and HTML. Microsoft Access is currently being used to contain the data, with an eye toward moving to a more robust database solution when required. We are using Microsoft Office Web Components Version 10 (XP) to create the graphs. The graphs are created as .gif files on the server each time Office Web Components (OWC) is called from the browser. The graphs are also cleaned from the server at the same time, using the VBScript FileSystem object to check for any files in the gifs directory older than ten minutes. Active Server Pages/VBScript is used to query the database and pass the data on to OWC. A secure server is in place to make the graphs available to outsiders via password protection.

The process begins out in the field with the data logger, which sends data to a comma-delimited .dat file on a server. Once each day, the code in VadoseData.mdb executes, gathering the new data from each .dat file. These data are massaged at the database level to provide an extended date format (mm/dd/yyyy) from the Julian day and year in the data file and are then appended to the appropriate table. If the program fails or finds no new data, an email containing a description of the error is automatically sent to PNNL staff, i.e., Jennifer Carr and John Goreham. When an individual uses a web browser to request a page containing a graph of the data, the page sends a query via HTTP to the database and returns a recordset containing the relevant data. These data are then converted using the appropriate mathematical formula and calibration information for that dataset and then passed off along with graph display parameters to OWC. A graph in the format .gif is created in a dedicated directory on the server. This gif is then displayed in the browser. This will work in any browser that is compatible with the .gif file format. Each time a new .gif is created, a check is run on the directory, and any image older than 10 min (this time preference can be easily changed) is deleted from the directory to prevent the server space becoming filled with old images. Most of the data processing and graph creation are done via abstracted functions, making the administration and the addition of new data sets and graphs very simple. The data are retrieved for viewing on a controlled web site that requires PNNL permission to access. Contact the authors for the web address.

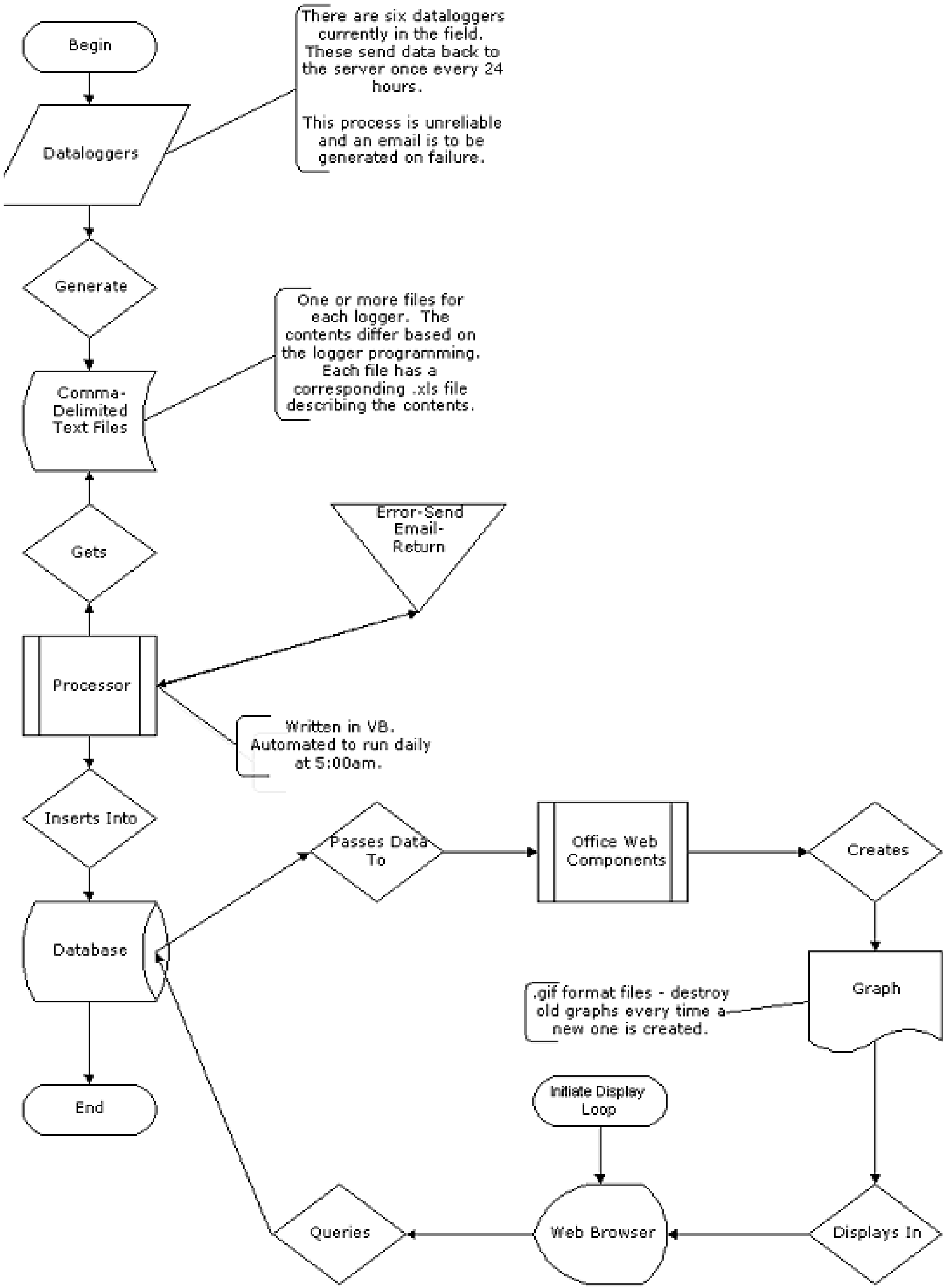

Figure 2.5. Flow Diagram of Data Stream for Treeline Data Sets

3.0 Results

Figure 3.1 shows the precipitation data for the 80-day monitoring period. Figure 3.2 shows the summary graph of the data stream that includes the irrigation (drip gage), the drainage (water fluxmeter), and the water storage changes for the 80-day monitoring period. It is clear that precipitation was a minor part of the water input—6 mm (0.24 in.) of precipitation vs. over 4000 mm (157.5 in.) of irrigation—for the 80-day monitoring period. Evapotranspiration (ET) was computed as difference between precipitation less water-storage change and drainage. The ET is approximate since the actual ET depends on the effective area of water removal from the soil. Based on expected overall water-removal rates, the area used for the ET calculation ranged between 3.9 and 4.2 m^2 (42 and 45 ft^2) (see Figure 2.1).

These data can also be converted into water volumes. The monitored irrigation at the tree line indicated that the drip emitters were discharging about 7.9 L per hour (2.1 gph) during the first 65 days of monitoring. This rate has been substantially reduced. During the last 7 days of monitoring, the discharge rate averaged 1.7 L per hour (0.44 gph). Subsequently, the drainage was correspondingly reduced from 6.4 L per hour (1.7 gph) to 2.9 L per hour (0.8 gph) for the same time periods. These values can be expressed also in terms of water thickness in a fashion similar to reporting rainfall (mm of water), so the reduction in drainage between the first 65 days and last 7 days of monitoring was from 36 mm/day down to 17 mm/day.

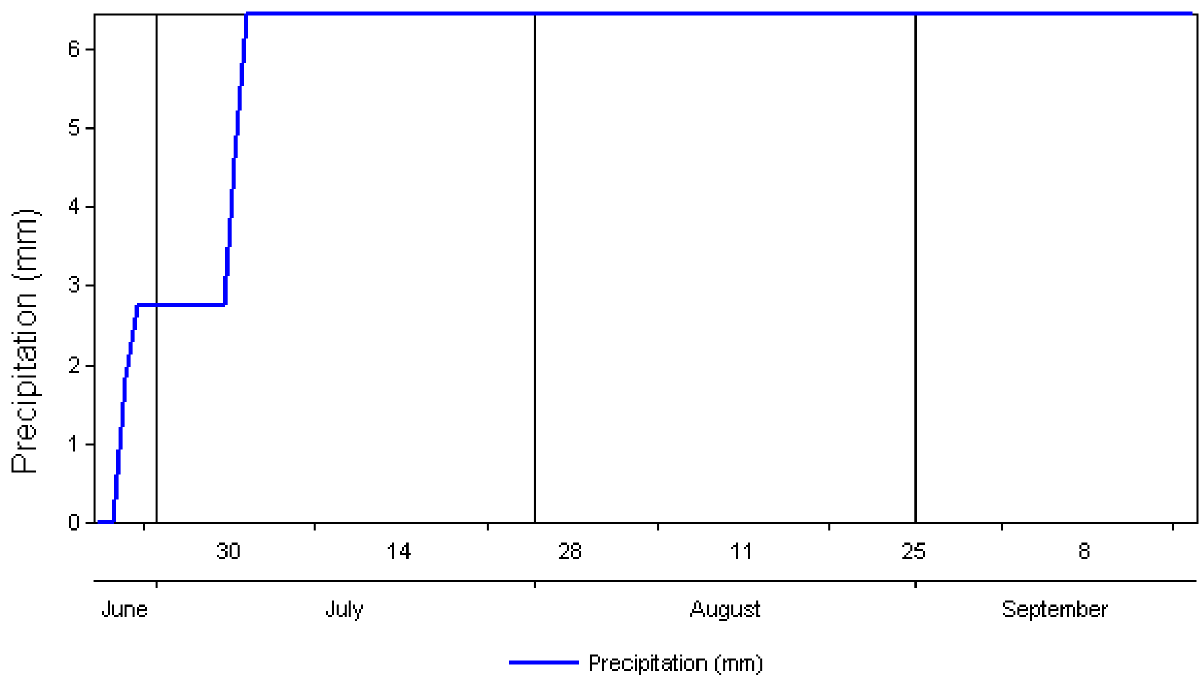

Figure 3.1. Precipitation Record for 80-Day Monitoring Period at Tree Line Site, 200 West Area, Hanford Site

In spite of the marked improvement in irrigation control, the irrigation and drainage rates are still excessive. The application rate still appears to be nearly three times the design rate of 57 L per day (15 gpd) per tree. This translates to an emitter discharge of 0.6 L per hour (0.16 gph). Emitter discharges can be controlled by pressure regulation and also by timing (on-off cycles). It is recommended that the emitters be regulated so that there are lower applications of water in future irrigation applications. In contrast to the tree line, there has been no drainage from the sand dune site or the site near Dayton Avenue. This was expected since there has been little rain during the monitoring period, and these sites have not been subjected to irrigation.

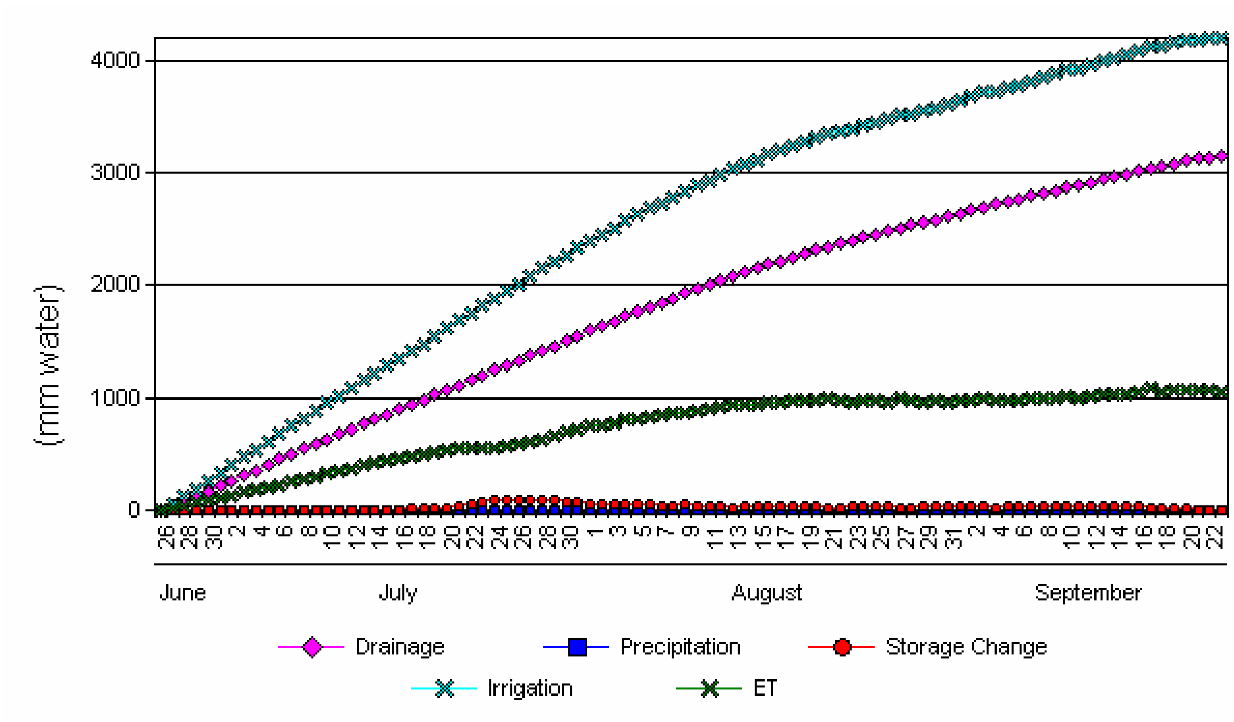

Figure 3.2. Water Balance Data for 80-Day Monitoring Period, Including Irrigation, Drainage, Water Storage Change and Evapotranspiration Expressed in mm of Water (equivalent height)

Data from the tensiometer (not shown here) are displayed on the web page daily in the form of total head profiles. The data show, as expected, that unit gradient conditions have persisted in the tree line during the irrigation period. The tensiometers will continue to be monitored to assess the impacts when the water is shut off and plants continue to transpire and subsequently dry the soil out. Pressures in the soil water should reflect those drying conditions when they occur. For now, it is expected that the tensiometers will continue to track closely the drainage events and because of the wet conditions confirm that the flux rates are high and drainage is persisting at this tree-line site.

4.0 Summary

A vadose-zone monitoring system has been set up at the tree wind break in the 200 W Area near Dayton Avenue and the solid-waste burial grounds. Water balance data (precipitation, irrigation, water-storage changes, and drainage) are being retrieved, processed and archived on a daily basis through a PNNL-operated data-acquisition system. Data from the site are reported for the period June 26, 2002, through September 24, 2002. There has been little rain—6 mm (0.24 in.)—since early July 2002, so water applied to the soil has been almost exclusively from irrigation. During the first 65 days of monitoring (26 June through 30 Aug), the water application rate averaged 734 L per day, i.e., 194 gallons per day (gpd), per tree, nearly 13 times the design application rate of 57 L per day (15 gpd) per tree. Recent adjustments have reduced the application rate to 159 L per day (42 gpd), still 2.8 times the design objective. Feedback from the monitoring data and adjustments in drip-line water application rates have resulted in subsequent reductions in drainage rates within the tree line. Drainage within the tree line from irrigation has exceeded 3100 mm (>10 ft) of water for the 80-day monitoring period. The drainage rate has been reduced more than half, from 36 mm/day, for the first 65 days, to 17 mm/day for the past 7 days, i.e., through September 24, 2002. Virtually no drainage has occurred outside of the tree line to date. Continued monitoring will provide an evaluation of the overall efficiency of the irrigation system, assist in irrigation control, and help assess the impact of the drainage on the subsurface.

5.0 References

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