THESIS

COMPARISON OF ALTERNATIVE ESTIMATORS OF DEEP PERCOLATION IN FULL AND DEFICIT IRRIGATION

Submitted by

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ABSTRACT

COMPARISON OF ALTERNATIVE ESTIMATORS OF DEEP PERCOLATION IN FULL AND DEFICIT IRRIGATION

Farmers are increasingly selling their water rights to growing municipalities and abandoning their farms (buy and dry). A loss of food production in the midst of a growing population is a recipe for food shortages. There is a need for municipalities to meet their water demand from the water rights held by farmers while farmers continue to produce crops. One solution to prevent a 'buy and dry' scenario is for farmers to lease a portion of their water rights to municipalities and continuing to farm under a deficit irrigation program. For this solution to work Colorado Water Law requires that return flows be maintained for down gradient water users. According to Colorado Water Law, deep percolation is any water in the unsaturated zone below the root zone (Colorado Foundation for Water Education, 2009). Deep percolation is also assumed to result in groundwater recharge.

The first objective of this study is to quantify deep percolation. The second objective is to determine an optimal deficit irrigation technique. The third objective is to evaluate the methods used to estimate deep percolation.

This study investigated three different cornfields (referred to as Blocks) in 2011 in Greeley, Colorado. Each block practices different flood irrigation techniques for the purpose of finding an optimal deficit irrigation plan. Block 2 practices traditional flood irrigation, Block 1 applies water at the same frequency as in Block 2 but uses half the volume of water, and Block 3 only irrigates twice during the growing season but applies large volumes of water per irrigation.

Three methods were used to estimate deep percolation in each block: Lysimeters, Unsaturated Zone Water Balance (UZWB), and Darcy Flux. At the same time as this study, the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) estimated deep percolation using a water balance method. The lysimeter method found an average deep percolation for Block 1 at 58mm, Block 2 at 334 mm, and Block 3 at 238 mm. The UZWB method found an average deep percolation for Block 1 at 291mm, Block 2 at 518 mm, and Block 3 at 516 mm. The Darcy flux method found an average deep percolation for Block 1 at 209 mm, Block 2 at 160 mm, and Block 3 at 1,246 mm. The USDA-ARS found an average deep percolation for Block 1 at 391 mm, Block 2 at 838 mm, and Block 3 at 635 mm. Corn was harvested by the USDA-ARS at the end of the season and yields were estimated. Block 1 produced 149 bushels/acre, Block 2 produced 196 bushels/acre, and Block 3 produced 84 bushels/acre.

All methods found the irrigation strategy applied to Block 3, in relation to the other Blocks, resulted in the greatest percentage of deep percolation compared to water applied. The lysimeter method determined that the irrigation plan used in Block 1 was the least efficient in creating deep percolation while the UZWB and Darcy Flux method found that the irrigation applied to Block 2 was the least efficient. Although Block 3 was the most effective in producing deep percolation it produced the least amount of corn.

The UZWB method was thought to be the most valuable method in this study. Installation of the neutron probe access tubes caused minimal disturbance to the soils and this method investigated the entire unsaturated zone below the zero flux plane, which accounted for most vertical heterogeneity. The lysimeter method was the most direct method, but installation caused extensive soil disturbances. However, once the soil settled over time the lysimeter

method provided consistent and reliable results. In this study the Darcy Flux Method provided the greatest range in results compared to the other methods. The primary concern in using the estimates from this method was the quality of the data collected by the sensors.

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CHAPTER 1

1: INTRODUCTION

1.1 Motivation

As of 2009, agricultural water use for irrigation accounted for 86% of the total water use in Colorado and in the western United States while water devoted to municipalities accounted for 7% (Colorado Foundation for Water Education, 2009). As population increases, municipalities are consuming water that was previously used for agriculture. Water used for agriculture is sought after by municipalities because 1) a large portion of water use in Colorado is for agriculture and 2) farmers in Colorado tend to possess the most senior water rights. A senior water right means that the owner possesses priority use of water, for example from a ditch or an aquifer. However, water rights also require that a portion of the water used for irrigation return to the ditch or aquifer for use by other water rights holders downstream. This is referred to as return flow. Currently, municipalities will buy the entire rights to a farmer's water then the land previously used for farming will be left dry. Recharge ponds are then constructed in the abandoned farm fields to recharge the aquifer in order to abide by Colorado Water Law. Abandoning farming negatively affects the local economy and is not sustainable when population is increasing and food is in greater demand. A solution to meet the need for water and still maintain productive farms is for farmers to lease a portion of their consumptive water use to municipalities. This solution is possible if it can be proven to the State of Colorado that after leasing a portion of their water, farmers are not using more for farming than was allotted to them in their water rights and that they are meeting the return flow requirements. This solution and the motivation for this project require the quantification of return flows to the aquifer.

1.2 Objectives

The first objective of this study is to quantify deep percolation return flows beneath three irrigated corn fields. According to Colorado Water Law, deep percolation is any water that travels beneath the root zone and recharges the aquifer (Colorado Foundation for Water Education, 2009). The second and third objectives of this study include 2) using the quantities of deep percolation to determine an optimal deficit irrigation technique and 3) evaluate the methods used to estimate deep percolation to determine the best method. Figure 1 illustrates the components of the water balance considered in this study.

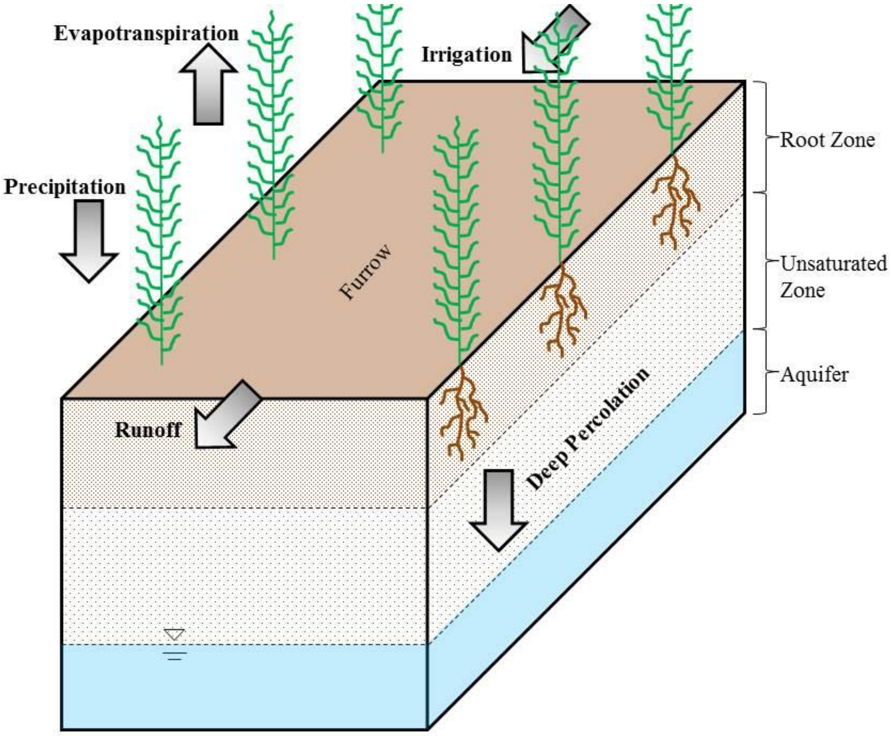


Figure 1: Illustration of water balance components.

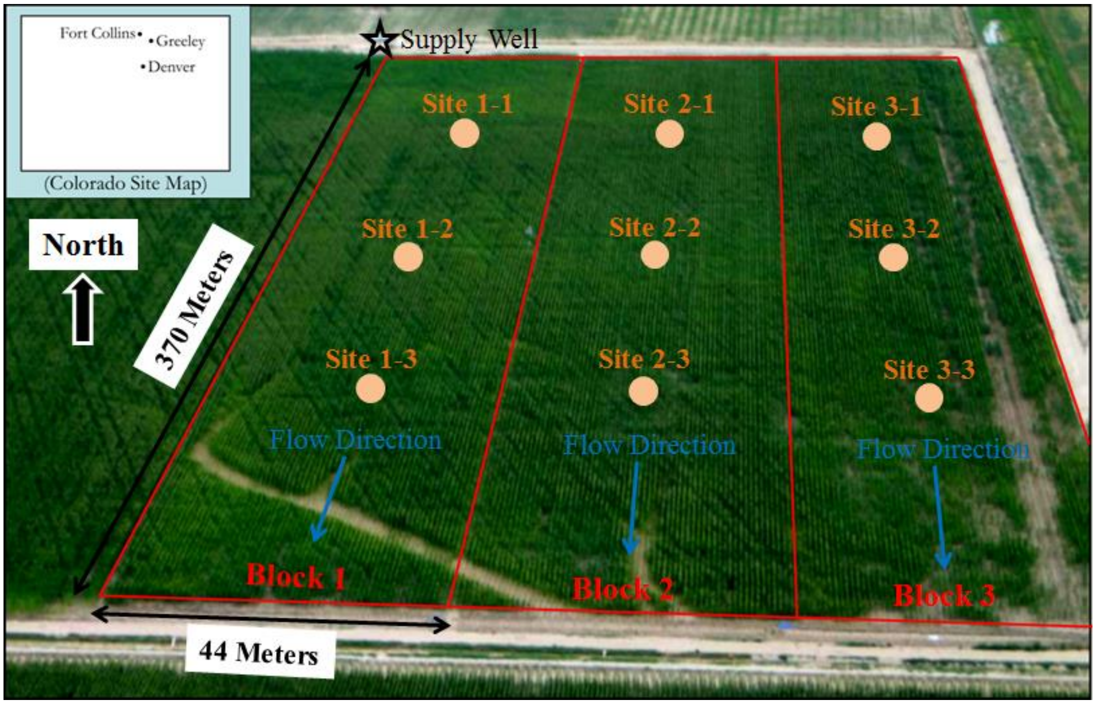
This study was performed in 2011 using three different flood irrigation techniques in a furrowed field. The selection of the irrigation techniques is based on finding an optimal deficit irrigation plan. An optimal deficit irrigation plan saves consumptive water use compared to traditional irrigation techniques, produces an acceptable and profitable crop, and supplies return flows required by Colorado Water Law. Four methods were proposed to estimate deep percolation; Lysimeters, Unsaturated Zone Water Balance, Darcy Flux, and the Water Table Fluctuation (Derby et al., 2000; Arnold, 2011; Hubbell, 2004; Healey and Cook, 2002). In 2010 equipment was installed at the research site to apply each of the methods including drainage lysimeters to collect water, neutron probe access tubes to measure water content, sensors for measuring water content and water potential, and monitoring wells for measuring water table elevations. Each method contains potential errors, such as sampling size and the quality of field measurements. If various methods for estimating deep percolation are implemented a more reliable deep percolation volume can be estimated than if just one method is used.

CHAPTER 2

2: SITE DESCRIPTION

2.1 Location and Site Use Overview

Field data collection for this project was conducted in a 48,562 square meter cornfield in Greeley, Colorado (Figure 2.1). The study area, Northern Colorado Research Facility (NCRF), is managed by Regenesis Management Group, United States Department of Agriculture-Agricultural Research Service (USDA-ARS), and Colorado State University for the primary purpose of studying deficit irrigation techniques. The NCRF is planted with corn and is divided into three sections, each 370 meters long by 44 meters wide. Each block practices different flood irrigation techniques for the purpose of finding an optimal deficit irrigation plan (Figure 2.2). Block 2 practices traditional flood irrigation, Block 1 applies water at the same frequency as in Block 2 but uses half the volume of water, and Block 3 only irrigates twice during the growing season but applies large volumes of water per irrigation.



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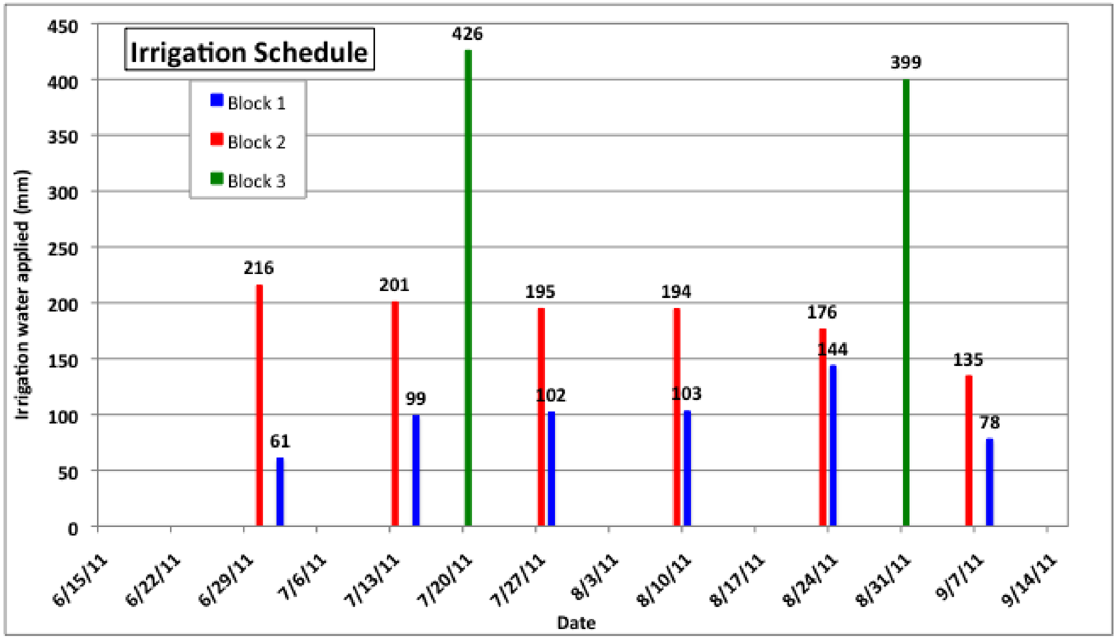


Figure 2.2: Irrigation Schedule (Thomas Trout (USDA-ARS-WMRU), personal communication, January 2012).

2.2 Hydrogeology

The study area is located on the edge of the Denver Basin underlain by bedrock approximately 30 meters below the surface (Arnold, 2011). The bedrock is of the upper Cretaceous age (Robson and Banta, 1987). The alluvium in this region consists of sand and gravels with a saturated thickness ranging from 15 to 27 meters thick (Robson et al., 2000). The soils in the upper section of the alluvium at the site mostly consist of clay loams (#41 in Figure 3) except for an area of fine sandy loams (#47 in Figure 3) in the northwest (USDA - Natural Resource Conservation Service (NRCS) Custom Soil Resource Report). The USDA-NRCS soils report describes the clay loams areas as clay loams extending to 74 cm below the surface then sandy loams between 74 to 152 cm depth. Areas of fine sandy loams are described as fine sandy loams extending to 25 cm below the surface, sandy clay loams between 25 to 64 inches deep, and fine sandy loams between 64 and 152 inches deep.

The depth to the water table in 2011 at the site ranged from 4 to 8 meters below the ground surface. Prior to the start of irrigation the water table gradient was towards the south.

Figure 3: USDA-NRCS Custom Soil Resource Report (Natural Resource Conservation Service, 2014). 41-clay loam, 47-fine sandy loam

2.3 Climate

The study area is in a semi-arid environment. From 1967-2005 the lowest temperatures typically occurred in January at about -9° C and highest temperatures were typically recorded in July at about 32° C average (Arnold, 2011). For the same period, mean annual precipitation was 356 mm, of which 70% occurred from April to September. The monthly maximum and minimum temperatures and monthly precipitation for 2011 are provided in Table 1 (CoAgMet, 2013). In 2011 the maximum temperature (37.6° C) was recorded in July. This is about 5° C higher than the average high temperature recorded from 1967-2005. The most precipitation (97.3 mm) in 2011 was recorded in May. In 2011 the total annual precipitation measured at the study area was 280 mm, which is below the annual mean of 356 mm from 1967-2005. Thirty four percent (34%) of the annual precipitation in 2011 fell in May, the month the corn was planted, and 80% of the total fell between April and September.

Table 1: 2011 Climate Summary for CoAgMet Station Greeley 04 adjacent to the study area. (CoAgMet, 2013)

	Temperature (°C)		**Precipitation (mm)**	
	Maximum	*Minimum*	*Maximum*	*Sum*
January	18.2	-26.5	0.3	0.5
February	20.8	-26.6	0.8	1.3
March	23.8	-11.4	1.8	5.1
April	28.9	-7.6	4.6	21.3
May	30.5	-5.0	33.0	97.3
June	35.8	6.5	8.1	20.3
July	37.6	10.7	13.5	40.6
August	36.2	10.4	14.2	25.1
September	35.0	0.9	9.1	21.8
October	30.5	-11.9	22.9	39.4
November	19.7	-12.9	4.6	6.4
December	15.8	-23.5	0.3	1.3

CHAPTER 3

3: METHODS

3.1 Background

Multiple methods should be applied when determining deep percolation because of the inherent uncertainties associated with each method (Scanlon et al., 2002). Difficulties in calculating deep percolation arise in part from the difficulty of collecting field measurements. Another difficulty is in transferring the small scale of point measurements to larger scales for an entire field. This section reviews four methods used to measure deep percolation: lysimetery, unsaturated zone water balance (UZWB), Darcy flux, and water table fluctuation (WTF).

In Chapter 4, deep percolation estimates calculated by a water balance model used by the United States Department of Agriculture - Agricultural Research Service (ARS) Water Research Management Unit (WRMU) in Fort Collins, Colorado will be presented. The model was described by Thomas Trout in the following paragraph (personal communication via email, February 25, 2015).

Deep percolation was estimated following irrigation or precipitation events as the difference between the effective (infiltrated) irrigation or precipitation amount and the soil water deficit in the root zone at the beginning of the event (Thomas Trout, personal communication via email, February 25, 2015). The soil water deficit was estimated from the soil water deficit measured prior to the event plus estimated accumulated evapotranspiration between the measurement and the event. Soil water content was measured with a neutron moisture meter (CPN Hydroprobe 503 DR, InstroTek, Martinez, CA) at 0.3m depth increments beginning at 0.3

m depth. Soil water content was measured in the 0 - 0.15 m surface layer by time domain reflectometry (MiniTrace, Soilmoisture Equipment Corp., Santa Barbara, CA). Both devices were field calibrated with gravimetric soil water content samples. Soil water content was generally measured within 24 hours prior to irrigation events. Field capacity for each soil layer was determined as the soil water content 24 hours after irrigation or precipitation events that created drainage to lower soil layers. Soil water deficit was calculated as the difference between field capacity and soil water content. The root zone for the corn crop was estimated at 1.05 m, so the soil water deficit was the sum of deficits in the 0-0.15, 0.15-0.45, 0.45-0.75, and 0.75-1.05 m soil layers. Irrigation or precipitation events that resulted in deep percolation were confirmed by increased measured soil water content in soil layers below 1.05 m following the event.

3.1.1 Lysimeter

Lysimeters are open-topped containers that capture water after it enters the ground. Lysimeters are traditionally placed near the surface and used to measure total change in storage (Healy, 2010). Weighing lysimeters were created to measure the rate of change in water storage used to estimate evapotransipration (Healy, 2010). The problem with traditional lysimeters is that water at the bottom of the soil column had no place to go and created unnatural pressure head profiles which disrupted the natural flow regime (Healy, 2010). Lysimeters used in drainage studies are buried deep enough to allow for free drainage. Lysimeters collect a volume of water that is equal to deep percolation making this the most direct method. Converting the volume of water collected to length units is useful, so the volume of deep percolation can be compared to other quantities, such as water added to the field or evapotranspiration. Equation 1 shows the conversion of a volume of deep percolation to length units.

$$\text{Deep Percolation [L]} = \frac{\text{Water from Lysimeter } [\text{L}^3]}{\text{Area of Lysimeter } [\text{L}^2]} \qquad \text{Equation 1}$$

When measuring deep percolation using a drainage lysimeter, the base must be at or below the bottom of the root zone to avoid the effects of evapotranspiration (Derby et al., 2002). In cases of deeply buried lysimeters it can be assumed that water flow no longer has a horizontal flow component (Figure 4).

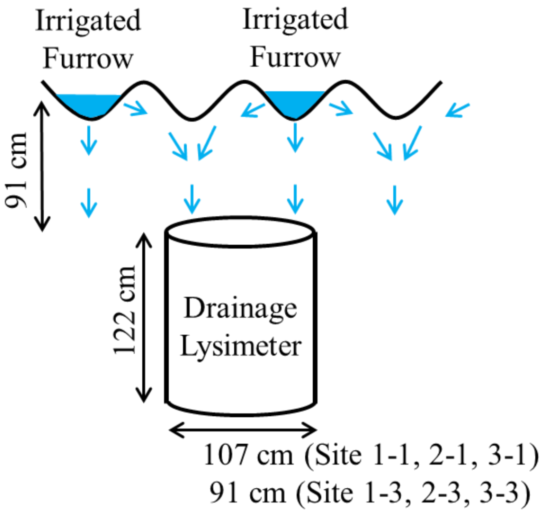


Figure 4: Schematic cross section of lysimeter collecting water. Arrows represent water flow directions.

Equilibrium-tension lysimeters are created to extract water from the base of lysimeters (Healy, 2010). The primary water extraction systems are ceramic soil water samplers near the base of the lysimeters, which are capable of collecting water held under tension in the soil. The soil water samplers are applied a vacuum relative to the soil water potential in order to mimic the natural flow of water through the soil. When soil water exists under positive pressure it flows through the lysimeter and into the reservoir at the base. Once the soil has drained and water is held under tension, the soil water samplers extract water from the soil. The combination of the reservoir and soil water samplers limits the chance that any deep percolation is not accounted for (Derby et al., 2002).

3.1.2 Unsaturated Zone Water Balance

The Unsaturated Zone Water Balance (UZWB) method estimates deep percolation by accounting for the changes in soil water storage in the unsaturated zone below the zero flux plane (ZFP) (Healy, 2010). The ZFP is the horizontal plane where the vertical hydraulic gradient is zero (Scanlon et al., 2002). Below this plane water movement is controlled by soil water tension and gravity (Healy, 2010). Above the ZFP soil water is acted upon by soil water tension and the forces of evapotranspiration (Healy, 2010). The significance of the ZFP is that soil water above this plane moves upwards, remains stationary, or is extracted by roots, while the water below this plane moves downward or remains stationary (Delin et al., 2000). The position of the ZFP changes according to changing soil water contents, evapotranspiration rates, rooting depths, and soil types (Healy, 2010). The ZFP depth is determined using soil water tensiometers (Delin et al, 2000). The UZWB method will underestimate deep percolation if the ZFP depth used in the calculation is determined to be shallower than what actually exists (Arnold, 2011). Similarly, if the ZFP is set deeper than what actually exists then this method would overestimate deep percolation (Arnold, 2011).

The UZWB method measures the change in soil water storage between two different times in the unsaturated zone below the ZFP and above the water table (Arnold, 2011). Soil water storage is the volume of water, usually expressed as a volume per area, stored in the unsaturated zone at one time. The change in soil water storage is the change in the quantity of water that exists in the soil between two different times, each time consisting of different soil water contents. Deep percolation is estimated by integrating the change in soil water storage between the ZFP and the water table (Figure 5; Delin et al., 2000; Healy, 2010).

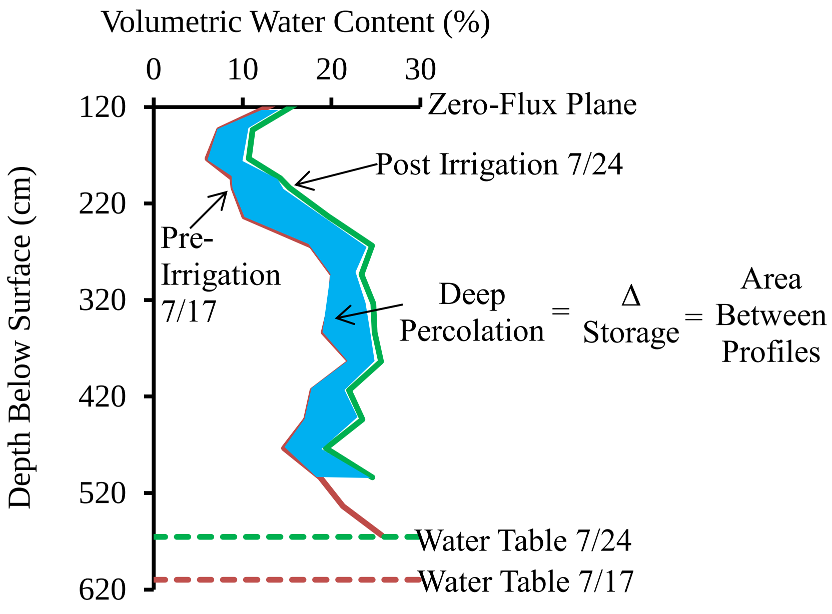


Figure 5: Plot showing the change in soil water storage used to calculate deep percolation by the UZWB method (following methods described by Arnold, 2011).

This method calculates deep percolation by finding the difference between water in storage prior to an irrigation event and maximum water in storage after an irrigation event (Arnold, 2011).

$$\Delta S = \sum_{i=1}^{N} \left[\frac{\Delta\theta_i + \Delta\theta_{i+1}}{2}\right] \Delta z \qquad \text{Equation 2}$$

- i indicates the depth of a water content measurement. N is the total number of measurement depths
- $\Delta\theta_i$ is the change in volumetric water content between the two times for sensor i [L^3/ L^3]
- Δz is the thickness of the unsaturated zone between measurement depths [L]

Soil water content is measured using either buried sensors connected to a data logger or a neutron probe placed inside a buried access tube. Soil water measurements near the water table are collected just above the capillary fringe (Arnold, 2010). Some applications of this method do not measure the change in soil water storage throughout the entire unsaturated zone. By collecting measurements throughout the entire unsaturated zone this method is an actual estimate of groundwater recharge (Healy, 2010). The soil water content measurements need to capture the leading and trailing edges of the pulse of water (Healy, 2010). This method is best applied where large fluctuations in soil water content exist and where the water table is deeper than the ZFP (Scanlon et al., 2002).

3.1.3 Darcy Flux

The Darcy Flux approach to estimating deep percolation in the unsaturated zone requires knowledge of the vertical total head gradient and hydraulic conductivity as a function of soil water content or soil water tension (Equation 3; Healy, 2010).

$$q = -K(\theta) * dH/dl \qquad \text{Equation 3 (Hubbell, 2004)}$$

- q: water flux [L/T]
- K(θ): hydraulic conductivity of the porous medium as a function of water content [L/T] at the time the measurement was collected
- θ: soil volumetric water content [L^3/ L^3]
- dH/dl: hydraulic gradient [L/L]
    - dH is the difference in the total hydraulic heads between depths
    - dl is the distance between depths

Unsaturated K values are estimated using the van Genuchten-Mualem Model (Schaap et al., 2001):

$$K(\theta) = K_s * \left(\frac{\theta(h) - \theta_r}{\theta_s - \theta_r}\right) * \left\{1 - \left[\left(\frac{\theta(h) - \theta_r}{\theta_s - \theta_r}\right)^{\frac{n}{n-1}}\right]^{1-\frac{1}{n}}\right\}^2 \qquad \text{Equation 4}$$

- K(θ): hydraulic conductivity dependent upon soil water content [L/T]
- K_S: saturated hydraulic conductivity of the porous medium [L/T]
- θ: volumetric soil water content [L^3/ L^3]
- θ_s: volumetric saturated soil water content [L^3/ L^3]
- θ_r: residual volumetric soil moisture content [L^3/ L^3]
- n**:** curve shape parameter of model, pore structure specific to soil type [-]
- h: soil water potential [L]

The parameters n, K_s, and the saturated and residual water contents are determined using a pedotransfer function (PTF) based upon the soil textural classification (Schaap et al., 2001).

PTF's relate soil properties (e.g. saturated hydraulic conductivity) to specific soil types (e.g. sandy clay loam). The main advantage of using PTF's is that it saves time in the lab (e.g. performing soil moisture retention curves). One PTF commonly used is called the Rosetta model (Schaap et al., 2001). The hydraulic parameters in the Rosetta model for each soil type are provided in Appendix E. The soil water content in this model is the only parameter that needs to be measured in addition to knowing the soil type. Soil types are found by conducting a soil textural analysis. An average hydraulic conductivity between two different layers is used in Equation 3. The average is the weighted based on the thicknesses of each layer (Hillel, 2004).

The vertical hydraulic gradient also needs to be measured in order to apply the Darcy Flux method. The hydraulic gradient can be calculated from soil water potential values measured by tensiometers buried at known depths. A vertical hydraulic gradient value of one is used where fluctuations in pressure head are not caused by precipitation or evapotranspiration, but instead under saturated conditions where the movement of water is caused by gravity (Healy, 2010). A value of one in Equation 3 makes the hydraulic conductivity equal to the flux. To calculate deep percolation, the modified Darcy equation is applied below the ZFP.

3.1.4 Water Table Fluctuation

The Water Table Fluctuation (WTF) method is based on the assumption that groundwater recharge causes the water table to rise in unconfined aquifers (Healey and Cook, 2002). The water table is defined as the upper boundary of an unconfined aquifer where the total hydraulic head is equal to the elevation of the water table. The WTF method is best applied to sites where the water table is shallow, but not so shallow that the effects of evapotranspiration reach the water table. In addition, rises in groundwater levels are assumed to be the result of recharge events rather than other causes like entrapped air or barometric pressure changes (Healy, 2010).

Recharge, R [L/T], is calculated using Equation 5 where Sy [L^3/ L^3] is the specific yield of the aquifer and dh/dt [L/T] is the change in the water table elevation with time (Healey and Cook, 2002).

$$R = S_y \frac{dh}{dt} \qquad \text{Equation 5}$$

Figure 6 shows how to derive dh and dt from an individual recharge event.

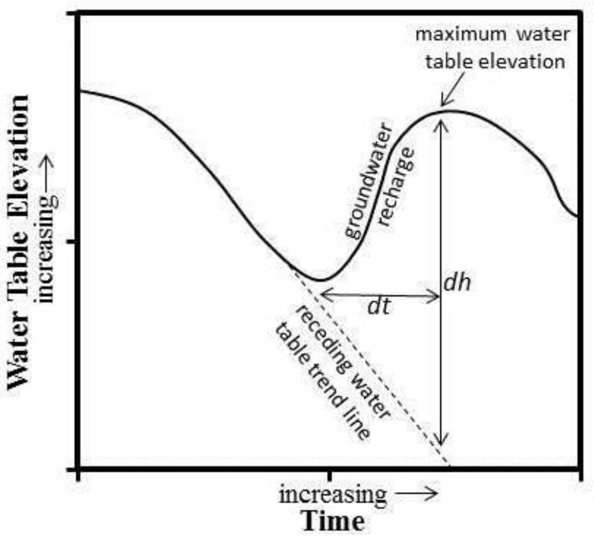


Figure 6: Plot describing process for deriving dh/dt in the Water Table Fluctuation Method (Healey and Cook, 2002)

The change in groundwater elevation is derived by extending the receding water level trend prior to the rise then taking the difference between the maximum groundwater elevation following the recharge event and the groundwater elevation at the same time along the extrapolated recession line.

There are several advantages to the WTF method. Unlike methods that rely on point measurements in the unsaturated zone (Lysimeters, UZWB, and Darcy Flux) the WTF method represents recharge over larger areas (Scanlon et al., 2002). Other methods require investigations in the unsaturated zone where groundwater processes are more complex and greater heterogeneity exists. Also, the elevation of the water table is relatively easy to measure in wells. The primary disadvantage of the WTF method is that specific yield of the aquifer can be difficult to determine. Methods for estimating specific yield are time consuming and values can vary greatly between methods (Scanlon, 2002). An aquifer test is a common method to determine the specific yield of the aquifer. If results of the aquifer test do not prove to be reliable then specific yield values provided in a table may be used (Loheide et al., 2005). Specific yield values from a table are chosen according to soil type.

3.2 Instrumentation

Three different irrigation techniques are compared in this study. For each irrigation technique, water is applied to every other furrow at the north end of the field then water flows south in the direction of the sloping ground surface. The field is divided into three different blocks (Figure 2.1). Each block uses a different irrigation technique and contains three study sites. The sites are numbered using the block number first followed by 1, 2, or, 3, which indicates if the site is at the north, middle, or south end of the block. The USDA-ARS estimated the water applied to each site by using a combination of data: a flume installed at the southern (outlet) end of the furrows, field measurements of water advancement in the furrows during irrigation, the use of flumes in the furrows to measure water volumes, a flow meter to record water volume from the supply well, and use of the Kastiakov curve (Table 2; Kastiakov, 1932). The total amount of water applied to each Block in Table 2 is the average of the estimates for the north and south sites in each block.

Table 2: Irrigation water applied in 2011. This table presents data from the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015). The estimates provided for the Blocks are the average of the estimates for the north and south sites in each block.

Blocks	**Irrigation by USDA-ARS Water Applied (mm)**
Site 1-1	954
Site 1-2	550
Site 1-3	157
Site 2-1	1590
Site 2-2	1096
Site 2-3	675
Site 3-1	1101
Site 3-2	902
Site 3-3	508
Block 1	556
Block 2	1133
Block 3	805

Block 2 is the control for this study and is irrigated using traditional techniques. It was irrigated six times during the season. Block 1 uses a deficit irrigation technique, which applies water at the same frequency as the control block, but uses approximately half the volume of water per irrigation event. Block 3 applies water only twice in the growing season, but uses a significantly larger volume of water per irrigation event.

Each block contains the same instrumentation. A total of nine sites are monitored. Since flood irrigation prevents water from being applied evenly throughout each block, three sites per block are required to observe the spatial distribution of water application and infiltration. Sites are located at ¼, ½, and ¾ positions lengthwise (north/south) in each block and centered widthwise (east/west) (Figure 2.1). Equipment at the sites is installed in line under the middle corn row (Figure 7).

Figure 7: Photograph of instrumentation at the ground surface at Site 3-1.

Monitoring equipment was installed prior to the start of irrigation in 2010. Figure 8 shows a cross section of the instruments at Sites 1-1 and 1-3.

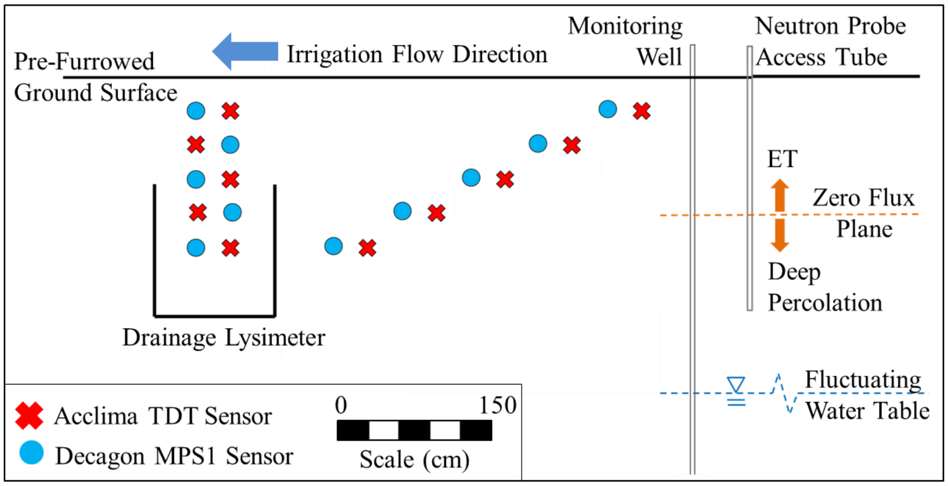


Figure 8: Schematic showing the instrumentation installed underground at Sites 1-1, 1-3, 2-1, 2-3, 3-1, and 3-1. The cross section at Sites 1-2, 2-2, and 3-2 are similar, but do not have the lysimeter or the sensors inside the lysimeter. Acclima TDT sensors are used to measure soil water content. Decagon MPS1 sensors are used to measure soil water potential.

Site 1-1 is the same configuration as Sites 2-1 and 3-1 and Site 1-3 is the same as Sites 2-3 and 3-3. The cross section of the instrumentation at Sites 1-2, 2-2, and 3-2 are similar to Figure 8, but do not have lysimeters (or the sensors inside the lysimeters).

Appendix A provides a detailed description of the instrumentation installed at the site. Sections within Appendix A include information on sensors, lysimeters (includes soil textures), and wells.

3.3 Design

3.3.1 Lysimeters

The only lysimeter measurement required in the field is the volume of water collected. No more than a day prior to an irrigation event a peristaltic pump is used to extract water from the gravel reservoir. During the same visit, the soil water samplers are emptied of water and a negative pressure is applied. A 713-cm vacuum is applied to the soil water samplers to remove soil water held under tension. The vacuum pressure was chosen per recommendation from Soil Moisture Equipment Inc. because it exceeds the estimated soil water tension for the sandy and loamy soils in the lysimeter, but does not create preferential flow paths (Derby et al., 2002). The secondary water extraction system is tubes set in a pea gravel reservoir at the bottom of the lysimeters.

Following irrigation events water is extracted from the soil water samplers and reservoir and a vacuum is reapplied to the soil water samplers. The timing of re-entering the field after an irrigation event varies and depends on when the ground is dry enough to walk on without damaging the furrow and ridge topography. The process of extracting water and reapplying a vacuum is done on average every other day until no more water is extracted from the lysimeter. Twice weekly visits are recommended to assure all water is being extracted.

3.3.2 Unsaturated Zone Water Balance

Neutron probe measurements are collected below the zero flux plane (ZFP). Soil water potential sensors placed between 30 cm and 152 cm below the ground surface were used to determine the location of the ZFP. The ZFP typically occurred at the base of the root zone for mature corn in this study, approximately 122 centimeters below the ground surface (Arnold, 2011). The groundwater level is measured prior to taking the readings to make sure the neutron probe is not placed in the water and to verify groundwater levels recorded by the pressure transducers. Measurements are collected prior to irrigation and multiple times following an irrigation. The first set of measurements following an irrigation is collected once the ground is dry enough to walk on without damaging the furrow and ridge topography. Multiple measurements are taken prior to the next irrigation to make sure measurements are collected at the time the maximum water in storage exists.

The first step in calculating deep percolation using the UZWB method is finding the difference between water in storage prior to an irrigation event and maximum water in storage after an irrigation event (Equation 2). The second step is determining the volume of water entering the aquifer between the start of the irrigation event and the time when the first set of neutron probe measurements are collected following the irrigation event. The reason for this calculation is to account for water recharging the aquifer that was not accounted for in the UZWB method. In other studies the UZWB method was thought to capture all the recharging water from an irrigation event because it was determined that the bottom pulse of water from the irrigation event was captured by the set of water content measurements collected after an irrigation event. In this study, entrance into the field was often delayed because of the muddy field conditions; therefore there is the possibility that water in addition to that estimated by the UZWB method recharged the aquifer. This water volume is determined by finding the average rate that water in the unsaturated zone recharges the aquifer and multiplying that rate by the number of days between the irrigation event and the time the maximum water in storage was measured. The average rate of water draining through the unsaturated zone into the aquifer is found by dividing the difference in the total amount of water in storage at two times by the length of time. The draining rates are calculated from the soil water content measurements collected during the drying period of the previous irrigation event (Figure 9).

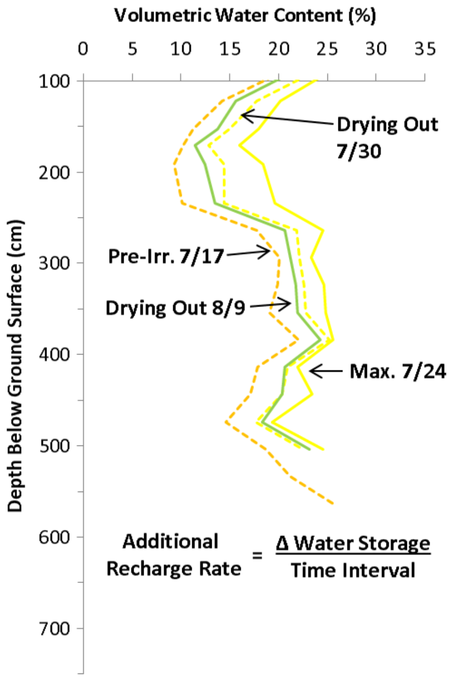


Figure 9: Plot showing the drying period from the previous irrigation event. The rate of water drainage found from this plot is used to calculate the extra water draining into the aquifer in the following irrigation event, which is not accounted for by the UZWB method.

3.3.3 Darcy Flux

Data loggers collect volumetric water content and soil water potential readings from the buried sensors every 15 minutes. A soil survey provided textural analyses of the soils at each site down to a depth of about 200 cm (Figure A.10). Hydraulic conductivity of the soils is determined from the textural analysis using the Rosetta model, a pedotransfer function described in Section 3.1.3. The process for conducting a soil textural analysis is first performing a preliminary textural analysis in the field. This preliminary analysis identifies soil textures by touch and is useful in determining the breaks between soil types in the profile. Soils are then placed in paper bags and delivered to the Soil, Water, and Plant Testing Laboratory at Colorado State University. The lab determines the percent of sand, silt, and clay using the hydrometer method (Colorado State University Soil, Water, and Plant Testing Laboratory, 2011). The hydrometer method is based on Stoke's law stating that the velocity of a spherical particle settling under gravity in a fluid of some density is proportional to the particles radius (Hillel, 2004). Soil textures from the lab are provided in Appendix A.

The first step in estimating deep percolation using the Darcy Flux method is determining the flux (q) in Equation 3. The hydraulic gradient in Equation 3 is determined by the difference between total soil water potential values measured by the Decagon MPS1 sensors at 120 and 152 cm depths. Total hydraulic head values are derived from the soil water potential values provided by the Decagon MPS1 sensors by adding an elevation. The ground surface elevation at each site was measured during a GPS survey using the NGVD29 elevation datum. The hydraulic conductivity, $K(\theta)$, is determined using the van Genuchten-Mualem Model (Equation 4, Section 3.1.3). The hydraulic conductivity was calculated for each depth at each time. The hydraulic conductivity used in the Darcy Equation (Equation 3) was the average of the hydraulic conductivities between the two depths or the value from just one depth was used if the other depth had no data for that time. A weighted average based upon soil layer thicknesses was not necessary because each layer was the same thickness of 30 cm (Prudic, 1991). The existing soil water content value used in Equation 4 is measured using the Acclima TDT sensors (Section 3.2.2: Sensors). The shape parameters and saturated and residual water content values used in Equation 4 are determined by entering the sand-silt-clay percentages from the soil textural analysis into Hydrus 1D (Simunek et al., 2011). Hydrus 1D is a numerical model used to simulate water, heat, and solute flow through saturated or partially saturated porous media.

Hydrus 1D uses the Rosetta model as its pedotransfer function providing hydraulic parameters for particular soil types.

The second step in estimating deep percolation by the Darcy Flux method is finding the total volume of water that passes between the sensors placed at 120 and 152 cm depths over a specified time interval (Equation 6).

$$\text{Deep percolation} = q \times \Delta t \qquad \text{Equation 6}$$

- deep percolation L
- q: water flux [L/T]
- Δt: time interval [T]

3.3.4 Water Table Fluctuation

Pressure transducers are installed and calibrated in the northern and southern monitoring wells to measure and record the depth to groundwater every 15 minutes. A water level meter is used to periodically record groundwater levels for quality assurance. Specific yield values were determined from an aquifer test performed at the site. The water supply well was used in the test to remove water from the aquifer. The other wells at the site were used to record water table drawdown. The Theis solution was to be used to estimate the specific yield of the aquifer. A specific yield of 0.218 was estimated from the well at Site 3-1, 0.018 at Site 2-1, and 0.079 at Site 1-1. Once it was decided that the Water Table Fluctuation (WTF) method was not applicable in this study the specific yield values were not estimated for the remaining wells. If this method had been applied, specific yield estimates from the southern wells (furthest from the supply well) were to be used. The southern wells were furthest from the supply well; therefore best represented the heterogeneity of the aquifer opposed to wells in closer proximity to the supply well (Healey, 2010).

No results for this method were calculated. The influence from the supply well withdrawing water from the aquifer would have made the application of this method too complex. The pump usage was recorded throughout the season to attempt to determine the effect from the supply well. Approximate withdrawal rates from the aquifer by the supply well were estimated. This method may have been possible with the use of two background wells. One background well would allow the investigator to decipher between groundwater level fluctuations caused by the pumping well from groundwater level fluctuations caused by regional influences. A second background well, placed in the adjacent field, would allow deciphering between groundwater fluctuations occurring as a result of irrigation on the adjacent field to groundwater fluctuations resulting from irrigation on the study field.

CHAPTER 4

4: RESULTS AND DISCUSSION

The following chapter provides the results of the study and a discussion of the findings. Data are provided in Appendices B, C, and D. Appendix B contains the volumes collected from the lysimeters. Appendix C contains soil water contents collected by the neutron probe in the access tubes extending to the aquifer. Appendix D contains soil water contents collected by the neutron probe in the access tubes managed by the United States Department of Agriculture – Agricultural Research Service (USDA-ARS). Data points from the sensors are not provided in this thesis, but are stored digitally and available upon request.

Soil cores were collected during the installation of the wells that extended into the aquifer and a soil textural analysis by touch was performed. The soil cores at the north end of the field extended approximately 4 meters below the surface while cores at the south end of the field extended approximately 8 meters. At the north end of the field the cores consisted largely of layers of fine sands, some gravel, and some clay at the greater depths. At the south end of the field the cores consisted of more clay intermixed with the fine sand and gravels. Robson et al. (2000) described the alluvium in this region as mostly sand and gravels, but the soil cores at the site also showed clay rich material. The results of the textural analysis generally agreed with the report by the United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS).

A more detailed soil survey was conducted at each site to a depth of 200 cm. A textural analysis was conducted in a lab using the hydrometer method (Figure A.10). The findings of the site soil survey indicate that surface soils are lighter (sandy clay loam) at the north end of the field and become heavier (clay) towards the south. In general the site soil survey agrees with the report by the USDA-NRCS, except more clays were found during the textural analysis.

4.1 Spatial and Temporal Trends

4.1.1 Water Table Elevation

Figure 10 shows the water table elevation over time in the wells at the north and south ends of the field. Prior to the pump being turned on the water table gradient is to the south. When the pump is turned on the elevation of the water table at the three northern wells drops quickly because the supply well is in close proximity. The water table gradient is still to the south and remains to the south throughout the season. The kilowatt-hours displayed on a meter connected to the pump were recorded periodically to help interpret groundwater level fluctuations (Figure 10). Water from the supply well is used to irrigate the study site in addition to adjacent fields, which are managed by a different farmer. The water table level recovers slowly after the water levels are drawn down. The recovery of water levels is caused by a combination of 1) the aquifer recovering to pre-existing conditions once the pump is turned off and 2) groundwater recharge from irrigation. During the irrigation events in the beginning of July water table elevations at Sites 1-1 and 2-1 initially decreased instead of increasing (Figure 10). This was the result of the supply well causing the effect of the drawdown to overshadow groundwater recharge. But after the July irrigation events the water table elevations started increasing (recovering).

The southern wells also react to the pump being turned on, but the change in the water table elevation is less pronounced and more delayed than at the northern wells due to the greater distance from the supply well. Also, the southern portion of the field receives irrigation water later than the northern wells.

In the beginning of the growing season, starting on April 22, 2011, the well was being used to water neighboring fields to the west and south. At the same time, groundwater levels were rising in the southern wells due to recharge caused by irrigation of the adjacent fields. Groundwater levels were also rising in the southern wells due to infiltration of water from the ditches located east and west of the study area. Groundwater levels were dropping in the northern wells as a result of water being drawn from the aquifer by the supply well.

When the pump was turned off on May 15, 2011 the groundwater levels to the south dropped (Figure 10). The drop in groundwater levels was caused by the lack of groundwater recharge. Groundwater levels in the northern wells rose since the supply well was no longer drawing water from the aquifer. After an initial drop in the groundwater levels in the southern wells, regional groundwater recharge from irrigation in the Greeley area caused the groundwater levels to start rising again in the southern wells. The supply well was turned on again July 3, 2011. Similar trends occurred throughout the remainder of the irrigation season, but at a smaller scale and less frequently.

On August 8, 2011 the groundwater elevations in the northern wells start to decrease because of an increase in the use of the supply well. The continuous drop of groundwater levels in the northern wells is likely caused by the increased use of the supply well to irrigate adjacent fields. The supply well was last used on September 8, 2011 at which time the groundwater levels in the northern wells began to rise because the supply well was no longer running and creating drawdown. The rise in water levels may also be attributed to an increase in the regional water table elevation resulting from the cumulative irrigation in the region. At the same time the groundwater levels began to fall in the southern wells. The falling groundwater levels in the southern wells was caused by the lack of irrigation water being applied to the surface and subsequently not recharging the aquifer.

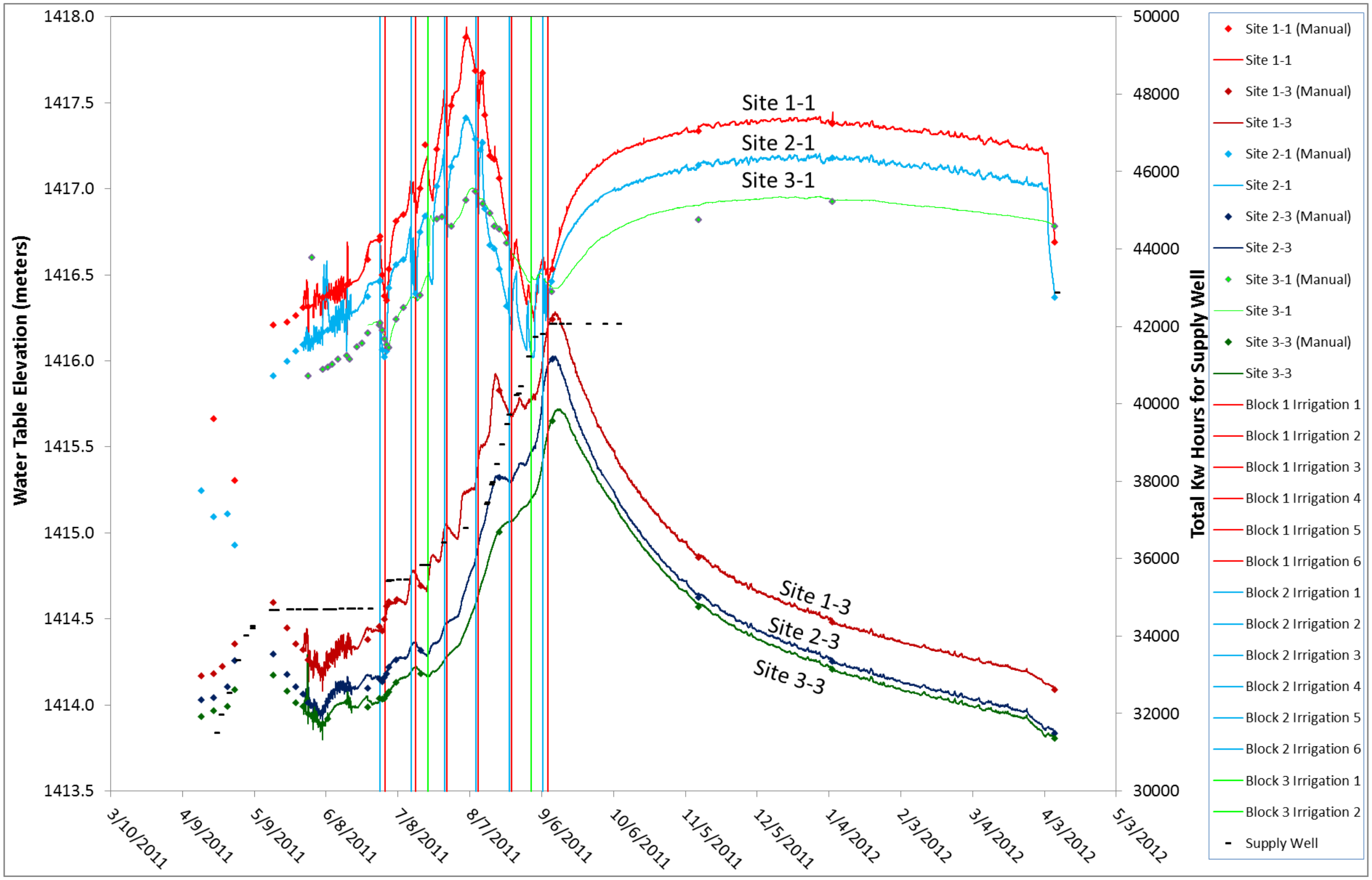


Figure 10: Plot of water table elevations measured over time. Data collected by pressure transducers are shown as solid lines. Data collected manually by a water level meter are shown as points. Vertical lines indicate the start of an irrigation event. Irrigation events usually lasted one day and no more than two days.

4.1.2 Soil Water Content

Sensors

Figures 11 and 12 show the volumetric water content over time from each of the sensors at different depths (30, 61, 91, 122, and 152 cm) in the native soil and in the lysimeters. The plots show that soil water content increases after irrigation water is applied and decreases after irrigation.

Soil gains moisture at a faster rate than when the soil loses moisture (Hillel, 2004). This is shown in the plots as steeper slopes when water content increases and shallower slopes when water content decreases. Site 2-2 in the native soil is a good example of these relationships. The rapid decrease in water content occurs because the soil remains highly saturated and hydraulic conductivity is high in saturated soils. In saturated soil the positive pressure overcomes tensional force. Tensional forces hold water in small pores in the soil. Gravity is the primary force acting on the water in the soil and moves it vertically downwards. Evapotranspiration also causes the loss of soil water content. After the soil loses some water and is not saturated, the rate of water content lost from the soil decreases. This point of change is called field capacity (Hillel, 2004). This is also observed at Site 2-2 in the native soil. This is the result of water in the smaller pores being held in the soil by tension. Under conditions that exceed field capacity the pressure of water in the soil is capable of overcoming the tension in partially saturated pores and water is more mobile in the soil. This is shown in the plots when the slopes of the water content decrease with time.

In general, the shallower sensors in the native soils show a greater range in water content fluctuations than deeper sensors. The deeper sensors in Block 1 (Sites 1-1,1-2,1-3) show little fluctuation in water content, but in Block 2 (Sites 2-1,2-2,2-3) and Block 3 (Sites 3-1,3-2,3-3) the deeper sensors show greater fluctuations in water content than the shallower sensors (Figure 11). This is because more water per irrigation event is applied to Blocks 2 and 3 than Block 1 and so water travels to greater depths. A greater decrease in soil water content is observed in shallower sensors (in the root zone) than deeper sensors (below the root zone) because of the effects of evapotranspiration. The effects of evapotranspiration vary throughout the season depending on the intake of water by the corn roots and evaporation rate at the ground surface. Below the root zone the decrease in soil water content is caused by deep percolation (Hillel, 2004).

Soil water contents are constant before the first irrigation event (Figures 11 and 12). This observation shows the small effect rainfall events have on soil moisture. Rainfall events on May 18, 2011 and May 19, 2011, 15 mm and 17 mm of precipitation respectively, increased the soil water content at all sensors at a depth of 30 cm. The increase in soil water content was not as great as the increase in water content caused by any of the irrigation events. This relationship is observed at all of the sensors at 30 cm (Figures 11 and 12).

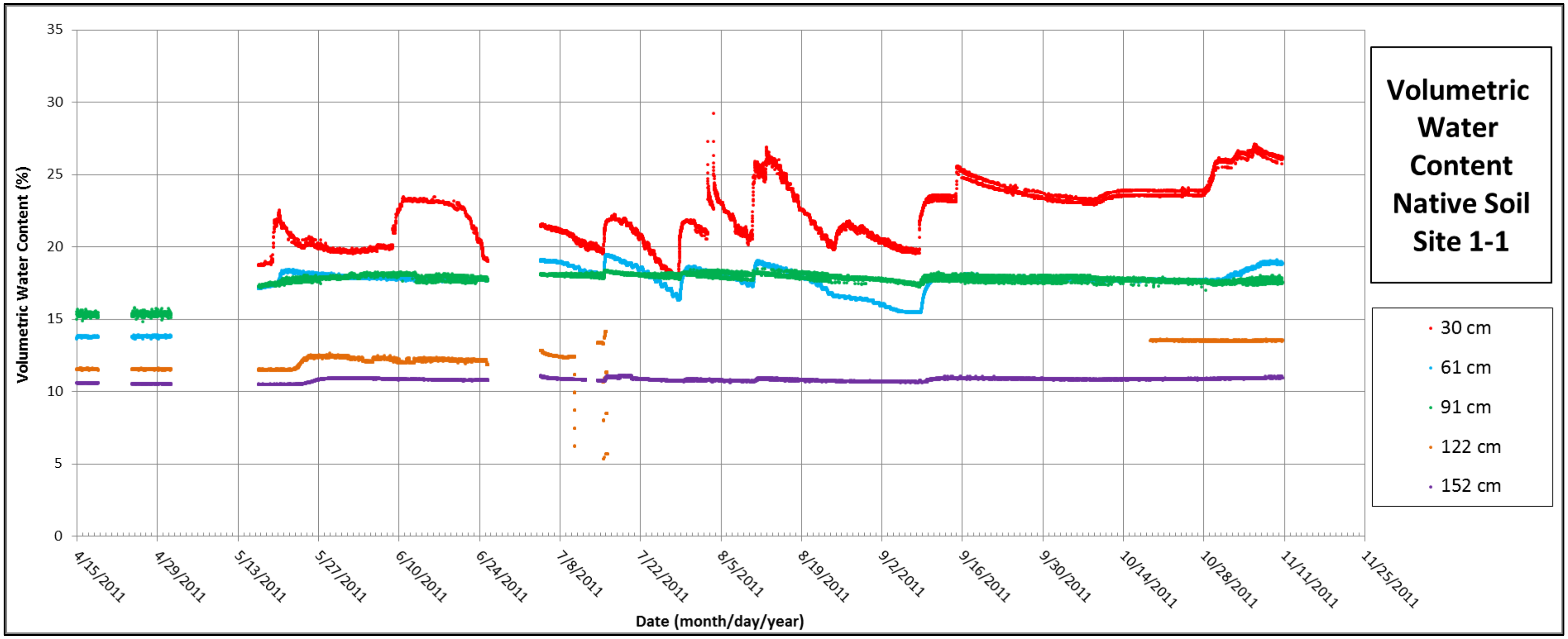
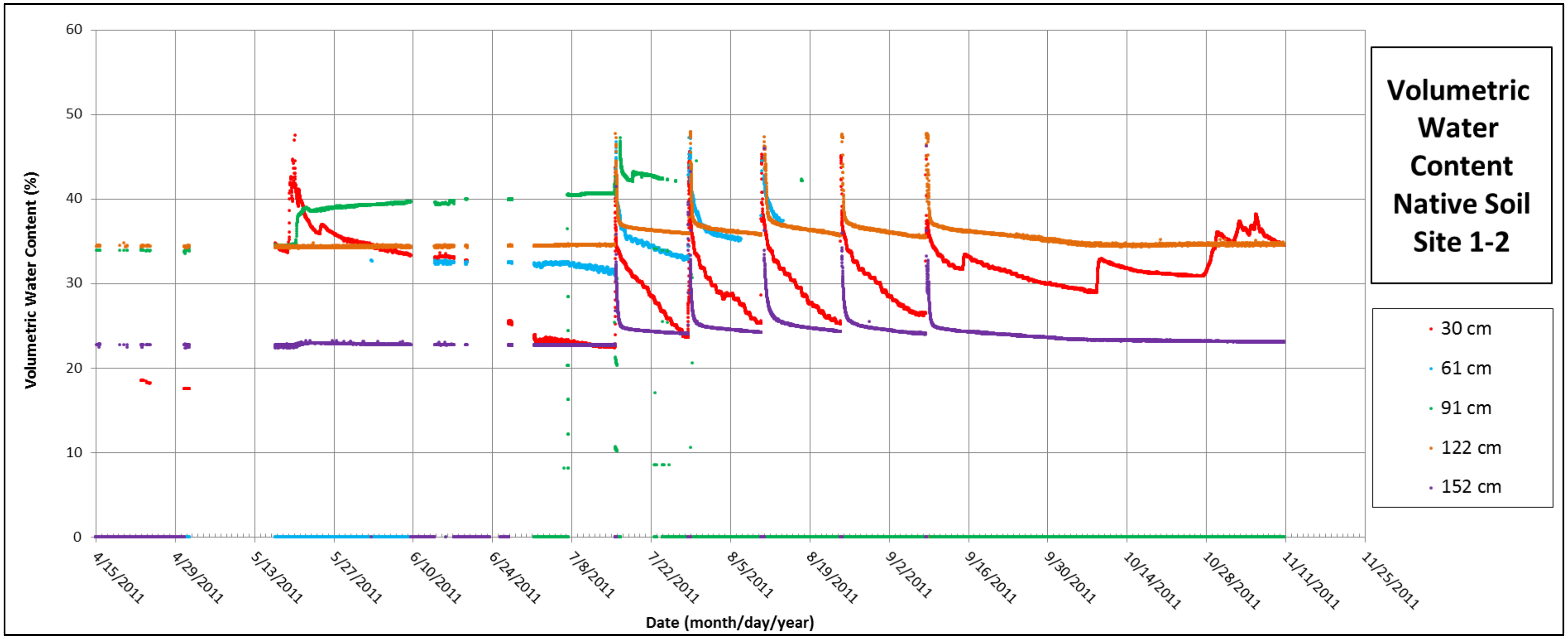


Figure 11: Plots of soil water content over time measured in the native soil (outside of the lysimeter) using the Acclima TDT soil moisture sensor.



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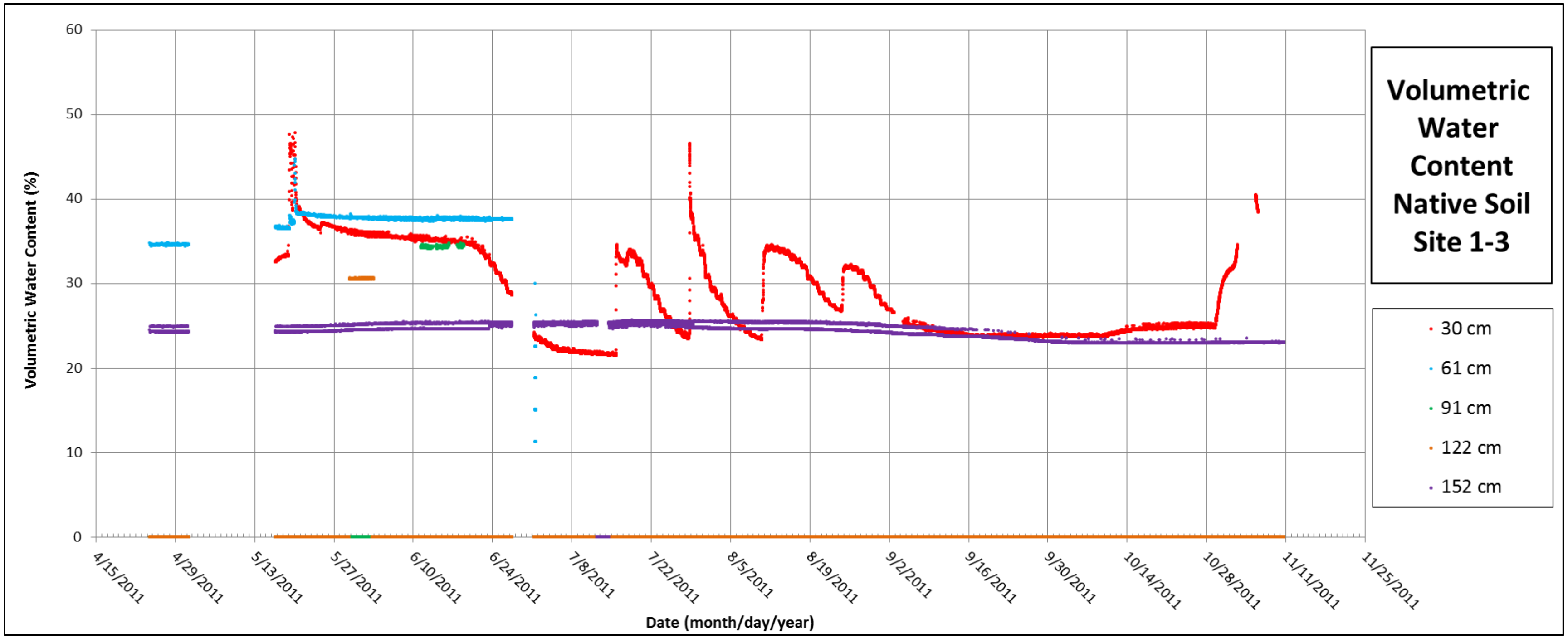

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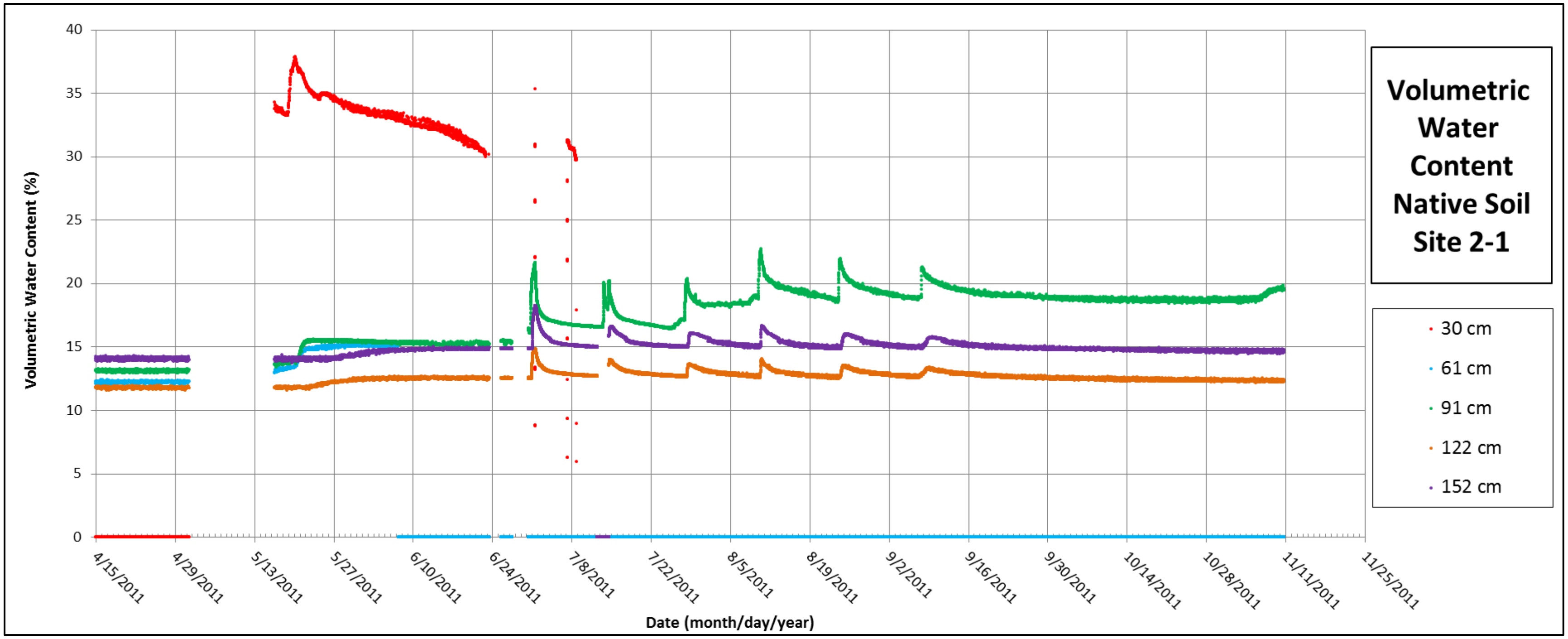

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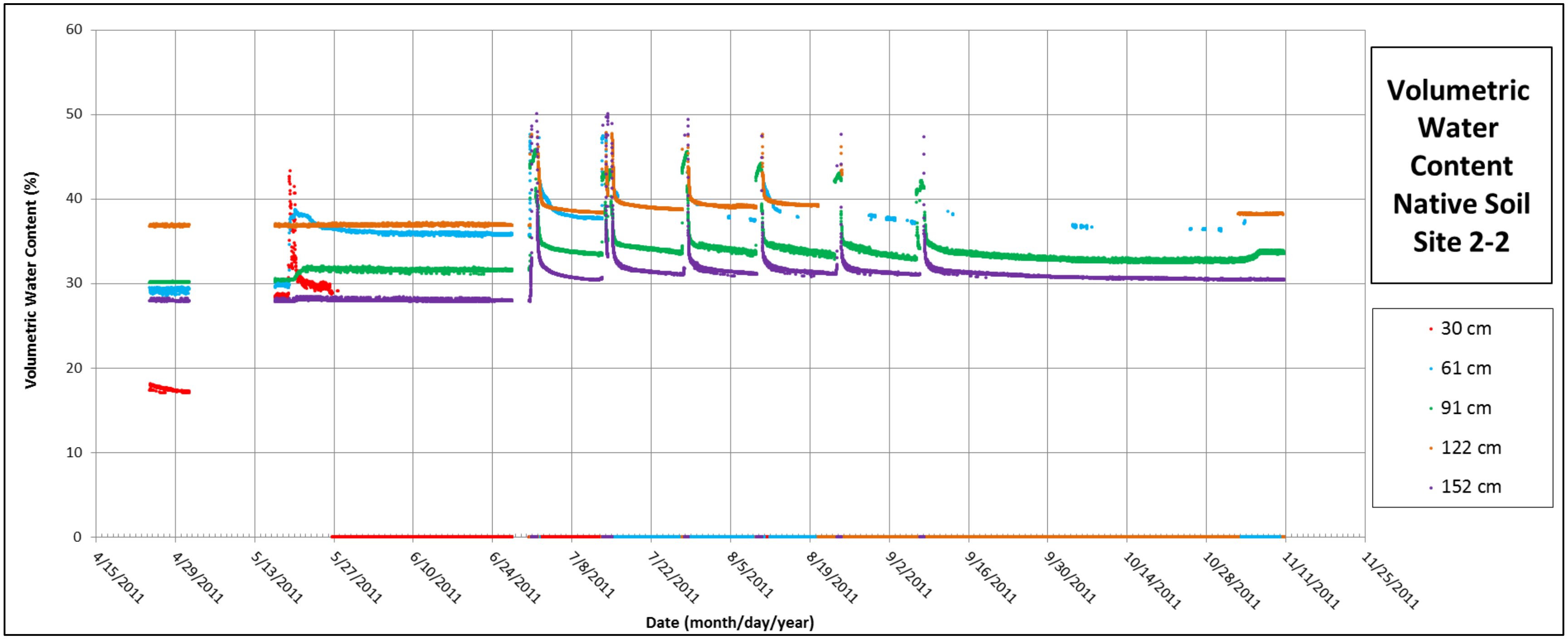

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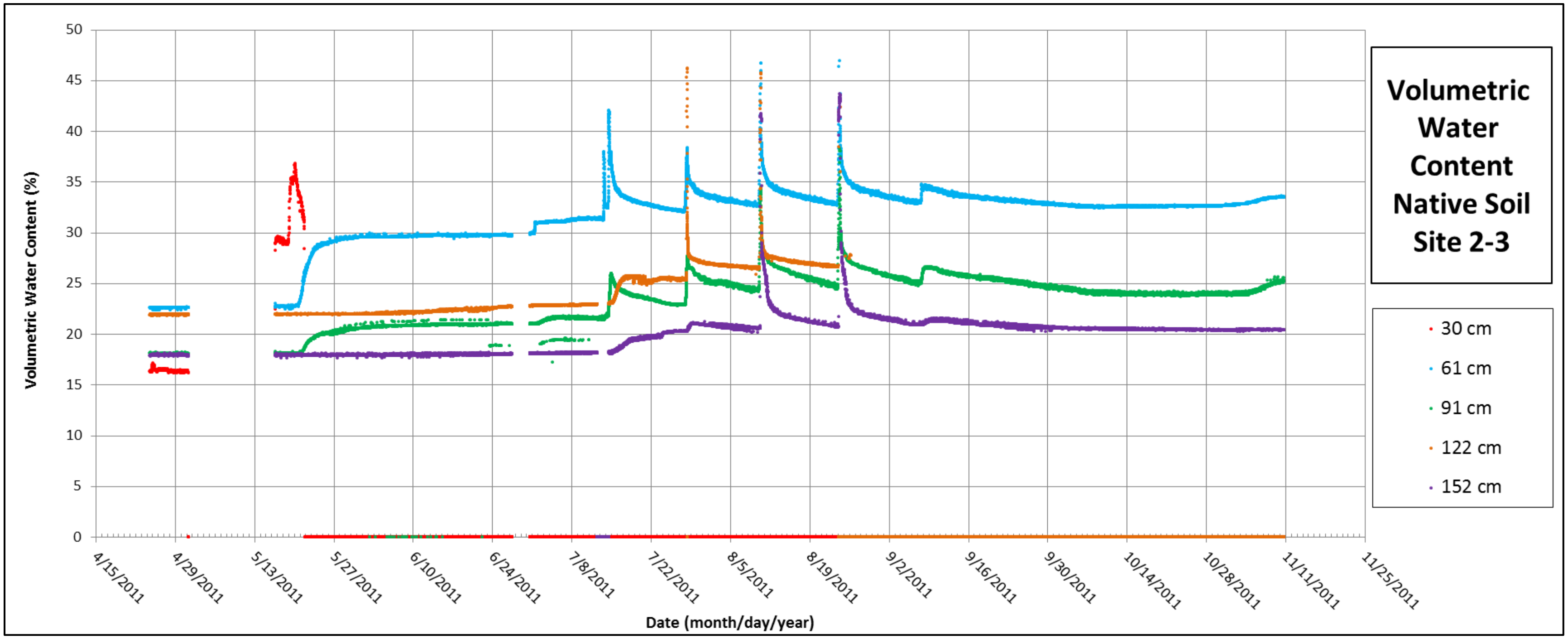

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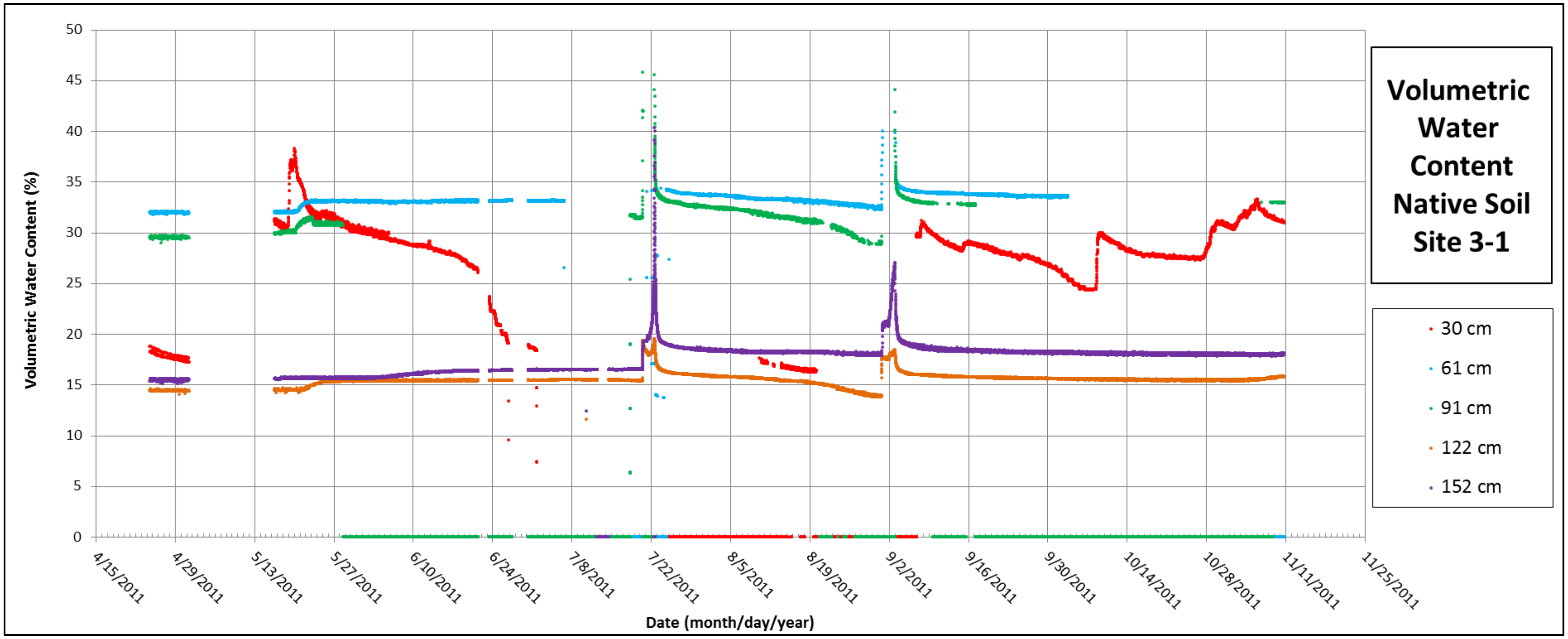

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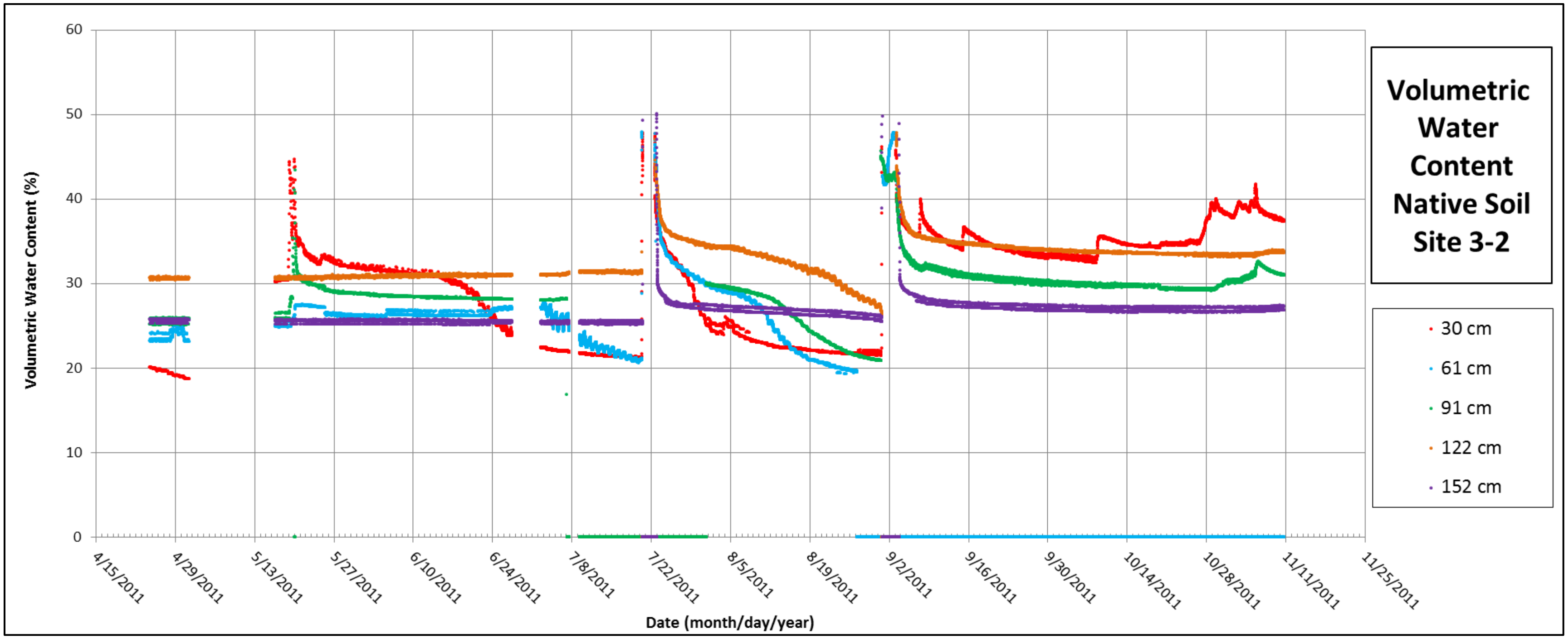

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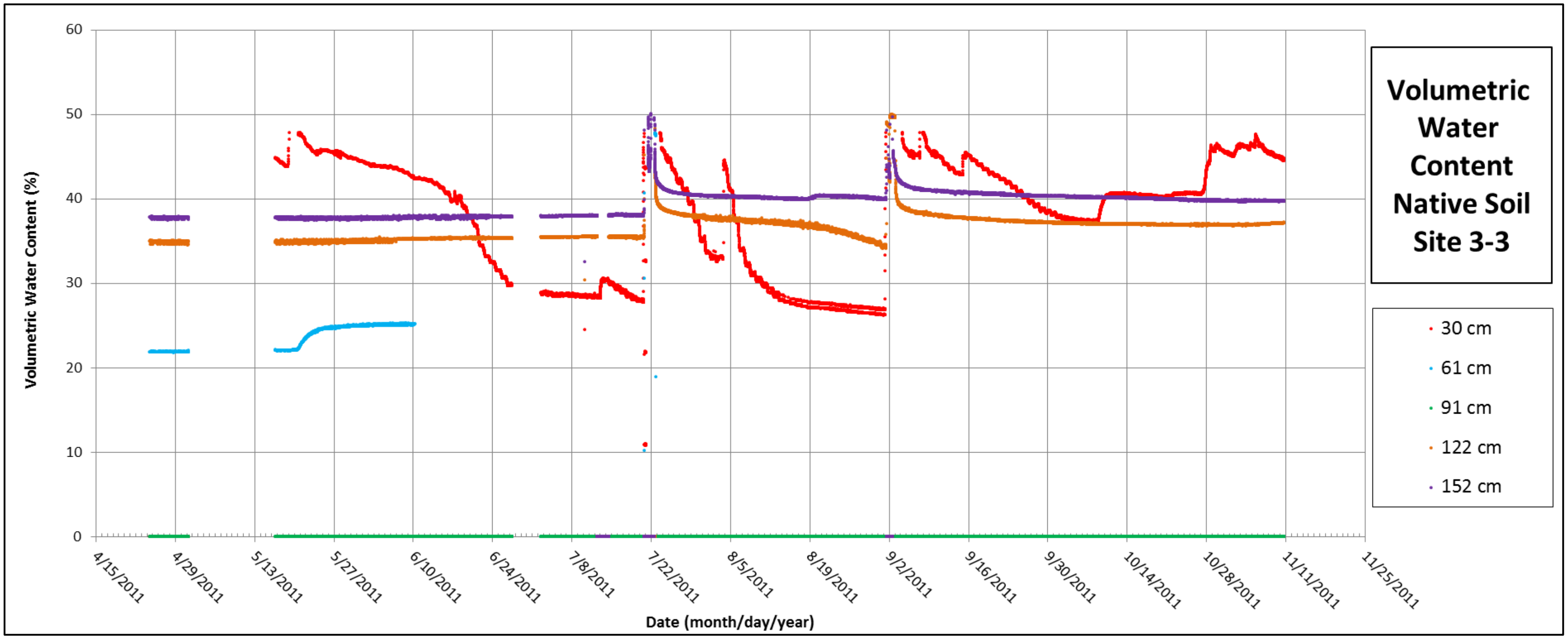

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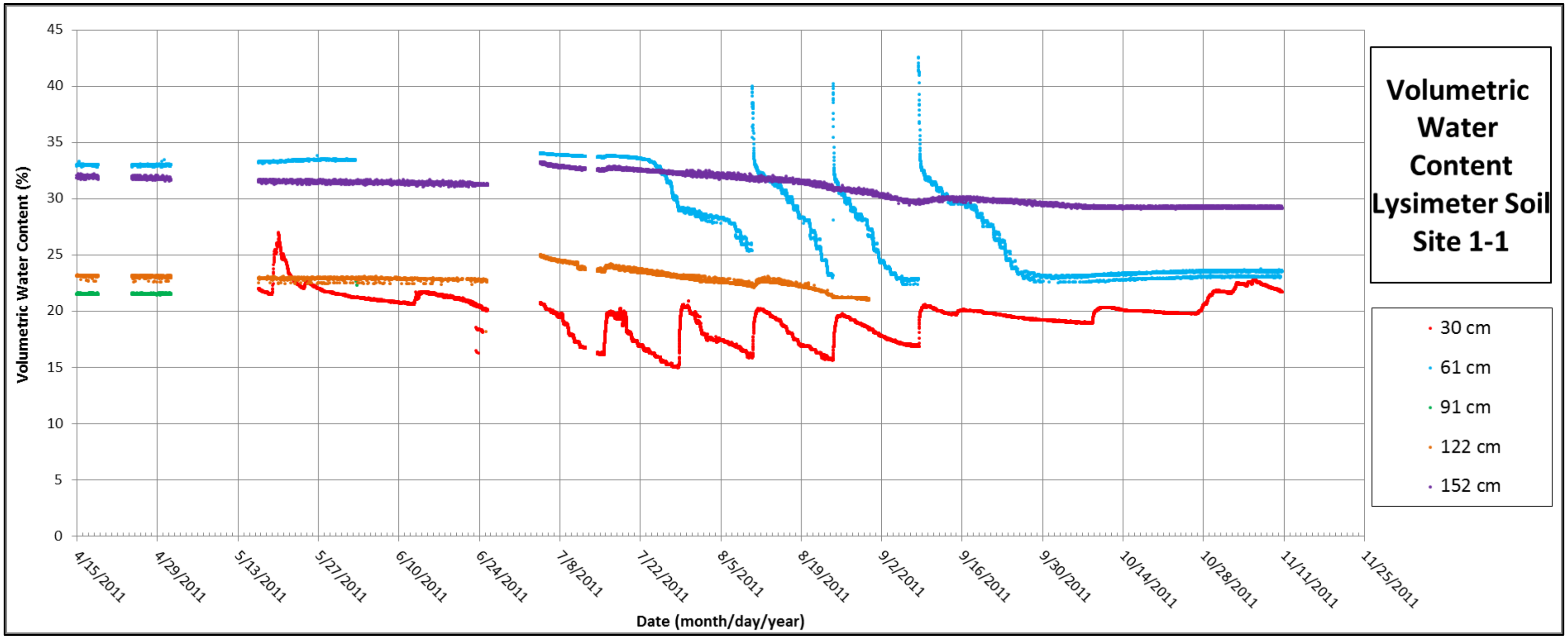
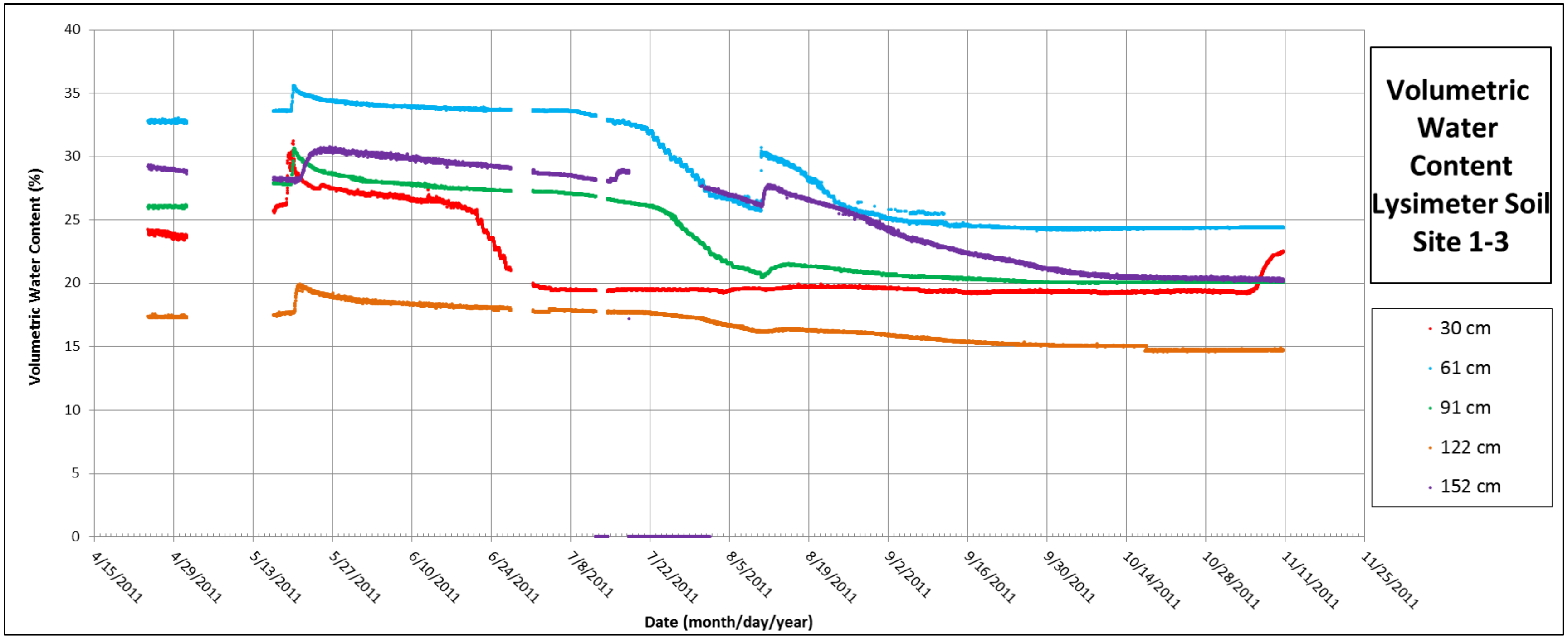


Figure 12: Plots of soil water content over time measured inside the lysimeters using the Acclima TDT soil moisture sensor.



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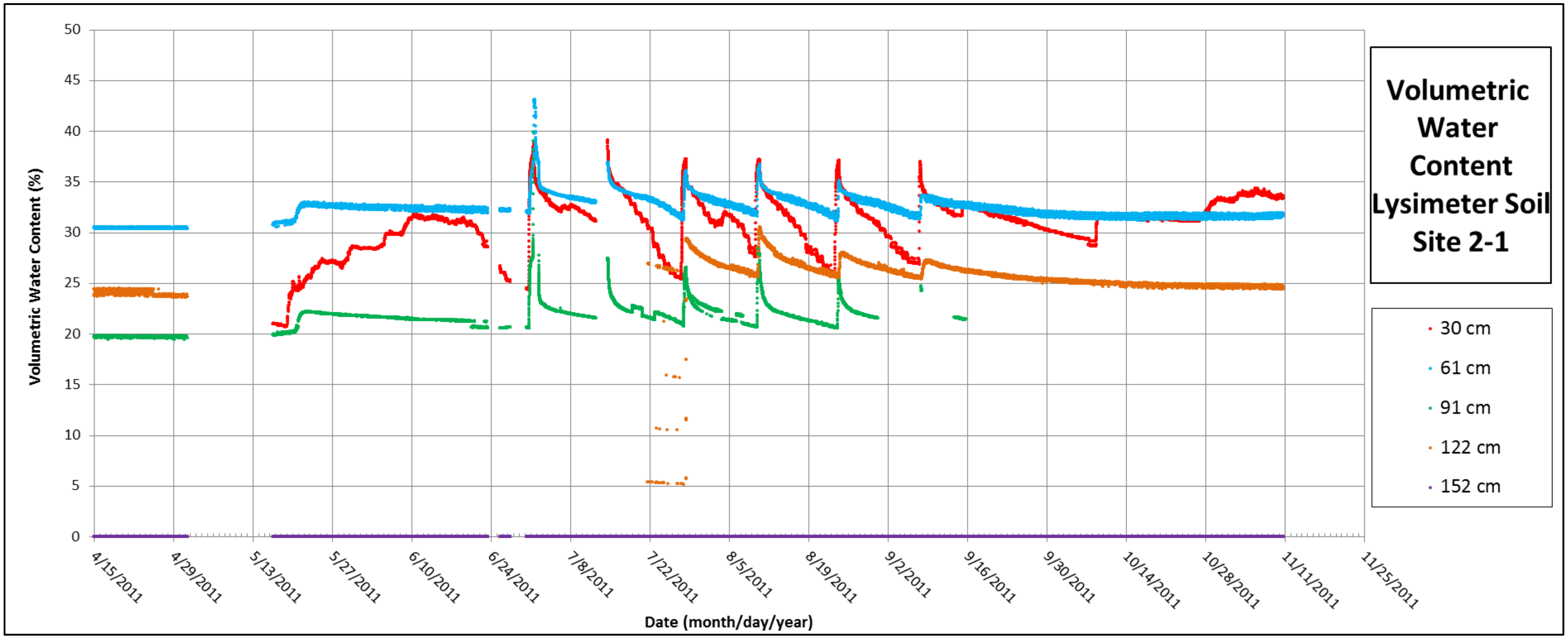

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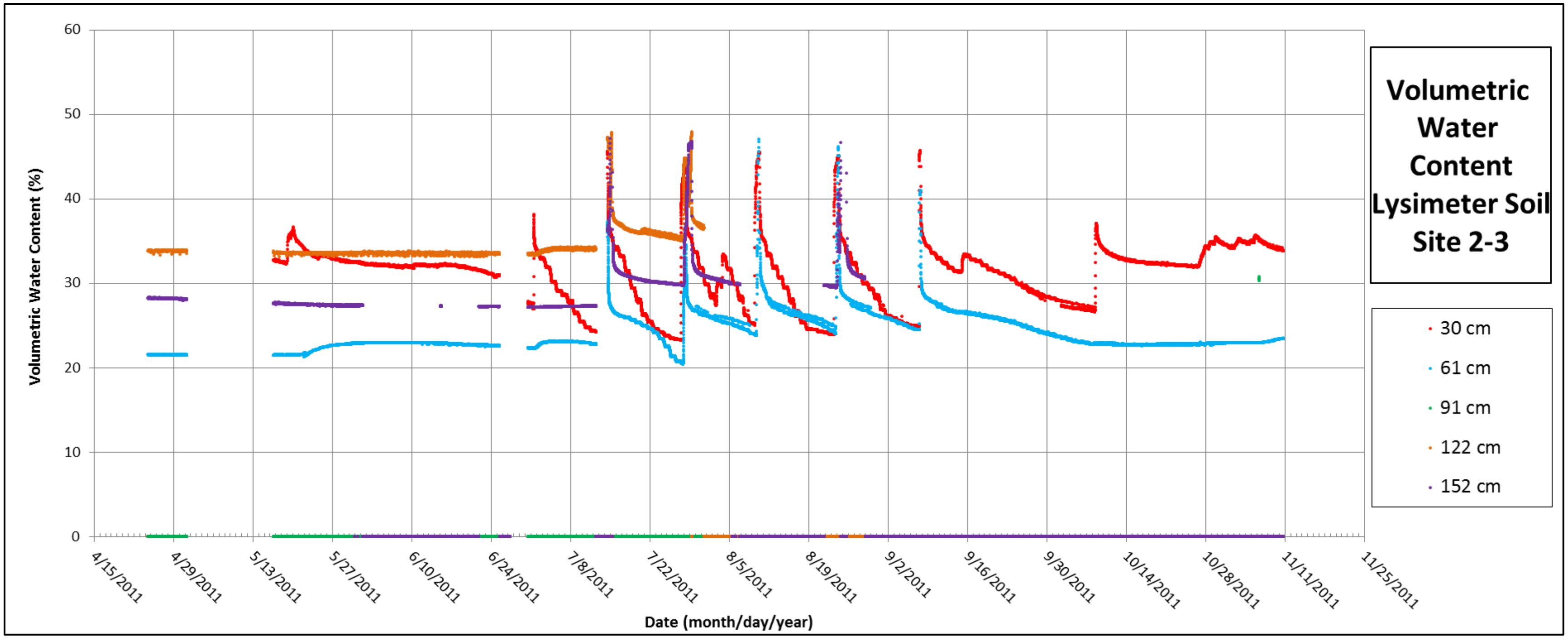

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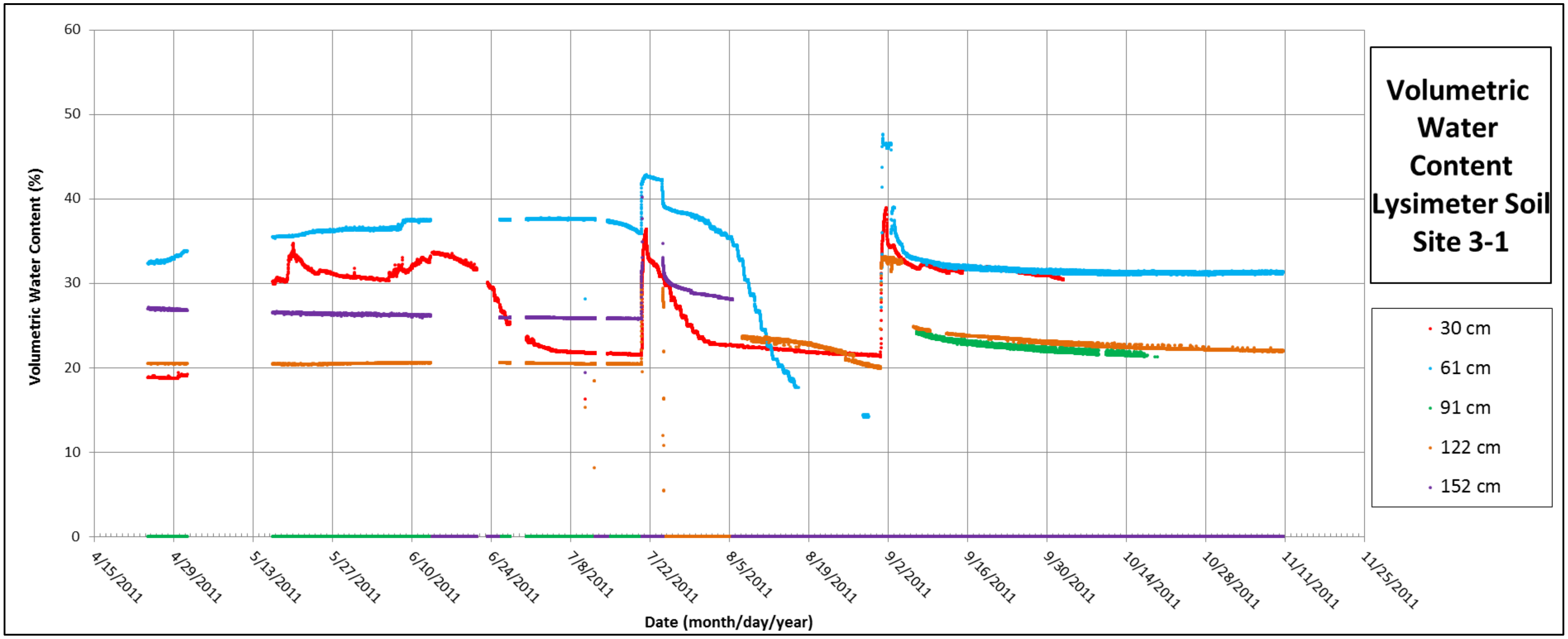

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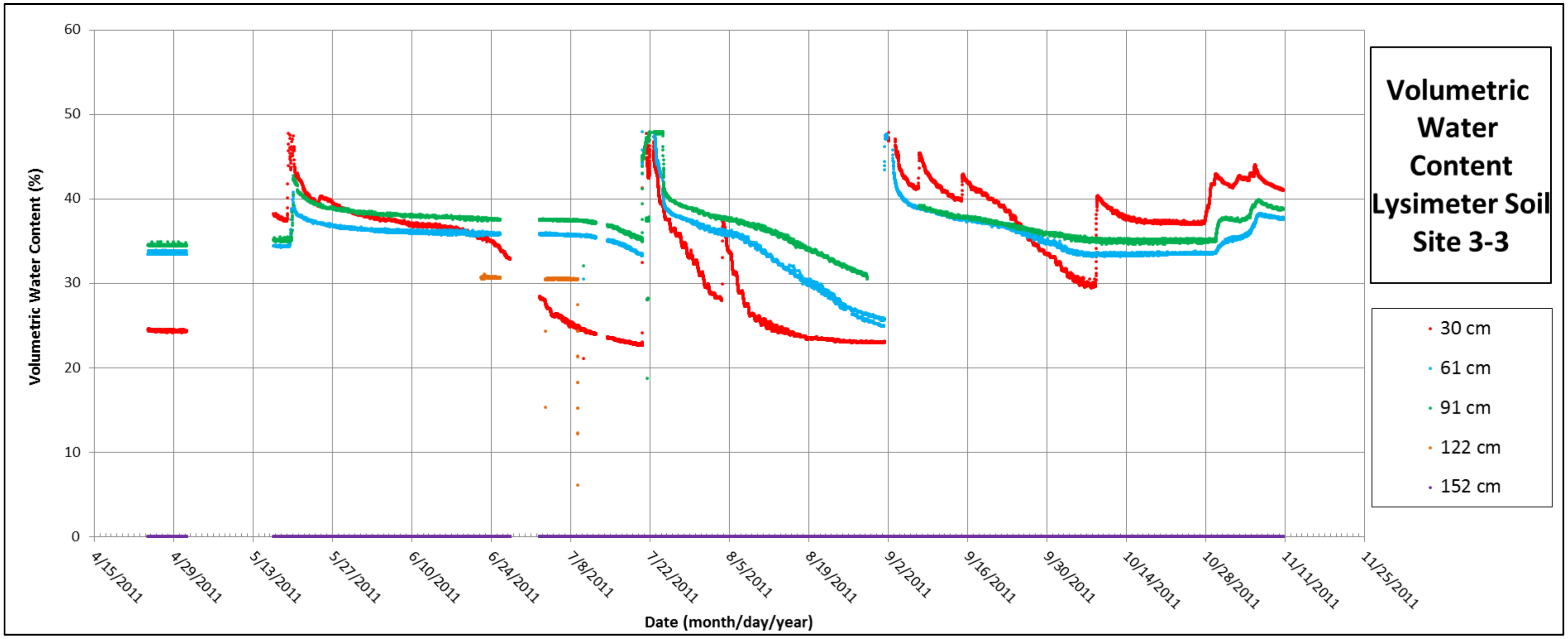

Figure 12: continued

At Site 1-1 the start of an irrigation event increases the water content most at the shallow sensors and some at the deeper sensors (Figure 11). At Site 2-3 the water content also increases in the three shallower sensors as a result of an irrigation event, but the water content does not increase in the two deeper sensors (Figure 11). Soil texture is likely the reason soil water content did not increase in the deeper sensors at Site 2-3. The south end of the field, Site 2-3 for example, consists of finer materials, which act as a barrier to water traveling to greater depths.

In general, soil water content prior to the first irrigation event of the season is less than the water content following irrigations. The combination of no plant cover and warm temperatures, prior to the first irrigation event, is capable of depleting water from the soil. However, the soil water content between irrigation events at some of the shallow sensors drop to less than soil water content prior to the first irrigation event. This occurred because the effects of evapotranspiration are greater in the summer due to warmer air temperatures and the increased demand for water from the corn. During the winter season the deeper soil will dry and set the conditions for the following growing season.

The shape of the soil water content curves in the lysimeters generally shared the same trends observed in the native soils. Steeper slopes were observed when the soil was being wetted than when the soil was drying (Figure 12, Site 2-1). The sensors placed at shallower depths experienced greater water content fluctuations than the deeper sensors (Site 1-1). The primary difference between water contents in the lysimeter to those in the native soil is that water contents in the lysimeter were generally higher (Site 2-1). This may be a result of soils in the lysimeters containing higher percentages of clay than soil outside the lysimeters. In some cases it was evident that inside the lysimeters the deeper sensors recorded higher water contents than the shallow sensors, opposite to what is observed in the native soil (Site 1-1). This may be the result of the lysimeter not providing a similar drainage environment which exists in the native soil. The most similar water contents between the soils inside a lysimeter and in the native soil were observed at Sites 3-1 and 3-3.

Some sensors did not work and others recorded only periodically, evident in Figures 11 and 12.

USDA-ARS Shallow Neutron Probe Access Tubes

The results from neutron probe measurements in the access tubes installed by the USDA-ARS are provided in Figure 13. The soil water content data from the neutron probe measurements were used by the USDA-ARS to estimate the soil water deficit in their water balance method described in Chapter 3.1. This data was not used to calculate deep percolation using the other four methods proposed in this study, but the data is presented because it provides insight into the soil water movement characteristics at the site.

The soil water content at each site increases just below the surface and then decreases with depth (Figure 13). Measurements were collected just before an irrigation event and again afterwards once the field was dry enough to walk in without ruining the furrow and ridge topography. No water content readings were collected when saturation was present at the surface. Figure 13 indicates that water content at the surface is less than at depths just below the surface because evaporation effects are strong at the surface (Figure 13). Just below the ground surface the effects of evaporation are dampened. The subsequent decrease in water content with depth is the result of transpiration from corn roots. Below the root zone the soil water content increases to a maximum. Below this depth, the soil water content slowly decreases with depth then remains relatively constant.

At the northern sites in each block the significant decrease in soil water content observed near the surface occurs at shallower depths than at the southern sites. Higher soil water contents generally were observed at the sites in the middle and south end of the field. The exception to this trend is at Site 2-3 where the soil water content at 30 cm is comparable to the three northern sites. Below 30 cm at Site 2-3 the water content increased beyond values found at the northern sites. The primary reason for higher water contents observed in the middle and south end of the field, despite receiving less irrigation water than the north end of the field, is the higher percentage of clay found in the soil. Higher water contents are observed in more clay rich soils because water is retained in smaller pores.

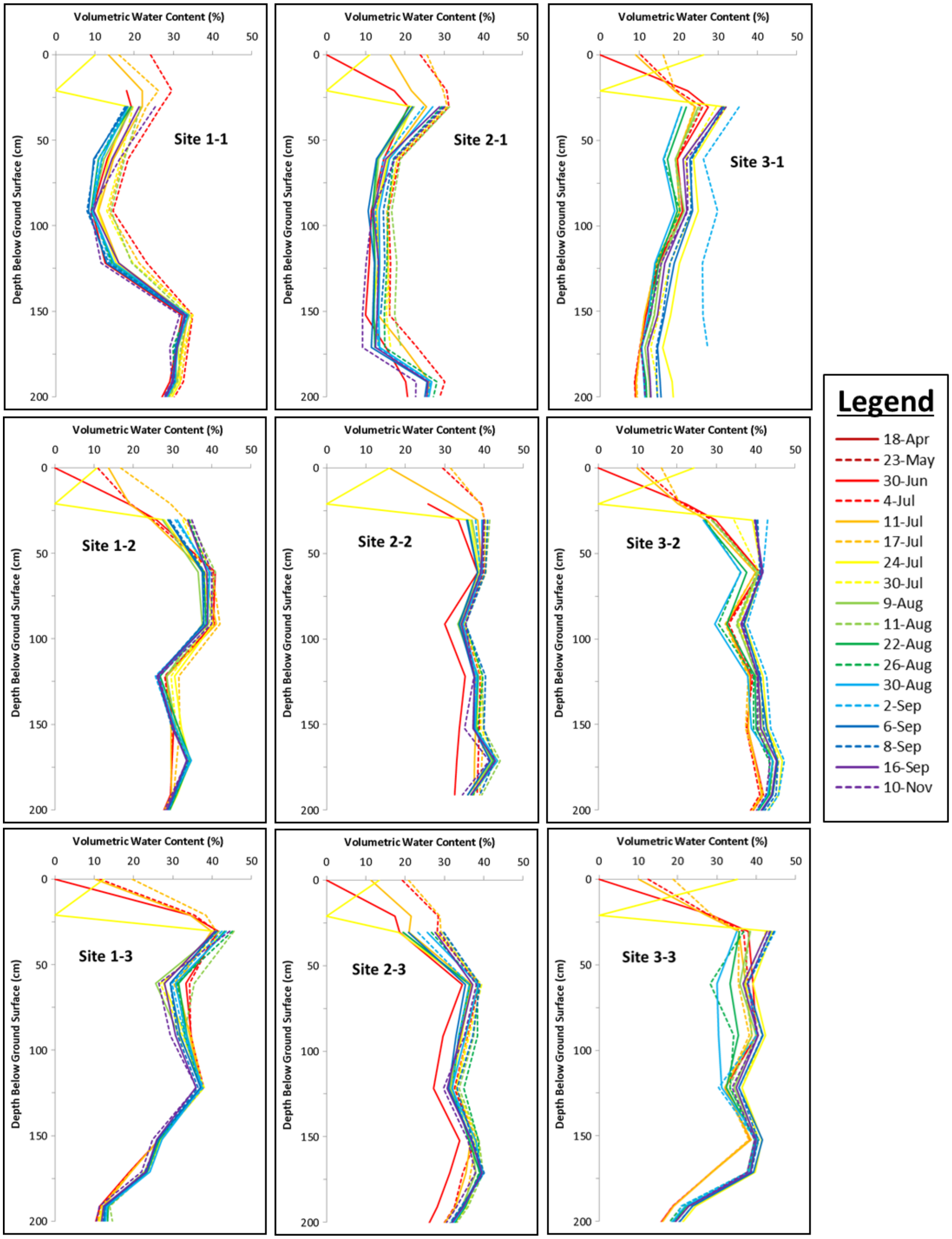

Figure 13: Profile plots of the soil moisture at multiple times throughout 2011 in the neutron probe access tubes installed by the USDA-ARS.

Deep Neutron Probe Access Tubes

Figure 14 contains soil water content profiles measured in the neutron probe access tubes extending to the aquifer. The Unsaturated Zone Water Balance (UZWB) method quantifies the area between soil water content profiles at different times (Section 3.1.2). After an irrigation event the water content profile shifts to the right, which indicates an increase in soil water content. The shift in soil water content profiles is the greatest in Block 3, less in Block 2, and the least in Block 1. Block 3 has the greatest volume of water applied to the surface per irrigation event, which creates a greater shift in the profile because a greater quantity of water enters the soil and a greater quantity of water travels through the profile. The long period of time between irrigation events in Block 3 (relative to Blocks 1 and 2) allows the soil to ‘dry out’ more than in the other blocks; therefore creating a larger difference between soil water content profiles. Less water is applied per irrigation in Blocks 1 and 2 than in Block 3 (Section 4.2), resulting in less water traveling through the profile. Larger shifts in water content profiles are observed in Block 2 than in Block 1 because Block 2 receives greater volumes of water per irrigation event than Block 1.

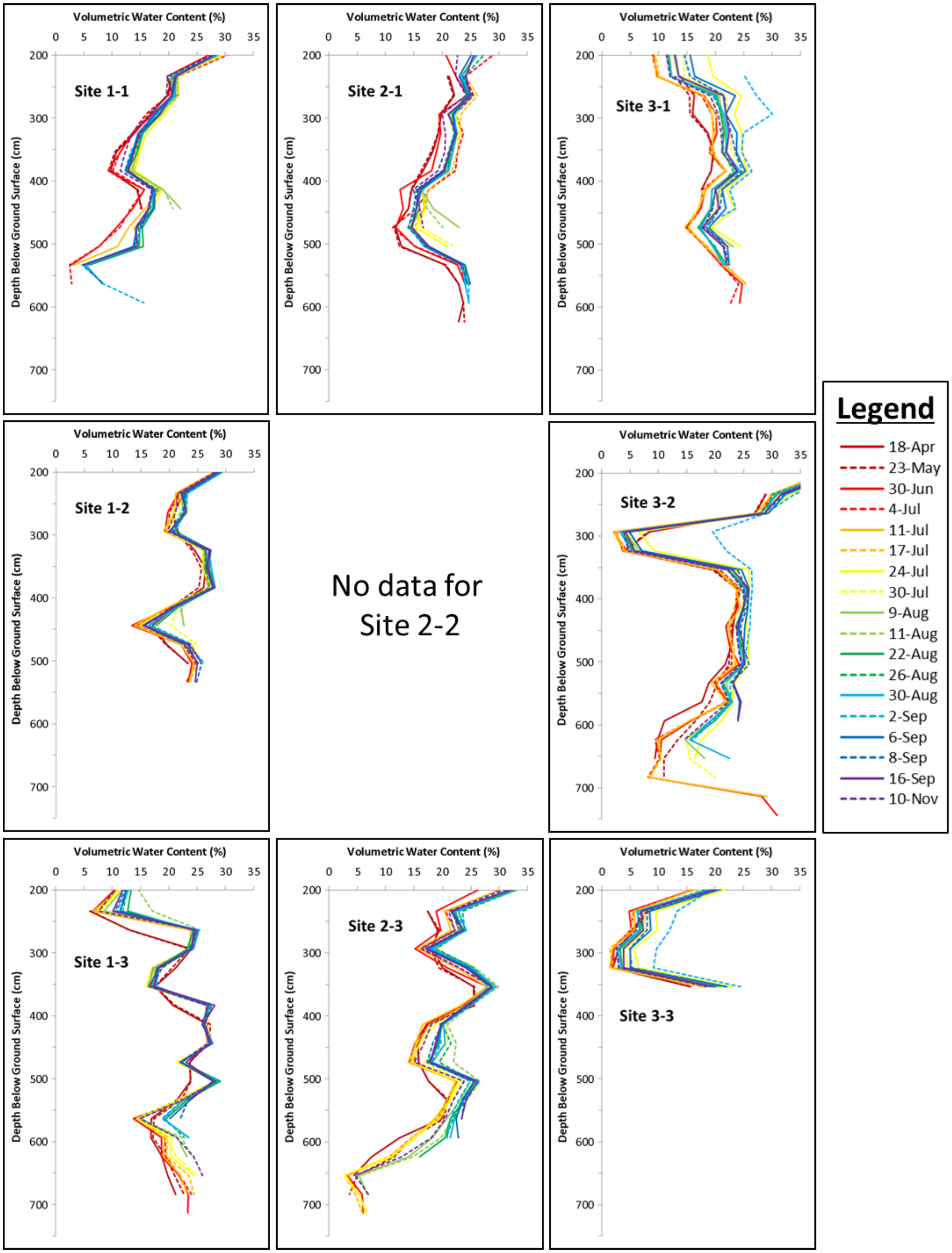

Figure 14: Profile plots of the soil moisture at multiple times throughout 2011 in the neutron probe access tubes extending to the aquifer.

4.1.3 Soil Water Potential

Soil water potential measures the tension which water is held in the soil. Greater tension equates to lower soil water potential. Soil water potential is inversely related to soil water content. Soil water retention curves express the relationship between soil water potential and soil water content (Figure 15).

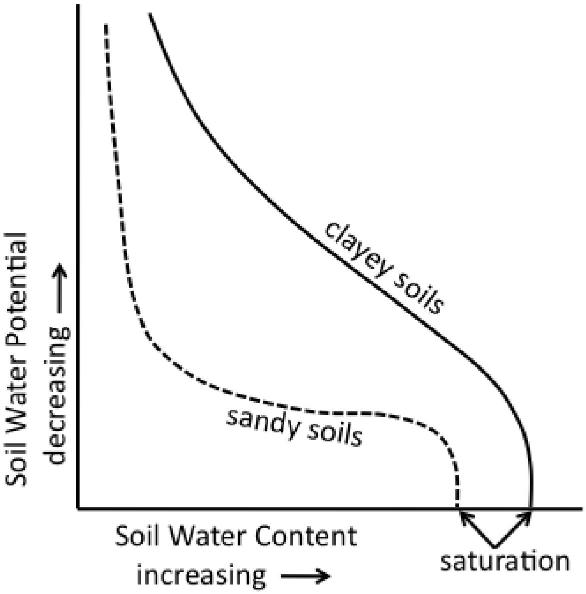

Figure 15: Soil moisture retention curve (Hillel, 2004)

Soil moisture retention curves are unique to each soil, but the general shape of the curve remains the same. An increase in suction (lowering the soil water potential) relates to lower soil water contents. Soil moisture retention curves were not created in this study. Soil water potential measurements were only used to 1) determine the zero flux plane (ZFP) and 2) quantify the vertical hydraulic gradient for use in the Darcy Flux Method.

The plots in Figures 16 and 17 shows the soil water potential measured at the study area in 2011. The trends in the soil water potential plots can be explained in a similar way that the trends were explained for soil water content because of the relationship between soil water potential and soil water content explained in the previous paragraph. An increase in soil water content following an irrigation event, results in an increase in soil water potential. A decrease in soil water content between irrigation events is reflected as a decrease in soil water potential.

Similar to the soil water content data (Figures 16 and 17), the soil water potential data (Site 1-1 in the native soil and in the lysimeter) also creates a steeper curve when the soil is wetting compared to a less steep slope in the curve when the soils are drying. Greater fluctuations in soil water potential occur at shallower depths than at greater depths. A good example of this is at Site 2-1 at depths of 30 cm and 60 cm. The sensors at 30 cm depth measured lower soil water potentials between irrigation events than deeper sensors (Site 2-1).

As with the soil water content sensors, the shape of the soil water potential curves in the lysimeters generally shared the same trends observed in the native soils. Steeper slopes were observed when the soil was being wetted than when the soil was drying (Figure 17, Site 1-1). The sensors placed at shallower depths experienced greater fluctuations than the deeper sensors (Site 1-1). The primary difference between the soil water potential in the native soils to that in the lysimeter is that soil water potential in the native soils were generally lower (Site 2-1). Another difference was only found at Site 2-3 where the soil water potential at 30 cm depth in the lysimeter experienced less fluctuation than in the native soil. In most cases the soil water potential fluctuated more in the native soil than in the lysimeter. As observed with the soil water content data, the most similar water potentials between the soils inside the lysimeter and in the native soil were observed at Sites 3-1 and 3-3.

Similar to the sensors used to measure soil water content, some sensors used to measure soil water potential did not work and others recorded only periodically, evident in Figures 16 and 17.

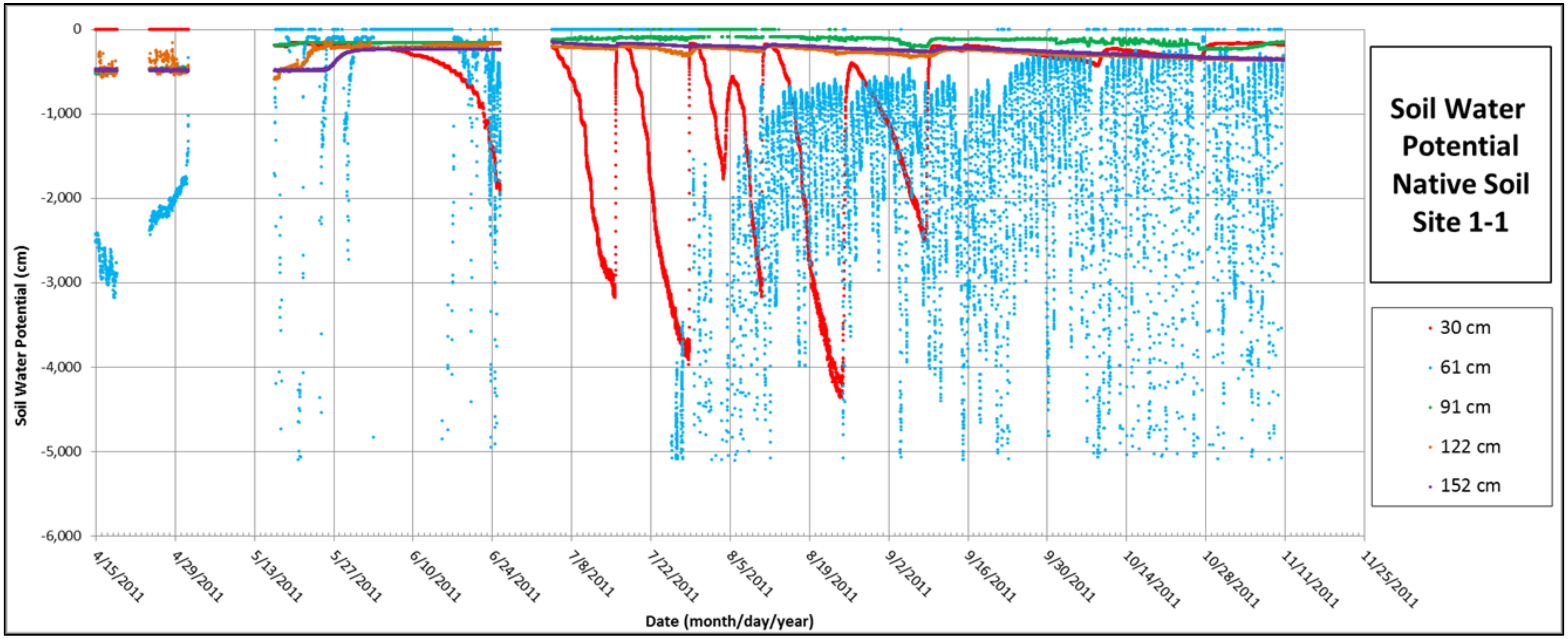

Figure 16: Plots of soil water potential over time measured in the native soil (outside of the lysimeter) using the Decagon MPS1 sensor.

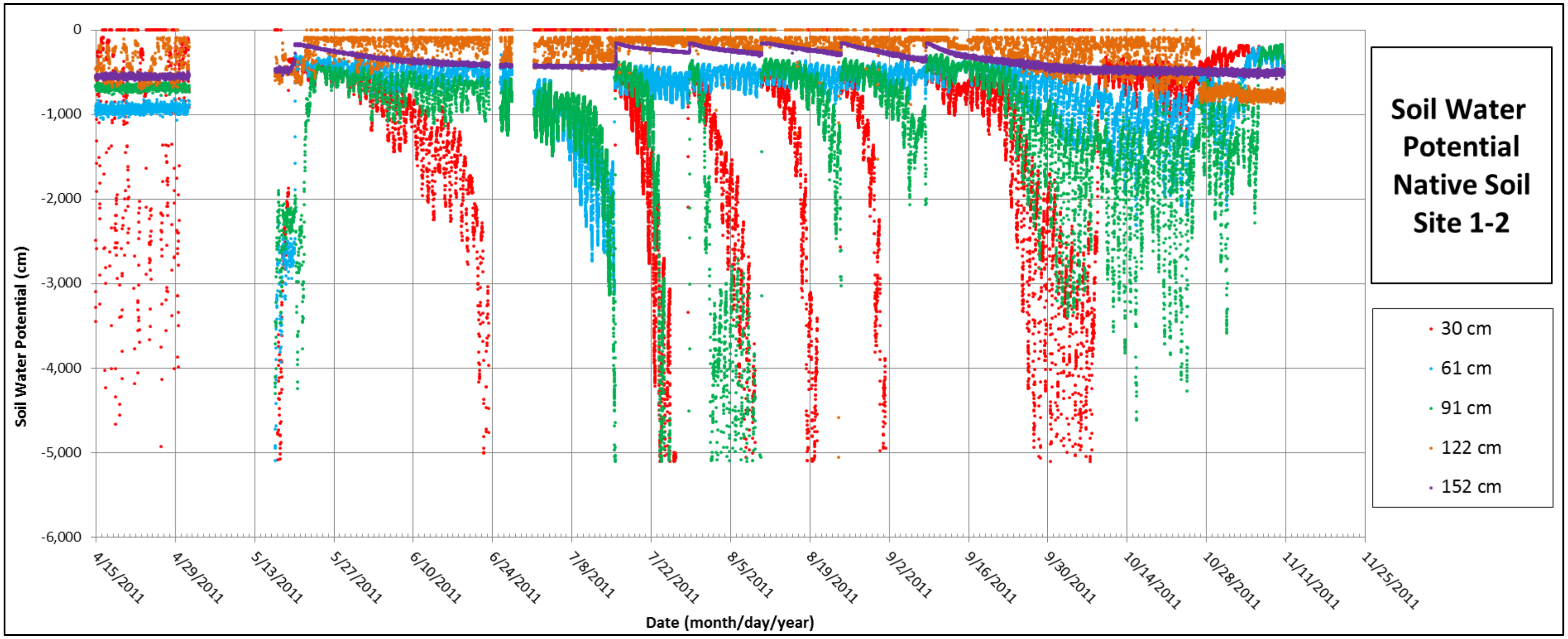

Figure 16: continued

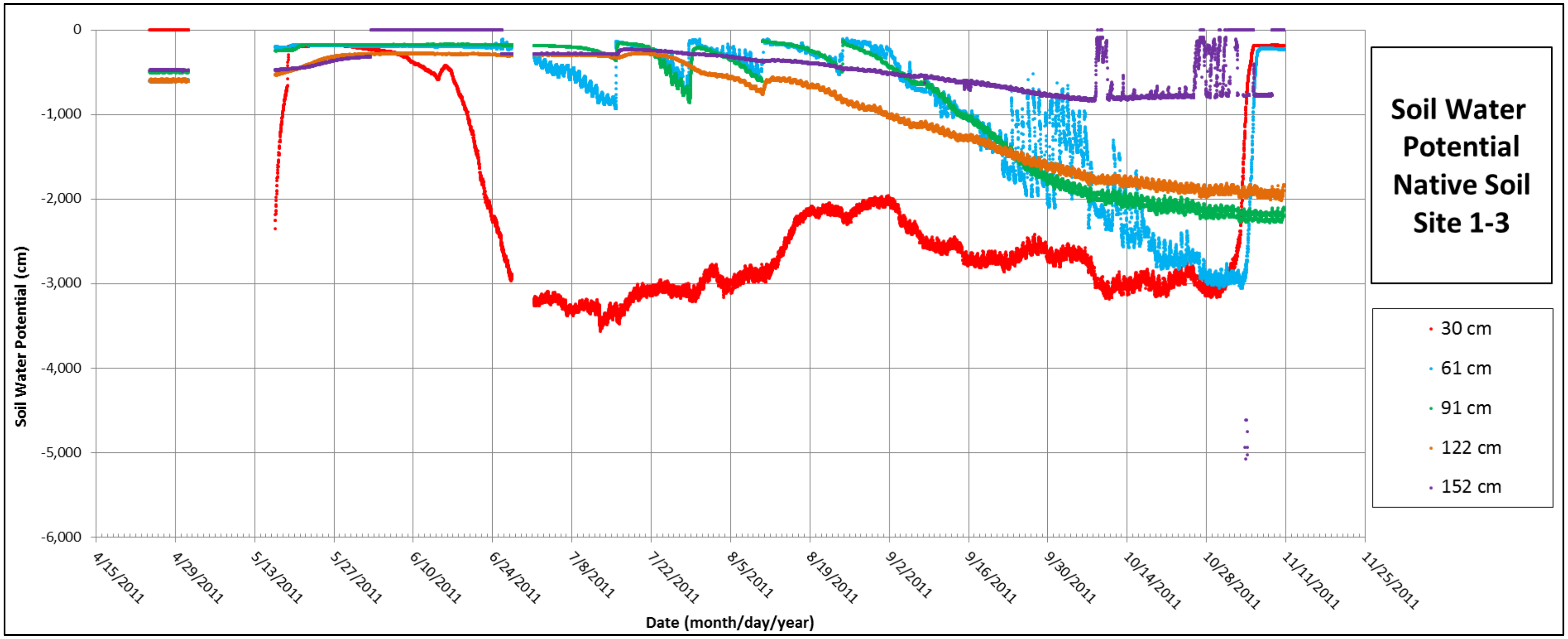

Figure 16: continued

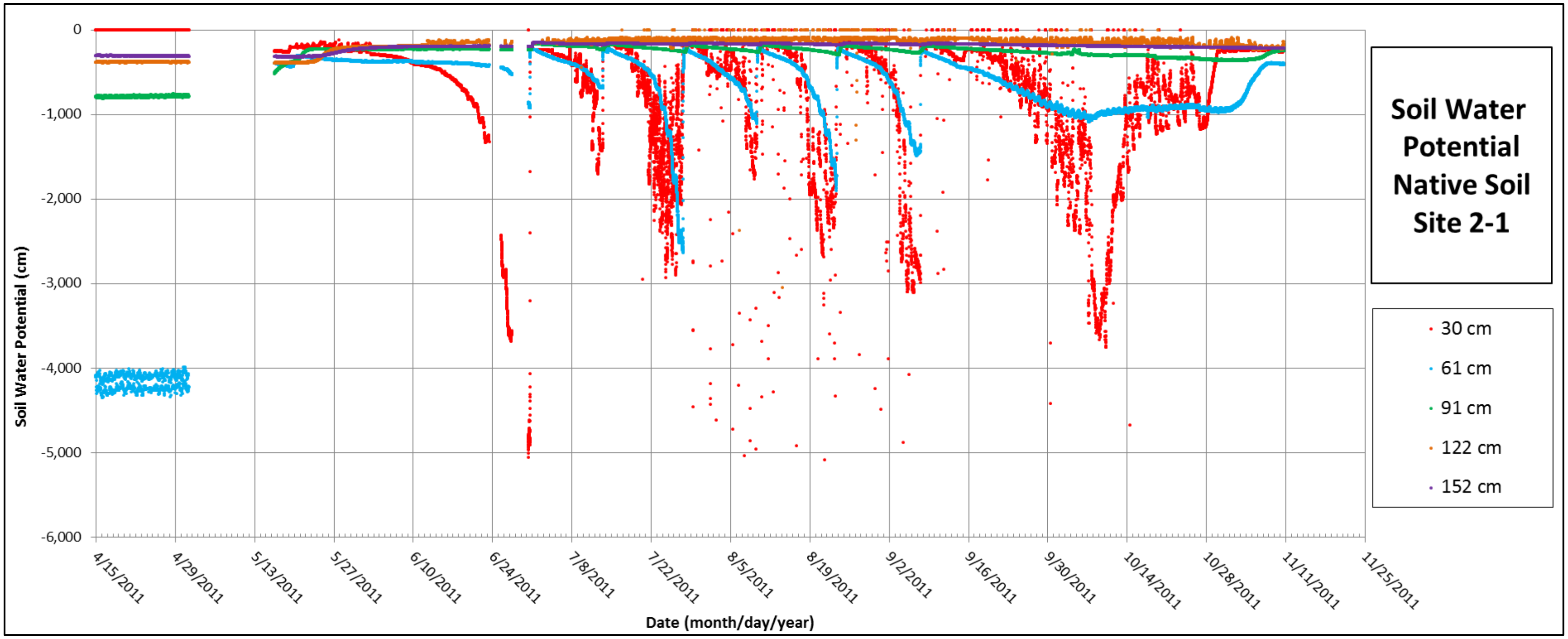

Figure 16: continued

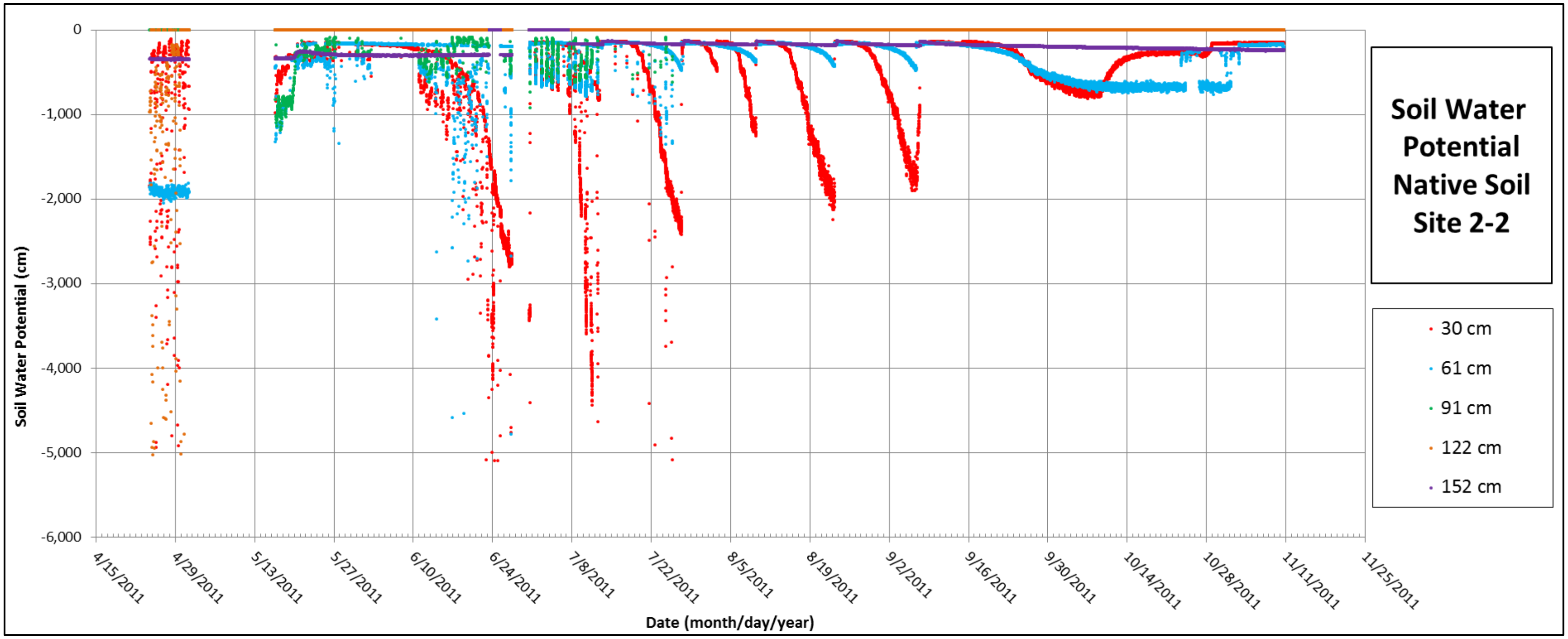

Figure 16: continued

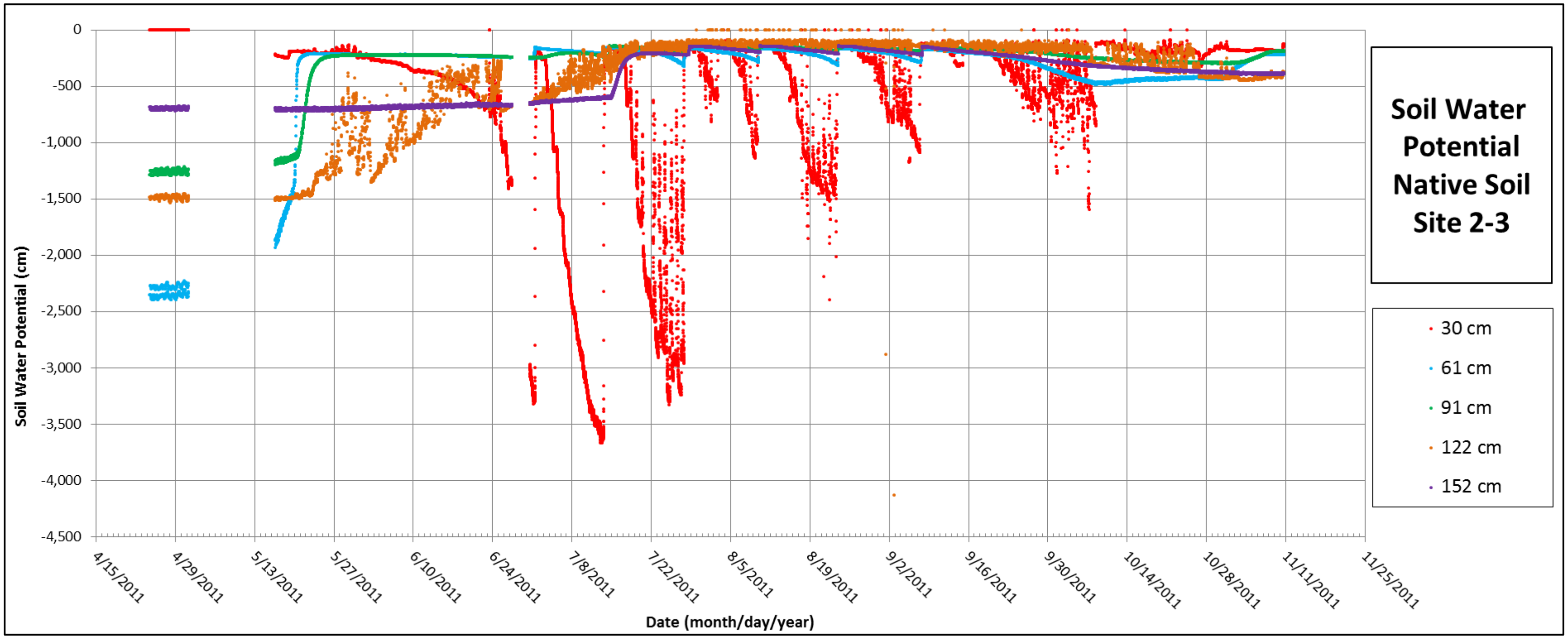

Figure 16: continued

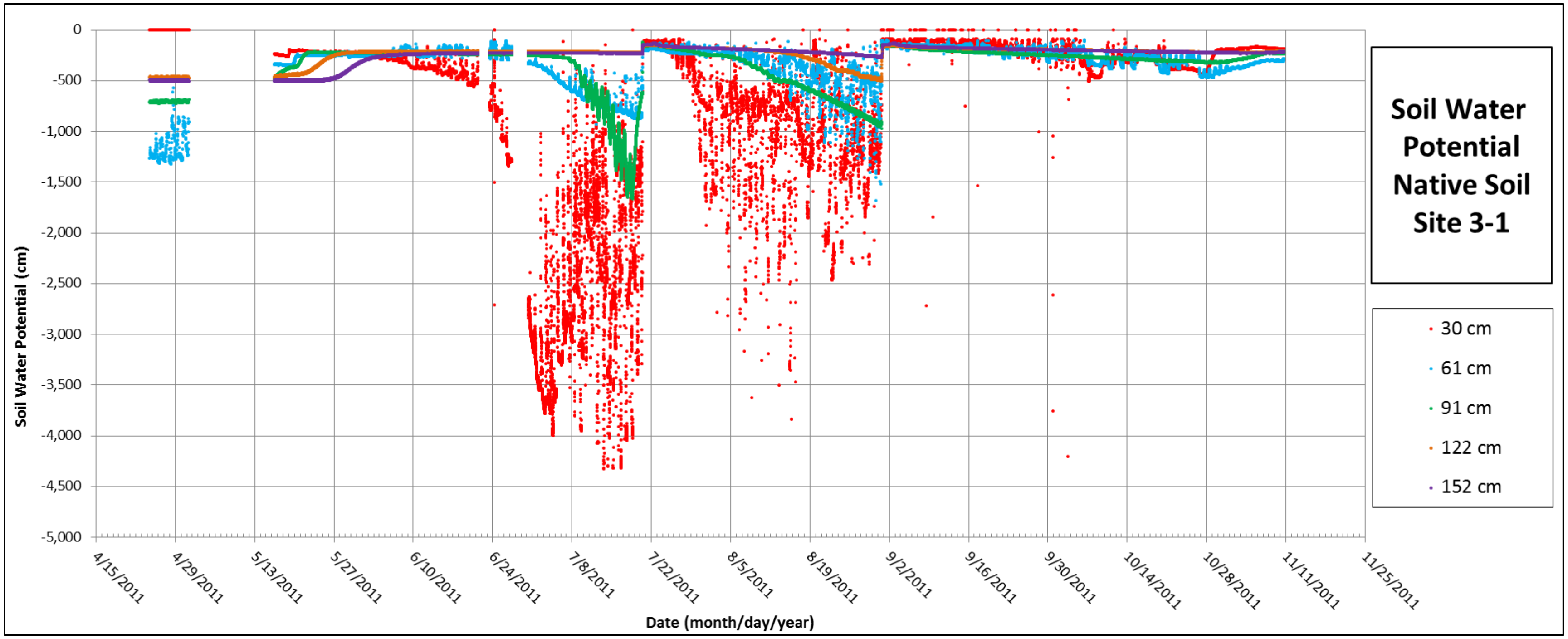

Figure 16: continued

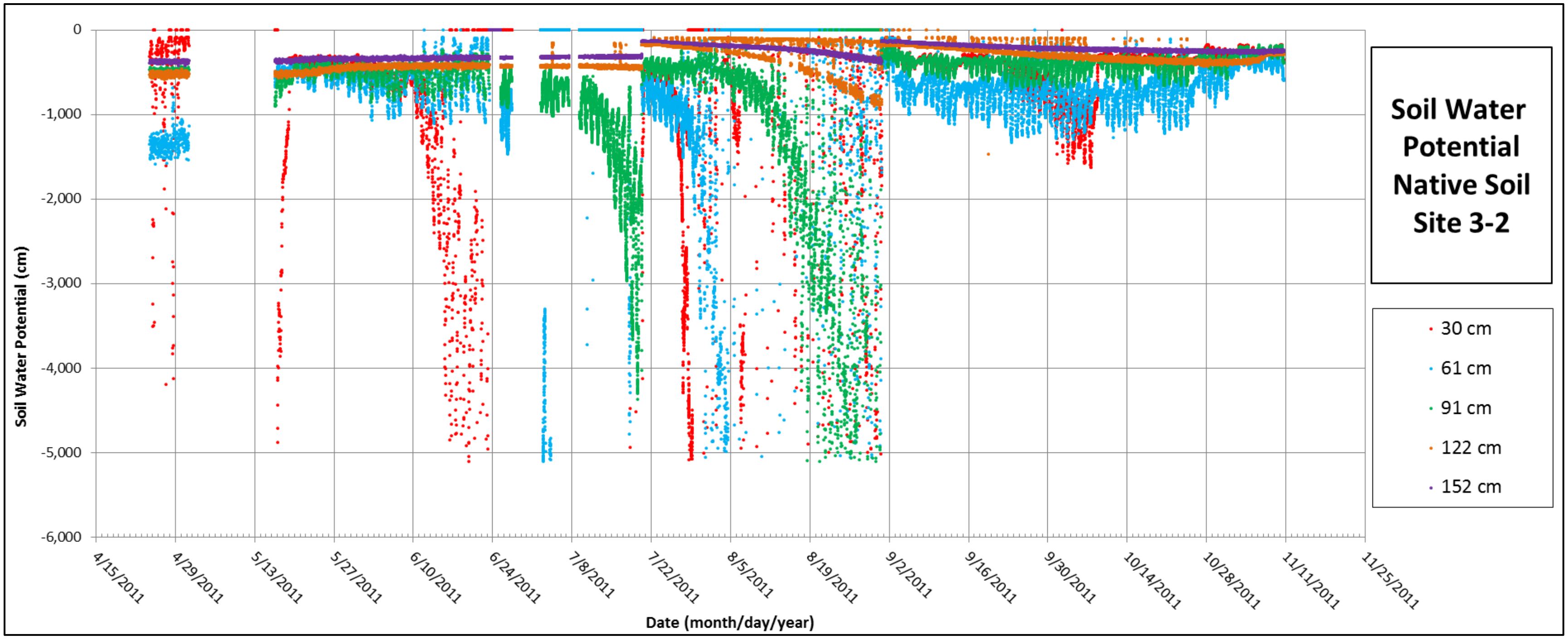

Figure 16: continued

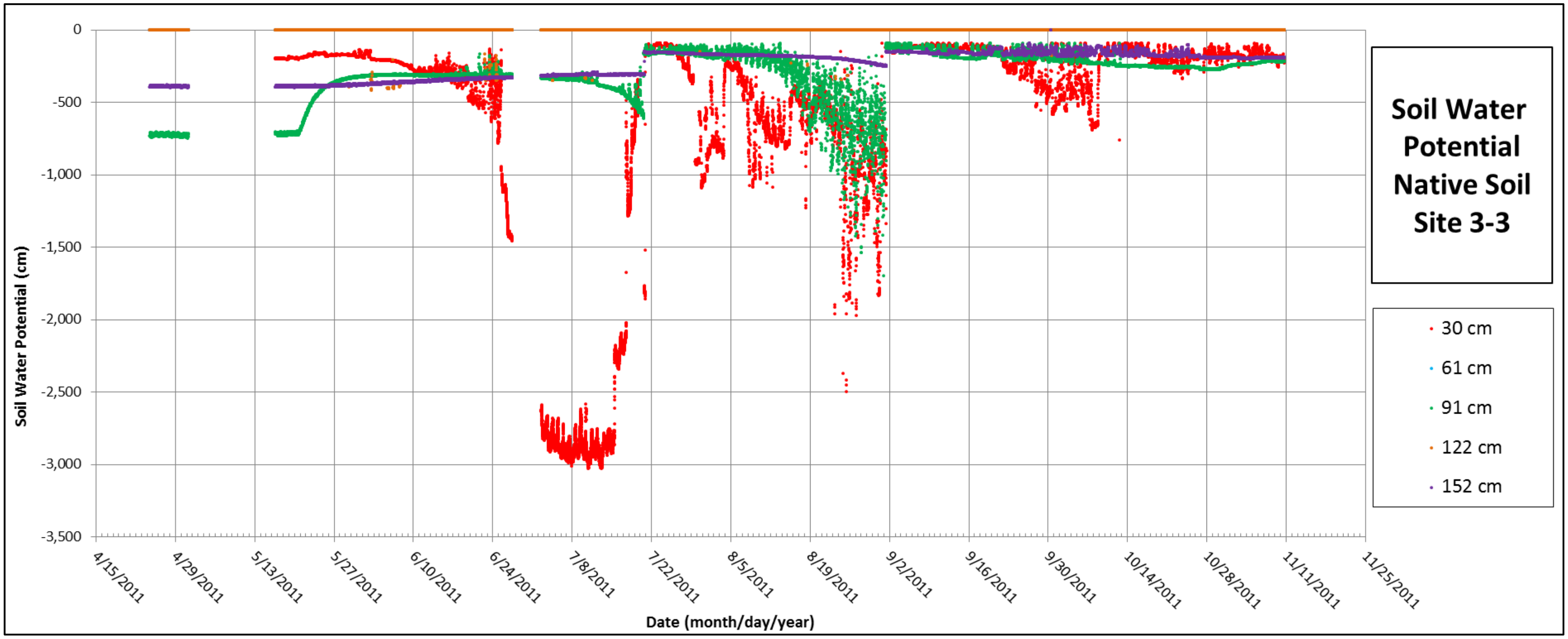

Figure 16: continued

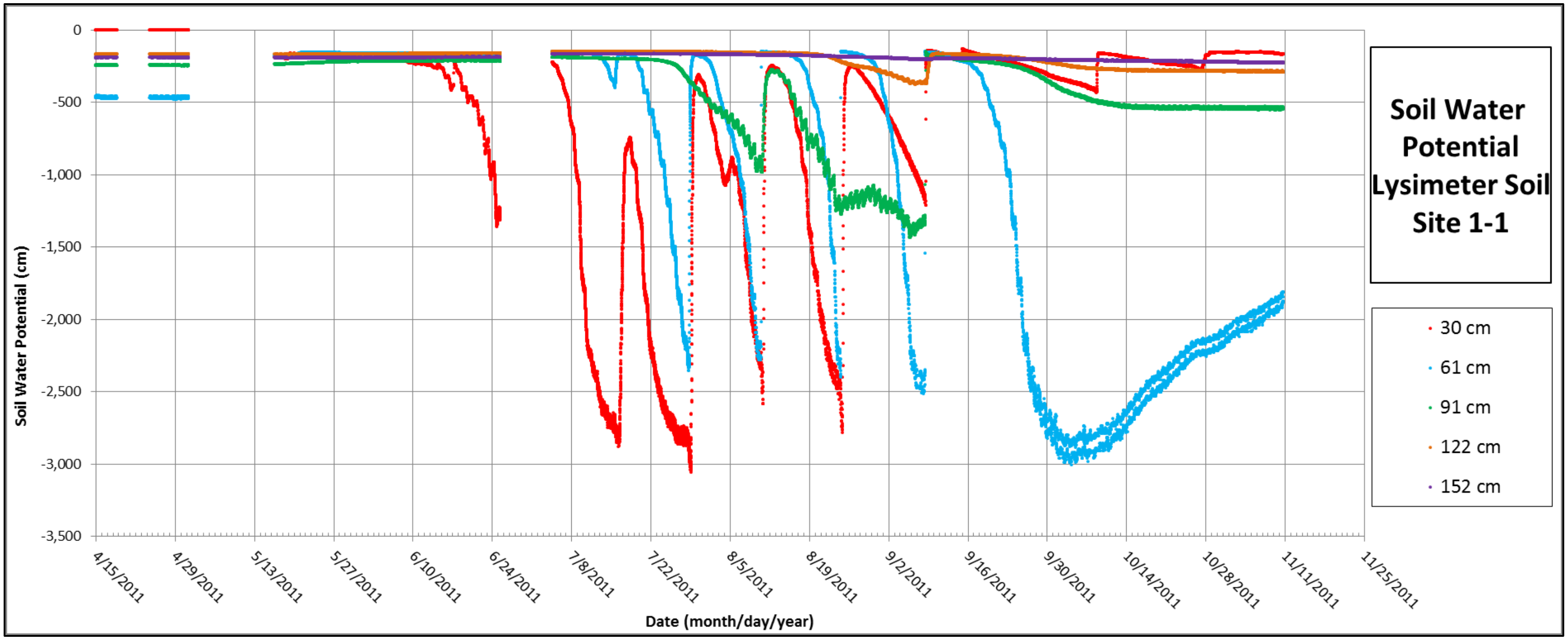

Figure 17: Plots of soil water potential measured over time inside the lysimeters using the Decagon MPS1 sensor.

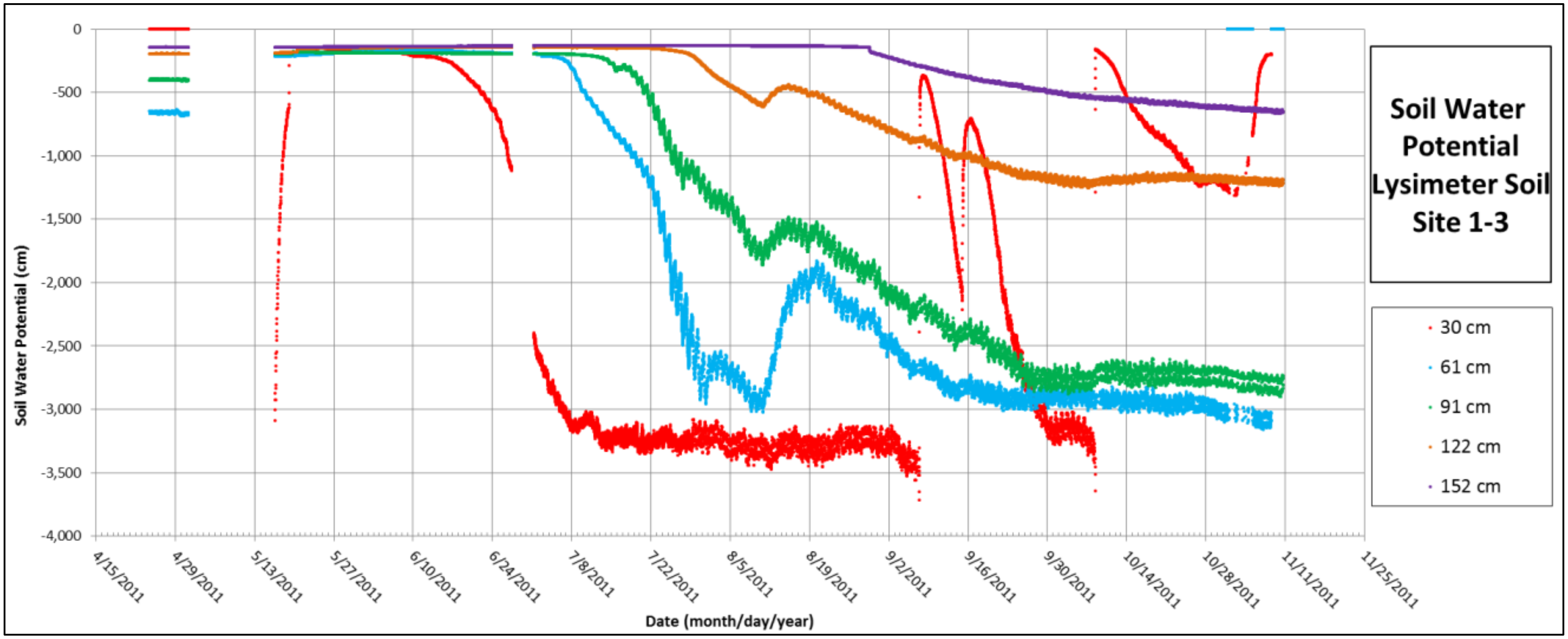

Figure 17: continued

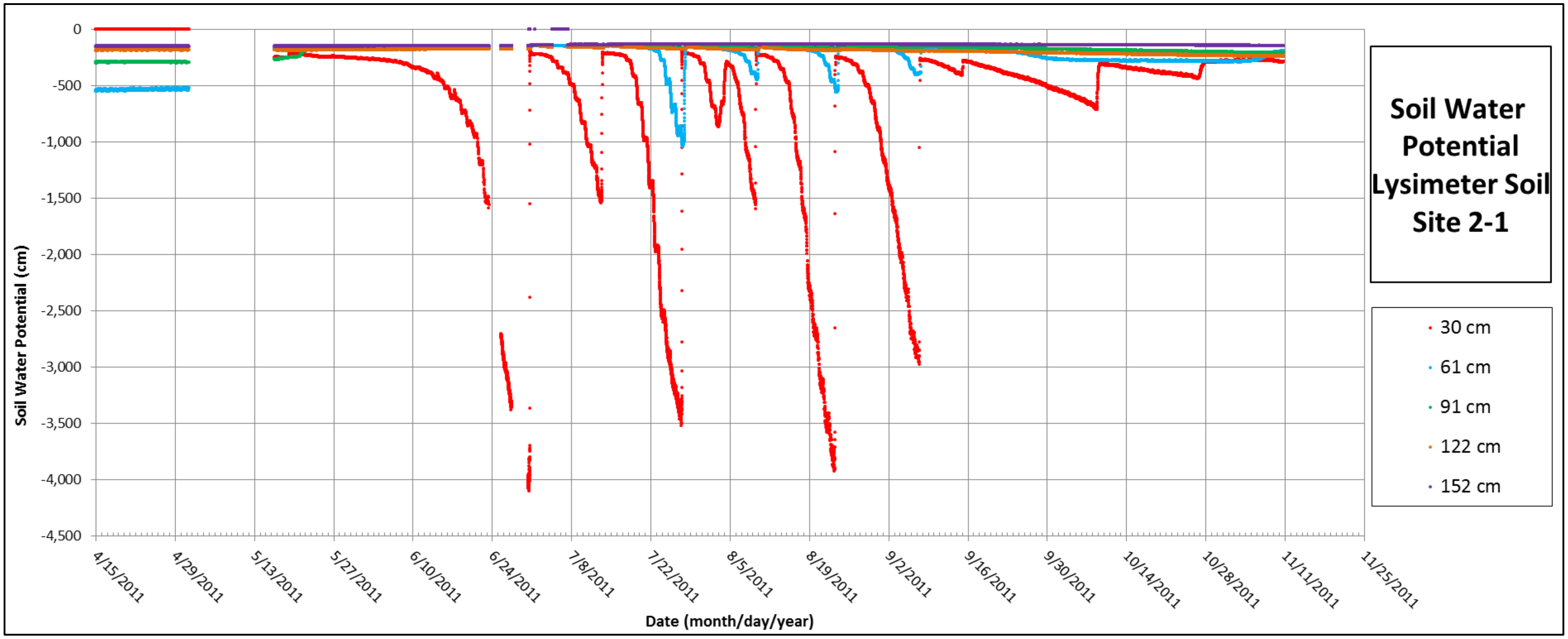

Figure 17: continued

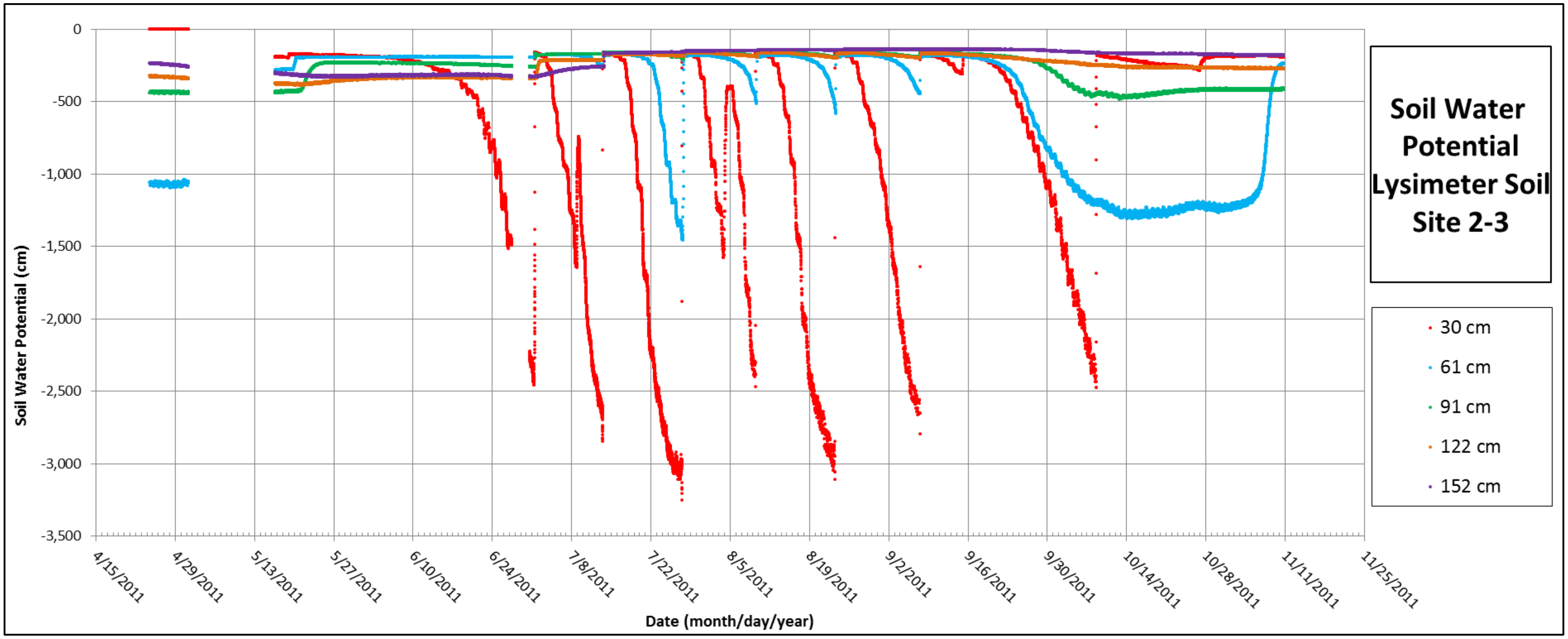

Figure 17: continued

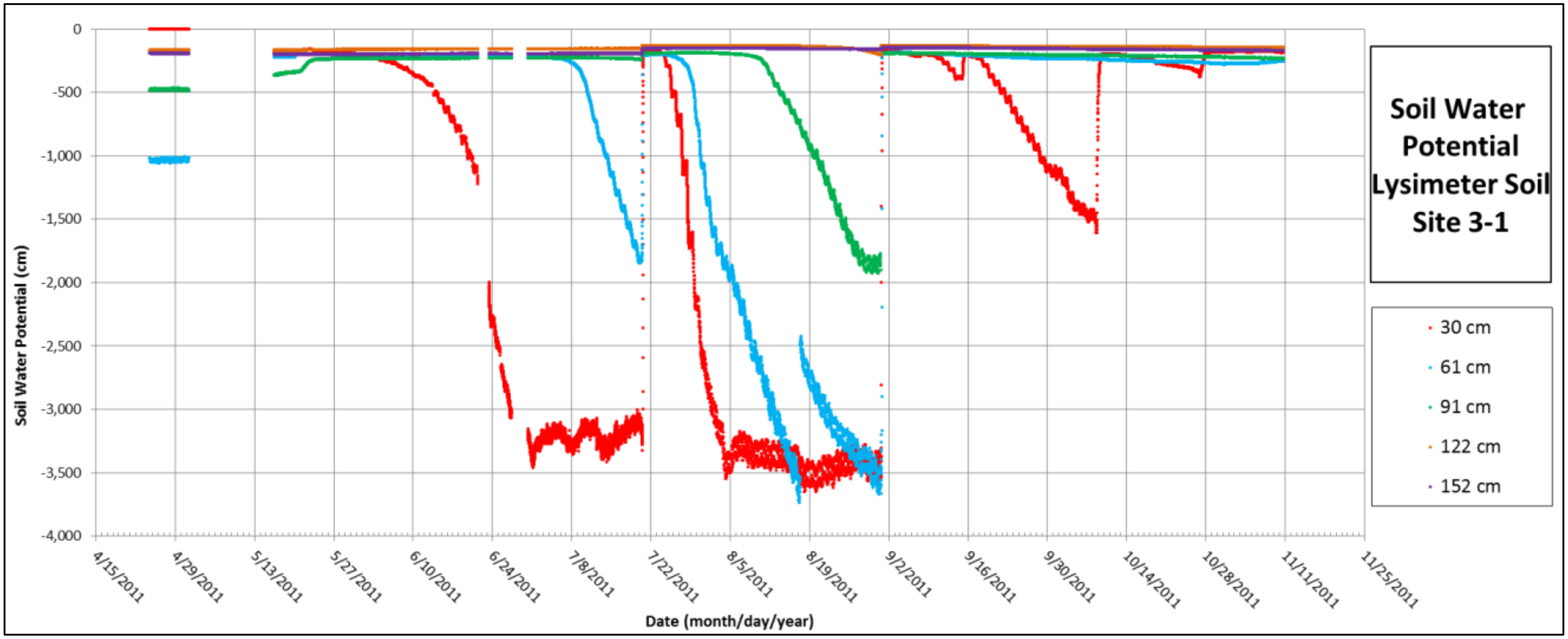

Figure 17: continued

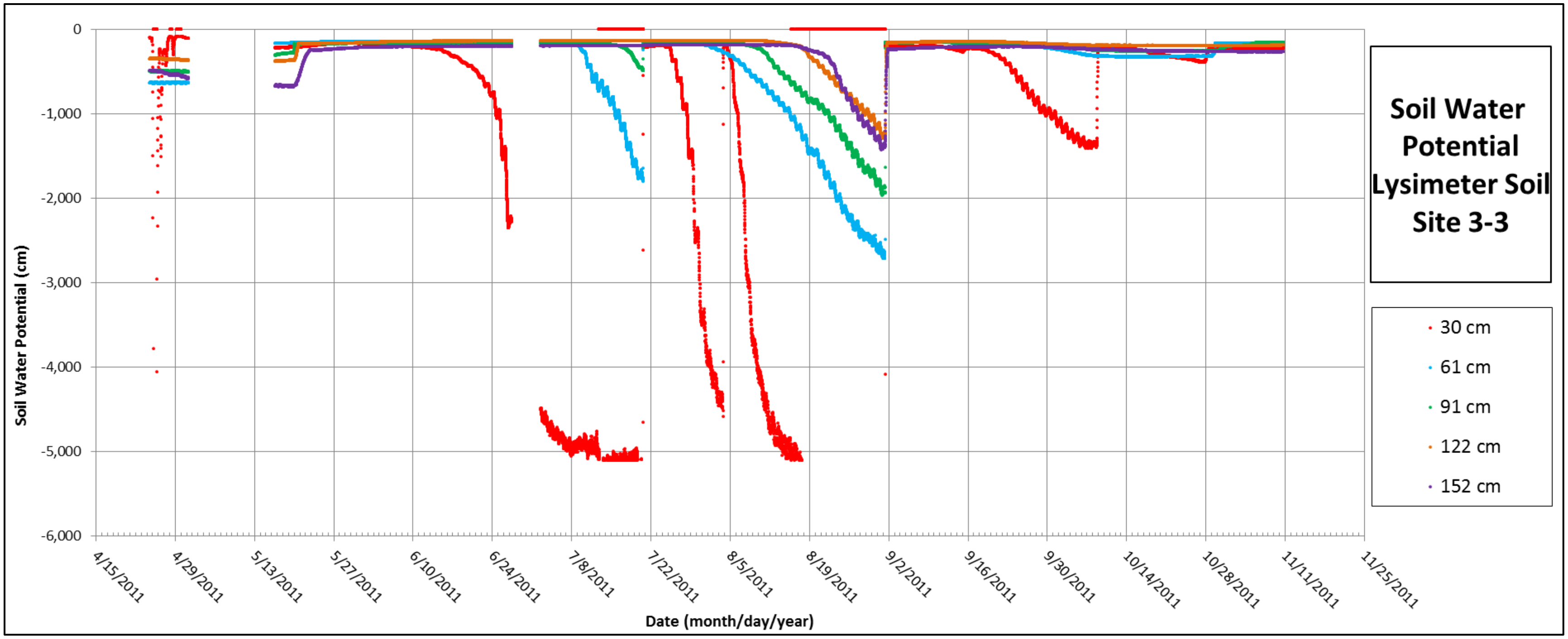

Figure 17: continue

4.2 Lysimeter

Deep percolation values are estimated using the volumes of water extracted from the lysimeters (Table 3). Volumes were converted to length units based on the surface area of the lysimeters. Lysimeters were placed at the northern and southern sites in each block. No lysimeters were placed in the middle of the blocks. Table 4 provides estimates of irrigation water applied to each site in length units

Table 3: Estimates of deep percolation from the lysimeter method and percentage of deep percolation compared to water applied from May – November 2011. The amount of water applied used to determine percentages were provided by the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015). The estimates provided for the Blocks are the average of the estimates for the north and south sites in each block. The middle sites were not included in the estimates for the Blocks because not enough data was available.

Site	**Lysimeter Deep Percolation (mm)**	**Percentage of Deep Percolation Compared To Water Applied**
Site 1-1	52	5%
Site 1-2	no lysimeter present	n/a
Site 1-3	64	41%
Site 2-1	283	18%
Site 2-2	no lysimeter present	n/a
Site 2-3	384	57%
Site 3-1	295	27%
Site 3-2	no lysimeter present	n/a
Site 3-3	180	35%
Block 1	58	10%
Block 2	334	29%
Block 3	238	30%

Table 4: Irrigation water applied in 2011, deep percolation estimated by the USDA-ARS in Fort Collins, CO., and the percentage of deep percolation compared to water applied. This table presents data received from the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015). The estimates provided for the Blocks are the average of the estimates for the north and south sites in each block.

Site	Irrigation by USDA-ARS Water Applied (mm)	USDA-ARS Deep Percolation (mm)	Percentage of Deep Percolation Compared To Water Applied (USDA-ARS)
Site 1-1	954	743	78%
Site 1-2	550	267	49%
Site 1-3	157	1	1%
Site 2-1	1590	1160	73%
Site 2-2	1096	716	65%
Site 2-3	675	267	40%
Site 3-1	1101	899	82%
Site 3-2	902	688	76%
Site 3-3	508	274	54%
Block 1	556	372	67%
Block 2	1133	714	63%
Block 3	805	587	73%

The most water was applied to Block 2 and the least to Block 1. Block 2 was the control block for the project and received frequent irrigations (6) in order to mimic traditional flood irrigation applications. Block 2 received 1,590 mm at Site 2-1, 1,096 mm at Site 2-2, and 675 mm at Site 2-3 in 2011. Block 3 was irrigated only twice, but received large volumes during both irrigation events. Block 3 received 1,101 mm at Site 3-1, 902 mm at Site 3-2, and 508 mm at Site 3-3 in 2011. Block 1 was irrigated at the same frequency as Block 2 but received approximately half of the water per irrigation event. Block 1 received 954 mm at Site 1-1, 550 mm at Site 1-2, and 157 mm at Site 1-3.

The largest volume of water was recovered from the lysimeters in Block 2 (334 mm average) and the smallest amount was recovered from lysimeters in Block 1 (58 mm average) (Table 3). One representative volume of deep percolation for each block was calculated as the average deep percolation estimates from the northern and southern sites (Table 3). Since deep percolation estimates are provided in length units an average of estimates is used instead of a sum because the area of each site is already accounted for. This relationship positively correlates to the amount of water applied to each block (Table 2). In Blocks 1 and 2 the southern lysimeters estimated more deep percolation than the northern lysimeters. In Block 3 the northern lysimeter estimated more deep percolation than the southern lysimeter.

Table 3 also provides the percentage of deep percolation by the lysimeter method compared to water applied. The southern positioned lysimeters recorded a greater percentage of deep percolation than the lysimeters to the north. Site 2-3 received the greatest percentage of deep percolation (57%). Site 1-1 resulted in the lowest percentage of deep percolation (5%). The average percentage of deep percolation for each block is greatest in Block 3 (30%), the least in Block 1 (10%), and an in between percentage in Block 2 (29%). The average percentage of deep percolation per block was calculated by dividing the average of the deep percolation estimates at the north and south ends of each block by the average volume of the water applied to the north and south ends of each block.

More deep percolation estimated at Site 2-3 than at Site 2-1 is likely the result of water infiltrating through surface cracks at Site 2-3, which formed between irrigation events (Figure 18). The cracks in the surface act as macro pores providing a conduit for surface water to enter the ground. Greater deep percolation estimated at Site 1-3 than at Site 1-1 is likely due to the presence of sands and gravels at the ground surface at Site 1-3. Although the sands and gravels at the surface were not included in the soil profile they did exist.

Figure 18: Photograph of surface cracks in soil at Site 2-3.

A primary goal of the lysimeter design is to recover all soil water drainage below the zero flux plane (ZFP), but in practice this may not be possible. Compared to other methods and to the estimates reported by the water balance model the lysimeter estimated less deep percolation at the northern end of the field in all blocks and southern end of the field in Block 3. The comparison with other methods is not a determination that the lysimeter estimates are too low, but it does present that possibility and provides a motivation to explain why the lysimeter method may underestimate deep percolation.

The potential that the lysimeter method is an under estimate of deep percolation can be explained by three factors. One factor is the soil water samplers in the lysimeters were not capable of extracting the full volume of deep percolation because they did not hold enough water volume and there was not a high enough vacuum to extract the water from the soil. Another factor is that in the process of backfilling soil into the lysimeters, a higher bulk density inside the lysimeters may have been created relative to the native soil. An increase in the bulk density decreases pore space, which decreases hydraulic conductivity resulting in less potential water storage in the soil (Hillel, 2004). An additional effect of higher bulk density in the lysimeters is that water is deterred from flowing into the lysimeter and instead flows away from the lysimeter in areas where lower bulk density exists. In the process of using the auger to extract the native soil for installing the lysimeters the soil was mechanically broken into smaller particles and mixed. Smaller sized particles and well mixed soils pack more closely together than larger particles and poorly mixed soils.

One reason that deep percolation estimates are potentially overestimated using the lysimeter method is due to the presence of sidewall flow (Derby et al., 2002). Sidewall flow is preferential flow created when there is a gap or disturbed soil between the soil inside the lysimeter and the inner wall of the lysimeter container. However, sidewall flow is more prevalent in other lysimeter designs when a soil core is extracted and replaced in the lysimeter (Derby et al., 2002).

4.3 Unsaturated Zone Water Balance

Soil water contents shown in Figure 14, collected from the neutron probe access tubes extending to the aquifer, are less than actual soil water contents. The same calibration equation used to convert neutron probe counts to soil water content in the narrower tubes installed by the USDA-ARS was also used for the larger diameter access tubes. Prior to estimating deep percolation using the Unsaturated Zone Water Balance (UZWB) method, a factor of 1.22 was multiplied by the change in soil water contents observed in the larger diameter access tubes.

Results from the UZWB method indicate Block 2 experienced the greatest volume of deep percolation (518 mm), but only slightly more than Block 3 (516 mm) (Table 5). The total volumes of deep percolation per block are calculated by averaging the deep percolation estimated at the northern and southern sites. The well at the middle site in Block 2 (Site 2-2) had water in the well casing up to the ground surface throughout the season so water content measurements were unable to be collected. Block 1 experienced the least amount of deep percolation (291 mm).

Despite receiving less irrigation than Block 2, the UZWB method calculated approximately the same amount of deep percolation in Block 3 as in Block 2. The irrigation treatment applied to Block 3 was largely for the purpose of creating deep percolation. Block 3 was only irrigated two times in the season, which allowed the soil to 'dry out' between irrigation events. The UZWB method compares the difference in soil water content before and after irrigation, so the drier the soil is before irrigation the greater volume of deep percolation estimated (Arnold, 2011). Also, Block 3 received large quantities of irrigation all at once, which caused a large change in soil moisture contents before and after irrigation.

Table 5: Estimates of deep percolation and percentage of deep percolation compared to water applied using the UZWB method from May to November 2011. The amount of water applied used to determine percentages were provided by the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015). The estimates provided for the Blocks are the average of the estimates for the north and south sites in each block. The middle sites were not included in the estimates for the Blocks because not enough data was available.

Site	**UZWB Method Deep Percolation (mm)**	**Percentage of Deep Percolation Compared To Water Applied**
Site 1-1	321	34%
Site 1-2	270	49%
Site 1-3	261	166%
Site 2-1	491	31%
Site 2-2	n/a	n/a
Site 2-3	545	81%
Site 3-1	727	66%
Site 3-2	610	68%
Site 3-3	304	60%
Block 1	291	52%
Block 2	518	46%
Block 3	516	64%

The UZWB method may have resulted in larger deep percolation values in Block 3 than what is presented in Table 5, if all depths had been factored into the calculation. Neutron probe measurements at Site 3-3 were not collected deeper than 300 cm because the well was bent.

More deep percolation was calculated by the UZWB method at the northern sites than at the southern sites, except in Block 2. In Block 2 mud cracks existed at Site 2-3 providing a conduit for water to percolate into the ground (Figure 18) resulting in greater deep percolation than at Site 2-1. The high clay content at Site 3-3 compared to Site 3-1 is likely the reason for more deep percolation at Site 3-1 than Site 3-3. Higher clay content limits water from infiltrating because clay has lower hydraulic conductivity than loamy soils such as those found at the northern sites. Typically, higher soil water content reflects a greater hydraulic conductivity. However, clay retains water, which is reflected by higher water contents, while also inhibiting water flow. The reason Site 1-3 received less deep percolation than Site 1-1 is because the least amount of water was applied to this block. The small volume of water applied to Block 1 resulted in a small volume of water reaching the south end of the field. The USDA-ARS calculated only applying 157 mm of water throughout the season to Site 1-3 compared to 508 mm of water applied to Site 3-3 (Table 4). The relatively small amount of water applied to Block 1 is also evident in the low volume of water recorded by the tail water flume set at the south end of the blocks (USDA-ARS, 2011). The USDA-ARS installed a tail water flume with a pressure transducer to calculate the volume of water passing through the south end of each block during irrigation events. From June 30, 2011 to September 8, 2011 the total amount of water to runoff Block 1 was 0 mm, 17 mm from Block 2, and 3 mm from Block 3.

4.4 Darcy Flux

The Darcy Flux method was applied using only data from the sensors placed at 120 cm and 152 cm depth because these sensors were assumed to be located below the zero flux plane (ZFP). Therefore, any movement of water would be downwards in the form of deep percolation. However, upward moving water was measured so the depth of the ZFP may have varied throughout the growing season. The hydraulic gradient was calculated using soil water potential measurements collected by sensors located at 120 cm and 152 cm below the surface. In some cases a unit hydraulic gradient of one was used as a substitute when the Decagon MPS1 sensors provided no data (Healey, 2010). The hydraulic conductivity between 120 cm and 150 cm was calculated using the van-Genuchten Muleam model. Soil water contents collected by the Acclima TDT sensors were used in the model. The data used from the sensors were filtered in Microsoft Excel spreadsheets to eliminate the use of measurements which exceeded realistic values. For example, soil water content values were not allowed to exceed the saturated soil water content value provided by the Rosetta model (Appendix D).

The estimated deep percolation using this method resulted in negative and positive values. The estimates of deep percolation reported in this section are the sum of only the negative values (Table 6). The formula used to find the water flux between 122 cm and 152 cm depths for each time period was calculated using Equation 3. The hydraulic gradient, dH/dl, between 122 cm and 152 cm depths was negative if there was upward flow and positive if downward flow. In the cases where the hydraulic gradient was positive, the flux was a negative value. Negative deep percolation values indicate water that moved downwards, while positive estimates indicate water that moved upwards. Downward moving water results in deep percolation, while water moving upwards is the result of evapotranspiration indicating that the vertical position of the ZFP fluctuated.

Table 6: Estimates of deep percolation and percentage of deep percolation compared to water applied using the Darcy Flux method from May to November 2011. The amount of water applied used to determine percentages were provided by the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015).

Site	Darcy Flux Method Deep Percolation (mm)	Percentage of Deep Percolation Compared To Water Applied
Site 1-1	194	20%
Site 1-2	5494 (unrealistic)	>100%
Site 1-3	223	142%
Site 2-1	231	15%
Site 2-2	3155 (unrealistic)	>100%
Site 2-3	89	13%
Site 3-1	48	4%
Site 3-2	1375 (unrealistic)	>100%
Site 3-3	2443 (unrealistic)	>100%

The sum of all the negative values for deep percolation at each site yielded some possible realistic and unrealistic values. Values were determined to be realistic and unrealistic based on their comparison to the results of other methods and compared to the volume of water that was applied to each block. Unrealistic values were a result of some sensors not working properly and others recording only periodically, evident in Figures 11 and 12. Realistic values were found at Sites 1-1, 1-3, 2-1, 2-3, and 3-1. Unrealistic values were found at Sites 1-2, 2-2, 3-2, and 3-3. Site 3-3 contains heavy clay soils, which may have resulted in poor contact between the sensor probe and the soil (Figures 11 and 12). Water could have gathered in the void between the sensor and soil resulting in the sensor recording saturated soil conditions even if the soil was not saturated. The Darcy Flux Method did not provide reliable estimates of deep percolation for this study.

4.5 Summary of Results

Table 7 is a summary of the deep percolation values estimated for each method and the volume of water applied for irrigation. Since the Darcy Flux method yielded unreliable results it is not discussed in this section. The percentages in parenthesis are the percentage of deep percolation compared to the water applied. The estimates provided for each Block are the average of the estimates from the northern and southern sites.

The lysimeter method estimated less deep percolation at the north end of the field than in the south end in Blocks 1 and 2. In Block 3, the lysimeter method estimated more deep percolation in the north end of the field than the south. The UZWB method estimated more deep percolation at all sites than the lysimeter method. The UZWB method estimated more deep percolation at the northern sites (Sites 1-1 and 3-1) than the southern sites (Sites 1-3 and 3-3) in Blocks 1 and 3. In Block 2 the UZWB method estimated less deep percolation at the northern site (Site 2-1) than the southern site (Site 2-3).

Table 7: Summary of deep percolation calculated by the following methods: Lysimeter, UZWB, USDA-ARS and the volumes of irrigation water applied. The percentages in parenthesis are the percentage of deep percolation compared to water applied. Values are in millimeters of water unless otherwise noted. The estimates provided for the Blocks are the average of the estimates for the north and south sites in each block. The middle sites were not included in the estimates for the Blocks because not enough data was available. The amount of water applied used to determine percentages were provided by the USDA-ARS (Thomas Trout (USDA-ARS-WMRU), personal communication, February 2015).

Site	Irrigation Applied (USDA-ARS) (mm)	USDA-ARS (mm)	Lysimeter (mm)	UZWB (mm)
Site 1-1	954	743 (78%)	52 (5%)	321 (34%)
Site 1-2	550	267 (49%)	no lysimeter	270 (49%)
Site 1-3	157	1 (1%)	64 (41%)	261 (166%)
Site 2-1	1590	1160 (73%)	283 (18%)	491 (31%)
Site 2-2	1096	716 (65%)	no lysimeter	no data
Site 2-3	675	267 (40%)	384 (57%)	545 (81%)
Site 3-1	1101	899 (82%)	295 (27%)	727 (66%)
Site 3-2	902	688 (76%)	no lysimeter	610 (68%)
Site 3-3	508	274 (54%)	180 (35%)	304 (60%)
Block 1	556	372 (67%)	58 (10%)	291 (52%)
Block 2	1,133	714 (63%)	334 (29%)	518 (46%)
Block 3	805	587 (73%)	238 (30%)	516 (64%)

Each method showed the least amount of deep percolation in Block 1, relative to the other blocks (Table 7). The lysimeter and UZWB method showed the greatest amount of deep percolation in Block 2. In Block 3, the lysimeter and UZWB methods estimated deep percolation values that were in between the estimates provided for Blocks 1 and 2.

Each method (Lysimeter and UZWB) found the irrigation technique applied to Block 3, in relation to the other Blocks, resulted in the greatest percentage of deep percolation compared to water applied (Table 7). The lysimeter method determined that the irrigation technique used in Block 1 was the least efficient in creating deep percolation. The UZWB method found that the irrigation applied to Block 2 was the least efficient.

The largest difference between deep percolation estimates calculated by the lysimeter and UZWB methods was 432 mm at Site 3-1. The smallest difference between methods was 124 mm at Site 3-3. In both cases the difference in deep percolation between the methods was nearly as much as the deep percolation estimated by the lysimeter. At Site 3-1 the difference of 432 mm actually exceeded the deep percolation estimate of 295 mm. The variation in results between methods and uncertainties in each approach emphasize the need for multiple methods to be applied (Scanlon, 2002).

4.5.1 Comparison to USDA Results

The estimates for deep percolation determined by the USDA-ARS provided the greatest percentage (63%-73%) of deep percolation compared to water applied for each Block in comparison to the other methods (Table 7). The results found that Block 1 produced 67% deep percolation, Block 2 63%, and Block 3 73%. Although more deep percolation was estimated by the USDA-ARS for the average of each Block, other methods estimated more deep percolation at individual sites. The estimates by the USDA-ARS found more deep percolation at the northern sites than each of the other methods estimated. The estimates determined by the UZWB method were closest to the USDA-ARS estimates for the northern sites. At the southern sites the deep percolation estimates using the lysimeter and UZWB methods are more than those estimated by the USDA-ARS at Sites 1-3 and 2-3. At Site 3-3 the USDA-ARS estimated more deep percolation than the lysimeter method and less than the UZWB method.

All methods found that the greatest percentage of deep percolation was produced in Block 3 (Table 7). The deficit irrigation plan in Block 3 (irrigated twice with large volumes of water) was for the purpose of creating deep percolation and was the most effective in producing deep percolation.

4.5.2 Meeting Objectives

Objective 1: Quantify Deep Percolation Return Flows

Deep percolation return flows were quantified and presented in Sections 4.2, 4.3, and 4.4, and Table 7.

Objective 2: Determine An Optimal Deficit Irrigation Technique

One objective of this study was to find a deficit irrigation strategy that used less water than traditional irrigation techniques and still produced an acceptable crop. In October and November 2011 the USDA-ARS harvested the field and calculated crop yields. Block 1 yielded 149 bushels/acre, Block 2 yielded 196 bushels/acre, and Block 3 yielded 84 bushels/acre. One approach to determining the efficiency of the irrigation strategies is to compare the ratio of corn produced to the quantity of irrigation used between Blocks. Ratios are presented as the number of bushels per acre to one millimeter of water. Block 1 produced the most yield compared to water applied (27:1), Block 3 produced the least yield (10:1), and Block 2 produced a 17:1 yield.

This study showed that the irrigation strategy in Block 3 was most efficient in producing deep percolation, but Block 1 produced the best yield compared to the amount of water applied. It is uncertain whether the deficit irrigation techniques used in Blocks 1 or 3 meet the objectives of this study. If it is determined that Block 1 did not maintain sufficient return flows via deep percolation, then the irrigation plan in Block 3 may be the best plan. But if Block 1 did maintain sufficient return flows in addition to producing the most yields compared to the amount of water applied then Block 1 may be determined the best plan.

Objective 3: Evaluation of Methods for Estimating Deep Percolation

Another objective of this study was to evaluate the methods used to estimate deep percolation. Each method has its strengths and weaknesses. In the case of all methods deep percolation is only being estimated in one location and that estimate is being used to represent the deep percolation for the irrigation technique applied to an entire block. In reality, physical heterogeneities exist throughout the blocks. Measurements collected in different locations within a block may result in different deep percolation estimates.

Heterogeneities not only exist horizontally in the field, but also exist with depth. In the lysimeter method the heterogeneities that exist within the lysimeters are accounted for in the deep percolation estimate. However, the soil in the lysimeter was disturbed making the estimates using the lysimeter method not as representative of the rest of the block because the soil properties are different. The lysimeters only investigate to a depth just below the root zone. For this project that is considered deep enough to estimate deep percolation. The lysimeter method is the most direct method for estimating deep percolation and the most reliable for collecting measurements.

The UZWB method was thought to provide the most valuable estimates of deep percolation in this study. Installation of the neutron probe access tubes caused minimal disturbance to the soils. The UZWB method investigated the entire unsaturated zone below the ZFP, therefore accounting for vertical heterogeneity. Sampling the entire unsaturated zone to the water table is also useful in attempting to capture the wetting front in the water content measurements. This is especially important in this study where entering the field is limited after irrigation because the field is too wet and the wetting front will have moved downwards by the time measurements are collected.

CHAPTER 5

5: CONCLUSIONS

The goal of this thesis is to estimate deep percolation beneath a cornfield using flood irrigation and evaluate the methods used. Results from this thesis are intended to be used in a larger effort to balance the water budget in a study to find a deficit irrigation technique which saves water, produces an acceptable crop, and follows the rules set by Colorado Water Law, including maintaining return flows (groundwater recharge).

Three irrigation techniques were investigated. Block 2 is a control and is irrigated using traditional non-water saving techniques. Block 1 uses a deficit irrigation technique, which applies water at the same frequency as the control treatment, but uses approximately half the volume of water per irrigation. Block 3 applies water only twice in the growing season, but uses a significantly larger volume of water per irrigation event than in Blocks 1 and 2.

Three methods are used to estimate deep percolation: Lysimeters, Unsaturated Zone Water Balance (UZWB), Darcy Flux. The lysimeter and UZWB method estimated the greatest volume of deep percolation in Block 2 and the least amount in Block 1 (Table 7). Both methods also showed that Block 3 experienced the greatest percentage of deep percolation compared to the water applied for irrigation and Block 1 experienced the lowest percentage of deep percolation (Table 7). The same trends were found in the estimates provided by the USDA-ARS. The Darcy Flux method provided unreliable estimates and was excluded from the final comparison between methods.

Results of the lysimeter and UZWB methods show that the deficit irrigation technique applied to Block 3 was the most effective in producing deep percolation and the irrigation technique applied to Block 1 was the least effective (Table 7). Corn was harvested at the end of the season corn and yields for each block were estimated by the USDA-ARS. Block 3 had the lowest yield (84 bushels/acre), Block 2 had the highest yield (196 bushels/acre), and Block 1 yielded 149 bushels/acre. Although Block 3 was the most effective in producing deep percolation it produced the least amount of corn. The best irrigation technique to meet the objective of this study depends on the acceptable tradeoff between consumptive use and the yield of corn, while maintaining return flows.

The UZWB method was decided to be the most valuable method for estimating deep percolation. It sampled the majority of the unsaturated zone, caused minimal disturbance during installation, and provided reliable and consistent results. The lysimeter method was the second most reliable method. It was the most direct method, but caused extensive soil disturbance during installation. The Darcy Flux method provided the most variable results mostly as a result of the high variability in the measurements collected by the sensors.

CHAPTER 6

6: RECOMMENDATIONS FOR FUTURE WORK

Based on the results of this study, the following recommendations are made for future work to improve estimates of deep percolation.

- Lysimetery
    - Assuring careful installation and proper functioning of the soil water content sensors and soil water potential sensors to compare conditions inside the lysimeter to those outside the lysimeter.
    - Plate shaped soil water samplers attached to a constant vacuum to maintain a more realistic soil water tension relative to the surrounding soils.
    - Capability of extracting water from the lysimeters even when entrance into the field is not possible because of soil moisture saturation at the surface.
- UZWB
    - Calibrating the neutron probe with native soils during the installation of the access tubes, including a full soil textural analysis of the soils that were collected during installation.
- Darcy Flux
    - Assuring careful installation and proper functioning of the soil water content sensors and soil water potential sensors.
    - Apply this method to the soil water contents collected using the neutron probe readings managed by the USDA-ARS.

- Water Table Fluctuation
    - Monitor the regional water table fluctuations using wells outside of the study area.
    - Not having the supply well for irrigation water on the site would prevent water table drawdown and recovery caused by the supply well from interfering with the water table fluctuations resulting from just groundwater recharge.

CHAPTER 7

7: LITERATURE CITED

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APPENDIX A – Instrumentation Details

Sensors
Lysimeters and Soils
Wells

Sensors

Two types of sensors are used to measure water flux (Figures A.1 and A.2). The Acclima TDT Series SDI12 sensor measures soil bulk permittivity, soil water temperature, and soil water conductivity, and calculates the volumetric water content (Acclima, 2008).

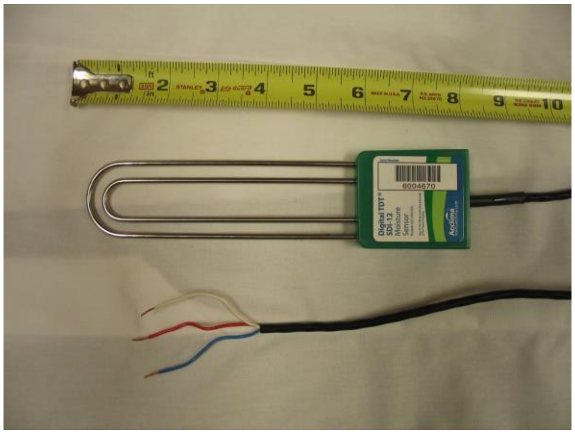


Figure A.1: Photograph of Acclima TDT soil moisture sensor.

The volumetric water content is determined by the dielectric constant (K) in the soil using the Topp equation (Topp et al., 1980).

$$\Theta_v = -5.3*10^{-2} + 2.92*10^{-2}K - 5.5*10^{-4}K^2 + 4.3*10^{-6}K^3 \qquad \text{Equation A.1}$$

The sensor works by measuring the propagation time of an electromagnetic wave through the soil.

The Decagon MPS1 sensor measures soil water potential. According to the Second Law of Thermodynamics, the water potential in the ceramic disks will reach a state of equilibrium with the water potential in the surrounding soil (Decagon Devices Inc., 2008-2009). This allows the user to assume the water potential reading of the disk is the same as in the soil. The Decagon MPS1 sensor measures the dielectric permittivity of ceramic disks to determine water content (Decagon, 2008-2009). Prior to shipping, Decagon Devices Inc. created a calibration curve for this ceramic by relating water content to a measurement of water potential.

Figure A.2: Photograph of Decagon soil water potential sensor (Decagon Devices Inc., 2008-2009).

The Acclima and Decagon sensors are buried underground in pairs (Figure 8). Sensors are installed at 30 cm vertical intervals starting at 30 cm below the pre-furrowed ground surface and extending to a depth of 152 cm. The 30 cm spacing between sensors is to prevent sensor interference. The reason for burying sensors between 30 and 152 cm depths is to observe drainage and evapotranspiration in the root zone and observe drainage just below the root zone. A push-point drill rig was used to create the holes for installing the sensors (Figure A.3).

Figure A.3: Photograph of equipment used to create holes for installing sensors (Photo courtesy of Stephen Smith of Regenesis Management Group).

The sensors at 30 cm are installed using a hand auger. When installing the sensors, the holes for the Decagon MPS1 soil water potential sensors are drilled to the target depth, but the holes for the Acclima TDT soil water content sensors are drilled to about 7 cm above the target depth so the midpoint of the waveguides will be at the target depth. Before setting the Decagon MPS1 sensors, loose soil from the bottom of the hole is collected, saturated with water, and then packed around the sensor to ensure contact between the soil and ceramic plates. Before setting the Acclima TDT sensors, a metal tool mimicking the shape of the probe is inserted into the soil at the base of the hole and removed leaving a slot to install the sensor. After the sensors are installed the holes are backfilled using the soil previously removed from the hole and then gently compacted. A trench digger and hand shovel are used to create a 60 cm deep trench, which is used to guide the wires from the sensors to the stickup located one row to the east (Figure A.4).

Figure A.4: Photograph of equipment used to create trench for burying wires and guiding the wires to the stickup pipe in the adjacent row.

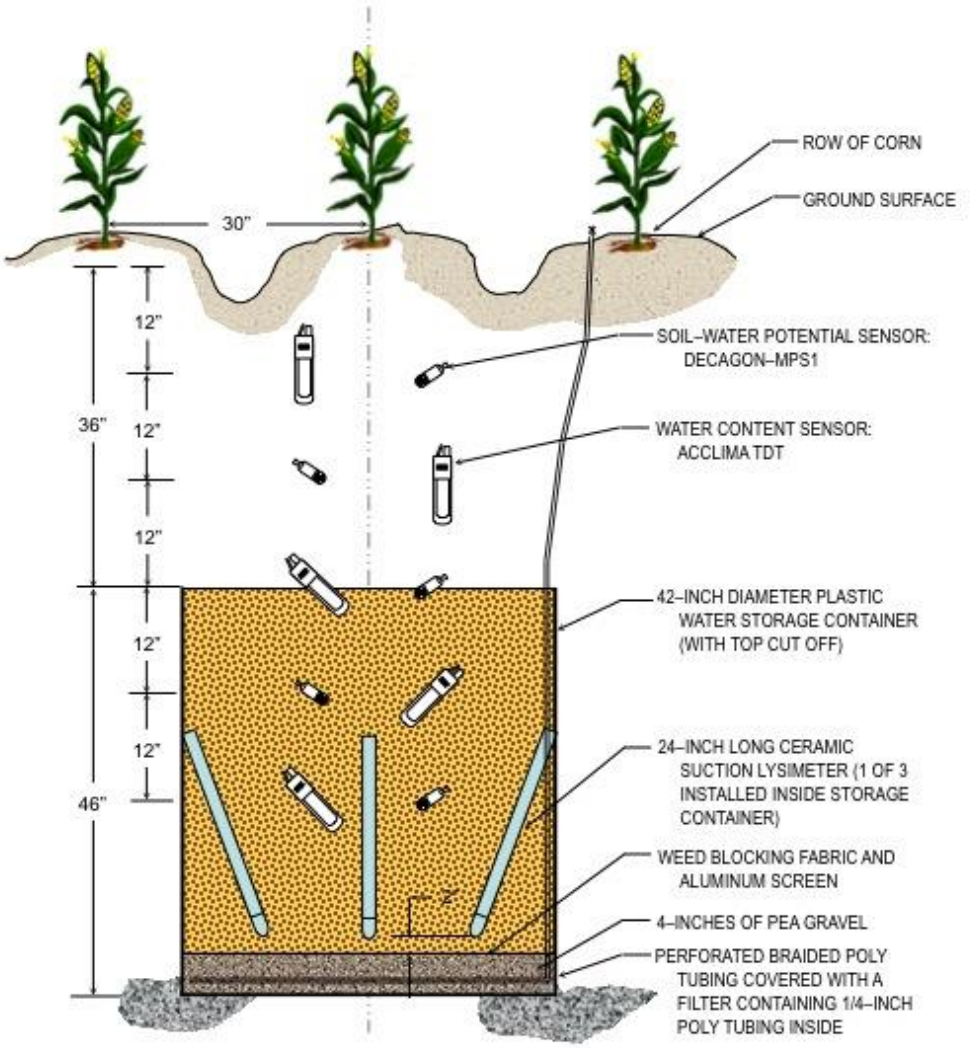
The stickup for the sensor wires is at the same location where the tubes and sensor wires from the lysimeters reach the surface. In order to keep the wires buried 60 cm below the surface, horizontal holes are manually created between the base of the trench and the wires sticking up from the previously backfilled holes for the sensors. Wires are placed in a PVC conduit in the trench.

The wires above the ground surface attach to a data logger inside a weather proof enclosure box, which is secured to a 213 cm (7 feet) steel pipe (Figure A.5). The box also contains a battery pack (PS100) connected to the data logger. On top of the steel pipe a solar panel recharges the battery in the weatherproof box. The Campbell Scientific CR1000 series data loggers are used at the northern and southern sites. The middle sites use the Campbell Scientific CR200 series data loggers. The CR1000 series loggers accommodate a greater number of sensors than the CR200 series. A program in each data logger collects one reading every fifteen minutes from each sensor.

Figure A.5: Photograph of weatherproof box containing data loggers connected to sensors.

Lysimeters and Soils

The lysimeter directly measures deep percolation. Figure A.6 shows a cross section of the drainage lysimeters installed at the study site. In this study, lysimeter refers to a drainage lysimeter. The sites in the middle of each block do not have lysimeters because the northern and southern sites provide a large enough range of deep percolation values, which better characterize the entire field than if the northern and middle sites are equipped with lysimeters and not the southern sites.



NOTES:

1. SOIL–WATER POTENTIAL SENSORS AND WATER CONTENT SENSORS ARE INSTALLED IN A SPIRAL PATTERN AROUND THE CENTER LINE OF THE ROW OF CORN
2. LYSIMETER ASSEMBLIES ON THE NORTH END OF THE PLOTS ARE 42–INCHES IN DIAMETER. LYSIMETERS ON THE SOUTH END ARE 34–INCHES IN DIAMETER.
3. WATER EXTRACTION TUBES AND WIRES ARE ROUTED SO THAT THEY TERMINATE ABOVE THE SOIL SURFACE.

Figure A.6: Cross section of lysimeters.. Figure drafted by Aqua Engineering (Aqua Engineering Inc. Innovative Water Solutions. Fort Collins, Colorado, personal communication, 2011)

The lysimeters are 122 cm tall plastic water storage cylinders with open tops (Figure A.7). The top of the lysimeter is buried 91 cm below the pre-furrowed ground surface. It is assumed that all groundwater flow paths converge by the time water reaches the top of the lysimeter (Figure 4). Since the lysimeters are centered under corn rows, the water that enters each lysimeter is representative of the deep percolation occurring from the two adjacent furrows; one dry and the other containing water. The lysimeters at the north end of the block are 107 cm in diameter and the lysimeters in the southern end of the blocks are 86 cm in diameter. The difference in lysimeter diameters is a result of available materials during installation. Drilling Engineers of Fort Collins used a 107 cm diameter auger to drill the holes (Figure A.8).

Figure A.7: Photograph of container used for lysimeter.

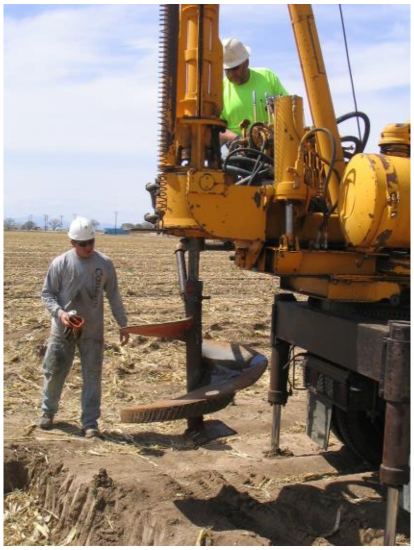


Figure A.8: Photograph of auger bit used to drill holes for lysimeters.

Soil is sorted from the auger at 30 cm intervals during drilling into piles on a plastic tarp next to the hole. The piles are labeled appropriately so when the lysimeters are backfilled, an attempt is made to place soil back to its original vertical position in the ground. In 2010, when lysimeters were backfilled, the mass of the soil remained about the same, evident in using all the soil from the piles, but the volume of the soil decreased, evident in the ground surface subsidence above the lysimeter. After subsidence more soil from the surrounding ground surface is used to finish backfilling over the lysimeters. Grab samples are collected from the piles so particle size analysis can be performed (Figure A.9). Soil profile sampling is also performed in the soil outside of the lysimeter so the differences between the profiles can be identified (Figure A.10). The soil types inside and outside of the lysimeter were determined to be generally similar. Slight changes in soil types and the depths at which soil types changed were observed.

The first step after placing the container in the hole is to install the reservoir extraction system. Five 0.64-cm (¼-inch) diameter polyethylene tubes are used to extract water from the pea gravel reservoir at the bottom of the lysimeter with the use of a peristaltic pump at the surface. Four tubes are placed evenly along the perimeter of the reservoir, positioned north/south and east/west and one tube in the middle. All of the tubes are placed inside a perforated vinyl braided tube to add structural stability so the overburden weight does not collapse the polyethylene tubes. Synthetic stockings are used as filters to keep the tubes from clogging with sediment, which is potentially leaching into the reservoir. Filters are attached to the end of the 0.64 cm (¼-inch) diameter polyethylene tubing and are wrapped around the vinyl tubing. Once this extraction system is in place, a 10 cm thick layer of pea gravel is placed on top of the extraction system. On top of the gravel a piece of metal screen and weed-blocking fabric prevents the soil above from leaching into the reservoir and clogging the pore spaces between the gravel (Figure A.11).

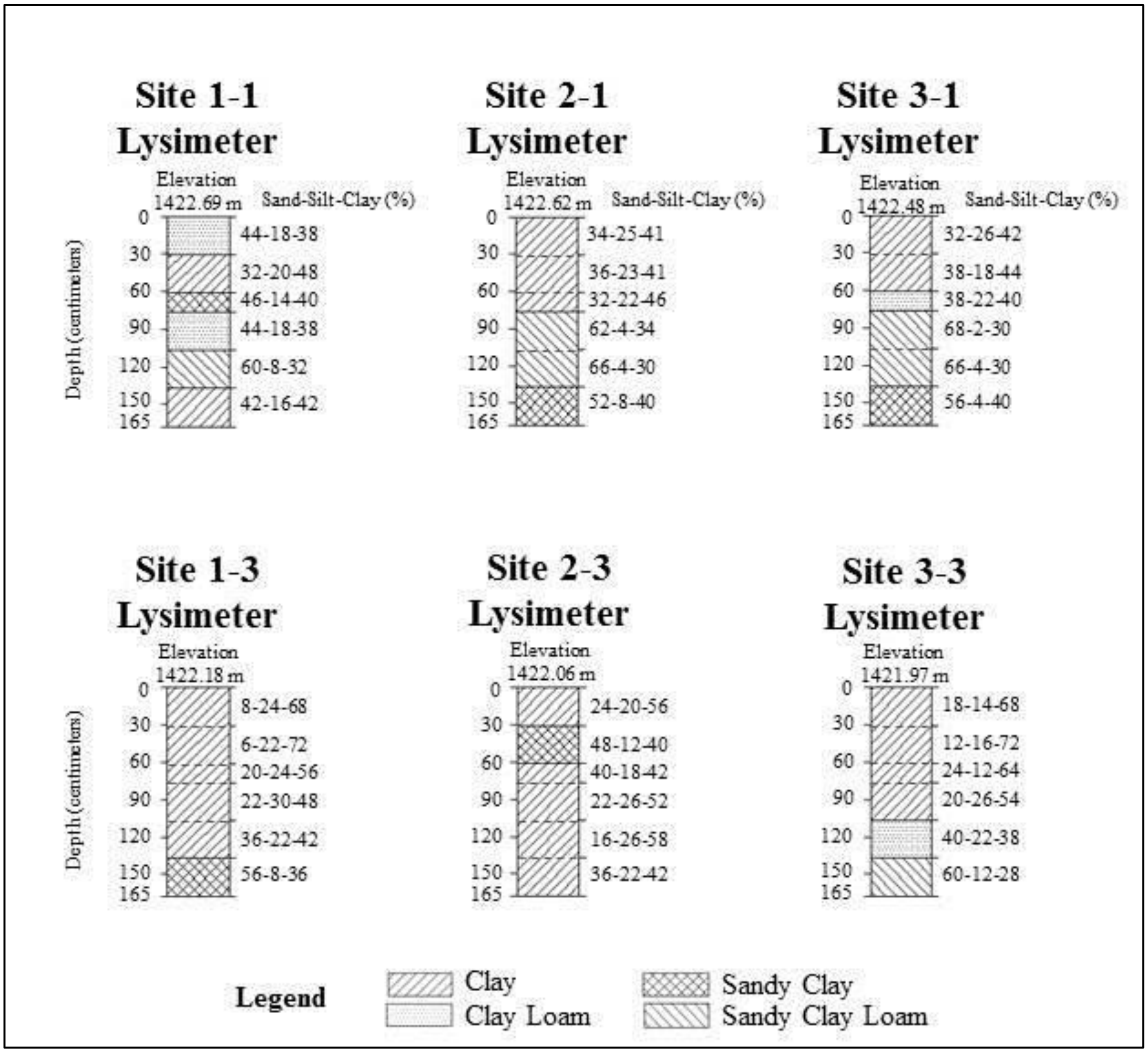


Figure A.9: Columns describing the soil textural analysis of the soil in the lysimeter at each site. Depths shown above indicate depth below the pre-furrowed ground surface. Ground surface elevations are provided for each site. Soil samples were collected during the installation of the lysimeters in the summer of 2010. Textural analysis was performed by the Soil, Water, and Plant Testing Laboratory at Colorado State University in November 2011. (Colorado State University Soil, Water, and Plant Testing Laboratory, 2011)

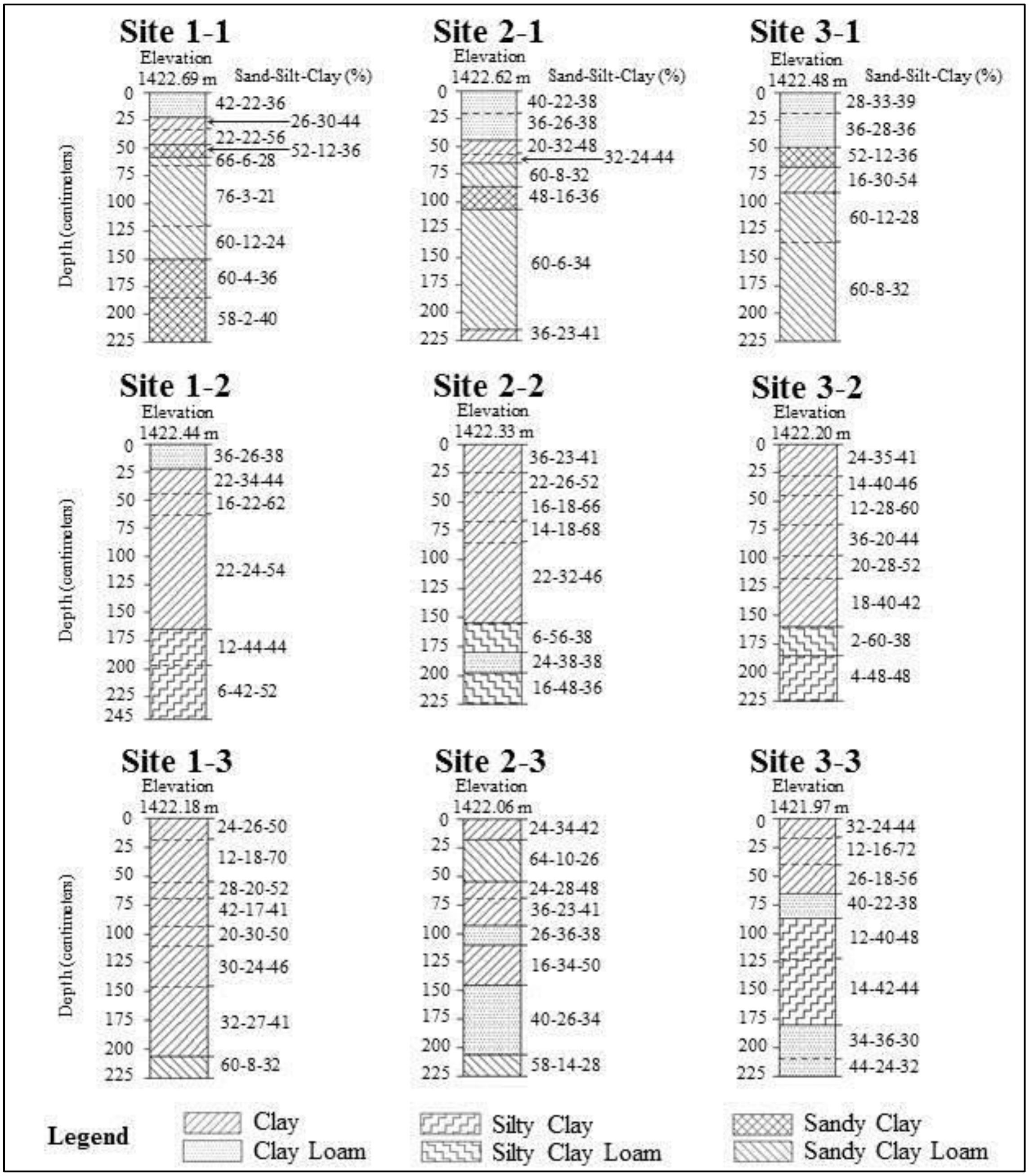


Figure A.10: Columns describing the soil textural analysis of the native soil at each site. Depths shown above indicate depth below the pre-furrowed ground surface. Ground surface elevations are provided for each site. Soil samples were collected in June 2011. Textural analysis was performed by the Soil, Water, and Plant Testing Laboratory at Colorado State University in November 2011. (Colorado State University Soil, Water, and Plant Testing Laboratory, 2011)

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Figure A.11: Photograph of metal screen and weed-blocking fabric placed on top of the pea gravel reservoir in the lysimeters.

Above the screen and weed blocker, soil from the piles created during augering is used to fill the lysimeter. Slight compaction is applied to the soil in an attempt to mimic the natural bulk density of the soil. Five centimeters above the screen and weed blocker are the ceramic cups of the soil water samplers (Figure A.12).

Figure A.12: Photograph of soil water samplers and sensors installed in lysimeters.

A soil water sampler is capable of removing water held under tension in the soil. Three soil water samplers are placed in each lysimeter to remove the water above the reservoir where the air-entry value has not yet been overcome (Derby et al., 2002). The top of the soil water sampler is angled so the top is resting against the wall of the container in order to prevent interference with the sensors. Good contact between the ceramics and the soil is achieved by adding a soil and water mix around the ceramics. A 2 mm sieve is used to gather the correct soil matrix, water is added, and the mixture is stirred until a mortar like consistency is reached (Soil Moisture Equipment, 2007). The Pressure-Vacuum Soil Water Sampler, model 1920F1, can store up to 500 milliliters of water (Soil Moisture Equipment, 2007). Two tubes from the soil water sampler go to the surface where a pump applies a vacuum to the ceramics. Once the soil water sampler takes water from the soil and has it stored in its chamber, pressure is applied to the same tube that the vacuum was previously applied and water comes out of the other tube. The tubes from the soil water samplers are spiraled around the inside of the lysimeter wall until they reach the eastern side of the container where they follow the path of the other tubes from the pea gravel reservoir to the surface. At the top of the lysimeter, 91 cm below the surface, the tubes start to angle to the east over the next vertical 30 cm until they reach the next corn row to the east. At the next corn row the tubes are directed vertically upwards to the surface. A PVC pipe stickup is used to guide the tubes to the surface during the growing season. The stickup is removed and the tubes are buried when farming practices occur, such as plowing.

The deepest set of sensors inside the lysimeters is 152 cm below the surface and 46 cm above the ceramic cups of the soil water samplers (Figure A.6). Sets of sensors inside the lysimeter are located at 30 cm vertical intervals extending from 30 cm below the surface to 152 cm deep. Sensors outside the lysimeter are located at similar depths (Figure 8). The sensors set at 90 to 152 cm deep are all angled at 45 degrees for two reasons: 1) to prevent interference between sensors at different depths and 2) in order for the wires to reach the lysimeter edge without kinking. The wires are placed along the sidewalls of the lysimeter where they follow the paths of the tubes to the surface. To further prevent interference between sensors, each depth of sensors is positioned in a different horizontal line, so that a vertical spiral pattern is created. The wires from the sensors reach the ground surface at the same point as the tubes for extracting water.

Wells

The purposes of the wells are to 1) monitor water table elevations and 2) measure soil water content in the unsaturated zone. Drilling Engineers of Fort Collins uses a Geoprobe Model 7822DT to install the wells using a push-point drilling method, which minimizes formation damage so the soil water content readings more accurately reflect the conditions in the native soil (Figure A.13). Adequate contact between the inside of the pre-drilled hole and outside of the well was observed.

Figure A.13: Photograph of the push-point drill used to install the combination water table monitoring wells and neutron probe access tubes.

The wells are comprised of 152 cm (5-foot) sections of threaded steel pipe, which have a 5 cm (2-inch) inside diameter and 0.5 cm thick walls. The base of the well consists of a 91 cm (3 foot) screened section with a metal point welded to the threaded pipe (Figure A.14).

Figure A.14: Photograph of well bottoms used for the combination water table monitoring wells and neutron probe access tubes.

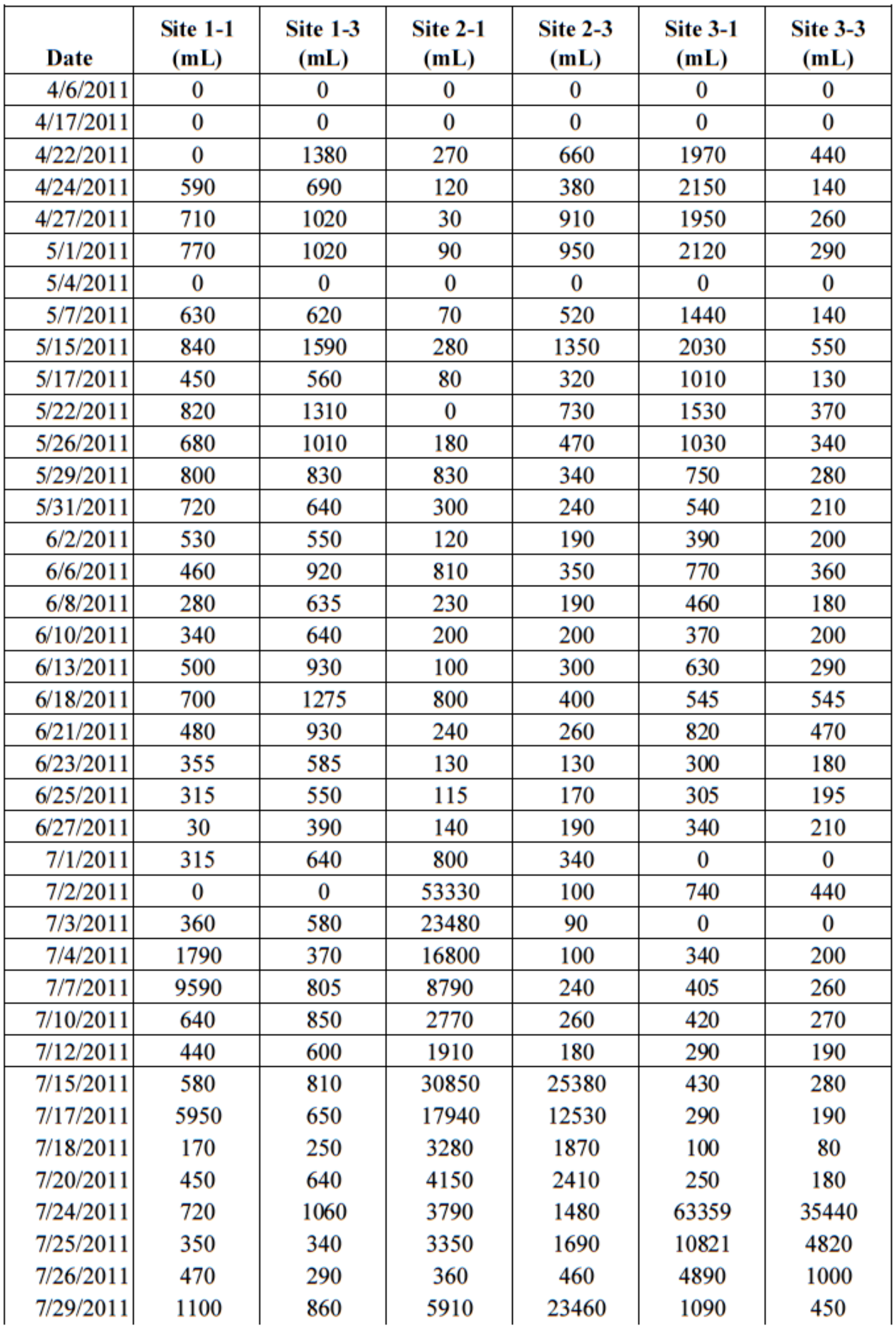
The wells penetrate the water table, so the screened section is below the water table or intersects it. The top of the wells terminate 45-60 cm below the pre-furrowed ground surface where there is a metal vault. A PVC pipe stickup is used to access the well from the surface during the growing season. The stickup is removed when farming practices occur. At the southern site in each block the wells were unable to be installed deep enough to capture the top of the water table throughout the year, but are deep enough to collect soil water content measurements in most of the unsaturated zone. Additional wells are installed at the southern sites to measure water table elevations throughout the year. These additional wells are 2-inch (5 cm) inside diameter PVC pipe installed using a rotary auger and a screened interval extending from the base of the well to above the water table. A gravel filtration pack surrounds the screened interval and a bentonite seal is placed on top of the gravel pack to prevent preferential water flow. Elevations at the top of well casings are determined using a survey level starting at a known elevation point determined by a survey grade GPS.

Vented pressure transducers (In Situ Troll 200) are installed in the northern and southern (PVC) wells to collect groundwater levels every fifteen minutes. Manual measurements are occasionally collected using a water level meter for quality assurance. A neutron probe (model CPN 503DR Hydroprobe) is used to collect soil moisture readings in the wells at 30 cm intervals between 90 cm and the water table. A neutron probe emits fast moving neutrons in the soil and records the slow moving neutrons (Hillel, 2004). Slow moving neutrons are the result of collisions with nuclei in the soil, most common of which are hydrogen nuclei that are present in the water atom. The slow moving neutrons are counted and a calibration equation is used to convert the counts into volumetric water content. Readings are taken just before an irrigation event and then consecutive days after to observe drainage. In the situation that irrigation events do not occur at frequent intervals, readings are taken at least two times per week to monitor changes in soil moisture. Prior to taking measurements with the neutron probe the well is swabbed with a dry cloth to remove any moisture along the inside edge of the well casing.

Soil moisture is also measured in separate aluminum tubes adjacent to the wells. These tubes were installed by the USDA-ARS of Fort Collins, Colorado. Soil moisture readings are collected in these tubes at 30-200 centimeters below the ground surface at 30 cm intervals. The same calibration curve used to translate neutron probe counts to soil water contents in the access tubes installed by the USDA-ARS was also used for these tubes. The well access tubes are larger in diameter than the access tubes installed by the USDA-ARS and have thicker walls. A comparison of changes in soil water contents collected at the same depths between the two types of access tubes was performed by the USDA-ARS. It was found that a 1% soil moisture content change in the access tubes installed by the USDA-ARS was equal to a 0.78% change in soil moisture content in the access tubes that extend to the aquifer. This relationship indicates that the soil moisture contents shown in Figure 14 are an underestimate.

While drilling for the wells, soil cores are collected throughout the entire length of the well casing. Additional soil samples are collected at each site in the top 200 cm of the soil profile while installing the access tubes managed by the USDA-ARS.

APPENDIX B – Water Volumes Extracted from Lysimeters



Date	Site 1-1 (mL)	Site 1-3 (mL)	Site 2-1 (mL)	Site 2-3 (mL)	Site 3-1 (mL)	Site 3-3 (mL)
4/6/2011	0	0	0	0	0	0
4/17/2011	0	0	0	0	0	0
4/22/2011	0	1380	270	660	1970	440
4/24/2011	590	690	120	380	2150	140
4/27/2011	710	1020	30	910	1950	260
5/1/2011	770	1020	90	950	2120	290
5/4/2011	0	0	0	0	0	0
5/7/2011	630	620	70	520	1440	140
5/15/2011	840	1590	280	1350	2030	550
5/17/2011	450	560	80	320	1010	130
5/22/2011	820	1310	0	730	1530	370
5/26/2011	680	1010	180	470	1030	340
5/29/2011	800	830	830	340	750	280
5/31/2011	720	640	300	240	540	210
6/2/2011	530	550	120	190	390	200
6/6/2011	460	920	810	350	770	360
6/8/2011	280	635	230	190	460	180
6/10/2011	340	640	200	200	370	200
6/13/2011	500	930	100	300	630	290
6/18/2011	700	1275	800	400	545	545
6/21/2011	480	930	240	260	820	470
6/23/2011	355	585	130	130	300	180
6/25/2011	315	550	115	170	305	195
6/27/2011	30	390	140	190	340	210
7/1/2011	315	640	800	340	0	0
7/2/2011	0	0	53330	100	740	440
7/3/2011	360	580	23480	90	0	0
7/4/2011	1790	370	16800	100	340	200
7/7/2011	9590	805	8790	240	405	260
7/10/2011	640	850	2770	260	420	270
7/12/2011	440	600	1910	180	290	190
7/15/2011	580	810	30850	25380	430	280
7/17/2011	5950	650	17940	12530	290	190
7/18/2011	170	250	3280	1870	100	80
7/20/2011	450	640	4150	2410	250	180
7/24/2011	720	1060	3790	1480	63359	35440
7/25/2011	350	340	3350	1690	10821	4820
7/26/2011	470	290	360	460	4890	1000
7/29/2011	1100	860	5910	23460	1090	450

Date	Site 1-1 (mL)	Site 1-3 (mL)	Site 2-1 (mL)	Site 2-3 (mL)	Site 3-1 (mL)	Site 3-3 (mL)
7/30/2011	300	380	6730	9240	6520	2160
8/4/2011	720	1150	5040	4310	3665	1120
8/8/2011	20	1040	3755	1625	2805	1010
8/9/2011	250	290	350	450	0	0
8/11/2011	410	565	15670	24740	1585	345
8/12/2011	220	285	8400	10595	720	140
8/15/2011	570	760	6760	5480	1770	740
8/17/2011	375	530	2945	2370	1200	245
8/19/2011	410	520	650	820	1060	160
8/21/2011	415	560	3185	1320	920	245
8/22/2011	210	220	330	360	320	70
8/25/2011	3345	805	780	24710	1230	350
8/27/2011	330	430	600	10120	670	110
8/30/2011	510	660	2480	3460	1150	235
9/2/2011	490	610	710	1280	41540	28860
9/4/2011	0	0	0	0	36085	10335
9/5/2011	500	570	2780	1090	25020	2130
9/8/2011	450	530	2720	23355	16000	1310
9/10/2011	295	90	620	8810	3940	1250
9/13/2011	435	250	750	3135	3520	830
9/16/2011	415	450	730	1410	1450	340
9/20/2011	480	350	750	1280	1740	490
9/25/2011	520	510	740	1440	2870	795
9/29/2011	440	370	750	1260	2010	570
10/5/2011	360	460	730	1380	2200	390
10/24/2011	770	780	780	1500	2305	1120
11/9/2011	720	430	720	1550	2340	960

APPENDIX C – Soil Water Contents Measured with Neutron Probe in Wells Extending to the Aquifer

Soil water content is provided in percent.

The same calibration curve used to translate neutron probe counts to soil moisture contents in the access tubes installed by the USDA-ARS was used to translate neutron probe counts from these access tubes to soil moisture contents. These access tubes are larger in diameter than the access tubes installed by the USDA-ARS and have thicker walls. A comparison of changes in soil moisture contents collected at the same depths between the two types of access tubes was performed by the USDA-ARS. It was found that a 1% soil moisture content change in the access tubes installed by the USDA-ARS was equal to a 0.78% change in soil moisture content in the access tubes that extend to the aquifer. This relationship indicates that the soil moisture contents are an underestimate.

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
3	1-1	203.7					22.4		23.6	22.9
3	1-1	214.0	21.9	21.6	21.4	21.9				
3	1-1	233.7					19.7		21.6	21.7
3	1-1	244.0	19.9	20.4	20.6	20.0				
3	1-1	263.7					20.7		20.0	21.6
3	1-1	274.0	19.6	18.9	19.0	19.9				
3	1-1	293.7					17.2		16.5	19.1
3	1-1	304.0	15.5	14.6	14.5	15.1				
3	1-1	323.7					13.6		13.9	16.1
3	1-1	334.0	10.9	11.4	11.3	12.1				
3	1-1	353.7					11.5		11.5	14.9
3	1-1	364.0	10.7	10.2	10.7	10.6				
3	1-1	383.7					9.3		10.1	14.0
3	1-1	394.0	7.9	7.9	8.0	8.2				
3	1-1	413.7					15.8		15.7	18.5
3	1-1	424.0	17.6	17.9	17.8	17.2				
3	1-1	443.7					13.7		13.3	15.9
3	1-1	454.0	10.4	9.5	9.1	9.4				
3	1-1	473.7					10.8		11.4	12.9
3	1-1	484.0			16.7	17.3				
3	1-1	503.7					7.7		7.6	11.0
3	1-1	514.0			6.9	6.8				
3	1-1	533.7					2.8		2.5	3.3
3	1-1	544.0			3.0	3.5				
3	1-1	563.7							2.9	
3	1-1	574.0				2.8				
3	1-1	593.7								
3	1-1	604.0				19.4				

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
3	1-1	203.7		23.7	23.1	23.7		22.8	23.3	22.4
3	1-1	214.0								
3	1-1	233.7		21.1	22.2	21.4		21.0	21.6	20.3
3	1-1	244.0								
3	1-1	263.7		21.3	21.2	21.5		21.0	20.8	21.1
3	1-1	274.0								
3	1-1	293.7		18.3	19.3	19.3		18.2	18.0	18.7
3	1-1	304.0								
3	1-1	323.7		15.4	15.8	16.1		15.3	15.9	15.3
3	1-1	334.0								
3	1-1	353.7		14.6	14.2	14.9		14.2	14.5	14.4
3	1-1	364.0								
3	1-1	383.7		14.2	13.6	14.1		13.2	13.5	13.6
3	1-1	394.0								
3	1-1	413.7		17.4	18.3	18.8		17.7	20.2	18.9
3	1-1	424.0								
3	1-1	443.7		17.1	16.9	17.2		16.8	23.1	22.2
3	1-1	454.0								
3	1-1	473.7		13.9	14.4	14.8		14.5		
3	1-1	484.0								
3	1-1	503.7		14.9	15.2	15.0				
3	1-1	514.0								
3	1-1	533.7								
3	1-1	544.0								
3	1-1	563.7								
3	1-1	574.0								
3	1-1	593.7								
3	1-1	604.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
3	1-1	203.7								
3	1-1	214.0								
3	1-1	233.7	21.2	21.4	20.8	21.2	21.3	20.8	21.1	21.0
3	1-1	244.0								
3	1-1	263.7	21.8	20.9	21.3	21.3	21.0	20.8	20.5	21.0
3	1-1	274.0								
3	1-1	293.7	18.1	18.1	18.5	18.5	17.9	18.0	18.6	18.1
3	1-1	304.0								
3	1-1	323.7	15.2	14.3	15.2	14.6	15.6	15.6	15.4	14.3
3	1-1	334.0								
3	1-1	353.7	14.4	14.2	14.2	14.0	13.7	13.9	14.5	14.1
3	1-1	364.0								
3	1-1	383.7	13.4	12.6	13.9	12.7	13.0	13.1	12.8	13.0
3	1-1	394.0								
3	1-1	413.7	19.2	18.7	18.1	17.9	17.2	17.8	17.6	17.7
3	1-1	424.0								
3	1-1	443.7	20.7	21.3	20.4	18.2	17.2	18.0	17.5	17.5
3	1-1	454.0								
3	1-1	473.7			17.6	15.6	15.3	14.8	15.3	14.9
3	1-1	484.0								
3	1-1	503.7				17.5	16.3	16.0	15.5	14.8
3	1-1	514.0								
3	1-1	533.7							6.1	5.1
3	1-1	544.0								
3	1-1	563.7								
3	1-1	574.0								
3	1-1	593.7								
3	1-1	604.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
3	1-1	203.7								
3	1-1	214.0								
3	1-1	233.7	20.8	21.2	21.4	20.6		21.3		19.9
3	1-1	244.0								
3	1-1	263.7	20.8	21.0	21.1	21.4		20.8		20.8
3	1-1	274.0								
3	1-1	293.7	18.4	18.4	17.7	18.1		17.6		17.1
3	1-1	304.0								
3	1-1	323.7	15.6	14.5	15.2	15.4		14.6		15.3
3	1-1	334.0								
3	1-1	353.7	14.0	14.6	13.6	13.3		13.7		13.7
3	1-1	364.0								
3	1-1	383.7	12.5	13.1	12.5	12.3		12.4		12.6
3	1-1	394.0								
3	1-1	413.7	18.1	17.3	17.2	17.4		17.6		17.0
3	1-1	424.0								
3	1-1	443.7	16.8	17.2	17.2	16.5		17.4		16.6
3	1-1	454.0								
3	1-1	473.7	14.7	14.8	15.0	14.3		14.4		14.3
3	1-1	484.0								
3	1-1	503.7	14.7	14.4	14.8	14.4		13.7		14.0
3	1-1	514.0								
3	1-1	533.7	5.8	5.8	5.4	5.0		5.0		4.8
3	1-1	544.0								
3	1-1	563.7		8.8	8.3	8.5				8.6
3	1-1	574.0								
3	1-1	593.7				15.7				
3	1-1	604.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
3	1-1	203.7								
3	1-1	214.0								
3	1-1	233.7	20.7	20.3	20.8	21.2	20.6	20.8	20.5	19.9
3	1-1	244.0								
3	1-1	263.7	21.1	21.1	20.3	20.5	20.4	20.5	20.5	20.2
3	1-1	274.0								
3	1-1	293.7	18.2	17.7	18.4	18.4	17.0	17.9	17.7	16.7
3	1-1	304.0								
3	1-1	323.7	14.6	14.5	15.3	14.9	15.2	14.9	14.3	14.2
3	1-1	334.0								
3	1-1	353.7	13.7	13.0	13.4	13.9	13.7	13.4	12.9	13.0
3	1-1	364.0								
3	1-1	383.7	12.6	12.2	11.8	12.9	12.7	12.5	12.3	11.7
3	1-1	394.0								
3	1-1	413.7	17.4	17.0	17.2	17.4	16.6	17.5	17.3	16.8
3	1-1	424.0								
3	1-1	443.7	16.3	16.9	16.6	16.5	16.6	16.3	16.8	16.4
3	1-1	454.0								
3	1-1	473.7	13.8	14.3	13.9	14.2	14.4	14.0	13.9	13.9
3	1-1	484.0								
3	1-1	503.7	13.6	13.5	14.0	14.5	14.1	13.9	13.9	
3	1-1	514.0								
3	1-1	533.7	4.9	5.0	5.0	4.9				
3	1-1	544.0								
3	1-1	563.7	8.0	8.0						
3	1-1	574.0								
3	1-1	593.7								
3	1-1	604.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
3	1-1	203.7		
3	1-1	214.0		
3	1-1	233.7	19.8	19.8
3	1-1	244.0		
3	1-1	263.7	19.6	19.6
3	1-1	274.0		
3	1-1	293.7	16.9	16.4
3	1-1	304.0		
3	1-1	323.7	13.5	13.3
3	1-1	334.0		
3	1-1	353.7	12.4	12.5
3	1-1	364.0		
3	1-1	383.7	11.5	10.3
3	1-1	394.0		
3	1-1	413.7	17.1	16.9
3	1-1	424.0		
3	1-1	443.7	16.4	16.8
3	1-1	454.0		
3	1-1	473.7	15.2	15.4
3	1-1	484.0		
3	1-1	503.7		
3	1-1	514.0		
3	1-1	533.7		
3	1-1	544.0		
3	1-1	563.7		
3	1-1	574.0		
3	1-1	593.7		
3	1-1	604.0		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
3	1-2	203.7						22.5	22.9	23.8
3	1-2	214.0	23.7	23.9	24.4	23.9				
3	1-2	233.7						21.6	22.0	21.1
3	1-2	244.0	22.0	22.2	21.8	22.6				
3	1-2	263.7						19.7	20.0	20.9
3	1-2	274.0	18.1	17.9	18.3	18.3				
3	1-2	293.7						19.3	19.8	19.0
3	1-2	304.0	23.2	22.7	22.7	22.2				
3	1-2	323.7						26.2	27.0	26.3
3	1-2	334.0	27.2	26.8	26.6	26.7				
3	1-2	353.7						26.0	26.2	26.0
3	1-2	364.0	26.0	25.1	25.7	24.9				
3	1-2	383.7						27.0	27.8	27.1
3	1-2	394.0	26.1	25.5	26.1	26.3				
3	1-2	413.7						20.6	20.1	20.0
3	1-2	424.0	18.7	18.1	18.0	18.2				
3	1-2	443.7						13.4	14.1	13.9
3	1-2	454.0	13.6	13.2	13.3	14.0				
3	1-2	473.7						22.1	22.5	22.1
3	1-2	484.0	22.5	22.4	22.4	23.0				
3	1-2	503.7						24.0	24.6	24.3
3	1-2	514.0	24.7	25.2	24.6	24.8				
3	1-2	533.7						23.3	23.1	23.6
3	1-2	544.0				24.0				

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
3	1-2	203.7		23.4	23.7	23.5		23.6	24.3	23.4
3	1-2	214.0								
3	1-2	233.7		21.9	22.0	22.2		22.2	22.7	22.0
3	1-2	244.0								
3	1-2	263.7		20.8	21.1	20.6		21.7	22.1	22.6
3	1-2	274.0								
3	1-2	293.7		19.8	19.8	19.5		19.6	20.2	20.3
3	1-2	304.0								
3	1-2	323.7		26.4	26.8	26.9		26.0	26.6	27.2
3	1-2	334.0								
3	1-2	353.7		27.1	26.4	26.6		25.9	26.6	26.0
3	1-2	364.0								
3	1-2	383.7		27.5	27.5	28.2		27.3	27.3	28.0
3	1-2	394.0								
3	1-2	413.7		20.0	20.9	21.0		21.6	22.2	21.9
3	1-2	424.0								
3	1-2	443.7		14.7	15.0	15.0		20.3	22.0	22.6
3	1-2	454.0								
3	1-2	473.7		23.0	23.1	24.1		24.8	25.3	
3	1-2	484.0								
3	1-2	503.7		25.1	25.4	25.6				
3	1-2	514.0								
3	1-2	533.7		23.7	24.6					
3	1-2	544.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
3	1-2	203.7								
3	1-2	214.0								
3	1-2	233.7	23.2	22.6	22.7	22.2	23.0	22.8	23.2	22.2
3	1-2	244.0								
3	1-2	263.7	23.2	23.6	23.1	23.6	22.8	22.4	22.6	22.6
3	1-2	274.0								
3	1-2	293.7	20.6	21.3	20.5	21.1	21.1	21.1	21.1	21.0
3	1-2	304.0								
3	1-2	323.7	27.2	26.7	27.5	26.7	27.1	27.2	27.3	26.6
3	1-2	334.0								
3	1-2	353.7	26.1	25.8	26.3	26.7	27.3	26.8	27.1	27.0
3	1-2	364.0								
3	1-2	383.7	27.8	28.1	27.3	27.7	27.8	27.5	28.0	26.8
3	1-2	394.0								
3	1-2	413.7	22.2	21.9	22.3	22.5	23.1	22.0	21.7	21.8
3	1-2	424.0								
3	1-2	443.7	22.5	22.5	21.4	21.6	22.0	21.3	17.7	16.5
3	1-2	454.0								
3	1-2	473.7								23.9
3	1-2	484.0								
3	1-2	503.7								
3	1-2	514.0								
3	1-2	533.7								
3	1-2	544.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
3	1-2	203.7								
3	1-2	214.0								
3	1-2	233.7	22.6	22.6	23.0	23.1		22.4		22.8
3	1-2	244.0								
3	1-2	263.7	22.8	23.1	22.9	22.1		23.0		22.6
3	1-2	274.0								
3	1-2	293.7	21.0	20.4	20.9	20.3		20.1		20.6
3	1-2	304.0								
3	1-2	323.7	26.3	27.9	27.0	27.0		26.4		27.3
3	1-2	334.0								
3	1-2	353.7	26.4	26.2	27.5	26.8		26.7		26.6
3	1-2	364.0								
3	1-2	383.7	27.2	27.9	28.1	27.7		27.8		28.0
3	1-2	394.0								
3	1-2	413.7	20.6	21.1	21.5	21.0		21.0		21.2
3	1-2	424.0								
3	1-2	443.7	16.9	17.0	16.4	15.7		15.4		15.4
3	1-2	454.0								
3	1-2	473.7	24.0	23.8	23.8	23.2		22.7		23.4
3	1-2	484.0								
3	1-2	503.7				26.3		25.1		25.7
3	1-2	514.0								
3	1-2	533.7								24.9
3	1-2	544.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
3	1-2	203.7								
3	1-2	214.0								
3	1-2	233.7	22.7	23.1	21.7	22.2	23.0	22.6	21.9	21.7
3	1-2	244.0								
3	1-2	263.7	22.4	22.1	22.2	23.0	22.6	22.3	21.2	21.8
3	1-2	274.0								
3	1-2	293.7	20.3	20.3	20.4	20.0	20.1	19.8	20.3	19.7
3	1-2	304.0								
3	1-2	323.7	27.3	27.0	26.8	27.0	27.0	26.9	26.4	26.8
3	1-2	334.0								
3	1-2	353.7	26.7	26.5	26.6	26.8	25.8	26.7	26.2	26.7
3	1-2	364.0								
3	1-2	383.7	27.7	27.8	27.2	27.7	27.3	27.8	27.4	26.8
3	1-2	394.0								
3	1-2	413.7	21.4	21.4	20.2	21.1	21.2	21.6	21.1	20.5
3	1-2	424.0								
3	1-2	443.7	15.7	15.8	15.6	15.7	15.9	15.8	16.1	15.9
3	1-2	454.0								
3	1-2	473.7	23.4	22.9	23.2	23.2	23.6	23.7	23.4	23.1
3	1-2	484.0								
3	1-2	503.7	24.8	25.6	25.3	24.9	25.4	25.7	25.9	26.0
3	1-2	514.0								
3	1-2	533.7	25.3	24.7	24.3	24.5				
3	1-2	544.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
3	1-2	203.7		
3	1-2	214.0		
3	1-2	233.7	21.6	21.9
3	1-2	244.0		
3	1-2	263.7	21.1	20.9
3	1-2	274.0		
3	1-2	293.7	19.7	20.0
3	1-2	304.0		
3	1-2	323.7	27.3	26.9
3	1-2	334.0		
3	1-2	353.7	26.6	26.1
3	1-2	364.0		
3	1-2	383.7	28.0	27.8
3	1-2	394.0		
3	1-2	413.7	20.8	20.8
3	1-2	424.0		
3	1-2	443.7	15.4	15.9
3	1-2	454.0		
3	1-2	473.7	23.7	24.7
3	1-2	484.0		
3	1-2	503.7	25.8	25.8
3	1-2	514.0		
3	1-2	533.7		
3	1-2	544.0		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
3	1-3	203.7						8.3	8.6	8.6
3	1-3	214.0	4.5	4.9	4.4	4.8				
3	1-3	233.7						6.6	6.8	6.8
3	1-3	244.0	6.9	6.9	6.4	6.7				
3	1-3	263.7						24.0	24.5	23.9
3	1-3	274.0	25.9	25.6	25.1	25.5				
3	1-3	293.7						23.8	24.1	23.9
3	1-3	304.0	23.1	22.7	23.4	23.5				
3	1-3	323.7						17.1	17.1	17.5
3	1-3	334.0	17.3	16.3	16.3	17.5				
3	1-3	353.7						16.6	16.5	16.2
3	1-3	364.0	17.8	18.2	17.9	18.4				
3	1-3	383.7						26.7	27.3	27.3
3	1-3	394.0	26.8	27.1	26.8	26.9				
3	1-3	413.7						26.3	26.0	26.4
3	1-3	424.0	26.9	27.5	27.3	26.9				
3	1-3	443.7						26.9	27.6	27.5
3	1-3	454.0	26.7	26.4	25.5	26.2				
3	1-3	473.7						22.2	22.1	21.8
3	1-3	484.0	22.3	22.3	22.3	21.7				
3	1-3	503.7						28.7	28.5	28.9
3	1-3	514.0	27.0	27.3	26.8	27.3				
3	1-3	533.7						22.8	21.8	22.4
3	1-3	544.0	18.8	19.7	19.9	19.6				
3	1-3	563.7						13.8	14.3	14.8
3	1-3	574.0	13.1	12.8	13.1	13.5				
3	1-3	593.7						18.7	19.4	19.2
3	1-3	604.0	18.7	19.4	19.3	19.0				
3	1-3	623.7						18.7	19.5	19.1
3	1-3	634.0	19.1	19.6	18.9	19.9				
3	1-3	653.7						21.9	22.0	22.1
3	1-3	664.0	20.1	21.7	21.2	21.3				
3	1-3	683.7						23.5	24.0	23.3
3	1-3	694.0	23.4	24.7	23.8	23.7				
3	1-3	713.7						23.4		

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
3	1-3	203.7		9.6	9.7	9.2		9.2	9.8	9.9
3	1-3	214.0								
3	1-3	233.7		7.3	7.7	7.7		7.9	8.1	8.6
3	1-3	244.0								
3	1-3	263.7		24.1	24.5	24.4		24.9	24.5	24.9
3	1-3	274.0								
3	1-3	293.7		23.4	23.7	23.8		23.5	23.5	24.0
3	1-3	304.0								
3	1-3	323.7		17.6	17.3	17.5		17.0	17.4	17.5
3	1-3	334.0								
3	1-3	353.7		16.2	16.8	16.2		16.0	16.4	16.2
3	1-3	364.0								
3	1-3	383.7		27.6	27.1	27.2		26.8	27.4	26.7
3	1-3	394.0								
3	1-3	413.7		26.7	26.7	26.6		26.0	26.3	26.1
3	1-3	424.0								
3	1-3	443.7		27.6	27.9	26.9		27.4	27.9	27.7
3	1-3	454.0								
3	1-3	473.7		21.5	22.2	22.3		21.5	22.2	22.1
3	1-3	484.0								
3	1-3	503.7		28.2	29.1	28.4		28.0	28.4	28.3
3	1-3	514.0								
3	1-3	533.7		23.3	22.5	23.1		21.7	22.5	22.8
3	1-3	544.0								
3	1-3	563.7		14.2	14.5	14.5		14.2	15.0	14.7
3	1-3	574.0								
3	1-3	593.7		19.9	19.6	20.5		19.4	21.0	21.5
3	1-3	604.0								
3	1-3	623.7		19.6	19.8	20.4		21.3	23.2	23.2
3	1-3	634.0								
3	1-3	653.7		23.6	22.9	24.4		25.1		
3	1-3	664.0								
3	1-3	683.7		24.5	24.3					
3	1-3	694.0								
3	1-3	713.7								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
3	1-3	203.7								
3	1-3	214.0								
3	1-3	233.7	17.1	15.9	15.0	13.6	13.3	12.8	12.7	12.8
3	1-3	244.0								
3	1-3	263.7	25.5	24.9	25.6	25.1	25.0	25.4	24.4	24.9
3	1-3	274.0								
3	1-3	293.7	24.1	24.0	23.7	24.5	24.1	23.4	23.3	24.4
3	1-3	304.0								
3	1-3	323.7	17.1	16.9	17.4	16.9	17.6	17.5	17.8	17.8
3	1-3	334.0								
3	1-3	353.7	16.8	16.8	16.2	16.5	16.1	16.5	16.9	16.9
3	1-3	364.0								
3	1-3	383.7	27.5	26.7	26.8	26.8	27.2	26.9	27.0	27.4
3	1-3	394.0								
3	1-3	413.7	26.1	27.0	26.4	26.0	26.5	26.9	26.3	26.5
3	1-3	424.0								
3	1-3	443.7	27.5	27.5	27.6	26.9	27.6	28.0	27.4	27.5
3	1-3	454.0								
3	1-3	473.7	22.1	21.7	21.7	21.7	21.2	22.1	22.2	21.8
3	1-3	484.0								
3	1-3	503.7	29.0	28.5	29.3	29.1	28.3	28.2	29.1	29.4
3	1-3	514.0								
3	1-3	533.7	22.3	22.6	22.4	22.5	22.9	23.0	23.3	23.6
3	1-3	544.0								
3	1-3	563.7	14.9	15.1	16.0	16.4	18.6	20.2	19.6	19.6
3	1-3	574.0								
3	1-3	593.7	22.2	22.9	22.7	22.6				
3	1-3	604.0								
3	1-3	623.7	24.1							
3	1-3	634.0								
3	1-3	653.7								
3	1-3	664.0								
3	1-3	683.7								
3	1-3	694.0								
3	1-3	713.7								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
3	1-3	203.7								
3	1-3	214.0								
3	1-3	233.7	11.9	11.4	11.3	10.8		11.5		10.5
3	1-3	244.0								
3	1-3	263.7	24.9	25.1	25.3	25.1		24.5		25.0
3	1-3	274.0								
3	1-3	293.7	23.5	24.2	24.4	24.0		24.0		23.7
3	1-3	304.0								
3	1-3	323.7	18.0	18.0	18.2	18.1		18.0		18.8
3	1-3	334.0								
3	1-3	353.7	16.7	16.7	17.8	17.6		17.5		17.1
3	1-3	364.0								
3	1-3	383.7	27.2	27.4	27.1	27.0		27.1		27.5
3	1-3	394.0								
3	1-3	413.7	26.0	27.0	26.3	26.1		25.9		26.3
3	1-3	424.0								
3	1-3	443.7	27.7	28.0	27.5	27.6		27.8		27.6
3	1-3	454.0								
3	1-3	473.7	22.2	21.6	22.3	22.0		22.2		22.3
3	1-3	484.0								
3	1-3	503.7	29.1	29.0	28.4	28.6		27.8		28.3
3	1-3	514.0								
3	1-3	533.7	23.3	23.6	22.8	22.6		23.8		23.5
3	1-3	544.0								
3	1-3	563.7	19.4	18.7	19.0	18.8		20.2		22.1
3	1-3	574.0								
3	1-3	593.7	22.7	23.7	23.6	23.5				
3	1-3	604.0								
3	1-3	623.7								
3	1-3	634.0								
3	1-3	653.7								
3	1-3	664.0								
3	1-3	683.7								
3	1-3	694.0								
3	1-3	713.7								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
3	1-3	203.7								
3	1-3	214.0								
3	1-3	233.7	10.9	10.8	10.5	10.2	9.1	9.2	8.8	8.1
3	1-3	244.0								
3	1-3	263.7	24.7	25.1	25.2	24.6	24.2	24.9	24.7	24.2
3	1-3	274.0								
3	1-3	293.7	23.5	24.0	23.9	24.0	23.9	24.1	24.4	23.7
3	1-3	304.0								
3	1-3	323.7	18.1	18.3	17.9	18.2	18.4	18.3	17.9	18.1
3	1-3	334.0								
3	1-3	353.7	17.3	17.4	17.4	17.3	17.2	17.4	17.0	17.2
3	1-3	364.0								
3	1-3	383.7	26.5	27.2	27.0	28.1	26.5	27.5	27.2	27.3
3	1-3	394.0								
3	1-3	413.7	26.6	25.8	26.3	26.0	26.1	25.9	26.0	26.3
3	1-3	424.0								
3	1-3	443.7	27.8	27.2	27.9	27.2	27.7	27.7	27.6	28.0
3	1-3	454.0								
3	1-3	473.7	22.3	22.0	22.4	23.1	22.5	22.7	22.7	21.9
3	1-3	484.0								
3	1-3	503.7	28.4	28.7	29.1	28.0	28.7	28.5	29.0	28.6
3	1-3	514.0								
3	1-3	533.7	23.1	24.4	23.5	23.8	23.5	23.4	23.4	22.7
3	1-3	544.0								
3	1-3	563.7	22.1				21.1	20.2	18.4	16.8
3	1-3	574.0								
3	1-3	593.7						23.8	22.6	22.0
3	1-3	604.0								
3	1-3	623.7								
3	1-3	634.0								
3	1-3	653.7								
3	1-3	664.0								
3	1-3	683.7								
3	1-3	694.0								
3	1-3	713.7								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
3	1-3	203.7		
3	1-3	214.0		
3	1-3	233.7	7.7	7.3
3	1-3	244.0		
3	1-3	263.7	25.0	25.3
3	1-3	274.0		
3	1-3	293.7	24.1	23.3
3	1-3	304.0		
3	1-3	323.7	18.4	17.7
3	1-3	334.0		
3	1-3	353.7	16.6	16.4
3	1-3	364.0		
3	1-3	383.7	26.7	28.2
3	1-3	394.0		
3	1-3	413.7	26.5	26.4
3	1-3	424.0		
3	1-3	443.7	27.0	27.1
3	1-3	454.0		
3	1-3	473.7	22.1	22.0
3	1-3	484.0		
3	1-3	503.7	28.2	29.0
3	1-3	514.0		
3	1-3	533.7	22.6	22.6
3	1-3	544.0		
3	1-3	563.7	15.0	14.3
3	1-3	574.0		
3	1-3	593.7	21.4	20.7
3	1-3	604.0		
3	1-3	623.7	24.4	21.2
3	1-3	634.0		
3	1-3	653.7	26.0	25.5
3	1-3	664.0		
3	1-3	683.7		25.0
3	1-3	694.0		
3	1-3	713.7		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
1	2-1	203.7					15.7		24.9	21.3
1	2-1	214.0	18.9	18.7	18.7	18.8				
1	2-1	233.7					22.5		24.1	23.3
1	2-1	244.0	22.4	22.1	22.2	22.5				
1	2-1	263.7					24.5		25.5	24.4
1	2-1	274.0	21.8	21.7	21.8	21.6				
1	2-1	293.7					19.5		22.4	22.0
1	2-1	304.0	18.8	18.6	18.1	19.1				
1	2-1	323.7					19.7		23.7	22.5
1	2-1	334.0	20.4	20.7	20.4	20.4				
1	2-1	353.7					19.0		22.7	21.9
1	2-1	364.0	17.3	16.8	17.3	16.9				
1	2-1	383.7					18.2		22.4	20.6
1	2-1	394.0	15.3	15.3	15.3	15.3				
1	2-1	413.7					12.6		17.7	16.5
1	2-1	424.0	14.2	14.2	14.3	14.6				
1	2-1	443.7					13.1		15.5	16.9
1	2-1	454.0	13.7	13.8	13.6	13.6				
1	2-1	473.7					11.8		11.2	14.3
1	2-1	484.0	10.8	10.4	10.5	10.5				
1	2-1	503.7					15.2		15.3	17.4
1	2-1	514.0	17.0	16.7	17.4	17.5				
1	2-1	533.7					22.7		23.1	23.2
1	2-1	544.0	22.2	22.6	22.9	23.7				
1	2-1	563.7					24.0		24.2	
1	2-1	574.0	24.3	23.5	23.3	23.9				
1	2-1	593.7								
1	2-1	604.0	23.5	23.8	24.0	24.8				
1	2-1	623.7								
1	2-1	634.0	21.8	24.0						

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
1	2-1	203.7	24.9	23.9	23.2	20.6		21.4	21.6	19.8
1	2-1	214.0								
1	2-1	233.7	24.6	24.2	24.2	23.4		23.7	23.9	23.9
1	2-1	244.0								
1	2-1	263.7	24.5	26.1	24.8	24.9		24.8	25.0	25.1
1	2-1	274.0								
1	2-1	293.7	22.3	23.3	22.5	22.4		21.1	21.7	21.8
1	2-1	304.0								
1	2-1	323.7	22.7	23.1	23.5	23.3		22.8	22.3	22.3
1	2-1	334.0								
1	2-1	353.7	21.5	22.7	21.9	21.3		21.1	22.2	21.8
1	2-1	364.0								
1	2-1	383.7	20.2	21.7	21.5	20.6		21.0	21.1	21.0
1	2-1	394.0								
1	2-1	413.7	16.1	17.6	17.4	16.6		15.8	17.0	16.3
1	2-1	424.0								
1	2-1	443.7	16.1	17.1	17.4	17.2		15.7	19.0	18.4
1	2-1	454.0								
1	2-1	473.7	13.8	15.0	15.9	15.3		16.3	23.0	23.0
1	2-1	484.0								
1	2-1	503.7	16.9	17.6	20.3	20.9		22.1		
1	2-1	514.0								
1	2-1	533.7	24.5	24.0	24.1					
1	2-1	544.0								
1	2-1	563.7	24.6							
1	2-1	574.0								
1	2-1	593.7								
1	2-1	604.0								
1	2-1	623.7								
1	2-1	634.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
1	2-1	203.7								
1	2-1	214.0								
1	2-1	233.7	24.2	24.8	23.7	24.2	24.0	23.4	23.5	24.0
1	2-1	244.0								
1	2-1	263.7	24.8	25.1	25.1	24.8	25.1	24.9	24.3	25.4
1	2-1	274.0								
1	2-1	293.7	21.3	21.9	21.8	21.9	21.5	21.6	21.7	21.4
1	2-1	304.0								
1	2-1	323.7	22.6	22.5	22.8	23.3	22.8	22.5	22.4	21.8
1	2-1	334.0								
1	2-1	353.7	21.6	22.2	22.3	22.0	21.9	21.1	21.3	21.4
1	2-1	364.0								
1	2-1	383.7	20.5	21.0	21.8	22.1	20.9	20.4	21.1	20.7
1	2-1	394.0								
1	2-1	413.7	16.6	16.4	16.5	17.3	17.0	16.1	15.7	15.7
1	2-1	424.0								
1	2-1	443.7	17.3	17.9	17.4	17.0	15.9	15.8	16.0	15.3
1	2-1	454.0								
1	2-1	473.7	20.1	20.1	20.0	17.2	15.6	15.2	14.4	13.7
1	2-1	484.0								
1	2-1	503.7			24.0	22.7	20.8	20.0	17.7	17.1
1	2-1	514.0								
1	2-1	533.7				24.2	24.0	24.3	24.0	24.2
1	2-1	544.0								
1	2-1	563.7							24.3	
1	2-1	574.0								
1	2-1	593.7								
1	2-1	604.0								
1	2-1	623.7								
1	2-1	634.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
1	2-1	203.7								
1	2-1	214.0								
1	2-1	233.7	23.9	24.2	23.4	23.6		23.0	23.8	23.7
1	2-1	244.0								
1	2-1	263.7	24.7	25.1	25.0	25.1		24.6	25.1	25.3
1	2-1	274.0								
1	2-1	293.7	21.3	22.1	22.0	22.2		21.9	20.8	21.7
1	2-1	304.0								
1	2-1	323.7	22.1	22.1	22.6	22.4		22.2	22.4	22.2
1	2-1	334.0								
1	2-1	353.7	21.1	21.5	21.9	21.9		21.3	21.2	21.6
1	2-1	364.0								
1	2-1	383.7	20.1	20.7	21.1	21.1		20.5	20.3	20.1
1	2-1	394.0								
1	2-1	413.7	15.6	16.2	16.4	16.1		16.3	15.7	15.5
1	2-1	424.0								
1	2-1	443.7	15.5	15.4	15.5	15.3		15.4	15.6	15.0
1	2-1	454.0								
1	2-1	473.7	13.9	13.9	14.5	14.6		14.7	14.3	14.1
1	2-1	484.0								
1	2-1	503.7	17.6	17.3	16.8	16.9		17.3	17.0	17.0
1	2-1	514.0								
1	2-1	533.7	23.6	23.8	23.5	23.2		24.0	23.1	23.5
1	2-1	544.0								
1	2-1	563.7	24.4	24.4	24.1	24.6		25.0	24.8	24.5
1	2-1	574.0								
1	2-1	593.7			24.7	24.7				
1	2-1	604.0								
1	2-1	623.7								
1	2-1	634.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
1	2-1	203.7								
1	2-1	214.0								
1	2-1	233.7	23.7	23.5	23.8	24.2	23.4	23.5	22.9	22.9
1	2-1	244.0								
1	2-1	263.7	24.7	24.9	24.7	25.0	25.1	24.4	24.5	24.0
1	2-1	274.0								
1	2-1	293.7	20.7	20.7	21.3	21.1	21.3	20.9	20.2	20.2
1	2-1	304.0								
1	2-1	323.7	21.4	21.9	22.4	22.5	22.0	21.5	21.7	20.7
1	2-1	334.0								
1	2-1	353.7	21.2	21.0	21.2	21.4	21.1	21.1	21.1	21.1
1	2-1	364.0								
1	2-1	383.7	20.1	19.5	20.4	20.3	20.0	19.8	19.8	19.1
1	2-1	394.0								
1	2-1	413.7	15.6	15.7	15.8	15.9	15.0	15.2	15.2	14.6
1	2-1	424.0								
1	2-1	443.7	15.2	15.4	15.7	15.5	15.9	16.0	15.5	15.3
1	2-1	454.0								
1	2-1	473.7	14.4	13.6	13.6	14.6	14.7	15.0	15.0	15.6
1	2-1	484.0								
1	2-1	503.7	16.4	16.7	17.1	17.7	18.9	20.5	21.1	
1	2-1	514.0								
1	2-1	533.7	23.7	23.4	24.0	23.6				
1	2-1	544.0								
1	2-1	563.7	24.0	24.3						
1	2-1	574.0								
1	2-1	593.7								
1	2-1	604.0								
1	2-1	623.7								
1	2-1	634.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
1	2-1	203.7		
1	2-1	214.0		
1	2-1	233.7	22.3	22.4
1	2-1	244.0		
1	2-1	263.7	24.2	23.5
1	2-1	274.0		
1	2-1	293.7	20.0	19.6
1	2-1	304.0		
1	2-1	323.7	20.6	20.0
1	2-1	334.0		
1	2-1	353.7	20.4	19.8
1	2-1	364.0		
1	2-1	383.7	19.3	18.1
1	2-1	394.0		
1	2-1	413.7	14.9	14.6
1	2-1	424.0		
1	2-1	443.7	16.0	16.0
1	2-1	454.0		
1	2-1	473.7	16.7	17.2
1	2-1	484.0		
1	2-1	503.7		23.8
1	2-1	514.0		
1	2-1	533.7		
1	2-1	544.0		
1	2-1	563.7		
1	2-1	574.0		
1	2-1	593.7		
1	2-1	604.0		
1	2-1	623.7		
1	2-1	634.0		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
1	2-3	203.7					9.6		11.9	11.0
1	2-3	214.0	10.8	11.0	11.3	11.1				
1	2-3	233.7					18.9		20.6	20.4
1	2-3	244.0	20.6	20.6	20.6	21.0				
1	2-3	263.7					19.7		22.2	21.5
1	2-3	274.0	16.3	17.2	16.5	16.8				
1	2-3	293.7					15.2		16.4	15.7
1	2-3	304.0	19.4	18.4	19.5	18.8				
1	2-3	323.7					20.8		23.0	22.5
1	2-3	334.0	21.1	21.4	21.4	21.5				
1	2-3	353.7					27.9		28.6	27.9
1	2-3	364.0	27.6	27.8	28.0	28.2				
1	2-3	383.7					23.6		23.2	23.2
1	2-3	394.0	21.1	20.9	21.4	22.3				
1	2-3	413.7					17.2		17.2	16.6
1	2-3	424.0	15.6	15.4	16.1	15.8				
1	2-3	443.7					15.1		15.7	15.3
1	2-3	454.0	16.0	16.1	16.5	16.1				
1	2-3	473.7					14.2		14.9	14.5
1	2-3	484.0	15.8	15.7	15.3	15.5				
1	2-3	503.7					22.6		22.5	22.3
1	2-3	514.0	21.2	21.5	20.9	21.9				
1	2-3	533.7					21.3		21.0	21.2
1	2-3	544.0	20.6	20.9	20.7	19.7				
1	2-3	563.7					19.2		19.3	18.6
1	2-3	574.0	18.2	18.8	18.2	18.6				
1	2-3	593.7					15.0		14.6	15.1
1	2-3	604.0	9.7	12.5	12.5	12.5				
1	2-3	623.7					10.8		10.7	11.1
1	2-3	634.0	3.2	9.6	9.1	9.6				
1	2-3	653.7					3.3		3.2	3.1
1	2-3	664.0	5.1	2.8	2.7	3.0				
1	2-3	683.7					5.9		5.3	5.2
1	2-3	694.0		5.3	5.9	5.5				
1	2-3	713.7					6.0			
1	2-3	724.0			6.0	6.1				

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
1	2-3	203.7	16.7	15.7	15.4	14.3		15.8	14.1	14.3
1	2-3	214.0								
1	2-3	233.7	22.7	22.2	22.3	22.0		22.3	21.6	21.8
1	2-3	244.0								
1	2-3	263.7	23.8	22.8	23.6	23.2		23.5	23.3	22.9
1	2-3	274.0								
1	2-3	293.7	18.3	18.3	17.7	17.5		18.2	17.3	17.2
1	2-3	304.0								
1	2-3	323.7	24.6	24.8	24.2	25.2		25.0	24.2	24.2
1	2-3	334.0								
1	2-3	353.7	28.6	28.3	28.7	28.9		28.2	28.6	28.1
1	2-3	364.0								
1	2-3	383.7	23.5	23.9	24.3	24.0		24.3	23.8	23.9
1	2-3	394.0								
1	2-3	413.7	17.1	17.8	17.6	18.8		20.5	19.9	20.0
1	2-3	424.0								
1	2-3	443.7	15.4	15.6	15.5	16.0		20.9	19.8	19.4
1	2-3	454.0								
1	2-3	473.7	14.5	14.0	15.4	14.6		16.7	18.0	17.7
1	2-3	484.0								
1	2-3	503.7	22.5	22.3	22.7	22.8		23.6	24.3	25.0
1	2-3	514.0								
1	2-3	533.7	21.4	20.8	21.7	21.3		21.6	22.9	23.2
1	2-3	544.0								
1	2-3	563.7	18.7	18.9	19.1	19.6		19.1	20.7	20.8
1	2-3	574.0								
1	2-3	593.7	15.5	14.9	15.0	14.7		15.3	18.3	18.3
1	2-3	604.0								
1	2-3	623.7	11.1	10.5	11.7	11.2		10.5	12.8	14.1
1	2-3	634.0								
1	2-3	653.7	2.7	2.9	3.1	2.8		2.8	3.2	5.3
1	2-3	664.0								
1	2-3	683.7	5.3	4.7	5.5	5.4		5.4	5.5	6.8
1	2-3	694.0								
1	2-3	713.7		5.9	6.7	6.5		6.8		
1	2-3	724.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
1	2-3	203.7								
1	2-3	214.0								
1	2-3	233.7	22.8	22.0	23.0	23.4	22.4	21.4	22.3	22.4
1	2-3	244.0								
1	2-3	263.7	24.0	24.2	24.1	24.3	23.0	23.9	23.4	24.4
1	2-3	274.0								
1	2-3	293.7	18.7	18.1	18.5	18.3	17.6	17.0	17.6	18.5
1	2-3	304.0								
1	2-3	323.7	25.7	25.7	25.6	25.2	25.4	25.0	24.9	26.2
1	2-3	334.0								
1	2-3	353.7	29.8	28.5	28.7	29.1	28.3	28.2	28.8	29.1
1	2-3	364.0								
1	2-3	383.7	25.1	24.5	25.0	24.8	24.4	24.2	24.6	25.3
1	2-3	394.0								
1	2-3	413.7	20.8	20.7	20.4	20.1	19.8	20.4	19.7	20.9
1	2-3	424.0								
1	2-3	443.7	22.5	21.8	21.9	20.9	20.0	19.9	19.5	21.7
1	2-3	454.0								
1	2-3	473.7	21.9	20.7	20.8	19.2	19.1	17.8	17.5	19.4
1	2-3	484.0								
1	2-3	503.7	26.6	25.7	26.1	26.1	25.2	25.7	25.7	26.2
1	2-3	514.0								
1	2-3	533.7	24.4	23.8	23.3	24.2	23.2	23.1	23.8	23.6
1	2-3	544.0								
1	2-3	563.7	21.7	22.1	22.2	21.5	21.9	21.6	21.4	21.8
1	2-3	574.0								
1	2-3	593.7	19.8	20.9	20.6	20.8	20.9	20.2	20.5	20.8
1	2-3	604.0								
1	2-3	623.7	14.8	15.8	16.5	15.9	15.2	15.8	16.0	
1	2-3	634.0								
1	2-3	653.7	5.7	6.5	7.0					
1	2-3	664.0								
1	2-3	683.7								
1	2-3	694.0								
1	2-3	713.7								
1	2-3	724.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
1	2-3	203.7								
1	2-3	214.0								
1	2-3	233.7	23.5	22.9	22.8	22.1		21.7	21.5	21.7
1	2-3	244.0								
1	2-3	263.7	23.9	24.4	24.2	24.2		23.8	24.0	23.1
1	2-3	274.0								
1	2-3	293.7	18.9	18.0	18.2	17.7		17.5	21.8	17.4
1	2-3	304.0								
1	2-3	323.7	25.5	25.6	25.1	24.6		24.6	25.3	24.4
1	2-3	334.0								
1	2-3	353.7	29.0	29.2	29.4	28.1		28.7	28.2	28.6
1	2-3	364.0								
1	2-3	383.7	25.0	24.6	24.9	24.9		24.1	24.3	24.6
1	2-3	394.0								
1	2-3	413.7	20.0	21.3	20.2	19.5		19.9	19.4	19.9
1	2-3	424.0								
1	2-3	443.7	21.5	21.5	20.5	19.7		19.1	18.6	18.4
1	2-3	454.0								
1	2-3	473.7	19.5	19.9	18.2	18.1		17.8	17.4	17.3
1	2-3	484.0								
1	2-3	503.7	25.6	26.3	26.4	24.9		25.6	26.0	25.5
1	2-3	514.0								
1	2-3	533.7	23.5	23.9	23.8	22.9		23.5	23.8	23.8
1	2-3	544.0								
1	2-3	563.7	21.8	22.0	22.2	21.4		22.4	22.3	23.5
1	2-3	574.0								
1	2-3	593.7	20.7	21.2	21.4	20.8		22.8	23.5	
1	2-3	604.0								
1	2-3	623.7		16.4						
1	2-3	634.0								
1	2-3	653.7								
1	2-3	664.0								
1	2-3	683.7								
1	2-3	694.0								
1	2-3	713.7								
1	2-3	724.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
1	2-3	203.7								
1	2-3	214.0								
1	2-3	233.7	21.9	22.0	22.1	21.5	21.6	21.8	21.4	20.3
1	2-3	244.0								
1	2-3	263.7	23.1	23.7	22.9	23.6	23.2	22.9	22.7	22.6
1	2-3	274.0								
1	2-3	293.7	17.5	16.9	17.3	17.1	16.8	16.7	16.7	16.8
1	2-3	304.0								
1	2-3	323.7	23.9	24.8	23.9	24.1	24.3	24.2	23.7	23.6
1	2-3	334.0								
1	2-3	353.7	28.6	29.2	28.7	28.7	28.8	28.6	28.6	27.8
1	2-3	364.0								
1	2-3	383.7	24.7	24.8	24.3	24.1	23.7	24.1	23.8	23.8
1	2-3	394.0								
1	2-3	413.7	19.1	19.1	19.7	19.7	19.0	19.3	18.8	18.3
1	2-3	424.0								
1	2-3	443.7	19.2	18.9	19.6	18.8	18.6	17.8	17.1	17.3
1	2-3	454.0								
1	2-3	473.7	17.5	17.2	17.4	17.9	16.6	16.2	16.2	15.2
1	2-3	484.0								
1	2-3	503.7	25.4	25.6	25.8	26.1	25.4	24.4	24.6	24.0
1	2-3	514.0								
1	2-3	533.7	23.8	23.4	24.1	24.2	23.5	22.8	22.6	22.7
1	2-3	544.0								
1	2-3	563.7	23.0	23.3	23.1	23.3	22.4	22.6	21.2	21.1
1	2-3	574.0								
1	2-3	593.7						23.2	20.7	18.4
1	2-3	604.0								
1	2-3	623.7							15.4	
1	2-3	634.0								
1	2-3	653.7								
1	2-3	664.0								
1	2-3	683.7								
1	2-3	694.0								
1	2-3	713.7								
1	2-3	724.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
1	2-3	203.7		
1	2-3	214.0		
1	2-3	233.7	21.1	20.8
1	2-3	244.0		
1	2-3	263.7	22.1	22.6
1	2-3	274.0		
1	2-3	293.7	16.2	16.9
1	2-3	304.0		
1	2-3	323.7	22.9	23.2
1	2-3	334.0		
1	2-3	353.7	28.9	28.0
1	2-3	364.0		
1	2-3	383.7	24.6	24.6
1	2-3	394.0		
1	2-3	413.7	18.0	18.0
1	2-3	424.0		
1	2-3	443.7	16.7	15.5
1	2-3	454.0		
1	2-3	473.7	15.1	15.0
1	2-3	484.0		
1	2-3	503.7	23.8	23.1
1	2-3	514.0		
1	2-3	533.7	22.0	22.0
1	2-3	544.0		
1	2-3	563.7	20.5	19.2
1	2-3	574.0		
1	2-3	593.7	18.0	16.4
1	2-3	604.0		
1	2-3	623.7	12.8	12.4
1	2-3	634.0		
1	2-3	653.7	4.6	3.8
1	2-3	664.0		
1	2-3	683.7	7.0	6.0
1	2-3	694.0		
1	2-3	713.7		
1	2-3	724.0		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
2	3-1	203.7					7.6		7.8	8.1
2	3-1	214.0	7.1	6.8	6.8	7.3				
2	3-1	233.7					9.8		9.8	9.6
2	3-1	244.0	17.2	16.0	16.5	17.0				
2	3-1	263.7					18.0		17.6	18.2
2	3-1	274.0	14.6	14.5	14.8	15.1				
2	3-1	293.7					20.1		19.4	19.4
2	3-1	304.0	16.8	16.1	16.6	16.2				
2	3-1	323.7					20.3		19.8	19.7
2	3-1	334.0	22.8	23.3	23.1	23.4				
2	3-1	353.7					19.1		18.9	19.5
2	3-1	364.0	18.1	18.1	18.2	18.2				
2	3-1	383.7					21.7		21.8	21.7
2	3-1	394.0	21.6	21.7	21.5	21.8				
2	3-1	413.7					18.3		17.8	18.4
2	3-1	424.0	15.5	15.5	15.5	15.3				
2	3-1	443.7					17.5		17.5	17.1
2	3-1	454.0			17.7	18.2				
2	3-1	473.7					14.8		15.0	15.3
2	3-1	484.0			18.0	18.7				
2	3-1	503.7					18.3		18.1	18.4
2	3-1	514.0			20.3	20.2				
2	3-1	533.7					21.1		21.1	21.8
2	3-1	544.0			19.7	19.3				
2	3-1	563.7					24.8		24.1	25.4
2	3-1	574.0			24.2	24.3				
2	3-1	593.7					24.3		22.7	
2	3-1	604.0			21.6	22.9				

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
2	3-1	203.7		9.0		15.3	13.0	11.8	11.2	10.3
2	3-1	214.0								
2	3-1	233.7		10.2		19.7	16.4	14.4	13.9	13.5
2	3-1	244.0								
2	3-1	263.7		17.8		24.6	22.5	21.8	20.7	20.7
2	3-1	274.0								
2	3-1	293.7		20.1		23.4	21.9	22.2	21.6	21.2
2	3-1	304.0								
2	3-1	323.7		19.9		24.7	23.2	22.6	21.6	21.8
2	3-1	334.0								
2	3-1	353.7		19.1		24.8	24.0	22.8	21.7	21.9
2	3-1	364.0								
2	3-1	383.7		22.1		25.6	24.7	25.2	24.4	24.3
2	3-1	394.0								
2	3-1	413.7		17.9		22.0	20.5	21.0	20.8	20.6
2	3-1	424.0								
2	3-1	443.7		17.1		23.5	21.4	20.4	20.2	20.4
2	3-1	454.0								
2	3-1	473.7		14.7		19.4	19.0	17.7	18.4	18.3
2	3-1	484.0								
2	3-1	503.7		18.7		24.6	23.1	22.5	23.1	23.2
2	3-1	514.0								
2	3-1	533.7		21.3						
2	3-1	544.0								
2	3-1	563.7		25.6						
2	3-1	574.0								
2	3-1	593.7								
2	3-1	604.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
2	3-1	203.7								
2	3-1	214.0								
2	3-1	233.7		13.0		12.7	12.8	12.5	12.3	
2	3-1	244.0								
2	3-1	263.7		20.3		20.6	20.4	20.0	20.3	
2	3-1	274.0								
2	3-1	293.7		21.0		21.2	21.0	20.9	21.0	
2	3-1	304.0								
2	3-1	323.7		22.4		22.1	22.1	21.6	21.6	
2	3-1	334.0								
2	3-1	353.7		21.1		21.9	22.0	21.7	21.2	
2	3-1	364.0								
2	3-1	383.7		24.4		24.3	24.3	24.0	23.7	
2	3-1	394.0								
2	3-1	413.7		20.1		20.4	20.1	20.0	19.5	
2	3-1	424.0								
2	3-1	443.7		19.7		20.0	20.0	18.6	19.1	
2	3-1	454.0								
2	3-1	473.7		18.1		17.5	17.3	17.1	17.1	
2	3-1	484.0								
2	3-1	503.7		22.4		21.7	20.7	21.6	19.8	
2	3-1	514.0								
2	3-1	533.7							22.1	
2	3-1	544.0								
2	3-1	563.7								
2	3-1	574.0								
2	3-1	593.7								
2	3-1	604.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
2	3-1	203.7								
2	3-1	214.0								
2	3-1	233.7	12.1		12.3	25.2	19.8	16.4		15.5
2	3-1	244.0								
2	3-1	263.7	19.6		19.9	27.3	23.6	23.6		21.6
2	3-1	274.0								
2	3-1	293.7	21.2		21.5	30.0	23.7	21.9		21.8
2	3-1	304.0								
2	3-1	323.7	21.3		22.1	25.0	23.5	23.9		22.8
2	3-1	334.0								
2	3-1	353.7	21.4		21.7	24.6	24.5	23.8		23.5
2	3-1	364.0								
2	3-1	383.7	23.2		24.4	26.4	25.0	25.3		24.8
2	3-1	394.0								
2	3-1	413.7	20.0		19.4	22.6	21.9	21.2		21.2
2	3-1	424.0								
2	3-1	443.7	19.5		19.3	23.7	23.0	21.9		20.9
2	3-1	454.0								
2	3-1	473.7	17.0		17.5	17.3	19.6	18.9		18.5
2	3-1	484.0								
2	3-1	503.7	20.0		19.6	19.8	24.2	22.2		21.6
2	3-1	514.0								
2	3-1	533.7	21.5		21.6	21.3	22.4	22.4		22.4
2	3-1	544.0								
2	3-1	563.7								
2	3-1	574.0								
2	3-1	593.7								
2	3-1	604.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
2	3-1	203.7								
2	3-1	214.0								
2	3-1	233.7		14.4	13.8	13.6	12.7	13.3	12.4	12.2
2	3-1	244.0								
2	3-1	263.7		21.4	21.6	21.4	20.4	19.9	19.6	20.0
2	3-1	274.0								
2	3-1	293.7		21.9	22.2	21.9	20.6	21.4	21.3	20.7
2	3-1	304.0								
2	3-1	323.7		22.6	22.5	22.5	21.6	21.1	21.4	20.7
2	3-1	334.0								
2	3-1	353.7		23.0	22.2	22.0	21.8	21.3	21.7	21.0
2	3-1	364.0								
2	3-1	383.7		24.4	23.9	23.9	24.3	23.7	23.9	24.2
2	3-1	394.0								
2	3-1	413.7		21.3	20.4	20.1	19.7	20.7	19.7	20.0
2	3-1	424.0								
2	3-1	443.7		20.7	20.5	20.6	19.5	19.2	19.4	18.9
2	3-1	454.0								
2	3-1	473.7		18.1	17.3	17.7	17.2	17.0	17.3	17.0
2	3-1	484.0								
2	3-1	503.7		21.1	21.1	21.4	21.4	21.7	21.7	
2	3-1	514.0								
2	3-1	533.7		22.0	22.0	22.0	23.0			
2	3-1	544.0								
2	3-1	563.7		24.7	25.8					
2	3-1	574.0								
2	3-1	593.7								
2	3-1	604.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
2	3-1	203.7		
2	3-1	214.0		
2	3-1	233.7	12.0	11.8
2	3-1	244.0		
2	3-1	263.7	19.0	19.0
2	3-1	274.0		
2	3-1	293.7	20.4	20.9
2	3-1	304.0		
2	3-1	323.7	21.1	21.3
2	3-1	334.0		
2	3-1	353.7	21.3	21.2
2	3-1	364.0		
2	3-1	383.7	23.9	23.9
2	3-1	394.0		
2	3-1	413.7	20.0	19.7
2	3-1	424.0		
2	3-1	443.7	19.6	19.6
2	3-1	454.0		
2	3-1	473.7	17.9	17.5
2	3-1	484.0		
2	3-1	503.7	22.2	23.2
2	3-1	514.0		
2	3-1	533.7		
2	3-1	544.0		
2	3-1	563.7		
2	3-1	574.0		
2	3-1	593.7		
2	3-1	604.0		

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul	15-Jul
2	3-2	203.7						30.8	31.8	31.6	
2	3-2	214.0	31.1	30.7	30.2	31.1					
2	3-2	233.7						29.9	30.3	30.0	
2	3-2	244.0	27.9	28.0	28.5	27.8					
2	3-2	263.7						28.0	27.8	27.1	
2	3-2	274.0	25.4	24.7	24.4	25.5					
2	3-2	293.7						2.6	2.3	2.5	
2	3-2	304.0	0.1	0.1	0.2	0.4					
2	3-2	323.7						3.7	4.5	4.2	
2	3-2	334.0	12.1	11.8	12.6	11.4					
2	3-2	353.7						20.4	20.9	20.4	
2	3-2	364.0	23.8	23.4	23.5	23.6					
2	3-2	383.7						23.7	24.5	23.6	
2	3-2	394.0	24.9	24.6	24.5	24.3					
2	3-2	413.7						24.0	23.7	24.4	
2	3-2	424.0	23.2	23.2	23.6	23.5					
2	3-2	443.7						21.9	22.8	22.4	
2	3-2	454.0	23.2	22.8	23.2	23.1					
2	3-2	473.7						22.5	22.9	22.8	
2	3-2	484.0	22.8	22.5	22.6	23.0					
2	3-2	503.7						24.2	22.9	23.8	
2	3-2	514.0	19.7	22.2	21.8	22.6					
2	3-2	533.7						20.1	19.8	19.3	
2	3-2	544.0	18.5	19.5	19.7	19.3					
2	3-2	563.7						22.2	21.9	22.1	
2	3-2	574.0	16.1	18.1	17.9	18.6					
2	3-2	593.7						15.8	15.5	15.4	
2	3-2	604.0	8.7	15.9	15.9	16.5					
2	3-2	623.7						10.5	9.5	9.7	
2	3-2	634.0	12.2	8.3	8.5	8.0					
2	3-2	653.7						10.3	10.2	10.5	
2	3-2	664.0	8.1	12.3	12.1	12.5					
2	3-2	683.7						8.4	8.2	8.4	
2	3-2	694.0		8.3	8.3	8.1					
2	3-2	713.7						28.2	28.5	29.0	
2	3-2	724.0			30.3	29.5					
2	3-2	743.7						30.9			
2	3-2	754.0			30.6	31.0					

Treatment	Site	Depth (cm)	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug	11-Aug	12-Aug
2	3-2	203.7	31.4		32.7	32.2	31.7	32.0	31.7		
2	3-2	214.0									
2	3-2	233.7	29.9		33.3	32.4	31.1	32.4	30.6		31.2
2	3-2	244.0									
2	3-2	263.7	27.9		29.2	28.6	28.9	28.4	28.8		28.8
2	3-2	274.0									
2	3-2	293.7	2.1		6.6	4.8	4.5	4.2	4.1		3.8
2	3-2	304.0									
2	3-2	323.7	3.9		9.3	7.5	6.8	6.5	6.6		6.2
2	3-2	334.0									
2	3-2	353.7	20.5		26.0	24.2	23.7	22.8	22.7		22.3
2	3-2	364.0									
2	3-2	383.7	24.3		25.9	25.7	25.3	25.0	25.4		25.2
2	3-2	394.0									
2	3-2	413.7	23.4		25.5	25.0	24.7	25.1	25.0		25.7
2	3-2	424.0									
2	3-2	443.7	22.2		25.6	25.1	24.5	24.3	23.9		23.7
2	3-2	454.0									
2	3-2	473.7	23.3		25.9	25.1	24.8	25.1	24.4		24.3
2	3-2	484.0									
2	3-2	503.7	23.5		25.8	25.5	25.4	25.5	24.8		24.8
2	3-2	514.0									
2	3-2	533.7	20.1		23.3	23.5	23.2	22.0	21.9		21.4
2	3-2	544.0									
2	3-2	563.7	22.5		23.1	23.2	22.8	23.2	22.8		22.3
2	3-2	574.0									
2	3-2	593.7	15.4		21.1	20.4	20.0	19.6	19.2		19.6
2	3-2	604.0									
2	3-2	623.7	10.1		17.5	16.0	15.0	14.6	14.7		14.9
2	3-2	634.0									
2	3-2	653.7	10.6		16.4	16.0	15.5	16.1	18.2		19.4
2	3-2	664.0									
2	3-2	683.7	8.5				20.0				
2	3-2	694.0									
2	3-2	713.7	29.1								
2	3-2	724.0									
2	3-2	743.7									
2	3-2	754.0									

Treatment	Site	Depth (cm)	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug	26-Aug	27-Aug	30-Aug
2	3-2	203.7									
2	3-2	214.0									
2	3-2	233.7		31.1	31.1	30.0	30.9		30.1		30.6
2	3-2	244.0									
2	3-2	263.7		28.2	28.3	29.4	28.0		28.8		28.7
2	3-2	274.0									
2	3-2	293.7		3.8	3.7	3.7	3.7		3.5		3.3
2	3-2	304.0									
2	3-2	323.7		5.9	6.1	5.8	5.7		5.6		5.3
2	3-2	334.0									
2	3-2	353.7		22.7	22.3	22.2	22.3		22.3		22.1
2	3-2	364.0									
2	3-2	383.7		25.2	25.2	25.7	25.7		24.8		25.2
2	3-2	394.0									
2	3-2	413.7		24.6	25.3	24.9	25.0		25.3		25.1
2	3-2	424.0									
2	3-2	443.7		24.6	24.1	23.8	23.7		24.0		24.3
2	3-2	454.0									
2	3-2	473.7		24.2	23.9	24.1	24.6		24.4		24.2
2	3-2	484.0									
2	3-2	503.7		25.2	24.4	24.5	25.2		24.5		24.9
2	3-2	514.0									
2	3-2	533.7		21.8	21.3	21.4	21.4		21.0		21.2
2	3-2	544.0									
2	3-2	563.7		23.2	23.4	22.5	23.0		22.6		23.0
2	3-2	574.0									
2	3-2	593.7		19.2	19.1	19.8	19.9		19.3		19.2
2	3-2	604.0									
2	3-2	623.7		15.8	16.2	16.4	15.5		16.0		15.5
2	3-2	634.0									
2	3-2	653.7		21.1	22.5	22.4					22.5
2	3-2	664.0									
2	3-2	683.7									
2	3-2	694.0									
2	3-2	713.7									
2	3-2	724.0									
2	3-2	743.7									
2	3-2	754.0									

Treatment	Site	Depth (cm)	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep	9-Sep	10-Sep	13-Sep	16-Sep
2	3-2	203.7									
2	3-2	214.0									
2	3-2	233.7	34.0	32.7	32.4		32.1		32.1	31.8	31.6
2	3-2	244.0									
2	3-2	263.7	28.9	30.1	29.3		28.7		28.7	29.1	28.6
2	3-2	274.0									
2	3-2	293.7	19.5	6.2	4.9		4.9		4.4	4.4	4.2
2	3-2	304.0									
2	3-2	323.7	22.0	8.7	7.1		7.1		6.6	6.0	5.9
2	3-2	334.0									
2	3-2	353.7	26.4	25.4	24.7		23.9		23.1	23.6	23.1
2	3-2	364.0									
2	3-2	383.7	26.5	26.4	26.0		25.6		25.4	25.4	25.9
2	3-2	394.0									
2	3-2	413.7	26.3	26.1	25.8		25.6		25.7	25.3	24.9
2	3-2	424.0									
2	3-2	443.7	26.2	25.1	25.3		24.5		24.4	24.5	24.0
2	3-2	454.0									
2	3-2	473.7	25.6	25.4	25.1		24.9		24.8	25.1	25.0
2	3-2	484.0									
2	3-2	503.7	25.2	25.7	25.1		26.0		24.9	25.0	25.0
2	3-2	514.0									
2	3-2	533.7	22.6	23.6	23.1		22.9		23.0	22.8	23.2
2	3-2	544.0									
2	3-2	563.7	22.8	23.9	24.3		24.5		24.0	23.6	24.5
2	3-2	574.0									
2	3-2	593.7	19.6	23.5	24.0		23.9		24.0	24.1	24.0
2	3-2	604.0									
2	3-2	623.7	16.1	23.3							
2	3-2	634.0									
2	3-2	653.7									
2	3-2	664.0									
2	3-2	683.7									
2	3-2	694.0									
2	3-2	713.7									
2	3-2	724.0									
2	3-2	743.7									
2	3-2	754.0									

Treatment	Site	Depth (cm)	24-Sep	1-Oct	7-Oct	18-Oct	10-Nov	5-Jan
2	3-2	203.7						
2	3-2	214.0						
2	3-2	233.7	30.9	31.5	30.6	31.0	31.5	31.1
2	3-2	244.0						
2	3-2	263.7	28.8	29.1	28.6	27.7	28.7	28.7
2	3-2	274.0						
2	3-2	293.7	3.9	3.8	3.8	3.7	3.9	3.8
2	3-2	304.0						
2	3-2	323.7	6.5	5.9	5.6	5.4	4.8	5.3
2	3-2	334.0						
2	3-2	353.7	22.2	22.4	22.7	21.9	22.1	21.7
2	3-2	364.0						
2	3-2	383.7	25.7	25.2	24.7	24.5	25.1	24.8
2	3-2	394.0						
2	3-2	413.7	26.1	25.8	24.8	24.9	25.1	24.5
2	3-2	424.0						
2	3-2	443.7	23.6	23.8	23.7	23.2	23.7	23.2
2	3-2	454.0						
2	3-2	473.7	24.2	24.6	25.0	24.3	24.0	23.4
2	3-2	484.0						
2	3-2	503.7	25.4	25.0	24.7	24.8	24.6	24.5
2	3-2	514.0						
2	3-2	533.7	21.7	22.0	21.2	21.1	21.0	20.7
2	3-2	544.0						
2	3-2	563.7	23.4	23.0	23.6	23.0	22.3	22.4
2	3-2	574.0						
2	3-2	593.7	23.2	23.0	22.3	20.5	18.5	17.8
2	3-2	604.0						
2	3-2	623.7					14.5	12.0
2	3-2	634.0						
2	3-2	653.7						13.3
2	3-2	664.0						
2	3-2	683.7						
2	3-2	694.0						
2	3-2	713.7						
2	3-2	724.0						
2	3-2	743.7						
2	3-2	754.0						

Treatment	Site	Depth (cm)	18-Apr	23-May	6-Jun	16-Jun	30-Jun	1-Jul	4-Jul	10-Jul
2	3-3	203.7						14.2	14.2	14.4
2	3-3	214.0	13.1	13.8	12.4	13.1				
2	3-3	233.7						4.9	5.6	5.7
2	3-3	244.0	5.4	5.6	5.0	5.1				
2	3-3	263.7						5.2	5.0	5.8
2	3-3	274.0	5.3	5.8	5.0	4.9				
2	3-3	293.7						2.2	1.9	1.9
2	3-3	304.0	2.0	1.6	1.9	1.4				
2	3-3	323.7						1.8	1.7	1.4
2	3-3	334.0	2.1	2.0	1.8	1.6				
2	3-3	353.7						18.4	17.8	18.1
2	3-3	364.0	22.5	22.7	22.7	22.6				

Treatment	Site	Depth (cm)	15-Jul	17-Jul	19-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug
2	3-3	203.7		14.2		18.1	17.8	17.2	17.0	16.6
2	3-3	214.0								
2	3-3	233.7		5.5		9.5	7.8	7.4	6.7	7.0
2	3-3	244.0								
2	3-3	263.7		5.2		9.7	7.9	7.9	7.6	7.1
2	3-3	274.0								
2	3-3	293.7		1.4		5.7	5.4	4.1	3.8	3.9
2	3-3	304.0								
2	3-3	323.7		2.0		6.5	5.4	4.6	3.9	3.7
2	3-3	334.0								
2	3-3	353.7		18.5		23.0	22.6	20.9	20.8	20.8
2	3-3	364.0								

Treatment	Site	Depth (cm)	11-Aug	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug
2	3-3	203.7								
2	3-3	214.0								
2	3-3	233.7		6.9		7.0	6.9	7.0	7.2	
2	3-3	244.0								
2	3-3	263.7		6.7		7.1	7.0	6.9	6.8	
2	3-3	274.0								
2	3-3	293.7		3.4		2.8	3.2	3.0	3.3	
2	3-3	304.0								
2	3-3	323.7		3.5		3.4	3.4	3.1	3.6	
2	3-3	334.0								
2	3-3	353.7		20.1		20.1	19.8	19.5	19.3	
2	3-3	364.0								

Treatment	Site	Depth (cm)	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep	8-Sep
2	3-3	203.7								
2	3-3	214.0								
2	3-3	233.7	6.4		6.3	13.4	9.3	8.5		8.0
2	3-3	244.0								
2	3-3	263.7	6.5		6.7	12.0	9.2	8.6		8.1
2	3-3	274.0								
2	3-3	293.7	2.9		2.8	9.7	5.8	5.0		4.9
2	3-3	304.0								
2	3-3	323.7	2.9		3.5	9.1	6.0	5.1		5.3
2	3-3	334.0								
2	3-3	353.7	19.9		20.3	24.6	21.5	22.0		22.2
2	3-3	364.0								

Treatment	Site	Depth (cm)	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
2	3-3	203.7								
2	3-3	214.0								
2	3-3	233.7		7.2	7.0	7.0	7.0	6.9	6.5	6.7
2	3-3	244.0								
2	3-3	263.7		7.4	7.3	7.3	6.7	6.6	6.7	6.3
2	3-3	274.0								
2	3-3	293.7		4.3	3.8	3.8	3.6	3.3	3.2	3.0
2	3-3	304.0								
2	3-3	323.7		4.3	4.4	3.9	3.3	3.4	3.0	2.8
2	3-3	334.0								
2	3-3	353.7		21.8	21.1	19.9	19.6	19.9	19.1	18.7
2	3-3	364.0								

Treatment	Site	Depth (cm)	10-Nov	5-Jan
2	3-3	203.7		
2	3-3	214.0		
2	3-3	233.7	6.9	6.7
2	3-3	244.0		
2	3-3	263.7	6.0	6.7
2	3-3	274.0		
2	3-3	293.7	2.5	2.9
2	3-3	304.0		
2	3-3	323.7	3.1	3.4
2	3-3	334.0		
2	3-3	353.7	18.9	18.8
2	3-3	364.0		

APPENDIX D – Soil Water Contents Measured with Neutron Probe in Access Tubes Managed by the USDA-ARS

The compilation of this dataset was performed by the USDA-ARS. Soil water content is provided in percent.

Treatment	Site	Depth (cm)	Intrument	9-Jun	10-Jun	16-Jun	30-Jun	4-Jul	12-Jul	15-Jul	17-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug	11-Aug
3	1-1	0.0	TDR	16.2			10.9	24.2	13.5		16.1	10.1		8.9	18.3	12.7	10.9
3	1-1	21.1	NP	22.5		22.7	18.2	29.7	22.1		26.2						
3	1-1	30.5	NP				19.3	26.8	22.1		23.2	18.6		19.7	21.6	19.6	21.7
3	1-1	51.1	NP	17.1		17.2	14.6	19.5	15.8		18.5						
3	1-1	61.0	NP				13.1	18.4	14.7		17.2	13.6		16.7	13.8	12.4	17.5
3	1-1	81.1	NP	12.3		12.5	9.5	14.5	10.9		14.0						
3	1-1	91.4	NP				9.3	14.7	10.9		13.5	10.7		13.0	9.8	9.2	14.1
3	1-1	111.1	NP	9.4		9.6	9.8	19.6	12.4		16.8						
3	1-1	121.9	NP				12.7	23.3	16.2		21.2	15.4		19.6	14.9	14.7	19.5
3	1-1	141.1	NP	26.2		26.4	32.5	36.2	33.4		35.1						
3	1-1	152.4	NP				32.3	34.9	33.8		34.7	34.0		34.9	34.1	34.1	33.7
3	1-1	171.1	NP									31.2		32.7	31.6	30.7	31.9
3	1-1	191.1	NP	28.5		28.7	29.1	32.6	30.9		31.9	31.8		31.3	30.8	30.8	31.1
3	1-2	0.0	TDR				11.4	10.9	13.7		16.8	10.8		9.4	18.5	15.1	11.5
3	1-2	21.1	NP			23.2	18.7	19.3	19.1		29.6						
3	1-2	30.5	NP				25.9	25.1	24.5		33.4	27.9		32.7	28.6	27.5	34.4
3	1-2	51.1	NP			36.6	37.7	37.0	35.2		39.5						
3	1-2	61.0	NP				41.0	40.4	38.3		40.1	37.7		38.0	36.4	36.6	41.0
3	1-2	81.1	NP			37.0	36.3	37.3	37.1		37.9						
3	1-2	91.4	NP				40.4	40.7	41.2		42.1	40.4		39.2	38.6	37.6	39.4
3	1-2	111.1	NP			33.0	31.7	31.1	31.4		34.4						
3	1-2	121.9	NP				28.3	28.0	28.5		31.6	30.6		29.6	29.3	28.5	28.4
3	1-2	141.1	NP			29.1	30.0	30.0	30.8		32.3						
3	1-2	152.4	NP				30.3	29.8	29.7		31.9	32.3		31.0	32.0	31.0	31.1
3	1-2	171.1	NP									34.4		34.9	35.0	34.2	34.0
3	1-2	191.1	NP			29.3	29.6	29.7	29.7		30.3	31.3		30.9	30.6	30.9	30.3
3	1-3	0.0	TDR				12.3	11.4	10.3		19.7	12.5		15.6	14.6	17.7	16.6
3	1-3	21.1	NP			33.6	34.5	35.5	34.4		38.4						
3	1-3	30.5	NP				41.6	41.2	39.9		41.1	40.9		43.6	43.5	41.8	45.6
3	1-3	51.1	NP			39.3	35.5	34.1	32.0		31.7						
3	1-3	61.0	NP				33.4	34.2	31.2		30.4	27.6		26.9	26.1	25.6	35.5
3	1-3	81.1	NP			39.0	35.9	35.6	35.1		36.2						
3	1-3	91.4	NP				34.7	34.6	34.3		34.7	33.1		32.5	32.6	31.7	32.9
3	1-3	111.1	NP			33.8	34.2	34.4	34.9		34.7						
3	1-3	121.9	NP				37.4	37.9	37.3		37.7	37.5		38.0	37.0	37.5	37.1
3	1-3	141.1	NP			30.9	29.9	29.3	29.5		29.5						
3	1-3	152.4	NP				26.6	26.6	26.5		26.7	27.0		26.8	27.4	26.7	27.3
3	1-3	171.1	NP									23.5		22.7	23.2	23.0	23.7
3	1-3	191.1	NP			13.9	11.5	11.5	12.4		11.9	12.2		12.8	12.6	12.7	14.0

Treatment	Site	Depth (cm)	Intrument	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep
3	1-1	0.0	TDR	10.6	13.6	10.4	11.6	12.0	12.3	9.2	11.7	9.8	9.4	12.3		14.0	14.0
3	1-1	21.1	NP														
3	1-1	30.5	NP	22.3	22.0	21.8	21.4	19.7	19.1	18.5	18.0	18.8	18.5	18.0		18.2	17.5
3	1-1	51.1	NP														
3	1-1	61.0	NP	17.0	16.8	15.2	13.8	13.6	11.0	10.9	11.9	11.5	11.8	11.0		9.7	9.5
3	1-1	81.1	NP														
3	1-1	91.4	NP	13.2	12.4	11.5	10.3	9.9	9.0	8.9	9.5	9.4	9.4	9.3		8.5	8.1
3	1-1	111.1	NP														
3	1-1	121.9	NP	18.4	17.4	17.2	15.7	15.8	14.7	14.1	14.2	14.3	14.9	14.0		13.0	13.5
3	1-1	141.1	NP														
3	1-1	152.4	NP	34.3	34.3	34.5	33.9	33.7	33.3	32.6	33.2	33.4	33.7	33.3		32.9	32.6
3	1-1	171.1	NP	31.2	32.5	31.1	31.8	31.4	30.6	30.4	29.9	30.6	31.1	30.4		30.8	30.1
3	1-1	191.1	NP	31.9	32.0	31.3	30.4	30.8	30.5	30.1	30.3	31.1	30.4	30.5		29.6	29.4
3	1-2	0.0	TDR	14.1	15.1	12.8	11.4	11.6	11.7	13.2	12.8	13.3	12.5	13.0		13.9	14.0
3	1-2	21.1	NP														
3	1-2	30.5	NP	34.1	33.8	33.0	31.6	30.5	28.8	33.6	34.1	33.7	31.3	30.8		29.0	28.8
3	1-2	51.1	NP														
3	1-2	61.0	NP	40.4	40.6	39.5	39.8	38.8	38.1	39.6	39.4	39.8	39.6	39.6		37.7	37.8
3	1-2	81.1	NP														
3	1-2	91.4	NP	40.0	39.8	38.8	39.1	38.3	38.5	39.3	38.6	40.8	39.0	38.7		38.0	37.7
3	1-2	111.1	NP														
3	1-2	121.9	NP	27.5	28.4	28.0	27.1	26.9	26.9	26.5	26.4	25.9	26.5	25.6		26.3	25.3
3	1-2	141.1	NP														
3	1-2	152.4	NP	30.8	31.0	31.0	31.8	30.9	31.6	31.5	30.5	30.6	30.9	30.1		30.4	29.7
3	1-2	171.1	NP	34.9	34.3	35.5	35.0	34.9	34.7	34.5	34.2	34.5	34.8	34.4		33.6	33.6
3	1-2	191.1	NP	30.6	31.5	30.3	31.3	30.7	31.0	30.9	31.0	31.0	30.5	30.7		30.5	30.6
3	1-3	0.0	TDR	21.0	15.0	20.7	17.1	15.9	14.6	15.0	13.6	17.7	16.2	15.3		13.4	14.0
3	1-3	21.1	NP														
3	1-3	30.5	NP	44.9	45.1	44.3	43.0	43.7	43.2	45.8	45.2	44.7	43.6	42.6		40.9	40.9
3	1-3	51.1	NP														
3	1-3	61.0	NP	34.3	34.1	33.9	33.5	32.1	31.5	31.0	31.2	31.6	30.7	29.8		29.3	29.0
3	1-3	81.1	NP														
3	1-3	91.4	NP	33.3	34.9	34.8	34.1	33.7	33.7	33.0	33.1	34.1	33.5	33.0		31.9	32.1
3	1-3	111.1	NP														
3	1-3	121.9	NP	37.2	37.3	37.3	36.1	37.6	37.4	36.3	37.1	37.4	37.3	37.7		37.0	36.9
3	1-3	141.1	NP														
3	1-3	152.4	NP	26.9	26.8	26.7	27.1	26.9	26.6	26.6	26.1	26.9	27.3	26.3		26.2	25.9
3	1-3	171.1	NP	23.9	23.4	24.4	24.1	24.0	23.5	23.9	23.0	24.1	24.1	23.4		23.3	23.3
3	1-3	191.1	NP	13.5	13.3	13.0	13.6	13.6	13.5	13.3	12.8	13.4	13.3	13.1		12.7	12.4

Treatment	Site	Depth (cm)	Intrument	8-Sep	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
3	1-1	0.0	TDR	20.0	19.0	18.0	16.0	14.0	13.0	12.0	17.1	13.0
3	1-1	21.1	NP									
3	1-1	30.5	NP	17.7	19.4	19.9	21.3	21.3	22.2	22.5	21.9	21.6
3	1-1	51.1	NP									
3	1-1	61.0	NP	10.0	15.8	15.6	14.2	14.4	13.2	12.6	12.1	11.8
3	1-1	81.1	NP									
3	1-1	91.4	NP	8.0	13.0	12.1	11.1	9.7	9.6	8.8	7.9	8.3
3	1-1	111.1	NP									
3	1-1	121.9	NP	13.6	20.6	18.6	16.6	16.1	13.4	13.5	11.8	12.6
3	1-1	141.1	NP									
3	1-1	152.4	NP	33.5	34.7	35.0	34.7	33.1	32.8	33.1	32.1	31.6
3	1-1	171.1	NP	30.3	32.0	32.4	31.1	31.0	29.9	30.1	29.6	30.1
3	1-1	191.1	NP	30.4	30.0	31.5	31.0	29.9	30.4	30.3	29.3	30.1
3	1-2	0.0	TDR	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.3	14.0
3	1-2	21.1	NP									
3	1-2	30.5	NP	29.4	33.8	32.8	32.4	33.9	32.0	32.3	33.2	31.7
3	1-2	51.1	NP									
3	1-2	61.0	NP	38.2	38.8	38.3	38.1	38.9	38.8	37.8	38.4	37.9
3	1-2	81.1	NP									
3	1-2	91.4	NP	37.9	38.5	38.6	39.1	39.0	38.2	39.2	39.0	38.7
3	1-2	111.1	NP									
3	1-2	121.9	NP	26.1	26.0	25.9	25.9	26.0	26.3	26.9	26.8	26.3
3	1-2	141.1	NP									
3	1-2	152.4	NP	29.9	30.3	29.9	29.0	30.3	29.5	30.4	30.3	29.9
3	1-2	171.1	NP	34.0	34.3	33.5	33.3	33.7	34.1	33.6	33.7	33.6
3	1-2	191.1	NP	30.5	30.2	29.9	30.6	30.2	30.3	30.1	30.0	29.8
3	1-3	0.0	TDR	14.0	14.0	14.0	14.0	14.0	14.0	14.0	15.0	14.0
3	1-3	21.1	NP									
3	1-3	30.5	NP	41.2	41.6	40.7	41.0	40.6	40.9	40.5	39.9	40.1
3	1-3	51.1	NP									
3	1-3	61.0	NP	29.4	28.8	28.3	27.5	28.0	26.3	25.9	25.4	25.5
3	1-3	81.1	NP									
3	1-3	91.4	NP	31.3	31.6	32.1	30.4	30.7	30.7	30.3	29.3	29.5
3	1-3	111.1	NP									
3	1-3	121.9	NP	36.4	37.3	36.5	36.4	35.9	35.9	36.1	35.3	36.0
3	1-3	141.1	NP									
3	1-3	152.4	NP	26.3	26.6	25.9	26.2	25.9	25.7	25.7	25.2	25.3
3	1-3	171.1	NP	22.8	23.4	23.3	23.3	23.1	22.9	22.6	21.9	21.4
3	1-3	191.1	NP	12.8	13.2	12.7	12.3	12.4	12.1	11.8	11.6	11.4

Treatment	Site	Depth (cm)	Intrument	9-Jun	10-Jun	16-Jun	30-Jun	4-Jul	12-Jul	15-Jul	17-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug	11-Aug
1	2-1	0.0	TDR				13.1	24.0	16.2	27.0	25.6	11.1		24.9	23.3	15.1	26.5
1	2-1	21.1	NP			23.1	17.2	30.7	21.6	32.6	29.8						
1	2-1	30.5	NP				20.8	31.2	25.6	32.3	30.9	21.9		30.3	25.3	22.3	31.4
1	2-1	51.1	NP			22.9	18.2	21.8	19.9	22.4	21.6						
1	2-1	61.0	NP				14.6	18.6	15.9	20.2	18.1	15.7		18.1	14.5	13.3	18.9
1	2-1	81.1	NP			11.4	11.3	15.0	12.8	17.8	15.1						
1	2-1	91.4	NP				11.4	15.9	12.8	18.4	15.5	12.6		15.7	12.6	12.1	16.6
1	2-1	111.1	NP			11.1	10.1	14.1	12.0	17.4	14.7						
1	2-1	121.9	NP				10.8	16.4	13.5	19.4	15.6	13.2		15.9	13.0	12.3	18.0
1	2-1	141.1	NP			12.0	11.6	16.9	13.2	19.8	16.3						
1	2-1	152.4	NP				10.0	16.0	13.2	19.4	16.0	11.9		15.3	12.4	11.8	17.4
1	2-1	171.1	NP											16.4	13.1	13.5	19.0
1	2-1	191.1	NP			16.4	20.2	30.2	26.3								
1	2-2	0.0	TDR		15.3		14.8	29.6	16.0	36.6	31.5	15.9		32.5	27.0	16.0	31.5
1	2-2	21.1	NP		26.9	27.0	25.8	39.3	31.9	41.7	39.0						
1	2-2	30.5	NP				33.5	40.1	38.4	41.4	40.2	36.6		40.4	39.7	36.9	41.4
1	2-2	51.1	NP		41.4	42.2	42.5	42.8	42.3	42.9	43.1						
1	2-2	61.0	NP				38.4	40.1	39.7	40.9	40.3	38.8		40.6	40.0	39.5	40.4
1	2-2	81.1	NP		34.6	35.6	33.6	38.0	36.1	37.9	37.5						
1	2-2	91.4	NP				30.0	35.0	34.2	35.9	35.1	34.1		35.1	34.9	33.4	35.4
1	2-2	111.1	NP		28.9	29.9	30.4	36.1	35.2	37.5	36.5						
1	2-2	121.9	NP				35.3	39.1	38.1	41.3	39.4	38.4		39.4	37.6	38.0	39.7
1	2-2	141.1	NP		28.8	29.3	28.1	33.4	32.7	36.6	34.3						
1	2-2	152.4	NP				33.7	38.9	37.9	40.5	40.0	38.3		39.2	36.7	37.4	39.9
1	2-2	171.1	NP									42.2		43.5	42.5	42.2	44.1
1	2-2	191.1	NP		33.2	33.9	32.6	38.3	37.4	40.0	38.9	36.8		37.1	37.4	36.0	39.4
1	2-3	0.0	TDR				11.4	19.4	11.4	22.0	20.9	13.4		12.2	21.1	14.6	14.8
1	2-3	21.1	NP			25.3	17.4	28.5	21.5	30.4	28.9						
1	2-3	30.5	NP				18.6	28.2	21.1	29.5	29.1	18.4		28.0	23.8	19.4	29.7
1	2-3	51.1	NP			21.4	24.2	29.8	27.6	30.9	29.7						
1	2-3	61.0	NP				34.6	38.9	37.0	39.6	38.5	36.4		39.5	36.3	36.2	38.8
1	2-3	81.1	NP			27.7	24.6	32.3	29.6	34.2	33.5						
1	2-3	91.4	NP				29.7	35.9	34.3	37.2	35.8	34.4		36.3	34.1	33.8	37.5
1	2-3	111.1	NP			35.5	28.8	32.2	31.1	34.0	33.0						
1	2-3	121.9	NP				27.3	32.6	31.6	34.7	32.9	31.8		33.1	31.4	31.3	33.7
1	2-3	141.1	NP			33.7	36.2	38.0	39.3	40.4	38.8						
1	2-3	152.4	NP				33.9	37.9	36.8	38.4	38.4	37.8		38.8	37.7	37.0	38.8
1	2-3	171.1	NP									39.1		39.1	38.1	38.1	39.9
1	2-3	191.1	NP			23.7	28.2	32.5	32.9	35.3	35.4	35.0		35.9	34.2	34.4	36.1

Treatment	Site	Depth (cm)	Intrument	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep
1	2-1	0.0	TDR	25.0	21.4	18.8	13.4	13.0	12.5	27.4	23.3	26.0	18.7	16.4		15.3	25.0
1	2-1	21.1	NP														
1	2-1	30.5	NP	30.2	30.2	28.7	25.9	23.7	21.2	30.5	29.4	29.6	27.2	24.7		21.9	26.8
1	2-1	51.1	NP														
1	2-1	61.0	NP	17.8	18.4	16.1	15.7	14.3	12.9	18.4	17.2	17.2	16.2	14.6		12.8	12.9
1	2-1	81.1	NP														
1	2-1	91.4	NP	15.8	15.1	13.9	13.1	12.5	11.8	16.0	15.7	14.2	13.4	12.5		10.7	11.1
1	2-1	111.1	NP														
1	2-1	121.9	NP	16.3	15.0	14.0	13.6	13.0	12.3	15.9	15.4	15.2	13.6	13.1		12.2	13.2
1	2-1	141.1	NP														
1	2-1	152.4	NP	16.4	15.4	13.5	12.9	12.5	12.2	16.1	14.8	14.8	13.3	12.9		11.9	12.2
1	2-1	171.1	NP	16.6	15.7	14.3	13.4	13.2	12.3	14.9	14.9	14.2	13.6	13.2		11.5	
1	2-1	191.1	NP							27.6	28.2		26.9	26.4		25.6	
1	2-2	0.0	TDR	34.2	30.4	27.2	21.9	18.4	14.8	35.8	28.9	33.9	27.8	24.1		16.6	33.0
1	2-2	21.1	NP														
1	2-2	30.5	NP	40.0	40.3	39.9	37.6	37.0	35.8	41.1	39.7	39.9	39.5	37.9		35.6	41.4
1	2-2	51.1	NP														
1	2-2	61.0	NP	40.4	40.2	40.8	39.7	38.7	38.5	40.5	39.8	39.9	39.7	39.1		38.4	39.6
1	2-2	81.1	NP														
1	2-2	91.4	NP	35.2	34.8	34.4	34.2	33.5	33.7	35.5	35.4	34.6	34.7	34.3		33.8	35.9
1	2-2	111.1	NP														
1	2-2	121.9	NP	40.0	39.8	39.2	37.7	38.4	38.5	39.4	39.7	39.1	38.3	37.9		37.5	40.2
1	2-2	141.1	NP														
1	2-2	152.4	NP	39.9	39.0	37.7	38.2	38.0	37.9	38.7	38.4	37.7	37.7	37.8		37.5	38.1
1	2-2	171.1	NP	43.2	43.6	42.8	43.3	42.8	42.6	43.3	42.6	43.5	43.5	42.8		41.7	42.1
1	2-2	191.1	NP	39.0	38.5	37.9	36.8	37.8	36.9	37.1	37.3	38.7	36.9	36.9		35.8	37.4
1	2-3	0.0	TDR	15.8	18.3	15.1	11.4	12.4	13.4	25.6	23.0	25.0	21.9	20.0		16.2	25.0
1	2-3	21.1	NP														
1	2-3	30.5	NP	28.4	27.8	26.6	24.4	21.6	19.5	29.8	26.7	28.9	25.7	23.3		20.9	30.6
1	2-3	51.1	NP														
1	2-3	61.0	NP	39.3	38.5	37.8	37.2	36.3	36.5	39.3	38.4	38.3	38.7	36.5		35.3	39.9
1	2-3	81.1	NP														
1	2-3	91.4	NP	37.1	37.1	36.3	35.3	34.6	33.7	36.7	38.4	36.3	35.4	33.7		32.9	34.9
1	2-3	111.1	NP														
1	2-3	121.9	NP	33.7	33.2	32.4	32.2	31.6	32.0	33.8	35.0	33.3	31.9	32.0		31.1	31.3
1	2-3	141.1	NP														
1	2-3	152.4	NP	37.5	38.3	37.1	36.8	37.8	36.3	39.0	38.7	37.8	38.0	36.7		37.0	37.1
1	2-3	171.1	NP	40.8	40.4	40.0	39.9	39.3	39.1	40.8	38.8	40.7	39.5	40.0		39.4	38.1
1	2-3	191.1	NP	36.5	35.5	35.0	35.2	34.0	35.4	36.3	35.3	35.2	34.9	34.9		34.5	34.6

Treatment	Site	Depth (cm)	Intrument	8-Sep	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
1	2-1	0.0	TDR	24.0	23.0	22.0	20.5	19.0	16.0	15.0	14.2	14.0
1	2-1	21.1	NP									
1	2-1	30.5	NP	29.8	30.3	29.9	28.3	28.9	26.3	25.0	24.9	24.7
1	2-1	51.1	NP									
1	2-1	61.0	NP	17.1	16.7	16.6	16.0	15.1	14.8	14.0	13.6	13.2
1	2-1	81.1	NP									
1	2-1	91.4	NP	14.5	14.4	14.1	11.9	11.9	10.9	10.8	9.8	10.3
1	2-1	111.1	NP									
1	2-1	121.9	NP	14.9	14.4	14.7	14.0	13.3	11.6	11.4	10.4	11.4
1	2-1	141.1	NP									
1	2-1	152.4	NP	13.8	14.4	14.5	13.6	12.9	11.6	11.1	10.0	10.4
1	2-1	171.1	NP					12.5	11.6	10.7	10.0	10.7
1	2-1	191.1	NP					25.9	25.6	24.4	22.7	23.7
1	2-2	0.0	TDR	32.0	31.0	30.0	27.0	24.0	20.0	19.0	18.0	17.0
1	2-2	21.1	NP									
1	2-2	30.5	NP	40.9	41.0	40.7	40.0	39.9	38.9	38.3	38.9	37.3
1	2-2	51.1	NP									
1	2-2	61.0	NP	40.5	40.5	39.5	40.3	39.2	39.2	39.4	37.7	38.4
1	2-2	81.1	NP									
1	2-2	91.4	NP	35.4	36.0	35.2	34.7	34.3	33.1	32.9	32.1	32.0
1	2-2	111.1	NP									
1	2-2	121.9	NP	40.4	39.7	39.3	38.8	37.6	37.7	37.8	35.8	36.2
1	2-2	141.1	NP									
1	2-2	152.4	NP	40.1	38.7	38.6	38.1	37.2	37.7	37.5	36.2	35.3
1	2-2	171.1	NP	42.8	43.8	43.6	42.2	42.9	42.0	41.6	41.3	41.6
1	2-2	191.1	NP	39.0	38.2	37.6	37.6	36.7	36.0	35.8	34.9	35.6
1	2-3	0.0	TDR	24.0	23.0	22.0	20.5	19.0	17.0	16.0	15.6	15.0
1	2-3	21.1	NP									
1	2-3	30.5	NP	29.9	29.0	28.9	27.7	27.6	26.2	26.3	26.2	24.9
1	2-3	51.1	NP									
1	2-3	61.0	NP	39.1	38.7	38.0	37.1	37.2	36.3	36.8	36.1	36.0
1	2-3	81.1	NP									
1	2-3	91.4	NP	37.2	36.8	36.8	35.4	34.1	33.1	32.5	31.4	30.6
1	2-3	111.1	NP									
1	2-3	121.9	NP	33.3	32.0	32.7	30.9	30.7	30.3	30.1	29.6	29.4
1	2-3	141.1	NP									
1	2-3	152.4	NP	37.3	37.8	37.2	37.7	36.9	36.5	36.5	36.4	36.6
1	2-3	171.1	NP	40.1	40.0	40.0	38.3	39.6	38.4	39.6	37.8	38.0
1	2-3	191.1	NP	34.2	34.9	35.0	34.5	34.8	34.3	33.7	33.1	33.7

Treatment	Site	Depth (cm)	Intrument	9-Jun	10-Jun	16-Jun	30-Jun	4-Jul	12-Jul	15-Jul	17-Jul	24-Jul	26-Jul	30-Jul	5-Aug	9-Aug	11-Aug
2	3-1	0.0	TDR				12.0	10.4	9.0	15.1	16.2	26.4	23.0	17.2	18.2	11.4	10.8
2	3-1	21.1	NP			27.7	22.4	19.7	19.0		19.2						
2	3-1	30.5	NP				27.5	26.1	24.4	24.0	24.0	32.0	31.7	29.5	26.6	25.1	25.5
2	3-1	51.1	NP			26.6	22.0	22.4	21.4		21.1						
2	3-1	61.0	NP				19.7	19.5	19.3	19.5	19.4	23.8	22.0	21.6	20.8	19.2	19.1
2	3-1	81.1	NP			22.3	22.1	22.4	21.8		22.2						
2	3-1	91.4	NP				21.0	21.1	20.3	20.4	20.2	25.0	24.0	23.4	21.8	21.3	20.5
2	3-1	111.1	NP			16.8	16.0	15.5	16.0		15.7						
2	3-1	121.9	NP				15.0	14.8	14.4	14.7	14.3	20.2	18.2	17.8	16.6	15.6	15.7
2	3-1	141.1	NP			11.3	11.0	10.7	11.0		11.1						
2	3-1	152.4	NP				11.7	11.5	11.4	11.4	11.3	18.0	15.9	15.0	14.4	13.8	13.7
2	3-1	171.1	NP									16.0	14.3	12.8	12.3	11.5	12.1
2	3-1	191.1	NP			7.9	8.9	8.8	9.2	9.1	9.3	18.4	16.3	14.4	12.9	12.4	12.6
2	3-2	0.0	TDR				12.0	11.1	9.8	13.8	16.2	24.3	20.0	15.7	18.5	14.5	14.2
2	3-2	21.1	NP			27.0	22.4	21.5	20.4		20.8						
2	3-2	30.5	NP				30.0	29.2	27.7	27.0	27.5	39.2	37.8	34.6	32.0	29.0	28.8
2	3-2	51.1	NP			43.1	43.4	43.1	42.4		41.6						
2	3-2	61.0	NP				41.1	41.2	40.1	38.9	40.0	41.6	41.7	41.0	41.5	40.7	40.3
2	3-2	81.1	NP			30.1	28.6	29.2	28.9		29.4						
2	3-2	91.4	NP				32.7	33.2	32.6	33.0	32.3	37.3	36.1	35.8	36.3	35.4	35.2
2	3-2	111.1	NP			35.0	36.5	36.5	36.8		37.1						
2	3-2	121.9	NP				38.9	39.4	38.5	38.8	38.1	41.9	41.5	40.8	40.7	40.3	40.8
2	3-2	141.1	NP			30.0	31.7	31.4	32.4		32.1						
2	3-2	152.4	NP				38.0	37.6	38.2	37.7	37.5	43.1	41.7	43.0	41.4	42.0	41.0
2	3-2	171.1	NP									46.8	46.2	45.9	45.6	44.3	44.5
2	3-2	191.1	NP			41.0	42.1	41.1	41.6	42.1	42.0	45.9	45.9	44.4	44.6	43.4	43.8
2	3-3	0.0	TDR	16.9			14.0	12.6	10.1	21.1	18.9	35.3	25.0	21.9	20.5	15.6	15.0
2	3-3	21.1	NP	34.6		37.4	28.7	28.2	27.3		28.8						
2	3-3	30.5	NP				38.0	36.8	35.6	35.2	35.7	44.1	42.6	42.5	40.7	38.6	38.3
2	3-3	51.1	NP	43.7		42.9	43.4	42.4	41.5		40.3						
2	3-3	61.0	NP				39.2	38.0	37.4	37.0	35.4	39.3	38.3	37.0	36.2	35.9	37.0
2	3-3	81.1	NP	29.8		32.0	31.7	31.9	30.2		28.6						
2	3-3	91.4	NP				40.0	40.2	39.0	39.7	38.3	42.4	41.4	41.7	40.6	40.0	39.0
2	3-3	111.1	NP	30.2		30.2	30.4	30.3	29.5		29.9						
2	3-3	121.9	NP				32.2	32.1	32.2	32.1	32.1	36.4	35.7	36.4	34.9	34.4	33.1
2	3-3	141.1	NP	34.9		36.7	36.0	37.3	36.8		37.7						
2	3-3	152.4	NP				38.6	38.6	38.7	38.2	38.2	41.4	40.6	40.7	40.9	40.1	40.8
2	3-3	171.1	NP									39.7	38.4	37.9	38.3	38.0	38.2
2	3-3	191.1	NP	17.7		17.4	18.9	18.8	19.0	19.0	19.0	24.6	24.2	22.9	22.6	22.3	23.3

Treatment	Site	Depth (cm)	Intrument	12-Aug	13-Aug	15-Aug	17-Aug	19-Aug	22-Aug	25-Aug	26-Aug	27-Aug	30-Aug	2-Sep	4-Sep	6-Sep	7-Sep
2	3-1	0.0	TDR	11.9		11.3	9.5	10.0	10.4		10.4	9.8	8.7	34.4	30.3	26.2	
2	3-1	21.1	NP														
2	3-1	30.5	NP	24.5		24.0	23.5	22.5	22.0		20.8	21.2	20.7	35.4	32.1	31.6	
2	3-1	51.1	NP														
2	3-1	61.0	NP	19.1		18.8	17.5	17.5	17.2		16.3	16.0	16.0	26.3	23.0	22.9	
2	3-1	81.1	NP														
2	3-1	91.4	NP	21.3		20.8	20.5	19.9	19.7		20.3	19.0	19.1	30.0	26.1	23.5	
2	3-1	111.1	NP														
2	3-1	121.9	NP	15.7		15.9	15.2	15.3	14.9		14.2	14.5	14.0	26.1	19.9	18.9	
2	3-1	141.1	NP														
2	3-1	152.4	NP	13.2		13.3	13.4	13.1	12.9		12.5	12.9	12.3	26.2	18.6	16.4	
2	3-1	171.1	NP	11.9		11.1	10.8	11.0	10.5		10.5	10.9	10.6	27.5	16.6	14.6	
2	3-1	191.1	NP	12.4		12.4	12.0	11.6	11.7		11.4	11.9	11.2		19.4	15.3	
2	3-2	0.0	TDR	12.1		14.1	11.8	11.1	10.4		10.5	10.7	11.7	17.4	23.2	28.9	
2	3-2	21.1	NP														
2	3-2	30.5	NP	28.6		28.5	27.4	27.8	26.9		27.2	26.8	26.7	43.1	40.8	40.2	
2	3-2	51.1	NP														
2	3-2	61.0	NP	40.6		39.9	39.0	38.6	37.7		36.1	35.9	36.3	41.9	40.9	41.4	
2	3-2	81.1	NP														
2	3-2	91.4	NP	34.7		34.2	34.0	33.4	32.7		30.6	31.3	29.7	38.0	36.6	37.1	
2	3-2	111.1	NP														
2	3-2	121.9	NP	40.6		41.2	40.3	39.3	39.8		39.5	39.6	38.1	42.8	41.6	41.0	
2	3-2	141.1	NP														
2	3-2	152.4	NP	41.2		41.3	40.4	40.6	40.1		39.5	39.8	39.0	43.8	42.7	42.8	
2	3-2	171.1	NP	44.8		44.6	44.3	44.9	44.4		43.5	44.5	44.4	47.3	46.0	45.7	
2	3-2	191.1	NP	43.0		43.1	42.7	42.6	43.4		43.4	43.3	43.1	45.9	46.0	44.4	
2	3-3	0.0	TDR	16.3		16.2	12.5	13.4	14.2		15.0	12.8	14.7	21.2	27.8	34.3	
2	3-3	21.1	NP														
2	3-3	30.5	NP	38.5		37.0	36.4	36.3	35.8		36.8	35.0	35.1	44.8	43.4	43.8	
2	3-3	51.1	NP														
2	3-3	61.0	NP	34.9		35.4	34.8	33.4	33.4		28.3	31.3	30.1	37.9	37.7	37.8	
2	3-3	81.1	NP														
2	3-3	91.4	NP	39.4		38.6	38.0	37.2	35.5		34.3	32.7	30.4	40.2	41.7	41.7	
2	3-3	111.1	NP														
2	3-3	121.9	NP	33.7		33.6	32.6	32.7	32.5		33.4	31.3	31.2	30.5	36.8	35.7	
2	3-3	141.1	NP														
2	3-3	152.4	NP	39.9		39.9	40.4	39.9	39.8		39.6	39.8	40.6	39.8	41.6	41.6	
2	3-3	171.1	NP	38.9		38.3	38.6	38.4	38.4		37.8	38.5	38.4	37.9	39.6	39.3	
2	3-3	191.1	NP	22.2		22.3	22.3	21.1	22.1		21.2	21.7	21.9	20.9	24.2	23.8	

Treatment	Site	Depth (cm)	Intrument	8-Sep	9-Sep	10-Sep	13-Sep	16-Sep	24-Sep	1-Oct	7-Oct	18-Oct
2	3-1	0.0	TDR	26.0		24.0	22.0	20.0	16.0	14.0	12.9	11.5
2	3-1	21.1	NP									
2	3-1	30.5	NP	31.2		31.3	30.8	31.0	29.9	29.2	29.5	27.8
2	3-1	51.1	NP									
2	3-1	61.0	NP	23.3		21.8	21.6	21.1	20.5	20.3	18.6	19.6
2	3-1	81.1	NP									
2	3-1	91.4	NP	23.1		22.5	22.4	22.1	21.0	21.1	20.9	20.9
2	3-1	111.1	NP									
2	3-1	121.9	NP	17.8		17.4	16.4	16.5	16.0	15.9	15.3	15.5
2	3-1	141.1	NP									
2	3-1	152.4	NP	16.0		15.6	14.9	14.6	14.1	13.4	13.5	13.1
2	3-1	171.1	NP	14.3		12.7	13.1	12.2	11.9	11.2	11.2	11.1
2	3-1	191.1	NP	14.4		13.9	13.4	12.8	12.4	12.2	10.8	11.6
2	3-2	0.0	TDR	26.0		24.0	22.0	20.0	17.0	16.0	15.0	14.0
2	3-2	21.1	NP									
2	3-2	30.5	NP	40.6		39.9	38.6	39.9	38.0	37.8	37.6	36.7
2	3-2	51.1	NP									
2	3-2	61.0	NP	41.1		41.6	40.5	41.8	41.0	40.8	40.2	41.2
2	3-2	81.1	NP									
2	3-2	91.4	NP	36.8		36.2	36.5	36.3	35.8	36.0	34.4	35.2
2	3-2	111.1	NP									
2	3-2	121.9	NP	41.3		40.5	40.4	40.7	40.7	40.5	39.4	39.5
2	3-2	141.1	NP									
2	3-2	152.4	NP	42.2		41.4	41.3	41.4	40.6	40.7	40.2	40.3
2	3-2	171.1	NP	45.7		45.9	45.1	45.3	44.1	44.3	44.3	44.5
2	3-2	191.1	NP	45.1		45.0	44.6	44.1	43.6	43.0	42.8	42.6
2	3-3	0.0	TDR	33.0		31.0	28.5	25.0	20.0	18.0	17.5	16.5
2	3-3	21.1	NP									
2	3-3	30.5	NP	44.6		43.1	43.4	42.8	42.6	42.8	42.9	42.8
2	3-3	51.1	NP									
2	3-3	61.0	NP	37.9		37.5	37.6	36.7	37.8	37.4	36.6	36.6
2	3-3	81.1	NP									
2	3-3	91.4	NP	41.6		41.2	41.4	40.6	39.9	40.2	39.4	39.8
2	3-3	111.1	NP									
2	3-3	121.9	NP	35.7		34.8	34.7	34.9	34.5	33.8	33.7	33.3
2	3-3	141.1	NP									
2	3-3	152.4	NP	40.5		40.4	40.6	40.0	40.1	40.8	39.9	39.5
2	3-3	171.1	NP	38.8		38.8	38.0	38.8	38.5	38.8	38.3	38.3
2	3-3	191.1	NP	23.8		23.7	23.6	22.9	22.2	23.1	22.6	21.9

APPENDIX E – Rosetta Class Average Hydraulic Parameters

The table below gives class-average values of the seven hydraulic parameters for the twelve USDA textural classes. For the θr, θ s, α, n and Ks parameters, the values have been generated by computing the average values for each textural class. For Ko and L the values were generated by inserting the class average values of θr, θs, α, n into Model C2 (see Rosetta's help file). The values in parentheses give the one standard deviation uncertainties of the class average values.(http://www.ars.usda.gov/Services/docs.htm?docid=8955)

Texture Class	**N**	**-- θr -- cm3/cm3**		**-- θs -- cm3/cm3**		**-- log(α) -- log(1/cm)**		**-- log(n) -- log10**		**-- Ks -- log(cm/day)**		**-- Ko -- log(cm/day)**		**-- L --**	
Clay	84	0.098	(0.107)	0.459	(0.079)	-1.825	(0.68)	0.098	(0.07)	1.169	(0.92)	0.472	(0.26)	-1.561	(1.39)
C loam	140	0.079	(0.076)	0.442	(0.079)	-1.801	(0.69)	0.151	(0.12)	0.913	(1.09)	0.699	(0.23)	-0.763	(0.90)
Loam	242	0.061	(0.073)	0.399	(0.098)	-1.954	(0.73)	0.168	(0.13)	1.081	(0.92)	0.568	(0.21)	-0.371	(0.84)
L Sand	201	0.049	(0.042)	0.390	(0.070)	-1.459	(0.47)	0.242	(0.16)	2.022	(0.64)	1.386	(0.24)	-0.874	(0.59)
Sand	308	0.053	(0.029)	0.375	(0.055)	-1.453	(0.25)	0.502	(0.18)	2.808	(0.59)	1.389	(0.24)	-0.930	(0.49)
S Clay	11	0.117	(0.114)	0.385	(0.046)	-1.476	(0.57)	0.082	(0.06)	1.055	(0.89)	0.637	(0.34)	-3.665	(1.80)
S C L	87	0.063	(0.078)	0.384	(0.061)	-1.676	(0.71)	0.124	(0.12)	1.120	(0.85)	0.841	(0.24)	-1.280	(0.99)
S loam	476	0.039	(0.054)	0.387	(0.085)	-1.574	(0.56)	0.161	(0.11)	1.583	(0.66)	1.190	(0.21)	-0.861	(0.73)
Silt	6	0.050	(0.041)	0.489	(0.078)	-2.182	(0.30)	0.225	(0.13)	1.641	(0.27)	0.524	(0.32)	0.624	(1.57)
Si Clay	28	0.111	(0.119)	0.481	(0.080)	-1.790	(0.64)	0.121	(0.10)	0.983	(0.57)	0.501	(0.27)	-1.287	(1.23)
Si C L	172	0.090	(0.082)	0.482	(0.086)	-2.076	(0.59)	0.182	(0.13)	1.046	(0.76)	0.349	(0.26)	-0.156	(1.23)
Si Loam	330	0.065	(0.073)	0.439	(0.093)	-2.296	(0.57)	0.221	(0.14)	1.261	(0.74)	0.243	(0.26)	0.365	(1.42)