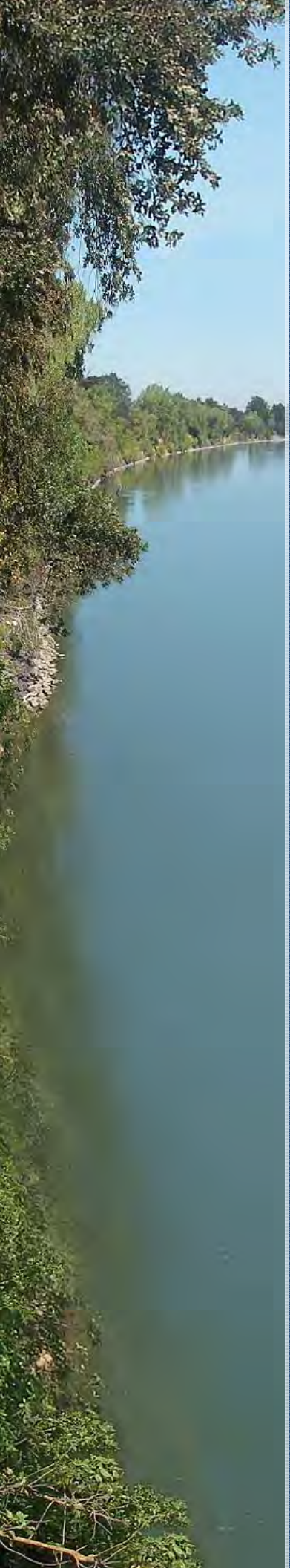

California Levee Vegetation Research Program

Influence of Tree Roots and Mammal Burrowing Activity on Levee Performance:
Volume 3. – Crown Trench Seepage Test, Northern Levee of Twitchell Island, Rio Vista, California

Michelle Shriro, Jonathan D. Bray, Nicholas Sitar, Diego Cobos Roa

University of California, Berkeley, CA

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Report UCB GT 13-03 vol.3

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SUMMARY

This volume summarizes the results of a second infiltration experiment performed by the project team as part of the California Levee Vegetation Research Program. This test was conducted along the crown of a bypassed levee adjacent to an oxbow segment of the Sevenmile Slough, Twitchell Island, Rio Vista, California. An 8 ft deep crown trench was excavated into the center of the levee to intersect the root system of a land side live oak tree, a water side valley oak tree, and a control section. This field test was designed to evaluate the effects of seepage in the vicinity of live tree root systems. During the test, the crown trench was flooded and maintained at constant head to simulate a flood condition with water delivered from the center of the levee. Piezometers and tensiometers were installed to measure positive and negative pore water pressures, respectively, within the zone of flow to describe the wetting and flow patterns as they evolved within the levee and to specifically assess the influence fo the live tree root systems. Burrow networks, soil fracturing, and void space within the levee soil matrix, as well as variability of stratigraphic conditions across the site added complexity. Visual observations were made during the flow test to view surficial seepage and flow patterns that occurred at the levee surface in addition to continuous monitoring of subsurface instruments. The site contained an extensive network of muskrat burrows in addition to burrows by other species and the initial advance of the wetting front appeared to be related to burrowing activity. With increased time and saturation of levee soils, flow through macropores appeared to diminish. The levee selected for this field test appears to have been founded on overbank deposits composed of lower permeability soils than the overlying levee fill. Water appeared to accumulate on this stratigraphic layer, driving seepage patterns on the landside of the levee. A discontinuity in these low permeability overbank deposits affected flow patterns, while the slope of this layer toward the discontinuity appears to have added a three dimensional aspect to flow patterns. Cracking was observed in the crown road along the levee crest within the first 24 hours of the flow test. After approximately 39 hours of flow, the waterside oak tree, initially leaning at an angle of approximately 44 degrees from horizontal, rotated approximately 20 degrees toward the adjacent slough, creating cracks and deformation along the waterside slope. A dye test was performed as a part of the experiment to better understand the extent of the burrows, their effect on flow patterns, and to better evaluate the role of these burrow networks in the deformations observed on the waterside slope during the flow test. Ground-based tripod light detection and ranging (T-LiDAR) technology was used to complement our efforts related and track deformations during the test. Detailed observations collected during the experiment and the basic interpretations of the observed processes are presented herein, and are further explored through analytical modeling in the fifth volume of this series.

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Prof. Alison Berry of UC Davis shared field equipment with us during this study. Field efforts were assisted by Mr. Roy Kroll of the CDWR, graduate students Nick Oettle, Chris Markham, and Connor Hayden of UC Berkeley. URS Corp. provided construction services as well as construction management and safety personnel. The assistance of Mr. Joe Barnes, Ms. Jackie Shulters, and their dedicated field crew consisting of Mr. Nelson Medeiros, Mr. Bud Romero, and Mr. James Nutter were especially appreciated. Drilling services were performed by Gregg Drilling. We would like to thank the County of Sacramento Environmental Compliance Division for their cooperation. We thank each of them for their hard work and commitment to the project.

The deformation analysis effort during and following the flow test incorporated Ground-Based Tripod Light Detection and Ranging (T-LiDAR) technology. Dr. Gerald Bawden of the USGS performed scans at key points before, during and after the flow test, providing detailed documentation of site conditions. A deformation analysis complementing the work discussed herein was performed by Dr. Gerald Bawden with assistance from Mr. James Howle and Ms. Sandra Bond of the USGS.

We had the good fortune of being advised by a number of key individuals whose advice benefited our study greatly. We would like to thank the entire advisory panel of the CLVRP and in particular Professors Dirk Van Vuren and Alison Berry of UC Davis, Dr. Les Harder of HDR Inc., Dr. Doug Shields of the USDA, Emeritus Prof. Donald Gray of the Univ. of Michigan, Prof. Chris Peterson of the Univ. of Georgia, Mr. George Sills, Mr. Mike Inamine of the Sutter Butte Flood Control Agency, and Mr. George Qualley of the Department of Water Resources. In addition, we would like to thank the USACE ERDC team for their collaboration and feedback on our work, especially Dr. Maureen Corcoran and Dr. Kyle McKay.

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1 OBJECTIVES OF FIELD TESTING

This work is part of a larger effort by the California Levee Vegetation Research Program (CLVRP) to evaluate the impact of vegetation on levee integrity. As part of this overall effort, UC Berkeley field test efforts are focused on developing an understanding of the effects of live and decomposing root systems on levee seepage and seepage-induced slope stability. The first of a this series of two field tests was designed and implemented to evaluate the effects of decayed and decomposed tree roots on seepage through an earthen levee, and the resulting potential for seepage-induced instability. This work, performed in Sacramento, California, was summarized in the second volume of this six volume series.

This third volume of the six volume series summarizes the results of our second field test. This effort involved constructing and executing a Crown Trench Seepage Test. The concept of the test involves excavation of an 8 foot deep trench through the levee crown and supplying the trench with water held at a constant head, simulating a flood condition where water is delivered from the center rather than the side. Instrumentation installed within the zone of flow captures positive and negative pore water pressures before, during, and after flow. A conceptual sketch of the second field test is provided as Figure 1-1. While the focus of the first field test was on the study of decomposing tree roots, this second field test was modified slightly to focus on the effects of live, native root systems on levee seepage and seepage-induced stability under conditions approximating steady state flow.

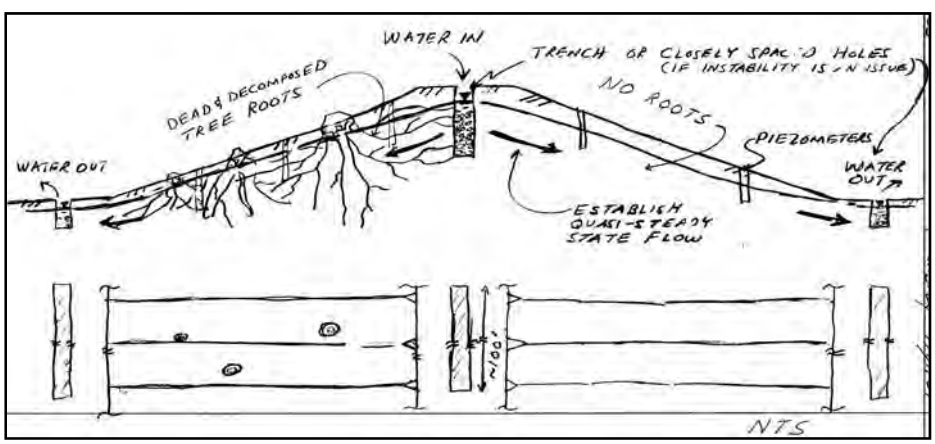


Figure 1-1. Conceptual Sketch of Crown Trench Seepage Test.

2 TWITCHELL ISLAND NORTH LEVEE: CROWN TRENCH SEEPAGE TEST

2.1 SITE SELECTION

Conceptually, the crown trench seepage test (Figure 1-1) is quite simple and elegant. However, the large scale and depth of the crown trench test combined with the destructive nature of the work involved in the experiment presented concerns for many reclamation districts maintaining active flood control levees. As a result, inactive or bypassed levees, or those with low consequences of failure were sought during site selection. Further, during the parallel trench wetting front test at the California Exposition and State Fair site in Sacramento ('Cal Expo') the majority of water was lost outside of the study area. Large water demands expected for a test of this size established a need for a water source near the test location. To minimize losses of water outside of the study area, a shallow water table or a low permeability layer below the study zone was sought in order to meet the objective of developing saturated flow within the study area. A site with soils sufficiently cohesive to allow for construction with vertical shores was sought, allowing safe entry and while maintaining trench wall visibility for logging and data collection. Tree species, position, and site configuration were also considered important factors. Valley Oaks (Quercus lobata) and cottonwoods (Populus fremontii) were sought out as the most appropriate species to include in our study as they are native to California and occur in abundance on levees throughout the State.

After a review of candidate sites, a site was selected within Reclamation District 1601 along an oxbow segment of the Sevenmile Slough, on the northern levee of Twitchell Island (Figure 2-1). This site lies within the Sacramento San Joaquin Delta. The paved levee served as the primary access road along the northern border of the island until a segment of levee about a third of a mile in length (including the study site) was bypassed in 2008. The levee is no longer maintained but retains water, protecting an approximately 8 acre stretch of unimproved land between it and the new flood control levee (Figure 2-2). The Sevenmile Slough is a gated channel used for irrigation of the island. Gates are operated from the neighboring Brannan Island at the eastern end of the slough at high tide and closed at low tide to allow farmers to siphon water for irrigation. Water levels within the slough are relatively stable, typically fluctuating only a few inches to a foot day-to-day. The slough was deemed suitable as a water source and the candidate levee segment had a suitable landside oak tree near a control segment with no trees on the land side and small trees and bushes on the water side (Figure 2-3). The site was selected primarily for the landside tree and uniform appearance of the landside levee. A waterside oak located between the landside oak and the control was included in the study due to a favorable site configuration that could easily accommodate the study of both, though topographic non-uniformity and limited access of the waterside levee made the landside tree the focus of the study design.

Figure 2-1. Site Vicinity Map.

Figure 2-2. Location of the study site along the Sevenmile Slough.

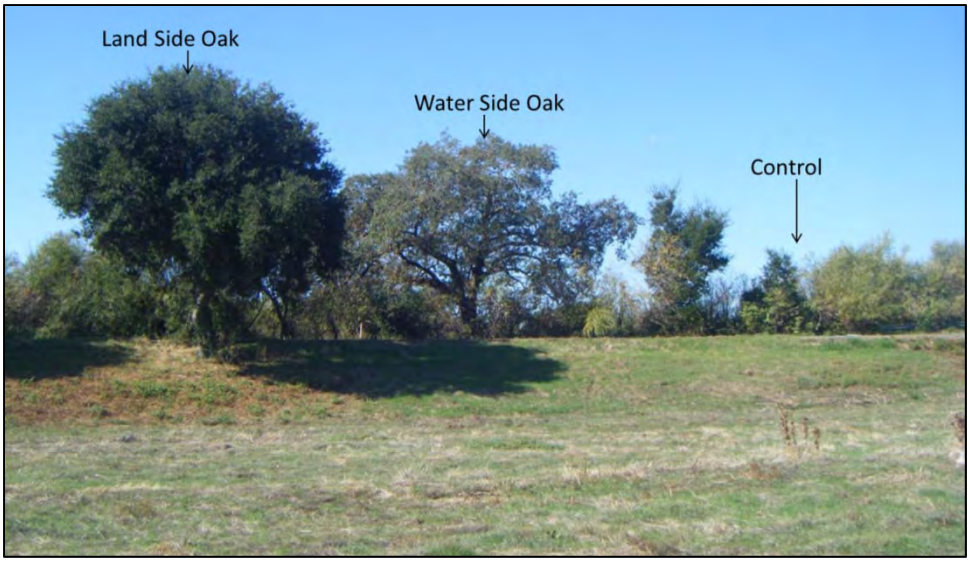


Figure 2-3. View looking west at landside oak, waterside oak, and study control section.

2.2 SITE DESCRIPTION

A 2001 topographic map of the selected site (KSN, 2001) showing the landside and waterside oak trees is provided as Figure 2-4. An additional, site specific topographic map was shot with a surveyor's level on June 1, 2012, just following the flow test. This map provides a higher degree of topographic detail for interpretation of site data. The limits of the topographic map are provided on Figure 2-5 and a detailed view of the study area topography is provided as Figure 2-6.

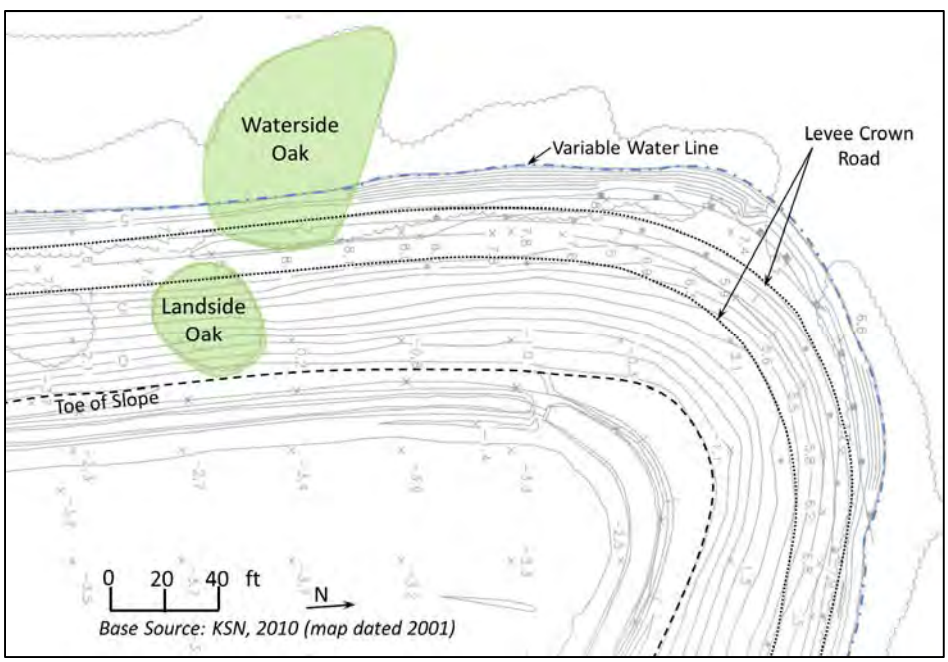


Figure 2-4. Topographic map of the studied levee as shot by KSN in 2001.

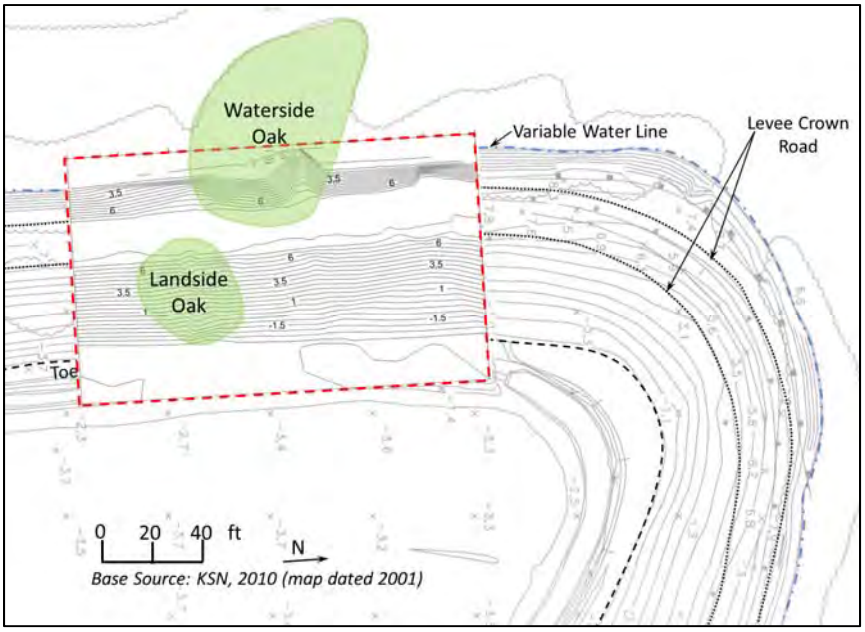


Figure 2-5. Topography of the studied levee following the flow test was captured with a surveyors level and is outlined in red and inset over 2001 topography by KSN.

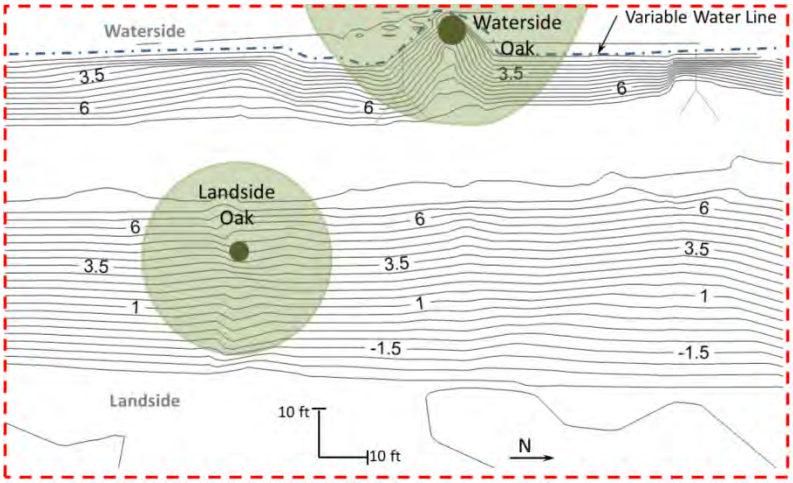


Figure 2-6. Topography of the studied levee following the flow test shot on July of 2012.

Figure 2-7 shows cross sectional topography of three identified sections across the site representing the landside oak tree, the waterside oak tree, and the proposed control area. The landside of the levee is inclined at a relatively consistent gradient of 4:1 (horizontal:vertical) with a total vertical height from crown to toe of just over 10 feet. The waterside slope has a variable gradient ranging from 4H:1V near the top and steepening to 1H:1V near the base. Section C is flatter than Sections A and B near the top with a larger portion of the slope inclined at a gradient of 1H:1V or steeper. Section C topography was difficult to capture due to access constraints associated with dense vegetation and overly steepened slopes.

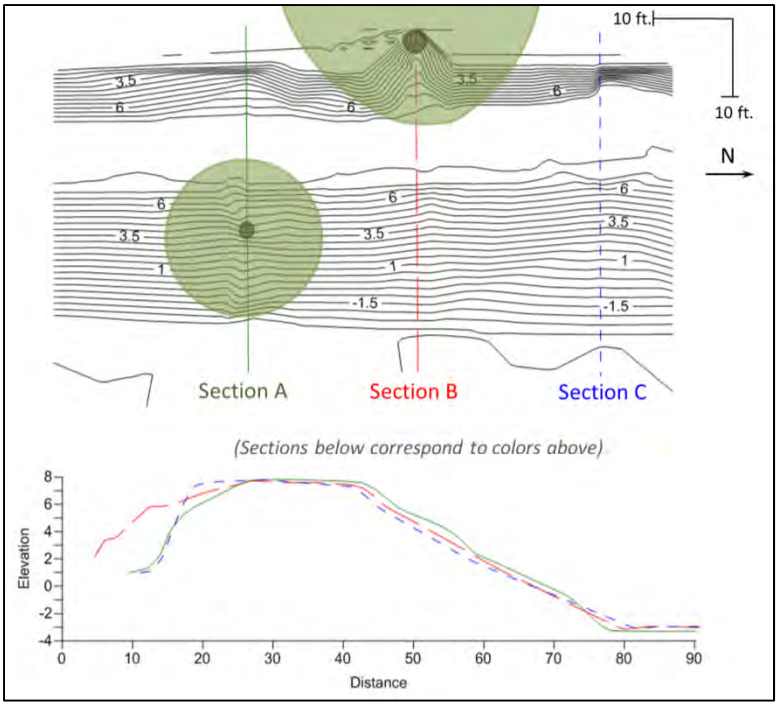


Figure 2-7. Cross-sectional topography at the landside oak tree (Section A), the waterside oak tree (Section B), and the proposed control section (Section C).

Historic topography and available historical documents were reviewed to provide an understanding of the age, construction methods, and materials used to construct the site levees. A historical account of reclamation of Twitchell Island and surrounding islands is provided by Thompson (2006). Twitchell Island, originally marshland, was reclaimed in 1869. Due to the presence of peat soils and high flows in the San Joaquin River at the southern border, the island suffered frequent floods between 1869 and 1875 and was temporarily abandoned. Levees were originally constructed to a height of 3 ½ to 5 feet with a 2 to 4 foot crown width. When this was found to be inadequate, levees increased in height by about 3 feet with a crown width of at least 6 feet and a base of 12 to 20 feet. Levees to the south were more problematic due to construction on peat foundation soils. Reclamation began again in 1894 and portions of the island were being leveed through 1904. Flooding problems continued in 1906, 1907, and 1909. In a 1910 topographic map, the levees appear to be in their current configuration. Flood impacts to northern levees, on firmer soils than southern levees, are not detailed. Figure 2-8 shows topographic maps of the site in 1932 and 1952. The Sevenmile Slough has been gated within this time window. High waters occurred in 1937 and 1950 (Paulson, 1988-89). Based on discussions with Mr. Rick Carter of RD1601, the gate was installed in part due to problems with scour. According to URS (2011), their engineer noted during a field reconnaissance interview that gate structures were constructed around 1950. The URS summary document also states that data related to levee segment improvements occurring between 1920 and 1960 were not available for review.

Figure 2-9 shows mapped soil conditions for Twitchell Island based on USDA mapping (1935), which indicates the site is underlain by alluvial soils, specifically Columbia silty clay (Co) with nearby deposits of Ryde silty clay loam (Rd).

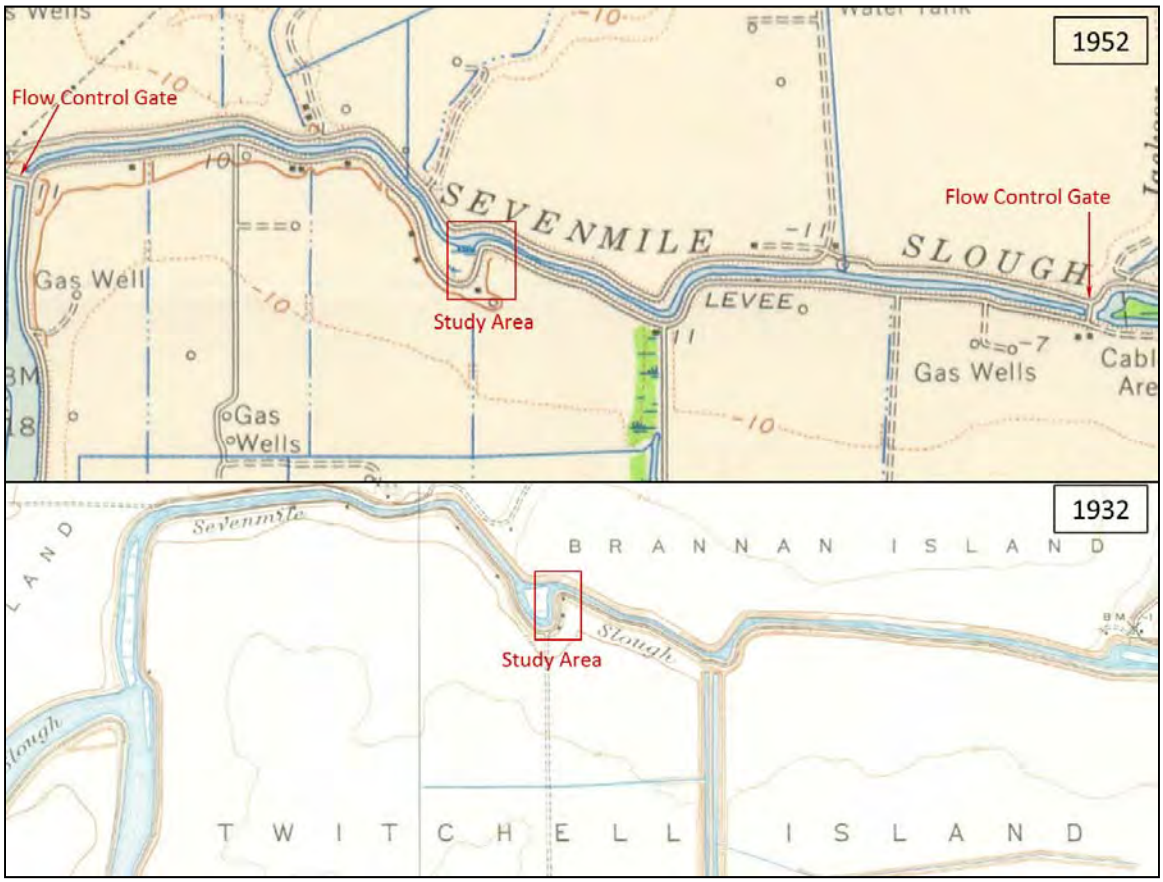


Figure 2-8. Historic topographic maps: USGS (1932) and USGS (1952). Note the position of structures (indicated by black squares) have changed along the Sevenmile Slough between 1932 and 1952. A flow control gate has been installed by 1952 and the oxbow section appears to be wetland.

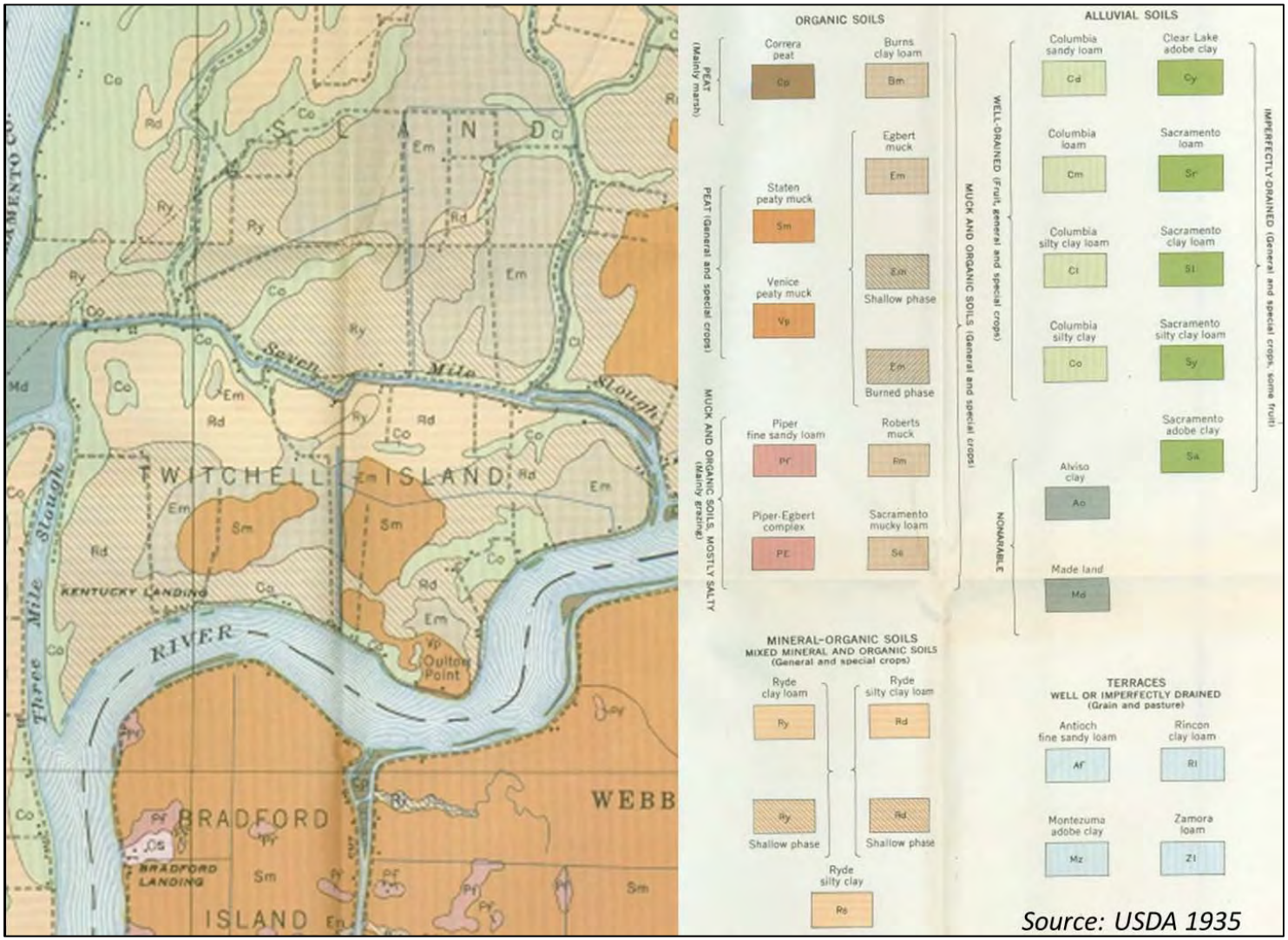


Figure 2-9. Soil conditions at Twitchell Island as mapped by the USDA in 1935.

The landside vegetation consisted primarily of low grass cover with patches of mowed and returning blackberry and included one oak tree (Figure 2-10), while the waterside was found to be densely vegetated, as shown on Figure 2-11. During the site reconnaissance, rustling sounds and moving vegetation were indicators of animal activity just north of the control site within a patch of blackberry brush.

Dr. Dirk Van Vuren of UC Davis visited the site as the CLVRP team expert to evaluate the potential for burrowing mammals at the Twitchell Island study site. During a site walkover on May 2, 2012, Dr. Van Vuren identified evidence of vole activity on the landside (Figure 2-12A and B) and noted that pocket gophers are likely present at this site as well. He suggested both are likely to dig shallow burrows with exits on the landside of the levee. Blackberry makes for a protected burrow entrance as well as a food source (Ordeñana et al., 2012). Evidence of gophers appeared during trench construction (Figure 2-12C).

Figure 2-10. Landside vegetation; views looking west (top) and north (bottom).

Figure 2-11. Waterside vegetation looking: south from the water (left); south from the waterside oak tree (top right); and north from the waterside oak tree (lower right).

Access to the waterside was limited due to dense vegetation and because trimming of elderberry , (*Sambucus mexicana*) an endangered shrub, was not allowed within the conditions of our permits. Access became somewhat easier when water levels in the slough were lowest. On the day of Dr. Van Vuren's reconnaissance, access was possible from the waterside oak tree. Several locations of likely abandoned muskrat burrows were identified during the reconnaissance (Figure 2-12D and E). Based on our discussion, muskrats typically enter their burrows below the water and excavate their burrows up from the water to create a dry den above the water line. Mr. Rick Carter, in charge of maintenance for RD1601, confirmed that muskrats had been a past problem, but had not been seen in that area in recent years.

Figure 2-12. Evidence of burrowing mammals on the landside consisting of voles (A and B) and pocket gophers (C) and evidence of muskrats found on the waterside (D and E).

The type, size and location of onsite vegetation was noted prior to commencement of construction. Professor Alison Berry of UC Davis assisted in vegetation identification. The landside oak tree was determined to be a Coast live oak based on its leaves and bark (Figure 2-13), native to California (Cooper, 1926). Based on our review of aerial photographs, no trees existed on the landside of the levee in 1978. By 1993, a small but established landside oak can be seen, along with several other landside trees. The even spacing and apparent simultaneous appearance on the levee suggests the trees were planted between 1978 and 1993. The landside oak tree has a canopy diameter of approximately 40 feet and is likely to have been approximately 25 years old at the time of our study.

Waterside vegetation within the study site consisted primarily of a blend of willow and elderberry. Just north of the waterside oak tree was a small Coast live oak amongst dense willow and elderberry. Figure 2-14 shows examples of typical waterside vegetation found within the study area. The waterside oak tree was identified by Professor Berry as a Valley Oak based on its leaves and bark (Figure 2-15). The tree was leaning at an angle of about 44 degrees from the horizontal with a large branch extending out over the water as shown on Figure 2-15 and Figure 2-16. The tree age was estimated at 60 years at the time of our study based on historic aerial photography and a growth ring count following the removal of the tree at the end of the project. The tree canopy had a diameter of approximately 80 feet in its

maximum direction, however, the width of the canopy along the levee road was estimated at 60 feet.

Figure 2-13. Landside Coast live oak tree bark (left), leaves (top right), and from a distance looking south (lower right).

Figure 2-14. Waterside vegetation consisting of primarily elderberry (A and B) and willow (E and F) with north-facing views of dense waterside vegetation (C and D).

Figure 2-15. View of the waterside Valley oak branches, leaves, and bark.

Figure 2-16. View of waterside oak looking west (left), north from a distance (top right), and north from close in (lower right).

The waterside Valley oak can be seen in the 1993 aerial image as shown in Figure 2-17. The tree appears to extend farther into the levee road in 1993 than in subsequent years which may indicate an increasing lean angle or pruning. Figure 2-17 shows the construction of the bypass levee in 2008, serving as both flood

protection and a paved primary access road along the north side of Twitchell Island and diverting traffic flows from the site under study. In September of 2008, an irrigation ditch interrupted by the bypass levee can be seen abandoned. Figure 2-18 shows the ditch intact in 2010 and overgrown or possibly removed by July of 2011. The site appears to have undergone minor re-grading by September of 2011 with the toe ditch completely removed in this photograph. The ditch was located at the toe of the landside levee within our study site.

Figure 2-17. Image of the study site in 1993 showing a small, but present, landside oak. Images between March and September of 2008 show the construction of the levee bypass.

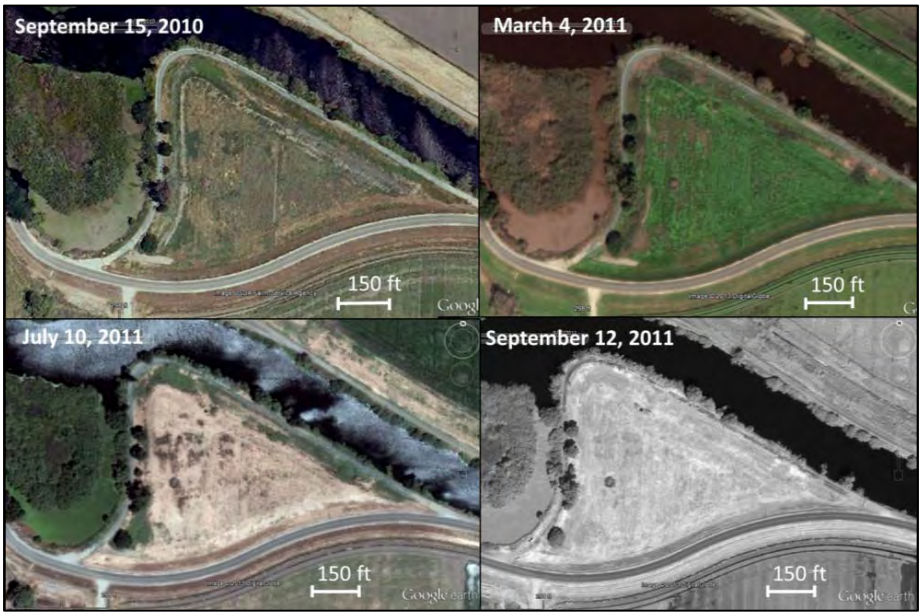


Figure 2-18. Aerial imagery in the years before the flow test show minor re-grading in 2011 to remove a toe ditch abandoned during the bypass installation.

2.3 TEST LAYOUT AND DESIGN

As discussed, the conceptual test design intended to simulate a flood condition where water is delivered into a trench through the levee crown rather than from the side. Upon site selection, the team modified the test concept slightly from that shown on Figure 1-1 to account for differences between waterside and landside site conditions. A control section and a study tree, the landside oak that was the focus of the study, exhibited the uniformity appropriate for a reasonable comparison to be made. As previously mentioned, given the layout of the site, with a waterside tree existing between the landside oak tree and a control section, the experiment was extended to include study of a waterside tree to be evaluated against a waterside control section. With the landside as the primary study site, the trench was shifted from the levee centerline toward the landside. A location was selected where the wall of the trench would be positioned approximately 3 feet from the hinge point of the landside slope. The new configuration allowed the 'tree trench' to intersect the root systems of both land and water side levee trees. In addition, a separate 'control' trench was constructed north of the tree trench, as shown on Figure 2-19.

The trenches were excavated to a width of 2 feet and a depth of 8 feet. The as-built length of the control trench was approximately 31.5 feet while the as-built length of the tree trench was 95 feet with an approximate 5 foot separation between them. Water was pumped from the main channel of the slough and delivered to the trenches via gravity from a 4900 gallon polyethylene water reservoir placed at the highest location at the southern end of the trenches (Figure 2-20).

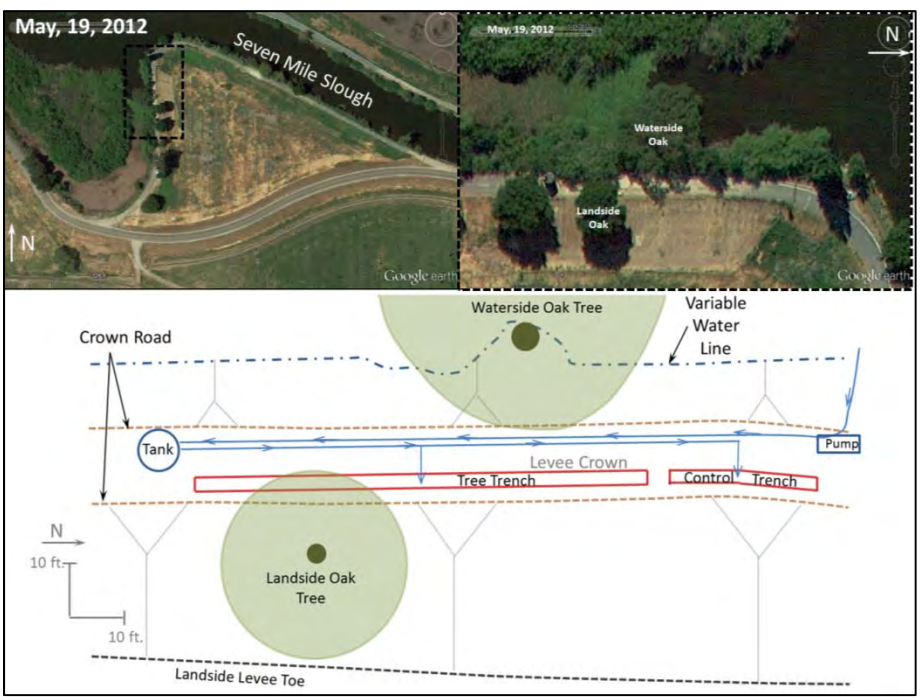


Figure 2-19. Layout of Twitchell Island Crown Trench Seepage Test. Aerial photos (top) taken on May 19, 2012, capture the flow test setup.

Figure 2-20. Pump and tank system (A and B). Image C shows valves used to control rate of flow into the trenches.

The water supply pump was a model DV-100c diesel unit with a minimum pump rate at idle of approximately 500 gallons per minute. The pump was activated by an automatic switch installed in the water tank that indicated when the water reached a maximum level. The reservoir was equipped with an overflow pipe with an outlet to the slough in the event of switch malfunction. Flow meters were installed on the water tank inflow pipe as well as th delivery lines into the trenches (Figure 2-21).

Figure 2-21. Typical flow meter (left) as installed on pipes flowing into and out of the 4900 gallon reservoir. Water delivery pipes and hoses are pictured to the right.

The trenches were filled with clean crushed gravel for stability during the experiment. A manifold of perforated pipes was installed to encourage rapid

delivery of water throughout the trench and vertical risers were used to monitor water levels (Figure 2-22). Delivery of water into the trenches was via a 4-inch diameter fire hose. The hose was equipped with 2-inch diameter removable adapter hoses connecting to mechanical float valves to maintain a constant head in each trench once flow volumes were sufficiently reduced (Figure 2-22D and E).

An instrumentation layout was designed to monitor positive and negative pore pressures in the vicinity of the landside and waterside oak trees and the control section. Sections A, B, and C represent the landside oak tree, the waterside oak tree and the control zones, the primary areas of study for this test. In the interest of evaluating the effect of distance from the tree center on seepage through a root system, supplemental instruments were placed at Lines D and E. Line D is placed at approximately two-thirds of the canopy radius to the north of the landside oak trunk. Similarly, Line E is placed at an approximate distance of ½ of the canopy radius to the south of the waterside oak tree as shown on Figure 2-23.

Figure 2-22. Gravel filled A) Control trench and B) Tree trench. The water delivery manifold (photo C), the constant head mechanical float (photo D), and the delivery hoses (photo E) are shown.

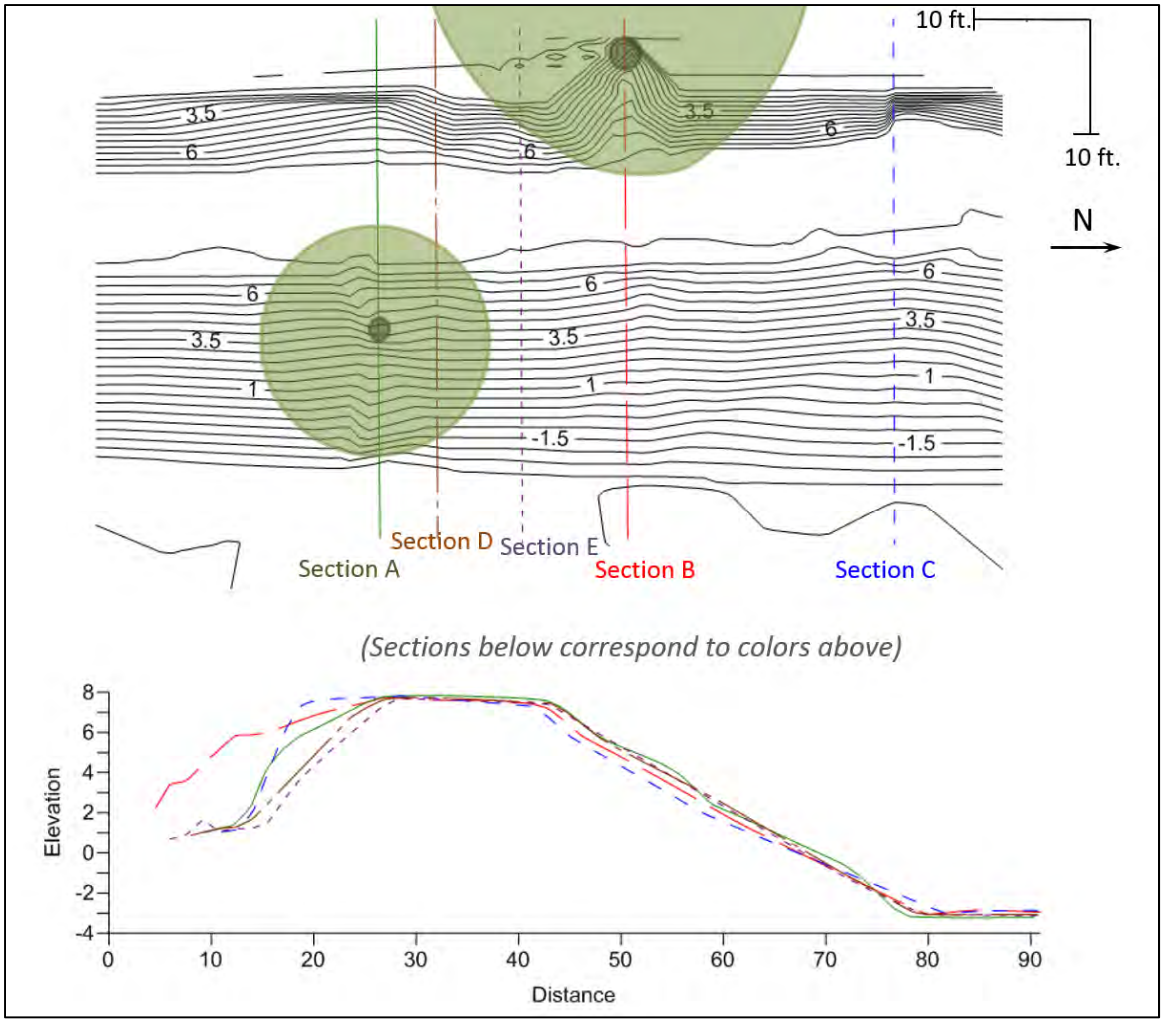


Figure 2-23. Location and topography of instrument lines showing supplemental lines D and E at a distance from the tree center of approximately half to two-thirds of the canopy radius.

Instrumentation was placed in rows with similar configuration at each primary line for ease of comparison. Instruments consisted of vibrating wire piezometers and tensiometers with electronic transducers. Piezometer Rows 1, 2, and 3 were placed earlier than other instruments as these borings provided early stratigraphic soil data needed to make modifications to the final instrument plan. Remaining piezometers – in Rows 4 through 6 – and all tensiometers were installed after construction of both trenches to minimize damage to the instruments. Figure 2-24 and Figure 2-25 show the position of instruments as well as the naming convention which calls out the row and line number for each and the depth for tensiometers. Piezometer depths are provided in Table 2-1.

The intent of Lines A and D was to understand the effects of the landside oak tree on levee seepage and stability, therefore waterside instrumentation was limited at these lines. Lines A and C had matching instrument layouts on the land side. Lines B and C had matching instrument layouts on the waterside and Line E was established

to supplement data for the zone around the waterside tree. A nearly complete landside instrument line was placed at Line B as redundancy to the control Line C. All instruments were wired into continuously reading recorders, as shown on Figure 2-26 and discussed further in a subsequent section of this report.

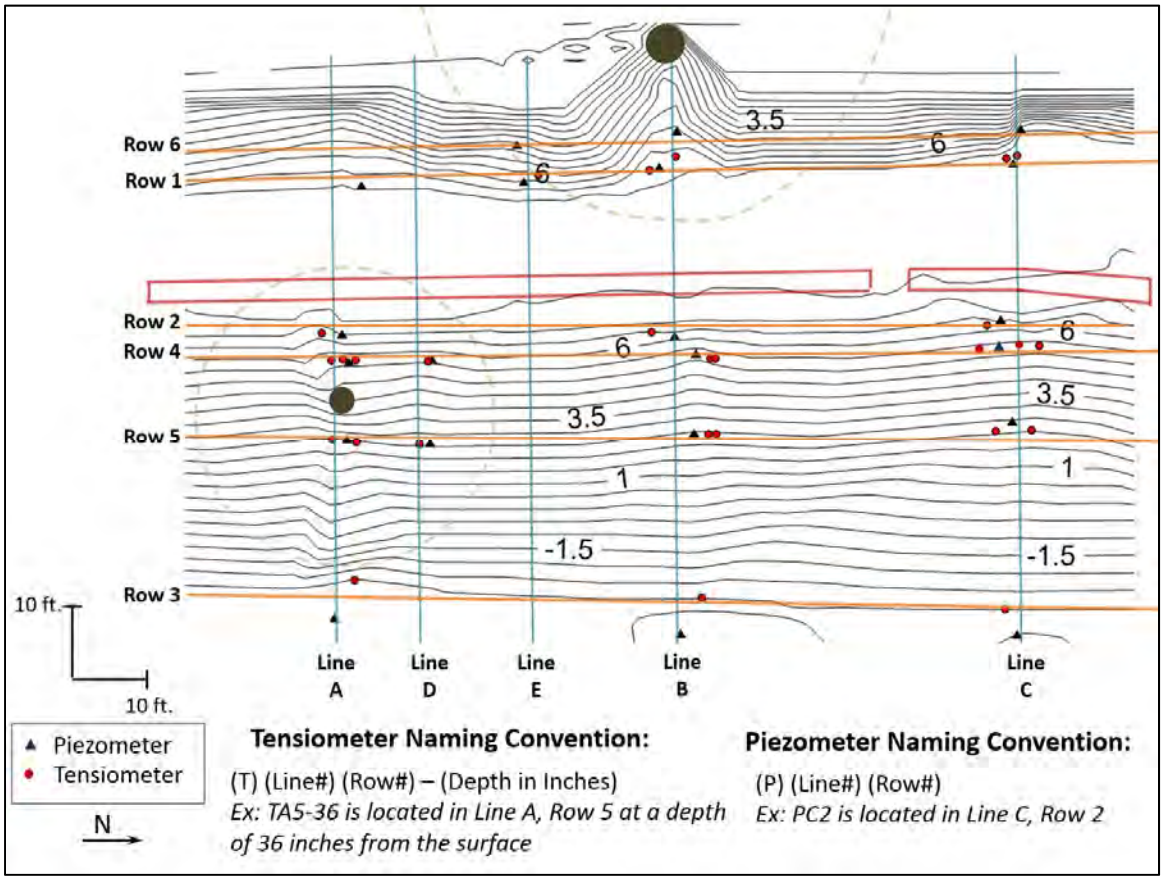


Figure 2-24. Instrument layout and naming convention.

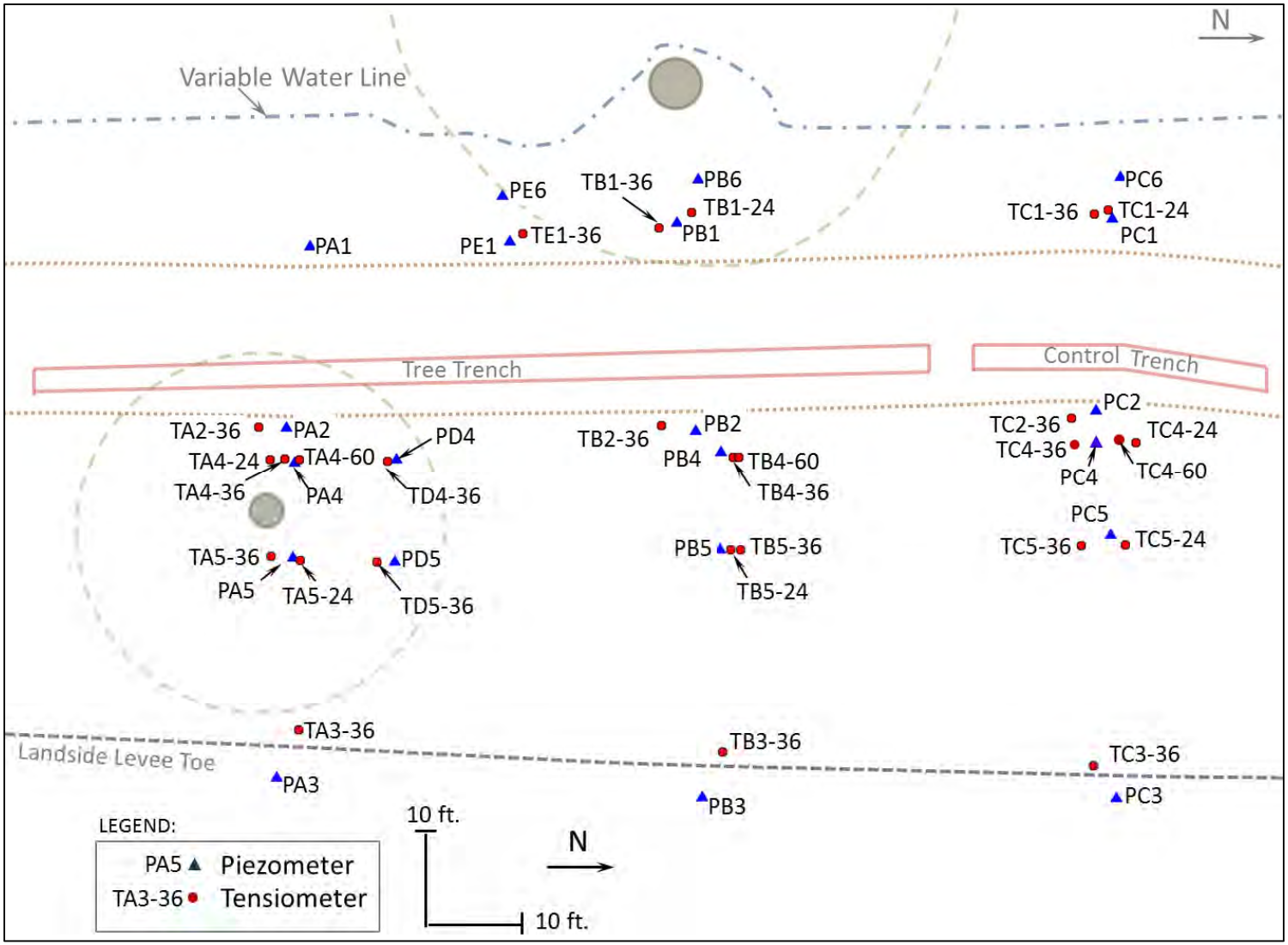


Figure 2-25. Instrument location plan.

Figure 2-26. Instruments (photos A through C), once installed, are wired into readout boxes (D) for continuous readings during the flow test.

Table 2-1. Piezometer model numbers and depths.

Instrument Number	Instrument Model	Depth (ft)	Instrument Number	Instrument Model	Depth (ft)
PA1	Geokon 4500AL (70 kPa)	5.9	PD4a	Geokon 4500AL (70 kPa)	2.4
PB1	Geokon 4500AL (70 kPa)	6.5	PD4b	Geokon 4500AL (70 kPa)	5.7
PC1	Geokon 4500AL (70 kPa)	6.2	PB4	Geokon 4500AL (70 kPa)	5.7
PE1	Geokon 4500AL (70 kPa)	6.5	PC4a	Geokon 4500AL (70 kPa)	2.4
PA2	Geokon 4500AL (70 kPa)	15.0	PC4b	Geokon 4500AL (70 kPa)	5.7
PB2	Geokon 4500AL (70 kPa)	15.9	PA5	Geokon 4500AL (70 kPa)	3.0
PC2	Geokon 4500AL (70 kPa)	12.4	PD5	Geokon 4500AL (70 kPa)	3.0
PA3	Geokon 4500AL (70 kPa)	7.9	PB5	Geokon 4500AL (70 kPa)	3.0
PB3	Slope Indicator (150 kPa)	13.5	PC5	Geokon 4500AL (70 kPa)	3.0
PC3	Geokon 4500AL (70 kPa)	8.5	PB6	Geokon 4500AL (70 kPa)	3.4
PA4a	Geokon 4500AL (70 kPa)	2.4	PC6	Geokon 4500AL (70 kPa)	3.4
PA4b	Geokon 4500AL (70 kPa)	5.7	PE6	Slope Indicator (150 kPa)	3.4

2.4 SUBSURFACE STRATIGRAPHY AND GROUNDWATER CONDITIONS

Understanding soil conditions is a critical part of the implementation of the test and interpretation of results. The site soils were characterized using the Unified Soil Classification System (USCS). Our exploration of the site included drilling nine soil borings with a conventional auger drilling rig (equipped with 8 inch diameter hollow stem augers) advancing 3 cone penetration tests (CPT) with frequent pore pressure dissipation readings, and hand auger borings at each instrument location. Test borings and instrument hole logs are summarized in Appendix 3A with associated laboratory testing presented in Appendix 3B. CPT logs and pore water pressure dissipation tests can be found in Appendix 3C. We reviewed available regional and local soil information in the Reclamation District 1601 Twitchell Island Five Year Plan (KSN, 2010) and the Sevenmile Slough Sites 1, 2, & 3 Levee Improvements report prepared by Neil O. Anderson and Associates (NOA, 2007). In Appendix 3D, we included relevant plans, logs and excerpts of these reports. During construction, trench walls were logged and are summarized in Section 2.5.2 and Appendix 3E.

Levee soils generally consisted of clayey and sandy silts and silty sands. In many locations, the silts were found to be thinly bedded with randomly oriented and variable bedding angles. These silts appeared to have retained much of the structure of a native deposit of fluvial soils, however the heterogeneity of the deposit and variable bedding angles would imply a method of construction that did not involve the proper blending and compaction, such as placement by a clamshell dredge. As such, voids were apparent in a number of locations, likely associated with construction techniques no longer meeting modern standards. Detailed photographs of soils and conditions encountered during trenching are provided in a subsequent discussion of trench construction in Section 2.5.2. Deposits on the waterside slope were found to be loose. A piece of old farming equipment was seen protruding from the waterside slope at Station 70 (Figure 2-27). The waterside oak tree was rooted within these loose deposits and had developed a lean of about 44 degrees from the horizontal prior to commencement of our work onsite.

At deeper elevations, about 4 to 6 feet within the levee, a layer of stiff to very stiff clayey plastic silt was encountered, which was relatively homogeneous and consistently present throughout most of the site. This deposit was named Material 4 during trench logging and it may be the Columbia clay silty clay deposit mapped by the USDA (1935) and shown on Figure 2-9. This soil is encountered in foundation soils and forms the shape of a small levee within the existing levee, as shown on the detailed stratigraphic sections at A, B, and C, provided as Figure 2-28, Figure 2-29, and Figure 2-30, respectively. According to the Twitchell Island 5-year plan:

> *"The peat accumulations eventually formed peat islands, with river channels and sloughs established around them and within some of the larger islands. During floods, rivers would overtop the banks of the peat islands, and as the water receded, would*

leave deposits of sand and silt that formed natural levees along the edges of the islands. Many of the levees currently in the Delta are founded on these natural levees, including most of the levees on Twitchell Island". *(KSN, 2010)*

Based on field observations of Material 4, the material is certainly older than overlying fills and may indeed be a natural deposit. This irregular layer is consistently present throughout the trench up to Station 37 at which point the layer dips below the bottom of the trench. The layer reappears at Station 42 and angles sharply up (shown on trench logs presented in Section 2.5.2). The discontinuity in the Material 4 layer was filled with a loose mix of alluvial soils suggesting the discontinuity may be related to past excavation activity (e.g. - pipeline installation) or it may be the result of past scour during a flood or a small break in the old levee.

Foundation soils encountered generally consisted of silts of low and high plasticity with some zones of lean clay overlying sands at depths of 20 to 30 feet below the crown of the levee. Sands ranged from relatively clean and poorly sorted (USCS classification SP) to silty sands (USCS classification SM).

The water table was encountered during exploration at a depth of approximately 24 feet below the crown of the levee at an approximate elevation of -16 feet. Pore water pressure dissipation tests performed during cone penetration testing provided an initial estimate of the groundwater table onsite (Appendix 3C). The water table was encountered during installation of piezometer PB3 and was consistent with the pore water pressure dissipation data. The elevation of water in the slough was found at an approximate elevation of 1 ft during testing (Figure 2-28 through Figure 2-30). It was determined that the low permeability plastic silt (Material 4) or the sediment within the base of the slough may be consistently present and functioning as a limiting layer allowing for a perched water condition above. This condition was considered beneficial for the purpose of achieving saturation within the root zone of the landside oak tree.

Surface soils extending into the water are loose silts, not strong enough to support the weight of a human without sinking. Away from shore, the depth to sediment within the slough adjacent to the site is generally on the order of 2 to 3 feet (measured from the water surface, given typical water levels encountered during the flow test). The depth to the base of the slough is about 25 feet at the center of flow, about 9 feet at the entrance to the oxbow section, and shallowing quickly with distance into the oxbow. As shown on Figure 2-8, prior to installation of the flow control gates within the slough, the oxbow section was still part of the primary flow channel. The section is shown as wetland by the time the flow control gate is installed (shown in 1952 topographic map), implying that the shallow sediment currently present had arrived either via filling or via a flood in that timeframe.

Figure 2-27. The wheel of what appears to be horse-drawn farming equipment protruding from the waterside of the levee (Sta TT 70). The axle and possibly the other wheel extend into the levee slope.

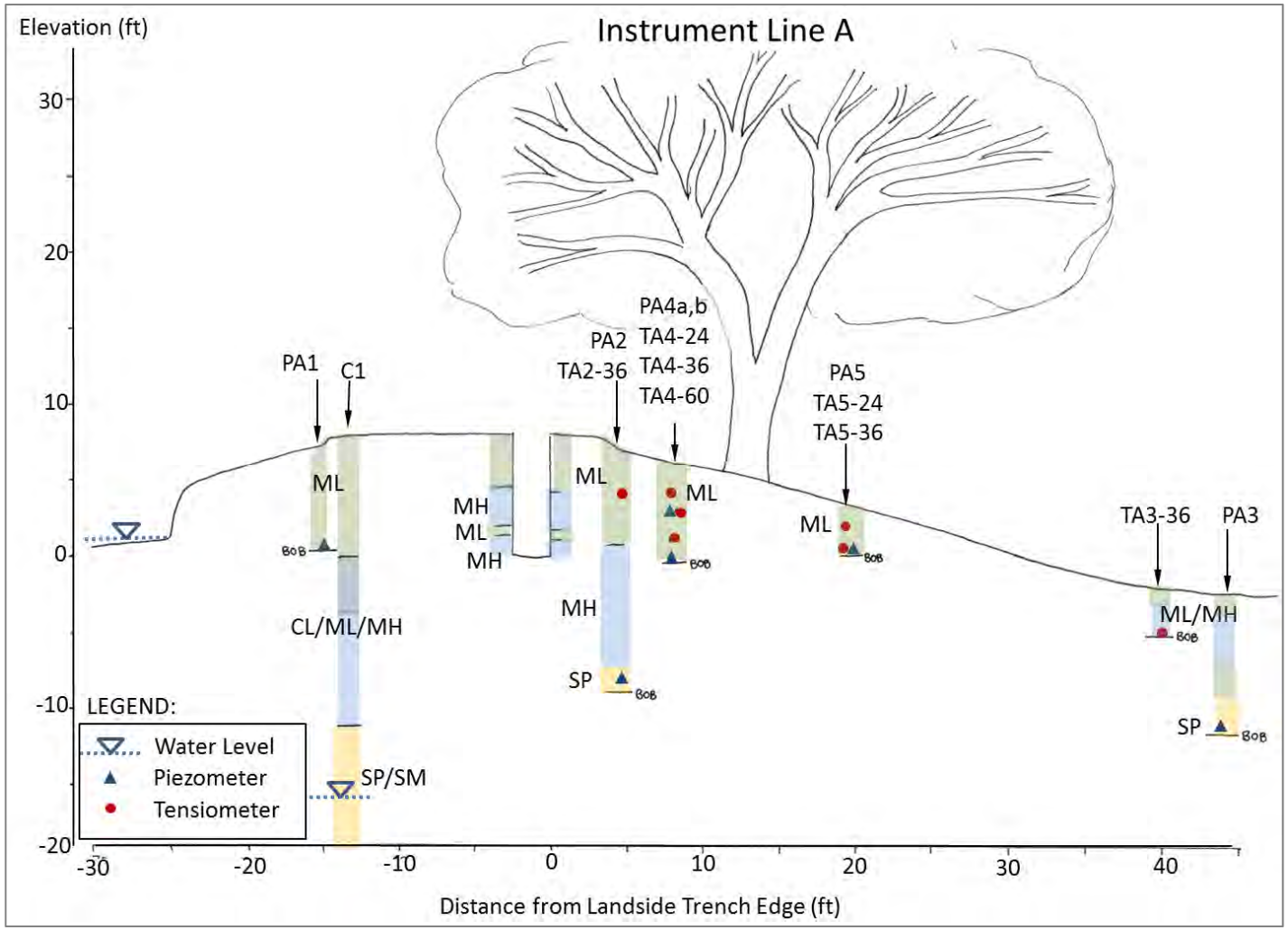


Figure 2-28. Levee section view of Instrument Line A (landside oak) showing instrument locations and generalized soil stratigraphy. Soil classifications based on ASTM D2487. ML and MH are low and high plasticity silts, respectively; SP is poorly sorted sand; CL is low plasticity clay; SM is silty sand. Cone penetration test C1 and instrument hole logs shown.

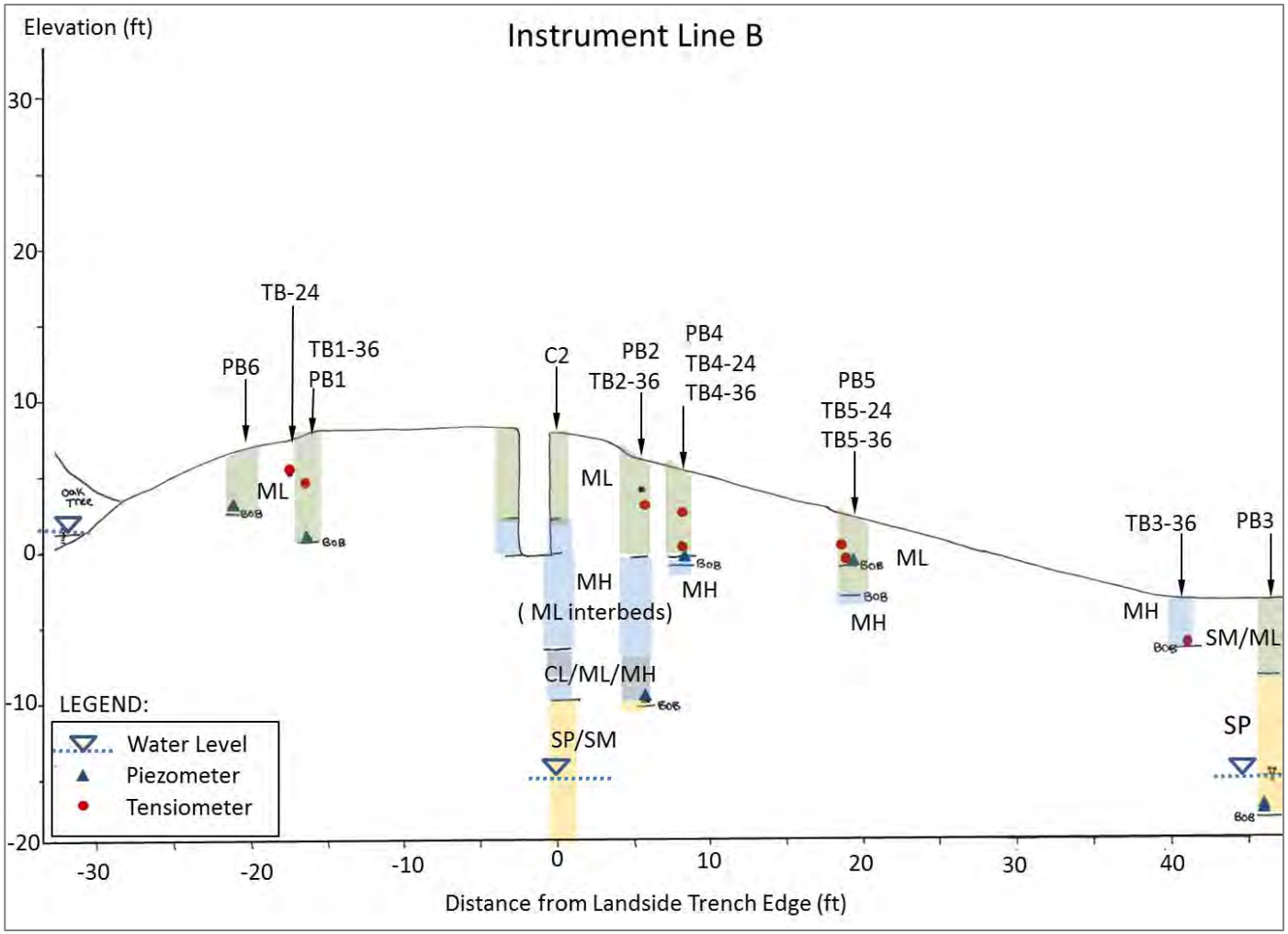


Figure 2-29. Levee section view of Instrument Line B (waterside oak) showing instrument locations and generalized soil stratigraphy. Soil classifications based on ASTM D2487. ML and MH are low and high plasticity silts, respectively; SP is poorly sorted sand; CL is low plasticity clay; SM is silty sand. Cone penetration test C2 and instrument hole logs shown.

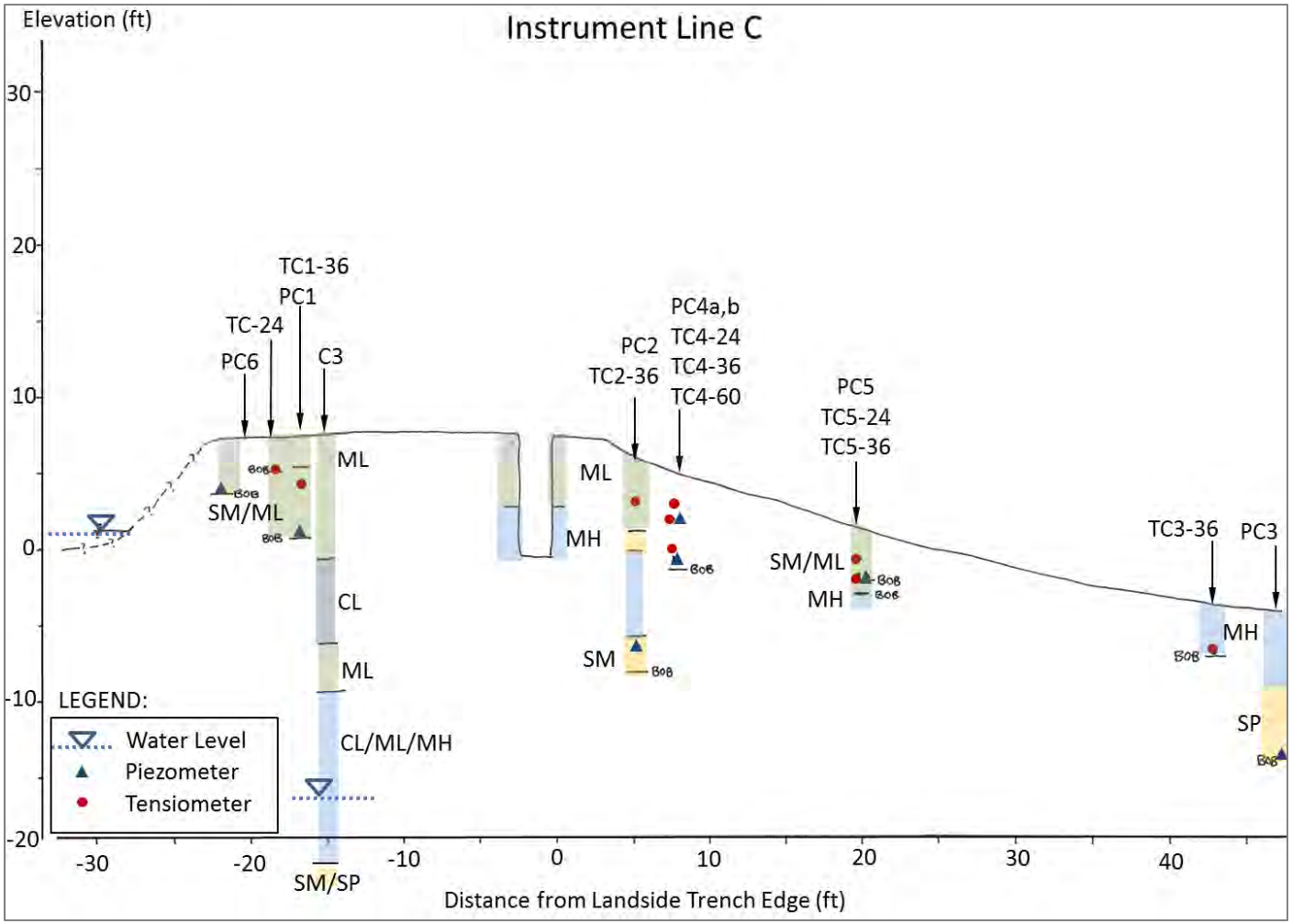


Figure 2-30. Levee section view of Instrument Line C (control) showing instrument locations and generalized soil stratigraphy. Soil classifications based on ASTM D2487. ML and MH are low and high plasticity silts, respectively; SP is poorly sorted sand; CL is low plasticity clay; SM is silty sand. Cone penetration test C3 and instrument hole logs shown.

2.5 FLOW TEST EXPERIMENT CONSTRUCTION

Construction for the proposed flow test began with excavation and logging of the trenches, followed by backfilling each trench with clean crushed rock for stability during the flow test. The water delivery system was then assembled and tested for functionality and piezometers and tensiometers were installed. Observations were made throughout construction and during instrument installation and consisted primarily of logging the test borings and developing cross sections detailing the stratigraphic conditions. These observations made during trenching provide a uniquely continuous picture of the heterogeneity of levee soils that cannot be made from explorations at discrete points (e.g.- soil borings or cone penetration tests).

2.5.1 Method of Trench Construction

Determining an appropriate method of trench construction was a challenge and critical to the successful execution of the experiment. The objective was to avoid disturbing roots and facilitate accurate mapping to better understand the nature of the root systems under study. Disturbances to the root system during excavation with heavy equipment could create void space between the root and surrounding soil. This type of disturbance could affect the natural relationship between the soil and the root, potentially affecting flow patterns and flow test results.

At our first flow test site near Cal Expo on the American River in Sacramento, where live and decomposing roots were encountered, an air knife operating with a compressor capable of compressing 375 cubic feet of air per minute (CFM) was used to excavate around live roots. In this manner, live roots were revealed, logged, and then cut prior to the flow test. It was elected that this method would used at this site where possible and safe, given the trench depth of 8 feet.

Prior to trench construction, the trenches were stationed with Control Trench stationing (CT) or Tree Trench stationing (TT). The control trench was stationed from CT 0 to CT 31.5. The five-foot separation zone between the tree and control trenches was stationed as CT 31.5 to CT 36.5 where CT 36.5 is equal to TT 0 at the northern end of the tree trench as shown on Figure 2-31.

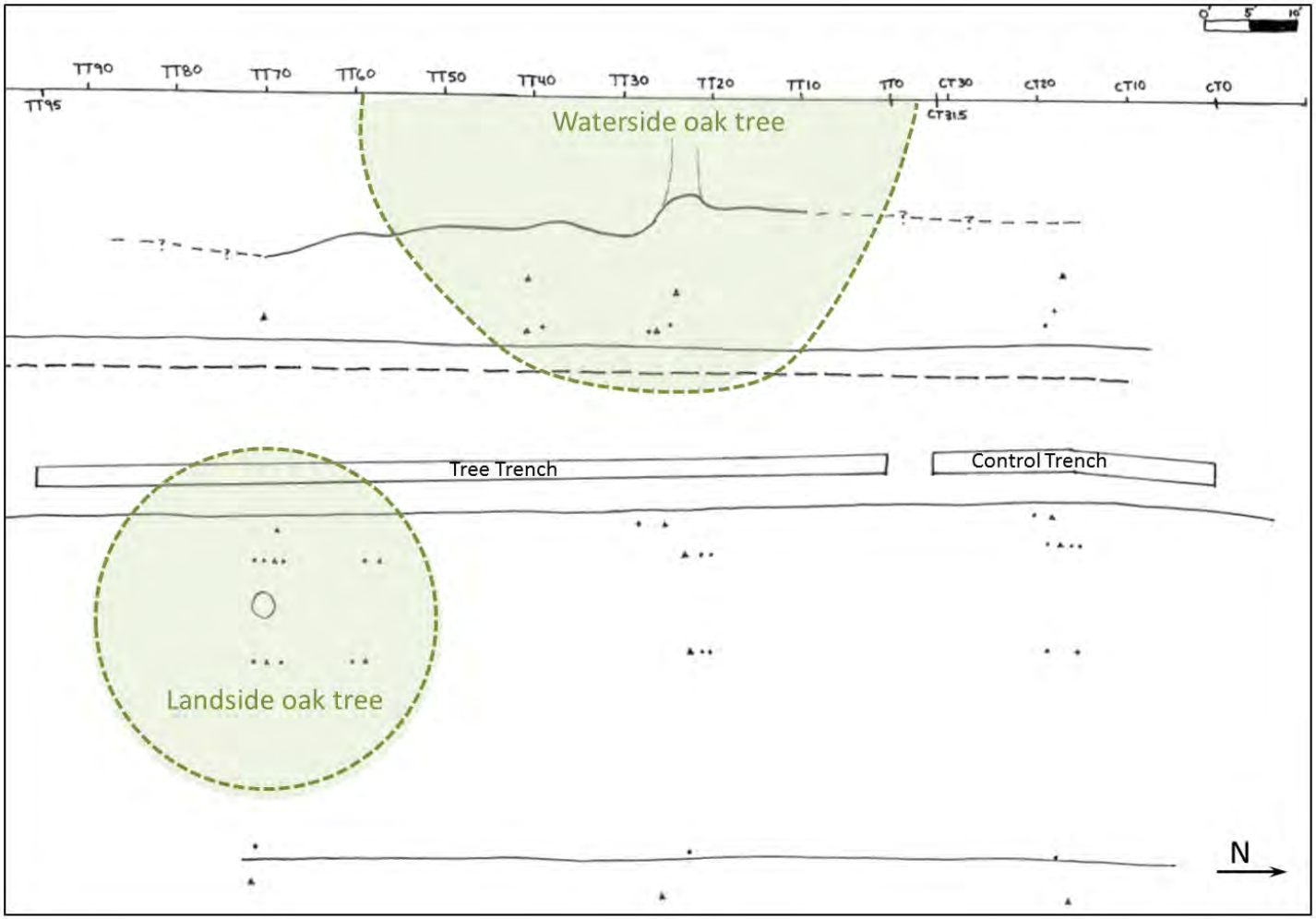


Figure 2-31. Field site plan showing stationing associated with control trench logging (CT) and tree trench logging (TT). Approximate instrument locations are shown as triangles (piezometers) and circles (tensiometers) for reference.

2.5.1.1 Control Trench

The control trench was excavated and backfilled prior to the tree trench to develop a suitable excavation technique prior to entering into a zone with abundant roots. Excavation began by excavating a segment from the northernmost end of the control trench (Station CT 0 to 5) with an excavator. Once the initial segment of the control trench was excavated and no significant roots were found, slow excavation continued to a depth of 4 feet proceeded using the excavator for the length of the trench (Figure 2-32). The land side and water side walls of the upper 4 feet of the control trench were carefully cleaned and logged (logs provided in Appendix 3E).

Figure 2-32. A) The control trench excavated to 4 foot depth; B) Walls are logged; C) Walls are sampled ahead between 4 and 8 feet; D) Excavation of small segments proceeds to 8 feet.

The walls were then shored, cleaned, and logged in 5-foot increments to a depth of 8 feet, using the excavator. Only small, isolated roots near the base of the excavation were encountered (Figure 2-33A,C, and D). Each 5 foot segment was mapped first in plan view for roots (when applicable), and then the side walls were mapped for soil conditions.

The last 5-foot increment of the control trench (station CT 25 to 31) encountered a cluster of large roots requiring a switch from excavation with the excavator to manual excavation (Figure 2-33B). Upon close inspection, some of the roots had

been broken in excavation and the area was carefully evaluated for damage to the walls from the root breakage. The location where the root entered the trench was revealed and found to be undamaged. The remainder of the segment was shored and hand excavated to reveal the root cluster (Figure 2-33B).

Figure 2-33. A) The control trench is shored for logging; B) Station 26 to 31.5 is shored for manual excavation and logging of first large roots; C) and D) Smaller roots are logged and trimmed from above prior to proceeding with excavation.

Once completed, the entire trench was backfilled to a depth of 4 feet with ¾ inch clean crushed rock. The manifold of perforated pipes (as described in Section 2.3) was installed at a depth of 4 feet to facilitate even water delivery throughout the trench (Figure 2-34). No compaction efforts were made other than light tamping and smoothing with the excavator bucket. From start to finish, the control trench was excavated and backfilled between April 12 and April 17 of 2012.

Figure 2-34. The control trench is partially filled with gravel, a manifold installed, and backfill with gravel is completed.

2.5.1.2 Tree Trench

Unlike the control trench, which was primarily cut with an excavator, an air knife was selected as the most appropriate tool for the excavation of the tree trench and was incorporated where possible, preserving the root systems of the waterside and landside oak trees for logging and avoiding disturbance to trench walls. A procedure for excavation was developed that evolved based on conditions encountered.

Beginning at north end of tree trench, an 'initial pit' was cut with an excavator prior to use of the air knife such that spoils could be aimed into the pit and then removed by excavator, revealing intact roots in adjacent segments. The 'initial pit' encountered some significant roots near the base and these roots were revealed through manual excavation. A root was broken during this excavation (Figure 2-35), the walls were carefully inspected for evidence of disturbance or void spaces, and none were not found (Figure 2-35C and D).

Figure 2-35. A) Root encountered during excavation of initial spoils pit at Station TT 0 to TT5; B) Trench is shored; C) and D) Roots damaged by excavation are carefully inspected at walls and found to be intact at connection to the wall.

Roots from the 'initial pit' were trimmed flush with the walls and spoils generated by air knife from the upper 4 feet of the adjacent 20 foot segment were directed into the pit (Figure 2-36). Spoils were periodically removed by excavator to make room for new spoils (Figure 2-37). The 4 foot deep segment was logged in plan view for roots. The roots were then cut flush and the walls cleaned to log soils on the landside and waterside walls.

The 20 foot segment (excavated to 4 feet deep) was deepened to 8 feet in 5 foot increments to minimize the length of open trench. Each segment was logged in plan view for roots, then shored, roots cut, and walls cleaned and logged for soil conditions and other observations (e.g. - burrowing activity). Once logged, each segment became the spoils pit for the next segment under excavation. It was possible for the air knife operator to stand on the ledge of the 4 foot trench and excavate to a depth of 8 feet by blowing the soils into the spoils pit as he backs up, removing the ground where he was previously standing (Figure 2-37A). Excavation permits required that no trench or segment deeper than 4 feet remain open overnight. Each evening all trench segments were temporarily backfilled with loose spoils for safety and to preserve moisture in the trench walls.

Excavation proceeded in a similar manner for the entire length of the tree trench. The tree trench excavation was completed over a three week period between April 17th and May 7th of 2012.

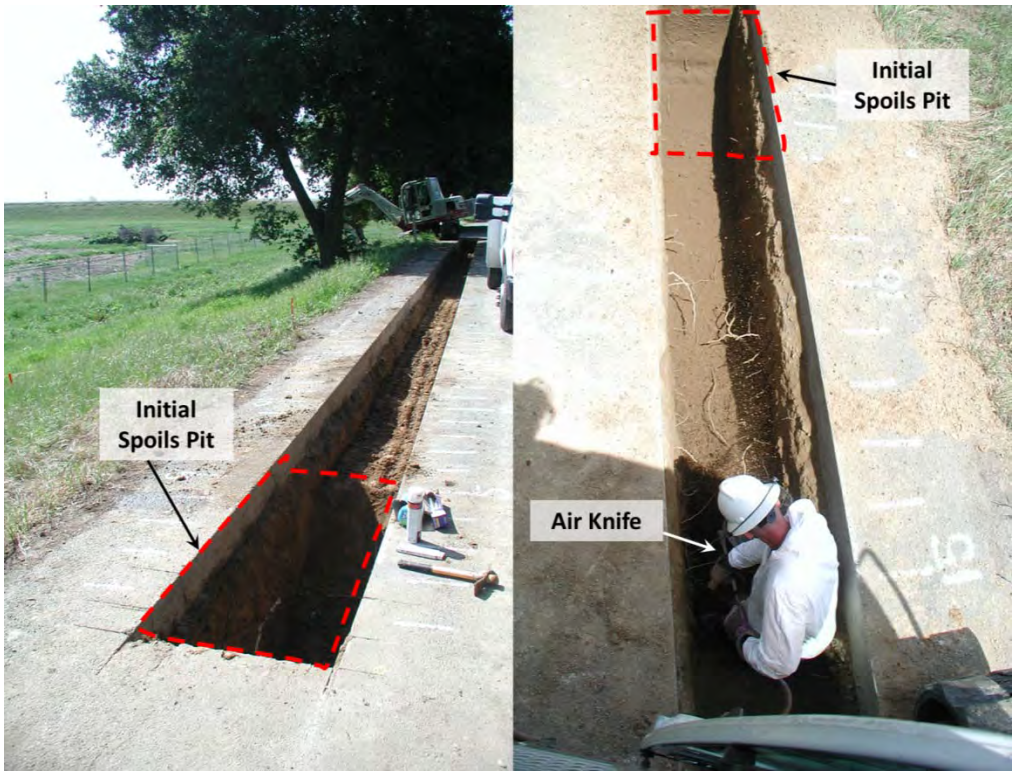


Figure 2-36. Initial spoils pit (left) and air knife operation revealing the upper 4 feet within Stations TT 5 to TT 15.

Rock backfill and manifold installation proceeded on May 8, 2012, beginning with excavation of temporary spoils placed within the trench, then placement of 4 feet of rock throughout the trench. A single perforated pipe was installed to the full trench depth (at the southern end) to view water levels and provide a way to pump water from the trench if necessary. The perforated manifold delivery system was installed and the trench backfilled with ¾ inch crushed rock as described in Section 2.3.

Figure 2-37. A) Air knife operator stands in 4 foot deep trench excavating to 8 feet; B) and C) New roots revealed as air knife spoils are blown in the previously logged segment; C) Spoils are used to stabilize previously excavated sections as new excavation proceeds.

Figure 2-38. A) Large root at Station TT 17; B) Logging; C) Burrow found during air knife excavation; D) Burrow patched prior to flow test.

2.5.2 Observations during Trench Excavation

Given that post-flow test excavation of the site (i.e. degrading of the entire levee) was not planned, the excavation of the control and tree trenches provided an important opportunity to evaluate the heterogeneity of site conditions. Root area ratios and typical root diameters with distance and depth along the trenches are presented in Appendix G.

2.5.2.1 Materials

Soils encountered during excavation were categorized into seven material types (Figure 2-39). In general, all of the material types found within the levee embankment were sandy and clayey silts. Materials 1 through 3 generally represented the shallower soils within the levee (Figure 2-40, Figure 2-41, Figure 2-42, and Figure 2-43), typically within the upper 4 feet, but extending deeper in some areas.

Material 4, a plastic silt, is an important soil as it is believed to have acted as a low permeability barrier to flow during the flow test (Figure 2-43 and Figure 2-44). Further, the consistency, density and apparent age of the material imply that the soil may have been a natural overbank deposit, as already indicated.

Material 5 was a lighter colored and lower plasticity silt layer that was found typically as a thin sublayer (less that about 6 inches to 1 foot thick) within the Material 4 soils near the base of the tree trench (Figure 2-46 and Figure 2-47).

Material 6 was a variant of Material 3 as trenching extended to the south. Materials 6 and 3 frequently occurred together in heterogeneous pockets of light brown and olive colored sandy silts.

Finally, Material 7 represented a variable but at times loose, unstable or unpredictable blend of Materials 2, 3 and 4 (Figure 2-45). This material was encountered at depth between Stations TT 37 to 42, but pockets were encountered between Stations TT 37 and TT 85 (for reference the landside oak was at Station TT 70 and the waterside oak was at Station 20).

Materials 2 and 7 were the most notable of the surficial silts as these deposits seem to have potential for sloughing, void space, and heterogeneity, while materials 4 and 5 tended to be more stable and consistent soils.

SOIL TYPES:

1. Clayey silt (ML), olive mottled with oxidation staining, moist, blocky structure with light cementation.
2. Clayey silt (ML), light brown, moist, thinly bedded, easily cleaves along bedding of variable orientation, gaps and cracks observed, prone to sloughing and instability, bed thickness 1-5mm (typ.) .
3. Sandy silt (ML) with pockets and lenses of silty sand (SM), light brown, moist.
4. Clayey silt (MH), dark olive brown with oxidation staining, moist.
5. Clayey silt (ML), reddish brown, moist
6. Sandy silt (ML), olive brown with oxidation staining, occasional silty sand pocket.
7. Sandy silt with clay (ML), pockets of olive with oxidation mixed with pockets of reddish brown with fine sand at cleavage planes in structure, material is highly unstable and consists of a mixture of soil types 2, 3, and 4.

Figure 2-39. Description of materials encountered during trenching. USCS classification and description of Materials 1 through 7 are provided.

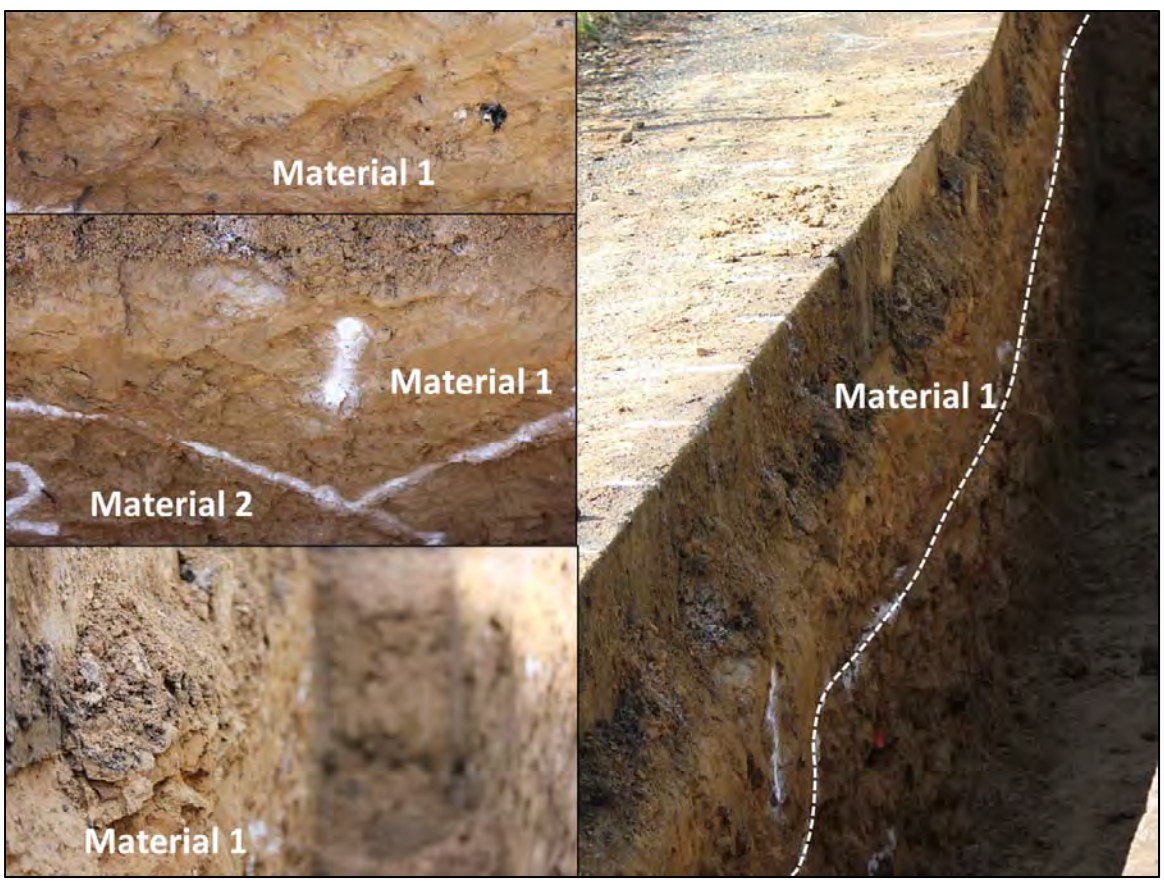


Figure 2-40. Photographs of Material 1, clayey silt found near the surface of the levee.

Figure 2-41. Photographs of Material 2, the thinly bedded silt. Notice variable bedding angles (upper left) and occasional voids within the material (lower photos).

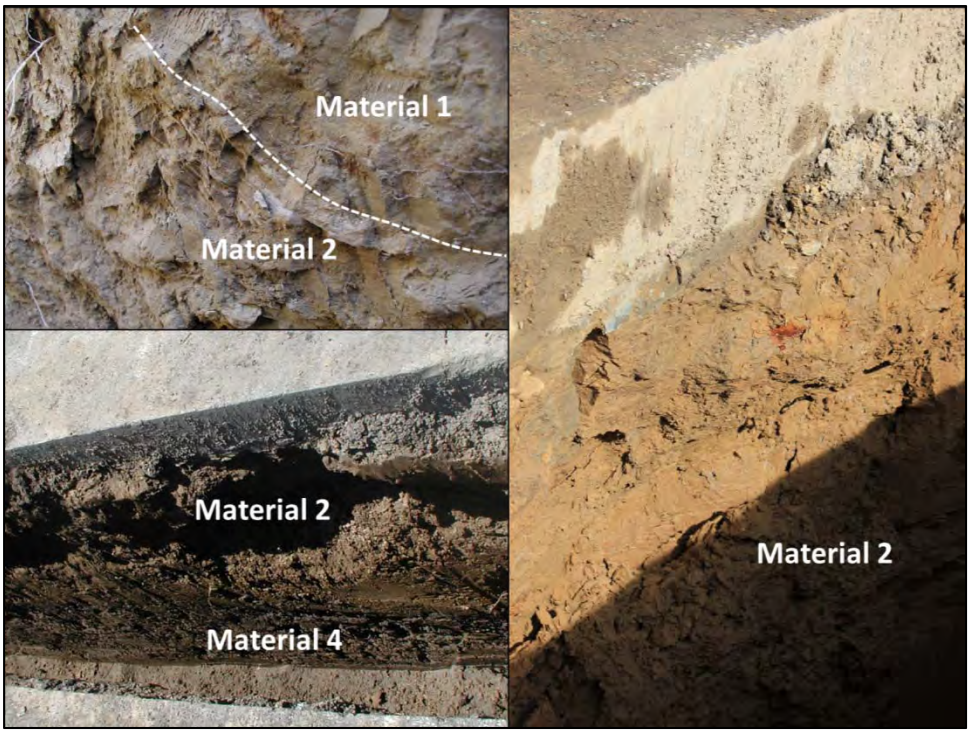


Figure 2-42. Materials 1 and 2. Material 2 was prone to sloughing (right and lower left).

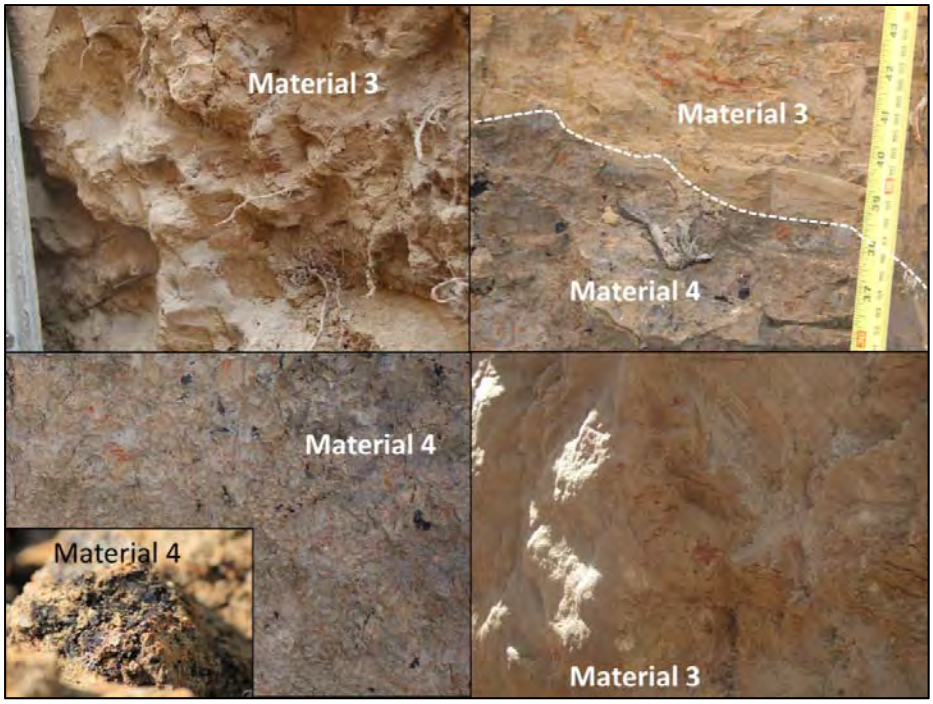


Figure 2-43. Material 3, a light brown sandy silt (USCS ML) with pockets of silty sand, is seen overlying Material 4, a plastic silt (USCS MH). Material 4 contains pockets of decomposed organic matter (lower left).

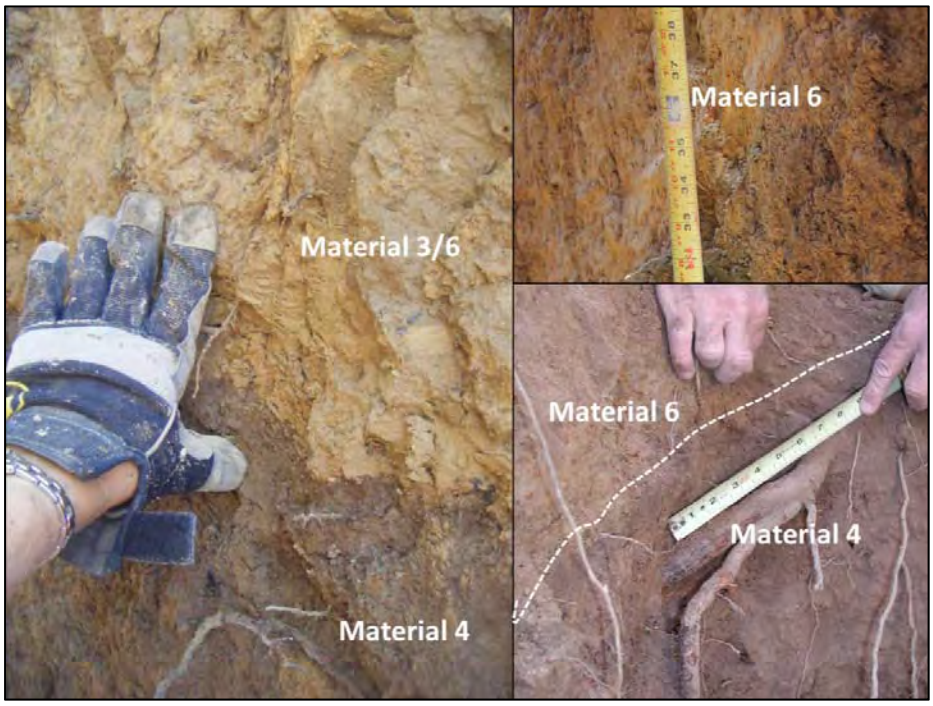


Figure 2-44. Pockets of Materials 3 and 6 (light brown and olive sandy silts, respectively) frequently occur together (left) and underlain by the plastic silt layer, Material 4.

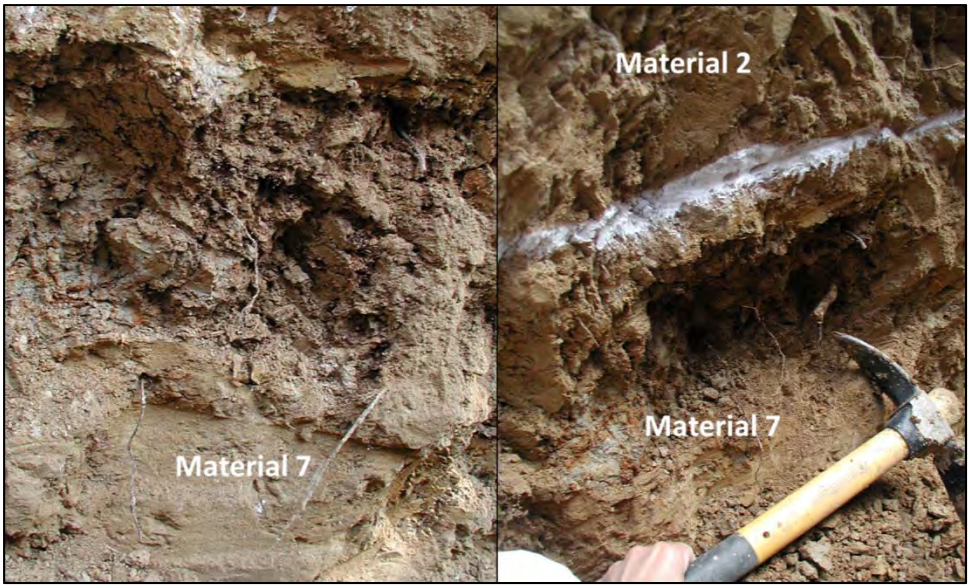


Figure 2-45. Material 7, encountered between Station TT 37 and TT 85, was highly unstable when encountered at depth and was comprised primarily of Materials 2, 3 and 4.

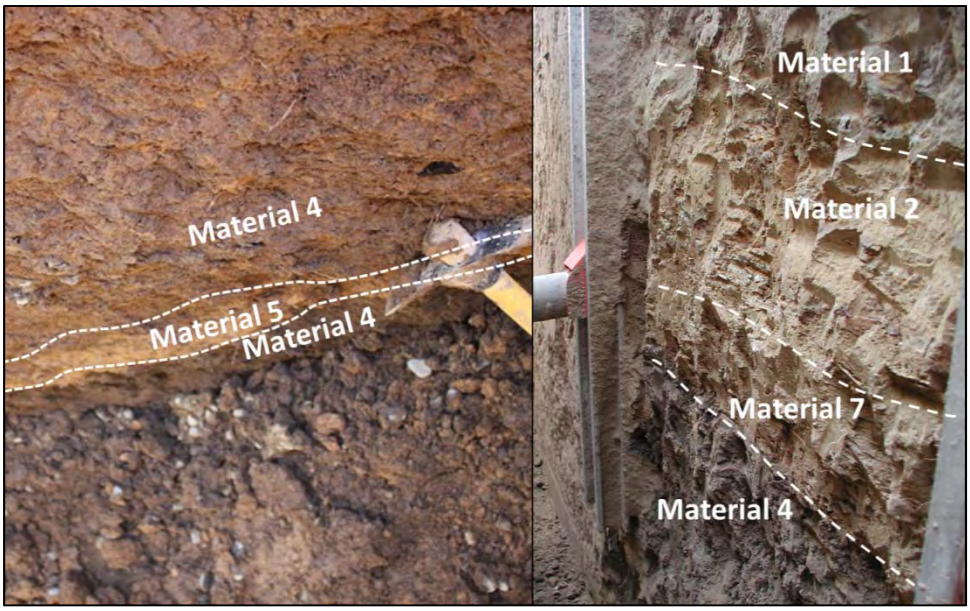


Figure 2-46. Near Station TT 70 to 75, Material 4 became slightly lighter in color (left). A thin lift of Material 5 (USCS ML) commonly occurs between zones of Material 4. Photo to the right shows typical layering with variable low plasticity silts (Materials 1, 2 and 7) overlying the plastic silt (Material 4) near the base of the 8 foot trench.

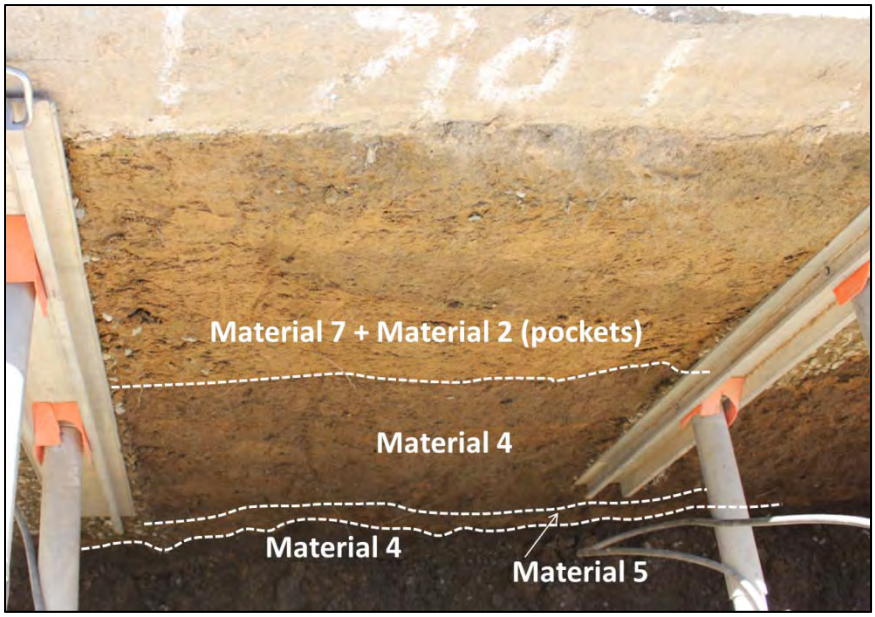


Figure 2-47. Typical layering with low plastic silts overlying plastic silt (Material 4) with a thin lense of Material 5 shown within the Material 4 layers.

Figure 2-48. Materials 1 and 3 (left) and Material 2 (right) exhibit manganese oxide staining on what appear to be fractures within the levee soils.

2.5.2.2 Control Trench

Root area ratios and typical root diameters with distance and depth along the control trench are presented in Appendix G. The control trench excavation began with continuous excavation and logging of the entire trench to a depth 4 feet below grade without shoring. Complete trench logs are provided in Appendix 3E. A 1 ½ inch diameter mammal burrow was discovered between Stations 11 and 12 at a depth of about 2 ¼ to 2 ½ foot below grade (Figure 2-49). Based on discussions with burrowing animal advisor to the CLVRP, Dr. Dirk Van Vuren of UC Davis the size and

depth were consistent with either pocket gopher or vole activity. Surficial evidence of both mammals was observed in the vicinity as previously discussed.

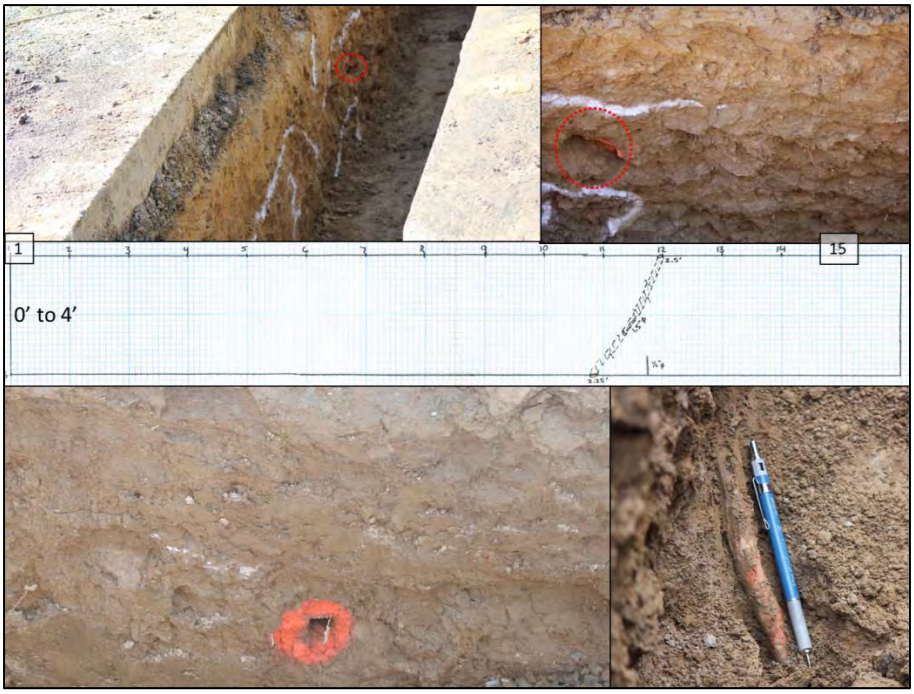


Figure 2-49. Root log Stations CT 1 to 15, depth 0 to 4 feet. Notable features of control trench 0 to 4 foot depth: A mammal burrow at Station CT 11 to CT 12 (diameter 1 ½ inch) and a single ½ inch diameter root at CT 12 (lower right).

Figure 2-50, Figure 2-51, and Figure 2-52 illustrate that Stations CT 0 to 27 of the control trench had few roots and one mammal burrow. As discussed previously, the thinly bedded silt (Material 2) was found to be sloughing on the waterside Stations CT 0 to 5 (Figure 2-42).

Figure 2-50. Root log Stations CT 1 to 15, 4 to 6 foot depth. Small woody root found (1/2" dia.)and cut when excavating to full depth of 8 feet within the control trench.

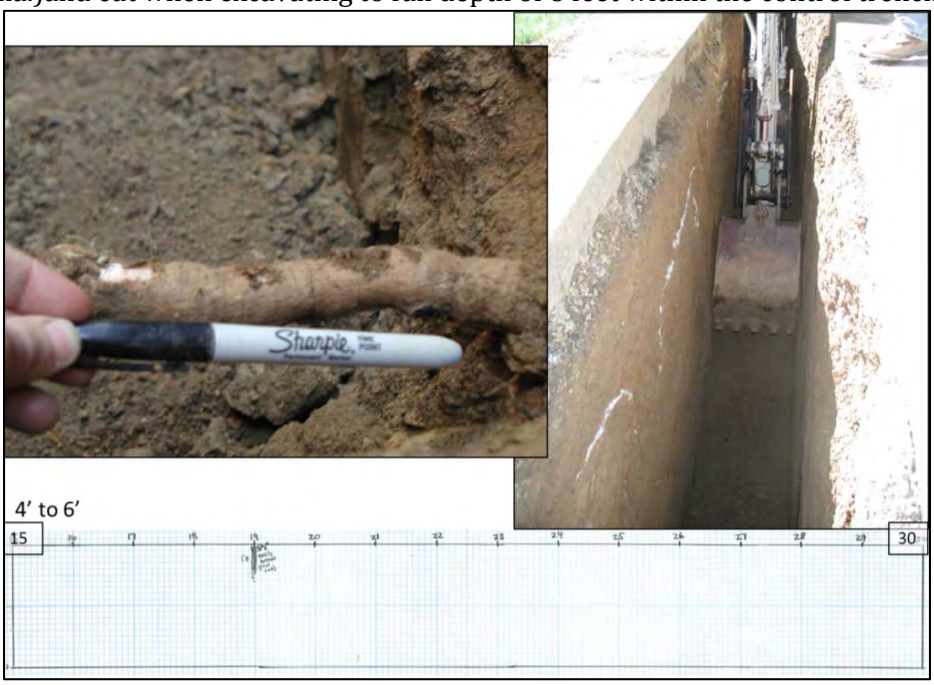


Figure 2-51. Root log Stations CT 15 to 30, 4 to 6 foot depth. A root (1" dia.) is encountered at Station CT 19. The inner core of the root is not woody in texture.

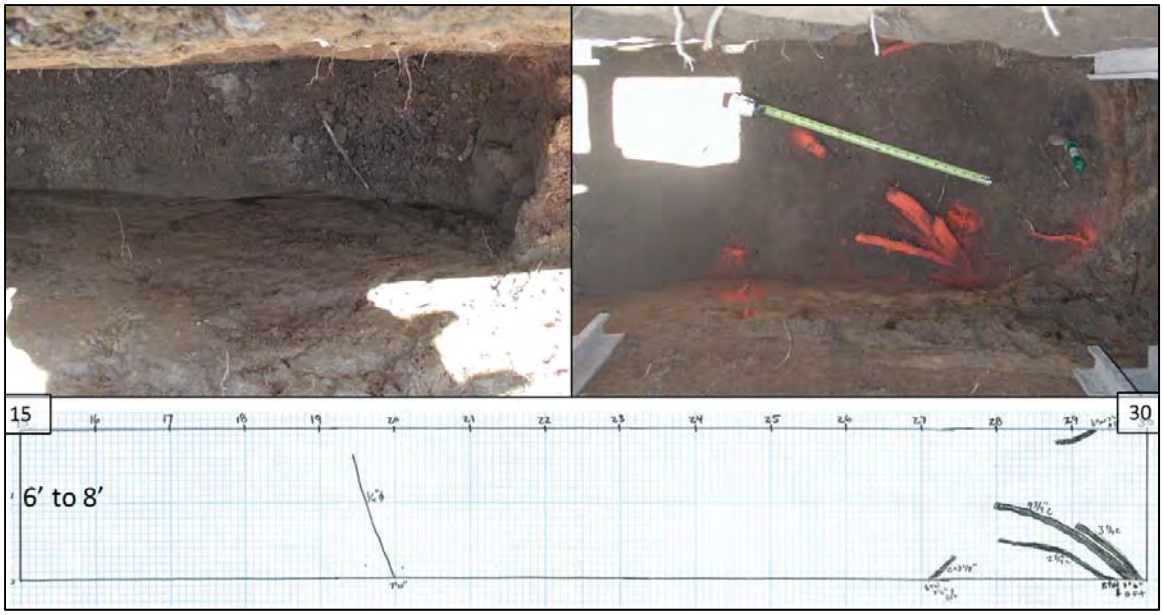


Figure 2-52. Root log Stations 15 to 30, 6 to 8 foot depth. Stations A cluster of roots ranging from about ¾ inch to 1 ½ inch diameter is encountered at Stations CT 27 to CT 30.

Trench logs for the land and water side walls of the control trench are provided in Figure 2-53. The figure is based on material types outlined in Section 2.5.2.1.

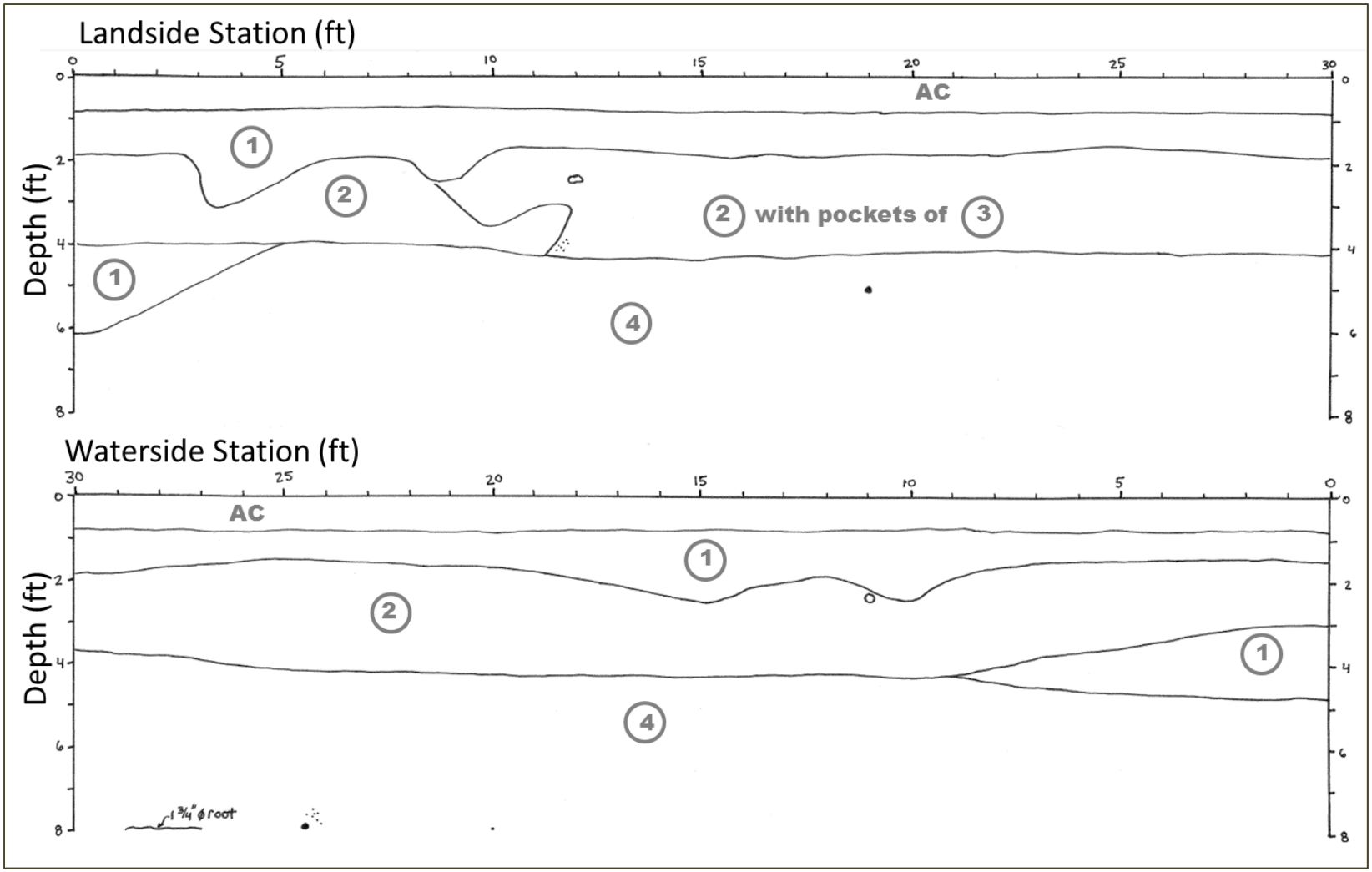


Figure 2-53. Landside and waterside control trench log for Stations CT 0 to 30. Hollow circles are mammal burrows, while solid dots represent roots.

2.5.2.3 Tree Trench: 0 to 4 Foot Depth

Root area ratios and typical root diameters with distance and depth along the tree trench are presented in Appendix G. The maximum root diameter found within the upper 4 feet of the tree trench was 1¼ inch. In general, roots smaller than about ½ inch in diameter were not logged. Root and mammal burrow locations are shown on plan view logs (figures and discussion below) and provided as complete field logs in Appendix 3E. Plan view field sketches were logged in three depth categories: 0 to 4 feet, 4 to 6 feet, and 6 to 8 feet. Stations TT 6 through TT 17 encountered abundant roots ranging from about ¼ inch to about 1 ¼ inch in diameter throughout the full depth profile (Figure 2-54 and Figure 2-55). The directionality of the roots was noted where branching indicated a waterside or landside origin. Roots of waterside origin were taken to be those of the waterside oak tree, as no other large tree was nearby. Between Stations 33 and 49 (Figure 2-56 and Figure 2-57), two roots on the order of ½ inch diameter were logged. Again, the origin of the roots was unclear but deeper roots in the vicinity originated from the waterside. At Stations TT 62 to TT 86 (the vicinity of the landside tree), abundant roots smaller than 1 inch in diameter were encountered (Figure 2-59 and Figure 2-60). Branching of these roots indicated a landside origin. Roots were not found at stations TT 0 to 6 (Figure 2-54), TT 19 to 33 (Figure 2-55 and Figure 2-56), TT 49 to 62 (Figure 2-57 and Figure 2-58), and TT 86 to 95 (Figure 2-60). No burrows were found in the upper 4 feet of the tree trench during logging.

Roots encountered were cut after logging. Some live roots wept upon cutting. No void space for flow around the root was observed, but the weeping occurred from the inside of the root (Figure 2-61). The logs below are oriented in plan view with landside always facing up and station numbers increasing to the right (or to the south). The orientation of the accompanying photographs varies.

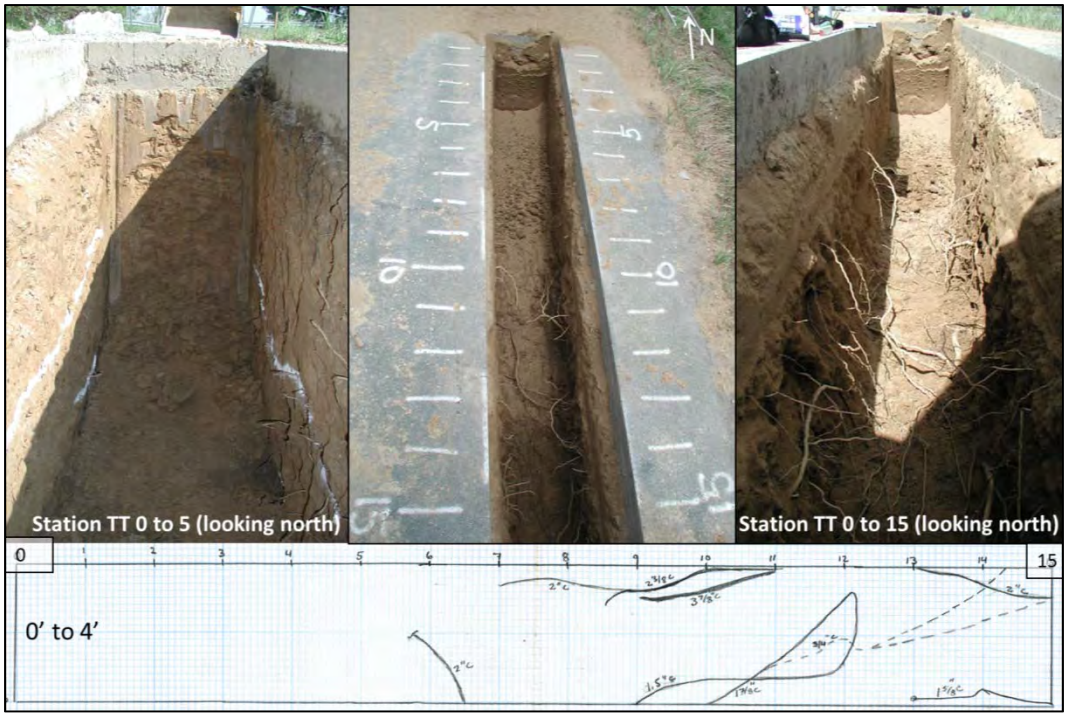


Figure 2-54. Root log at 0 to 4 foot depth. Station TT 0 to 15.

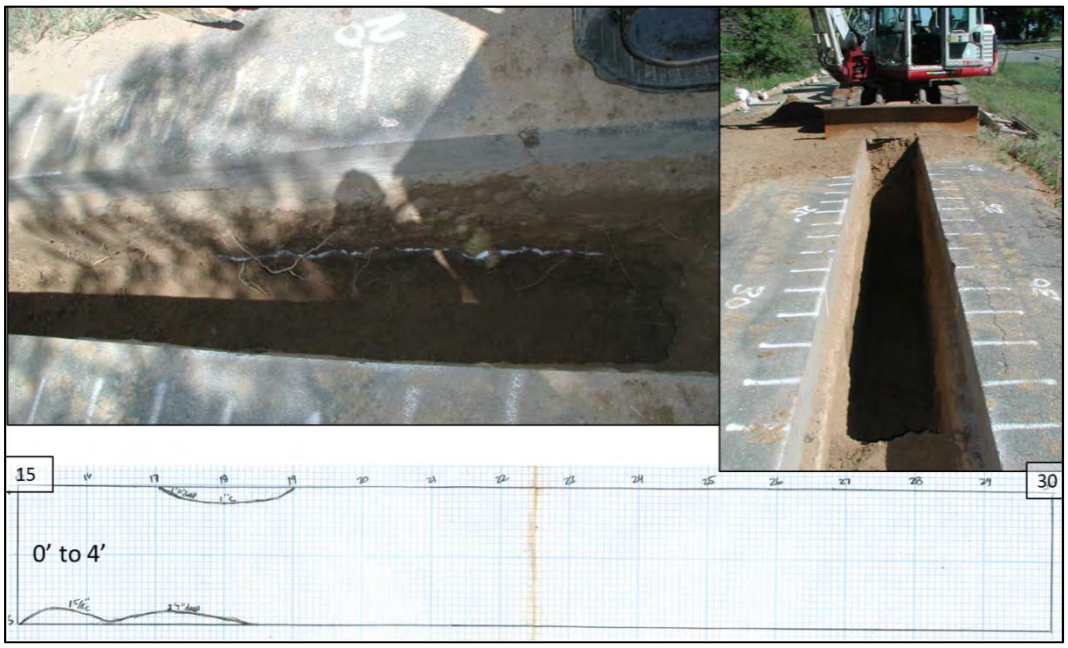


Figure 2-55. Root log at 0 to 4 foot depth. Station TT 15 to 30.

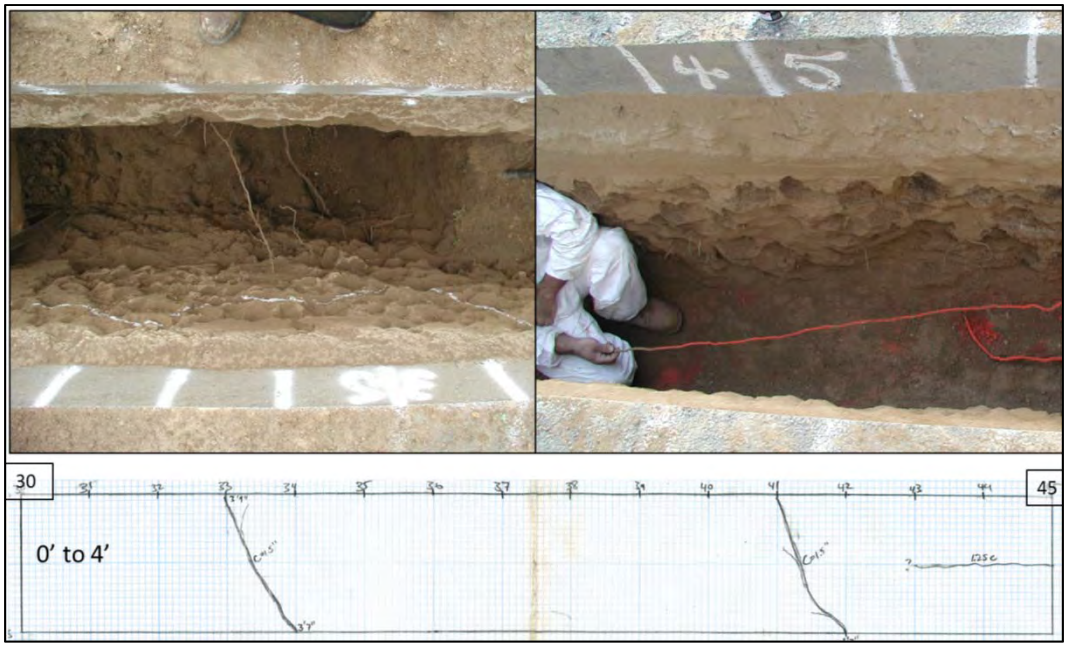


Figure 2-56. Root log at 0 to 4 foot depth. Station TT 30 to 45.

Figure 2-57. Root log at 0 to 4 foot depth. Station TT 45 to 60.

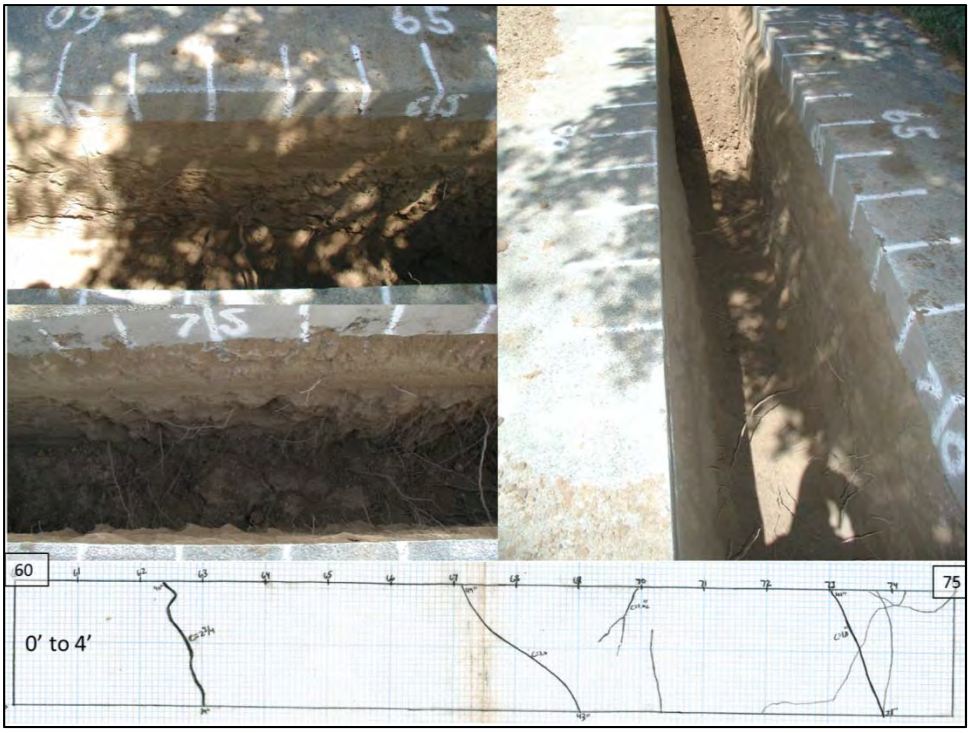


Figure 2-58. Root log at 0 to 4 foot depth. Station TT 60 to 75.

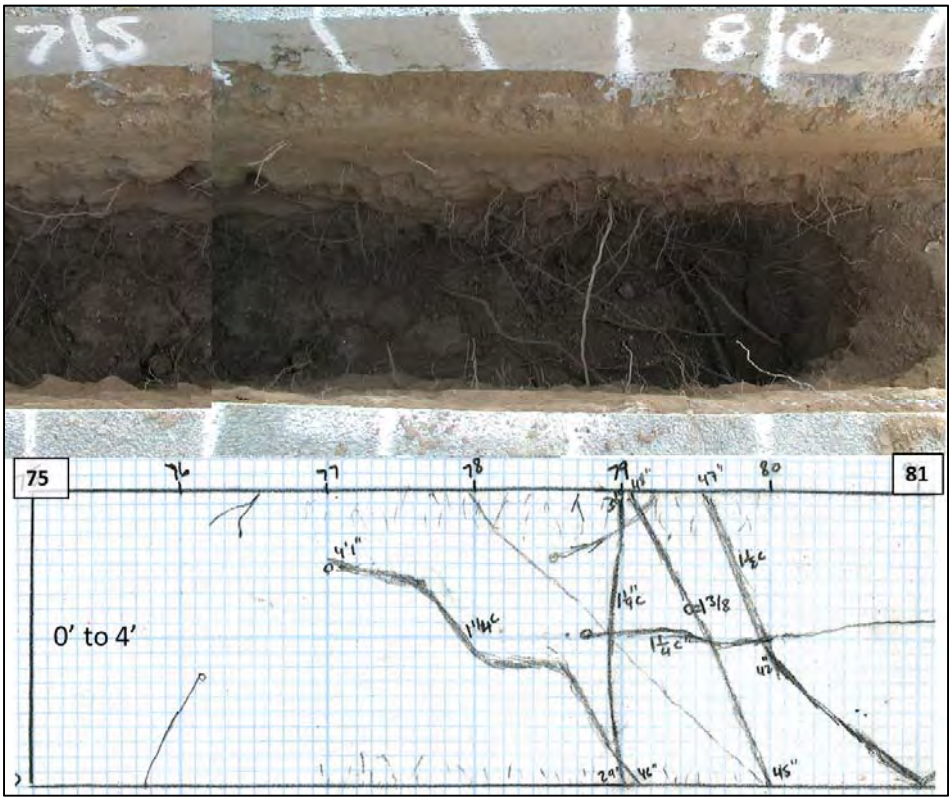


Figure 2-59. Root log at 0 to 4 foot depth. Station TT 75 to 81.

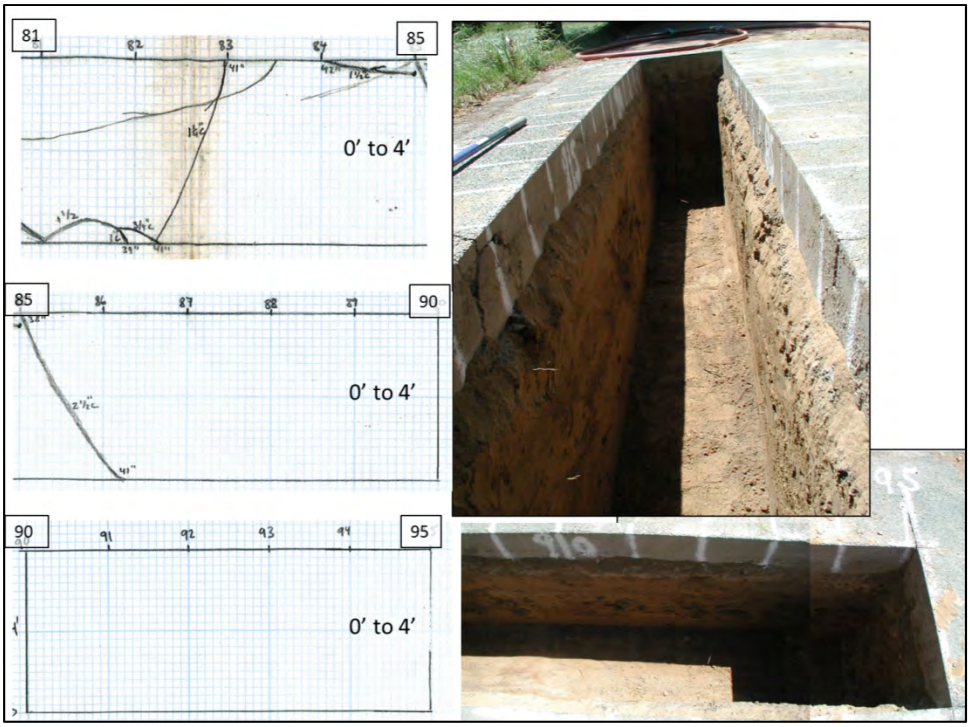


Figure 2-60. Root log at 0 to 4 foot depth. Station TT 81 to 95.

Figure 2-61. Some live roots wept from the inside of the root upon cutting. No void space around the root was observed.

2.5.2.4 Tree Trench: 4 to 8 Foot Depth

Root area ratios and typical root diameters with distance and depth along the tree trench are presented in Appendix G. In general, the root zone for the waterside oak tree (Station TT 20) extends from Station CT 27 to Station TT 50 (30 feet on either side of the trunk) with a few small (< ½ inch diameter) roots extending up to 7 feet beyond this zone. Root sizes measured in the upper 4 feet were smaller than 1 ½ inch in diameter. Roots of the waterside oak tree intersected by the trench became larger at depths of 6 to 8 feet below the levee crown, approximately the same elevation as the waterside oak tree. Detailed logs and photographs of roots associated with the waterside oak tree at depths greater than 4 feet are shown on Figure 2-62 through Figure 2-72.

The largest roots were found in the vicinity of Stations TT 17 and 18 (up to 3 ½ inches in diameter) (Figure 2-65 and Figure 2-66). Root sizes between Stations TT 18 and 45 were on the order of 1 to 2 inches with many smaller than 1 inch (Figure 2-67 through Figure 2-70). Between Stations TT 45 and 57, roots were on the order of ½ inch or smaller (Figure 2-71 and Figure 2-72).

Mammal burrowing activity was observed at Station 57 (Figure 2-73) and was extensive in the zone between Stations TT 64 and 81 (Figure 2-74 through Figure 2-81). Burrow diameters ranged from tiny holes on the order of ¼ to ½ inch, to moderately sized holes of 1 to 1 ½ inch, up to holes 2 to 3 ½ inches. Based on discussions with Dr. Van Vuren of UC Davis, the 1 to 1 ½ inch diameter holes were likely due to gopher or vole activity originating on the land side, but their depth of 6 to 8 feet was unusual. The larger burrow were likely muskrat originating on the water side. Dr. Van Vuren hypothesized the smaller rodents were taking advantage of pre-existing abandoned burrows created by the muskrat. This could explain the range in size of the mammal burrows as well as the unusual depth of the smaller rodent burrows.

The root system of the landside tree (centered at Station TT 70) was found to extend from Station TT 62 to TT 89 (Figure 2-76, Figure 2-78 through Figure 2-83). All roots emanating from the landside oak tree intersected by the tree trench were 1 inch in diameter or smaller. Unlike the waterside oak tree roots, the larger roots were found occurred between 3 and 8 feet deep with a range of sizes throughout the depth profile. Landside oak tree roots were generally not found at depths above 3 feet.

The last 5 feet of trench from Station TT 90 to 95 was devoid of roots (Figure 2-84). Trench wall logs for the tree trench show the material types (from Section 2.5.2.1) encountered on the waterside and landside walls of the tree trench. These logs are provided as Figure 2-85 through Figure 2-88. Of note is the sharp dip of the Material 4 layer at Stations 37 to 42 on the land and water side of the trench. This material is believed to be an older, possibly natural overbank deposit. The surface of Material 4 dips along with Material 5, implying that perhaps this was a low point, or a point

that settled to become a low point, in the overbank deposits. This depression is filled with the loose, highly variable Material 7, suggesting later infilling. The observations in this area are consistent with an old excavation or possibly a deep scour or breach location, backfilled with loose fills. Poor performance records were kept prior to the 1950s and a deep scour or breach could have occurred without having been recorded prior to this time.

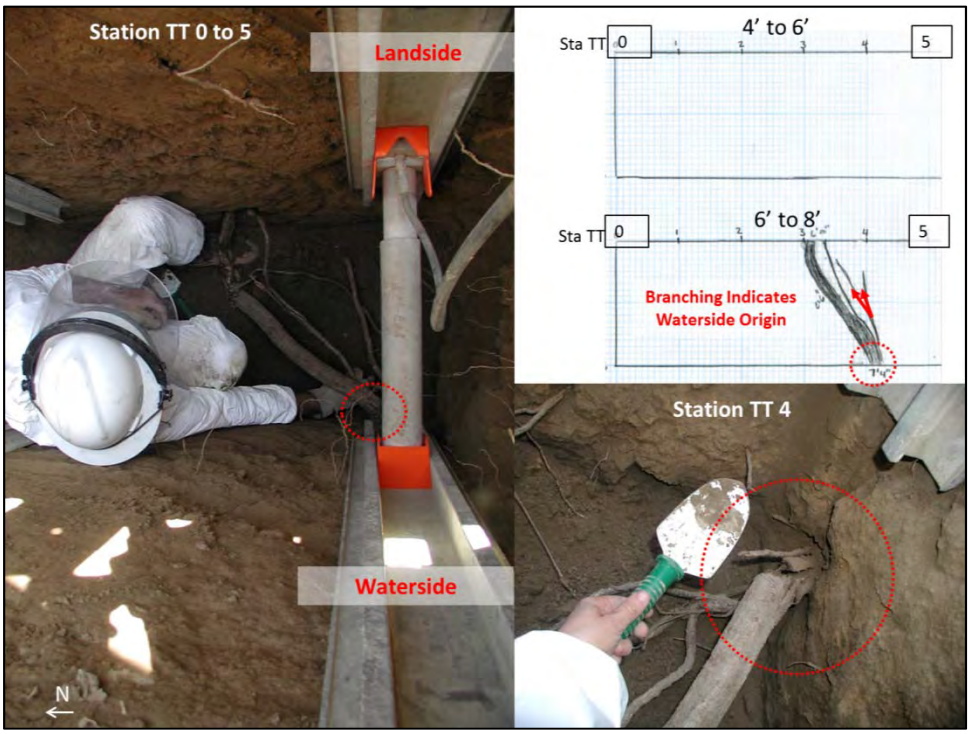


Figure 2-62. Root logs at 4 to 8 foot depth. Stations TT 0 to 5.

Figure 2-63. Roots at Station TT 5 to TT 10.

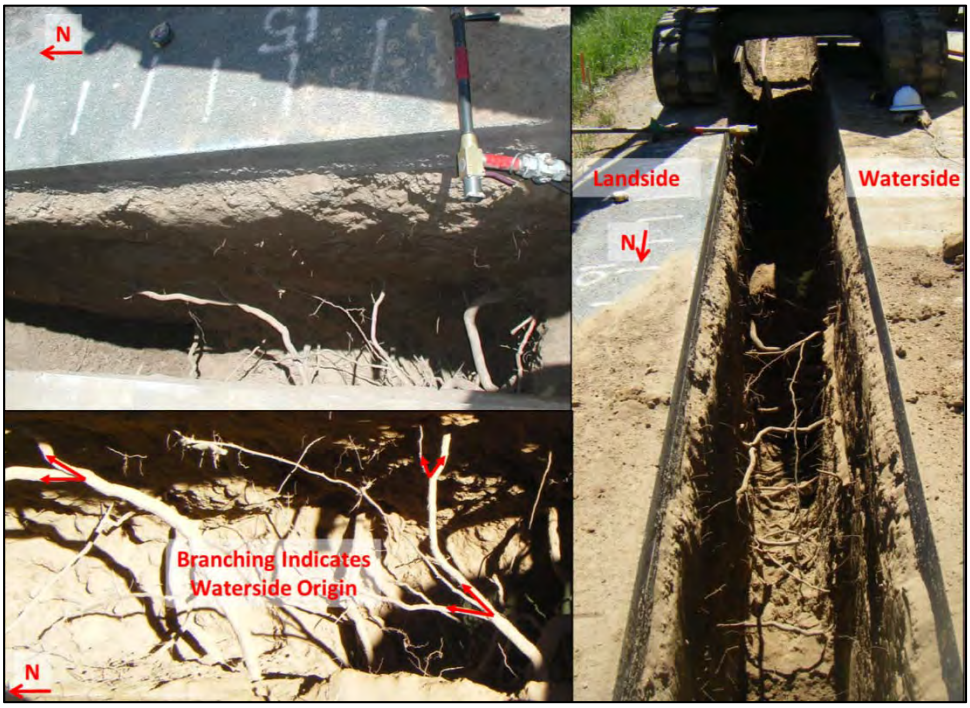


Figure 2-64. Roots at depths of 4 to 8 feet at Station TT 10 to 15.

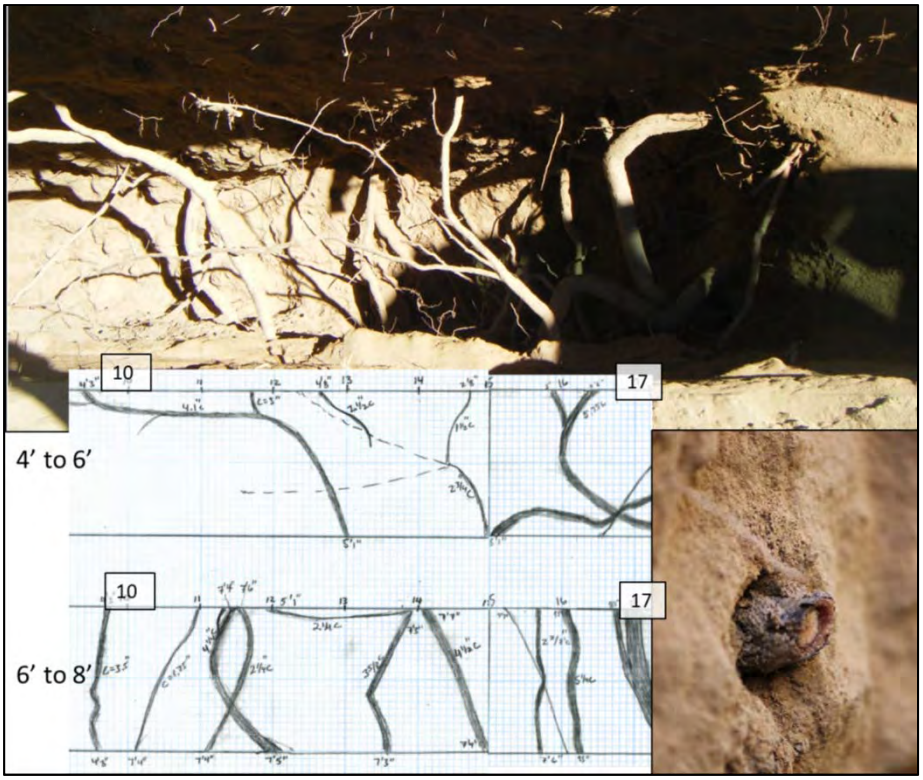


Figure 2-65. Root logs at 4 to 8 foot depth. Stations TT 10 to 17.

Figure 2-66. Station TT 15 to 20. Excavation extended below 8 feet to remove a 3.5 inch diameter root for constructability concerns (upper right, lower left). At a depth of approximately 7 to 8 feet, a void space was found in the soils at Station TT17 waterside (bottom center).

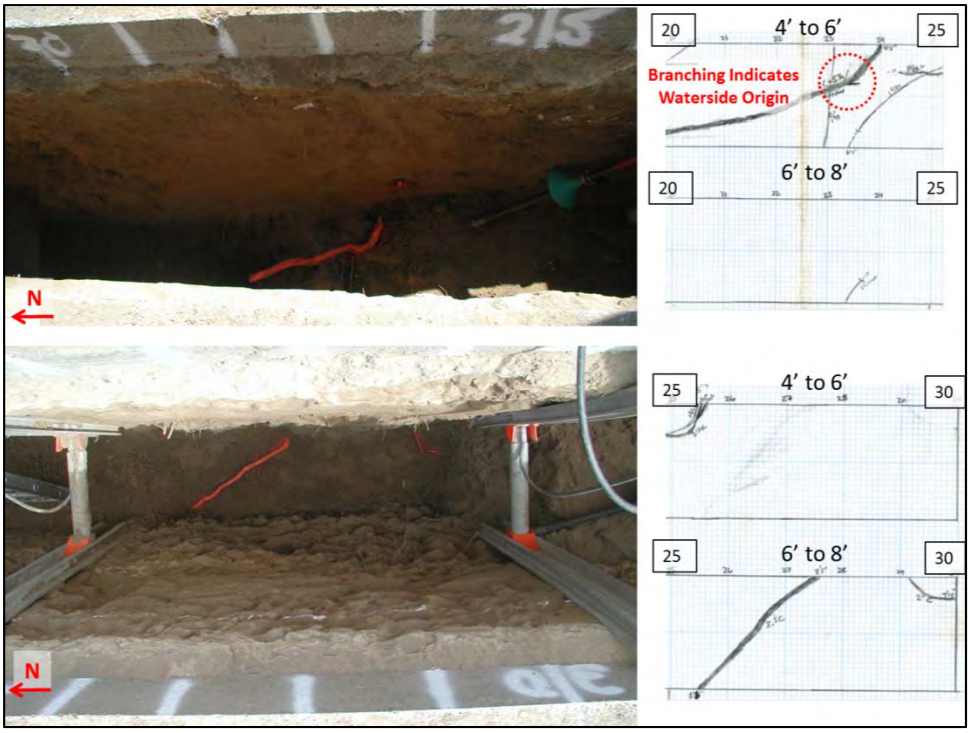


Figure 2-67. Root logs at 4 to 8 foot depth. Stations TT 20 to 30.

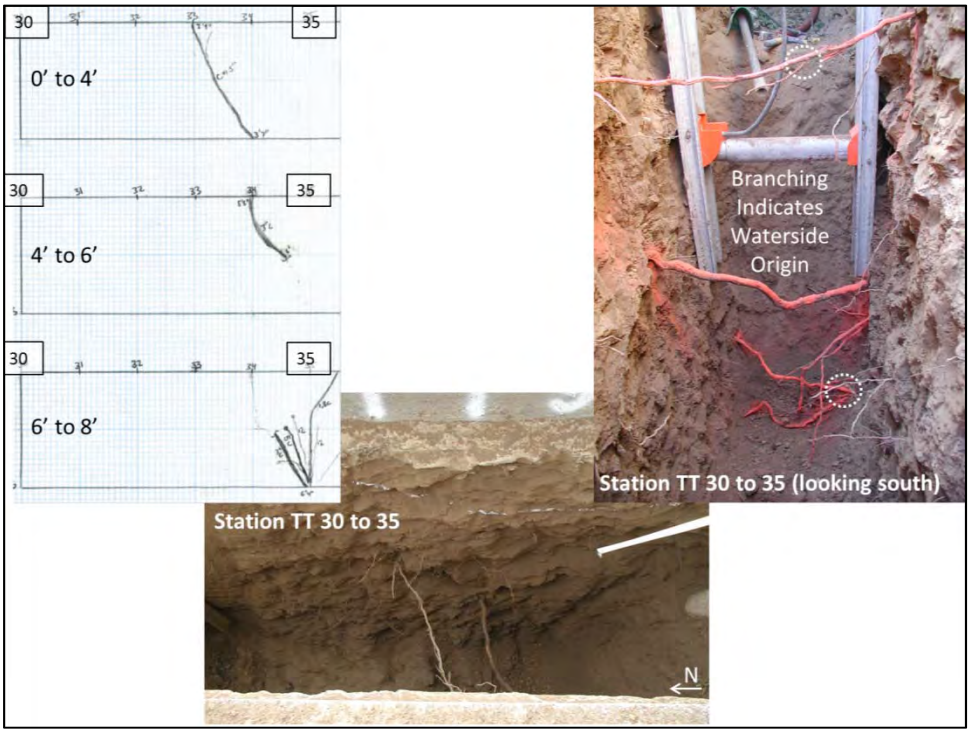


Figure 2-68. Root logs at 0 to 8 foot depth. Stations TT 30 to 35. Plan view log compared with view from above and inside trench. The difficulty of capturing three dimensional aspects of a root system in plan view logs is illustrated.

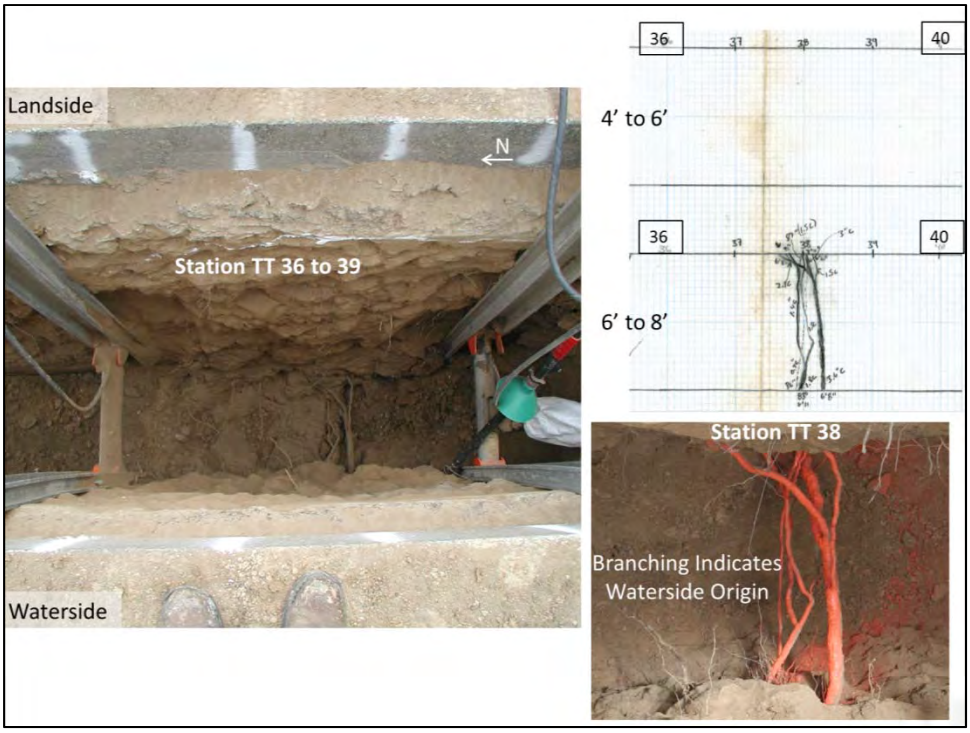


Figure 2-69. Root logs at 4 to 8 foot depth. Stations TT 35 to 40.

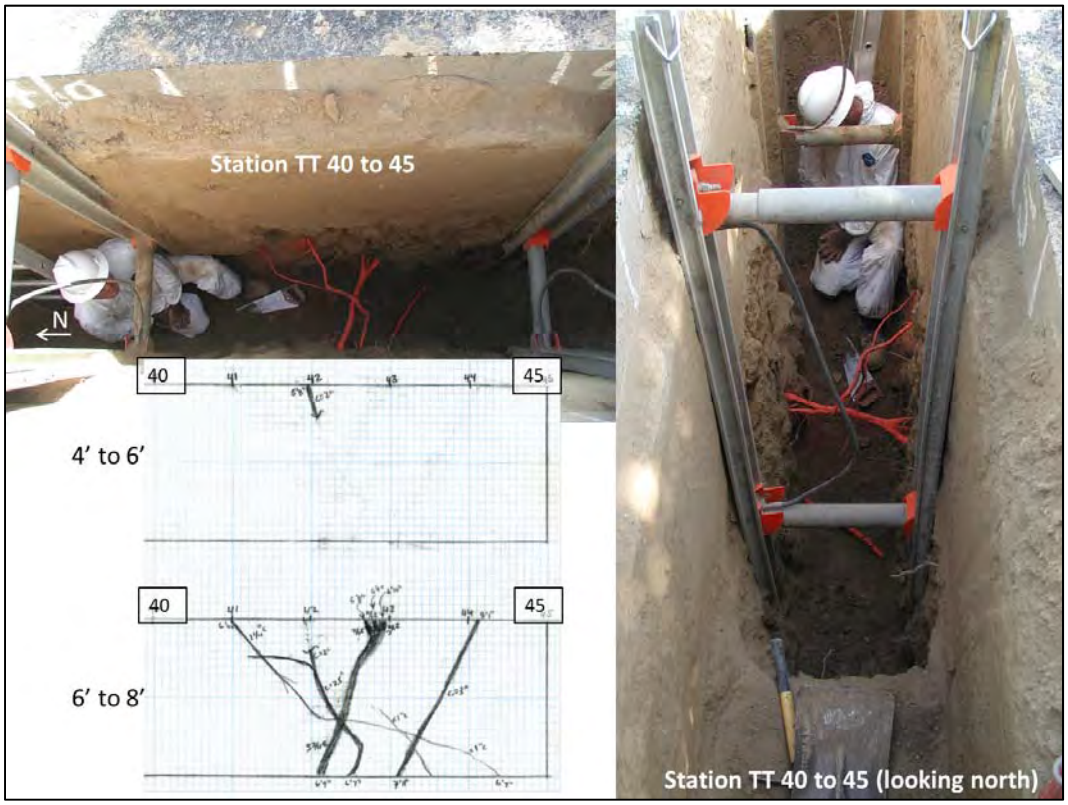


Figure 2-70. Root logs at 4 to 8 foot depth. Stations TT 40 to 45.

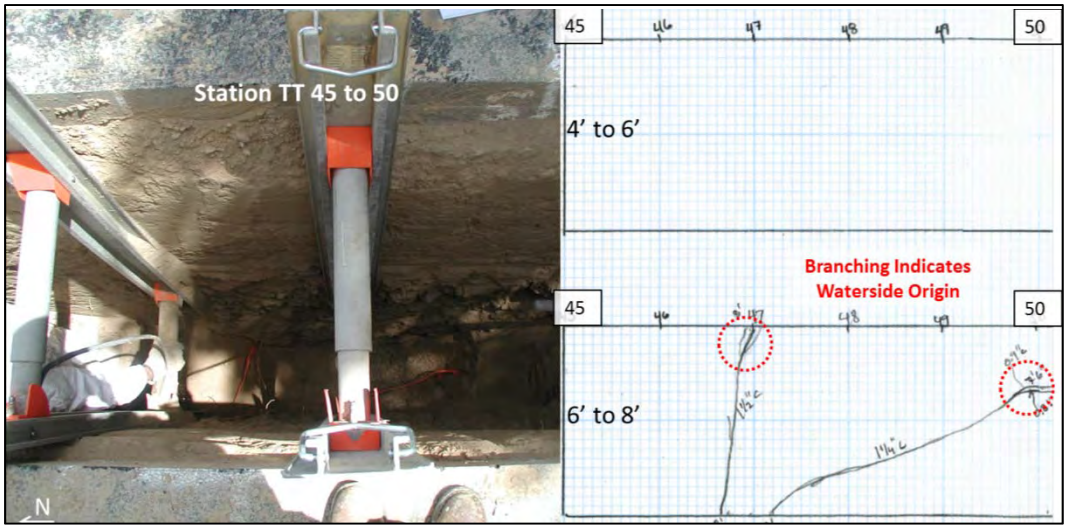


Figure 2-71. Root logs at 4 to 8 foot depth. Stations TT 45 to 50.

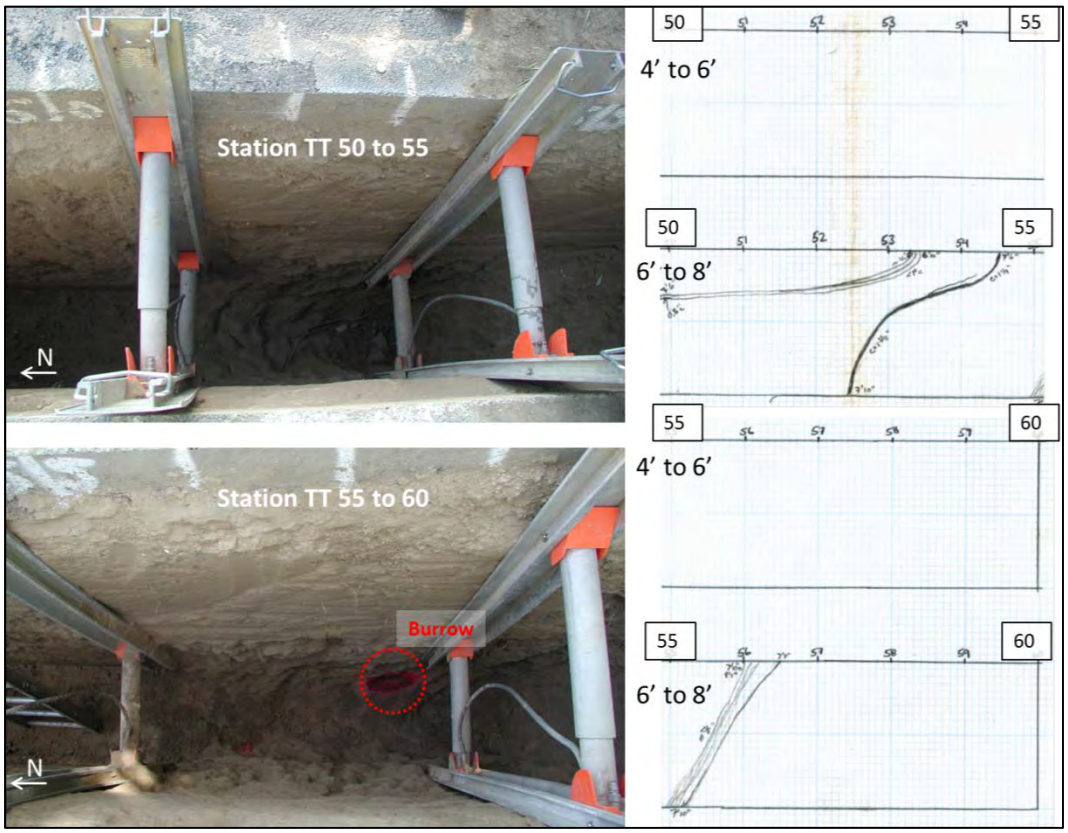


Figure 2-72. Root logs at 4 to 8 foot depth. Station TT 50 to 60. Note the first mammal burrow of the tree trench was encountered at landside Station TT 57 at a depth of 7 feet.

Figure 2-73. Burrow on landside, Station TT 57 at 7 foot depth. Vegetative debris and live root growth found inside 2 ½ diameter hole (left, top right). A plug of grout is placed (bottom right).

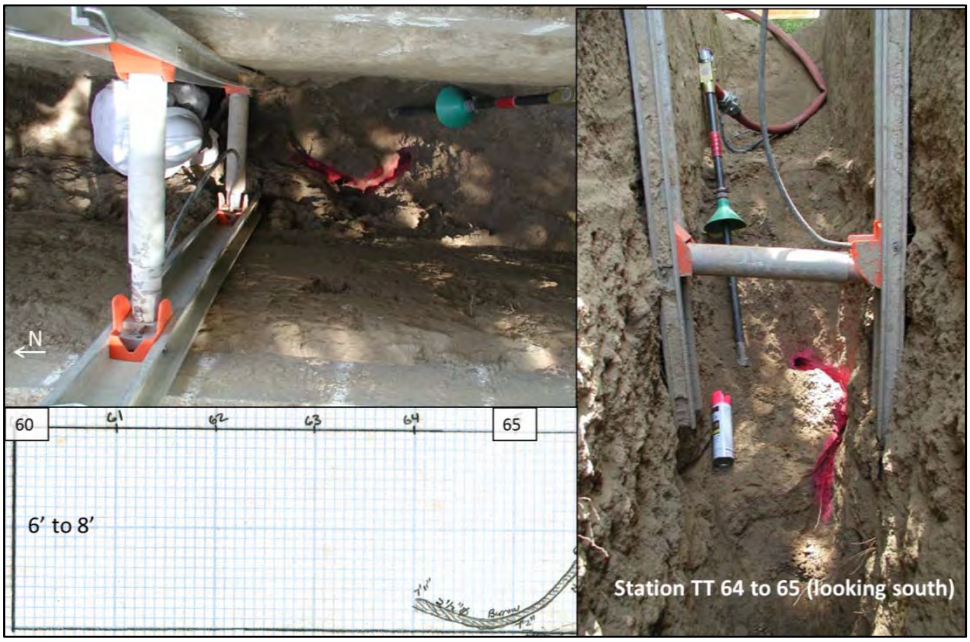


Figure 2-74. A mammal burrow is encountered during air knife work. The burrow is painted pink in photographs. Burrow diameter varies from 2 to 2 ½ inches.

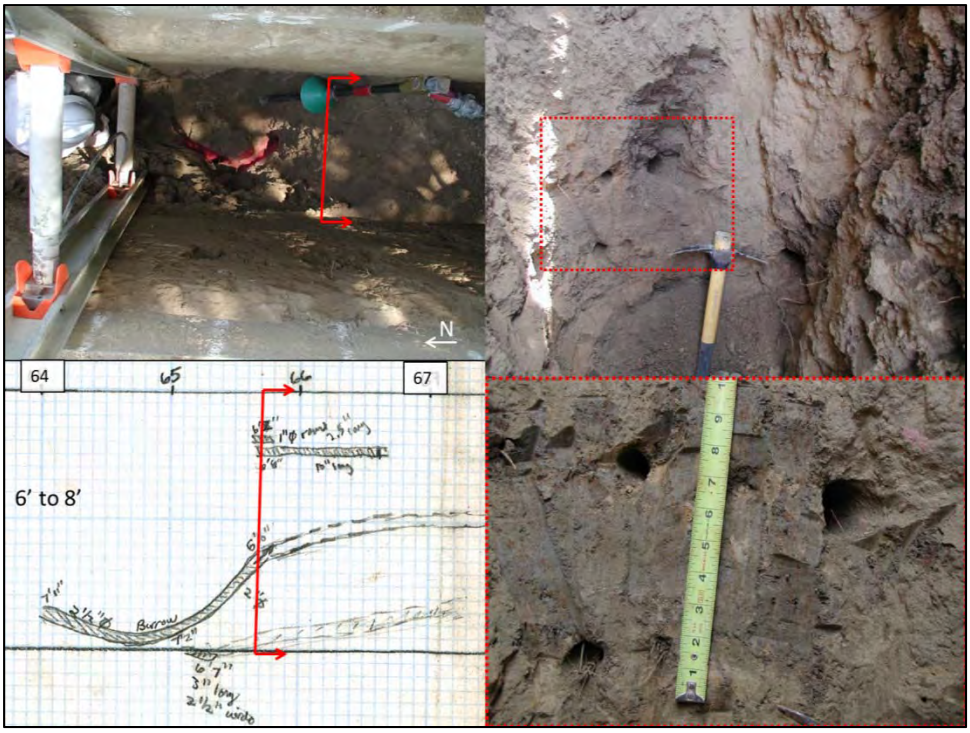


Figure 2-75. Views of mammal burrow network extending south from Station TT 66 (right). Burrows range from 1 to 2 inches in diameter.

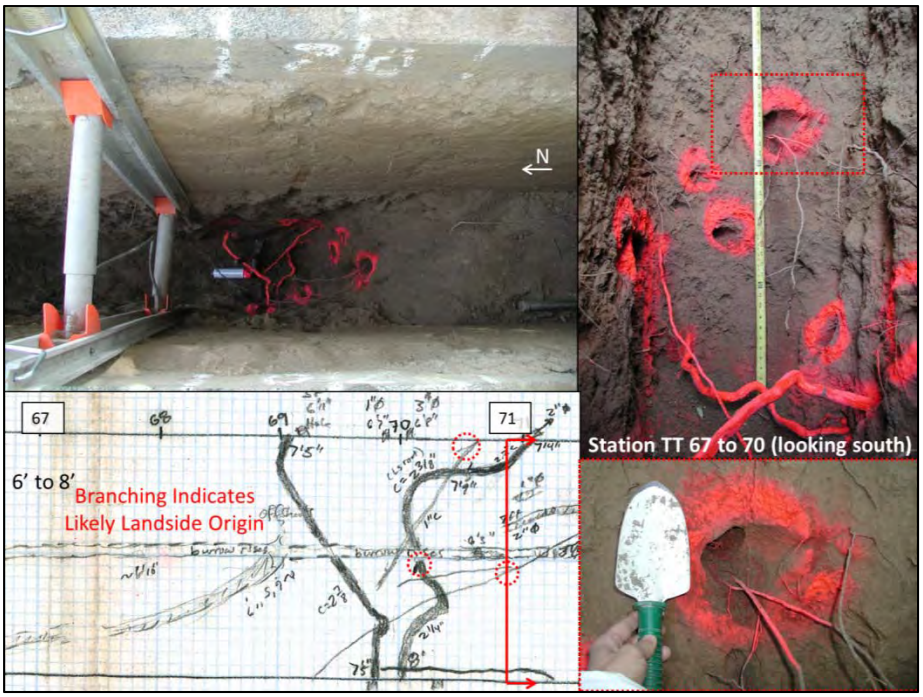


Figure 2-76. Root and mammal burrow log at depth of 6 to 8 feet at Station 70-71. Live root growth in burrows of 2 to 3 ¼ inch diameter.

Figure 2-77. Small holes, less than ½ inch in diameter observed near mammal burrows.

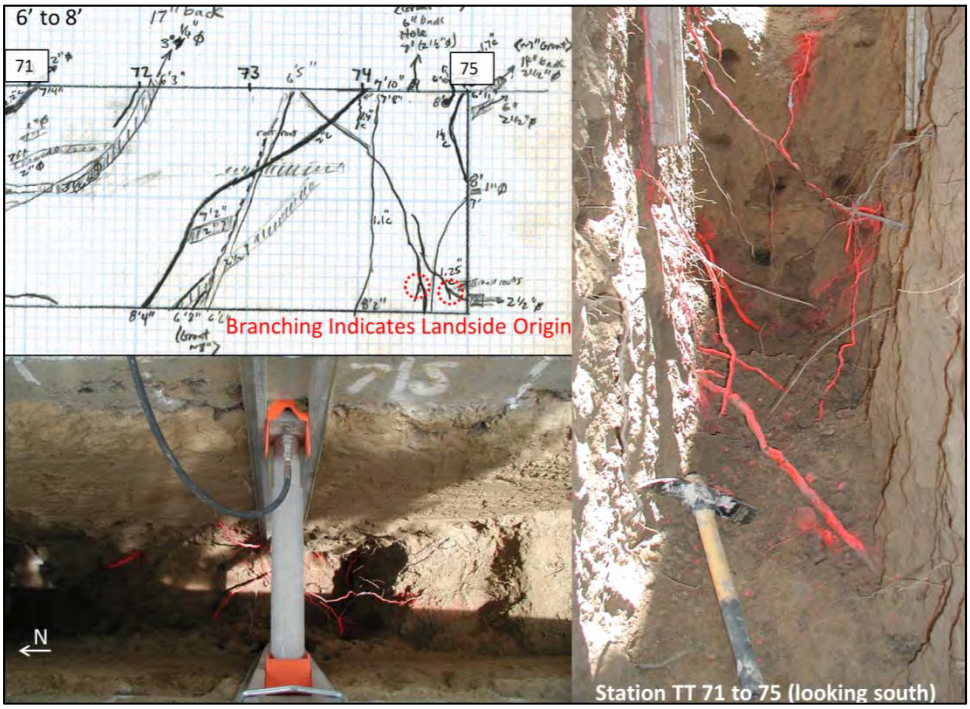


Figure 2-78. Root log (top left) at Stations TT 71 to 75 including plan view photo (bottom left) and trench view (right).

Figure 2-79. Close in view of mammal burrows with root growth and vegetative litter left by mammals (A, C, D) and an overview of extensive burrowing activity between Stations TT 70 and TT 75 (B). Burrows range in diameter from 1 to 2 ½ inches.

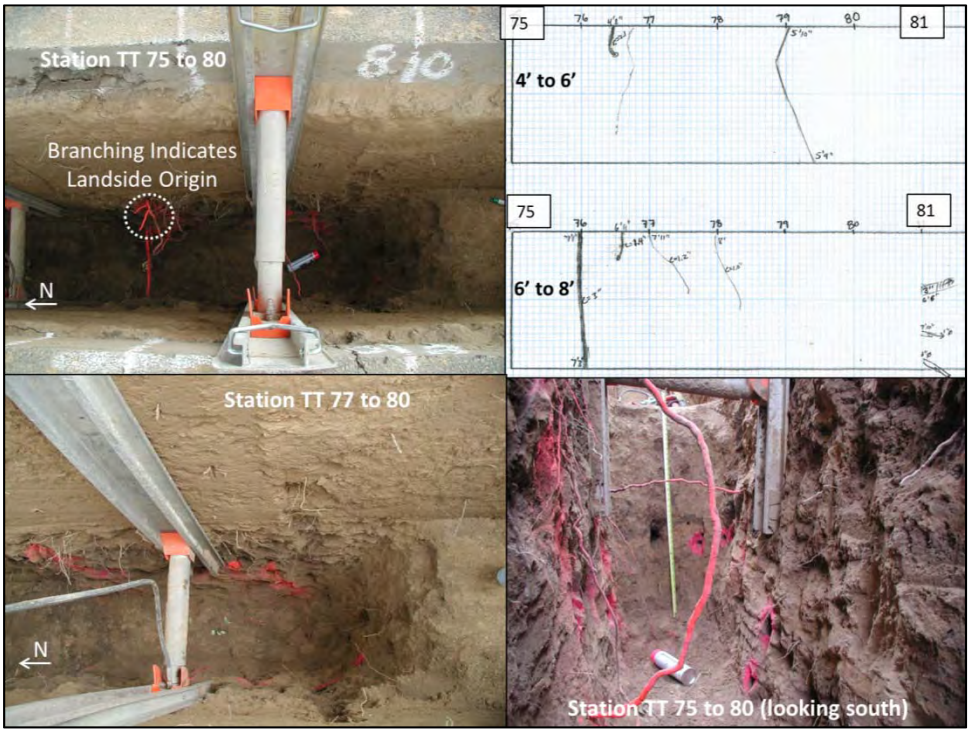


Figure 2-80. Mammal burrowing activity and root logs between Stations TT 75 and 81.

Figure 2-81. A) Overview of roots and burrowing activity (diameters from 1 to 3 inches) at Stations TT 77 to 80. B) View of 1 to 1 ½ in diameter mammal burrows at Station TT 81 waterside wall; C) View of 3 inch diameter mammal burrow at Station TT 81.

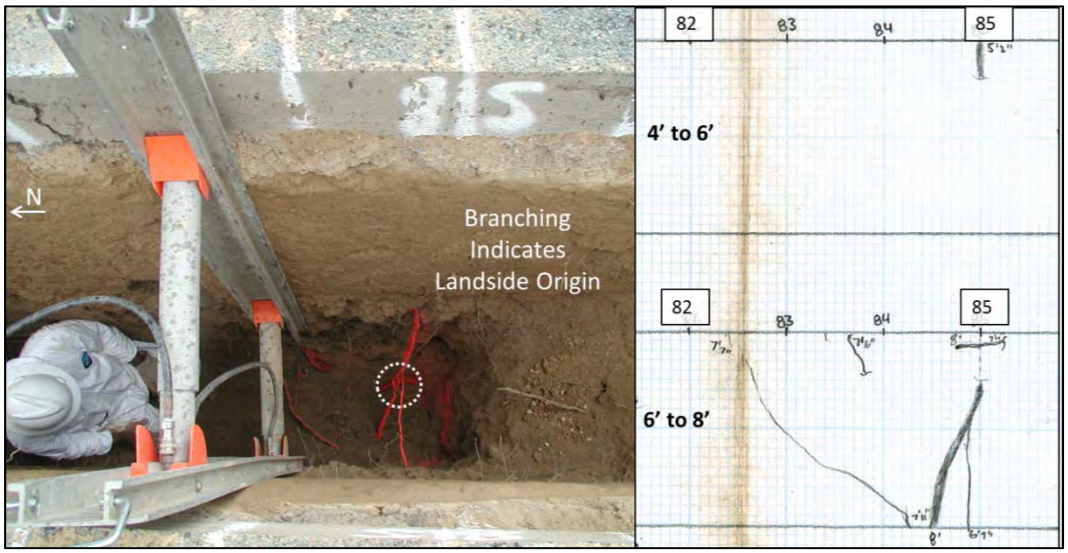


Figure 2-82. Root logs at depths 4 to 8 feet at Station TT 82 to 85 showing a 1 inch diameter root originating from the land side of the trench.

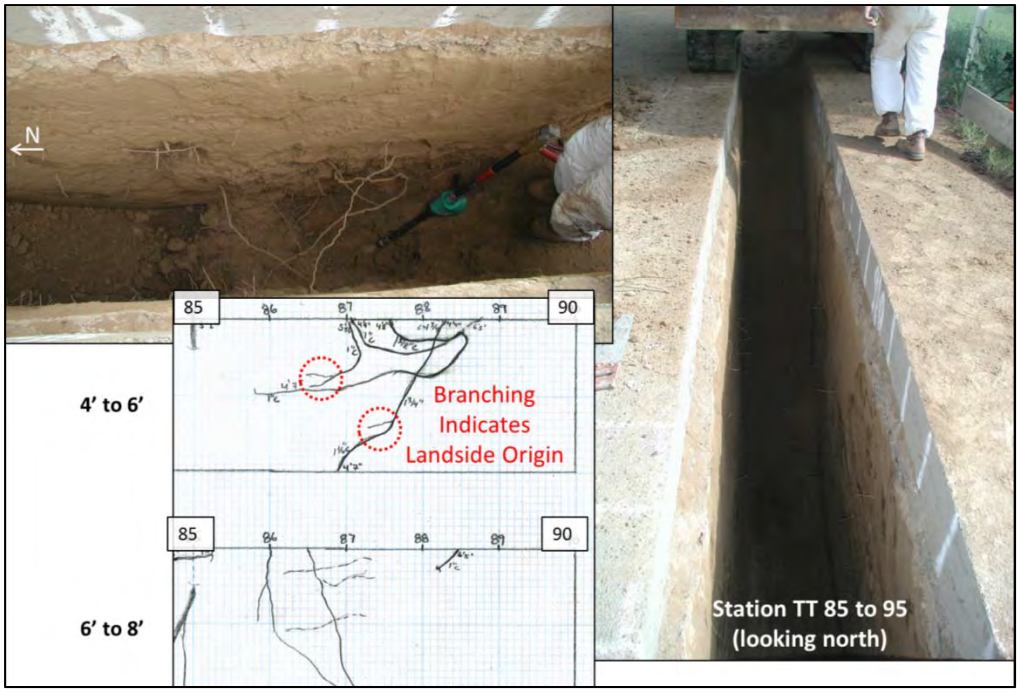


Figure 2-83. Root logs at depths of 4 to 8 feet at Station 85 to 90 showing the last cluster of roots (approx. ½ inch and smaller) that appear to originate from landside oak tree.

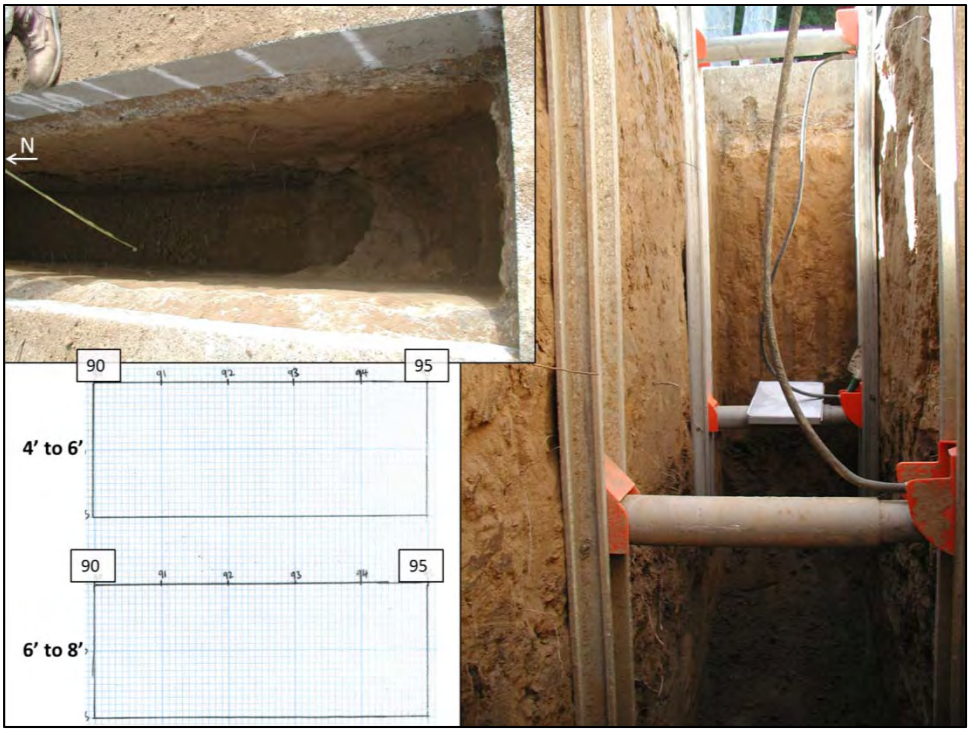


Figure 2-84. Root logs and photographs of the 4 to 8 foot depth range at Station 90 to 95 show an absence of roots and burrows.

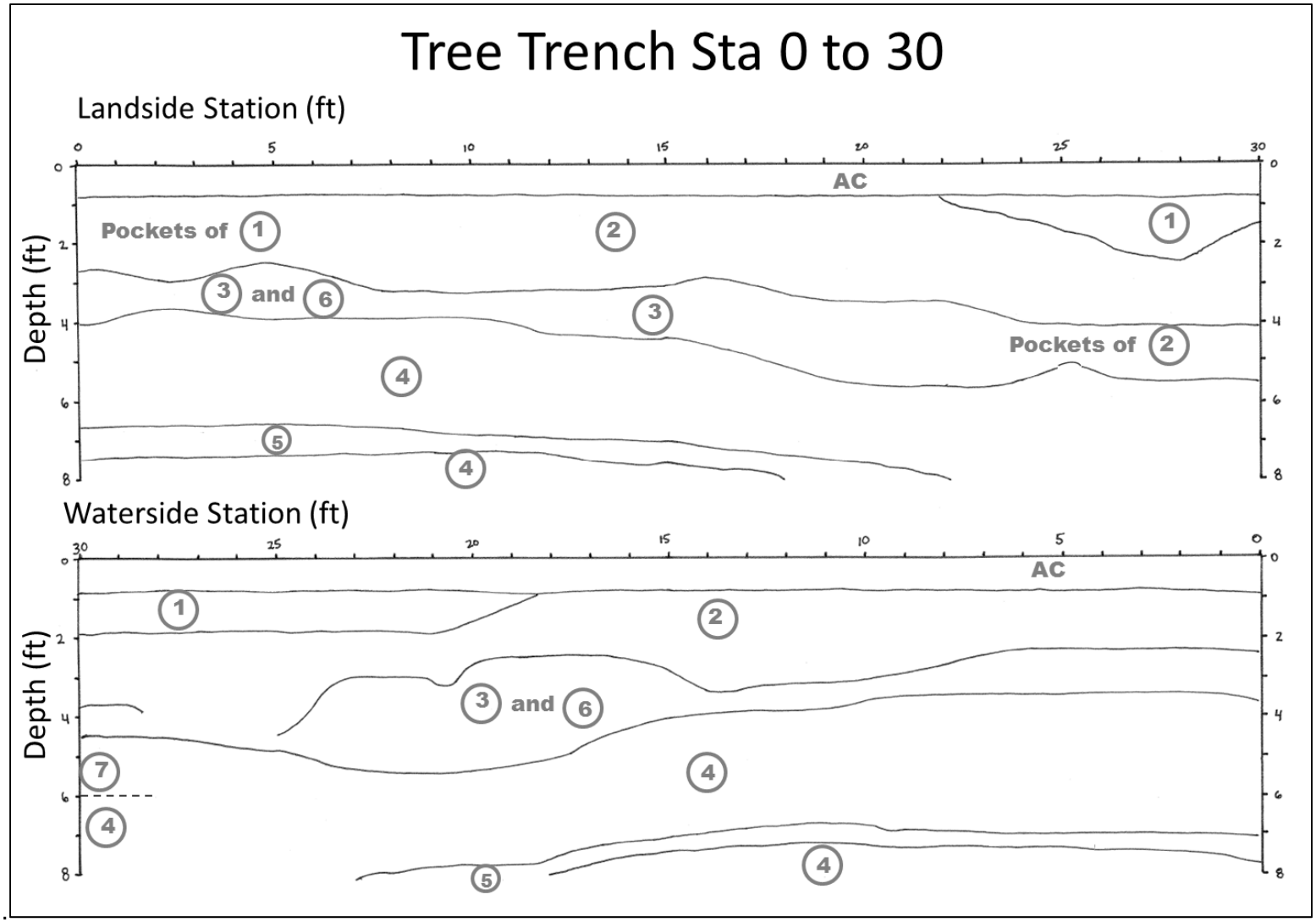


Figure 2-85. Tree trench landside and waterside wall logs, Station TT 0 to 30. Material numbers are described in detail in Section 2.5.2.1.

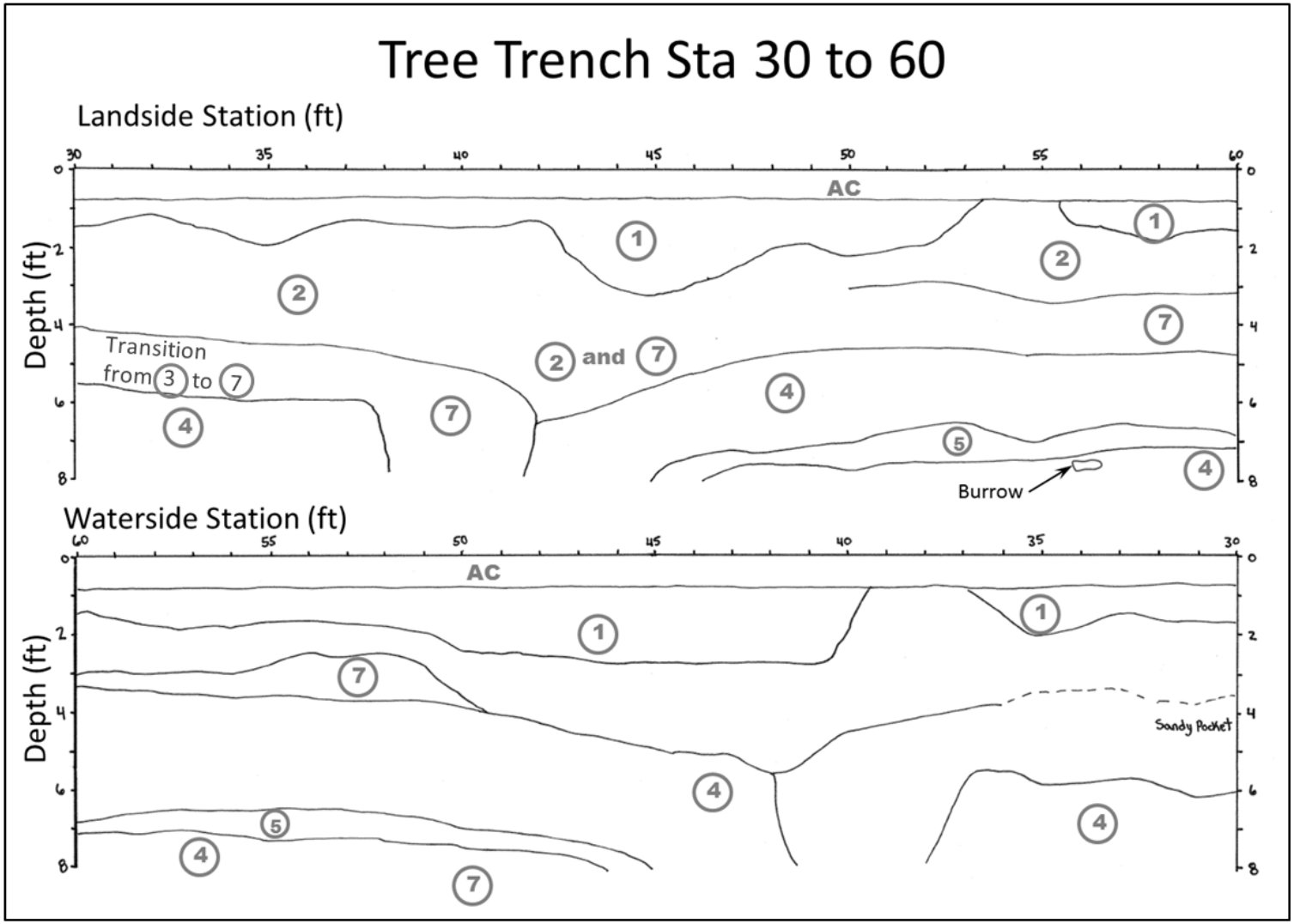


Figure 2-86. Tree trench landside and waterside wall logs, Station TT 30 to 60. Material numbers are described in detail in Section 2.5.2.1.

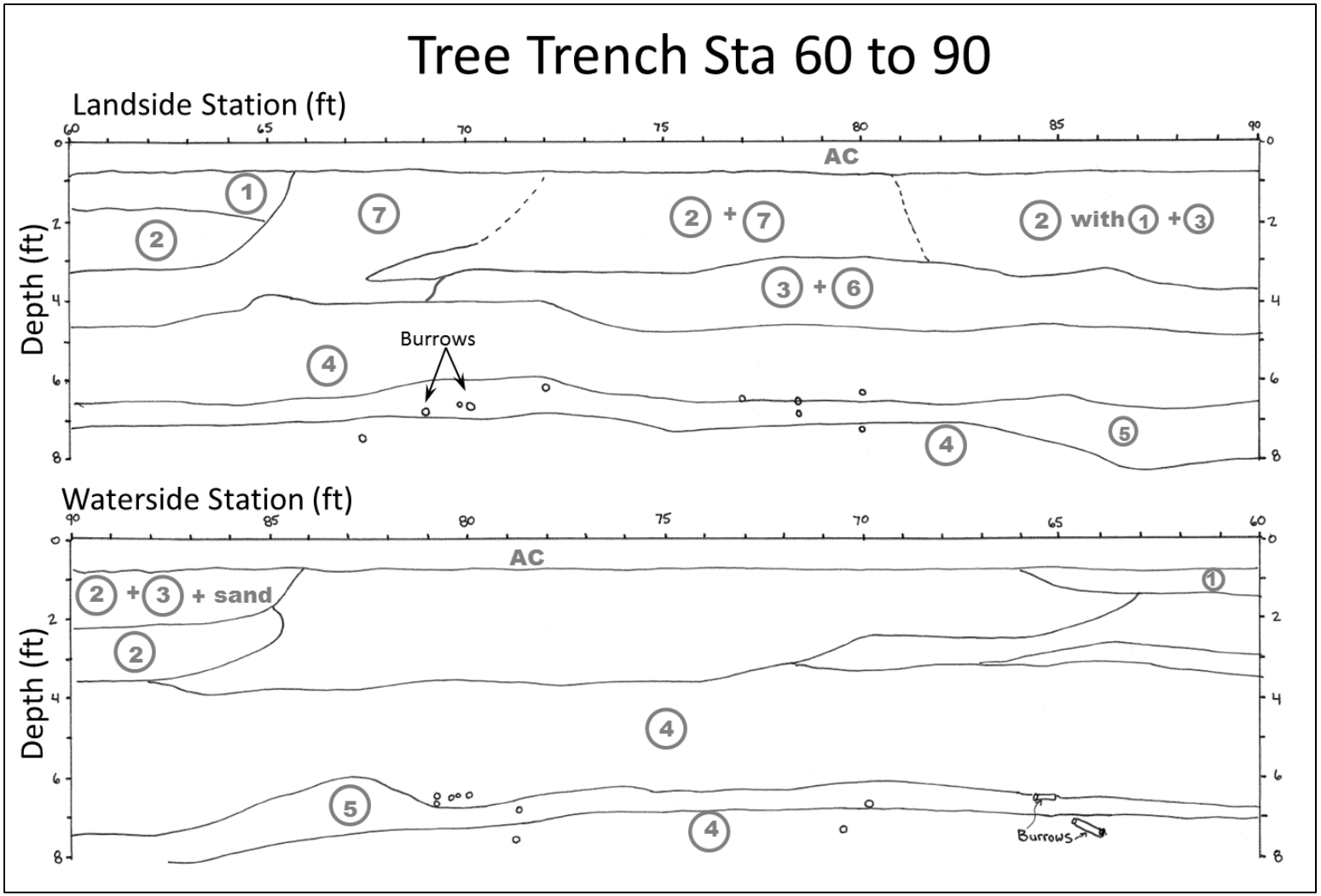


Figure 2-87. Tree trench landside and waterside wall logs, Station TT 60 to 90. Material numbers are described in detail in Section 2.5.2.1.

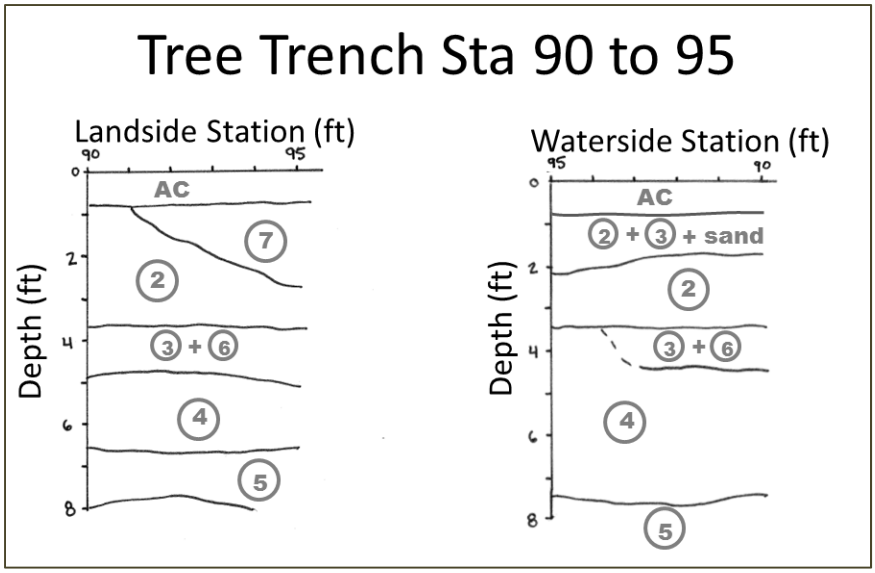


Figure 2-88. Tree trench landside and waterside wall logs, Station TT 90 to 95. Material types are described in detail in Section 2.5.2.1.

2.5.3 Installation of Instrumentation

Initial instrument equilibration and additional installation details are provided in Appendix F. Tensiometers were obtained from Soil Moisture, Inc. and equipped with a mechanical pressure gauge and a pressure transducer with maximum suction capacity of 100 kPa. They were pre-assembled and saturated prior to installation (Figure 2-89). All connections were cleaned, the gauge and transducer ensemble connected to the tensiometer, taking care to properly achieve a seal on each connection. The porous tips were pre-saturated in vacuum with de-aired water and brought to the site in de-aired water. They were connected to the tensiometers onsite just prior to installation. De-aired water was brought into each instrument through a suction pump attached at the top. Once the tensiometer was filled, the suction pump was used, along with tapping action, to remove trapped pockets of air from the gauge and transducer connections.

Tensiometers of 24, 48 and 60 inches were installed into the levee to depths of 18, 36, and 60 inches, respectively. All instruments were installed in accordance with the manufacturer's specifications. Holes were advanced with a gauge auger (provided by the manufacturer) with a diameter slightly larger than the instrument diameter of ¾ inch. The instrument holes were logged for soil conditions prior to installation.

With all seals checked and no observed leaks in the tensiometer, silica slurry (a mixture of water and silica flour with silt-sized particles) was used to create a seal between the surrounding soil and the porous ceramic tip of each tensiometer. This step is optional according to the manufacturer if the hole is snug to the tensiometer, but proved helpful in our soil conditions. De-aired water was periodically refilled by opening the instrument, losing tension, refilling, closing the instrument, and allowing time for re-establishment of tension. For convenience, many of the instruments were equipped with a reservoir cap to

facilitate refilling (Figure 2-89B), however the effect on soil tension was the same. The functionality of the instruments was checked after each refilling.

Figure 2-89. Tensiometer is leak-checked, saturated (A) and sealed into the ground (B and C). Grout is mixed (D) and piezometers are grouted into the ground (E).

Vibrating wire piezometers were pre-saturated and grouted into place upside down to prevent desaturation of the porous stone in accordance with the recommendations of the manufacturer, consultation with Mr. Eric Mikkelson, and available literature (Mikkelsen 2002; Mikkelsen and Green, 2003; McKenna, 1995). Piezometers were read continuously with two 16 channel Geokon LC-2 Series Model 8002-16 dataloggers. Frequency of readings was determined based on the observed rates of change in recorded pore pressures. Table 2-5 and Table 2-7 provide summaries of recorded piezometer data on the land and water sides. Data results are discussed in Section 2.6.4.

Approximate alignments of instrument lines are shown overlain onto site photography in Figure 2-90. Figure 2-91 through Figure 2-94 show photos of installed instrument lines on the landside and waterside of the levee. Piezometers are difficult to see in photographs as the only visible element is a wire protruding from the ground unlike tensiometers which have an above grade mechanical gauge and transducer.

Figure 2-90. Photographic view of instrument line locations on the levee landside and waterside.

Figure 2-91. Instrument line A looking west from toe (left) and east from the levee crown. (right)

Figure 2-92. Instrument Line B at waterside oak tree looking west (upper left, right) and north (lower left).

Figure 2-93. Waterside instrument line B (top images) and line E (bottom images).

Figure 2-94. Instrument line C from the toe of slope looking west (left) and from the crest looking west at waterside instruments.

2.6 FLOW TEST EXPERIMENT

Following instrument calibration and monitoring, the flow test experiment was initiated by filling the levee crown trenches with water on May 21, 2012. The experiment ran for approximately 4 days in the tree trench before the water supply was turned off, while water was supplied to the control trench for 6 additional days (10 days total) to accommodate variability in instrument saturation (i.e. some instruments were not fully saturated in the control trench, yet instruments indicated that the area of the tree trench had reached equilibrium). On May 31, 2012, dye was added to the water to better understand where water was being lost during the test, particularly on the water side. Following the dye test, water to both trenches was shut off and suction was allowed to build within the tensiometers as soils dried. Instruments were monitored through June 5, 2012, approximately 15 days after the start of the flow test. Some instruments were no longer functioning for a short period due to vandalism and theft. A detailed timeline showing the duration of each phase of testing and key observations is presented as Figure 2-95.

On May 21, 2012 at 1:47 pm, water from the 4900 gallon polyethylene water storage tank located at the crown of the levee was released to both the control and tree trenches to obtain a constant head of water. Water flowed through 2-inch input hoses connected to mechanical float valves located at the approximate centers of the tree and control trenches. Shortly after turning the water on, the hoses were disconnected from the float valves to

increase flow rates during filling of the trenches. Trenches seemed to be losing significant water - the water level at one point was not rising. Ultimately, to obtain the desired constant head of water, both trenches were filled with a 4 inch fire hose. The desired constant head of water was reached at 3 hours in the control trench, and after nearly 5 hours in the tree trench.

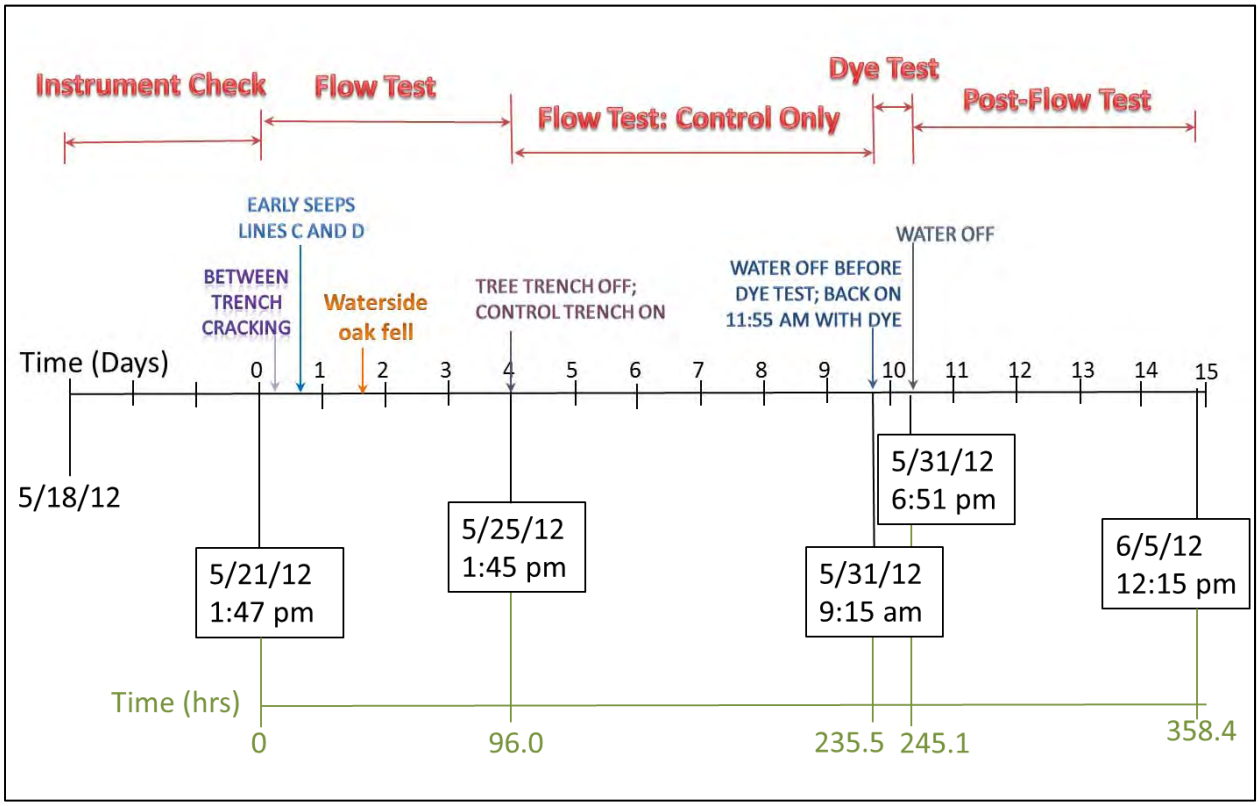


Figure 2-95. Timeline for Twitchell Island crown trench seepage test.

The constant head water surface elevation was set to approximately 9 inches below the edge of the pavement, or about 7 ¼ feet from the base of the trench to avoid overflow. The water level in the control trench, once full, was maintained using the mechanical float valve, as planned. The water volumes required to maintain constant head in the tree trench in excess of the capacity of the valve to deliver water under the available head. Water was delivered via the 4 inch hose while mechanically adjusting the volumes using valves on the delivery tank. At night, fine adjustments were made and visits were made every 4 to 6 hours to maintain water levels and make brief site inspections during the primary flow test.

Upon the commencement of water flow into the upper trench, a crack occurred between the control trench and the tree trench within about 2 ½ hours of the test start. The crack was monitored for changes throughout the duration of the flow test as discussed in a subsequent section. The first seep occurred at the waterside oak tree about 9 hours into the flow test. Seeps began to appear on the landside near the control line C in the middle of the night, about 13.3 hours into the flow test. By morning, more seeps were appearing in this area and also near instrument Line D, downslope from the extensive burrowing activity

that was encountered during trenching. Within a few hours, large seeps were appearing under instrument line D and also instrument line A below the landside oak tree. The area of seepage correlated well with the area of extensive burrowing encountered in the tree trench between Stations TT 56 and 82. Upon post-flow test inspection of the seepage areas on the slope, the surface expressions of the burrows were not apparent. The water at the slope face was observed to be exiting the slope through ¼ inch to ½ inch diameter macropores.. These holes were later inspected and are believed to be associated with a very active earthworm population. The earthworm burrows appear to have allowed for concentration of flows in the near-surface soils. It is not known whether these small holes were interconnected with mammal burrow networks.

Within the first 25 hours of the test, a pattern of seepage began to develop in a linear alignment extending across the slope at a vertical elevation about 2 feet higher than the toe of slope. This pattern continued throughout the test, where seepage and flow seemed to appear either along this alignment or from areas known to be riddled with burrows.

After a little over 39 hours of testing, and the monitoring of a growing seep at the base of the waterside oak tree, the tree rotated approximately 20 degrees and came to rest with the long branch of the tree providing support within the shallow oxbow section of the slough. Cracking and deformation was monitored around the tree, the waterside slope, and the pavement at the crown throughout the duration of the test. T-LiDAR scans were performed by Gerald Bawden and his team at the USGS to document deformations at the site. A pre-flow scan was taken as well as a scan following the primary flow test, and a scan following the final dye test. His results and deformation analysis are summarized in Bawden et al. (2013).

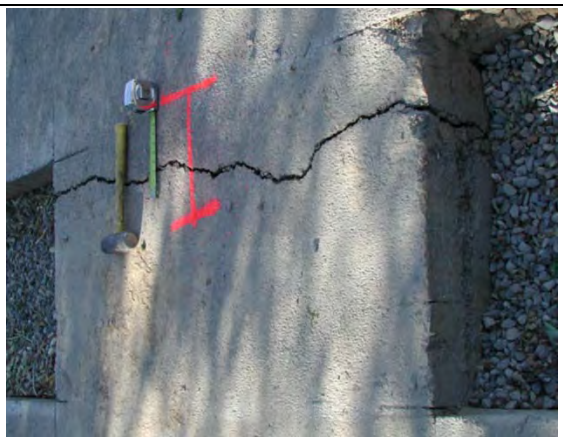
The constant head was held for 4 days at which time water flow to the tree trench was turned off. Steady state appeared to have been achieved in the area of the tree trench, based on instrument data, and Rows 3 and 5 of the control trench had not yet saturated. It was not clear if these instruments in the vicinity of the control trench would saturate or if steady state had been achieved without the wetting front reaching all of instrument line C. Flow to the control trench was allowed to continue. The tree trench was found not to drain completely upon turning the water off on the tree trench, while flow rates pumped into the control trench increased during this time period. The morning of May 31, 2012, water in both trenches was shut off for a few hours to allow levels to drop prior to a dye test. Blue Cole Parmer tracer dye was mixed into the tank and delivered into the trenches to determine the path of water losses, particularly those on the waterside. A series of land and waterside observations were made. Water levels in the slough were kept low by the operators of the gate in order to facilitate our inspections of waterside burrows. These burrows were difficult to access up close during the primary test due to soft soil conditions, high water levels, and dense brush, including Elderberry bushes that could not be cut for access due to permit restrictions.

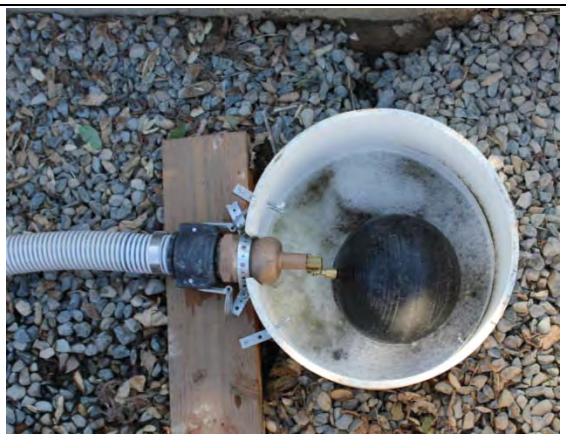
Visual observations were made over the 4 day primary flow test and during the dye test. Limited observations were made during the 6 days when water was delivered only into the

control trench. The instruments were disconnected on June 5, 2012 and removed shortly thereafter. The site was allowed several weeks to dry out prior to the repair phase.

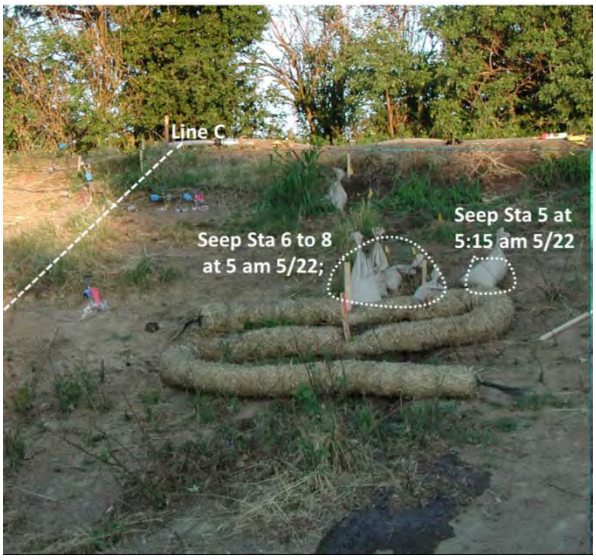
A photographic timeline is provided below detailing the primary events that occurred throughout the test (Table 2-2). Detailed discussions and photos of landside seepage patterns, waterside deformations and monitoring, the waterside oak tree, the dye test, and the findings of the T-LiDAR survey are summarized in the following sections. Instrument data is presented and discussed in the context of these observations. Detailed instrument data is presented in Appendix F.

Table 2-2. Overview Chronology of Observations

Time (hrs)	Date	Time	Observation	Photo or Illustration
0	5/21	13:43	Water flow begins at 1:43pm on 5/21/12. Mechanical float introduces bottleneck and is removed.	
1.32	5/21	15:02	2" diameter hose (connection to float) removed to allow flow through 4" diameter delivery hose. Flows were not sufficient to fill the trenches with 2" diameter hose.	
2.6	5/21	16:16	Noticed crack between Control and Tree Trenches. Nails installed to monitor separation. (also see Figure 2-111 through Figure 2-116).	

3.0	5/21	16:45	Control Trench nearly to target water surface elevation. Cannot maintain sufficient flows with float.	No photo
4.3	5/21	18:01	Crack between trenches grows and begins to develop vertical offset .	
4.8	5/21	18:30	Flows in Control Trench have stabilized and reduced to where the head can be maintained with the float.	

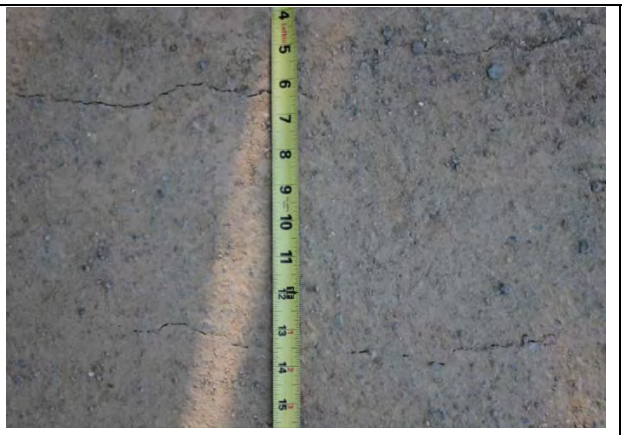
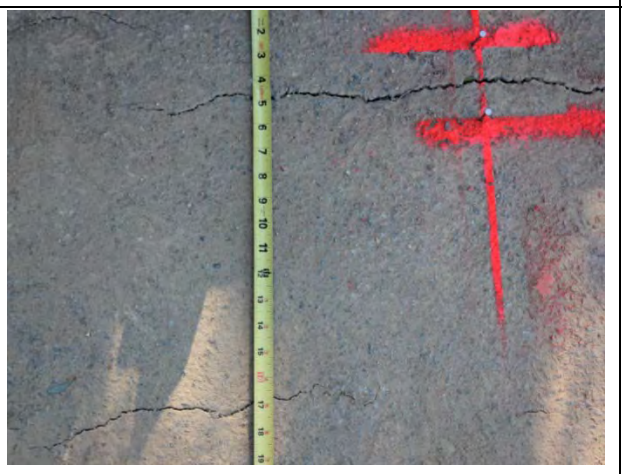
4.8	5/21	18:30	Tree Trench nearly to target water surface elevation, but capacity of mechanical float insufficient to maintanin constant head. Must use valve on tank to maintain target water surface elevation.	
7.3	5/21	21:00	¼ inch vertical offset measured at crack between the trenches.	
9.0	5/21	22:40	A seep was noticed at the waterside oak tree.	

13.3	5/22	03:00; photo at 05:30	Seep at oak had grown; Traced with string for photograph at 5:30am (shown) Seep recorded on the landside at Control Trench (CT) Stations 7 to 10 (no photo). Gravel bags not needed to contain.	
15.3	5/22	05:00	Seeps open at CT Sta 6 and 8 mid-slope landside; confirmed burrow (possible vole or gopher). Gravel bags placed. Two gravel bags added to seep at Stations 7 to 10.	

15.5	5/22	05:15	Sta CT 5 opened when gravel bag placed on seeps at CT Sta 6 and 8 midslope (at Time = 15.3 h); wattles and gravel bags required to prevent erosion.	
15.8	5/22	05:30	Seep at Sta TT 57 to 59 (Instrument Line D); no gravel bags placed.	

16.6	5/22	06:20	Crack width reaches a maximum; vertical offset continues to grow.	
19.3-20.0	5/22	09:00-09:45	Seep below landside oak Sta TT 68 to 77; Landside Sta 50 to 63 also seeping and expanding to the north.	
25.5	5/22	15:10	New cracking in pavement near landside oak tree. New monitor installed at Sta TT 58.5.	

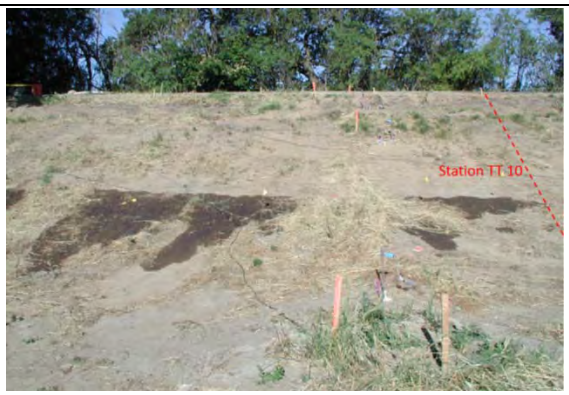
26.3	5/22	16:00	Three new seeps between Sta TT 34 and 44 on the landside mid-slope.	
27.9	5/22	17:35	New seep landside Sta 24 to 27; mid-slope in line with seeps at Sta TT 34 to 44.	
28.3	5/22	18:00	Visible flow is observable in waterside seeps, Sta TT 13 to 24.	

28.3	5/22	18:00	Cracks opening in pavement near Sta 82 to 88.	
28.6	5/22	18:20	Seeps on landside Sta TT 55 to 58 are flowing; suspect macropores.	
28.9	5/22	18:34	Widening Pavement Cracks at Sta TT 82 to 88. Gusting winds.	

38.5-38.8	5/23	04:15-04:30	New seeps Sta TT 17 to 21 landside; Moderate wind no gusts.	
38.8-39.0	5/23	04:30-04:45	Waterside seep at oak grown somewhat; photo taken shortly before departing site at 4:45 am.	
39.25-39.75	5/23	05:00-05:30	Based on instrument data, waterside oak tree likely fell within this time window.	

42.2	5/23	08:00	Inspected landside prior to discovering tree failure on waterside. Noticed seeps near control line on land side (Sta CT 5 to 10) had stopped flowing.	
43.5	5/23	09:15	Noted flow in seeps in vicinity of Instrument Line D, Stations 57 to 59. Flow seemed to be coming from small holes from ¼ to ½ inch in diameter.	

43.5-43.8	5/23	09:15-09:30	Waterside oak tree observed to have fallen; photographed site.	
51.8	5/23	17:30	Visit from team advisor Dr. Les Harder. Additional cracking observed beneath an erosion protection wattle and leaf litter. Cracking was mapped, photographed and further explored. Monitors were installed to track movements.	
54.3	5/23	20:00	New crack monitors installed between Stations TT 11 and 25.	
57.3	5/23	23:00	Small seep at landside TT 10; in line with seeps at Stations TT 20 to 85.	See photo at Time = 62.9 hours.

62.9	5/24	04:35	Mid-slope landside seeps have spread across the site all beginning at the same elevation on the slope. The seep at Station TT 10 is beginning to connect together with other seeps.	
92.3	5/25	10:00	Onsite meeting of the CLVRP funders and advisory team prior to completion of the flow test.	
96.0	5/25	13:45	Turned off water on tree trench while leaving the control trench running.	
235.5-245.1	5/31	09:14-18:51	Dye Test.	See Section 2.6.3
245.1	5/31	18:51	Water off; begin falling head test.	

2.6.1 Landside: Surficial Seeps and Macroporosity

As shown on Table 2-2, observations on the landside of the levee consisted of mapping the locations of seeps on the face of the slope and noting those that appeared to exhibit flows through macropores. Figure 2-96 through Figure 2-108 show sketches and associated photographs of wetting front patterns on the face of the landside slope between 15.8 and 92.8 hours from the time of initial inundation of the trenches. Sketches were made to support observations and photographs during this time window as visual changes were occurring rapidly, particularly over the first 48 hours.

Early seeps appeared to be related to macroporosity and likely burrowing activity. The earliest seeps were just north of the control instrument line C and by late morning (10 am on 5/22/12), the mid-slope seeps were rapidly flowing. Gravel bags were piled on to slow down the flow and an erosion control wattle was installed beneath the zone of rapid flow to prevent rilling of the slope. This rapid flow had begun to slow later in the afternoon and stopped by 8 am the following morning on May 23.

Another early seep was encountered just after those found north of instrument line C in the vicinity of instrument line D just north of the landside oak tree. The seeps started small and grew throughout the day on 5/22/12, the second day of the flow test. Later that morning flow from the seeps began and gravel bags were placed. By 9 am that same morning, another seep had appeared under the landside oak tree along instrument line A. By 3:40 pm (26 hours into the flow test), gravel bags were added to these seeps to control water flows. Shortly after, at 4 pm (time = 26.3 hours), three new seeps were discovered at Stations TT 34, 39, and 44. By 5:35 pm, another seep appeared at Station TT 25. All seeps appeared in a linear alignment about 2 feet (measured vertically) from the base of the slope (Figure 2-99 and Figure 2-100).

Figure 2-109 shows a sketch of seepage patterns observed plotted with a simplified log of the contact between the older levee (lower permeability clayey silt named Material 4 in Section 2.5.2.1) and the higher permeability, heterogeneous and sometimes loose and more recent silt fills above. Instrument data show that saturation occurred in deeper instruments before shallower ones. Further, the linear pattern of seepage that occurred implied that water may was traveling along this low permeability layer and flowing out the face along that contact. The Material 4 contact dips to the east as we saw in Figure 2-28 through Figure 2-30, but also dips from the control trench toward Station TT 37 where the layer disappears and reappears at Station TT 42. In general, there is also a dip from Station TT 50 to Station TT 42. Localized but distinct dips in the Material 4 contact were observed where water accumulated and was channeled out to the surface, especially where burrow networks accelerated flows. Such response was observed between Stations TT 70 and 85 and TT 50 and 65, which corresponds to early seeps as shown on Figure 2-98. The spatial gap between these seeps and those appearing to the north in Figure 2-99 may be related to the sudden drop in elevation or lack of a Material 4 contact. Figure 2-110 shows the 5/25/12 seepage patterns overlain with the original location of blackberry at the site. Locations where macroporosity was observed correlate well to these areas. Though an

extensive burrowing area was near the landside oak tree, the tree did not appear to play a significant role in the flow test.

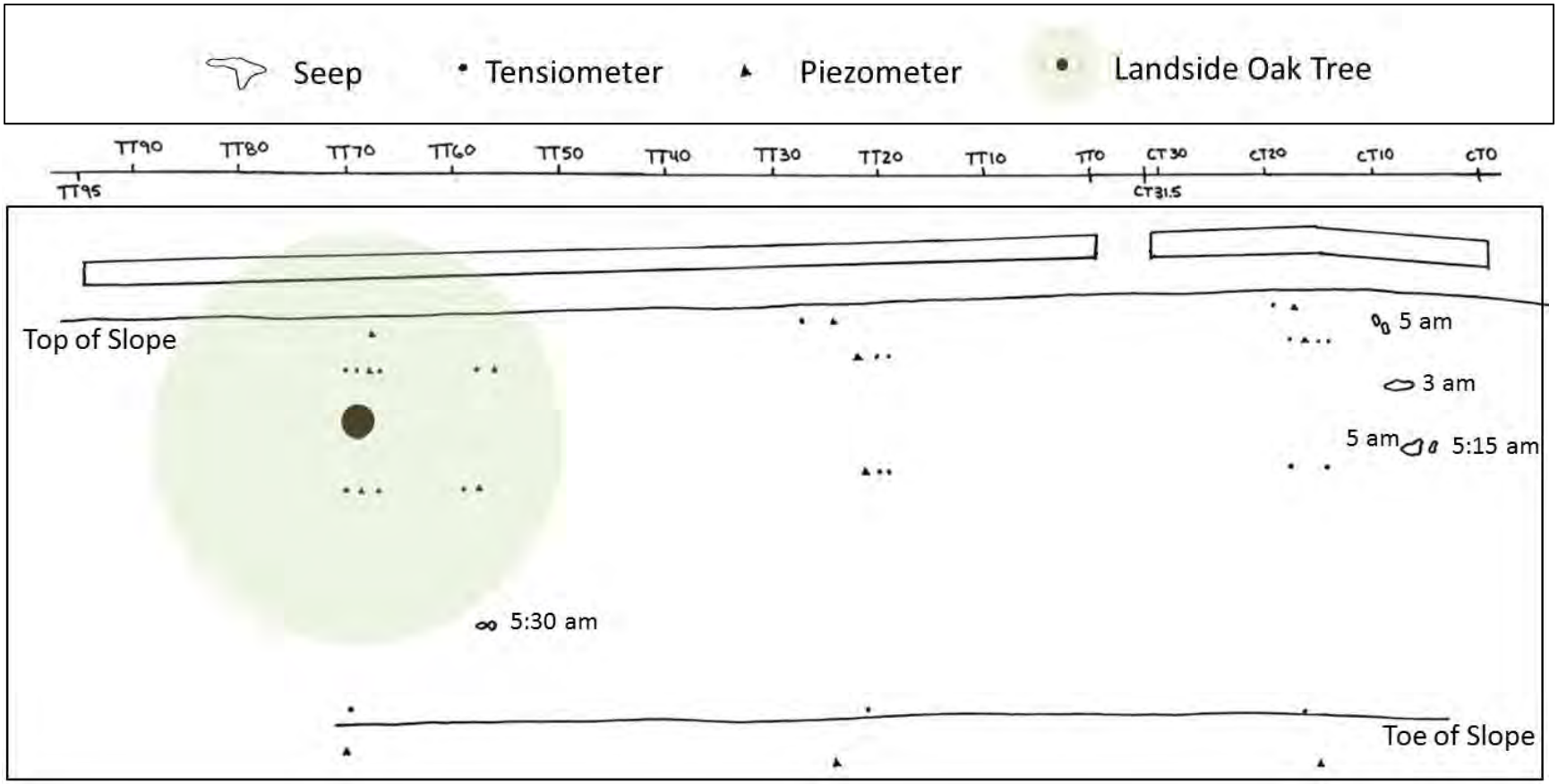


Figure 2-96. Sketch of landside seepage patterns: Time=15.8 hrs (5:30 am on 5/22/12). Time of seep appearance listed next to seep.

Figure 2-97. Time = 15.8 hours (5:30 am 5/22/13): Seeps at Line D (left), macropore flow near Line C (top right), and active gopher activity to north of control line (lower right).

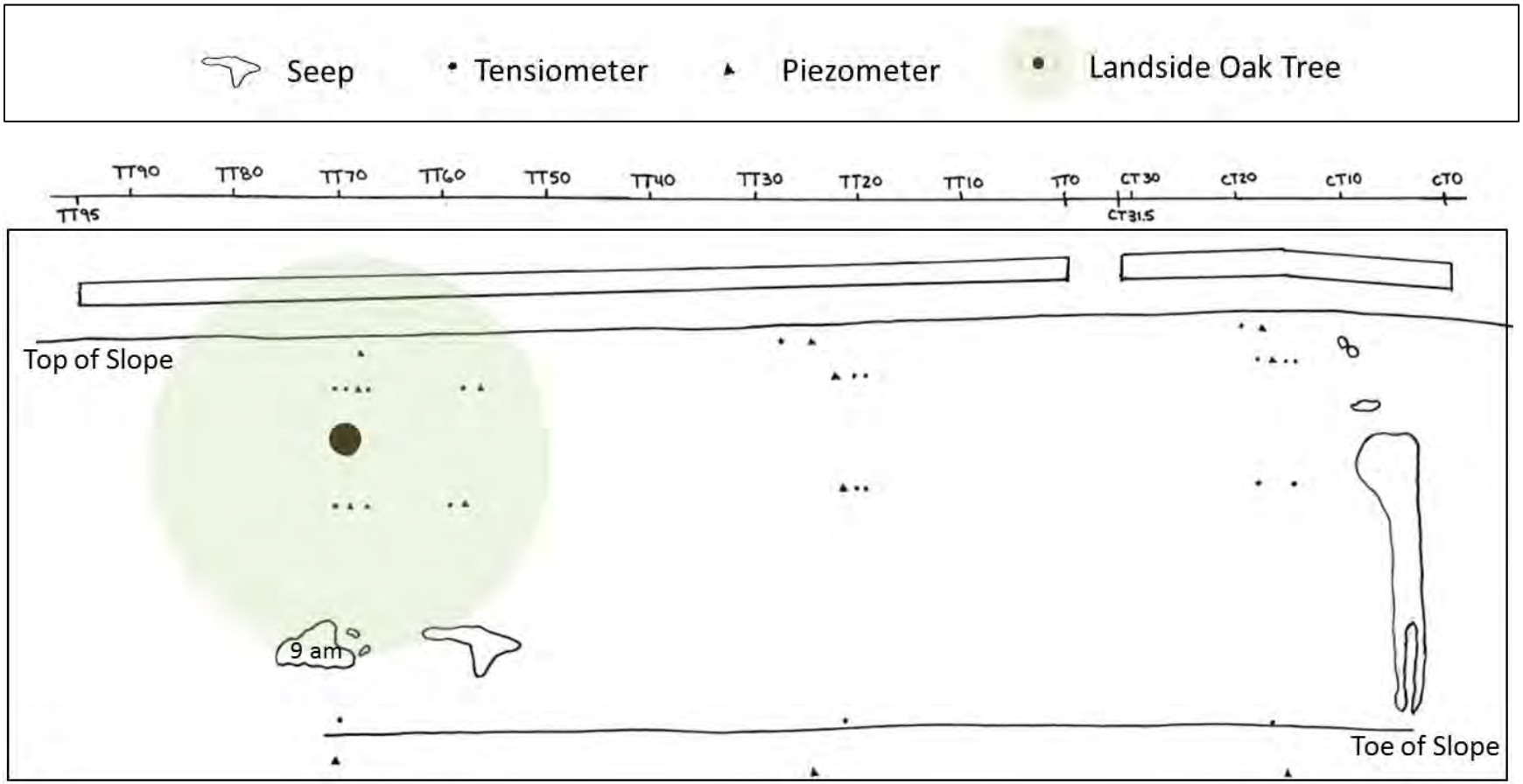


Figure 2-98. Sketch of landside seepage patterns: Time=20 hrs (9:45 am on 5/22/12).

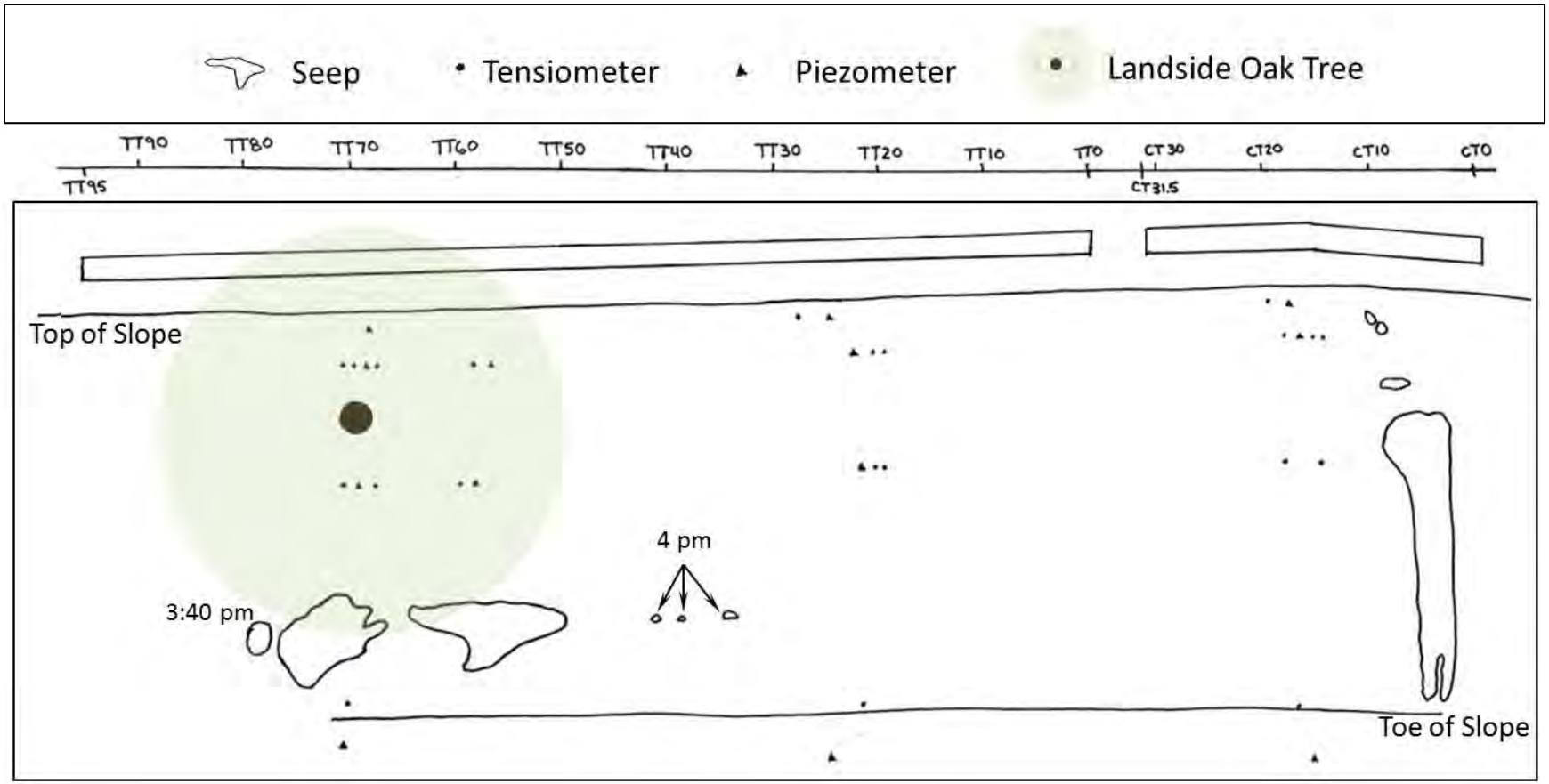


Figure 2-99. Sketch of landside seepage patterns: Time=26.3 hrs (4:00 pm on 5/22/12); Seep to the north of control line C has begun to produce less flow.

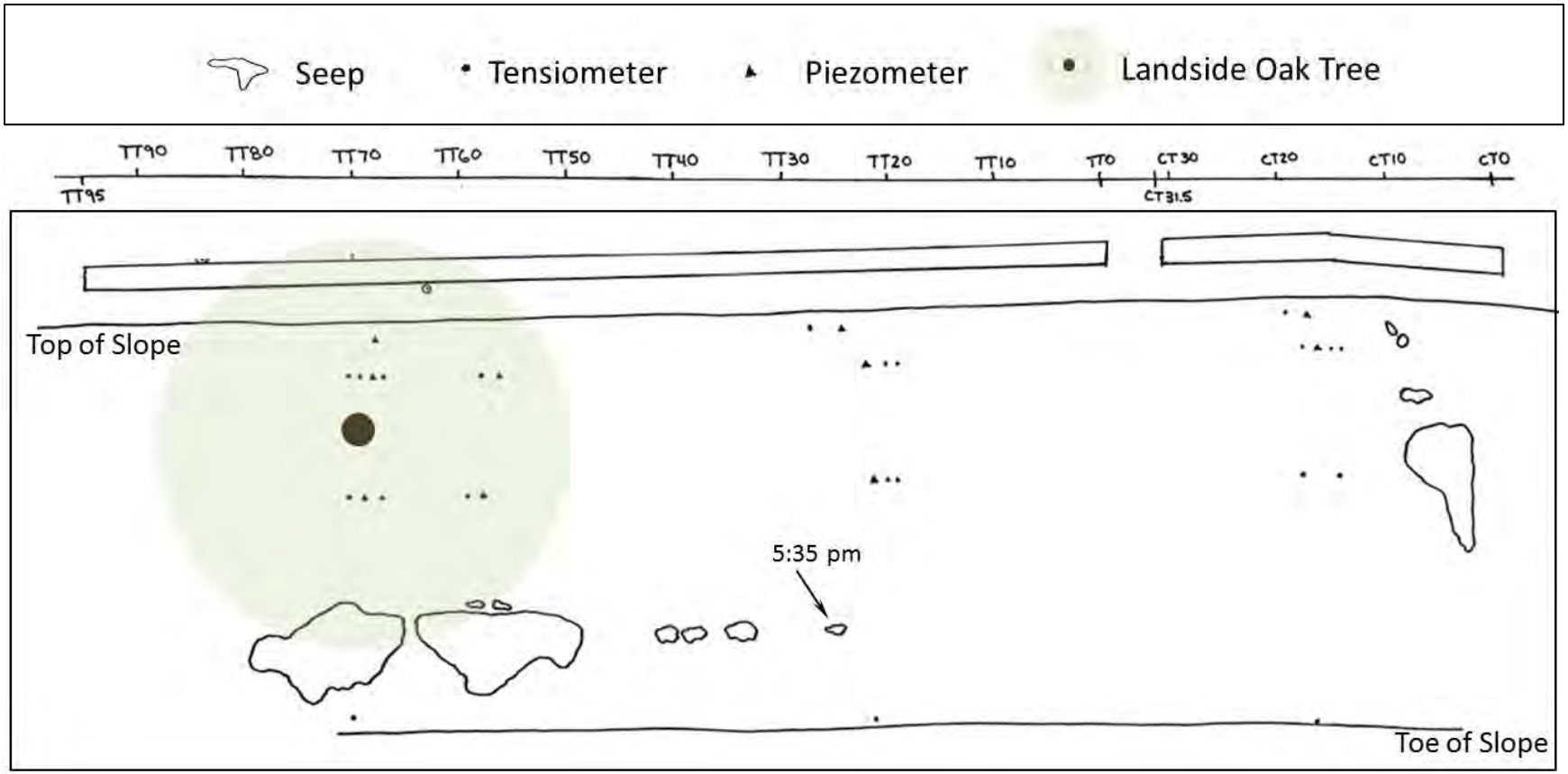


Figure 2-100. Sketch of landside seepage patterns: Time=28.3 hrs (6:00 pm on 5/22/12); Rills from seep to the north of control line C have begun to dry up.

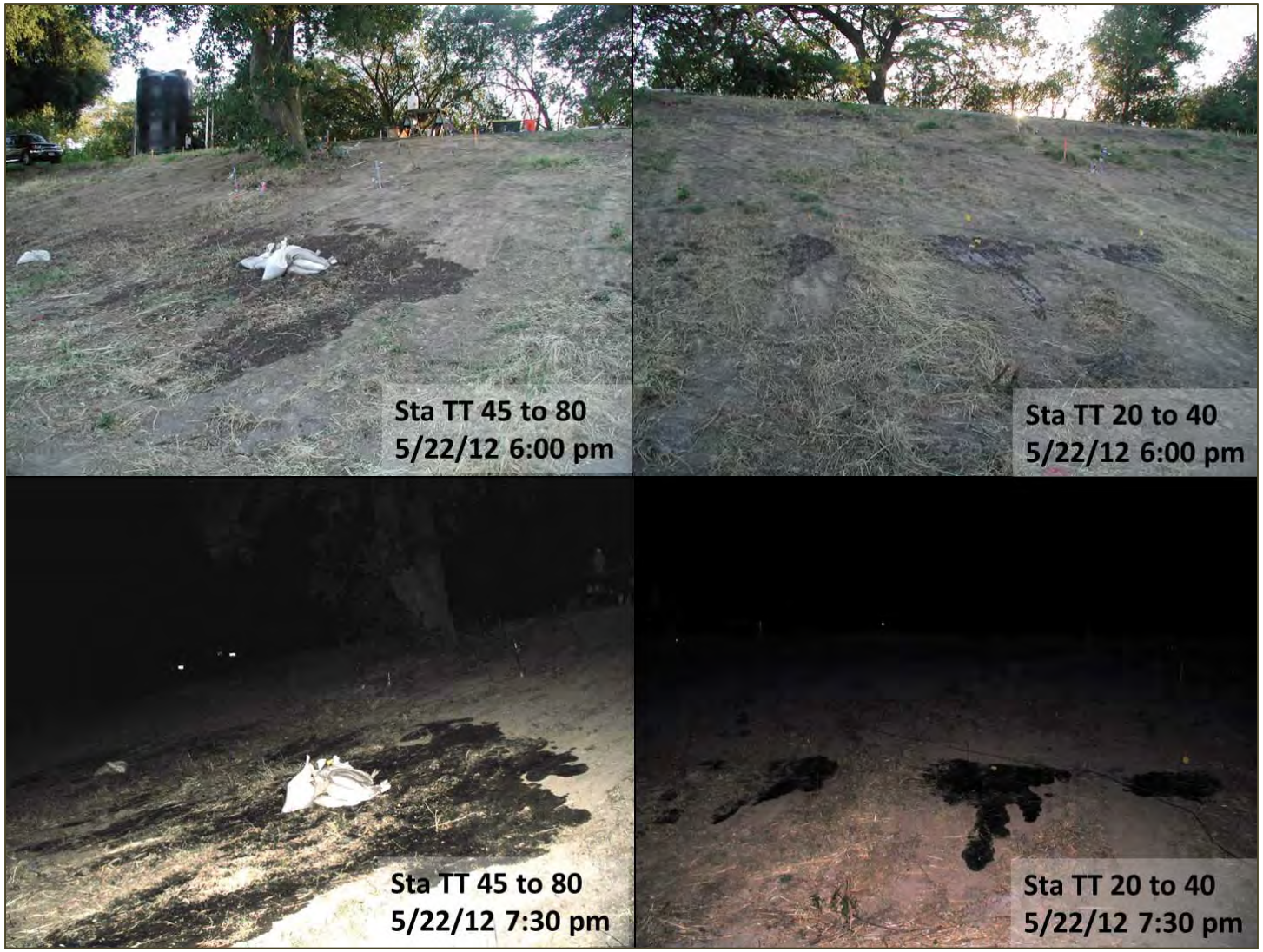


Figure 2-101. Time = 28.3 to 29.8 hours. Seeps continue to expand slowly, growing closer together with a small amount of free water flow from the newer seeps at Sta. TT 20 to 40 (right) as well as continued steady seepage from larger seeps at Sta. TT 45 to 80 (left).

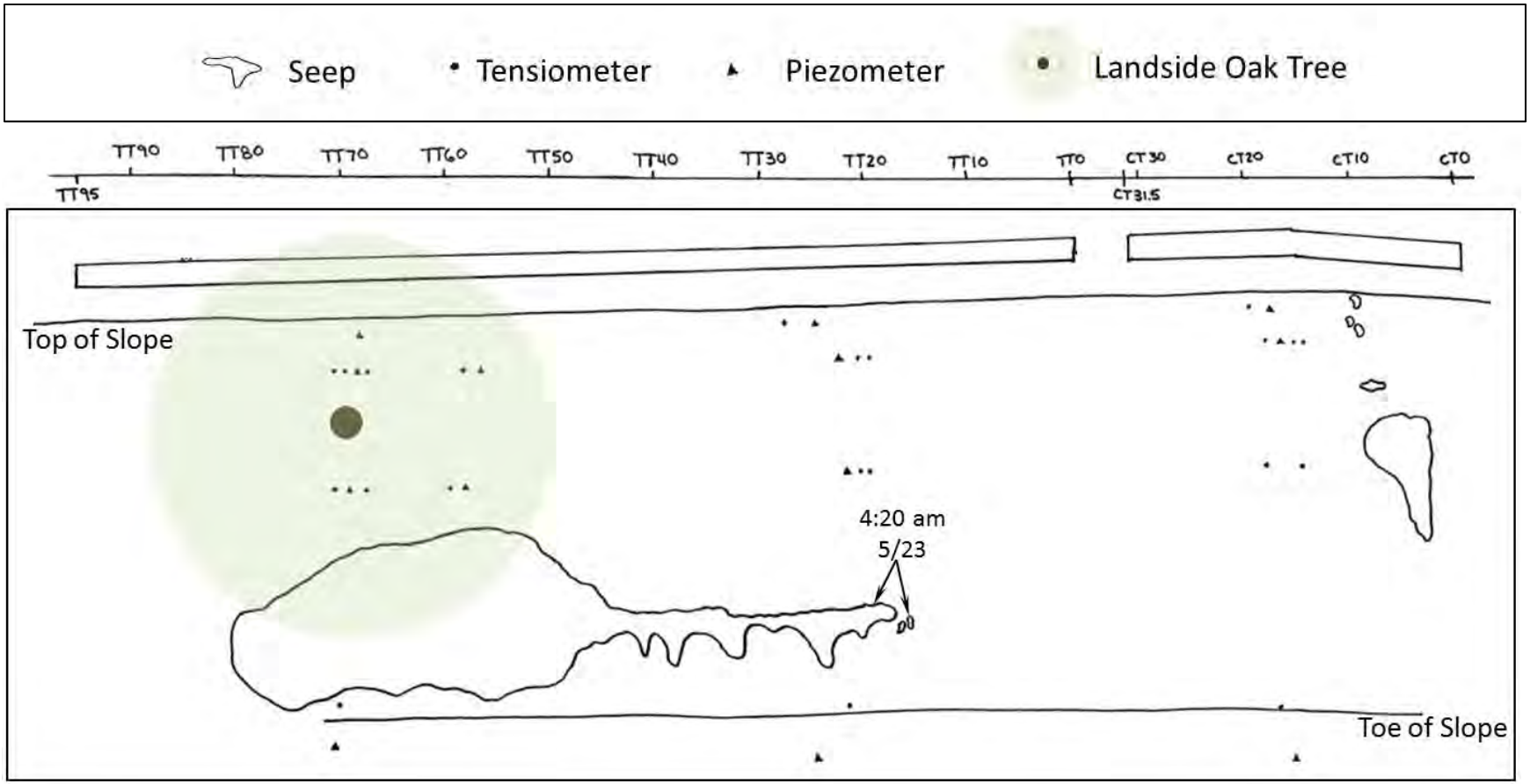


Figure 2-102. Sketch of landside seepage patterns: Time=43.8 hrs (9:30 am on 5/23/12).

Figure 2-103. Time = 43 hours (8:45 am on 5/23/12) Seepage on the landside Line C has significantly slowed in concentrated flow at macropores. Notice the waterside oak looks different in this series (top right, lower left) – it had rotated 20 degrees into the slough and was discovered just after this series of photographs was taken.

Figure 2-104. Time = 43 hours (8:45 am on 5/23/12). In the vicinity of Stations TT 45 to 60, seeps are observed to be flowing from tiny holes on the order of ¼ to ½ inch in diameter (lower photos). Later exploration revealed worm burrows in these locations as discussed in subsequent sections.

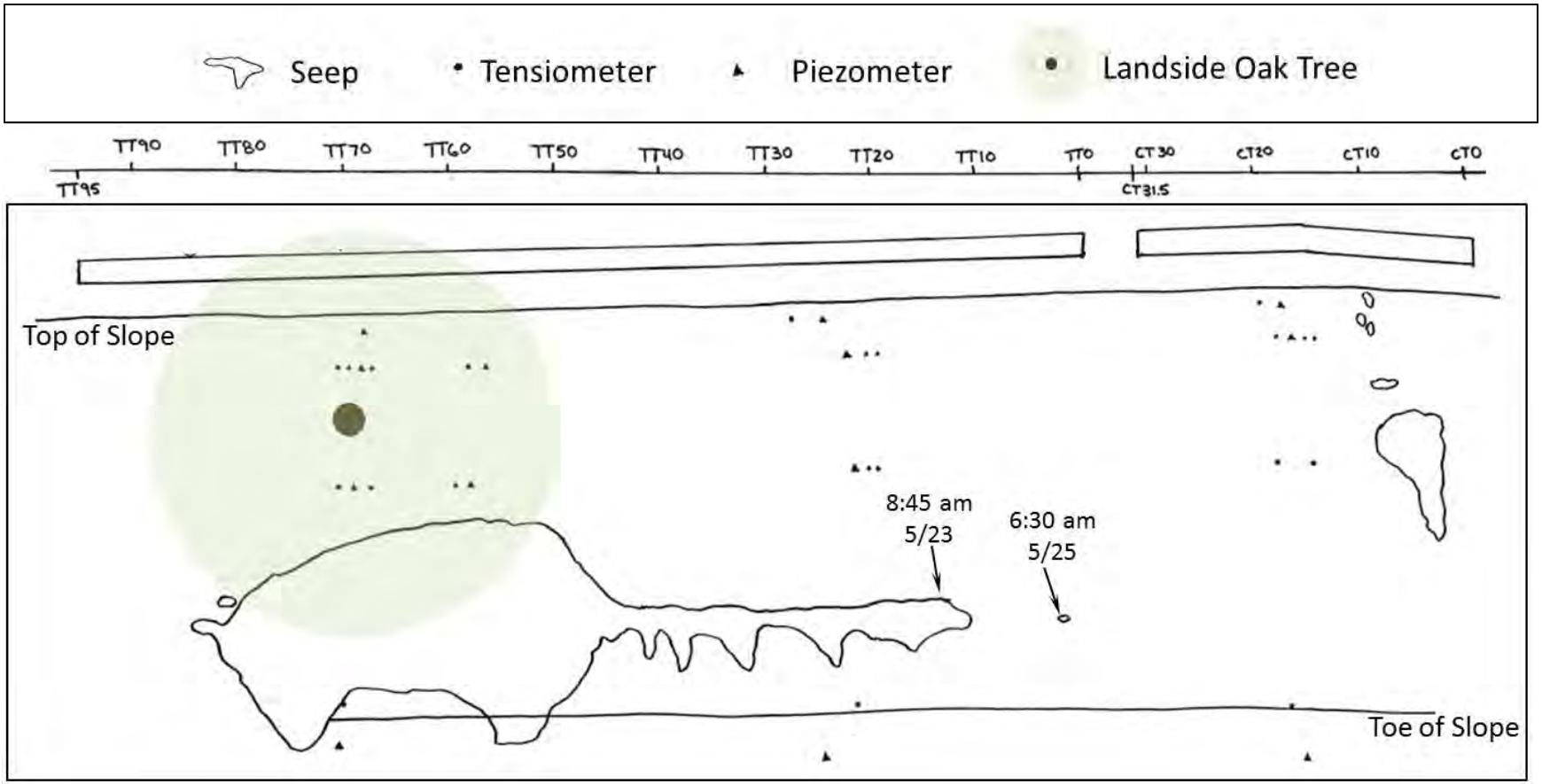


Figure 2-105. Sketch of landside seepage patterns: Time=92.8 hrs (6:30 am on 5/25/12).

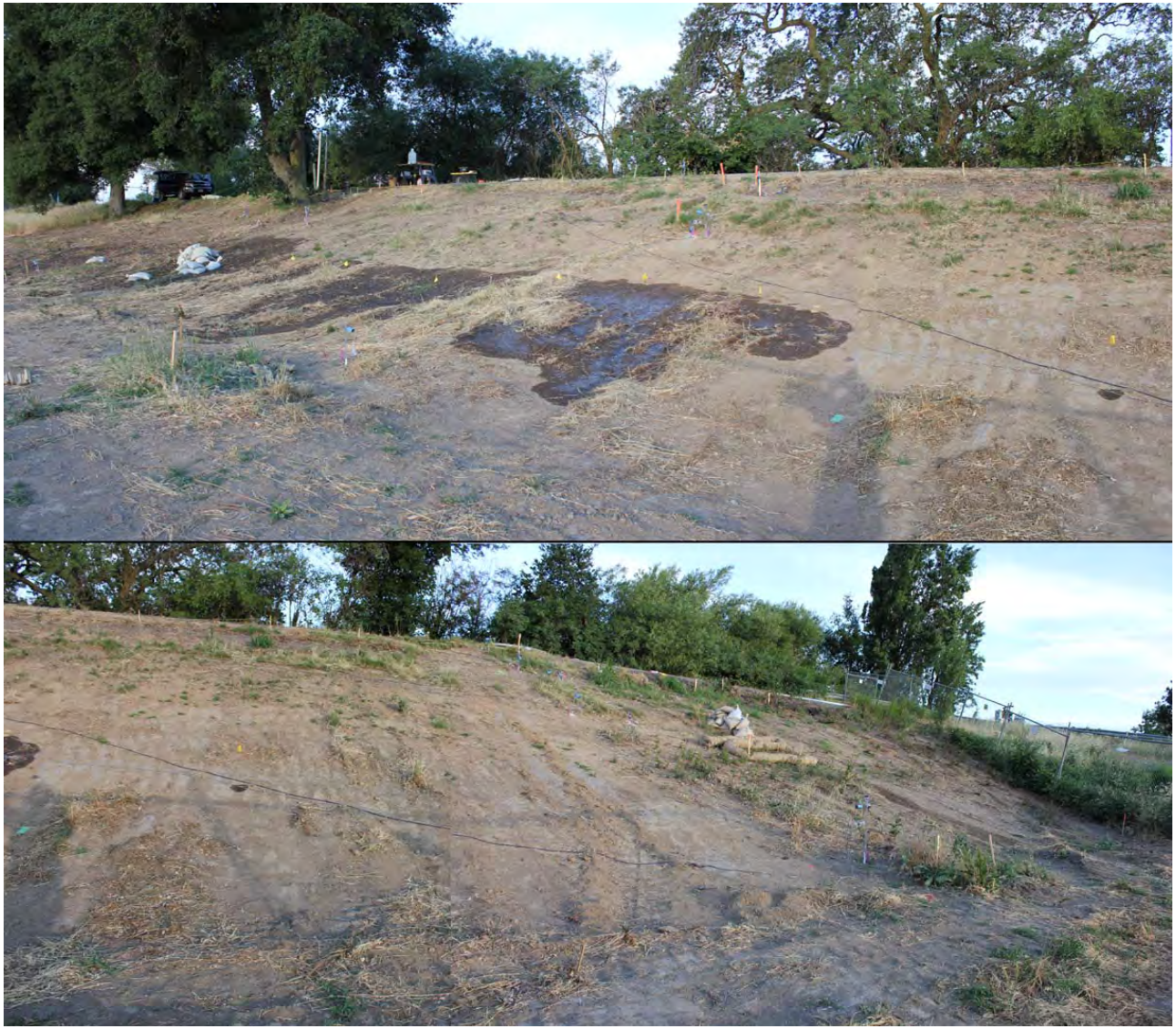


Figure 2-106. Time = 93 hours (6:45 am on 5/25/12); Small new seep near Station TT 3 while seeps to the south expand.

Figure 2-107. Time = 93 hours (6:45 am on 5/25/12). View west of Stations TT 45 to 90 (top) and Stations TT 60 to CT 10.

Figure 2-108. Time = 168.9 hours (5/28/12 at 2:35 pm). Tree trench was turned off on 5/25 at 1:45 pm and site has begun to dry up despite the fact that water has not fully drained from the tree trench. Note the blackberry vegetation beginning to grow back around the seepage areas north of instrument line C (lower right).

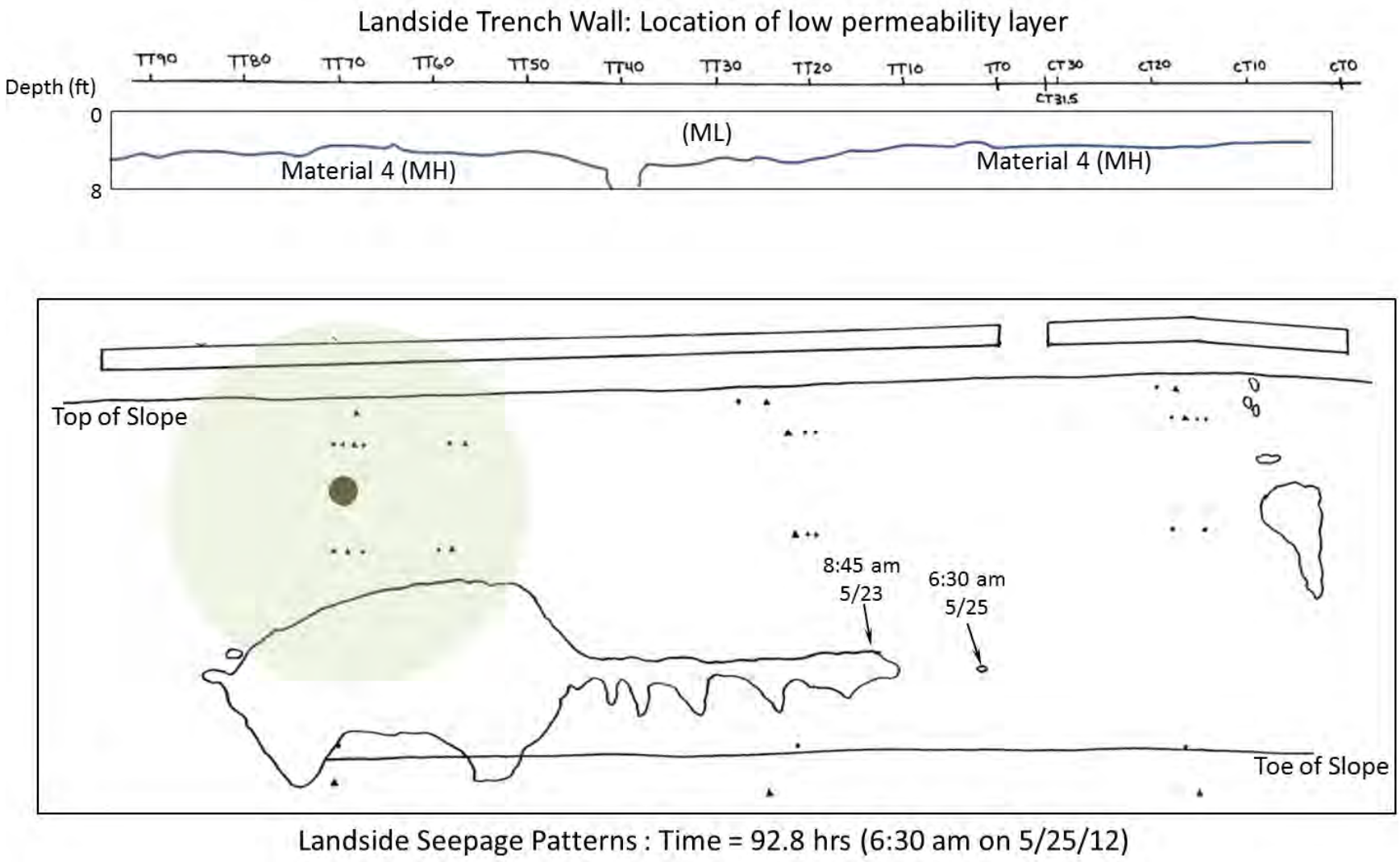


Figure 2-109. Simplified trench wall log showing the pattern of Material 4, the plastic silt that may be acting as a low permeability layer. The contact begins to dip to the south at Station TT0, disappears below the trench bottom between TT 37 and 42, and dips from Station TT 50 toward Station TT 40.

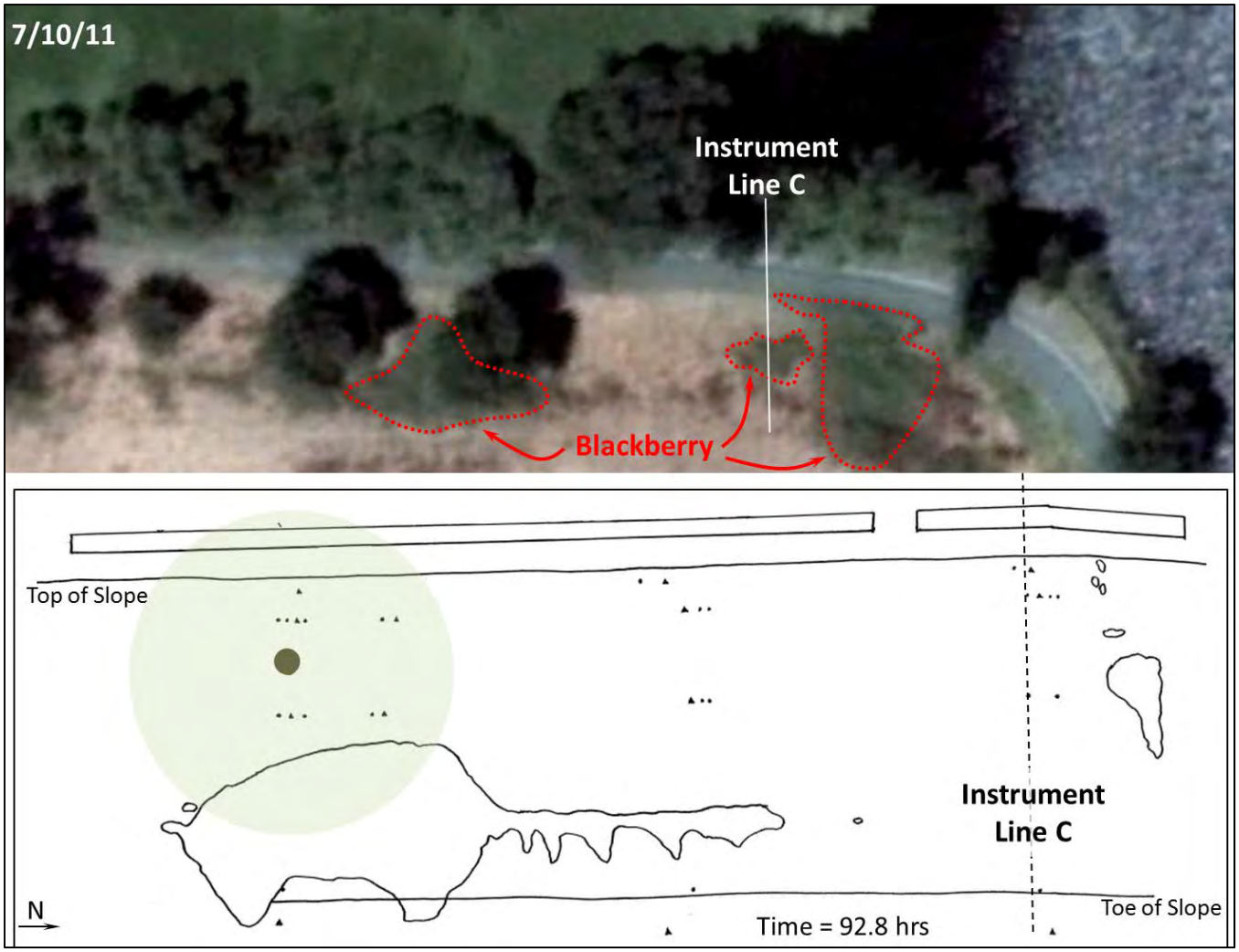


Figure 2-110. Seepage patterns at time = 92.8 hrs as compared with patterns of blackberry growth in the pre-test condition in July of 2011. Blackberry was dense in the locations indicated prior to our testing. Burrowing activity in areas north of the control instrument line C could be heard during the construction phase. Burrow activity was observed in both locations during trench construction.

2.6.2 Waterside: Seepage, Macroporosity, and Deformations

Deformations were observed at the site within the first 3 hours of flow and the first seep on the waterside, at the waterside oak, was observed about 9 hours into the test. Deformations consisted of those observed in pavements and slopes through observable cracks. Seepage records include those observed during the primary flow test. Access to the water side was limited due to high water levels during the flow test. Water levels were lower during the dye test (Section 2.6.3), allowing for a closer examination of seepage patterns and flow through macropores.

2.6.2.1 Pavement Crack Development and Monitoring

Figure 2-111 shows the location of a crack that appeared between the tree trench and the control trench less than 3 hours into the flow testing program. The crack continued to grow throughout the first day and began to develop a visible vertical offset by the end of the first day, about 9 hours into the flow test (Figure 2-112). Overnight, crack growth continued, reaching a maximum width of just under 0.6 inch and a vertical offset of $^{3}/_{8}$ inch at 13.3 hours into the flow test (Figure 2-113 and Figure 2-114).

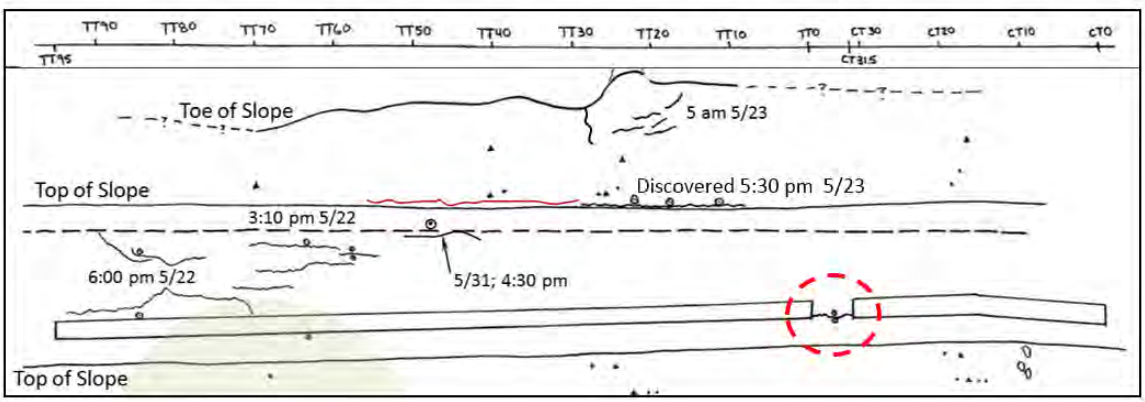


Figure 2-111. Cracking was observed in the pavement between the trenches (between Station CT 31.5 and TT 0) at 4:16 pm on the first day of the flow test (Time = 2.6 hours)

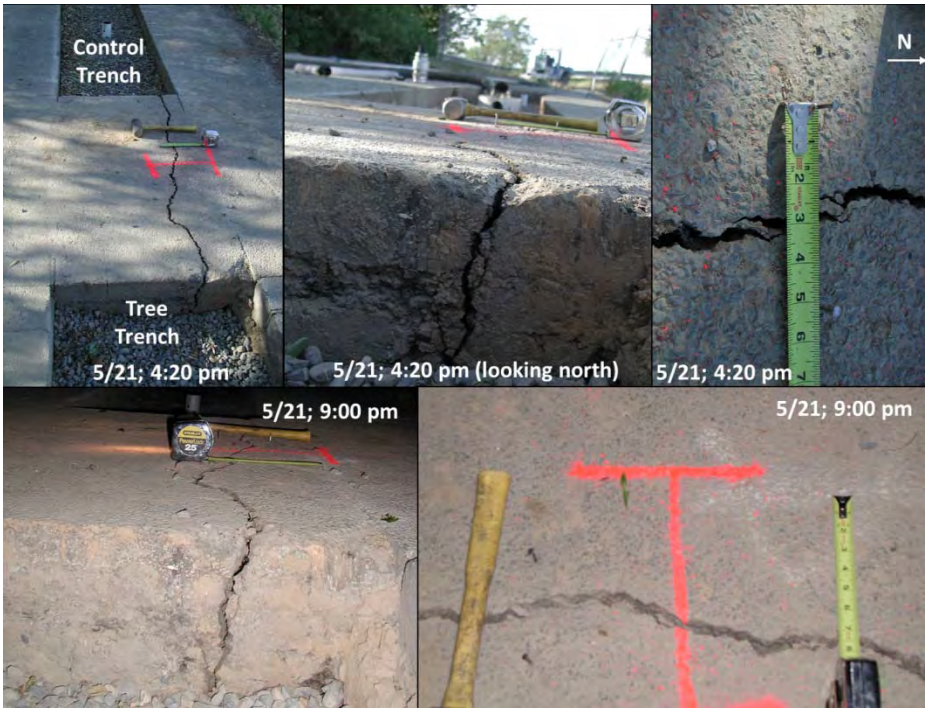


Figure 2-112. Cracking between tree trench on the first day of the field test (Time = 2.6 hours to 7.3). The crack grew and the waterside began to drop relative to the landside

Figure 2-113. Crack between trenches on the second day of the field test (Time = 16 to 30 hours). The crack achieved maximum size early in the morning and began to shrink throughout the day

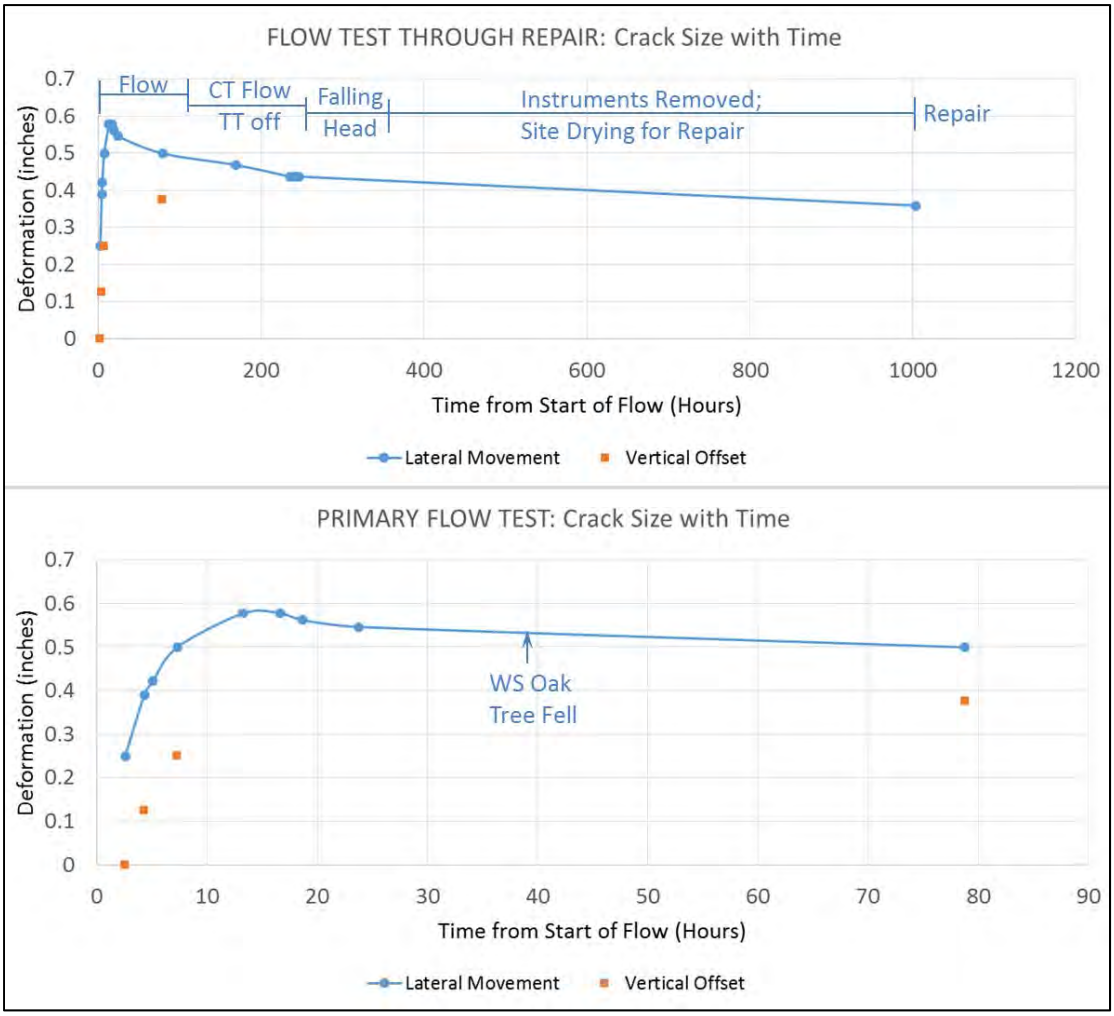


Figure 2-114. The size of the crack between the tree trench and the control trench was monitored as it grew to a maximum size and then began to get smaller. The crack peaked in size at about 13 hours into the flow test.

It was determined through analysis of photographs taken during construction that the crack may have been pre-existing. In Figure 2-115, the lower right photograph, taken after a rain, shows a dark spot appearing to be water in a crack in a location corresponding to the area moving during the flow test. The photo to the left shows the pavement, which looks like it may have an old crack in the appropriate location. Figure 2-116 shows a view of the cracking during the repair phase in July of 2012, after the flow test, as compared to the same section of pavement during trench construction. Based on the photo, the crack is more apparent on the control side than it is on the side of the tree trench. Further, in the photos, it appears as if the pavement has been overlain with a thick (approximately 6 inch) overlay. This type of overlay implies that the original pavement section was distressed, though implies nothing of the locations of the distress.

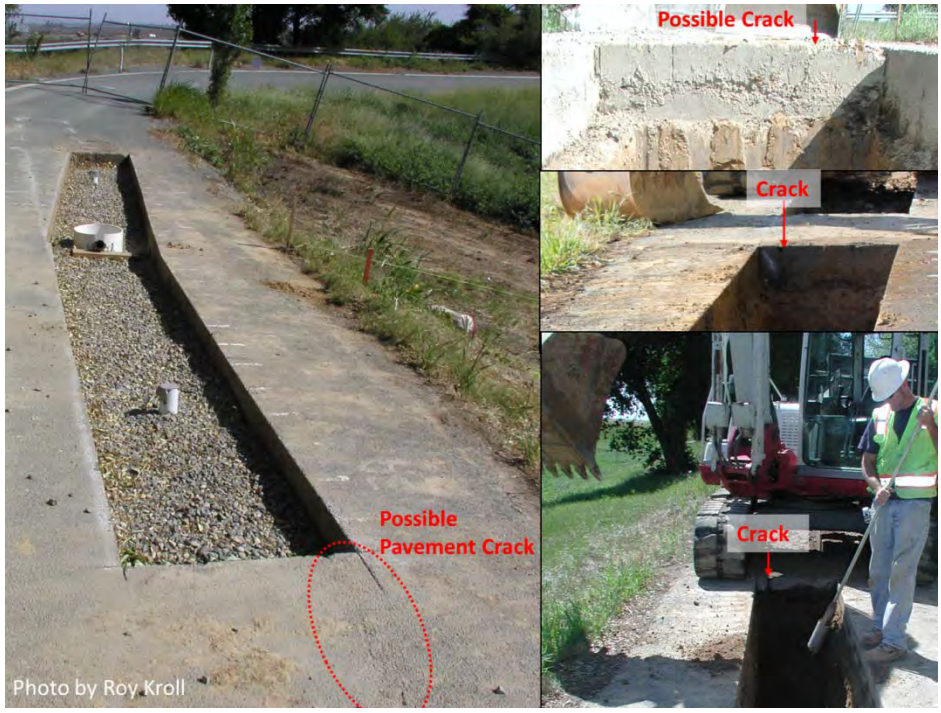


Figure 2-115. A crack may have existed between the trenches (left) prior to the flow test. Photos during trench construction show a clear crack on the control trench side (right middle and bottom) but it may not have extended to the tree trench side (upper right).

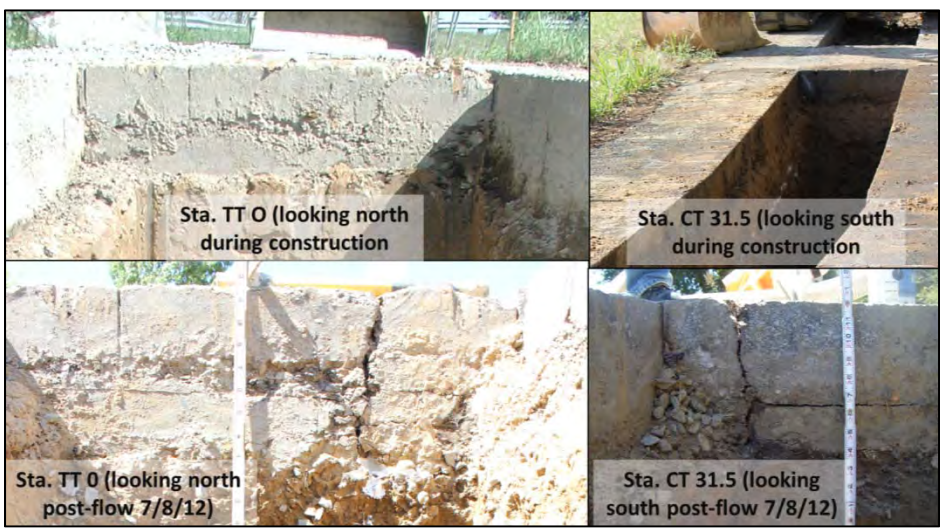


Figure 2-116. A close-in view of cracking in the asphalt between the trenches before (top) and after (bottom) the flow test. The pavement appears to have been overlaid as evidenced by the horizontal splitting of the lower section from the upper section (lower right).

In the afternoon of 5/22/12, a little over 25 hours into the flow test, a series of fine cracks opened up in the vicinity of Station TT53 to 73 ranging in size from hairline to $^{1}/_{8}$ inch (Figure 2-117). Monitors were installed (Figure 2-118) but did not yield measureable

movements after the cracks were observed. The cause of the cracking was not entirely clear, as discussed later.

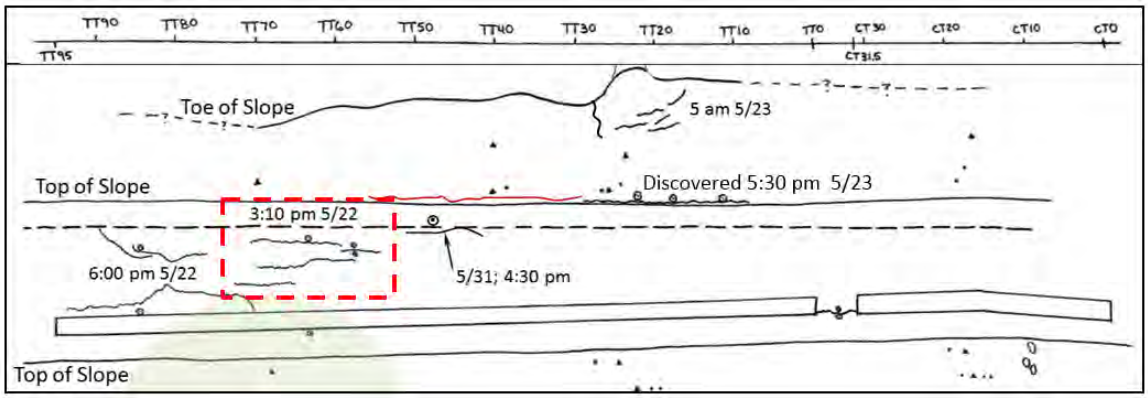


Figure 2-117. Cracking was observed in the pavements at approximate Stations TT 53 to 73 at 3:10 pm on the second day of the flow test (Time = 25.5 hours).

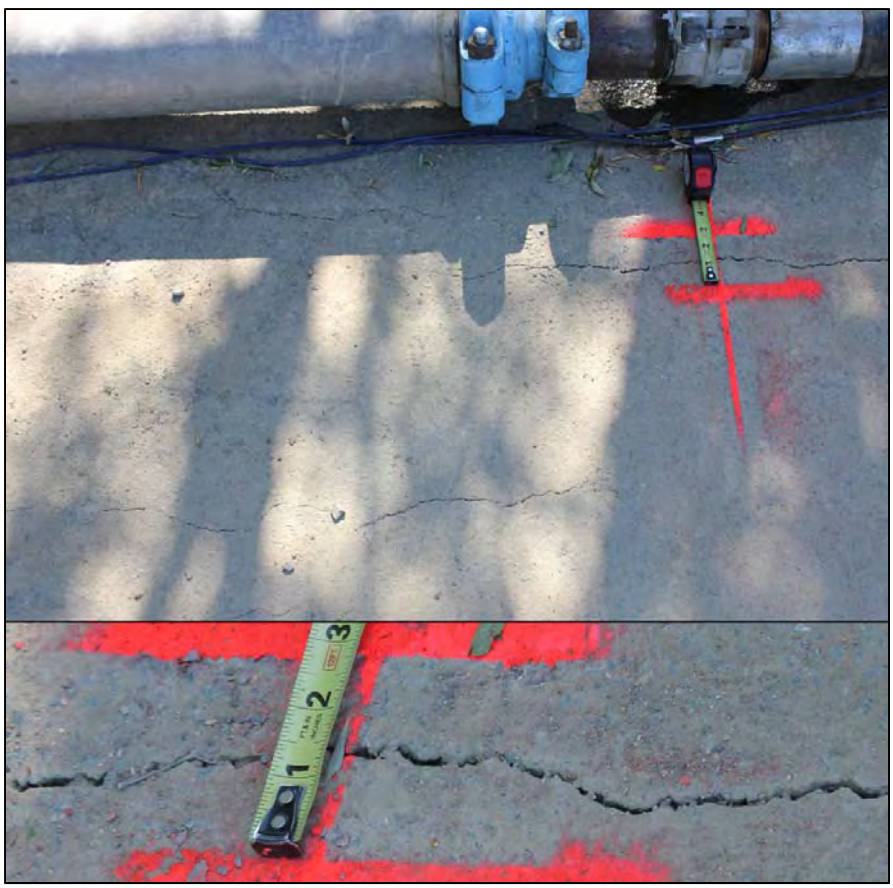


Figure 2-118. View of Stations TT 57 to 62 where cracking was observed in pavement 25.5 hours into the flow test. A monitor was installed at Station TT 58.5.

Figure 2-119 highlights cracking in the vicinity of Stations TT 70 to 95 first observed at 6 pm on 5/22/12, a little over 28 hours into the flow test. Cracking along the west side of the crown road appeared that it may continue into the waterside slope. Once the flow test was over, pipelines moved, and vegetation trimmed to allow for access, the area was inspected and a trace of the crack could not be found located (Figure 2-120).

The crack adjacent to the trench within this zone was first noticed during construction (Figure 2-119 and Figure 2-121). The crack may have been pre-existing, but grew during trench construction to have an offset of about $^{3}/_{8}$ inch before the flow test began (Figure 2-122). At the time of construction, there was a question as to whether the pavement had slid on the soils under equipment loading or if a segment of soil had moved with the pavement. Walls were cleaned and inspected along this segment of trench with special focus placed on the zones extending down the wall from where the cracks intersected the trench. Cracking extended a few inches into the soil and soils beneath appeared to be intact (Figure 2-122D and E). At a time of 28.3 hours into the flow test, signs of fresh movement were observable, though it was unclear whether movements were occurring towards the trench or whether the waterside block of soil was moving to the west.

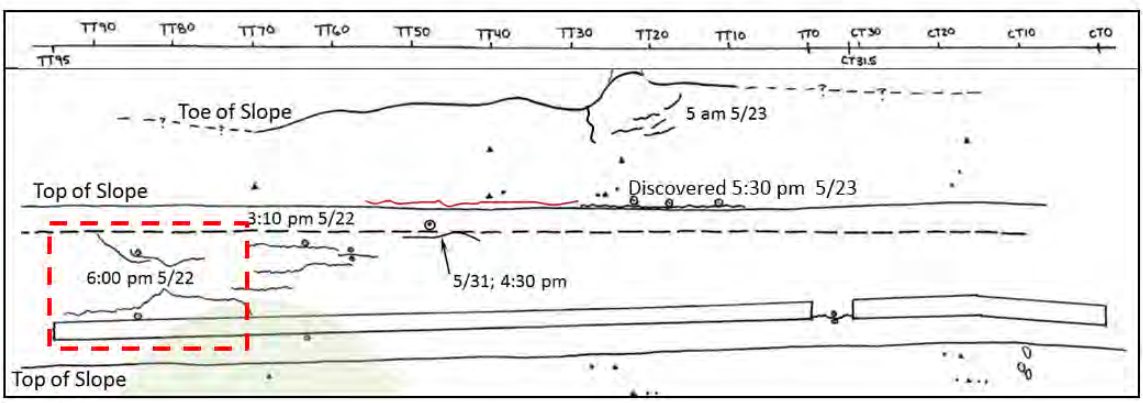


Figure 2-119. Cracking was observed in the pavements at approximate Stations TT 70 to 95 at 6 pm on the second day of the flow test (Time = 28.3 hours).

Figure 2-120. Waterside Station TT 85 to 90 on 6/8/12 after the tank, pipes, and wattles had been removed. Vegetation was locally cleared and the crack was not found extending outside of pavements.

Figure 2-121. Crack at Stations TT 70 to 95 seen through wide angle lens on 5/31/12 facing south. Cracking observed during original excavation but grew slightly (<1/8") during flow testing.

Figure 2-122. During trench construction Stations TT 70 to 95. A) Original crack appeared during 0 to 4 foot excavation but showed no offsets; B) During backfill with rock, 3/8" offset visible; C) Cracking may have been present before construction as it is seen on landside and waterside at Station TT 80-81; D) and E) Wall inspection at Station 70; crack not continuous down wall face.

Though the cause of movements between Stations TT 70 to 95 during the flow test is difficult to determine, Figure 2-123 shows this section during site repair after equipment loads collapsed the segment between Station TT 65 and 88. A clear failure plane is visible and in many locations the failure followed weak zones within the thinly bedded silt material (Material 2 as described previously) and along zones with dark staining appearing to be manganese oxides, commonly indicating previously existing fractures. Manganese oxide staining along fractures was discussed in an earlier description of materials encountered during trench construction. These stains were encountered throughout trenching activities, particularly in the most unstable wall sections. Dark staining can be seen in the overall wall failure photographs on Figure 2-123 with a close-in view on Figure 2-124.

Figure 2-123. Station TT 65 to TT 88 failed under equipment loading during repair. Dark staining appearing to be manganese oxides appear along the failure plane in numerous locations indicating possible pre-existing fracturing within the leve

Figure 2-124. Trench wall failure at Stations 65 to 88. Close in view at Station 75 shows fractures focused within weak zones of Material 2, thinly bedded sandy silt (top), and zones stained with manganese oxide, indicating previous fractures (bottom).

A crack of about $^1/_8$ to $^1/_4$ inch in size opened between the water delivery pipelines between Stations TT 40 and 52 on 5/31 in the afternoon of the dye test just a couple of hours before the end of the test (Figure 2-125 and Figure 2-126). A crack monitor was installed and the crack was inspected several times post-flow, displaying no additional movements.

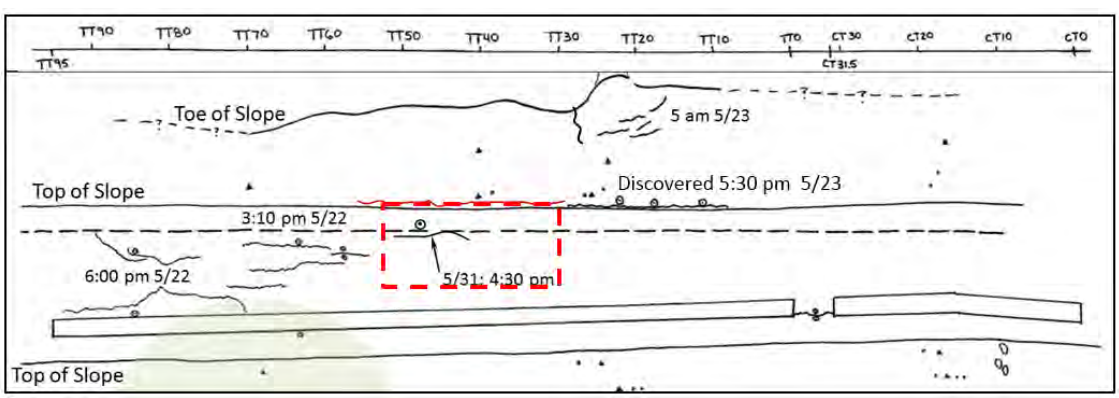


Figure 2-125. Cracking was observed in the pavements at approximate Stations TT 40 to 52 at 4:30 pm on 5/31, the last day of flow (Time = 242.8 hours)

Figure 2-126. Crack discovered on 5/31/12. No additional movement was recorded on the monitoring device (Stations TT 40 to 52).

2.6.2.2 Water Side Oak Tree, Slope Deformation, Seepage, and Burrows

On 5/23/12, the third day of the flow test, between about 4:45 am and 8:00 am (39 to 42.3 hours into the flow test), the waterside oak tree rotated approximately 20 degrees toward the oxbow section of the Sevenmile Slough, leaving a set of slope cracks that were apparent upon morning inspection of the site (Figure 2-127 through Figure 2-129). The likely time of the fall is somewhere between 5 and 5:30 am based on instrument data (discussed in subsequent sections). Figure 2-130 shows the study site from a distance before and after the tree fell.

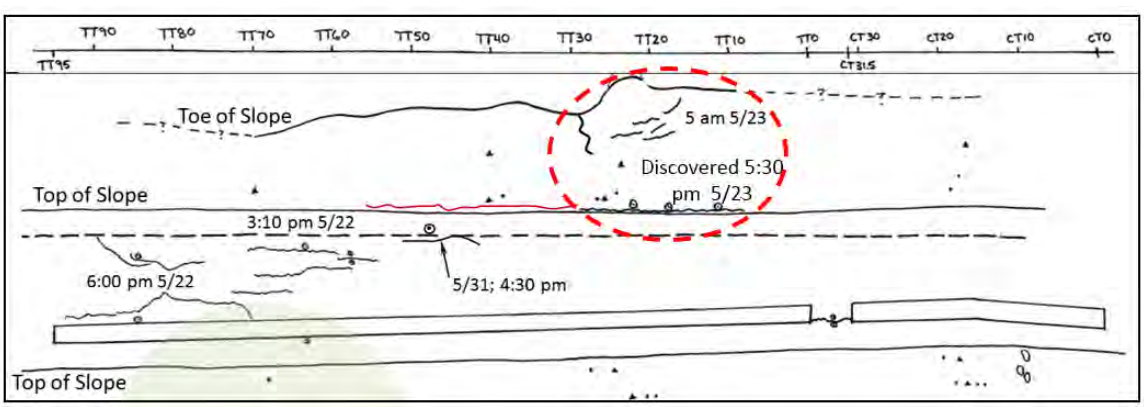


Figure 2-127. On 5/23, the third day of flow, the waterside oak tree was found to have fallen between 4:45 and 8 am (Time = 39 to 42.3 hours). Based on instrument readings, this may have been at about 5:00 to 5:30 am.

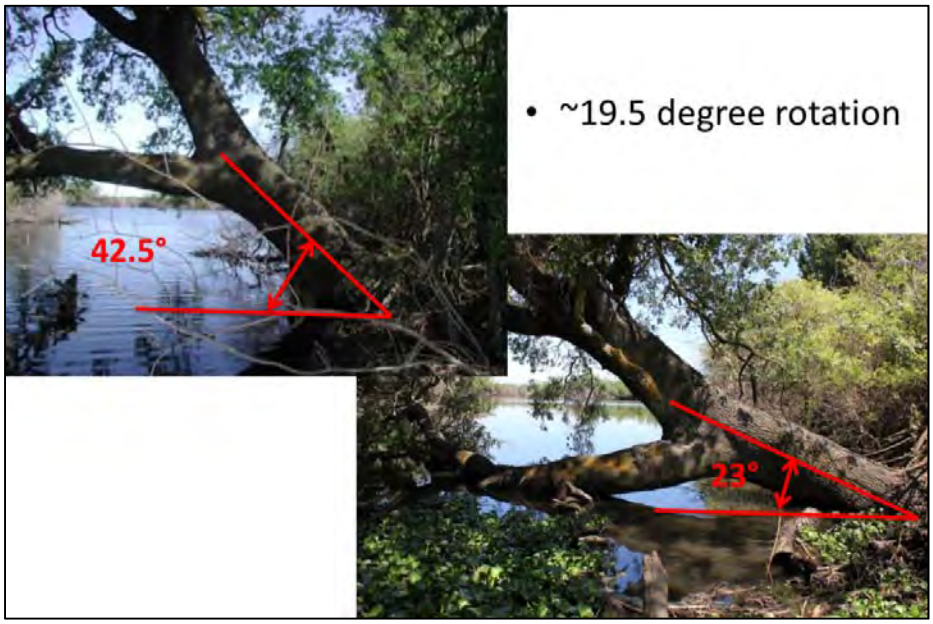


Figure 2-128. The waterside oak rotated just under about 20 degrees to rest the long waterside branch in the shallow oxbow section of the Sevenmile Slough.

Figure 2-129. The fallen waterside oak photographed from land (left) and the water (right).

Figure 2-130. View of the site from a distance showing the waterside tree before (top) and after (bottom) it had fallen.

A stake was placed in the slough just north of the waterside oak tree prior to the beginning of the flow test and was photographed periodically to track small variations in water level throughout the test. Based on discussions with the operator of the gate structure controlling flows into the Sevenmile Slough, the water levels typically vary not more than 2 feet but are based on tides and water uses of the local residents (as discussed under section titled Site Description). Gates are opened at high tide and closed as the tide retreats, trapping water for use by residents and farmers of Brannan and Twitchell Islands. As seen on Figure 2-131, the water level was relatively constant on 5/21/12 and 5/22/12 with an approximate water depth at the stake of 6 to 7 inches. The water level appears to have risen 5 inches to a depth of 11 inches by 4:30 am the morning of 5/31/12, just before the tree failure. The role that water level may have played is unclear, but saturation of the slope can soften soils and reduce strengths (Duncan and Wright, 2005), as discussed later.

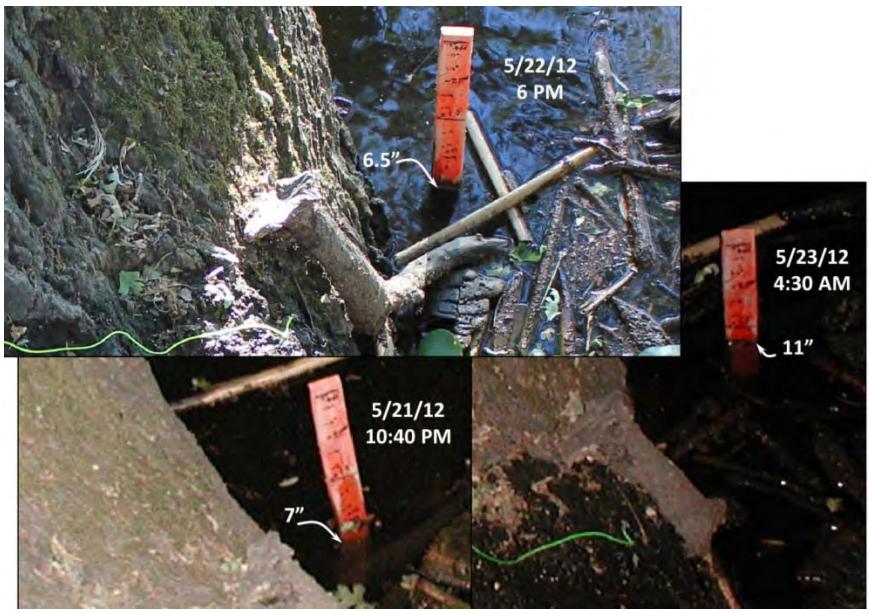


Figure 2-131. The water level in the slough had been about 6-7 inches deep prior to the failure. In the last photograph taken before the tree fell, the water level in the slough has risen 5 inches overnight.

Figure 2-132 through Figure 2-134 detail the deformation of the waterside slope that are believed to be directly associated with the movement of the waterside tree. Large cracks, one displaying about 12 inches of vertical offset, were present in the loose soils on the pathway leading down to the waterside tree, directly around the root ball (Figure 2-132). Figure 2-133 shows a view of these cracks taken from the fallen tree looking east at the levee access road, including a sketch of cracking found to the south of the tree. Figure 2-134 provides a detailed view of this cracking as well as a sketch of the approximate location. As shown on Figure 2-127 as well as Figure 2-133 through Figure 2-137, a crack was uncovered at the top of slope, running parallel to the levee just off the paved crown road. A small blackberry bush marked the end of the fresh crack and where an old crack extended along

the same alignment, not displaying movement in this event (Figure 2-136). The fresh crack intersected the grout of a piezometer that was installed prior to testing (Figure 2-137).

The size of the crack along the top of slope was initially 1 to 1 ½ inches in width at the time of discovery and was monitored for changes in size throughout the remainder of the flow test and repair effort with results presented as Figure 2-138. The crack grew throughout the primary flow test (ending at about 96 hours from the start of flow) and either retreated slightly or stayed the same size once the water to the tree trench was turned off. The crack began to grow again during the dye test, but all segments of the fresh crack had reduced in size at the time of repair in July of 2012.

Figure 2-132. The fallen waterside oak as seen from the crown road (left and upper right) and the access path to the water at instrument line E.

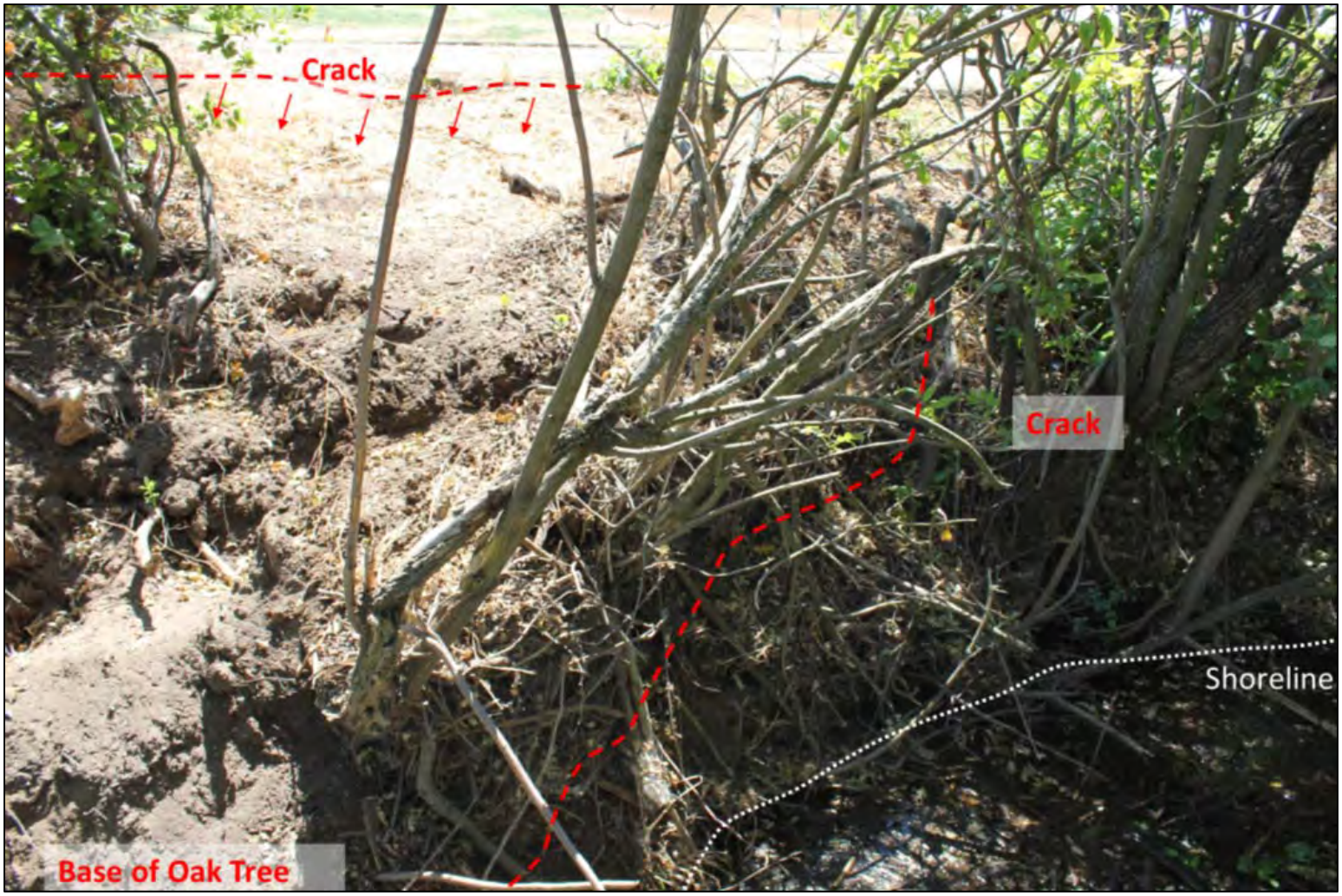


Figure 2-133. View of from the fallen waterside oak showing cracking patterns at the base of the tree and at the top of the slope.

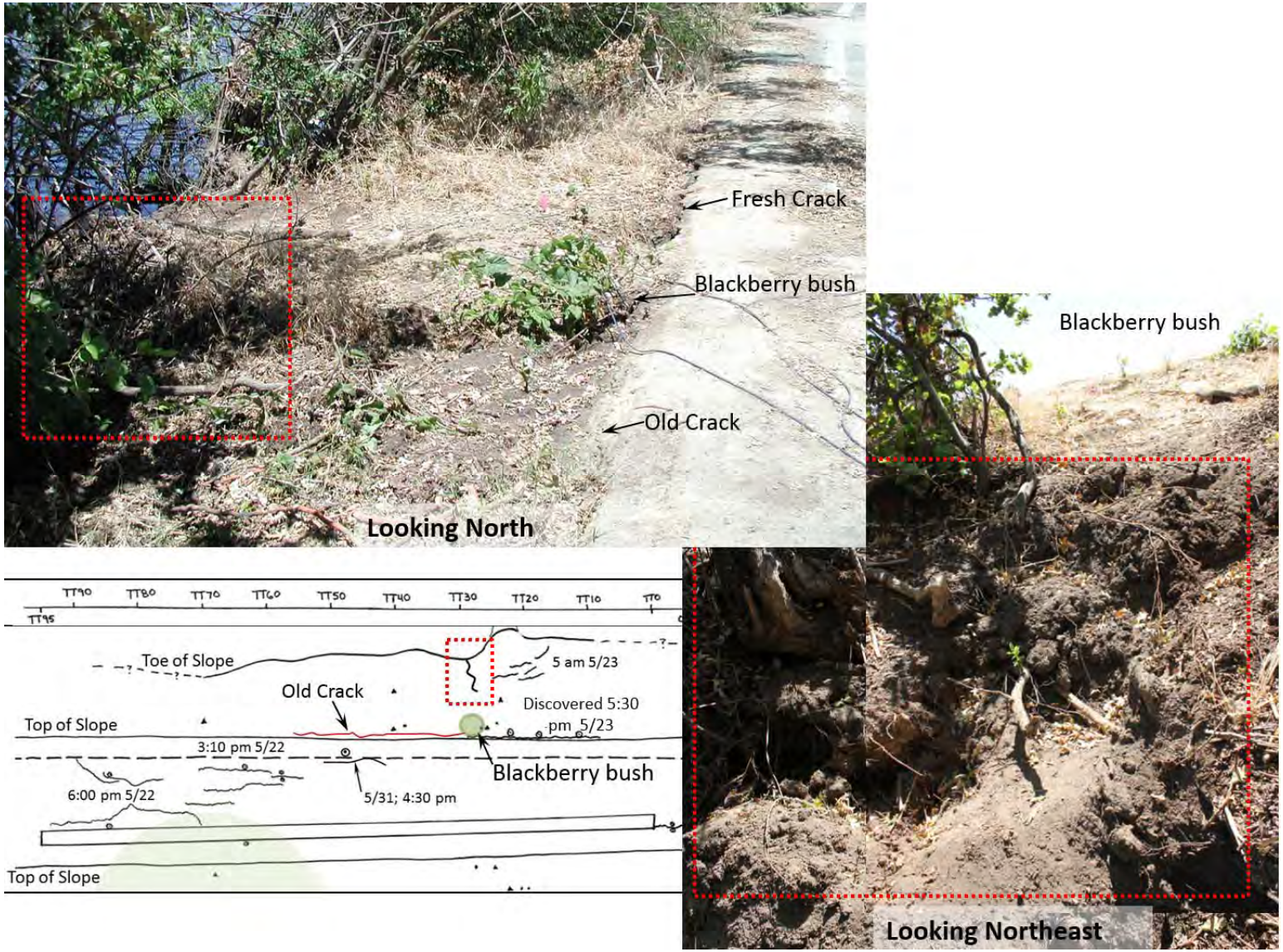


Figure 2-134. A view of the cracking within the loose waterside soils surrounding the fallen tree (right). Surficial excavation did not reveal a connection between this crack and cracking at the top of slope (upper and lower left).

Figure 2-135. In the afternoon of 5/23, during a visit from Dr. Les Harder of HDR, a fresh crack was revealed along the top of slope, previously concealed by leaves and an erosion control wattle.

Figure 2-136. A blackberry bush is the transition point between the fresh crack (left) and an older crack (right).

Figure 2-137. The grout of piezometer PB1 is intersected by the crack at the top of slope at the waterside oak.

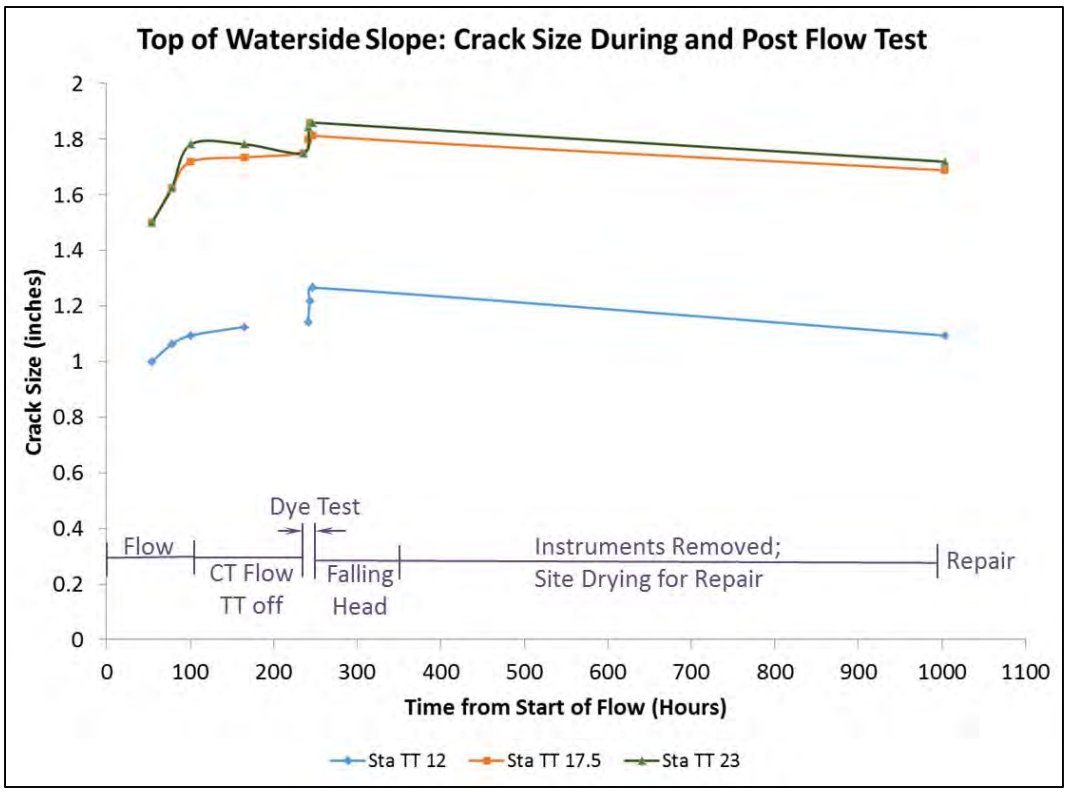


Figure 2-138. The crack at the top of the waterside slope was discovered on 5/23/12, the day the tree fell. The size of the crack was monitored throughout the flow test and just prior to repair.

An old crack was discovered extending along the top of slope just south of the actively moving top of slope crack as shown on Figure 2-139. The crack began at the southern end side of the blackberry bush shown on Figure 2-134 and Figure 2-136. Dead vegetation was found growing out of portions of it (Stations TT 49 to 55) as shown on Figure 2-140. Crack widths ranged from ½ to ¾ inch on this segment. Other segments appear to be little more than distressed pavement at the edge of the road (Figure 2-140), but showing small amounts of lateral offset toward the waterside (on the order of ½ inch or less). Fresh movement was not observed in these cracks during or in the weeks following our flow test.

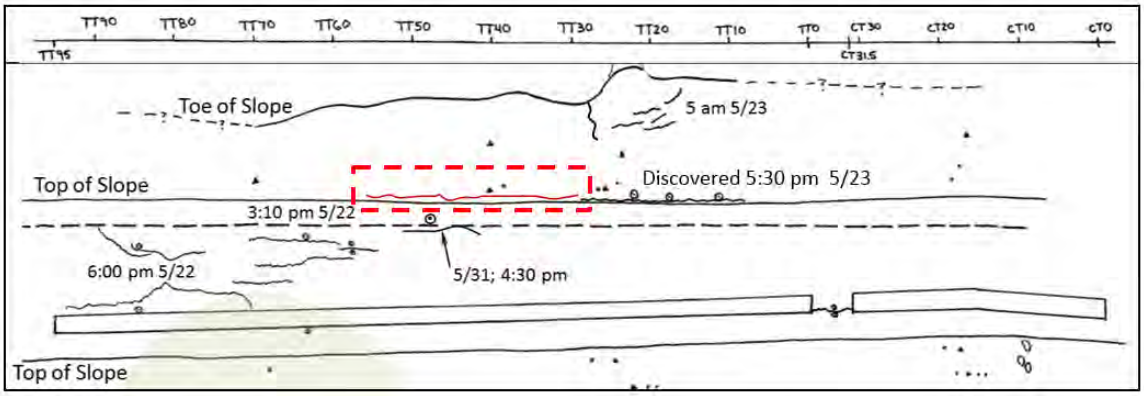


Figure 2-139. A crack at the top of slope (Stations TT 30 to TT 55) was found on 5/25. The crack did not exhibit signs of recent movement but rather is evidence of past deformation.

Figure 2-140. An older crack at Stations TT 30 to 55. Note dead plants rooted into the crack.

Seepage at the waterside oak tree was the first location that moisture was observed coming out of the slope at approximately Station TT 20. The seep was first spotted at 10:40 pm on 5/21/12, 9 hours into the flow test, at the location shown on Figure 2-141. By 6 pm the following day, nearly 29 hours into the flow test, seeps were encountered at Station TT 13 (just north of waterside oak) and TT 24 (just south of waterside oak). These seeps were coming from burrows that had been identified as likely muskrat burrow entrances during a visit by Dr. Van Vuren. Photographs of these burrow entrances are shown on 5/2/12 (the day of the walkover with Dr. Van Vuren) and on 5/23/12 at 1:40 pm, 48 hours into the flow test (Figure 2-142). The rate of flow within the burrows had slowed from the day prior, particularly the burrows to the south of the tree at Station TT 24.

Figure 2-143 shows the first seep, located at the waterside oak tree, just prior to the movement of the tree, as compared with photos of that location approximately 12 hours after the tree failure. The seep at that location appears to have subsided or the path of water outlet changed due to the tree movements. Water was not observed to seep from that location for the remainder of the experiment.

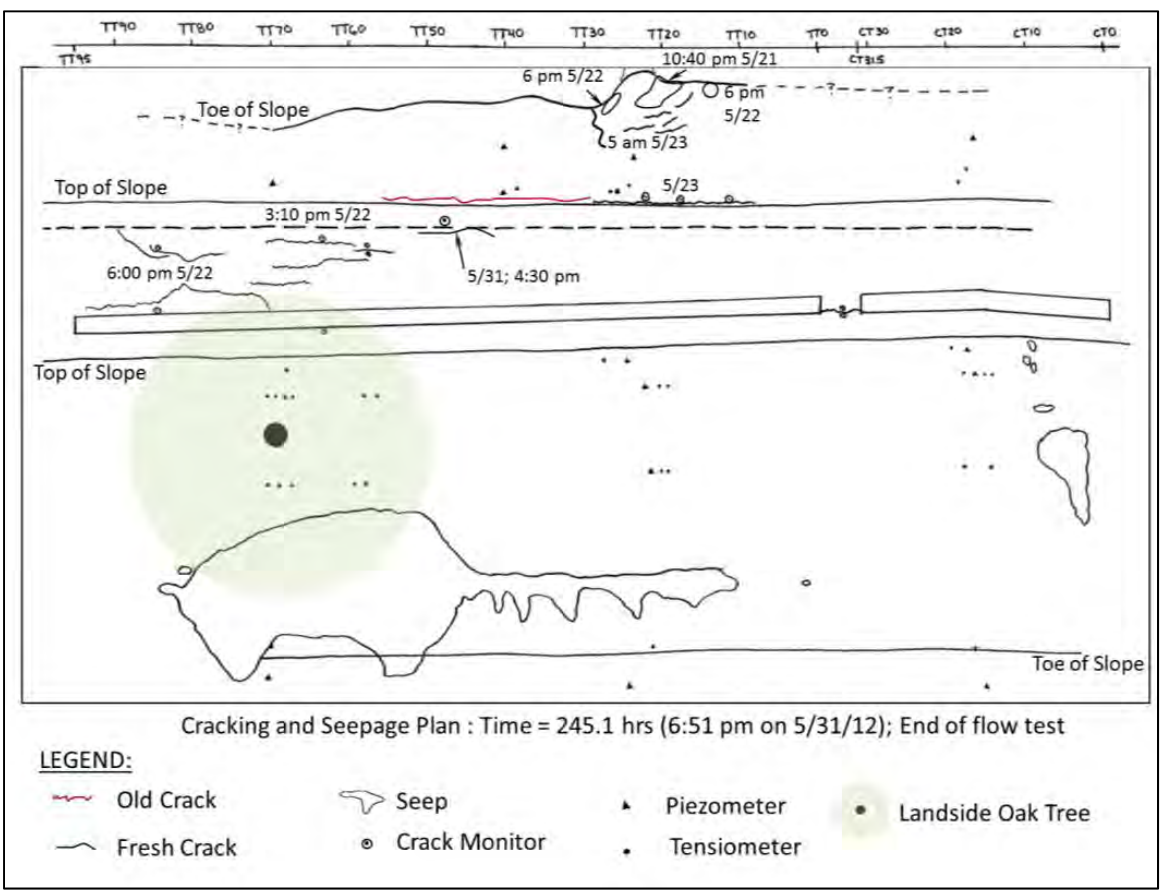


Figure 2-141. Cracking and seepage locations at the end of the flow test (Time = 245.1 hrs). Details for landslide seeps were presented previously.

Figure 2-142. Top photos show locations of suspected muskrat burrows identified by Dr. Dirk Van Vuren on 5/2/12. Photos below show corresponding locations (Station TT 13, left and Station TT 24, right) seeping during the flow test.

Figure 2-143. Location of first seep (found at 10:40 pm on 5/21) at the base of the waterside oak tree before (5/22 at 1:44 pm) and after the oak tree fell (6 pm on 5/23). Seepage at this location had ceased and begun to dry 12 hours after the tree fell.

2.6.3 Dye Test

The flow rates during the test were on the order of 7300 gallons each hour during the primary flow test. These rates were higher than expected for the 100-foot long 8-foot deep trench. In an effort to better understand the water losses at the site, a dye test was devised to improve our ability to identify locations where large water losses were occurring. Two gallons of Cole Parmer blue dye concentrate were used to perform the test. The water was turned off to both trenches between 9:15 am and 11:55 am on 5/31/12. The dye was mixed slowly into the water reservoir, one cup at a time, and the dye-tinted water was released into the trenches at 11:55 am. Figure 2-144 shows the location of seepage observed throughout the day. Generally, landside seepage patterns during the dye test mimicked those encountered during the primary flow test (Figure 2-145). Blue tinted water emerged from the landside at the locations and times indicated on Figure 2-144. Each of the locations correspond with burrowing activity observed within the trench excavation or at the slope surface, as further discussed in a photographic timeline of the dye test included as Table 2-3 at the end of this section.

Waterside seeps observed between Stations TT 13 and 24 during the primary flow test began to dry up following the fall of the waterside oak tree, as previously discussed. Figure 2-146 shows an early seep location, drying after the waterside oak has fallen and almost completely dry 4 hours into the dye test. The seeps surrounding the waterside oak tree did not flow during the dye test, while seepage was observed away from the tree. The water level in the Sevenmile Slough was held low during the dye test, by request of our team to the gate operator at Brannan Island. Access was possible with waterproof boots and careful footing. A boat was also made available by Mr. Rick Carter of RD 1601. Given these factors, we were able to make observations of seepage during the dye test in areas that were inaccessible during the primary flow phase. Seeps were photographed between Stations CT 15 and TT 0 as well as from Stations TT 45 to TT 70. Seeping burrows could be seen north of Station CT 15 and south of Station TT 70, but the locations could not be accessed.

Figure 2-147 provides photographic examples of seeping waterside burrows observed during the dye test. Blue dye was not observed flowing from the majority of the burrows during the limited timeframe of our dye test. Figure 2-148 shows a burrow at Station TT 70 that flowed blue-tinted water at a rate of approximately ½ gallon per minute. The burrow flow rate was measured with a graduated cup and timer at 6:30 pm (5/31/12). This burrow displayed the fastest flow rate observed in any burrow that was seen during our inspections, while the majority of burrows were found to slowly weep. Figure 2-149 shows burrows along the waterside slope toe on 6/1/12, the day after the dye test. Weeping of water had stopped. The photographs indicate the density of burrows along the toe of slope, typically out of view due to higher water levels. According to Dr. Van Vuren, muskrats prefer entry under the water. A detailed photographic timeline is provided for the events and key observations associated with the dye test on 5/31/12 (Table 2-3) while dates are provided for previously observed features.

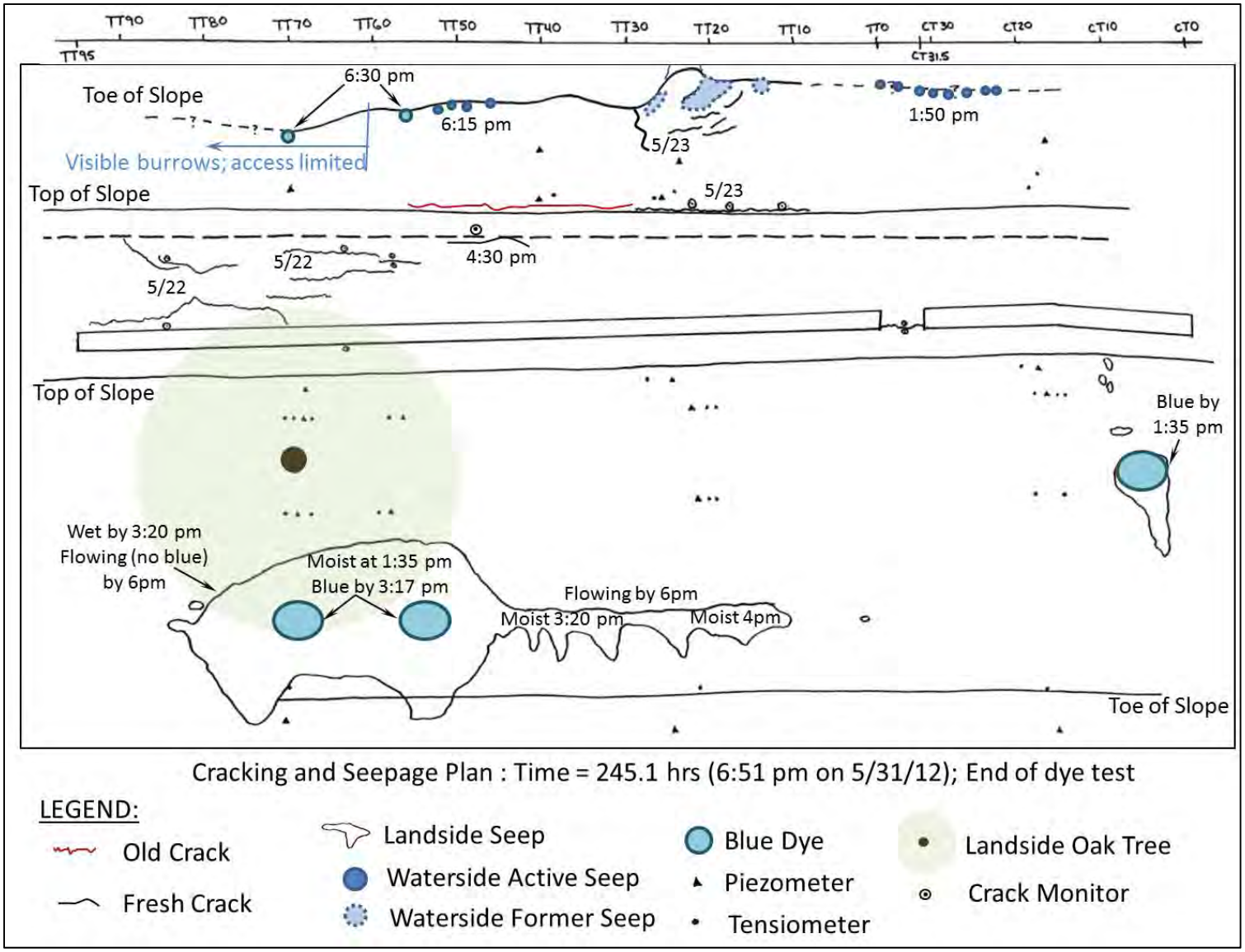


Figure 2-144. Cracking and seepage plan showing findings of dye test on 5/31/12. Dye began at 11:55 am (Time = 238.2 hours).

Figure 2-145. Flow on the landside at the end of the dye test (Time = 245.1 hours).

Figure 2-146. Several hours into the dye test, early seep discovered at waterside oak ceased flowing once the tree fell (left) and did not begin flowing again during the dye test on 5/31 (right).

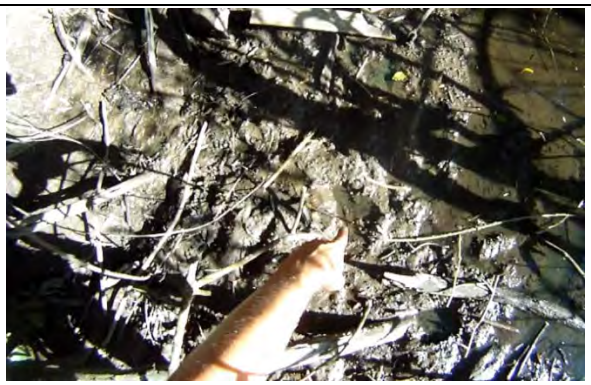
Figure 2-147. Burrows were observed flowing during the dye test both to the north and south of the waterside oak tree. Note a crawdad at the entrance to a burrow (top right).

Figure 2-148. Burrow at Station TT 70 flows blue-tinted water at a measured rate of about ½ gallon per minute from a 2 ½ inch diameter burrow, likely muskrat.

Figure 2-149. Photos taken on 6/1/12, the day after completion of the flow test. The waterside burrows are photographed and observed to have stopped flowing.

Table 2-3. Observational timeline during the dye test on 5/31/12

235.5	5/31	09:14	Turned off water to control trench in an effort to concentrate the pulse of dye injected into the test	
238.2	5/31	11:55	Turn on water to both control and tree trenches using visible range blue dye to help determine locations of concentrated water flow	
239.7	5/31	12:38	Trenches filled with dye-infused water	

239.9	5/31	13:35	Seep observed with blue dye at Stations CT 3 to 7 in area where gravel bags were placed during the primary flow test	
169.6	5/31	15:17	Seep Station TT 70 appears blue (photo right) while Stations TT 75 to 84 are running clear. Stations TT 48 to 84 appearing wet and Stations TT 20 to 48 appear to have moistened	
244.8	5/31	18:30	Blue dye is found in water seeping from a waterside burrow at Station TT 56.	
245	5/31	18:43	Flow rate is measured at ½ gallon per minute in burrow at Sta. TT 70.	See Figure 2-148

245.1	5/31	18:51	Water off; begin falling head test	

2.6.4 Instrument Data

Tensiometers and piezometers measured negative and positive pore water pressures before, during, and after the flow test. For this discussion, results are broken into landside instruments and waterside instruments. Complete results of all instruments including a discussion of instruments used and their calibration are presented in Appendix F.

2.6.4.1 Landside

Landside tensiometer results during the 4-day primary flow test and the complete 15-day flow test with post flow period are summarized by instrument line and presented below. The primary flow test represents the time when both trenches were filled to a constant head. Figure 2-150, Figure 2-151, Figure 2-152 and Figure 2-153 show results of instrument lines A, B, C, and D, respectively, during primary flow. Some instruments experienced problems retaining water and sustaining suction, possibly due to an imperfect seal. Tensiometers TC3-36, TB5-36, TA3-36, TC4-24, and TA5-24 began to drop water levels and suction potentially while the instrument is still re-gaining suction after the instrument was opened for filling. In many cases, the data are sufficient to determine the arrival of the wetting front, but the peak values of suction may not have been reached and, therefore, reported values may not be reliable other than to provide a lower bound on the suction value.

Landside piezometer results are presented as analogous rows plotted together beginning with row 2 at the top of the levee (Figure 2-154) followed by row 4, just above the landside oak (Figure 2-155 and Figure 2-156), row 5, just below the landside oak (Figure 2-157), and row 3 at the toe of slope (Figure 2-158). For ease of comparison, summaries of time of arrival of the wetting front and saturation are provided for each landside tensiometer on Table 2-4. Similarly, time to wetting front arrival, the value of and time of steady state pore pressure for each piezometer are provided on

Table 2-5.

Instrument line C, at the control trench, began with saturation of the 36 inch deep instrument at row 2 and the 60 inch instrument at row 4. Looking at Figure 2-30, these instruments are in close proximity to one another. They may be connected by a sand lens, a burrow, or fracture as they saturated at close to the same time. TC4-24 is the only shallow instrument on site that saturated before the adjacent instrument at a depth of 36 inch. This

24 inch deep tensiometer was positioned closest to the burrow encountered during trenching as well as those discovered in post-flow exploration, as will be discussed in a subsequent section. In row 4, the 60 inch deep tensiometer saturates at 3.9 hours, the 24 inch instrument saturates in 9.8 hours, and the 36 inch instrument between them saturates in 11 hours. This is an indication of non-uniform flow, likely related to the burrowing activity that we have seen evidence of. Burrows seen at this location have been shallow, in the upper 3 feet of the control trench.

In comparison, row 2 of instrument lines A and B takes 2.5 to 3 times longer to arrive at TB2-36 and TA2-36 than TC2-36. Arrival of the wetting front is again faster at line C for Row 4 at 24 inch and 60 inch depths. Arrival times at row 4 between all three instruments are comparable at 36 inch depth. Comparison of piezometer PA4a and b, PD4 a and b, and PC4a and b show pore water pressures at steady state to be increased by about 40 percent in the zone behind the landside tree root system. This was calculated by averaging the steady state pore water pressure for instrument lines A and C and comparing it against analogous instruments of Lines B and C.

Within a few hours of saturation at row 4, instrument line A sees a progression of the wetting front to row 5, below the landside tree. Wetting front arrival times and pore water pressures are very consistent between lines A and D. All line A and D instruments show an arrival of wetting about 12.5 hours into the flow test. Three hours later, water was seen seeping from the slope below row 5 instruments.

Row 5 of instrument lines B and C exhibited different behavior. Although instrument Line C saturated at Rows 2 and 4 ahead of line A, row 5 never saturated and took nearly 6 days for the wetting front to arrive at TC5-36 and over 8 days to arrive at TC5-24. As discussed previously, stratigraphic sections show a low permeability layer that appears to be an original levee, or possibly a natural levee (Material 4), beneath loosely placed, more recent silt fills. A steeply dipping gap in the otherwise consistent Material 4 is shown on trench logs (Figure 2-86) dipping toward this gap segment (Station TT 37 to 42). The shape and loose backfill of this feature are indicative of a possible historic breach or scour event or excavation at this location. The older levee embedded within the existing levee may have features and contours that affect flow patterns, possibly developed and erosion rills from past flooding. The water may be re-directed through such a feature, or through macroporosity within the shallower soil layers. There does, however, in viewing trench logs (Figure 2-85 to Figure 2-88) seem to be a general tilt in the material 4 layer toward this possible breach, which could be affecting flow patterns at instrument lines B and C. Steady state at instrument line C was not a saturated condition for rows 5 and 3, indicating that stratigraphy may have added a three dimensional effect to data interpretation.

Row 3, at the toe of slope, yielded little in the way of results at the tensiometer instruments as instrument line A shows zero suction throughout the test and seems to not be able to maintain suction. TB3 eventually saturates at 65 hours, while TC3 maintains the same suction throughout the test.

Piezometers located in row 3 at the toe of slope are not all the same depth. PB3 was installed deeper and under the groundwater so that effects on the groundwater table could be monitored. The instruments were building pore water pressure steadily and had not achieved steady state. PB3 predictably begins to build water pressure before PA3 and PC3. PA3, however, begins to build pore pressure prior to the arrival of hydrostatic water pressures as measured by PB3.

It should be noted that there is a gap in the data of some of the piezometers between 72 and 99 hours into the field test due to an equipment difficulty. Most instruments have reached steady state before this data gap, but pore water pressures at piezometers P3B and P3C were still rising. The comparison of total head provided in Table 2-5 is based on the readings at 99 hours for PA3, PB3, and PC3 rather than 96 hours (when the water was turned off) for best comparison between the instruments.

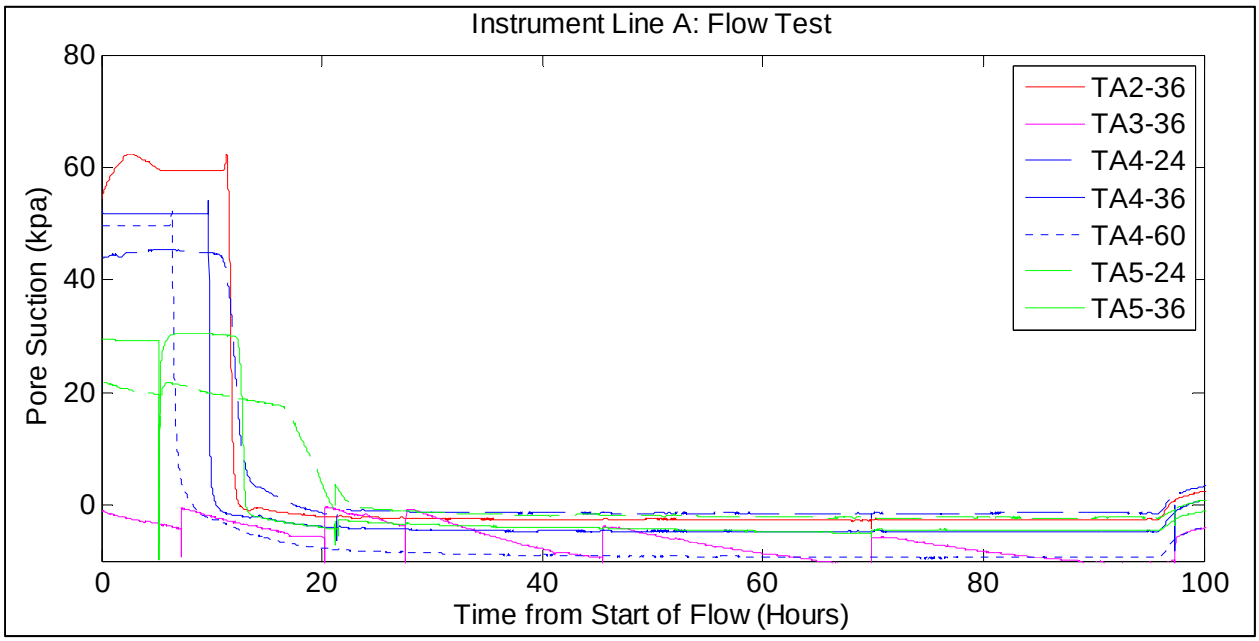


Figure 2-150. Tensiometer data for the primary flow test at instrument line A.

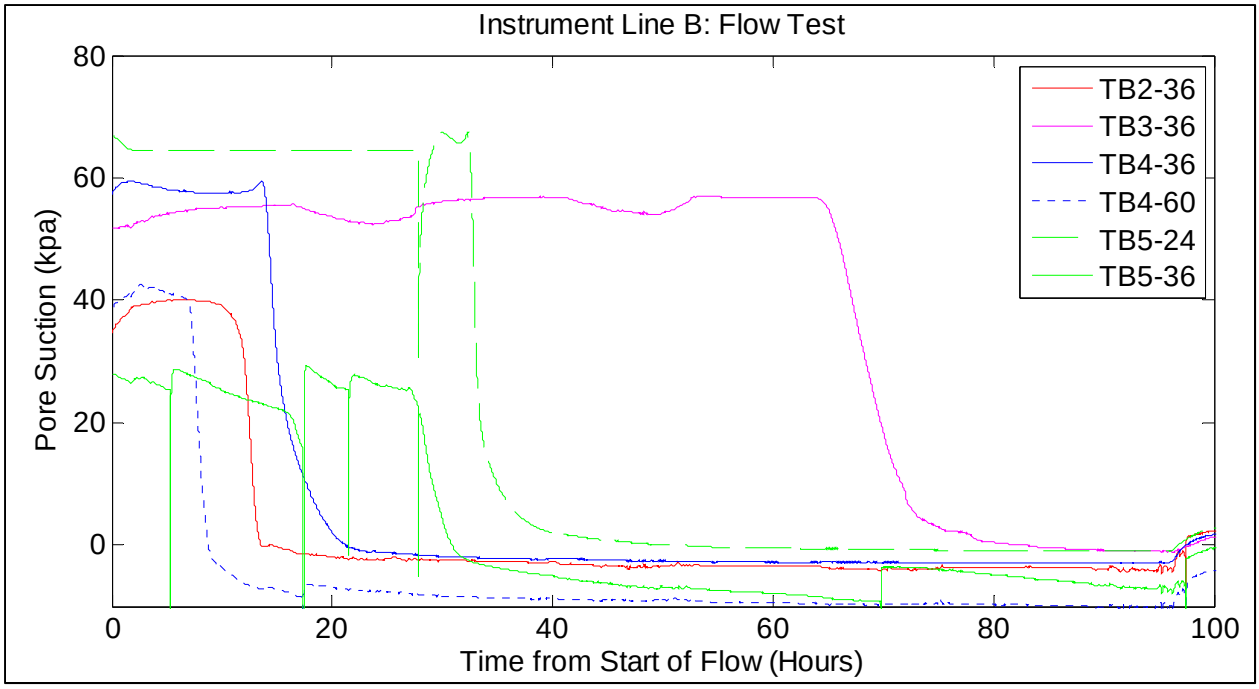


Figure 2-151. Tensiometer data for the primary flow test at instrument line B.

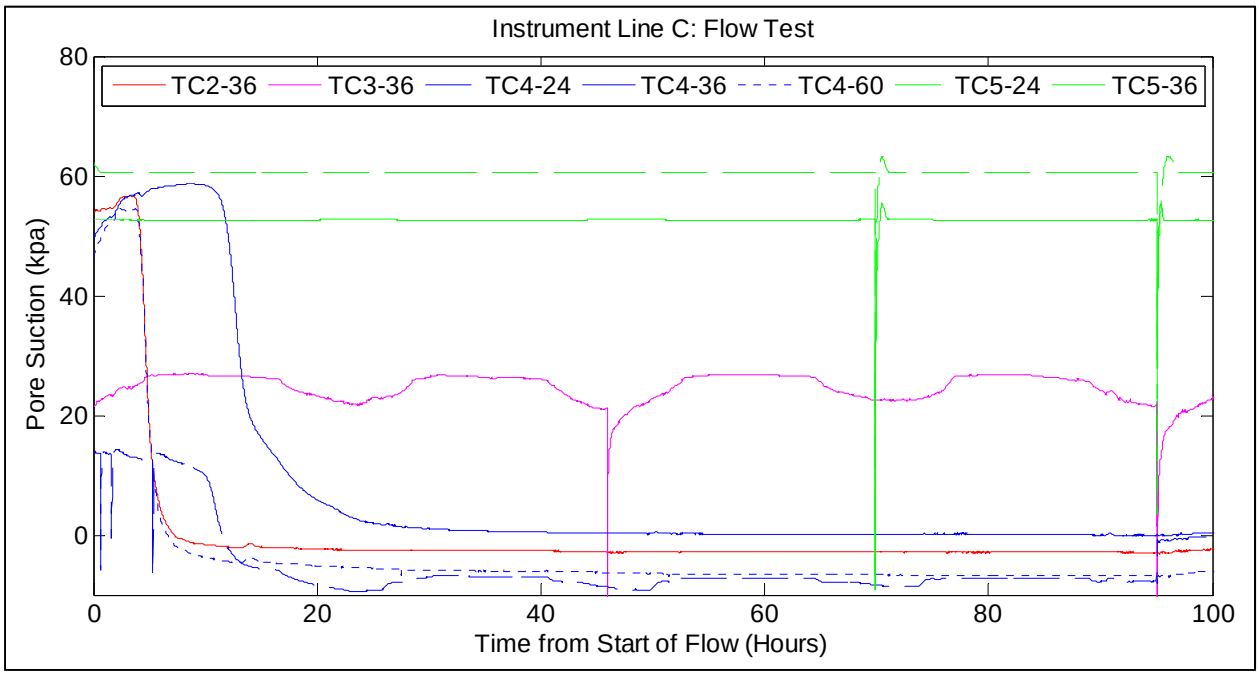


Figure 2-152. Tensiometer data for the primary flow test at instrument line C.

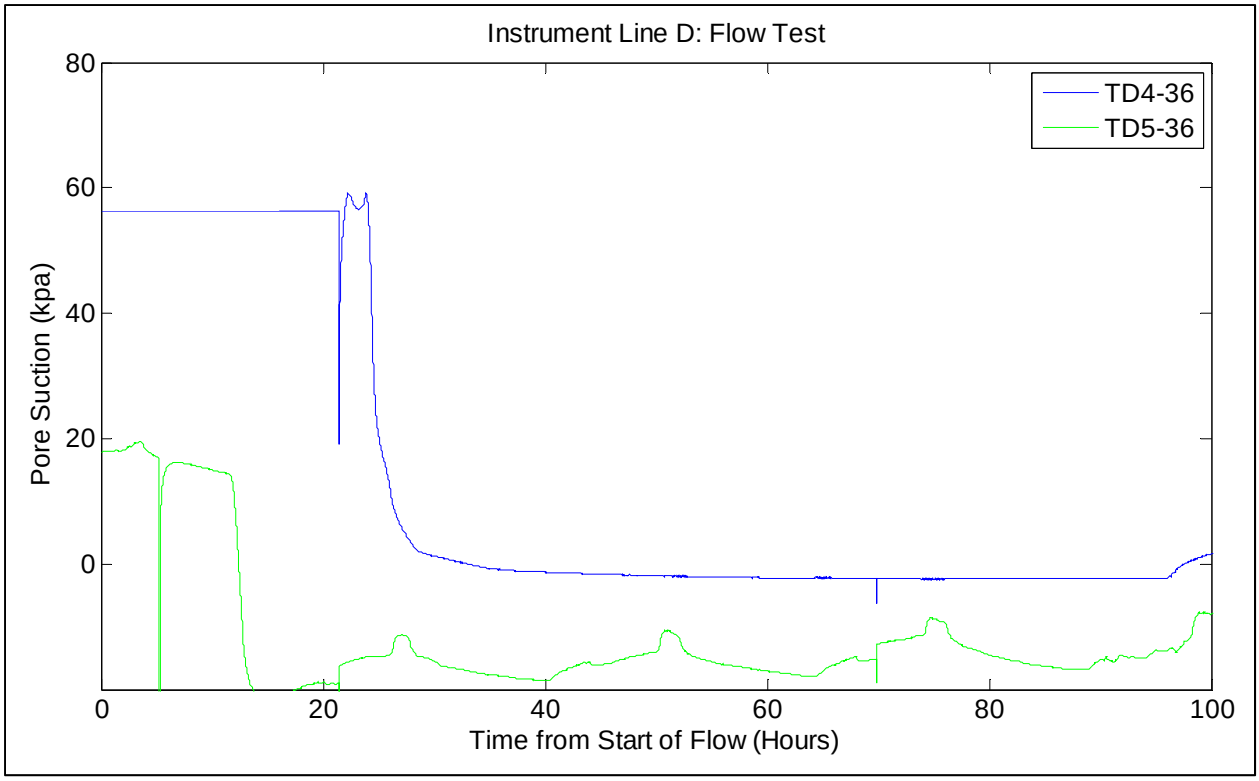


Figure 2-153. Tensiometer data for the primary flow test at instrument line D.

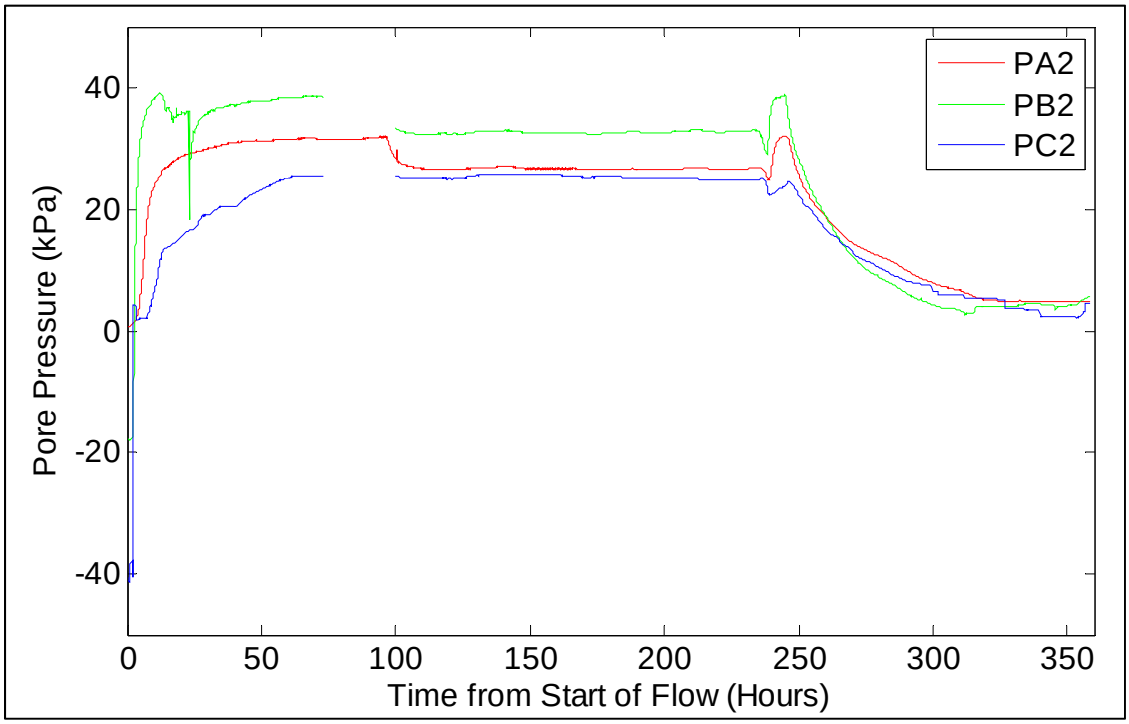


Figure 2-154. Piezometer data for the 10-day flow test and post flow at instrument row 2 (at the top of the slope) at depths of 15, 15.9, and 12.4 feet for lines A, B, and C, respectively.

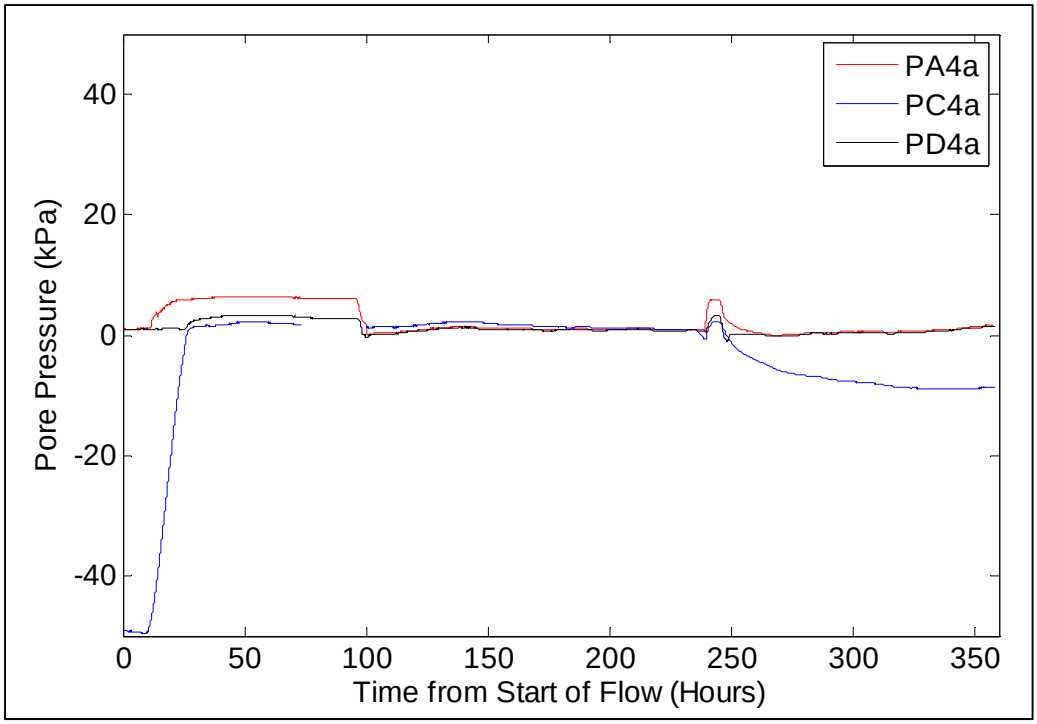


Figure 2-155. Piezometer data for the 10-day flow test and post flow at instrument row 4 (elevation just above the landside oak) at depths of 2.4 feet below grade.

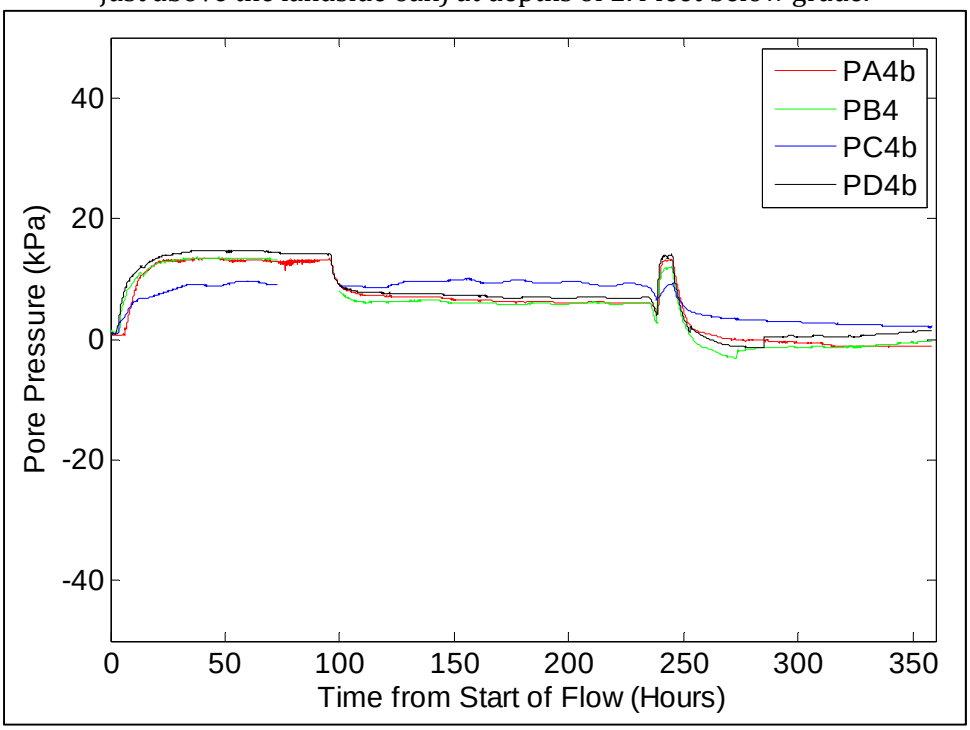


Figure 2-156. Piezometer data for the 10-day flow test and post flow at instrument row 4 (elevation just above the landside oak) at depths of 5.7 feet below grade.

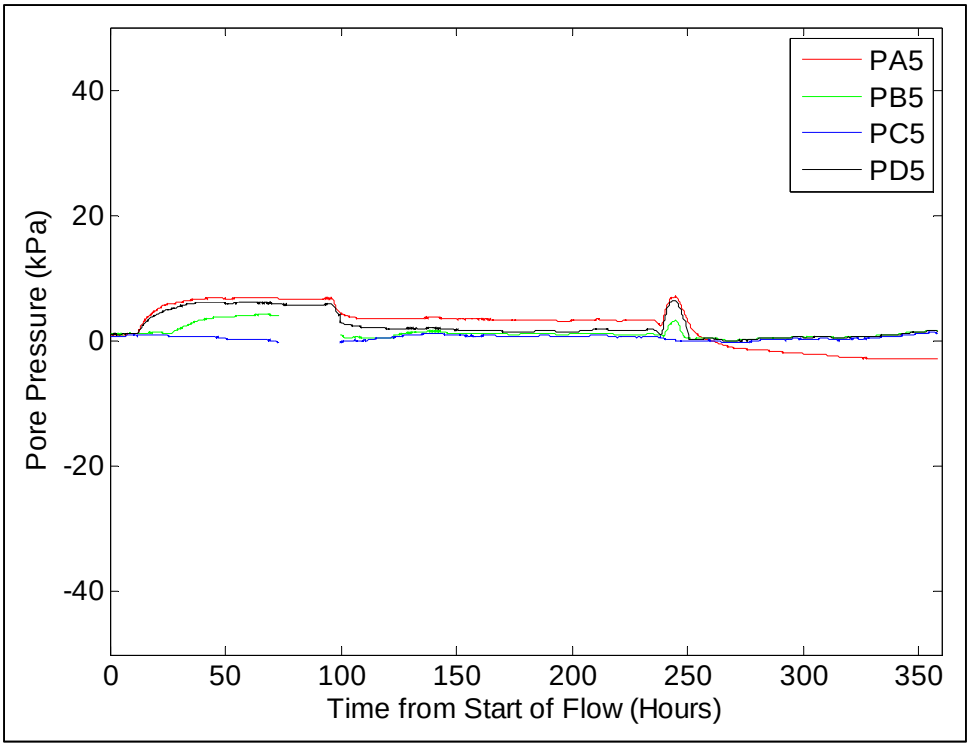


Figure 2-157. Piezometer data for the 10-day flow test and post flow at instrument row 5 (elevation just below the landside oak) at depths of 3 feet below grade.

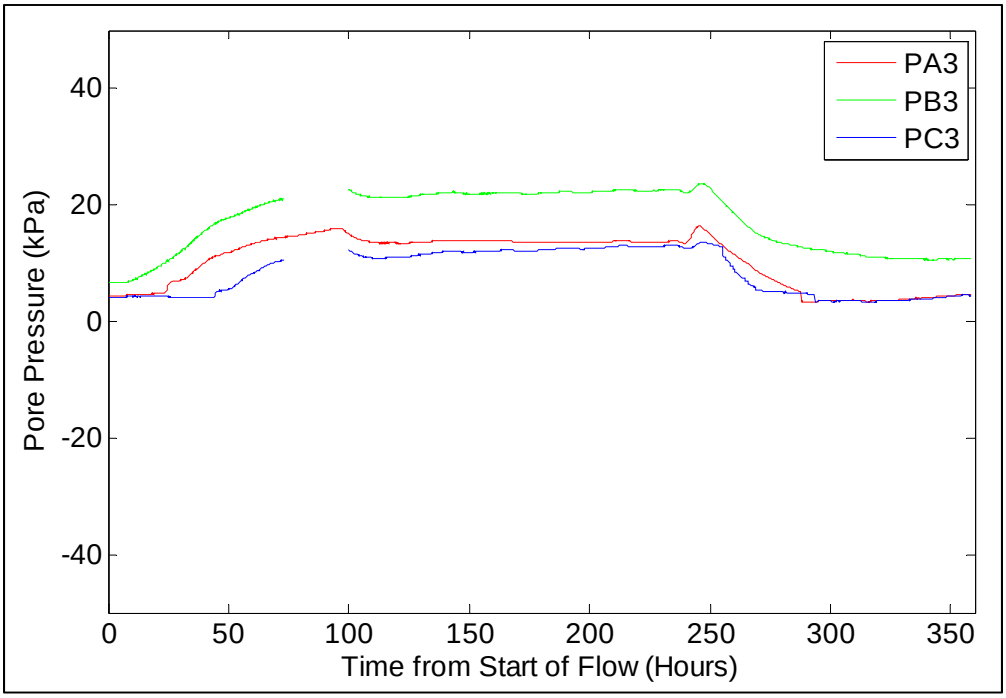


Figure 2-158. Piezometer data for the 10-day flow test and post flow at instrument row 3 (at the toe of slope) at depths of 7.9, 13.5, and 8.5 feet below grade for lines A, B, and C, respectively.

Table 2-4. Landside tensiometer result summary table.

Instrument Name	Wetting Front Arrival (hrs)	Time to Saturation (hrs)	Steady State Suction for Unsaturated Instruments (kpa)*	Saturation Achieved? (y/n)	Time of Steady State (hrs)
TA2_36	11.5	12.5	Pressure	y	-
TA4_24	11.0	17.4	Pressure	y	-
TA4_36	9.7	10.4	Pressure	y	-
TA4_60	6.4	8.3	Pressure	y	-
TA5_24	16.8	20.9	Pressure	y	-
TA5_36	12.4	13.1	Pressure	y	-
TA3_36	Not Reached	-	-	-	-
TD4_36	24.1	33.0	Pressure	y	-
TD5_36	11.9	12.4	Pressure	y	-
TB2_36	10.2	13.6	Pressure	y	-
TB4_36	13.9	21.2	Pressure	y	-
TB4_60	7.0	8.8	Pressure	y	-
TB5_24	32.5	51.5	Pressure	y	-
TB5_36	27.3	30.9	Pressure	y	-
TB3_36	65	82.7	Pressure	y	-
TC2_36	3.8	7.2	Pressure	y	-
TC4_24	9.8	11.6	Pressure	y	-
TC4_36	11.0	-	0.2	n	51
TC4_60	3.9	6.6	Pressure	y	-
TC5_24	195	Not reached	lowest suction: 24.7	n	not reached
TC5_36	133	Not reached	lowest suction: 7.5	n	not reached
TC3_36	Not Reached	-	-	-	-

*Some instruments indicated pressures which are not reported. Instrument calibrations do not support pressures

Table 2-5. Landside piezometer result summary table.

Instrument Name	Wetting Front Arrival (hrs)	Time to Steady State (hrs)	Steady State Pressure (kpa)*	Elevation of Instrument (ft)	Total Head (ft)
PA2	1.5	45.6	31.3	-8.2	2.2
PA4a	11.9	24.7	5.9-6.3	3.2	5.2
PA4b	6.5	20.2	12.7-13.4	-0.1	4.2
PA5	12.3	37.9	6.7-6.9	-0.6	1.7
PA3	24.1	Not reached	-	-11.2	-6.1
PD4a	25.9	32.9	2.7-3.3	3.2	4.2
PD4b	3.3	27.9	14.1-14.8	-0.1	4.7
PD5	12.4	38.9	6.1	-0.4	1.7
PB2	1.6	45	37.6- 38.6	-9.6	3.2
PB4	3.9	33.7	13.4	-0.5	4.0
PB5	27.7	62	4.2	-0.6	0.8
PB3	6	Not reached	-	-16.3	-8.9
PC6	Not reached	-	3.8-4.3	4.3	5.7
PC2	2	60.1	25.2	-6.0	2.5
PC4a	10.7	47.2	2.1	2.9	3.6
PC4b	3.4	35.8	8.8-9.6	-0.4	2.6
PC5	Not reached	-	0	-0.6	-0.6

* Data not corrected for barometric pressure

Figure 2-159, Figure 2-160 and Figure 2-161 show the entire 10-day flow test (including 4 days of primary flow, 5 ½ days of control trench flow only and ½ day of dye testing) and 5 days of post-flow readings as site soils begin to dry and rebuild suction.

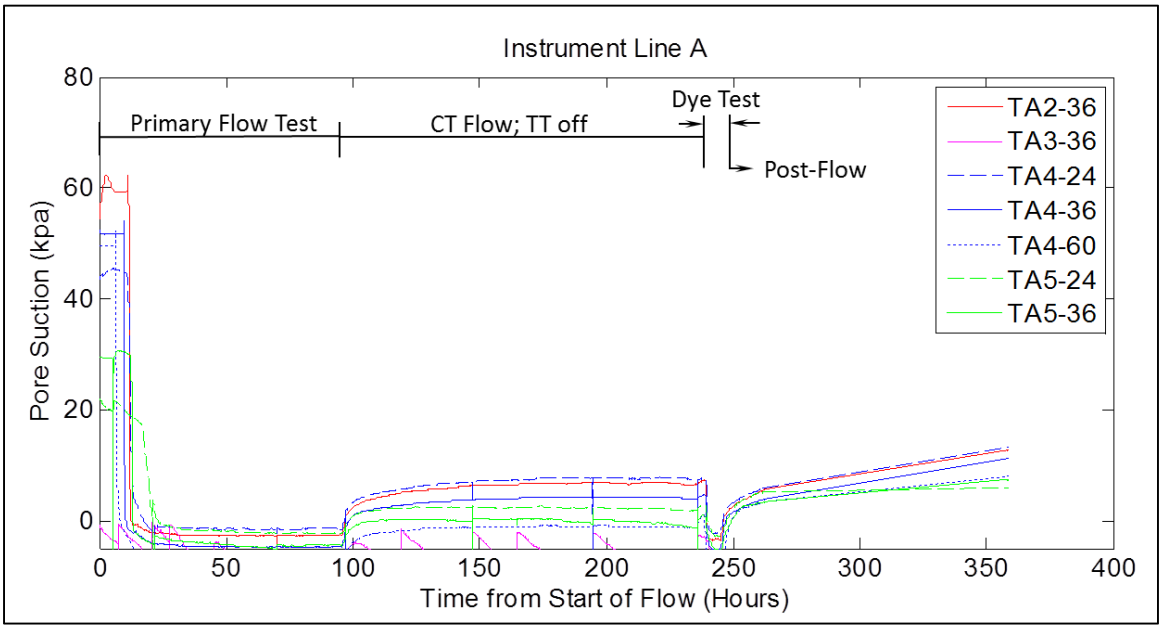


Figure 2-159. Tensiometer data for 10-day flow test and post flow at instrument line A.

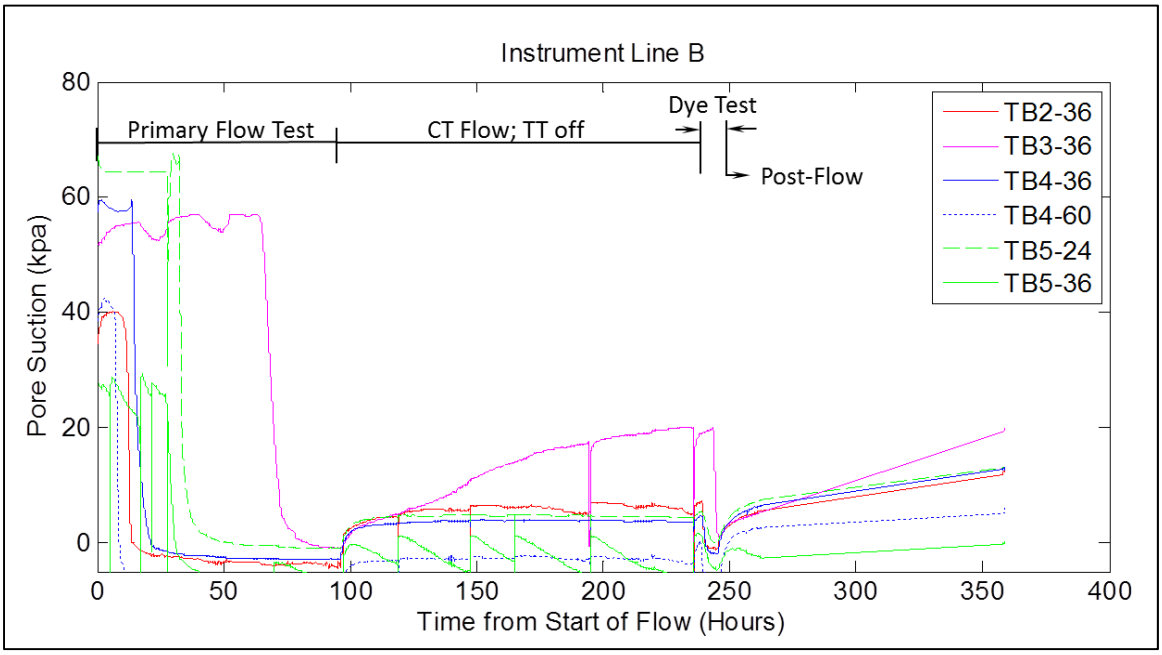


Figure 2-160. Tensiometer data for 10-day flow test and post flow at instrument line B.

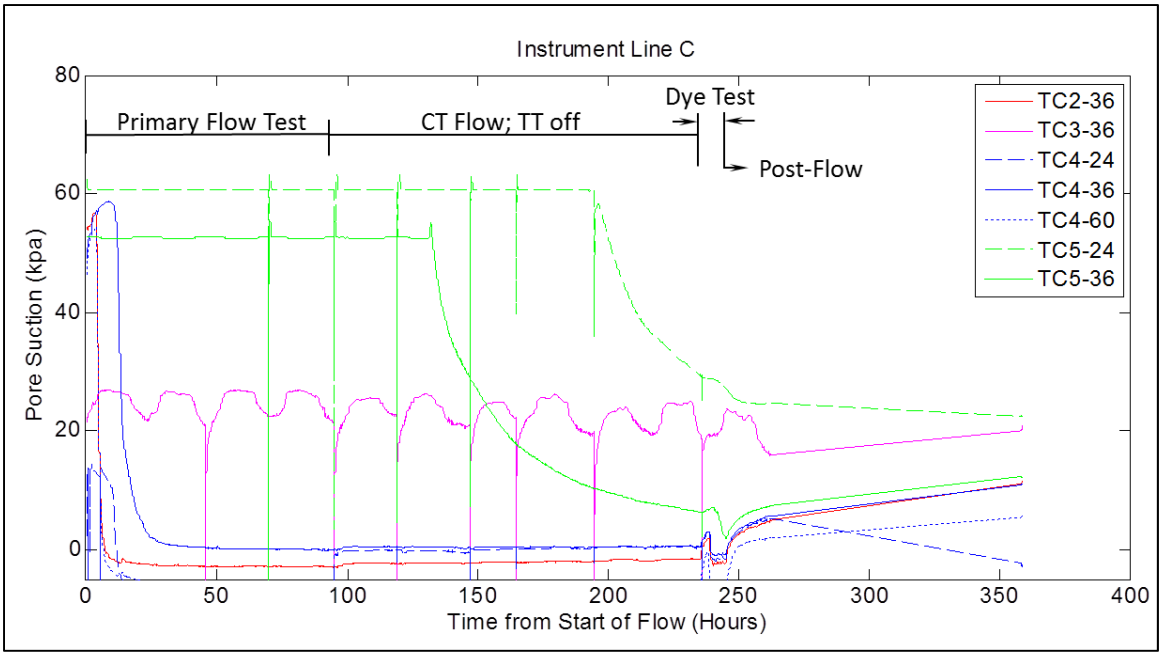


Figure 2-161. Tensiometer data for the 10-day flow test and post flow at instrument line C.

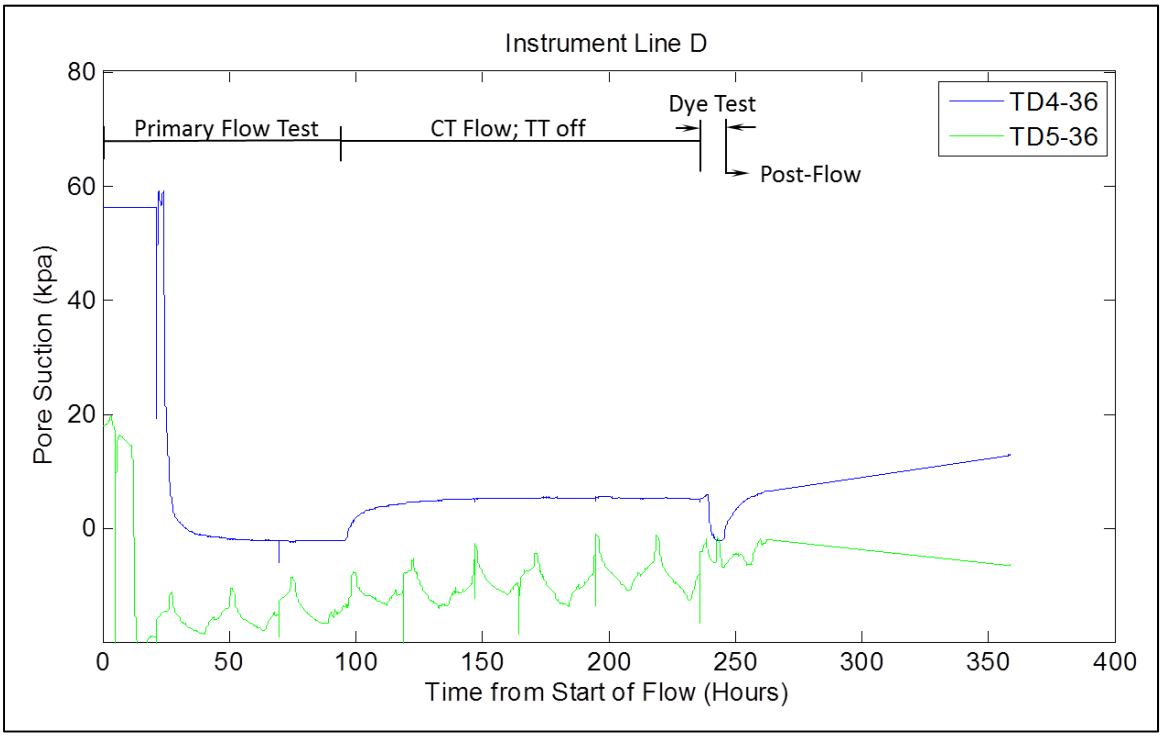


Figure 2-162. Tensiometer data for the 10-day flow test and post flow at instrument line D.

2.6.4.2 Waterside

Waterside tensiometer results during the 10-day flow test with post flow period are summarized by row and instrument depth and presented below on Figure 2-163 and Figure 2-164. Waterside piezometer data are plotted by row (1 and 6) and provided as Figure 2-165 and Figure 2-166. For ease of comparison, summaries of time of arrival of the wetting front and saturation are provided for each waterside tensiometer on Table 2-6. Similarly, time to wetting front arrival, the value of and time of steady state pore water pressure for each piezometer are provided on Table 2-7.

At line E, tensiometer TE1-36 appears to have problems maintaining suction, however sufficient suction is able to be maintained to estimate the time of saturation as evidenced by the low (below zero) value following re-filling of the instrument and regaining of suction. This instrument saturates at 6.8 hours as compared to analogous instruments at line B (9.6 hours) and line C (16.4 hours). Piezometer time to wetting follows the same pattern where line E experiences wetting at 1.5 hours (PE1), line B in 4 hours (PB1), and line C in 9 hours (PC1). Row 6 displays a different pattern where PB6 is wetted by 6 hours, and PE6 is wetted in 9.2 hours. A number of factors could be at play here including higher permeability through the possible breach zone backfilled with loose soils at Stations TT 37 to 42, fractured levee soils, and burrowing activity (particularly muskrat). Water arrived later to PA1, and PC1. The path of macroporosity in unknown and the degree to which each factor affects flow is not clear.

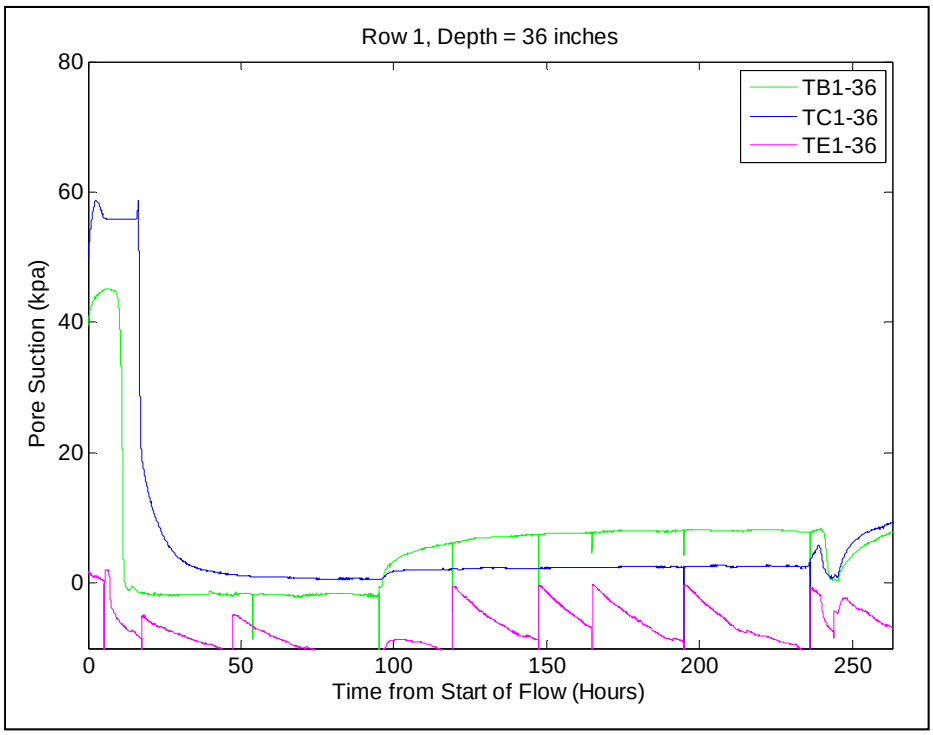


Figure 2-163. Tensiometer results for Row 1, 36 inch depth, for the 10-day flow test and early post-flow.

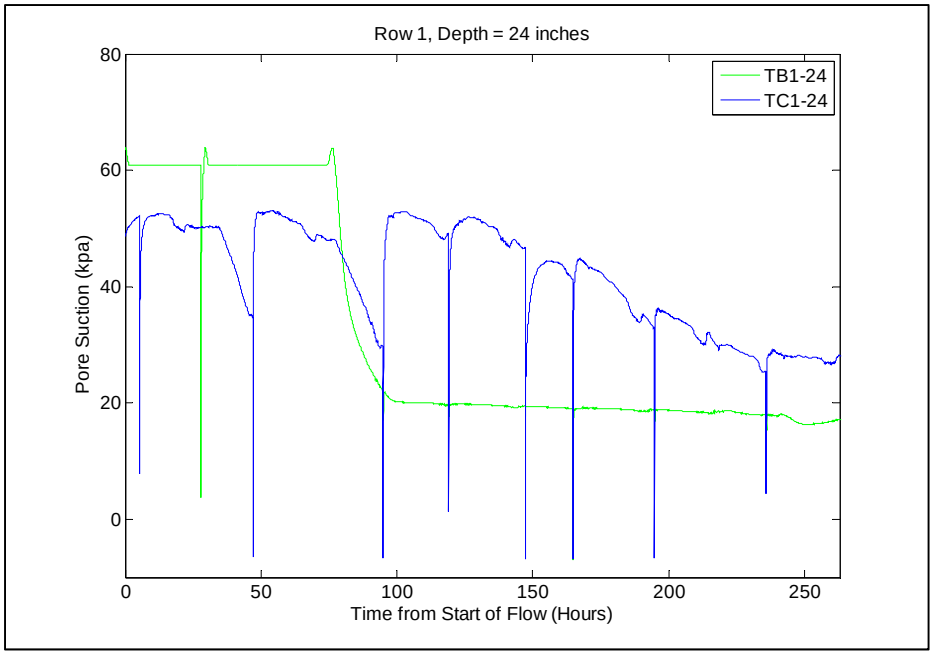


Figure 2-164. Tensiometer results for Row 1, 24 inch depth, for the 10-day flow test and early post-flow.

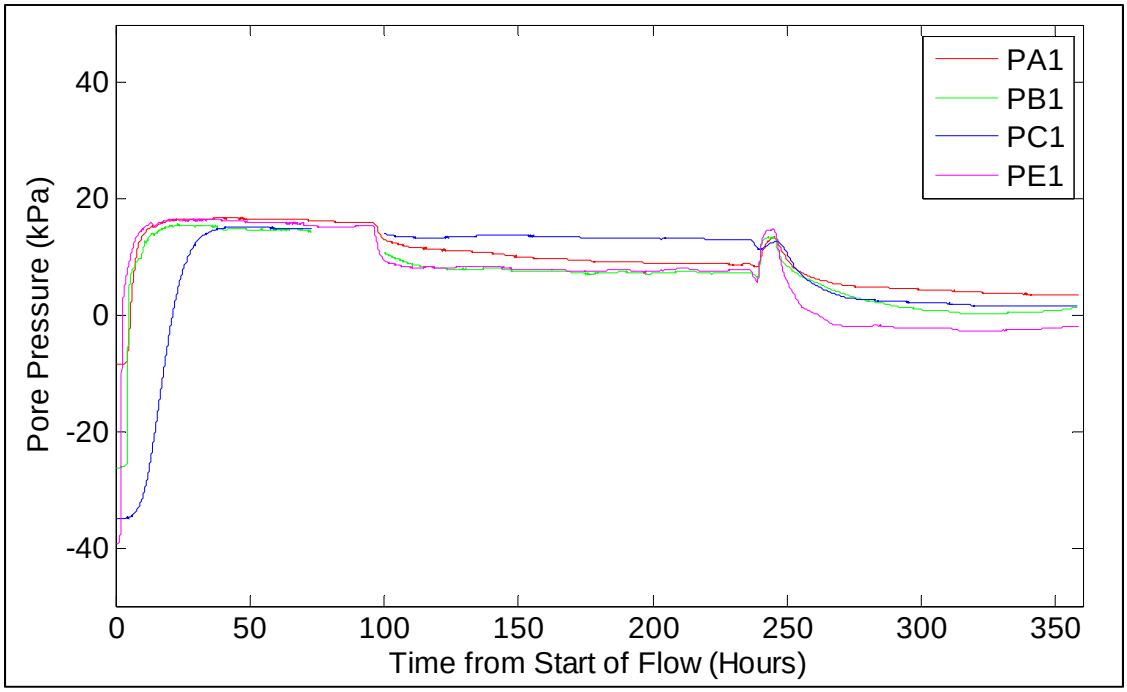


Figure 2-165. Piezometer data for the 10-day flow test and post flow at instrument row 1 (top of waterside slope) at a depths of 5.9, 6.5, 6.2, and 6.5 feet below grade for lines A, B, C, and E, respectively.

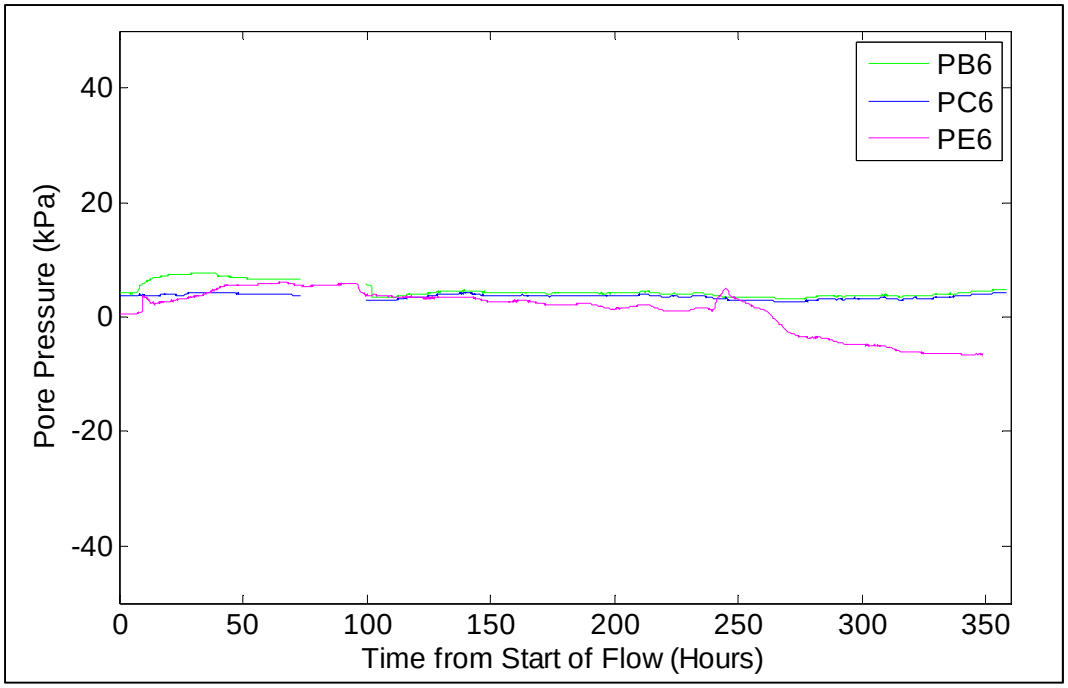


Figure 2-166. Piezometer data for the 10-day flow test and post flow at instrument row 3 (middle of waterside slope) at depths of 3.4 feet below grade.

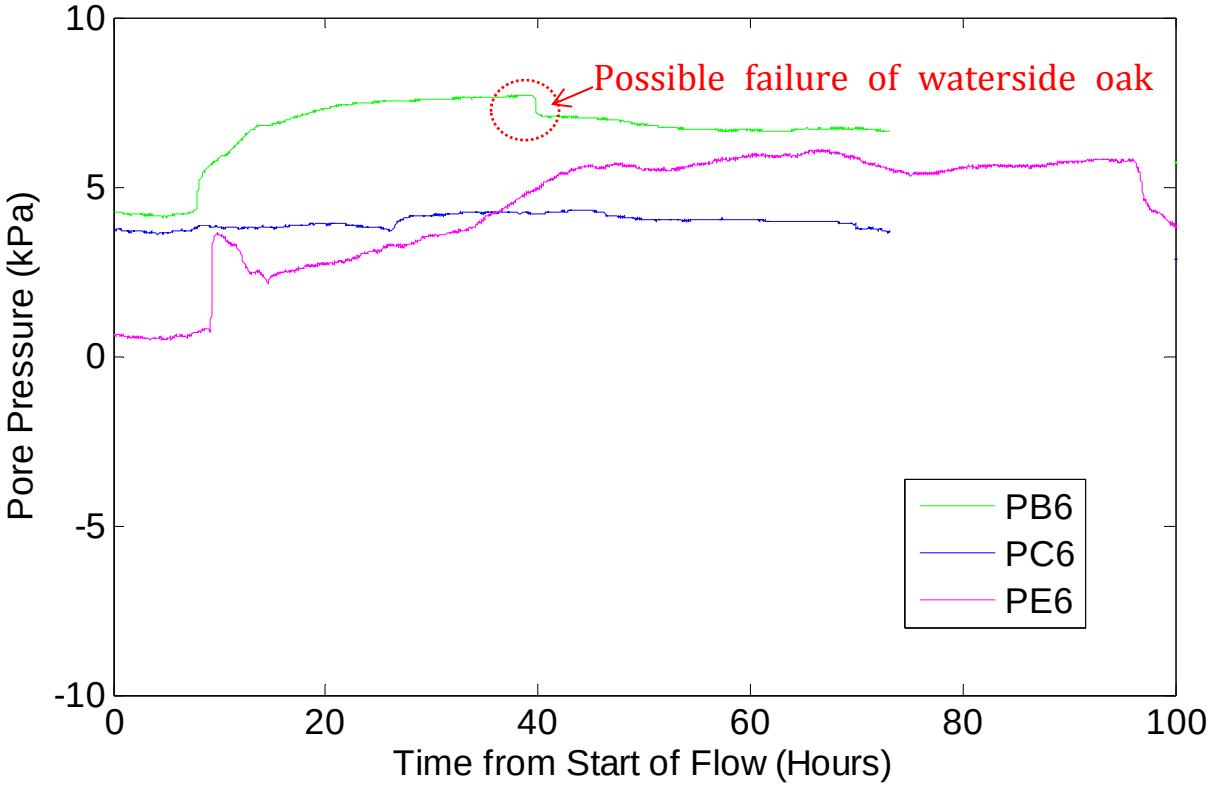


Figure 2-167. Piezometer PB6, at the waterside oak, shows a notable dip in pore pressure. The time of the dip is 39.7 hours, or 5/23/12 at 5:25 am and could be the time of tree failure.

Table 2-6. Waterside tensiometer result summary table.

Instrument Name	Wetting Front Arrival (hrs)	Time to Saturation (hrs)	Steady State Suction for Unsaturated Instruments (kpa)*	Saturation Achieved? (y/n)	Time of Steady State (hrs)
TC1_24	140	-	28	n	not reached
TC1_36	16.4	-	2	n	69
TB1_24	77.3	-	20-21	n	95
TB1_36	9.6	12.1	Pressure	y	-
TE1_36	6.8	7.1	Pressure	y	-

*Some instruments indicated pressures which are not reported. Instrument calibrations do not support pressures

Table 2-7. Waterside piezometer result summary table.

Instrument Name	Wetting Front Arrival (hrs)	Time to Steady State (hrs)	Steady State Pressure (kpa)*	Elevation of Instrument (ft)	Total Head (ft)
PA1	3.7	23.3	16.5	1.4	6.9
PE1	1.5	15.5	15.9-16.6	-0.1	5.3
PE6	9.2	41.4	5.4-6.0	1.2	2.8
PB6	6	25	7.5	3.2	5.7
PC1	7	42.8	15.2	1.5	6.6
PC6	-	-	3.8-4.3	4.3	5.7

* Data not corrected for barometric pressure

2.6.5 Flow Volumes

During the 10-day flow test, a total of 1,212,500 gallons of water was pumped into the reservoir and released by gravity into the control and tree trenches (Figure 2-168). As previously described, flow monitoring devices were installed on the inlet pipeline into the reservoir as well as both outlet lines into the control and tree trenches.

Monitoring gauges were designed so as not to be a limiting factor in water delivery into the trenches. Delivery lines were somewhat oversized and as a consequence, flows into the trenches were not high enough to turn the volume-tracking wheel within the meter reliably. As a result, the inflow meter from the pump to the tank was considered the most reliable meter for estimation of total water delivered. Based on the first day of data, the mechanical flow meters (which track total flow volume through each meter) showed that about 82 percent of the total water was going to the tree trench and 18 percent to the control trench. The problem with the flow meter not having enough water to turn the meter is exacerbated in the control trench, which is smaller and requires less water than the tree trench. Flow gauges showed flow rates to be 80 gallons per minute to the control trench and 200 gallons per minute into the tree trench, a breakdown of 71 percent to the tree trench and 29 percent to the control trench. A simple ratio based on the size of each trench would yield a breakdown of 76 and 24 percent for the tree and control trenches, respectively. This estimate seems reasonable in the absence of better data. The control trench delivery line volume trip meter and flow rate gauge stopped functioning completely after the first day of flow. Given inaccuracy issues, it was not replaced. Volumes were calculated from the total inlet volume readings, read periodically, and combined with levels of water in the tank at the time of the readings. A detailed plot of flow rates and cumulative volumes of flow into the trenches is provided with time on Figure 2-168. A volume breakdown of flow into the control trench and tree trench during the primary flow test, when both trenches are full, is assumed to be 76 percent delivered to the tree trench and 24 percent delivered to the control trench.

Total flow during each test phase is broken out in Table 2-8. Best estimates are provided for the breakdown of flow rates between the control trench and the tree trench in Table 2-9. During trench filling, flow rate estimates to each trench were not made. In the primary flow phase and during the dye test, the breakdown discussed above was assumed. Flow to the tree trench was turned off after 4 days of flow while water continued to be delivered to the control trench for over 5 days until the beginning of the dye test. During the timeframe when only the control trench was running, delivery volumes to the control trench increased, as observed by the fact that the mechanical float valve could no longer maintain a constant head in the trench. The valve was bypassed and controlled manually until the morning of the dye test. When we returned for the dye test, the control trench was about 4 inches low and the water in the tree trench contained about 3 feet of water at the base that had not drained.

Reviewing Figure 2-168 and Table 2-9, flow rates are seen to decrease at about 40 hours into the flow test. This corresponds to the failure of the waterside oak tree. Observations of reduced seepage to this area following the tree failure could mean that the tree falling

introduced discontinuities in the previously active flow pathways leading to a reduction in overall flow through the network of macropores at the site. The flow rate into the trenches was higher at the beginning of the dye test after water to the tree trench had been cut off for several days and then restarted. Once the test had run for several hours, the flow rate decreased to a similar rate observed at steady state during the primary flow phase, a little over 100 gallons per minute.

During post-flow inspection of the trenches (Section 2.6.6), a burrow was found to have opened between the tree trench and the control trench, allowing the trenches to share flows during this phase. If the control trench is assumed to have a constant flow once the tree trench is turned off, it the flow through the burrow can be approximated. The total flow rate increased over time, possibly due to the growing size of the hole between the trenches allowing for increased delivery of water from the control trench into the tree trench. The most reliable value for understanding volumes is the total flow volumes and rates, while breakdowns between trenches are best estimates based on available data.

Based on assumed unit weights of onsite soils of 110 to 115 pounds per cubic foot, and measured moisture contents ranging from about 20 to 40 percent, the fraction of void space in the materials is estimated to be on the order of 40 to 45 percent with 10 to 15 percent capacity to take on moisture to reach saturation. If all soils within 5 feet of the levee toe on land and water side and extending to the depth of the water table were to become completely saturated, the total volume of water require to accomplish this saturation is estimated to be just under 150,000 gallons of water. If site soils had been completely dry at the beginning of the project, the volume to accomplish saturation would be about 660,000 gallons. The volume of the trench is about 13,700 gallons. The volume of water that flowed through the site was 1,212,500 gallons of water, with estimated water losses offsite of 1,062,500 gallons.

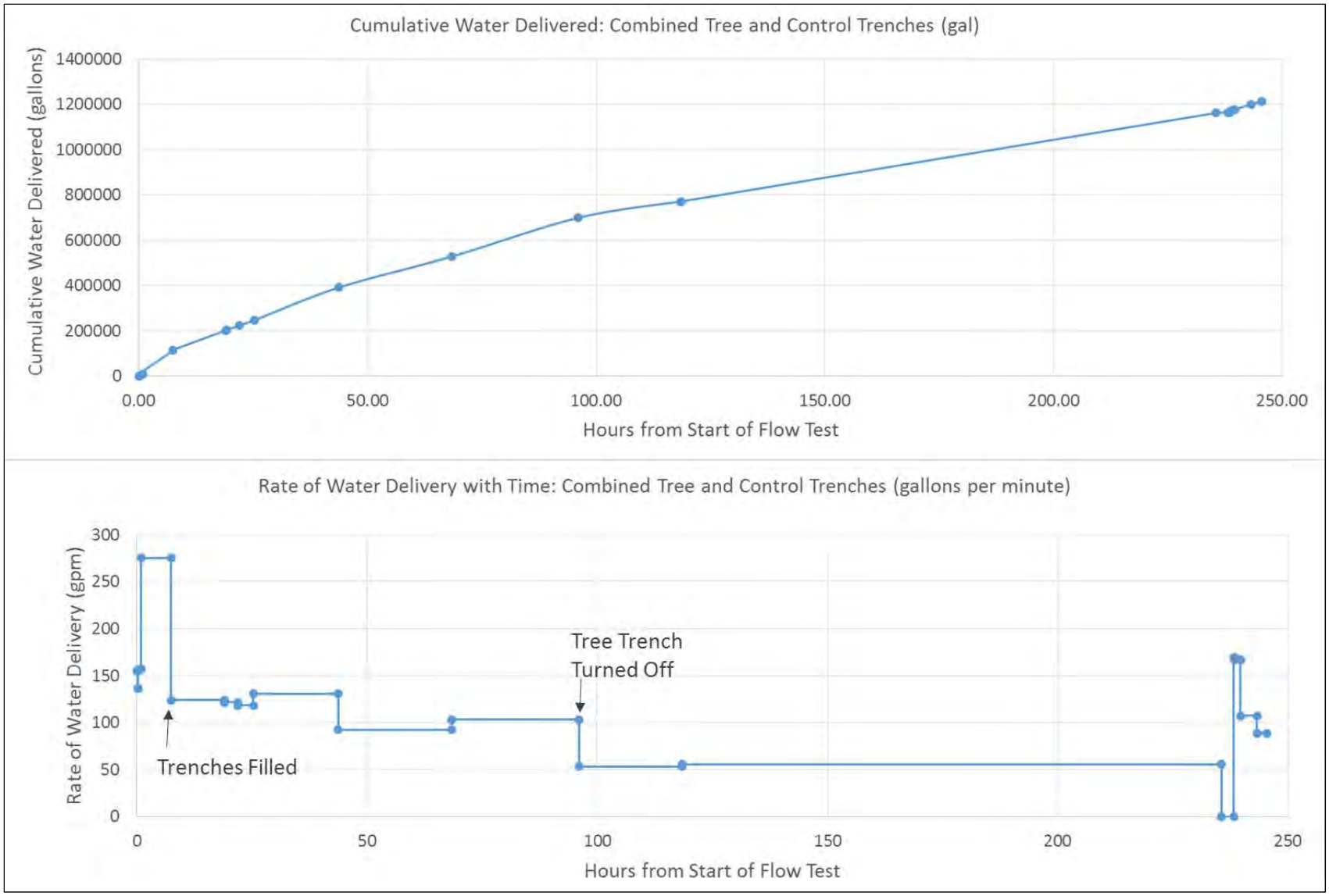


Figure 2-168. Water flow cumulative volumes over time (top) and corresponding flow rates (below).

Table 2-8. Flow volume breakdown by flow phase

Flow Phase	Flow Volume (gallons)	Time Interval (hrs)
Primary Flow	699,500	96
CT on, TT off	462,600	139.5
Dye Test	50,400	10

Table 2-9. Flow rate breakdown with flow phase

	Time Interval (hrs) from start of flow			Estimated Water Delivery Breakdown		
Flow Phase	Start	End	Calculated Flow Rate (gpm)	Control Trench	Tree Trench	Comments
Primary Flow	0	0.95	150	-	-	Trench filling, 2" delivery pipe
	0.95	5	368	-	-	Trench filling, 4" delivery pipe
	5	25.2	123	30	93	CT and TT filled
	25.2	43.7	131	31	100	
	43.7	68.4	92	22	70	
	68.4	96	105	25	80	
CT on, TT off	96	118.5	53	25	28	TT receiving water through burrow
	118.5	235.5	56	27	29	between CT and TT
Dye Test	235.5	238.2	0	0	0	Water turned off before pulse of dye
	238.2	238.9	169	-	-	Filling trenches
	238.9	239.7	167	-	-	Filling trenches
	239.7	243.3	108	26	82	Trenches are full
	243.3	245.5	89	21	68	Water turned off at Time = 245.5 hrs

2.6.6 Post Flow Test Observations

After completion of the flow test, instruments were left in to monitor the beginning of the drying phase as pore pressures dropped and soils began to dry and rebuild suction. On June 5, 2012, the instrument monitoring phase ended. Tensiometers were removed on June 8, 2012. During this visit, gravel bags were removed and zones of high flow were inspected in an effort to determine what caused the concentrated flow.

On the landside slope of the control trench, between Stations CT 6 and 10, mid-slope and top of slope gravel bags were placed to prevent erosion of the slope under concentrated flows. Near the top of slope, at Stations CT 7 to 10, two seeps were encountered at 3 am on 5/22, a little over 13 hours into the flow test. A photograph of the findings at that location is provided as Figure 2-169. Two burrows were encountered (1 ½ inch diameter each) consistent in size with gopher or vole. Similarly, Figure 2-170 shows the mid-slope burrow beneath the pile of gravel bags at Station CT 7. Upon lifting the gravel bags, worms and traces of worms were found through the soils under the bag. Armadillidiidae, also known as pill bugs, were abundant and disappeared into the burrows and worm traces when the gravel bags were lifted.

Figure 2-169. Two burrows (left) encountered at Station CT 9 near the top of slope (upper right). The burrows were about 1.5 inches in diameter.

Figure 2-170. The gravel bags were parted (lower right) and a single burrow was revealed at Station CT 7. The burrow was about 1 ½ inch in diameter and the top of the burrow extended into the slope.

The seep areas at instrument lines A and D were inspected and no traces of mammal burrows could be found in this area. Similar to the burrow at instrument line C, however, earthworms and pill bugs were observed to be in abundance as shown on Figure 2-171 through Figure 2-173. Occasional holes on the order of ¼ inch diameter and traces of earthworms, some still occupied by a worm, were seen under each gravel bag. These were noted, as no other mammal burrow could be located. Further, water had been recorded about 19 hours into the flow test flowing from small holes (¼ to ½ inch diameter) at the location of these seeps near Station 56 at instrument line D. The small holes were found beneath gravel bags at all locations where gravel bags had been placed, but it is unclear whether the holes had been present during the flow test or were created post-flow.

Figure 2-171. Station TT 57 to 59 seepage location upon lifting gravel bags. Worm traces were abundant and ¼ inch diameter holes entering into the slope were occasional.

Figure 2-172. View beneath gravel bags at Station TT 50, 8 days post-flow. Note earthworm traces and pill bugs in abundance.

Figure 2-173. Gravel bag Station 73 below landside oak tree. Pill bugs seemed to disappear into a cavity that, upon excavation, did not seem to extend anywhere or resemble a burrow. Worm traces were found to be abundant as in other locations.

After the site had been allowed one month to dry, the restoration phase occurred between July 2 and July 6, 2012 to remove the gravel in the trench and refill with compacted backfill. A decision was made not to repair site cracking and slope deformations as the levee is not considered a flood control structure due to the bypass levee constructed in 2008. The fallen waterside oak tree was slated for removal following the backfill work and at the convenience of RD 1601 and DWR.

During the removal of gravel, an effort was made to preserve the condition of the walls and base of the trench so that key observations could be made. Gravel was carefully removed with a vacuum truck or backhoe bucket centered such that the walls were not disturbed within zones to be inspected. All walls were inspected to a depth of 4 feet and selected sections were viewed to 8 foot depth looking for holes, fractures, roots of interest, or other anomalies that may have affected flow patterns. Features were logged and photographed.

The crack between the trenches was explored. White paint was funneled into the crack prior to excavation of the gravel in an effort to reveal the pattern and depth of cracking. The crack had partially closed by the time of repair as discussed previously and shown on Figure 2-114. The crack did not follow a clean path as the soils are heterogeneous and may pull apart along several planes rather than forming a single clean crack. Figure 2-174 and Figure 2-175 show the trench wall at Station CT 31.5 looking south, while Figure 2-176 shows the trench wall at Station TT 0 looking north. A burrow was encountered connecting the trench walls positioned a distance of 43 inches from the top of the asphalt at Station CT

31.5 and a distance of 24 inches from the top of pavement at Station TT 0 (size = 2.5 inches high, 3.5 inches wide). A crack was seen on the control trench end wall extending down to a depth of 82 inches from the surface, beginning at the crack between the trenches (Figure 2-174 and Figure 2-175). In some places the crack becomes very visible and in other places concealed within looser deposits. On the tree trench endwall at Station TT 0, the visible crack extends down to the burrow location and then transitions into as deposit of Material 2, the thinly bedded silt material, which cleaves readily along predefined planes. Figure 2-176 shows cracking at the end wall of Station TT 0 with the lower right photo showing Material 2 with vertical bedding, exhibiting small separations along beds of fine sand between silt layers. Evidence of soil deformation could not be found at depths below 43 inches as the stratigraphy transitioned into Material 4, a plastic silt material discussed previously.

Figure 2-174. View looking south at the upper 4 feet of control trench end wall at Station CT 31.5 (left) with close-in views of cracking near the top of the trench (upper right) and just above and to the left of the burrow.

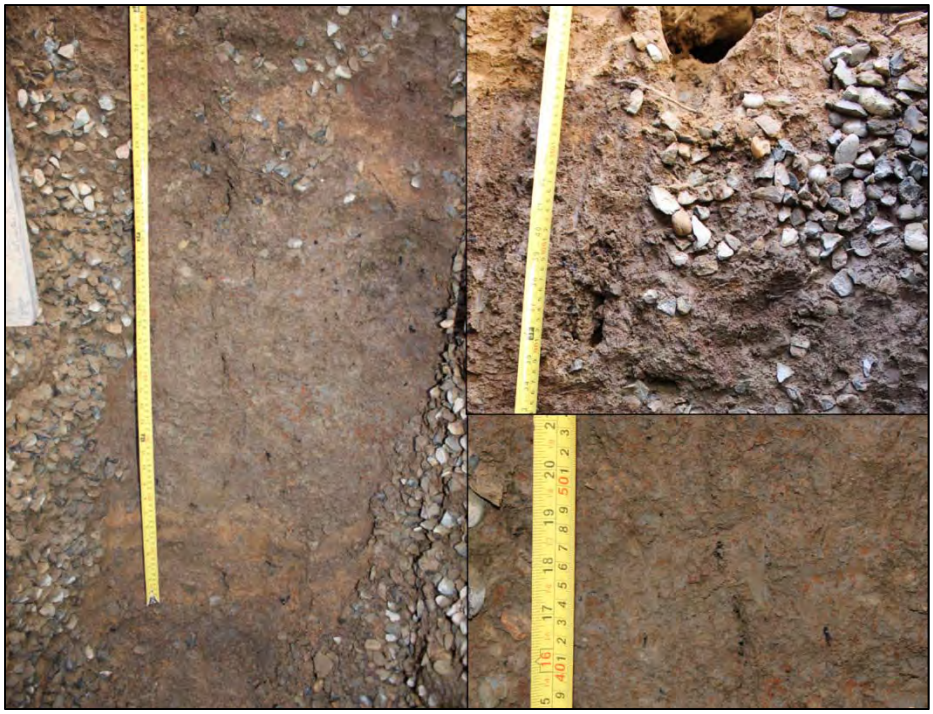


Figure 2-175. View looking south of 8 foot deep trench at end wall of control trench at Station CT 31.5 showing cracking to a depth of 82 inches.

Figure 2-176. View north of tree trench end wall at Station TT 0 showing a burrow (2 feet deep) and a series of vertical tension cracks along bedding planes of Material 2 (thinly bedded silt).

The area at Station TT 17 to 18, particularly the waterside wall, was inspected for the condition of roots and the condition of the trench bottom. The trench bottom was inspected looking for cracks extending below the trench (Figure 2-177). No cracking was found along the walls or base in this area. Large roots had been encountered and cut prior to the flow test. These roots were viewed and nothing abnormal was discovered. The roots did appear to have begun to decay between the time of excavation and the post-flow repair (about 2 months), but did not show clear signs of pullout or deformation due to falling of the waterside tree (Figure 2-177).

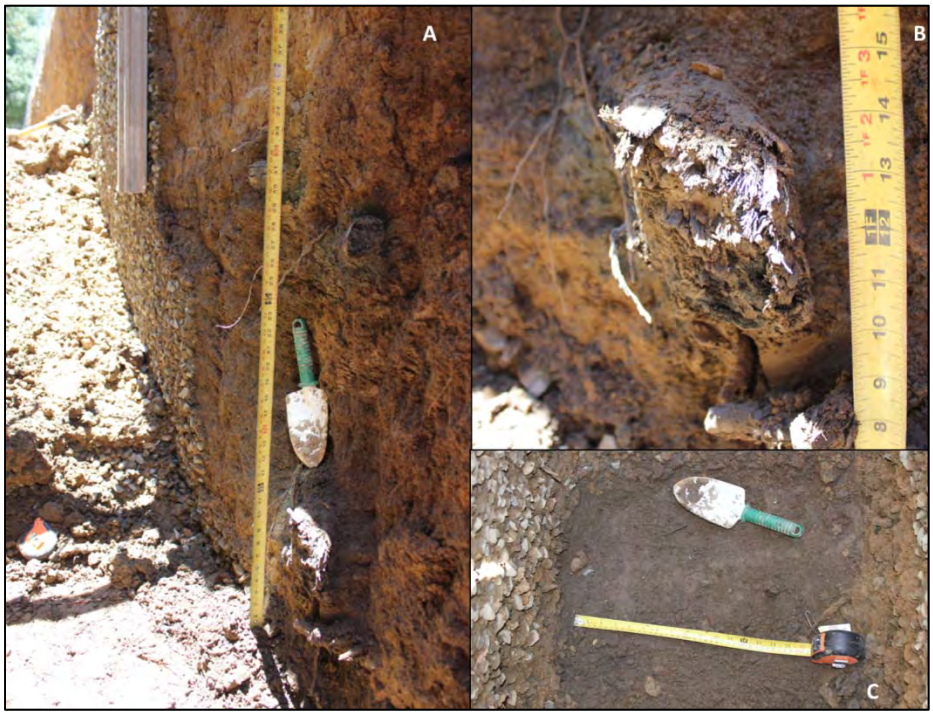


Figure 2-177. Roots at Sta 17; and bottom inspection for cracks at base of trench.

Burrowing activity is believed to have played a key role in influencing the flow patterns during the flow test. Inspections determined whether additional burrows had opened or whether plugs that had been placed during construction had held up over the 10 day flow test. Figure 2-178 shows the locations of two new burrows within the control trench that were not found or plugged during trenching operations. Both burrows were on the land side at Station CT 10 (depth 18 inches, diameter 1 ½ inch) and at Station CT 3 (depth 3 feet, diameter $^{3}/_{8}$ inch). Figure 2-179 shows a zone of burrow patches located within Stations 70 to 73. For reference, the landside tree is centered at Station 70 with the canopy spanning from approximate Stations TT 50 to TT 90. Three burrows can be seen in the photo and all are intact following the flow test. All burrow patches are found intact except one waterside burrow at Station 11 within the control trench. At this burrow, the burrow patch was missing and the hole had grown in size since initial discovery during the trenching phase (Figure 2-180).

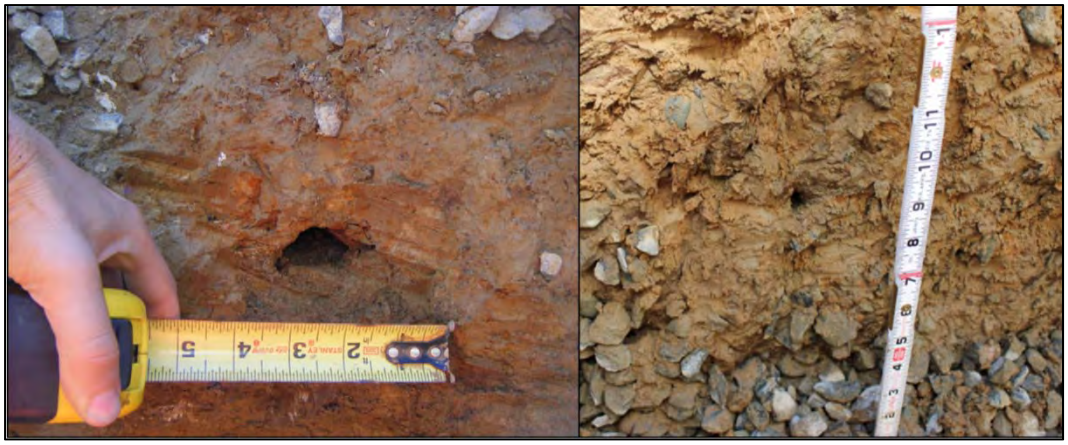


Figure 2-178. New burrow landside Station CT 10 at 18 inches deep (left) and new small burrow at landside CT 3 (right).

Figure 2-179. Patched burrows Station TT 70 to 73. A) overview of patched burrows, B) and C) Initially intact burrow patch is removed and viewed; D) intact landside burrow patch; E) intact waterside burrow patch.

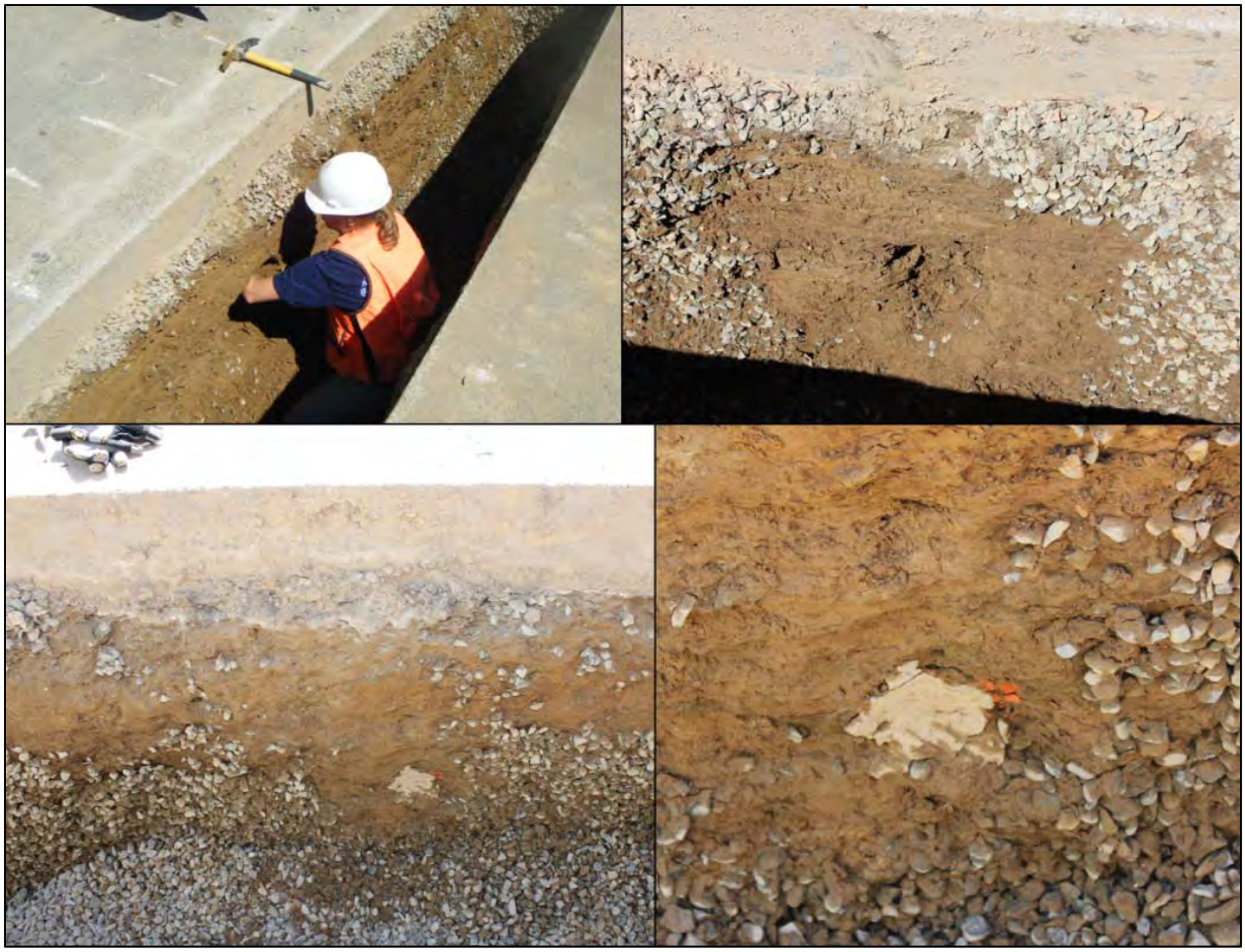


Figure 2-180. Open burrow at waterside Station CT 11 (top images) and intact patch on burrow at landside Station CT 12 (bottom images).

Once the site repair had been completed, temporary fencing was removed and photographs were taken showing the site after vegetation returned several weeks following the flow test (Figure 2-181). Patterns of aggressive blackberry growth within the zones of highest burrowing activity are apparent in the photographs.

Figure 2-181. Vegetation patterns post-flow show blackberry growing back aggressively and coinciding with areas of observed burrowing activity.

2.6.7 T-LiDAR Findings

Baseline scans with tripod-based light detection and ranging (T-LiDAR) equipment were performed prior to trench construction. This work was performed by Dr. Gerald Bawden and his team with the USGS. The USGS team subsequently scanned the site following the primary flow phase of the test and the dye test for the purpose of improving upon standard field data gathering methods to monitor deformations associated with the flow testing at the site. The USGS team has compiled their findings and published a report summarizing their work under separate cover (Bawden et al., 2013-DRAFT). Figure 2-182 shows a T-LiDAR image from the pre-scan condition shot on April 9, 2012 before trenching began

overlain with an image shot on May 29th, 2012 following the primary flow test and failure of the waterside oak tree. The image shows the rotation of the waterside oak tree.

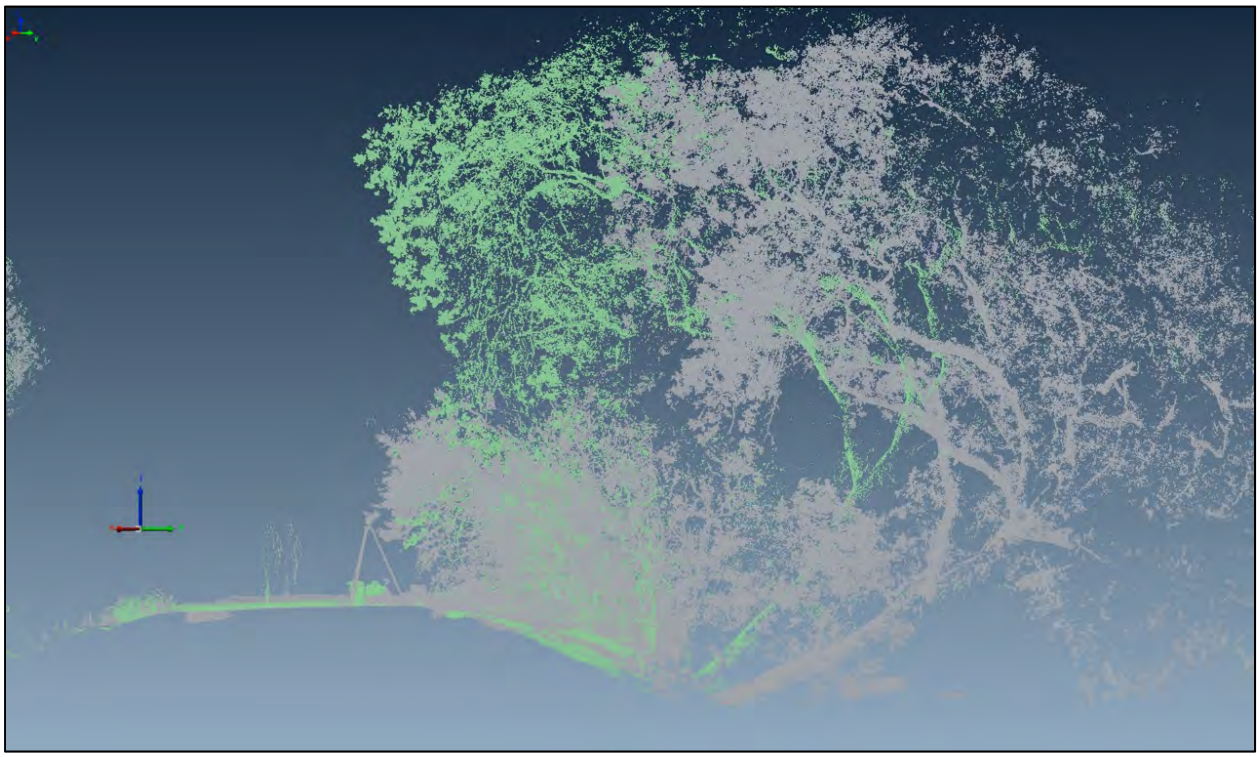


Figure 2-182. T-LiDAR images shot and analyzed by Gerald Bawden and his team from the USGS. The image shows the rotation of the waterside oak tree between April 2012, prior to construction of the trenches, and May 29, 2012, after the failure of the tree on May 23.

Figure 2-183 shows the vertical deformation across the study area as determined by the USGS T-LiDAR study (Bawden et al, 2013-DRAFT). Subsidence on the order of 6 cm (2.5 in) is seen in a semi-circular pattern on the waterside between trench Stations TT 20 and 50. Smaller deformations on the order of 1.5 cm (0.6 in) are visible on the landside of the trench between Stations TT 35 and 45. The unstable trench zone that eventually failed during trench backfill (Figure 2-124) can be seen on Figure 2-183 and Figure 2-184 to have undergone subsidence on the order 3 ½ cm (1.4 in). These deformations appear to be moving in the direction of the trench. Given that the T-LiDAR study has captured these as total deformations that occurred between scans before and after the study, it is unclear when exactly these deformations occurred. Surface expression of the deformations was not visually apparent as these deformations were apparently occurring over the span of the entire road.

Figure 2-184 is a similar figure to Figure 2-183, but limits the scale to 2 cm of displacement to focus in on areas of smaller displacements. A subsidence of 1 ½ to 2 centimeters (0.6 to 0.8 inch) of the waterside trench wall is seen relative to the landside wall in the vicinity of the

crack located between the control and tree trenches. Field measurements found the crack to have a vertical offset of 0.5 to 0.6 inch, relatively consistent with determinations by the USGS team.

Cracking was noted on the west side of the crown road during the dye test on 5/31/12, the last day of flow (Figure 2-125 and Figure 2-126). It can be seen on Figure 2-183 and Figure 2-184 that this cracking is just on the outer edge of the movement area and may be associated. During trench construction, the zone between Station TT 37 to 42 was noted to have a zone of highly unstable soils where the most stable competent soils (Materials 4 and 5) were found to dip below the trench bottom (Figure 2-86). While other deformations onsite were visually apparent and measured in the field, the discovery of subsidence within this zone by the USGS team will provide aid in the interpretation of the study, as this deformation was very gradual, over a broad area, providing few visual clues to be detected by eye in the field.

Additionally, the USGS team noted that a small rotation of the landside oak tree, on the order of 5 cm (2 inches) at a height of 2 meters up the tree (about 6.5 feet), was detected in the study. For a mid-slope tree experiencing saturation of its root system and gusting winds (as were observed on May 22, 2012), a rotation of this nature is not unexpected given the softening of soils within the root zone and the existing lean angle of the tree, slightly off vertical in the downhill direction. With pruning and the tree's natural ability to maintain balance in response to small deformations, this type of deformation may be considered tolerable, depending on the situation, with proper maintenance and inspection. The rotation could not be visually detected, nor were there any signs of distress in the zone around the landside oak tree.

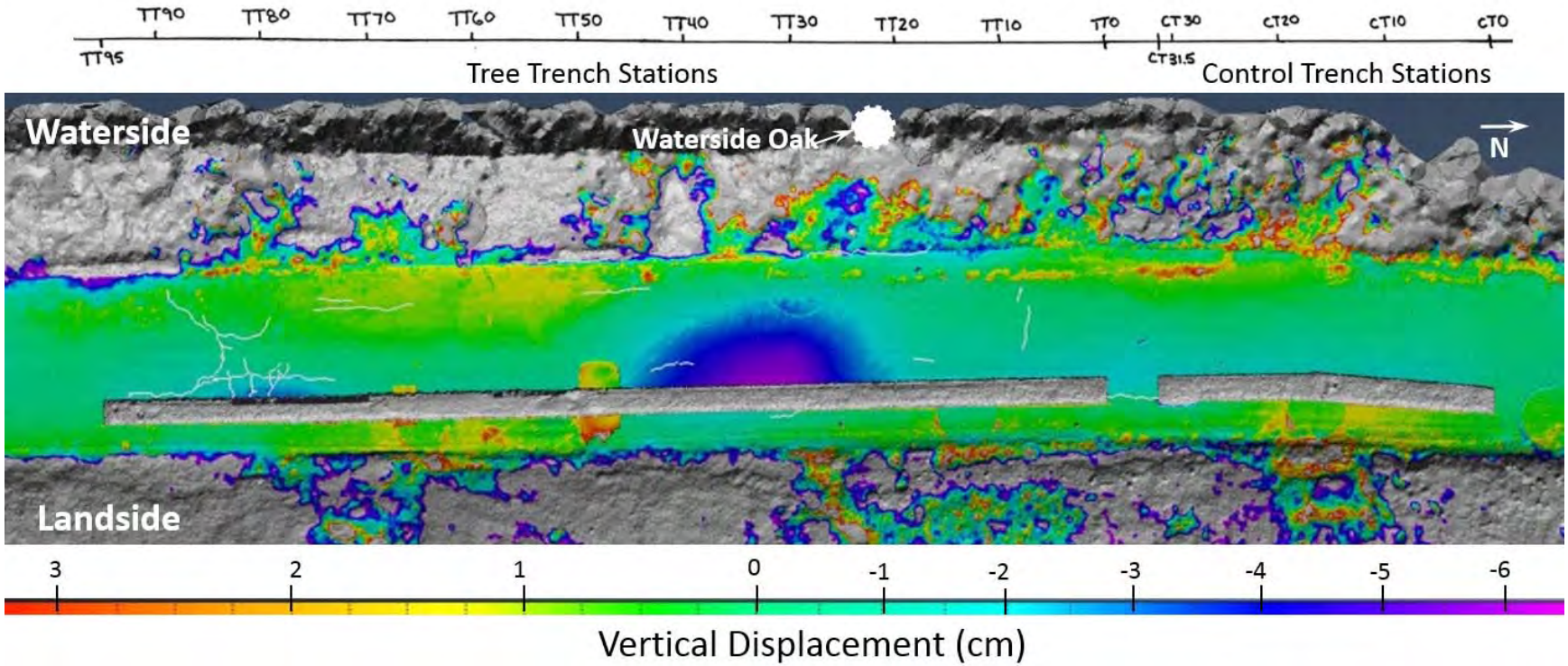


Figure 2-183. Image showing vertical deformations along the length of the trench. Settlements of up to 6 cm (2.4 inches) were observed at Stations TT 20 through 48 through comparison of T-LiDAR scans (4/9/12 and 6/4/12). These movements were not visually apparent during testing. Image provided by Gerald Bawden of the USGS.

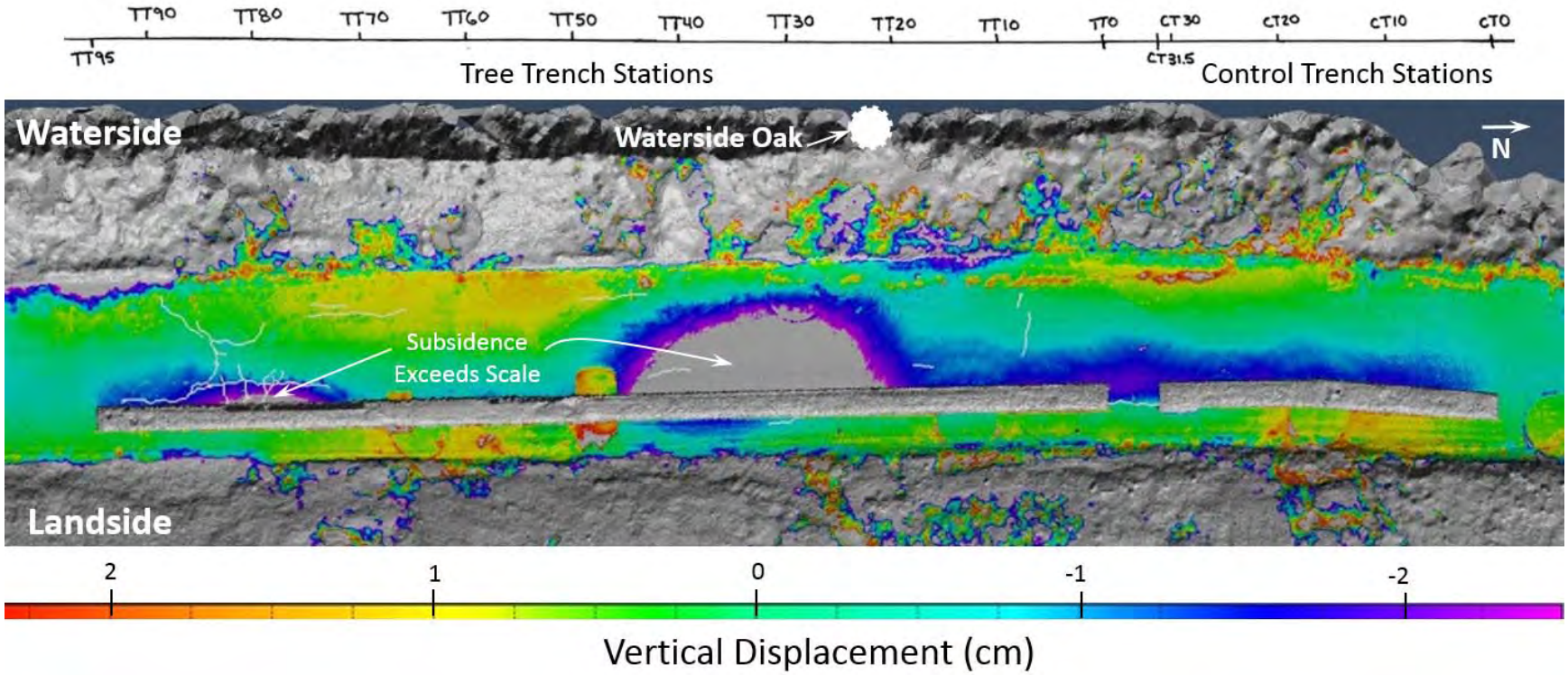


Figure 2-184. T-LiDAR scan comparison of 4/9/12 and 6/4/12 images. Similar to Figure 2-183 but zoomed in to focus on vertical movements less than 2 cm to better define deformations associated with cracking between the control and tree trenches. Image provided by Gerald Bawden of the USGS.

3 DATA INTERPRETATION

A discussion of observations and interpretations associated with the Twitchell Island field experiment follows. A detailed discussion of the tree load mechanics associated with the landside and waterside trees is provided in Appendix G.

3.1 DISCUSSION OF OBSERVATIONS

Observations and data collection were made before site construction, during trenching, throughout the 10-day flow test, after flow, and during restoration of the levee and backfill of the trenches. Data collected included:

- A 130 foot stretch of a delta levee logged in detail to a depth of 8 feet (10-foot levee height). Logs include detailed sketches of the root systems of nearby trees, burrows, and variable soil conditions.
- Pre-flow test inspection with Dr. Dirk Van Vuren of UC Davis to look at burrowing animal activity at the site.
- Soil borings and logging for each instrument location as well as 3 cone penetration tests along the levee crown.
- Continuous monitoring of positive and negative pore water pressures before, during, and after the flow test using a network of 48 instruments, including piezometers and tensiometers.
- Field observations of time and location of observed seeps along the surface of the levee.
- Field observations and monitoring of cracks and their progression throughout the test. This included observations associated with a fallen tree on the water side of the levee.
- Deformations associated with the studied trees and the crown road, analyzed through T-LiDAR analysis by Dr. Gerald Bawden and his team with the USGS.
- Manual monitoring of flow volumes through reading of a mechanical gauge connected to the pump system.
- Observations of seepage and preferential pathways during a 1-day tracer dye test.
- Post-flow site inspections to evaluate conditions that may have affected flow and to evaluate the age (60 years) of the fallen waterside tree.

Figure 2-185 summarizes the most notable site observations including the profile of the old (possibly natural) levee on which the existing levee is founded, cracking associated with the failure of the waterside oak tree, zones of discontinuity in the old levee and loose backfill of the void, zones within the trench where burrowing was abundant, landside and waterside seepage areas, delineation of T-LiDAR-detected subsidence between 1.5 and 6 cm, and extent of blackberry vegetation. Information is presented in the context of the test layout, including locations of the landside and waterside oak trees, the position of the trenches, and the limits of the levee slopes, and crown road (at top of slope).

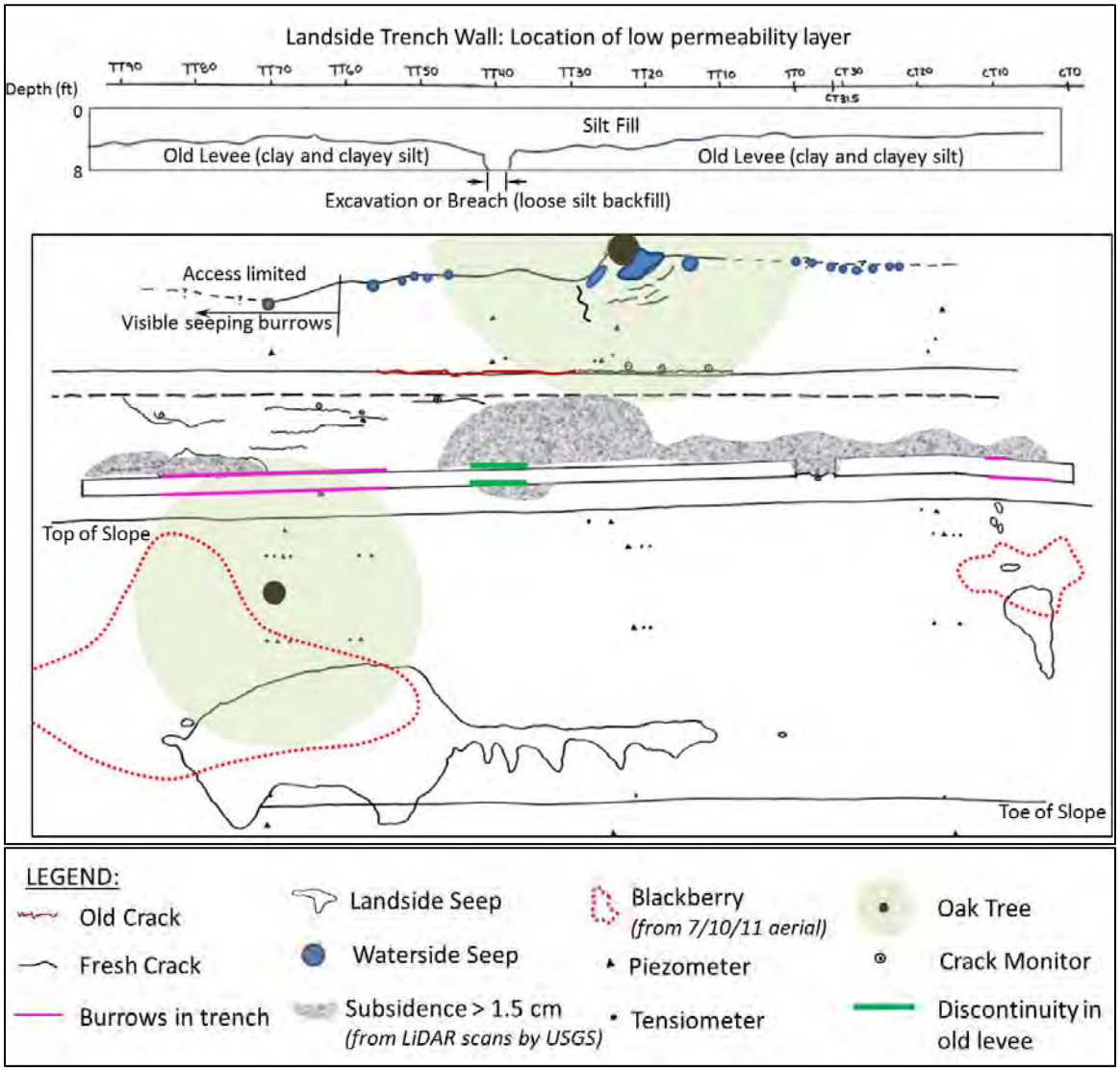


Figure 2-185. Overlay of relevant features of the crown trench seepage test. Includes site layout and instrumentation, relevant vegetation, burrow and stratigraphic data recorded during trenching, cracking and seepage observed during the entire 10 day flow test.

In addition to data collected during the test, available reports and soil data, historical records, aerial photography, and historic topography were reviewed and incorporated into the analysis of the crown trench seepage test. The documents revealed:

- Twitchell Island was first reclaimed in 1869 (Thompson, 2006). Many of the levees at Twitchell Island were founded on natural levees (KSN, 2010). The southern levees, bordering the San Joaquin River are vulnerable due to their peat foundation, while northern levees more stable due to their foundation on alluvial soils (Thompson, 2006). Twitchell Island is reported to have flooded repeatedly between 1870-1875, and 1894 to 1909, while the island was temporarily abandoned between 1875 and 1894.

- The oxbow section of Sevenmile Slough flowed as part of the slough as of 1932. Around 1950, the Sevenmile Slough was gated. Topography in 1952 shows the flow channel of the oxbow section at the study site as a wetland. Two structures and an access road are present in the vicinity of the study area in 1932 and gone by 1952. Poor records exist for the period between 1920 and 1960 (URS, 2011).

- Aerial photography shows that the levee under study was bypassed in the summer of 2008. A toe ditch at the study site was rendered inactive at that time and appears to have been filled by 2011.

- Aerial images were used to date vegetation and determine extent. The approximate age of the landside oak tree is estimated to be on the order of 25-30 years old. Blackberry groundcover corresponds well to where burrowing was most abundant at the site and aerial images helped to delineate the limits.

Figure 2-186 shows the study area overlain on 1932 topography in order to create interpreted stratigraphic sections of the levee for the purposes of seepage and slope stability modeling. Sections are shown extending across the former flow channel. Depth to sediment within the main channel of the slough was measured at 25 feet below the water line at the time of study, while shallow, loose sediments were found at depths of 2 to 3 feet from the water line within the oxbow section of the slough. Exploration to define site stratigraphy and geotechnical conditions did not extend into the slough. Interpreted stratigraphic sections are shown on Figure 2-187 through Figure 2-189. Where geologic contacts are bounded by exploratory points, solid contacts are shown, while queried contacts are shown in areas where contacts were approximated. It is unknown whether the current depth of the slough represents the original depth of the oxbow section, but it was considered to be an upper bound on the depth for the purpose of our analysis. The natural levee and sand deposits were extended in the stratigraphic sections based on available data. The natural levee clays and clayey silts may disappear beneath the channel, but a low permeability layer exists, separating the flow of water in the slough from the groundwater at depth, and so the layer is shown beneath the sediment.

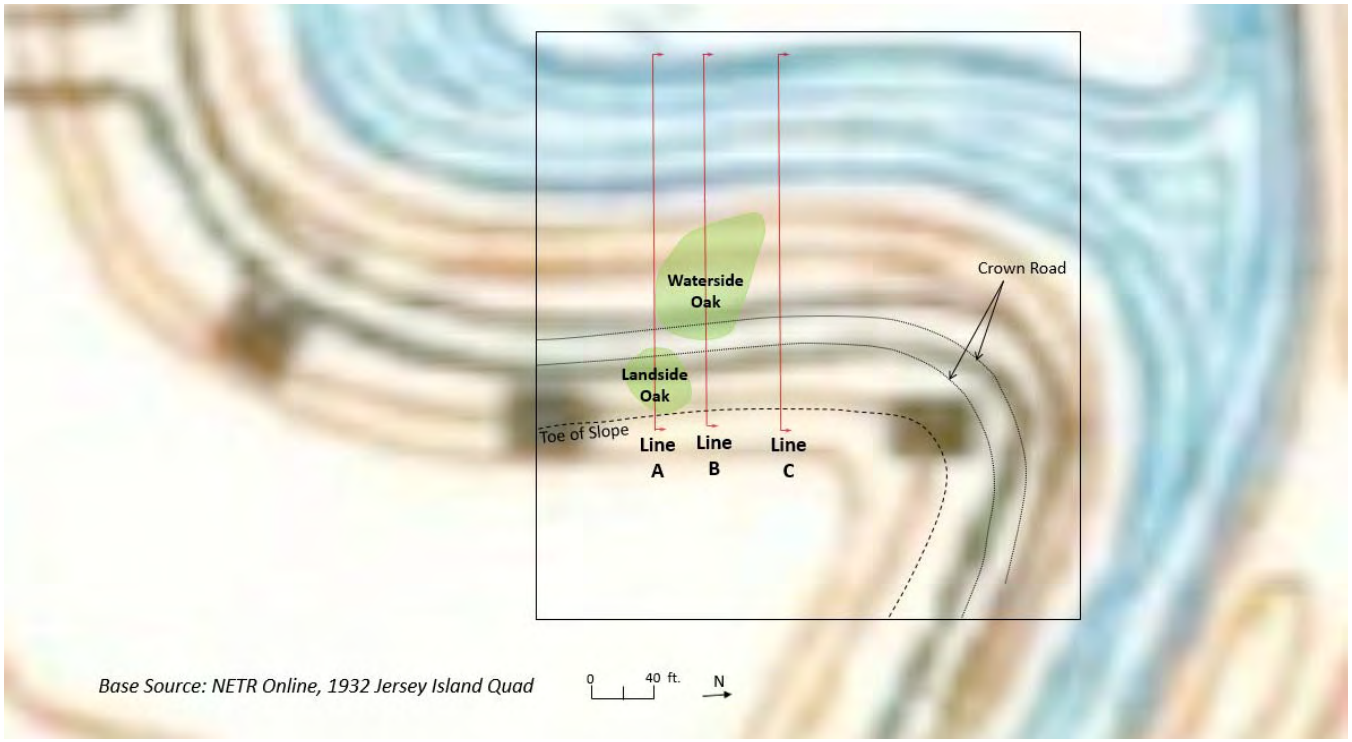


Figure 2-186. Section locations and oak trees under study overlain onto 1932 Jersey Island Quadrangle to estimate waterside channel geometry for interpreted sections.

185

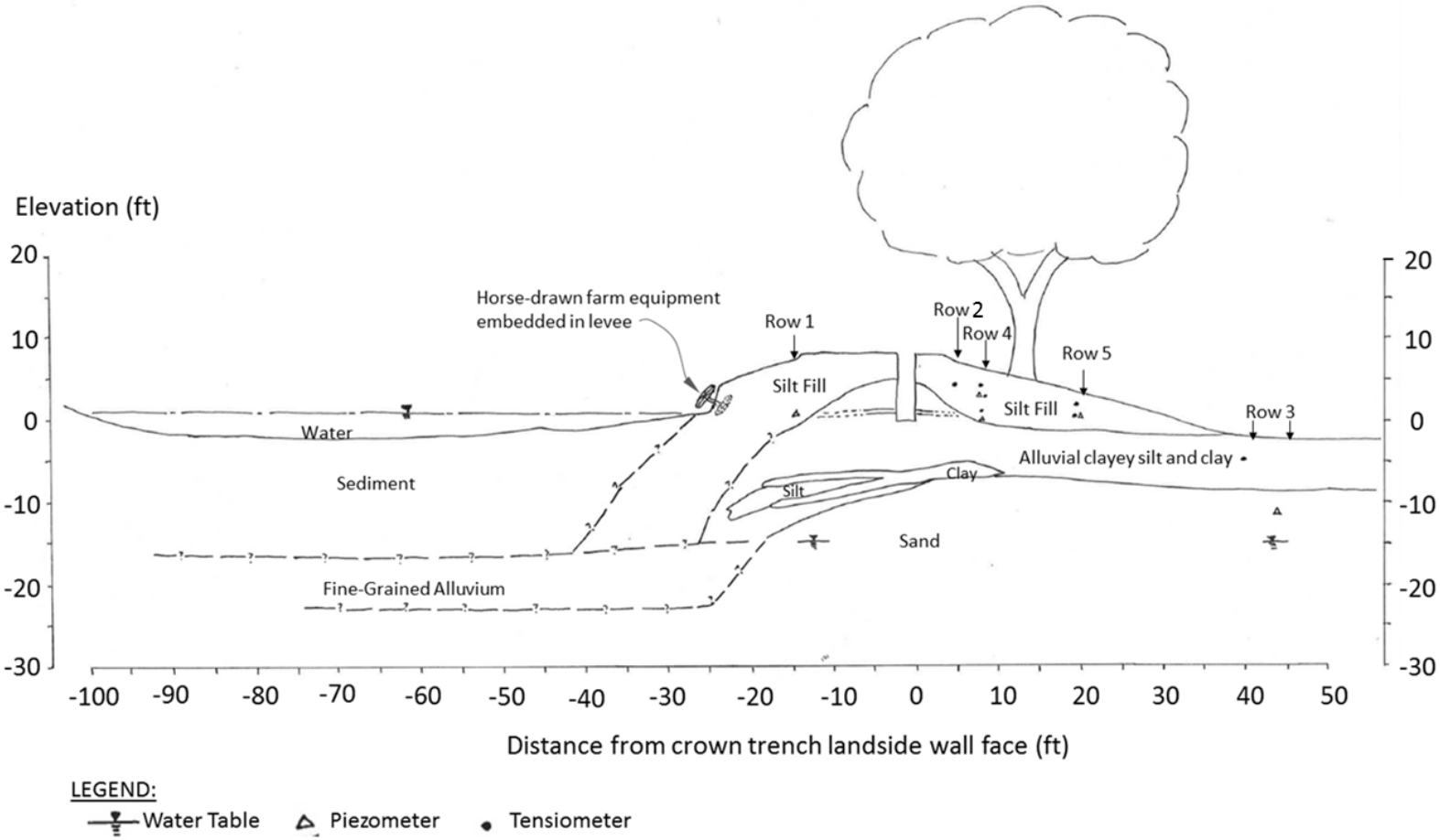


Figure 2-187. Interpreted stratigraphic section at instrument line A, through the landside oak tree. Instrument rows 1 through 5 are shown.

186

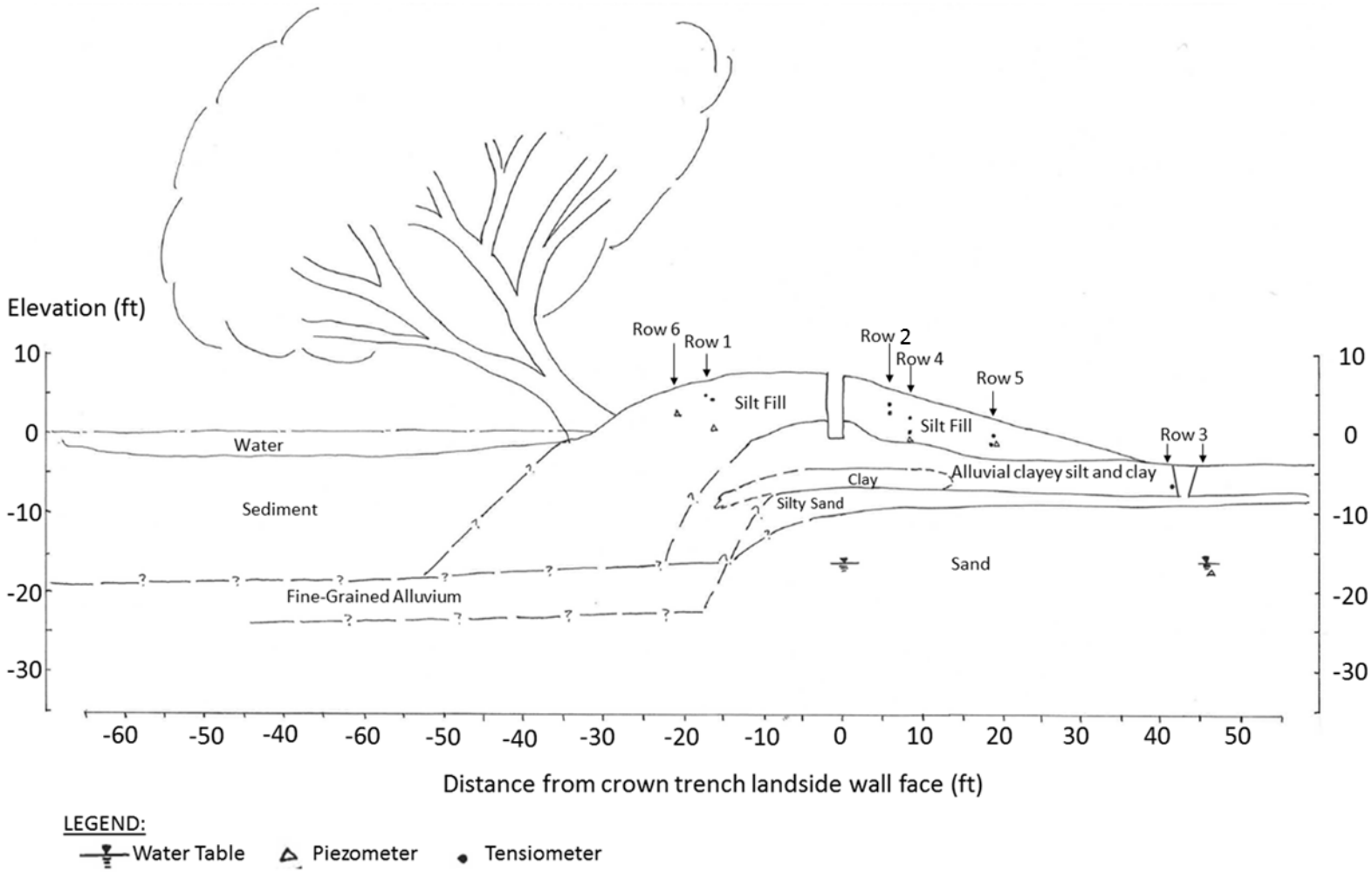


Figure 2-188. Interpreted stratigraphic section at instrument line B, through the waterside oak tree. Instrument rows 1 through 6 are shown.

187

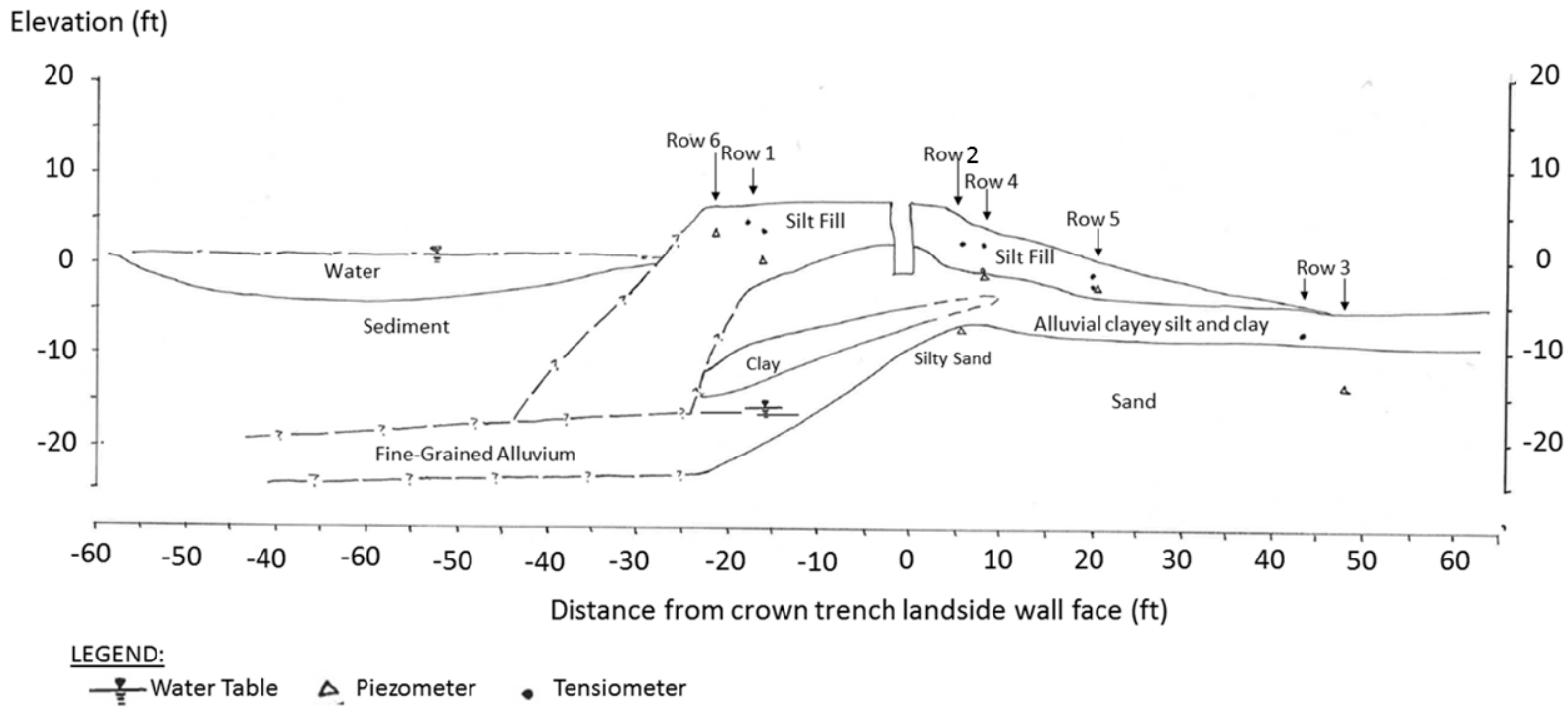


Figure 2-189. Interpreted stratigraphic section at instrument line C, within the control trench. Instrument rows 1 through 6 are shown.

188

3.1.1 Landside Flow Patterns

Landside flow patterns were found to be heavily influenced by (1) macroporosity associated with burrowing activities, and (2) site stratigraphy and heterogeneity.

Early seeps on the landside were observed to flow rapidly in the vicinity of Stations 8 to 10. Active mammal populations were observed just north of this area before construction began, and burrows were found at the slope surface at these locations following testing. Gravel bags placed on the seeps slowed flow, and the burrow flow slowed with time as permeability of the burrow walls increased with increased wetting which allowed the water to be absorbed by levee soils faster than it could flow into the burrow, consistent with Beven and Germann (1982).

Early seeps in the vicinity of instrument Lines A and D produced flows less rapidly than near the control instrument Line C, but they seemed to advance the wetting front over a broad area. In general, the primary seepage areas correlated well with where burrows were encountered in the trenches and with areas of blackberry groundcover (Figure 2-185). Based on flow observations, seeps in the vicinity of instrument Lines A and D, are likely influenced by burrows (intersected by the tree trench and plugged but not seen to outlet at the slope face) that do not form a direct pipe between the water source and the seepage points. The only holes that were found to outlet to the slope surface in this zone are worm holes. These small and relatively shallow holes were seen to concentrate flows within the shallow, surficial levee soils.

At the landside oak, pore water pressures were found to be elevated in piezometer PA4a relative to comparable instruments on other lines. This instrument is at a depth of 3 feet and located between the water source and the root ball of the landside oak tree. PA4b at a depth of 6 feet was not elevated. It is unclear whether there was a local effect from the root ball or from another anomaly, such as one of the numerous burrows in the vicinity.

Numerous researchers have found that the influence of macropores on flows through a soil matrix are greater in soils with higher clay content than in soils that are more granular in nature (Beven and Germann, 1982; Green and Askew 1965). Macropores require inflows into the pore that exceed lateral losses through the walls of the pore for flow to occur (Beven and Germann, 1982). Unless saturation is achieved, capillary forces within the soil matrix tend to hold water within the pores of the soil rather than allowing for flow into a macropore. Upon saturation of the area around the macropore, inflows into the pore are limited by the permeability of the pore walls. Rapid flows were observed north of the control instrument line C (Station CT 6 to 10) where a burrow was found to be rapidly flowing, likely connected directly to the control trench. In general, the landside of the levee performed well despite burrowing activity that appeared to advance the wetting

front in the vicinity around instrument lines A and D. Flood fighting efforts were effective and, though water seeped from the levee slope face, visible signs of distress were not apparent during the test.

The water delivery trench was located within the crown of an early, and possibly natural, levee of lower permeability than soils used in raising the levee (Figure 2-28 through Figure 2-30 and Figure 2-187 through Figure 2-189). A discontinuity in the natural overbank deposits (Material 4 of Section 2.5.2.1) extends below the explored depth of the 8 foot deep trench at Stations TT 37 to 42, between the landside and waterside trees. This gap suggests a possible old breach or an area that was locally excavated and then loosely refilled (Figure 2-185). The old levee appears to slope toward this discontinuity from the north and south between Stations TT 2 and TT 50. The slope of this material may divert water from the control instrument Line C, providing a possible explanation for instruments failing to saturate in this area.

The limits of this loose zone were well defined by the subsidence zone detected by T-LiDAR between Stations 22 and 47 (Figure 2-183 and Figure 2-185). To the south of this possible breach or previously disturbed area, burrowing activity within the old levee soils was found beginning at Station TT 56 and extending to Station TT 82 (Figure 2-185). The reason for such active burrowing activity at this location is unclear as is the role of the landside vegetation, both the landside oak tree and the blackberry groundcover around and below the tree. Smaller burrows within the 8 foot deep zones of the tree trench are consistent in size with those of voles and gophers, but not in typical behavior according to Dr. Van Vuren. These rodents enter from the landside and may have taken advantage of existing burrows, but in Dr. Van Vuren's opinion would be unlikely to themselves have burrowed to these depths. Muskrats enter from the waterside and inactive muskrat entrances were found in abundance along all accessible and visible areas we were able to inspect. Loose backfill of the gap in the old levee may have affected muskrat burrow patterns, since burrows were observed to occur preferentially in more stable soils where collapse is less likely. Given that the evidence of burrowing within the trench was only found within the old levee soils in this area and burrows had roots growing through them and were deemed inactive, it is possible that these burrows predate the tree. The age of the burrowing activity at this location is unknown and, according to Dr. Van Vuren, burrows can persist in stable cohesive soils for many years, and can be re-activated by animals over generations.

3.1.2 Landside Slope Stability

In general, signs of slope instability or distress were not observed on the landside of the levee during trench construction, the 10 day flow test, or repair of the site. T-LiDAR scans noted a small rotation of the landside tree, on the order of 0.12 degrees (or about 2 inches measured 6.5 feet up from the base of the tree). Given the deformations that occurred onsite, lining up the various T-LiDAR scans involved

significant judgement, as spheres used to align scans fell within areas that had experienced deformation. Additional analysis may be required to resolve whether these deformations, as well as upward movements at the waterside top-of-slope, could be related to these challenges in data alignment. A detailed discussion of the loading and tree root assumptions to be made in future modeling efforts is provided in Appendix G.

3.1.3 Waterside Flow Patterns

Patterns of water flow and saturation on the waterside of the levee show that water arrived at the waterside oak tree to instrument line E (Stations TT 38 to 40) before arriving at instrument line B (Station TT 20 to 25). Burrows may have played a role in these flow patterns, as burrow entrances were observed all along the waterside toe. A single individual burrow could skew saturation results, however burrows were not found in these zones extending to the trench. As discussed previously, burrows that outlet to the slope face and are not connected to the water source may concentrate seepage but are less likely to advance the wetting front. Waterside flow patterns may have been advanced by the zone of loose soil filling the gap in the old levee between Stations TT 37 to 42 and subsidence was observed in the T-LiDAR scans (Figure 2-185 and Figure 2-183). These loose and relatively more permeable soils may have allowed the wetting front to arrive at piezometer PE1 before other nearby instruments. Instruments at the control line were slower to saturate, with muskrat burrow entrances observed along the shoreline but without knowledge of how deeply they penetrate into the site. The control line is more uniform in soil conditions than the tree trench, without obvious pockets of loose soils or rapid changes in stratigraphy like those observed in the tree trench.

Pore water pressures in row 6 instruments (at the toe of the waterside oak tree as shown on Figure 2-187 through Figure 2-189) were evaluated to determine whether elevated values could be found upslope of the waterside oak tree, and no discernible pattern was found. Seepage was observed at the waterside oak tree at about 9 hours into the flow test. Water appeared to be seeping out of burrow entrances all along the waterside toe, and the area adjacent to and upslope of the tree trunk. When the tree fell, the pore water pressure dropped by about 0.25 feet of head at PB6 (Row 6 of Figure 2-188). Seepage stopped from the areas around the oak tree and pore pressures never returned to the level previously achieved prior to the fall of the tree. The fall of the tree seemed to render previously preferred macropore pathways inactive, possibly by introducing discontinuities. During they dye test on the tenth day of flow, seepage was seen flowing only from burrow sites outside of the area of the waterside oak tree (Figure 2-144; discussed in detail in Section 2.6.3). The complexity of preferred pathways created by muskrat burrow networks along the waterside slope seem to have a larger effect on pore water pressure accumulation than the presence of the root ball of the waterside oak tree.

3.1.4 Waterside Slope Stability

A series of deformations were observable during the 10 day flow test. These deformations are discussed in detail in Section 2.6.2 and summarized on Figure 2-185. The following primary areas of deformation are of interest:

- Cracking between control and tree trench: This crack began opening a little over 2 hours into the flow test, before trenches were full. The crack peaked in size 13 hours into the test and began to shrink after 15 hours. It is unclear whether these early cracks were connected to movements associated with the waterside oak tree prior to failure. The waterside oak tree fell 39 hours into the test.

- Older and fresh cracking observed at the top of the waterside slope: The cracks were buried under a wattle and leaves and were not discovered until after the tree fell. Once discovered, the fresh crack continued to move during the flow test

- Pavement cracking (Stations TT 55 to 90): Minor cracking was observed near southern end of tree trench. Crack patterns appear to outline movements toward the waterside, though T-LiDAR data shows upward movements of 1 to 1.5 cm. Thick pavement overlay (6" on a 4" original section) provides evidence of past poor performance and cracking. A localized section of the trench wall failed into the tree trench upon repair (Stations 65 to 88), revealing manganese oxide staining on a possible pre-existing fracture planes within the levee fills.

- Subsidence of up to 6 cm between Stations TT 20 and 50: An area subsided up to 6 cm (observable in the T-LiDAR scans but not noted during testing), coincident with loose soils associated with the dip in the natural levee (Material 4) and the gap at Stations TT 37 to 42 (Figure 2-185). Timing of deformation is unknown, but a crack at Stations TT 40 to 50 opened late in the test (day 10 of flow). The crack lies near the zone of subsidence captured by analysis (Figure 2-185). The subsidence could be caused by settlement of the loose materials at this location toward the trench, as implied by the semicircular patterns on both land and water sides. Lateral offsets of pavement at the trench was not observed at this location, and trench walls did not collapse during the repair phase as they did at Stations 65 to 88 (Figure 2-123).

- Cracking in the area of the tree rootball after failure of the tree (Stations TT 16-28): Observed at 9:30 am on 5/23/12, coincident with the discovery of the tree failure

Cracking in the localized area of the root ball of the waterside tree between Stations TT 16 to 28 appeared when the tree fell and is considered attributable to the tree failure. Movement was seen in the embankment prior to observable tree movements. The extent to which deformations of the embankment (cracking at the top of slope and cracking between the control and tree trenches) were influenced by the presence of and movement of the waterside oak tree is unclear and will be discussed below and explored further through modeling. Waterside fills were observed to be loose, with farm equipment embedded into the levee in one location

(Figure 2-187 and Figure 2-27) and buried barbed wire fencing at the control section. The waterside tree is 60 years old (by ring count on the fallen tree that has since been cut), indicating that the tree did not appear on the loose soils of the waterside edge until after the slough was gated in 1950. As discussed above, historical data in combination with exploratory data were used to arrive at interpreted sections for modeling. These sections are presented on Figure 2-187 through Figure 2-189. The sections show the extent of the loose silt fills as well as a zone of weak clay within the old levee that was found in boring and CPT data.

The instability of loose soils along the waterside slope as well as potential sliding along the weak clay seam will be considered to explain the cracking observed at the southern end of the tree trench. A photograph taken just following a rain at the beginning of trench construction is shown on Figure 2-190. The photograph shows zones of water ponding in linear patterns west of the centerline of the levee crown road and tapering toward the waterside pavement edge near the southern end of the tree trench. Cracking patterns observed in the field follow a similar pattern. Subsidence may have occurred at pre-existing crack locations from past movements along the waterside slope. An old crack was found at the top of the waterside slope at Stations TT 28 to 55.

Vertical deformations on the order of 1.5 to 2 cm (0.6 to 0.8 inch) were captured by T-LiDAR (Figure 2-183) along the entire length of the control trench and extending to the previously discussed deformation zone at Station TT 20 to 50 (Figure 2-185). These deformations were tracked as they were able to be monitored at the gap between the trenches. The deformations began early in the flow test and grew as the wetting front progressed through the waterside instruments (TC1-36 saturated at 16.4 hours into the flow test). After about 13 to 15 hours of flow, deformations tapered and the crack began to stabilize and then decrease in size (Figure 2-114). In this same timeframe, piezometer P2B was recording a sharp dip in recorded pressure, consistent with a sudden event opening a new avenue for water flow and causing a rapid loss in building pore water pressures (Figure 2-154). Perhaps a previously blocked avenue for water flow suddenly opened at that time, such as a burrow or a crack. We do not know the time when the top of slope crack opened (Figure 2-135 through Figure 2-138) and if it was before the tree was observed to have fallen or in the same event. A seep was observed at the waterside oak at 9 hours into the flow test which may have relieved some pore water pressures. Other waterside seeps could not be inspected at that time as the water surface elevation in the slough was too high to allow for the type of access available during the dye test. The tree did not fall until about 39 hours into the flow test, after the deformations along the control and tree trench had occurred and stabilized. A progressive failure scenario will be considered in our modeling efforts where the influence of the tree (including both the static loading as well as root reinforcing) is evaluated under the following scenarios:

1) A large failure plane extending back to the control and tree trenches using transient pore pressures at 2.5 hours into the flow test when movements were first observed.

2) A smaller failure envelope extending from the crack at the top of the waterside slope at a time 13 hours into the flow test (the time when this crack would have to have opened in a progressive failure scenario)

3) A failure scenario including only the root ball at 39 hours into the test versus a scenario extending to the top of the waterside slope

4) A failure scenario of the embankment movement without the presence of a tree or reinforcing elements at 2.5, 13, and 39 hours into flow as well as at steady state

Figure 2-190. Pattern of pavement cracking (right) is similar to pattern of ponding in the pavement just following a rain event and prior to trench construction. Asphalt sections show evidence of a thick overlay, an indication of previous pavement distress.

The conditions of an individual tree can impact the stability as well. The overall embankment stability is a key factor to be considered as well as the health of the tree and root system. The waterside oak tree is a valley oak. Cooper (1926) states that "It is plain that the oaks are excluded from the subaqueous soils because of saturation and consequent lack of aeration". Valley oaks are, however, the most tolerant of the oak species to wet conditions (Cooper, 1926; Jacobs et al., 1997). Low oxygen, or hypoxia, can decrease tree vigor (Kozlowski, 1985) and pre-dispose the tree to disease, insect pests, and root rot (Heritage and Duniway, 1985; Miller and Burke, 1977). The health of the waterside valley oak tree prior to the study was not

known, but given the lean and the loose fills upon which the tree was founded (uncompacted soils along the waterside slope along with thick, soft sediments within the slough), this tree was not likely to have been supported adequately on this levee. A detailed discussion of the stability and loading associated with the waterside tree is provided in Appendix G.

4 CONCLUSIONS

Flows at the Twitchell Island test site were controlled by macroporosity and stratigrapic conditions related to the presence of an old levee on which the existing levee is founded. Zones of macropores associated with burrowing activities of muskrats (from the waterside), as well as voles and gophers (from the landside) advanced the wetting front when burrows intersected (or nearly intersected) the water source. As observed at the Cal Expo test site (discussed in the second volume of this series), flow of water through macropores which advanced the wetting front diminished with time. Concentrated seepage mitigation efforts during testing consisting of placing gravel bags over flowing seeps was sufficient to control flows until surrounding soils became saturated and concentrated flows reduced. Where burrows were far from the water source with open outlets, seepage was observed to increase at these outlets as the soils surrounding the burrows saturated. Flows through these burrows were limited by the permeability of the soils surrounding the burrow and as such, flows were slow and did not appear to trigger erosion. One burrow, mid-slope near the control line, appeared to have a direct connection to both the water source and the levee slope. A large pile of gravel bags and a straw waddle controlled flows and erosion of the slope until wetting of the burrow walls increased the permeability of the walls such that inflow did not exceed outflow and the burrow ceased to flow about 42 hours into the flow test.

Elevated pore water pressure was observed in one piezometer located at a depth of 3 feet directly behind the landside oak tree. The instrument within the same hole at a depth of 6 feet did not show elevated pore pressure relative to comparable instruments. A similar pattern was not found behind the waterside oak tree, though pressures behind the tree were observed to drop by 0.25 feet of head when the tree fell and pressures in an adjacent instrument increased by a similar amount. Observed seepage around the tree and surrounding muskrat burrows ceased once the tree had fallen and preferred water pathways appeared to shift to burrows to the north and south of the waterside oak tree. The leaning waterside tree was founded on soft, debris-laden, loose soils of the waterside slope and the thick and soft deposits of silts found within the adjacent oxbow section of the slough. There are many leaning and fallen trees along the waterside slopes of the Sevenmile slough. A tree like the waterside oak tree should be evaluated for health of the tree, size, and balance of the tree with consideration to species, soil strengths, benefits to erosion resistance of the levee, consequences of failure, consequences of removal given practical and cost constraints, and other relevant factors specific to each circumstance. The landside tree performed acceptably under saturated conditions

and gusting wind conditions, showing a modest rotation of about 0.12 degrees (or about 2 inches measured 6.5 feet up from the base of the tree) based on LiDAR data provided by Gerald Bawden of the USGS.

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APPENDIX A: SOIL BORINGS AND INSTRUMENTATION LOGS

Appendix A

Prior to site selection, available soil boring logs and geotechnical information were reviewed and are presented in Appendix D. Our exploration of the site included a review of available information for the region (presented in Appendix D), drilling nine soil borings with a conventional auger drilling rig equipped with 8 inch diameter hollow stem augers, augering 12 soil borings with a 3 ¼ inch diameter hand auger, advancing 3 cone penetration tests (CPT) with frequent pore pressure dissipation readings, and trench logging and sampling during construction of the centerline trench.

This appendix provides a summary of all soil borings performed on the site. Material types are noted in many of the logs and are presented as Figure A- 1. Each hole was located at the site of a tensiometer or a piezometer, as shown on Figure A- 2. One to two instruments were installed as part of the backfill procedure. Boring numbers generally match instrument names except where two instruments are installed in the same hole. In this case, 'a' and 'b' are added to the boring number distinguish piezometers of different depth installed within a single boring. Piezometers were installed within each of the nine holes drilled by an auger rig. The remaining instruments, consisting of tensiometers and piezometers, were installed within the hand auger borings shown on Figure A- 2. Laboratory testing associated with all types of exploration are provided in Appendix B. CPT and pore pressure dissipation results are provided in Appendix C. Excerpts from available studies performed at the site including soil borings and laboratory testing by others are provided in Appendix D. Trench logs are provided in Appendix E.

Borings drilled with an auger rig were performed by Gregg Drilling. These were performed at the locations of piezometers PA1, PA2, PA3, PB1, PB2, PB3, PC1, PC2, and PC3 as shown on Figure A- 2. These logs are presented as Figure A-3 through Figure A-11. Hand auger boring logs are presented in list format at the back of this appendix.

SOIL TYPES:

1. Clayey silt (ML), olive mottled with oxidation staining, moist, blocky structure with light cementation.
2. Clayey silt (ML), light brown, moist, thinly bedded, easily cleaves along bedding of variable orientation, gaps and cracks observed, prone to sloughing and instability, bed thickness 1-5mm (typ.) .
3. Sandy silt (ML) with pockets and lenses of silty sand (SM), light brown, moist.
4. Clayey silt (MH), dark olive brown with oxidation staining, moist.
5. Clayey silt (ML), reddish brown, moist
6. Sandy silt (ML), olive brown with oxidation staining, occasional silty sand pocket.
7. Sandy silt with clay (ML), pockets of olive with oxidation mixed with pockets of reddish brown with fine sand at cleavage planes in structure, material is highly unstable and consists of a mixture of soil types 2, 3, and 4.

Figure A- 1. Legend showing soil types 1 through 7 as detailed in Section 2.5.2.1

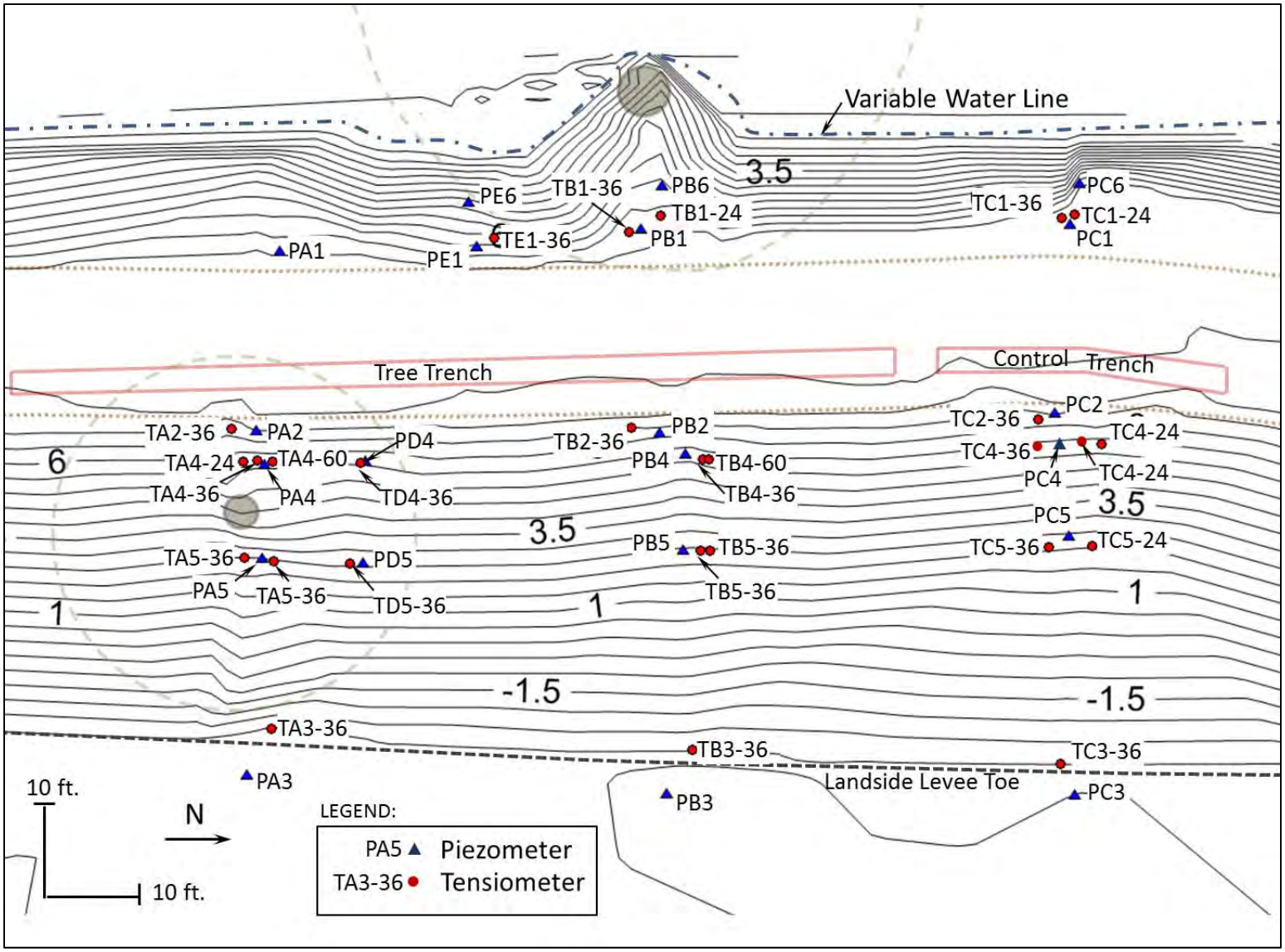


Figure A- 2. Site map and instrument layout

Instrument Logs

PA1 – Installed by drill rig with hollow stem augers

See Figure A-3.

PA2 – Installed by drill rig with hollow stem augers

See Figure A-4.

TA2-36 – Drilled with 1" gouge auger and sledgehammer

No log of top of hole.

Log of sample at 30-36":

Sandy silt (ML), light brown, moist, sandy pockets.

Bottom of boring at 36"

PA3 – Installed by drill rig with hollow stem augers

See Figure A-5.

TA3-36 – Drilled with 1" gouge auger and sledgehammer

0 – 12" Sandy Silt (ML) to silty sand (SM), brown, moist.

12"-36" Clayey silt (MH), dark olive brown with reddish mottling, moist, stiff (Material 4).

Bottom of hole at 36"

PA4 –Installed with a 3 1/4 inch diameter hand auger

0"-6" Silt (ML), light brown, loose, slightly moist, organics (topsoil).

6"-30" Sandy silt (ML), light brown, moist (Material 3).

30"-36" Clayey silt (ML), light brown, moist, thinly-bedded, easily cleaves along bedding planes (Material 2).

36"-48" Sandy silt (ML), light brown, moist (Material 3).

48"-76" Clayey silt (ML), light brown, moist, thinly-bedded, easily cleaves along bedding planes (Material 2). ¾ inch live roots at 49" and 56".

Bottom of boring at 76"

TA4-24 – Drilled with 1" gouge auger and sledgehammer

0"-24" Clayey silt (ML) with sand, light brown and olive with oxidation staining, moist (Material 1).

Bottom of boring at 24"

TA4-36 – Drilled with 1" gouge auger and sledgehammer

0"-36" Sandy silt (ML) with interbeds of silty sand (SM), light brown, moist lightly cemented.

Bottom of boring at 36"

TA4-60 – Drilled with 1" gouge auger and sledgehammer

0 – 6" Silty sand (SM), brown, moist.

6"-32" Sandy silt (ML) with silty sand interbeds (SM), light brown, layered structure

(Material 2).

32"-54" Silt (ML) with clay, olive brown with reddish oxidation (Material 3).

54"-60" Sandy silt (ML), light brown, moist, layered structure (Material 2).

Bottom of boring at 60"

PA5 –Installed with a 3 1/4 inch diameter hand auger

0"-22" Sandy silt (ML) with clay, olive brown with oxidation staining, moist.

22"-43" Silty sand (SM) with clayey silt interbeds (ML), light brown, moist.

½ inch live root at 35" depth.

Bottom of boring at 43"

TA5-24 – Drilled with 1" gouge auger and sledgehammer

0"-18" Sandy silt (ML) with fine sand, olive with reddish mottling, some layering structure, moist, Material 3 with sandy pockets

18"-24" Silt (ML) with clay and trace fine sand, olive with reddish mottling (Material 3 with clayey pockets).

Bottom of boring at 24"

TA5-36 – Drilled with 1" gouge auger and sledgehammer

0"-36" Silt (ML) with fine sand, light brown, matrix of Material 3 with pockets of Material 2 layered bedding structure.

Bottom of boring at 36"

PB1– Installed by drill rig with hollow stem augers

See Figure A-6

TB1-24 – Drilled with 1" gouge auger and sledgehammer

0"-12" Clayey silt (ML), dark brown with reddish oxidation, high organic content (topsoil)

12"-24" Silty sand (SM), light brown with orange mottling (Material 3) with pockets of sandy silt (ML), light brown, layered structure (Material 2).

Bottom of boring at 24"

TB1-36 – Drilled with 1" gouge auger and sledgehammer

No log of top of hole.

Log of sample at 30-36":

Sandy silt (ML), light brown with occasional pockets of dark brown clayey silt (ML), moist, light brown matrix soils have layered structure (Material 2).

Bottom of boring at 36"

PB2 – Installed by drill rig with hollow stem augers

See Figure A-7

TB2-36 – Drilled with 1" gouge auger and sledgehammer

No log of top of hole.

Log of sample at 30-36":

Sandy silt (ML), light brown with reddish oxidation, moist (Material 3), blended with pockets of silt (ML) with sand in a layered structure (Material 2).

PB3 – Installed by drill rig with hollow stem augers

See Figure A-8

TB3-36 – Drilled with 1" gouge auger and sledgehammer

0" to 43" Clayey silt (MH), dark olive brown with oxidation mottling, moist (Material 4).

Bottom of boring at 43"

PB4 –Installed with a 3 1/4 inch diameter hand auger

0"-9" Clayey silt (ML), reddish brown, moist.

9"-30" Clayey silt (ML), olive with reddish mottling, moist.

30"-70" Sandy silt (ML), olive with reddish mottling, moist (Material 7).

70"-76" Clayey silt (ML), olive brown with thin layered structure and sands at interfaces (Material 2).

Bottom of boring at 76"

TB4-36 – Drilled with 1" gouge auger and sledgehammer

0"-18" Sandy silt (ML), light brown, moist, layered bedding (Material 2), organics in upper 3".

18"-36" Sandy silt (ML) with silty sand interbeds (SM), brown with light oxidation staining.

Bottom of boring at 36"

TB4-60 – Drilled with 1" gouge auger and sledgehammer

0"-6" Silty sand (ML), dark brown, slightly moist

6"-36" Sandy silt (ML) with pockets of silty sand (SM), light brown, moist, layered structure (Material 2).

36"-54" Sandy silt (ML) with layers of silty sand (SM), olive, moist (Material 3).

54"-60" Sandy silt (ML), light brown, moist, layered structure (Material 2).

Bottom of boring at 60"

PB5 –Installed with a 3 1/4 inch diameter hand auger

0"-9" Sandy silt (ML), reddish brown, moist.

9"-15" Silty sand (SM) light brown, moist.

15"-43" Clayey silt (ML), light brown, moist, pockets of silty sand (SM).

TB5-24 – Drilled with 1" gouge auger and sledgehammer

0 – 12" Sandy silt (ML) with pockets and lenses of silty sand (SM), light brown, moist (Material 3/6).

12"-24" Sandy silt (ML) light brown, thinly-bedded, easily cleaves along bedding, moist.

Variation of Material 2.

Bottom of hole at 24"

TB5-36 – Drilled with 1" gouge auger and sledgehammer

0 – 18" Sandy silt (ML) with pockets and lenses of silty sand (SM), light brown, moist (Material 3/6).

18"-36" Sandy silt (ML) light brown, thinly-bedded, easily cleaves along bedding, moist.

Variation of Material 2.

Bottom of hole at 36"

PB6 –Installed with a 3 1/4 inch diameter hand auger

0"-9" Silt (ML) with sand and clay, light brown, organics including small roots ($^{1}/_{16}$" to ¼")

9"-36" Sandy silt (ML), light brown, moist, lightly cemented, barbed wire at 22".

36"-48" Clayey silt (ML), olive brown with thin layered structure and sands at interfaces (Material 2).

Bottom of boring at 48"

PC1 – Installed by drill rig with hollow stem augers

See Figure A-9

TC1-24 – Drilled with 1" gouge auger and sledgehammer

0"-12" Clayey silt (ML), dark brown with reddish mottling, high organic content (topsoil)

12"-24" Sandy silt (ML), light brown, layered structure (Material 2).

Bottom of boring at 24"

TC1-36 – Drilled with 1" gouge auger and sledgehammer

No log of top of hole.

Log of sample at 30-36":

Sandy silt (ML), light brown with occasional pockets of dark brown clayey silt (ML), moist, light brown matrix soils have layered structure (Material 2).

Bottom of boring at 36"

PC2 – Installed by drill rig with hollow stem augers

See Figure A-10

TC2-36 – Drilled with 1" gouge auger and sledgehammer

No log of top of hole.

Log of sample at 30-36":

Clayey silt (ML), olive mottled with oxidation staining, moist, sandy pockets.

Bottom of boring at 36"

PC3 – Installed by drill rig with hollow stem augers

See Figure A-11

TC3-36 – Drilled with 1" gouge auger and sledgehammer

0"-43" Clayey silt (MH), dark olive brown with oxidation mottling, moist (Material 4).

Bottom of boring at 43"

PC4 –Installed with a 3 1/4 inch diameter hand auger

0"-15" Sandy silt (ML) with clay, dark olive brown, moist.

15"-30" Clayey silt (ML), light brown, moist, thinly-bedded, easily cleaves along bedding (Material 2).

30"-62" Clayey silt (ML), olive with reddish mottling, moist.

Decomposing organic matter at 46.

62"-76" Clayey silt (MH), dark brown with reddish mottling, moist (Material 4).

Bottom of boring at 76"

TC4-24 – Drilled with 1" gouge auger and sledgehammer

0"-12" Sandy silt (ML) with clay, dark olive brown, moist.

12"-24" Sandy silt (ML), light brown, moist fine sand, thinly bedded layered structure (variation of Material 2)

Bottom of boring at 24"

TC4-36 – Drilled with 1" gouge auger and sledgehammer

0"-12" Clayey silt (ML), olive brown mottled with oxidation, slightly moist (Material 1).

12"-24" Sandy silt (ML), light brown, moist (Material 3).

24"-36" Sandy silt (ML), light brown, moist, layered structure (Material 2).

Bottom of boring at 36"

TC4-60 – Drilled with 1" gouge auger and sledgehammer

0"-18" Clayey silt (ML), brown, moist.

18"-42" Silt (ML) with clay and sand, brown, moist, layered structure (Material 2).

42"-60" Sandy silt (ML) with silty sand interbeds (SM), olive brown with reddish mottling (Material 3 with pockets of Material 2).

Bottom of boring at 60"

PC5 –Installed with a 3 1/4 inch diameter hand auger

0 – 9" Sandy silt (ML), light brown mottled with reddish brown, moist. Material 3/6.

9"-24" Sandy silt (ML), olive with reddish mottling, moist.

24"-36" Silty sand (SM), light brown, moist. Gradually more silt with depth.

36"-43" Sandy silt (ML) with trace clay, light brown, weak cementation.

Bottom of hole at 43"

TC5-24 – Drilled with 1" gouge auger and sledgehammer

0"-24" Sandy silt (ML) with clay, light brown, moist, very fine sand, light cementation (Material 3)

Bottom of boring at 24"

TC5-36 – Drilled with 1" gouge auger and sledgehammer

0"-36" Sandy silt (ML) with silty sand pockets (SM), light brown, moist (Material 3).

Bottom of boring at 36 inches

PC6 –Installed with a 3 1/4 inch diameter hand auger

0"-9" Silt (ML) with sand and clay, light brown, moist, organics including leaf litter and live roots (sized fine to 1 ½ inch). Roots sheared easily with hand auger, likely originating from nearby bushes rather than oak trees.

9"-18" Sandy silt (ML) brown, moist, organic matter and small roots ($^1/_8$ inch diameter).

18"-48" Sandy silt (ML), light brown, moist, lightly cemented, small roots $^1/_8$ to ¼ inch diameter, ½ inch easily broken root and barbed wire at 22". Pockets of clayey silt (ML) and small roots ($^1/_8$ to ¼ inch diameter) abundant at 36".

Bottom of boring at 48".

PD4 –Installed with a 3 1/4 inch diameter hand auger

0"-8" Clayey silt (ML), brown, moist.

8"-30" Clayey silt (ML), olive mottled with reddish oxidation, moist, with fine sand becoming increasingly sandy with depth.

30"-48" Sandy silt (ML), light brown, moist, layered structure (Material 2)

48"-72" Clayey silt (ML) with pockets of sandy silt (ML), light olive with oxidation staining, moist (Material 3).

72"-76" Clayey silt (MH), dark olive brown, moist (Material 4).

Bottom of boring at 76"

TD4-36 – Drilled with 1" gouge auger and sledgehammer

0"-15" Sandy silt (ML) with silty sand pockets (SM), light brown, moist (Material 3).

15"-36" Sandy silt (ML), light brown, moist, thin lenses of sand between thin bedded thinly-bedded silt (Material 2) with pockets of Material 3.

Bottom of boring at 36"

PD5 –Installed with a 3 1/4 inch diameter hand auger

0”-3” Clayey silt (ML), brown, slightly moist, organics (topsoil).

3”-7” Clayey silt (MH), dark brown, moist (Material 4).

7”-12” Clayey silt (ML), olive brown with reddish mottling, moist.

12”-22” Sandy silt (ML) with pockets of silty sand (SM), light olive with reddish oxidation (Material 3), gradually increasing clay content with depth.

22”-43” Clayey silt (ML), light olive with reddish oxidation.

Bottom of boring at 43”

TD5-36 – Drilled with 1” gouge auger and sledgehammer

0”-24” Clayey silt (ML), olive mottled with reddish oxidation, moist.

24”-36” Sandy silt (ML), light brown, moist, thin lenses of sand between thin bedded thinly-bedded silt (Material 2).

Bottom of boring at 36”

PE1 –Installed with a 3 1/4 inch diameter hand auger

0”-7” Silt (ML) with clay and sand, dark brown, moist, organics (topsoil)

7”-30” Clayey silt (ML), yellow brown, moist, gradually becoming sandier with depth

30”-60” Sandy silt (ML), yellow brown, moist.

60”-85” Clayey silt (ML) with sand, olive with reddish mottling, increasing moisture content with depth, sandy pocket and ½ inch diameter root at 79”.

Bottom of boring at 85”

TE1-36 – Drilled with 1” gouge auger and sledgehammer

0”-24” Silt (ML), light brown, dry,loose with high organic content (thick topsoil)

24”-36” Clayey silt (ML), olive with orange mottling, moist, fine sand.

Bottom of boring at 36”

PE6 –Installed with a 3 1/4 inch diameter hand auger

0”-9” Silt (ML) with sand and clay, light brown, roots (1/16”-1/8” diameter) and organics (topsoil).

9”-24” Sandy silt (ML), mottled reddish brown and dark brown, moist.

24”-28” Clayey silt (ML), brown, moist.

28”-48” Sandy silt (ML), light brown, moist, trace clay, gradual color change with depth to olive with orange mottling.

Bottom of boring at 48”.

LOG OF BORING PA1

SHEET 1 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, LineA, Row 1

DRY ON COMPLETION ? Yes

DATE March 15, 2012

SURFACE ELEV. 7.3 FT.

START TIME 8:55 AM

END TIME 11:15 AM

BOTTOM OF HOLE DEPTH 6.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	FIELD RESULTS N	LABORATORY RESULTS LL	LABORATORY RESULTS PI	LABORATORY RESULTS %M	STRATUM DESCRIPTION
	1.0	2.5	PA1-1	SPT	1 2 2	4			34.9	2" of topsoil with asphalt and organics. Clayey Silt (ML), reddish brown, moist
2.5	2.5	4.5	PA1-2	SS						Interbedded Sandy Silt (ML) with Clayey Silt (ML), reddish brown, moist
5.0	5.0	6.5	PA1-3	SPT	2 2 2	4			26.1	1/4 " root encountered at 6 feet
7.5										Bottom of boring at 6.5 feet
10.0										

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-3. Boring at location of piezometer PA1 (Figure A- 2)

LOG OF BORING PA2

SHEET 2 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, LineA, Row 2

DRY ON COMPLETION ? No

DATE March 16, 2012

SURFACE ELEV. 6.8 FT.

START TIME 9:30 AM

END TIME 10:00 AM

BOTTOM OF HOLE DEPTH 16.0 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH 14.0 FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	N	LABORATORY RESULTS LL	PI	%M	STRATUM DESCRIPTION
										2" of topsoil and organics.
	1.0	2.5	PA2-1	SPT	1					Sandy silt (ML) with lenses of silty sand (SM), brown, moist
					2					
2.5					2	4			24.4	
				SS						
	4.0	6.0	PA2-2	SS						
5.0										
	7.0	8.5	PA2-3	SPT	3					Clayey silt (MH), olive mottled with reddish oxidation, moist, piece of decomposed black wood/peat at 7 ft
7.5					2					
					3	5			23.7	
10.0										Piece of live woody root at 10 feet.
	10.0	11.5	PA2-4	SPT	3					Soil becomes darker olive color, more moisture, softer
					4					
					5	9			37.9	
12.5										Clayey Silt (MH), grey, wet, soft
	12.5	14.0	PA2-5	SPT	2					
					1					
					2	3			40.1	
										Sand (SP), grey, wet, 2" of sample recovered
15.0	14.5	16.0	PA2-6	SPT	2					
					2					
					3	5			28.5	
										Bottom of boring at 16 feet
17.5										
20.0										

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-4. Boring at location of piezometer PA2 (Figure A- 2)

LOG OF BORING PA3

SHEET 3 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, LineA, Row3

DRY ON COMPLETION ? Yes

DATE March 16, 2012

SURFACE ELEV. -3.3 FT.

START TIME 10:15 AM

END TIME 10:35 AM

BOTTOM OF HOLE DEPTH 8.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH	SAMPLE DEPTH		SAMPLE	SAMPLE	FIELD RESULTS		LABORATORY RESULTS			STRATUM DESCRIPTION
	FROM	TO								
FT.	FT.	FT.	NO.	TYPE	Blow Count	N	LL	PI	%M	
										2" of topsoil with grass.
	1.0	2.5	PA3-1	SPT	3					Clayey Silt (ML), olive brown mottled with reddish oxidation, moist, fine roots
					4					
2.5					5	9			24.4	Sandy silt (ML) with clay, yellow brown, moist
	3.0	5.0	PA3-2	SS						
5.0	5.0	6.5	PA3-3	SPT	3					
					3				17.9	
					5	8			12.2	Sand with Silt (SP), yellow brown, moist, weakly cemented
7.5	7.0	8.5	PA3-4	SPT	5					
					4					
					4	8			8.3	
										Bottom of boring at 8.5 feet
10.0										

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-5. Boring at location of piezometer PA3 (Figure A- 2)

LOG OF BORING PB1

SHEET 4 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, Line B, Row 1

DRY ON COMPLETION ? Yes

DATE March 15, 2012

SURFACE ELEV. 7.1 FT.

START TIME 11:20 AM

END TIME 11:45 AM

BOTTOM OF HOLE DEPTH 6.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	FIELD RESULTS N	LABORATORY RESULTS LL	LABORATORY RESULTS PI	LABORATORY RESULTS %M	STRATUM DESCRIPTION
										12" of topsoil and organics
	1.0	2.5	PB1-1	SPT	1 1 2	3			33.7	Interbedded Sandy Silt (ML) with Clayey Silt (ML), reddish brown
2.5	2.5	4.5	PB1-2	SS						Silt (ML), yellow brown, layered structure, angled bedding, trace clay
5.0	5.0	6.5	PB1-3	SPT	3 2 3	5				Higher sand content at base of sample (very fine sand)
7.5										Bottom of boring at 6.5 feet
10.0										

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-6. Boring at location of piezometer PB1 (Figure A- 2)

LOG OF BORING PB2

SHEET 5 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, Line B, Row 2

DRY ON COMPLETION ? Yes

DATE March 15, 2012

SURFACE ELEV. 6.3 FT.

START TIME 1:35 PM

END TIME 2:15 PM

BOTTOM OF HOLE DEPTH 17.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	N	LABORATORY RESULTS LL	PI	%M	STRATUM DESCRIPTION
										6" of topsoil and organics. Clayey silt (ML) yellow brown, moist
	1.0	2.5	PB2-1	SPT	1 2 3	5			35.2	
2.5										
	4.0	6.0	PB2-2	SS						Silt with fine sand (ML) light brown with oxidation staining, moist, stuctured in thin beds, weakly cemented
5.0										
7.5	7.0	8.5	PB2-3	SPT	3 3 4	7			18.4 23.6	Clayey Silt (ML), olive with red oxidation mottling, moist, small pieces of black decomposed wood/peat
	9.0	11.0	PB2-4	SS						
10.0										
12.5	12.0	13.5	PB2-5	SPT	4 5 7	12			26.2	grades to higher clay content
15.0										
	16.0	17.5	PB2-6	SPT	3 4 5	9			14.8	Sand (SP) with trace silt,olive brown, moist
17.5										Bottom of boring at 17.5 feet
20.0										

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-7. Boring at location of piezometer PB2 (Figure A- 2)

LOG OF BORING PB3

SHEET 6 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, Line B, Row3

DRY ON COMPLETION ? No

DATE March 16, 2012

SURFACE ELEV. -2.8 FT.

START TIME 10:45 AM

END TIME 11:05 AM

BOTTOM OF HOLE DEPTH 14.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH 13.5 FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	FIELD RESULTS N	LABORATORY RESULTS LL	LABORATORY RESULTS PI	LABORATORY RESULTS %M	STRATUM DESCRIPTION
										6" of topsoil with grass. Silty Silty sand (SM) olive brown, moist
	1.0	2.5	PB3-1	SPT	3 4 5	9			17.6	
2.5										
	4.0	6.0	PB3-2	SS						
5.0										Sand (SP) with silt interbedded with sandy silt (SM), yellow brown, moist, clean and very fine sand
7.5										
	9.0	9.5	PB3-3	SPT	4 4 5	9			7.4	Sand (SP), reddish brown, moist, clean
10.0	10.0	11.5	PB3-4	SPT	3 4 4	8				
12.5	12.5	14.0	PB4-5	SPT	2 1 1	2			43.9	Sand (SP), grey brown, moist, clean Free water encountered at 13.5 ft
15.0										Bottom of boring at 14.5 feet

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-8. Boring at location of piezometer PB3 (Figure A- 2)

LOG OF BORING PC1

SHEET 7 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, Line C, Row 1

DRY ON COMPLETION ? Yes

DATE March 15, 2012

SURFACE ELEV. 7.7 FT.

START TIME 12:20 PM

END TIME 12:35 PM

BOTTOM OF HOLE DEPTH 6.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	FIELD RESULTS N	LABORATORY RESULTS LL	LABORATORY RESULTS PI	LABORATORY RESULTS %M	STRATUM DESCRIPTION
										12" of topsoil and organics consisting of sandy clay (CL) dark brown, moist
	1.0	2.5	PC1-1	SPT	2 2 4	6			25.2	Sandy silt (ML), yellow brown
2.5	2.5	4.5	PC1-2	SS						Silty sand (SM) interbedded with sandy silt (ML), yellow brown, moist
5.0	5.0	6.5	PC1-3	SPT	3 2 3	5			16	increasing soil structure with depth and streaks of orange weathering
7.5										Bottom of boring at 6.5 feet
10.0										

REMARKS:

Figure A-9. Boring at location of piezometer PC1 (Figure A- 2)

LOG OF BORING PC2

SHEET 8 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, Line C, Row 2

DRY ON COMPLETION ? Yes

DATE March 15, 2012

SURFACE ELEV. 6.4 FT.

START TIME 12:40 PM

END TIME 1:15 PM

BOTTOM OF HOLE DEPTH 14.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH FT.	SAMPLE DEPTH FROM FT.	SAMPLE DEPTH TO FT.	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	N	LABORATORY RESULTS LL	PI	%M	STRATUM DESCRIPTION
										6" of topsoil and organics.
	1.0	2.5	PC2-1	SPT	2 2 2	4			35.6	Clayey silt (ML) yellow brown, moist, with occasional thin layers 1/2 inch thick of sandy silt with very fine sand
2.5										
	4.0	6.0	PC2-2	SS						
5.0										Silty sand (SM), moist, yellow brown, weakly cemented, orange weathering veins
	7.0	8.5	PC2-3	SPT	3 4 5	9			23.4	Clayey silt (ML) olive mottled with reddish oxidation, moist
7.5										
	9.0	11.0	PC2-4	SS	No Recovery					Clayey Silt (ML), olive with red oxidation mottling, moist, small pieces of black decomposed wood/peat
10.0										
	11.0	13.0	PC2-5	SS						
12.5										Silty sand (SM), olive brown, moist
	13.0	14.5	PC2-6	SPT	3 4 4	8			26.7	
15.0										Bottom of boring at 14.5 ft.

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-10. Boring at location of piezometer PC2 (Figure A- 2)

LOG OF BORING PC3

SHEET 9 OF 9

DRILLER Gregg Drilling

LOGGED BY Michelle Shriro, UC Berkeley

BORING NO. / LOCATION Twitchell Island, LineC, Row3

DRY ON COMPLETION ? Yes

DATE March 16, 2012

SURFACE ELEV. -3 FT.

START TIME 11:15 AM

END TIME 11:35 AM

BOTTOM OF HOLE DEPTH 9.5 FT.

WATER LEVEL DATA (IF APPLICABLE)

DEPTH Dry FT.

ELEV. FT.

BORING ADVANCED BY: HOLLOW STEM AUGER (8" DIA) X ROTARY WASH

DEPTH	SAMPLE DEPTH FROM	SAMPLE DEPTH TO	SAMPLE NO.	SAMPLE TYPE	FIELD RESULTS Blow Count	FIELD RESULTS N	LABORATORY RESULTS LL	LABORATORY RESULTS PI	LABORATORY RESULTS %M	STRATUM DESCRIPTION
FT.	FT.	FT.								
										2" of topsoil with grass. Clayey Silt (MH), dark olive brown mottled with reddish oxidation, moist
	1.0	2.5	PC3-1	SPT	3					
					2					
2.5					3	5			24.1	
	3.0	5.0	PC3-2	SS						
5.0										Sand (SP), yellow brown, moist, clean
	6.0	7.5	PC3-3	SPT	5					
					4					
7.5					6	10			5.7	
	8.0	9.5	PC3-4	SPT	3					
					2					
					3	5			5.6	
10.0										Bottom of boring at 9.5 feet

REMARKS: SS = Shelby sampler; SPT = Standard Penetration Test

Figure A-11. Boring at location of piezometer PC3 (Figure A- 2)

Appendix B

Table B- 1. Moisture content by depth and material number in the tree trench

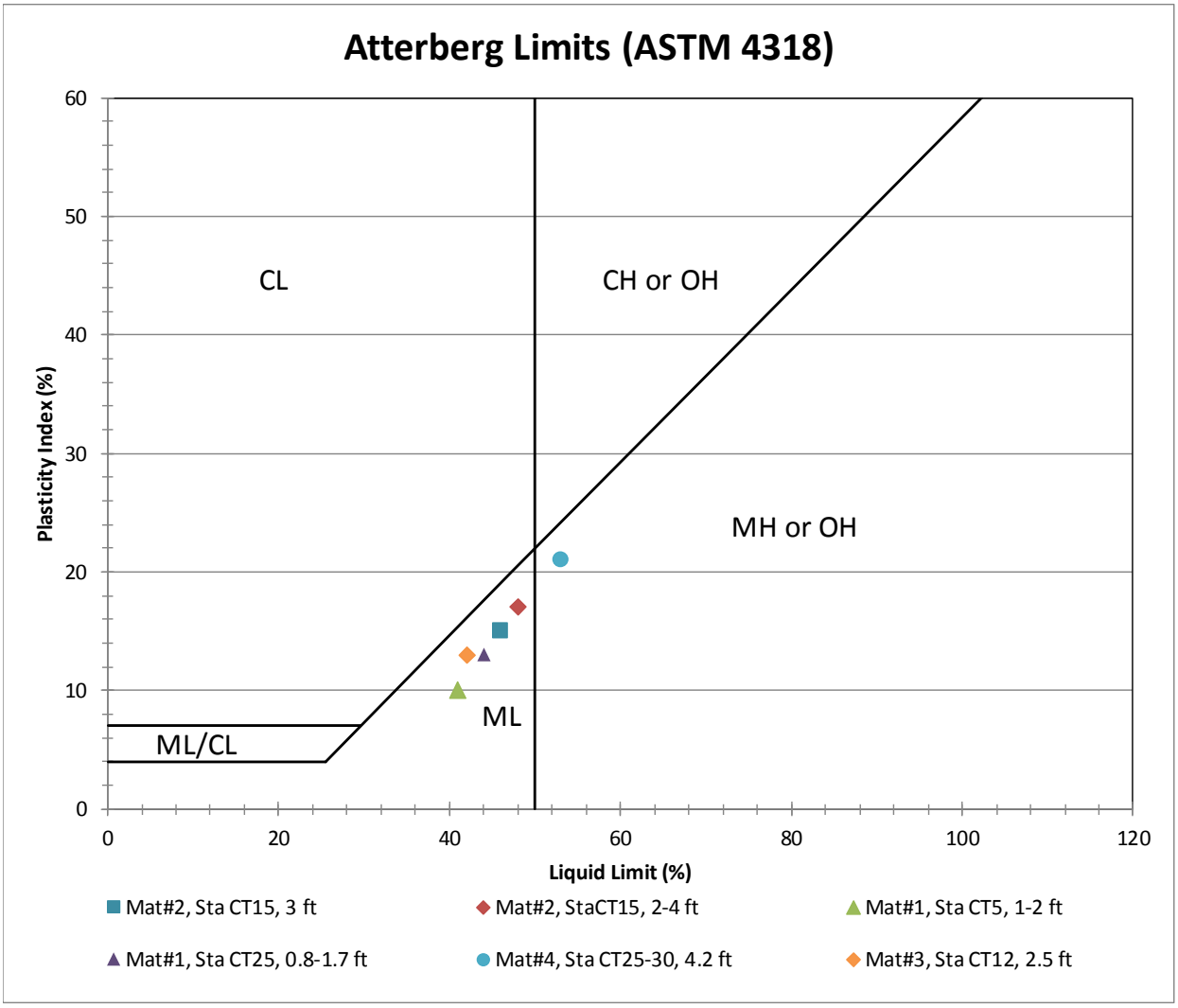
Station	Mat#	Depth (ft)	Moisture %
TT Sta 5	2	1-2.5	31.8
TT Sta 5	3	2.5-3.5	37.3
TT Sta 5	4	3.8-4	30.5
TT Sta 5	5	6.8-7.4	17.4
TT Sta 5	4	7.4-8	22.9
TT Sta 10	3	3-3.5	39.0
TT Sta 14	4	6.5	24.1
TT Sta 15	2	1-3	34.8
TT Sta 15	3	3.2-4	40.7
TT Sta 15	4	4-4.25	28.5
TT Sta 15	4	6	20.7
TT Sta 15	4	6.5	28.3
TT Sta 15	5	7.2	18.3
TT Sta 15	5	7.7-8	18.8
TT Sta 16	4	7.25-7.7	20.6
TT Sta 16	5	7.7-8	18.1
TT Sta 17	4	7.25-7.7	25.4
TT Sta 30	1	1-1.5	25.8
TT Sta 30	2	2-3	37.0
TT Sta 30	2+3+sand	3.5-4	19.3
TT Sta 30	4	7-8	23.0
TT Sta 33	2	3.5-4.5	16.5
TT Sta 33	2+3+sand	4.5-6	19.8
TT Sta 33	4	6-8	24.3
TT Sta 40	1	1-1.5	41.0
TT Sta 40	2	3-4	25.2
TT Sta 50	4	4-5	21.3
TT Sta 50	5	7.3-7.6	17.9
TT Sta 52	1	1	28.8
TT Sta 53	7	3	30.4
TT Sta 55	4	3.75-4	19.8
TT Sta 63	2	2	21.2
TT Sta 63	4	3.75-4	20.8
TT Sta 65	7	1-2.5	24.3
TT Sta 65	5	6.7-7	15.9
TT Sta 65	4	6-6.5	19.8
TT Sta 74	2	2-3	36.4
TT Sta 75	4	3.75-4	23.4
TT Sta 75	4	6-7	25.1
TT Sta 75	4	7.5-8	21.5
TT Sta 75	5	7	22.1
TT Sta 77	3+6	3-4	36.4
TT Sta 83	2+3+sand	2-3	35.9
TT Sta 83	4	3.75-4	23.8
TT Sta 83	7	2-3	26.3

Table B- 2. Moisture content by depth and material number in the control trench

Station	Mat#	Depth (ft)	Moisture %
CT Sta5	4	6-6.5	29.7
CT Sta5	4+5	4-4.7	33.3
CT Sta15	4	8	25.7
CT Sta15	4	7.3-7.8	26.0
CT Sta 5	4	7-7.5	25.6
CT Sta 15	4	6-6.5	26.9
CT Sta 25	4	7-7.5	24.7
CT Sta25	4	5-5.5	32.5
CT Sta 31.5	4	8-8.3	24.5
CT Sta15	2	3	20.5
CT Sta 5	2	2-4	38.8
CT Sta 5	1	1-2	35.2
CT Sta25	1	0.8-1.7	33.3
CT Sta25-30	4	4.2	25.9
CT Sta12	3	2.5	32.0

Table B- 3. Moisture content and material number at tensiometer tip

Instrument#	Mat#	Moisture%
TA2-36	3+6	21.0
TA3-36	4	18.3
TA4-24	1	23.7
TA4-36	3+6	18.3
TA4-60	2	17.2
TA5-24	3+6	20.1
TA5-36	3+6	16.6
TB1-24	2+3	16.6
TB1-36	2+3	23.1
TB2-36	2+3	25.4
TB3-36	4	20.0
TB4-36	3+6	29.3
TB4-60	2	23.0
TB5-24	2	25.1
TB5-36	2	17.0
TC1-24	2	14.9
TC1-36	2+3	16.3
TC2-36	3+6	30.5
TC3-36	4	18.5
TC4-24	2	32.3
TC4-36	2	25.2
TC4-60	2	29.4
TC5-24	3	21.9
TC5-36	3	19.2
TD4-36	2	17.4
TD5-36	2	20.8
TE1-36	2+3	25.5



Material #	Station	Depth (ft)	LL	PL	PI	In-Situ w%	USCS
2	CT 15	3	46	31	15	20.5	ML
2	CT 5	2 to 4	48	31	17	38.8	ML
1	CT 5	1 to 2	41	31	10	35.2	ML
1	CT 25	0.8 to 1.7	44	31	13	33.3	ML
4	CT 25 - 30	4.2	53	32	21	25.9	MH
3	CT 12	2.5	42	29	13	32.0	ML

Figure B- 1. Atterberg limits (ASTM 4318) test results for commonly occurring onsite materials

APPENDIX B: LABORATORY TESTING

APPENDIX C: CONE PENETRATION AND PORE PRESSURE DISSIPATION TESTING

Appendix C

Three cone penetration tests (CPTs) were performed at the locations shown on Figure C- 1. CPT C1 is located on the waterside of the levee crown road at instrument line A (Figure C- 2 and Figure C- 3), C2 on the landside of the levee crown road at instrument line B (Figure C- 4 and Figure C- 5), and C3 on the waterside of the levee crown road at instrument line C (Figure C- 6 and Figure C- 7). All tests included pore pressure dissipation testing at multiple intervals within the profile to confirm the depth to a hydrostatic groundwater table. Dissipation test results are provided on Figure C- 8 and Figure C- 9 for CPT C1, Figure C- 10 through Figure C- 14 for CPT C2 and Figure C- 15 through Figure C- 17 for CPT C3. In general, dissipation testing shows that the hydrostatic groundwater table at the time of testing was located about 23 to 25 feet below the levee crown road at the locations studied.

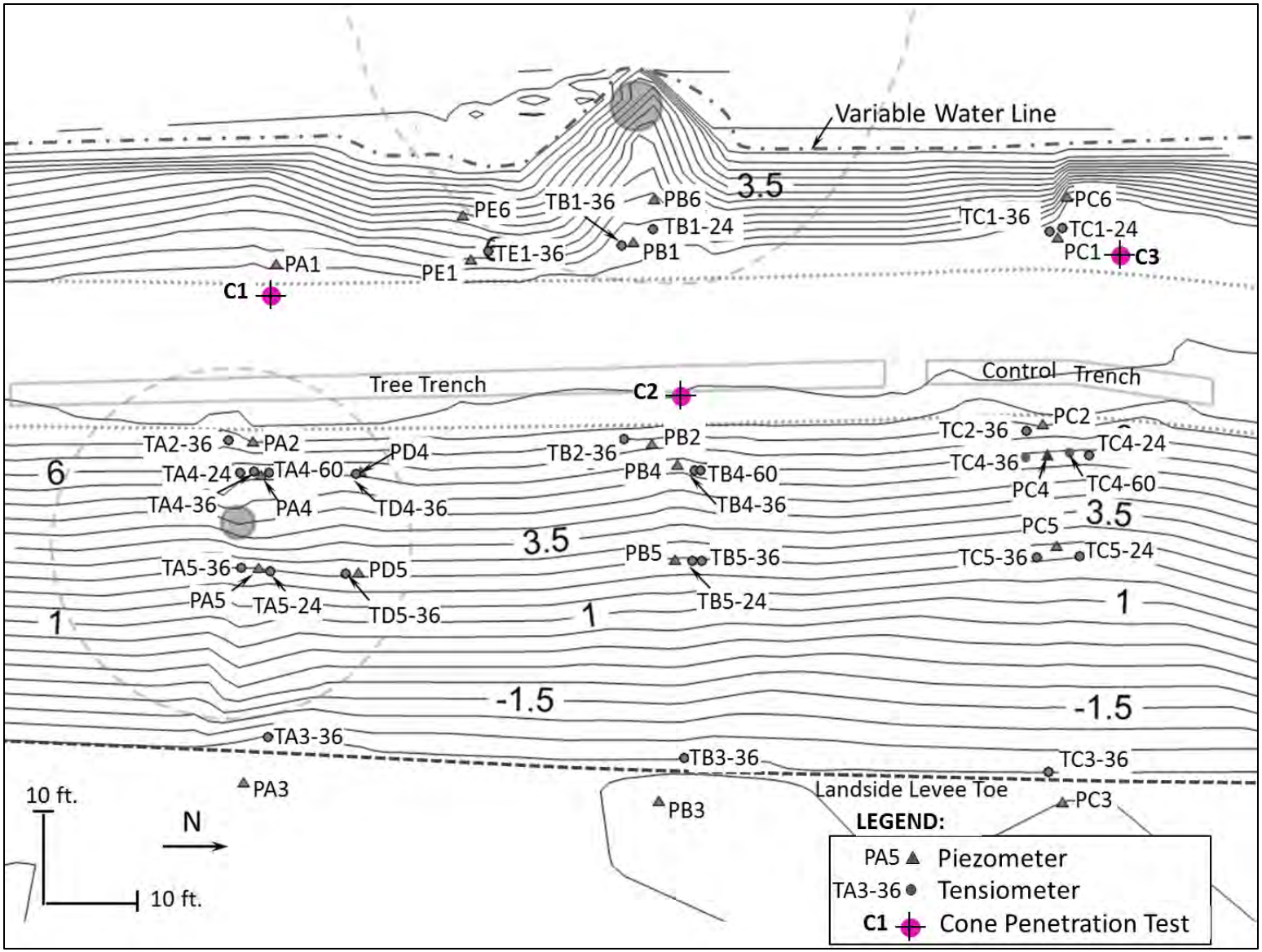


Figure C- 1. Cone Penetration Test (CPT) locations in the context of the site layout and instrumentation plan. Instrument locations were estimated based on nearby features

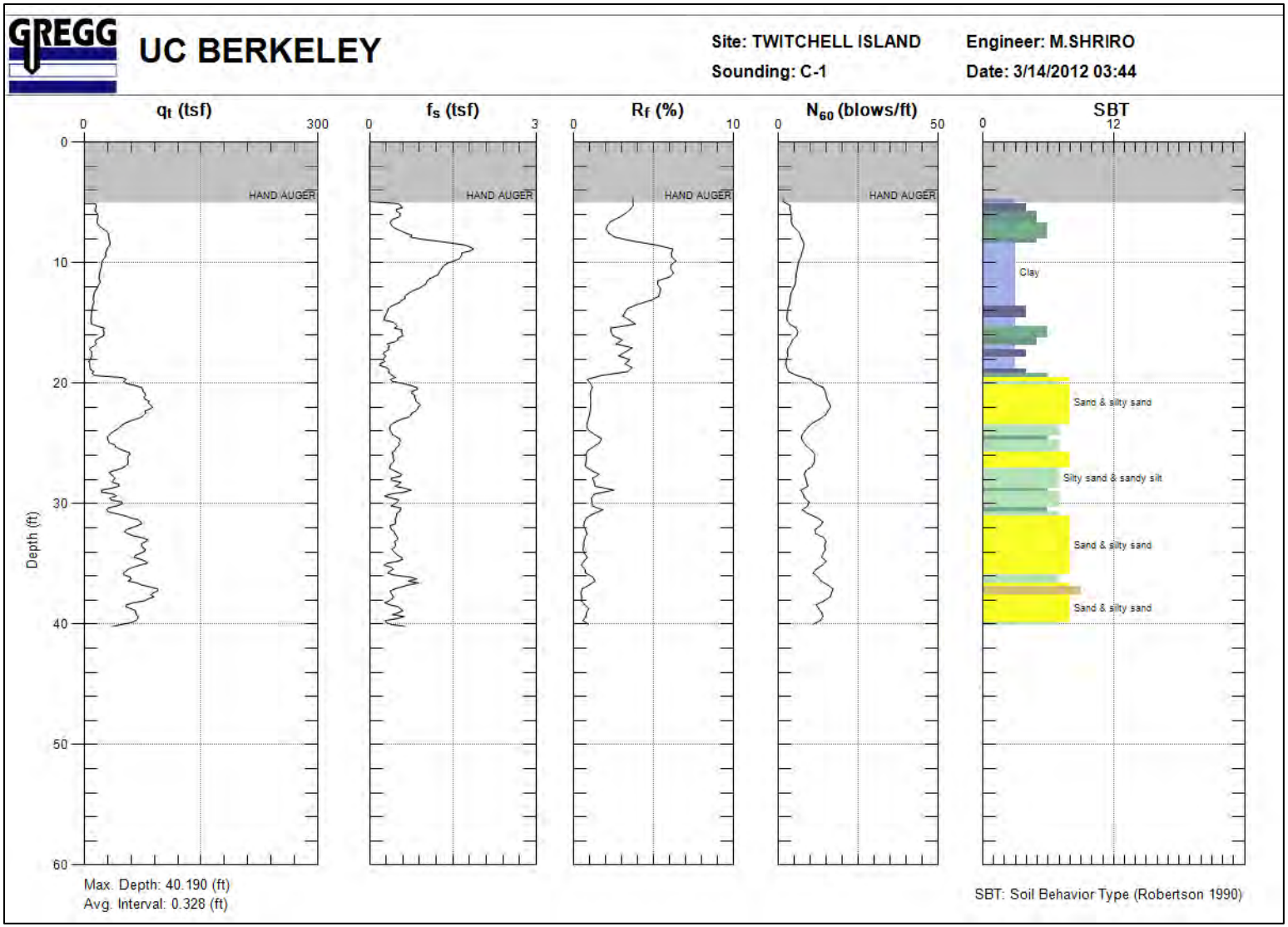


Figure C- 2. Cone Penetration Test Log at CPT location C1 at the waterside of the access road at instrument line A. Sheet 1 of 2.

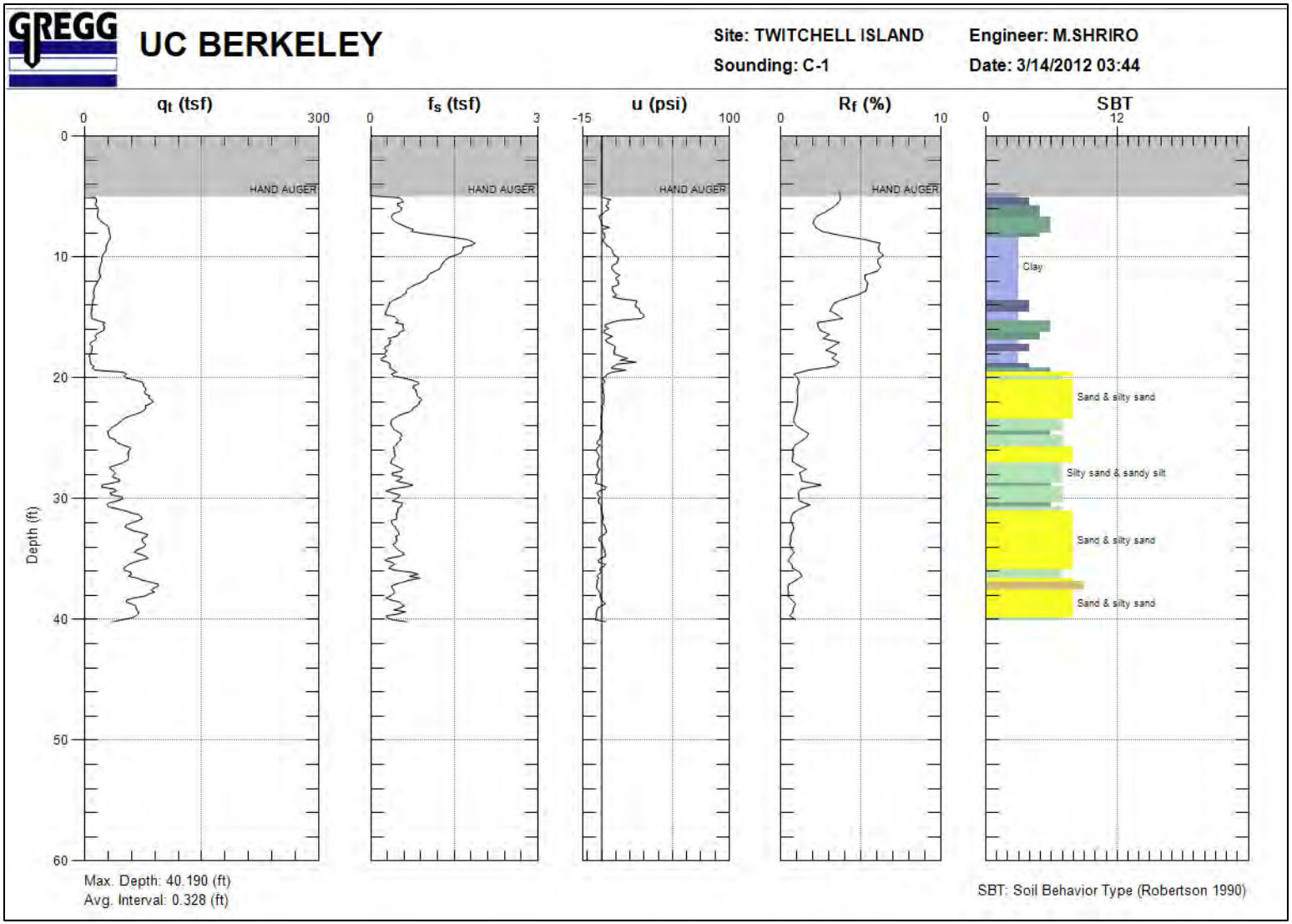


Figure C- 3. Cone Penetration Test Log at CPT location C1 at the waterside of the access road at instrument line A. Sheet 2 of 2.

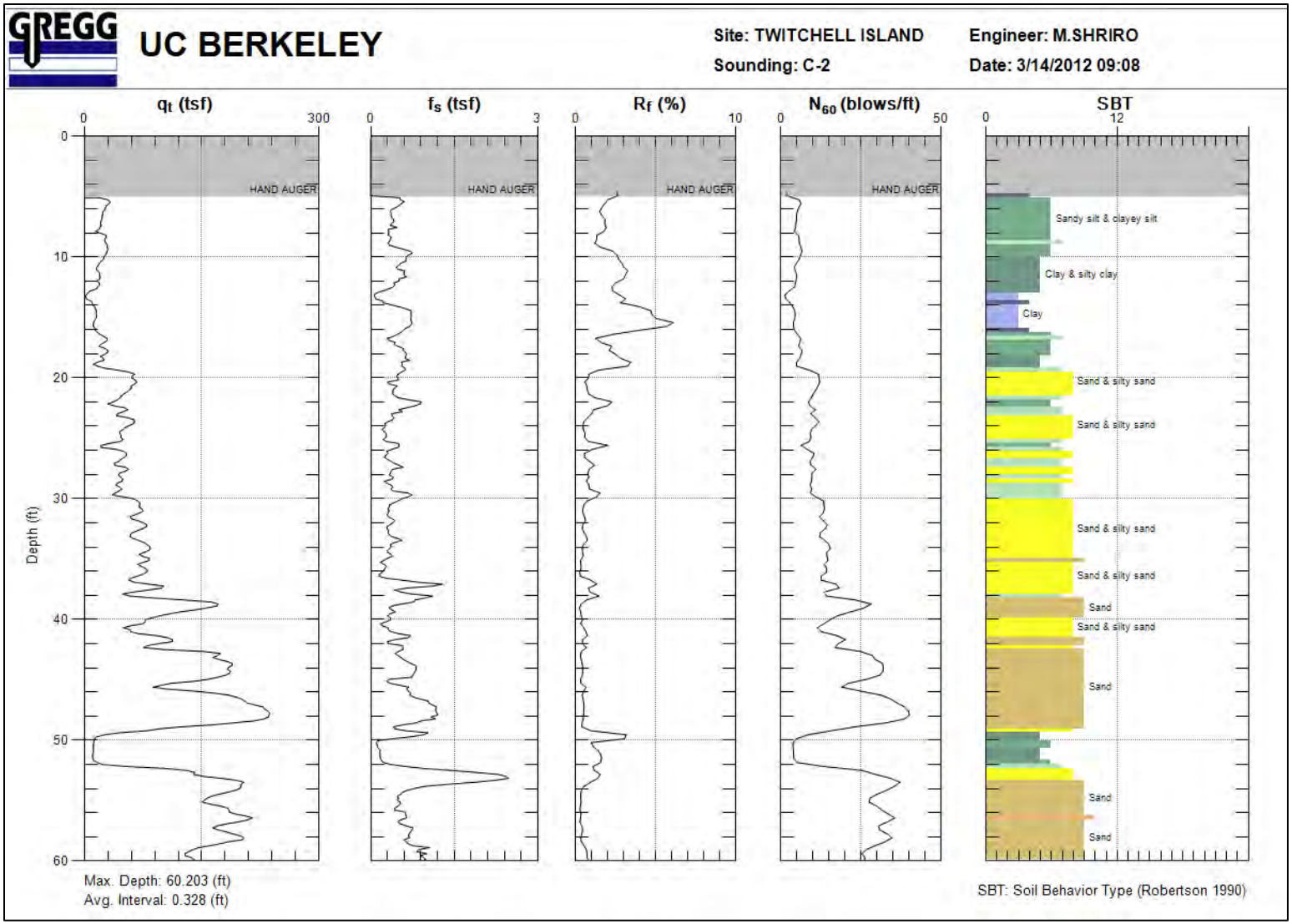


Figure C- 4. Cone Penetration Test Log at CPT location C2 at the landside of the access road at instrument line B. Sheet 1 of 2.

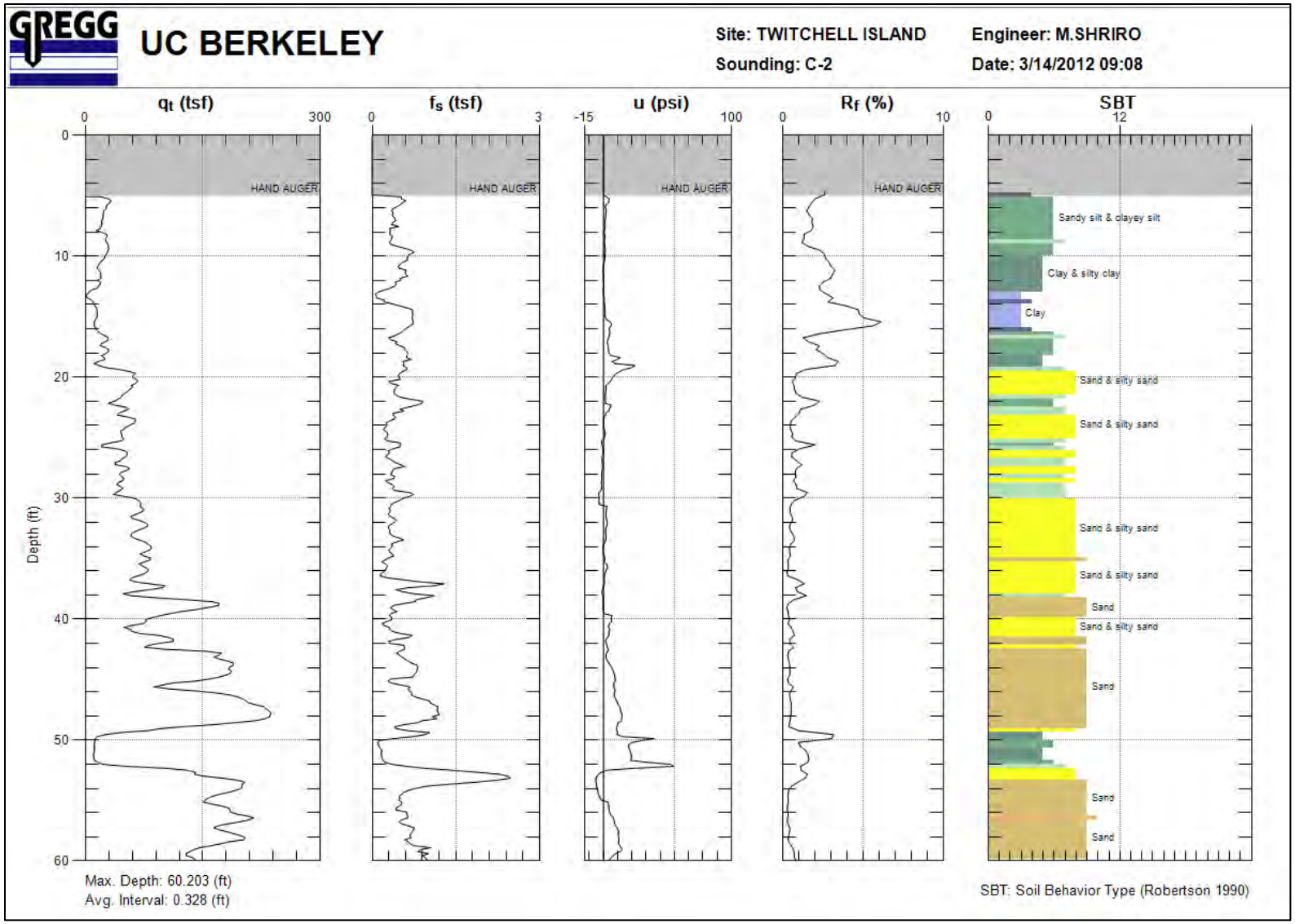


Figure C- 5. Cone Penetration Test Log at CPT location C2 on the landside of the access road at instrument line B. Sheet 2 of 2.

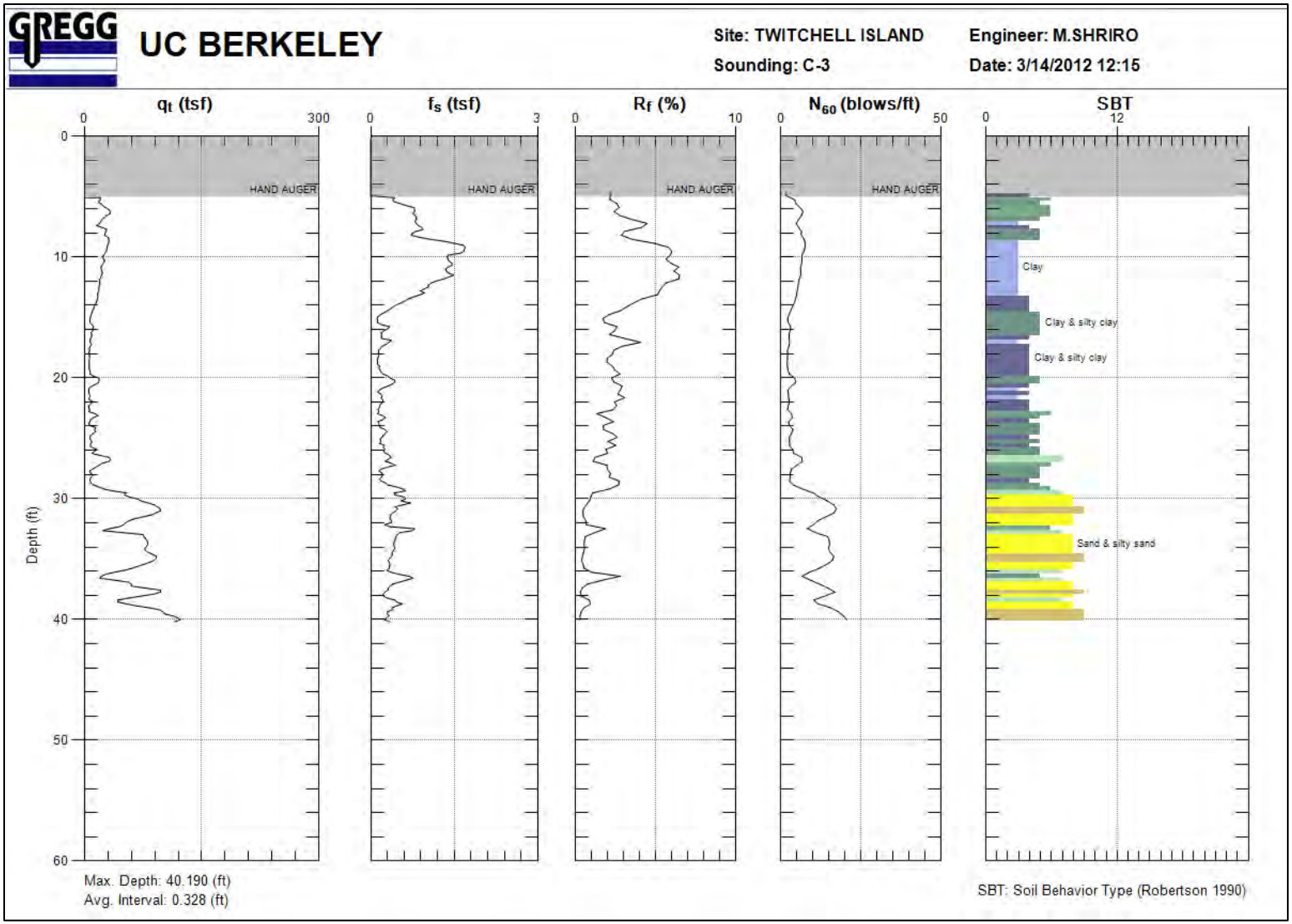


Figure C- 6. Cone Penetration Test Log at CPT location C3 at the waterside of the access road at instrument line C. Sheet 1 of 2.

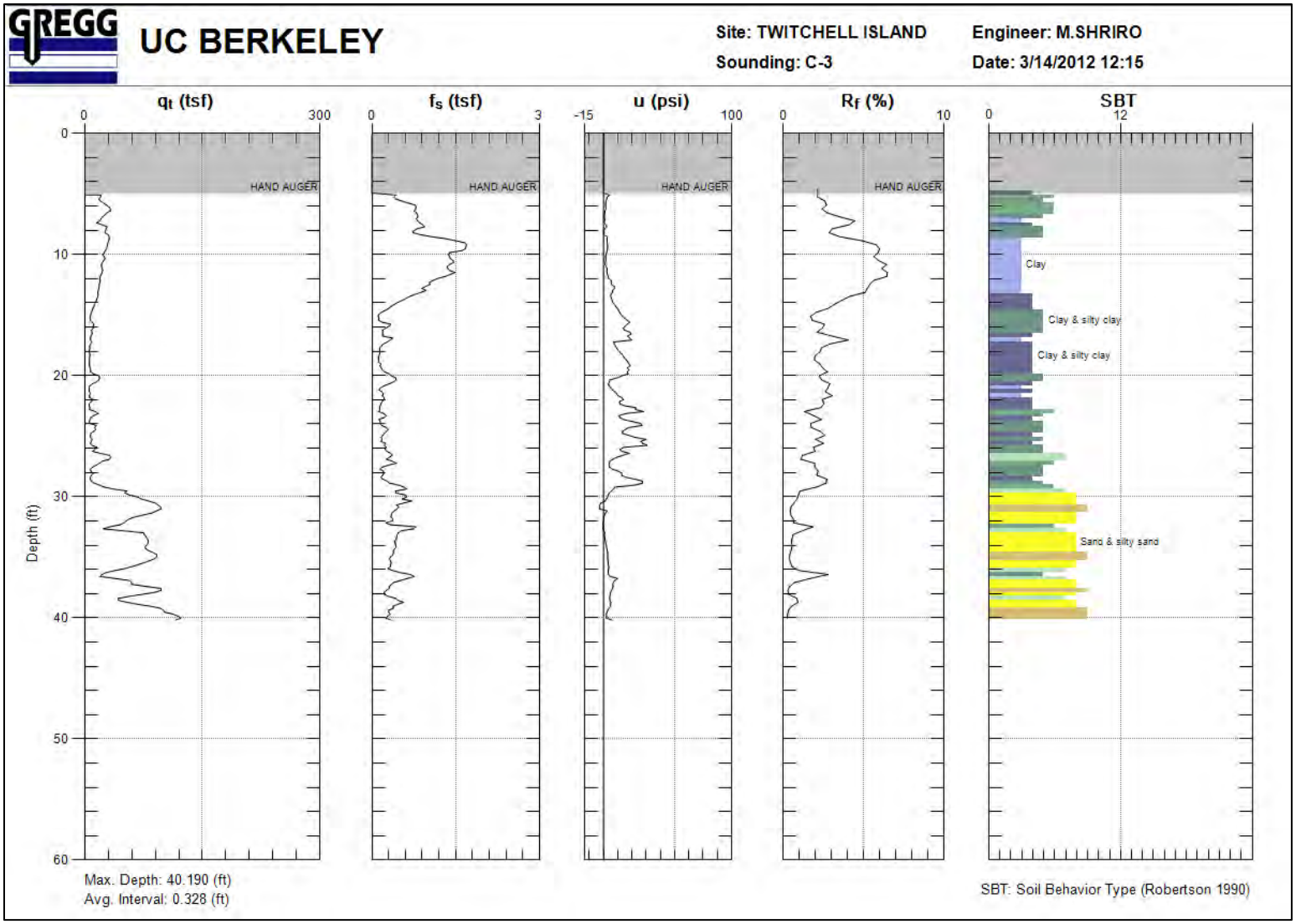


Figure C- 7. Cone Penetration Test Log at CPT location C3 at the waterside of the access road at instrument line C. Sheet 2 of 2.

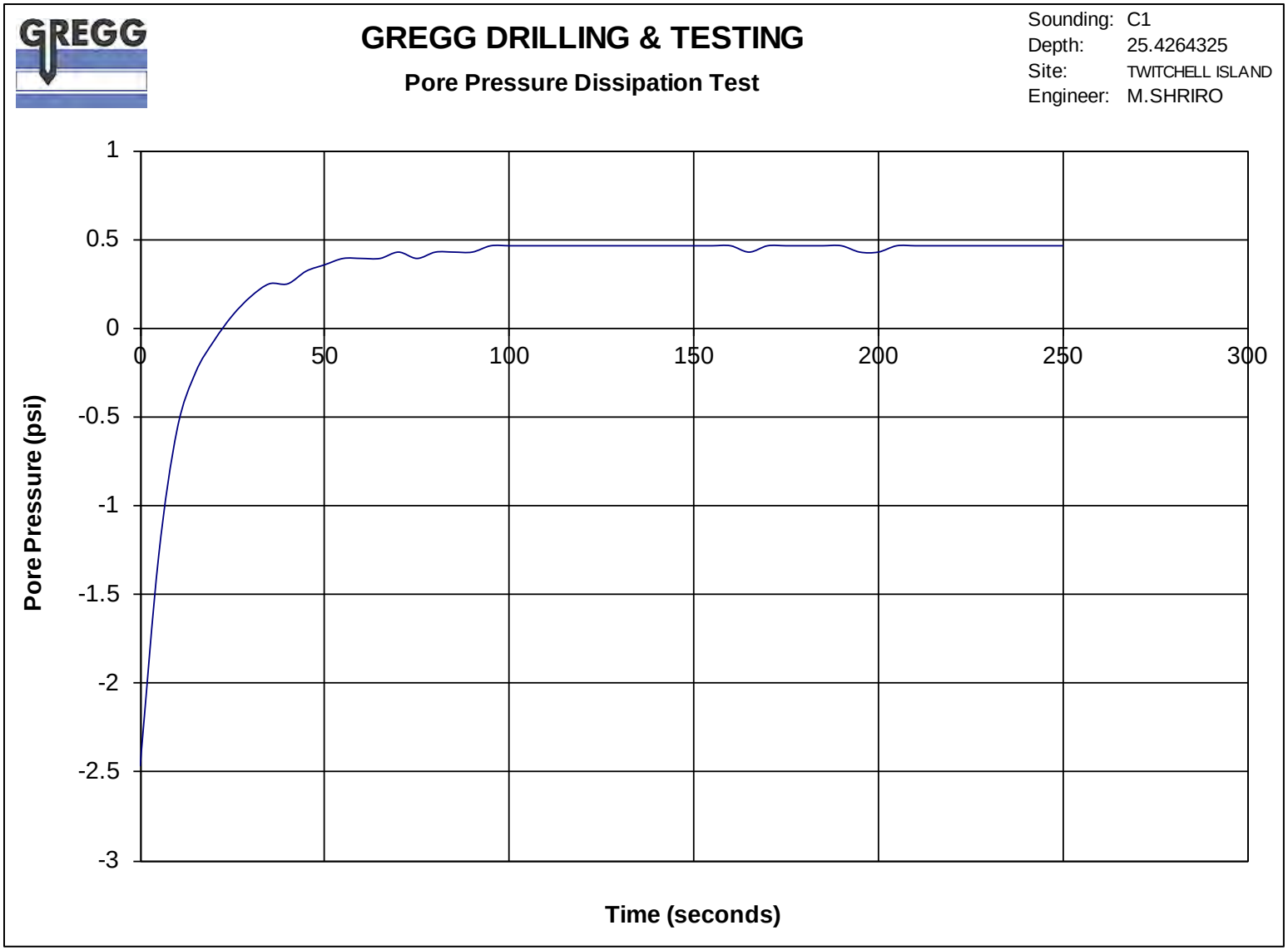


Figure C- 8. Pore pressure dissipation test at CPT location C1 at instrument line A, depth = 25ft

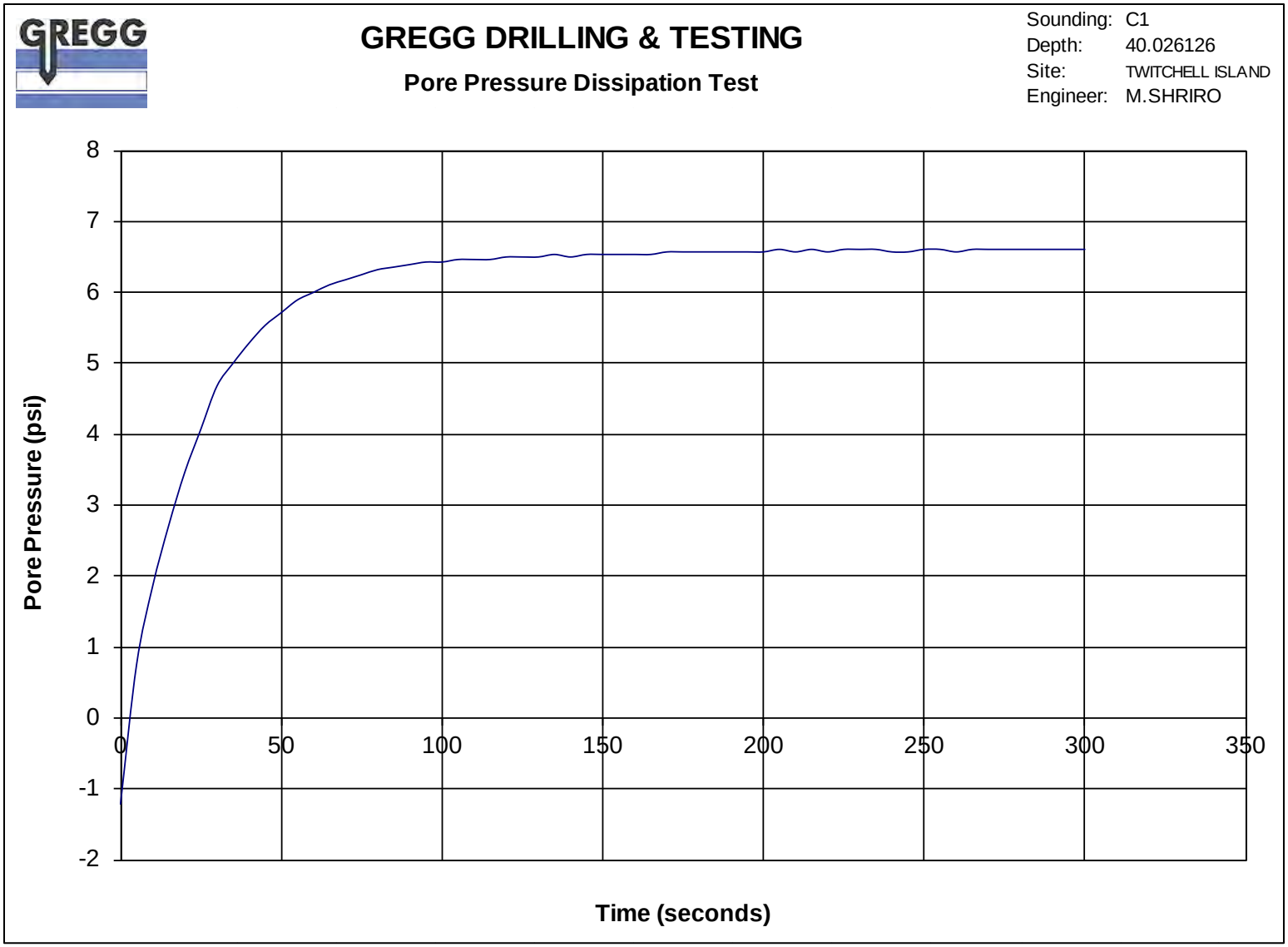


Figure C- 9. Pore pressure dissipation test at CPT location C1 at instrument line A, depth = 40ft

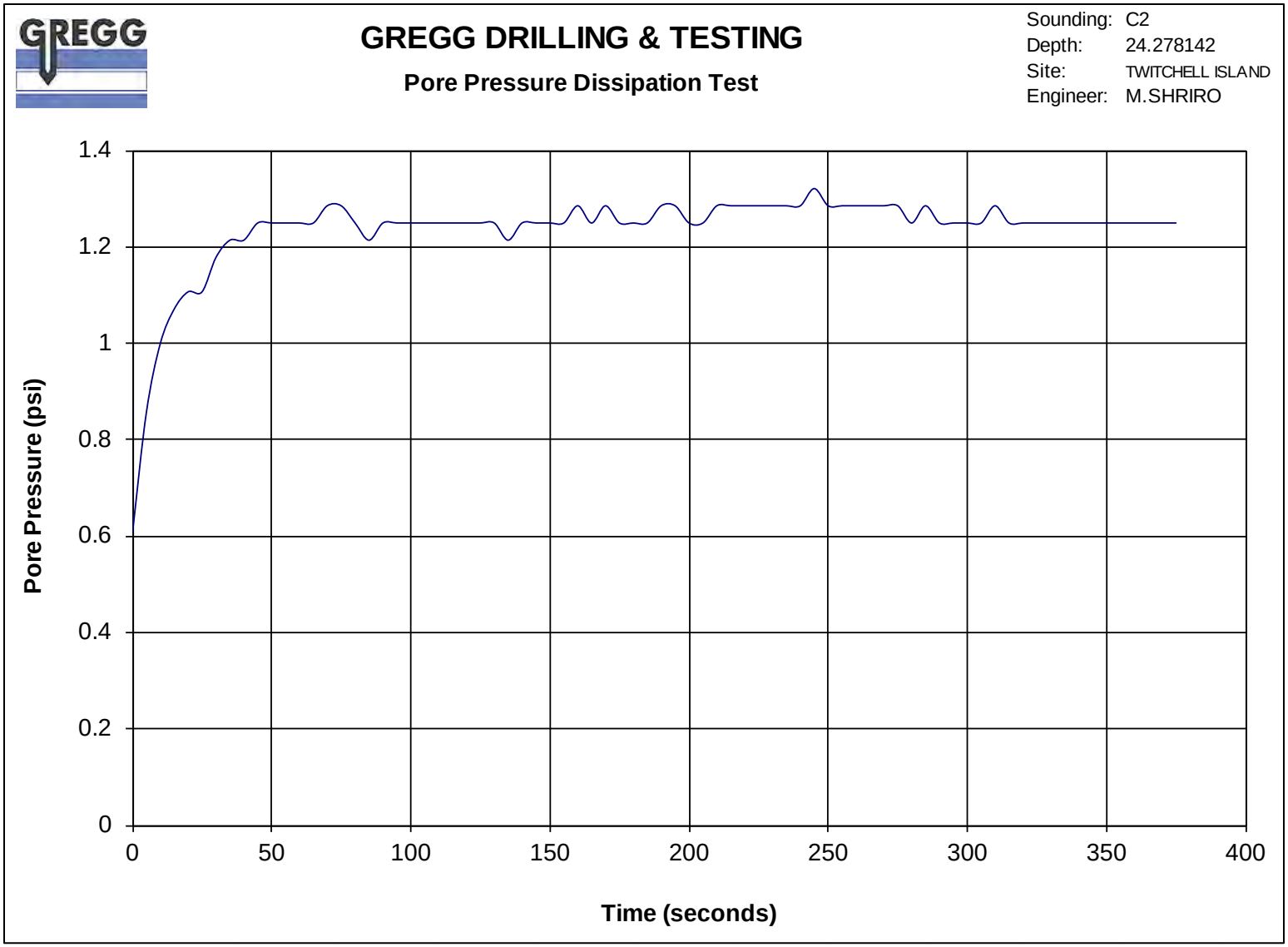


Figure C- 10. Pore pressure dissipation test at CPT location C2 at instrument line B, depth = 24ft

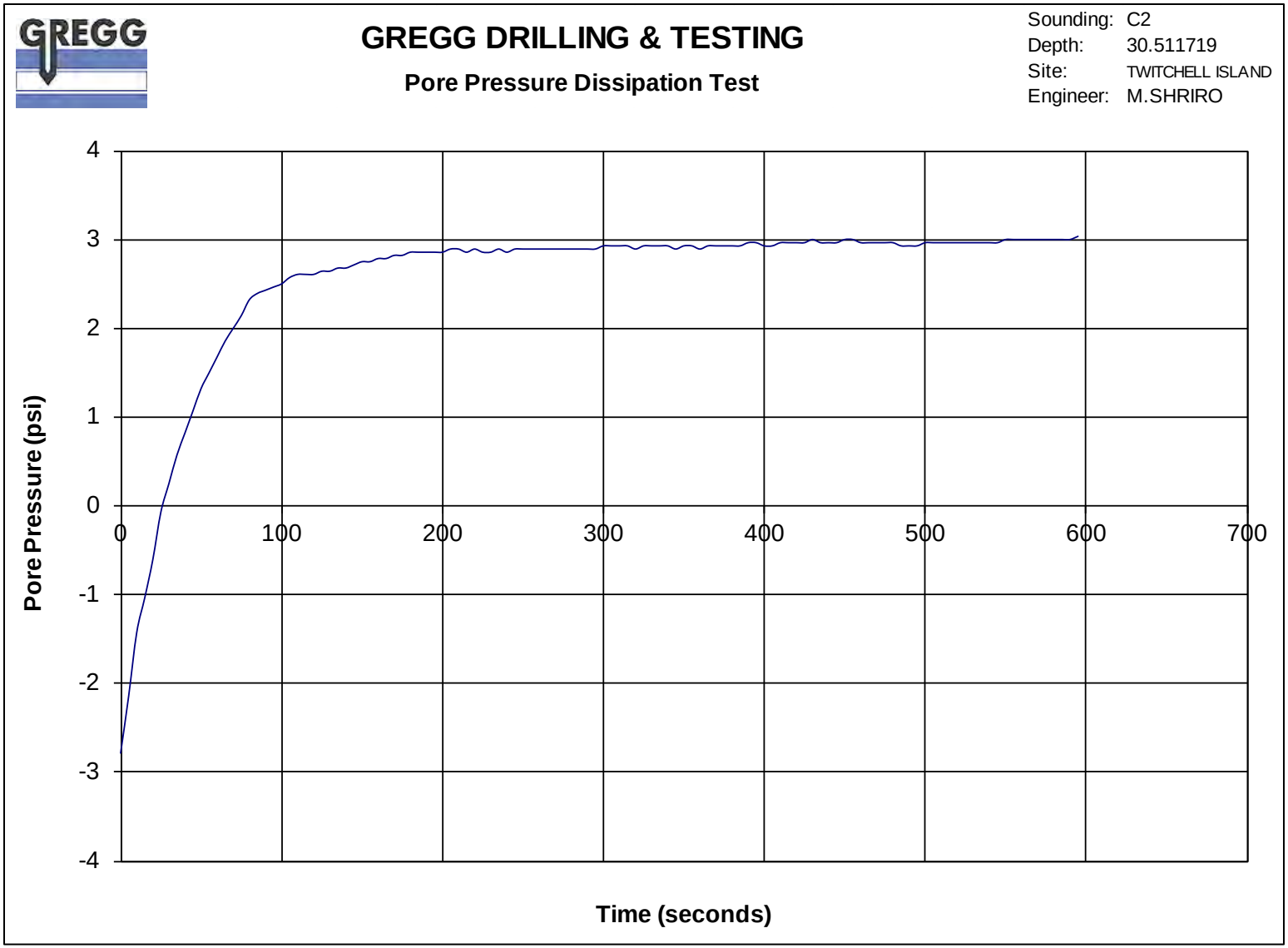


Figure C- 11. Pore pressure dissipation test at CPT location C2 at instrument line B, depth = 31ft

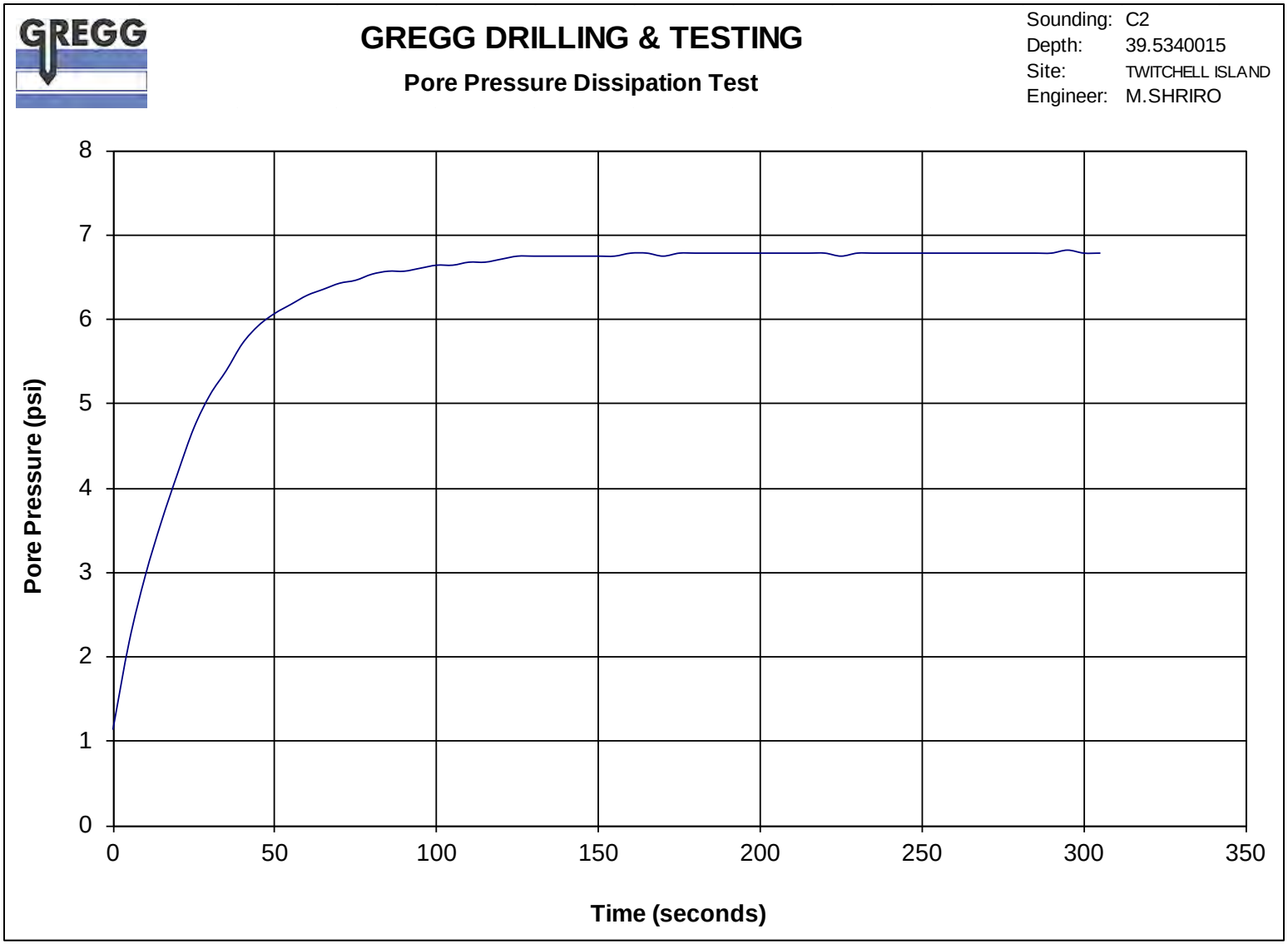


Figure C- 12. Pore pressure dissipation test at CPT location C2 at instrument line B, depth = 40ft

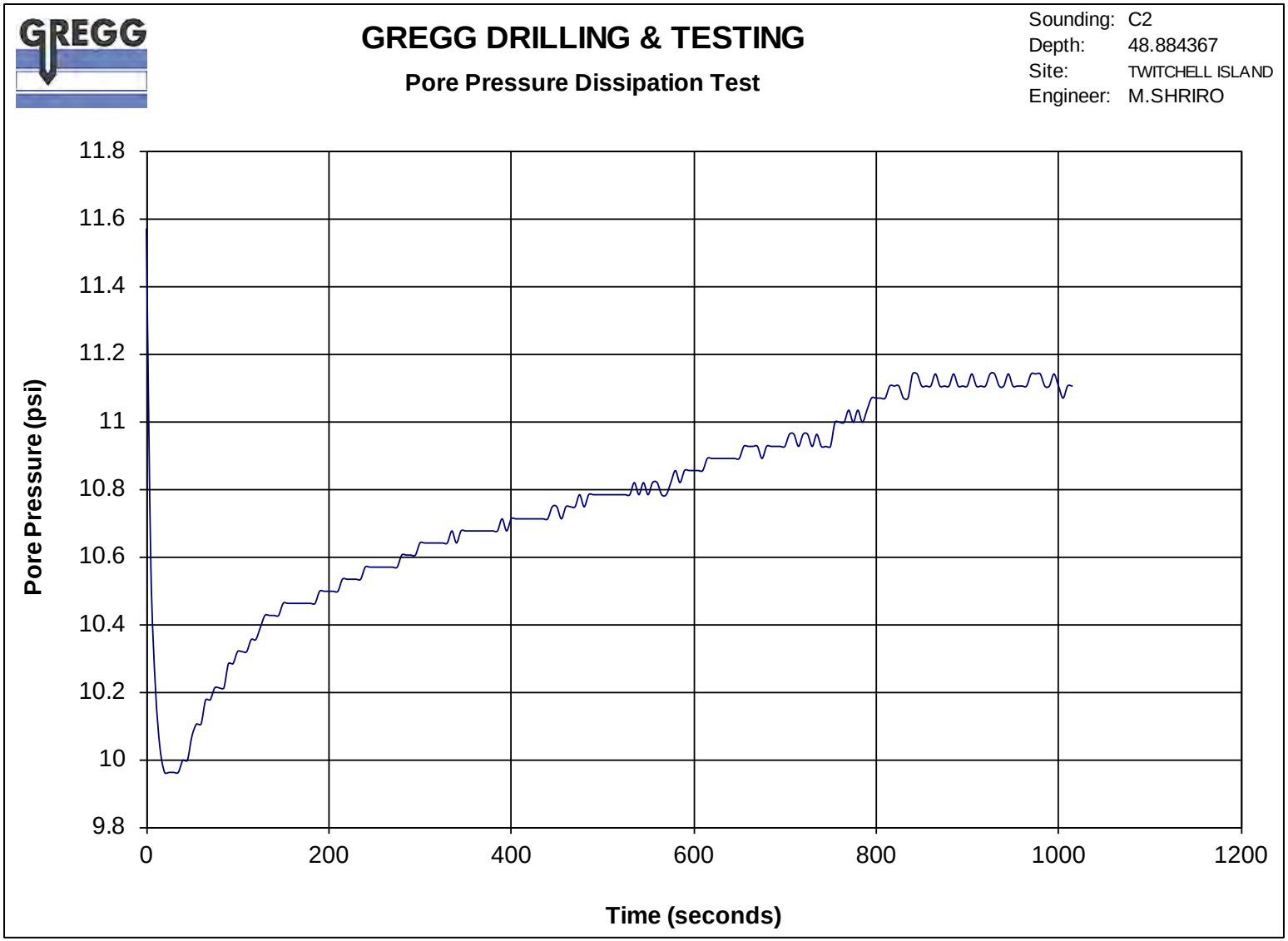


Figure C- 13. Pore pressure dissipation test at CPT location C2 at instrument line B, depth = 49ft

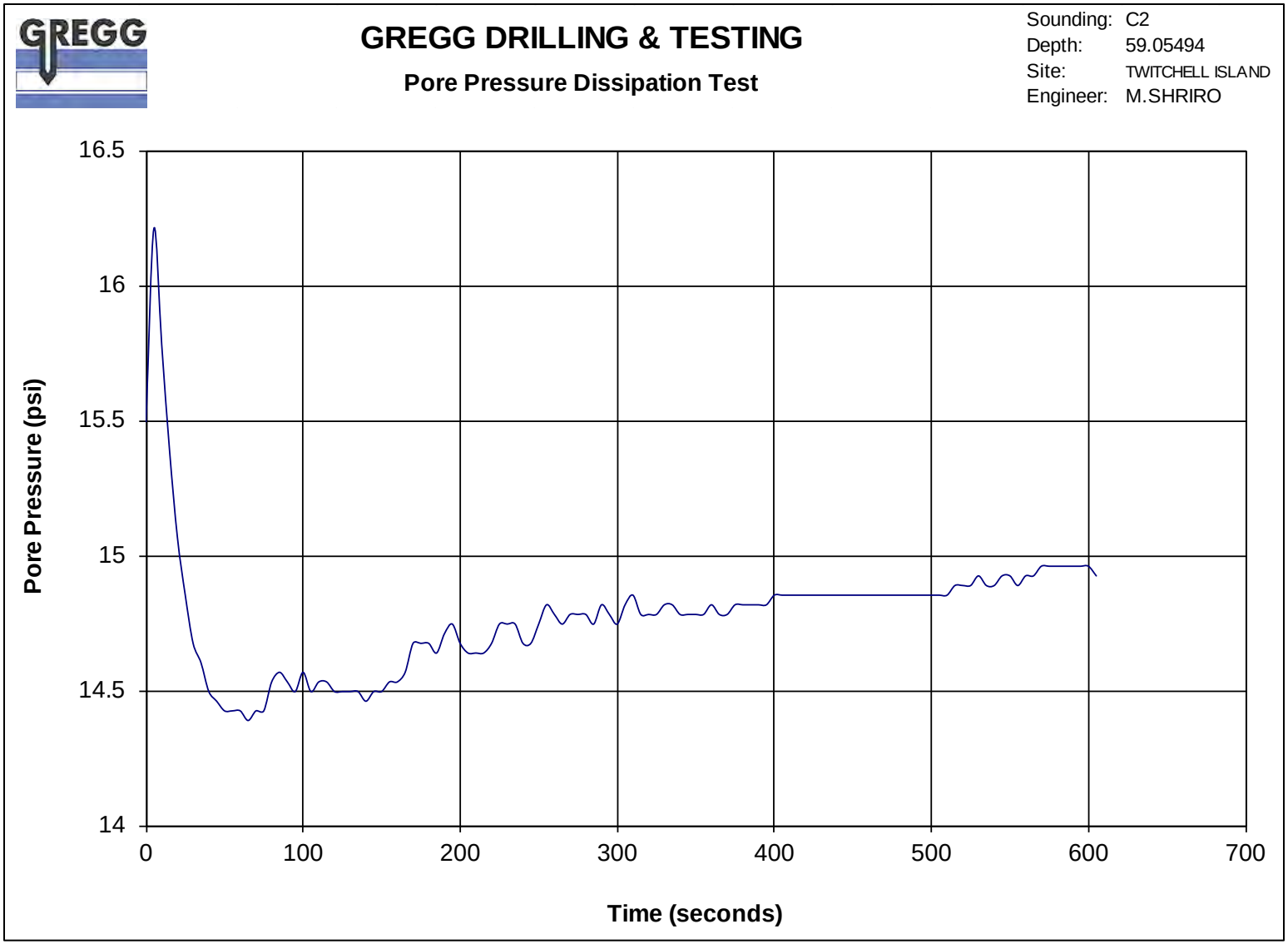


Figure C- 14. Pore pressure dissipation test at CPT location C2 at instrument line B, depth = 59ft

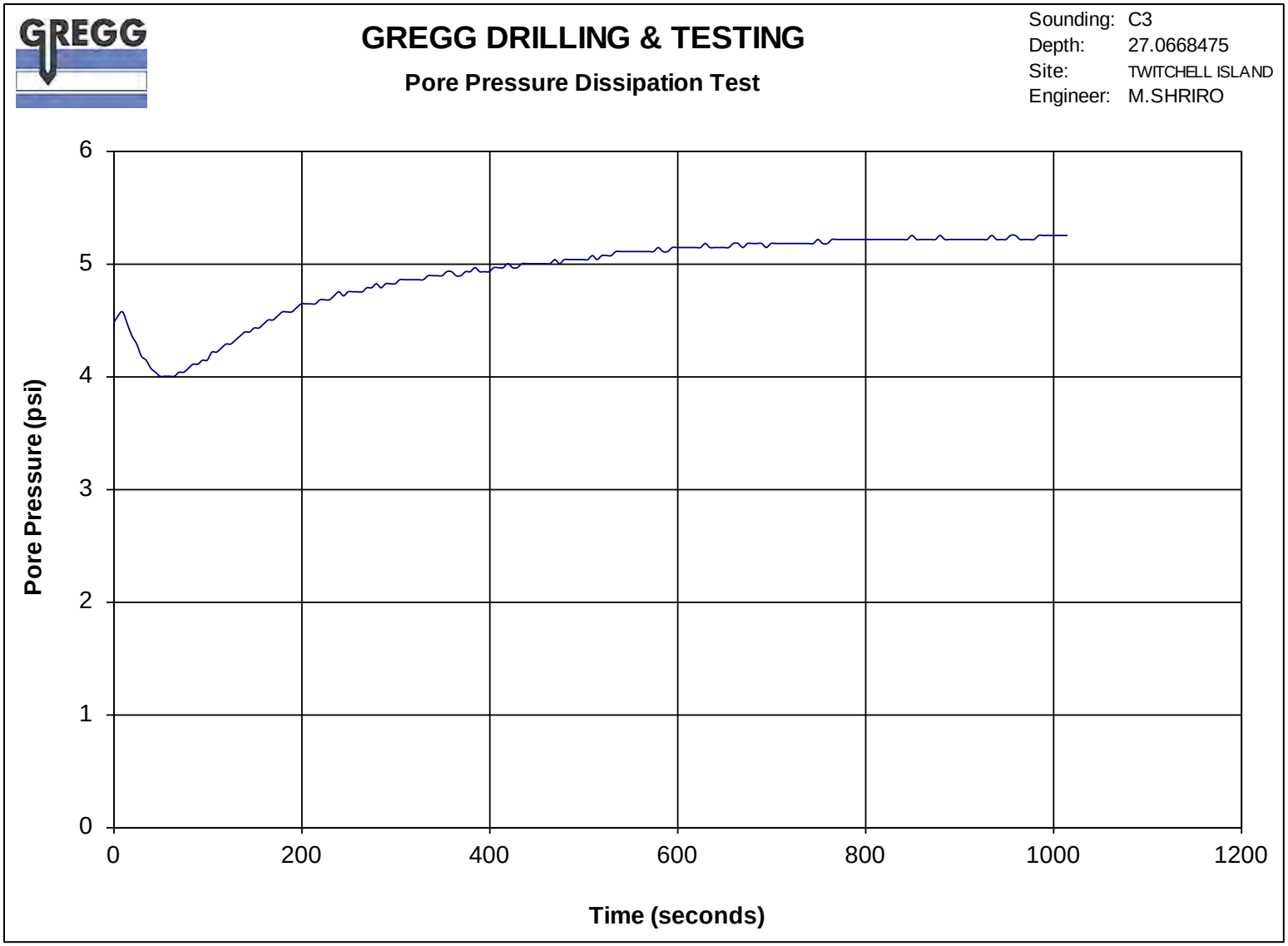


Figure C- 15. Pore pressure dissipation test at CPT location C3 at instrument line C, depth = 27ft

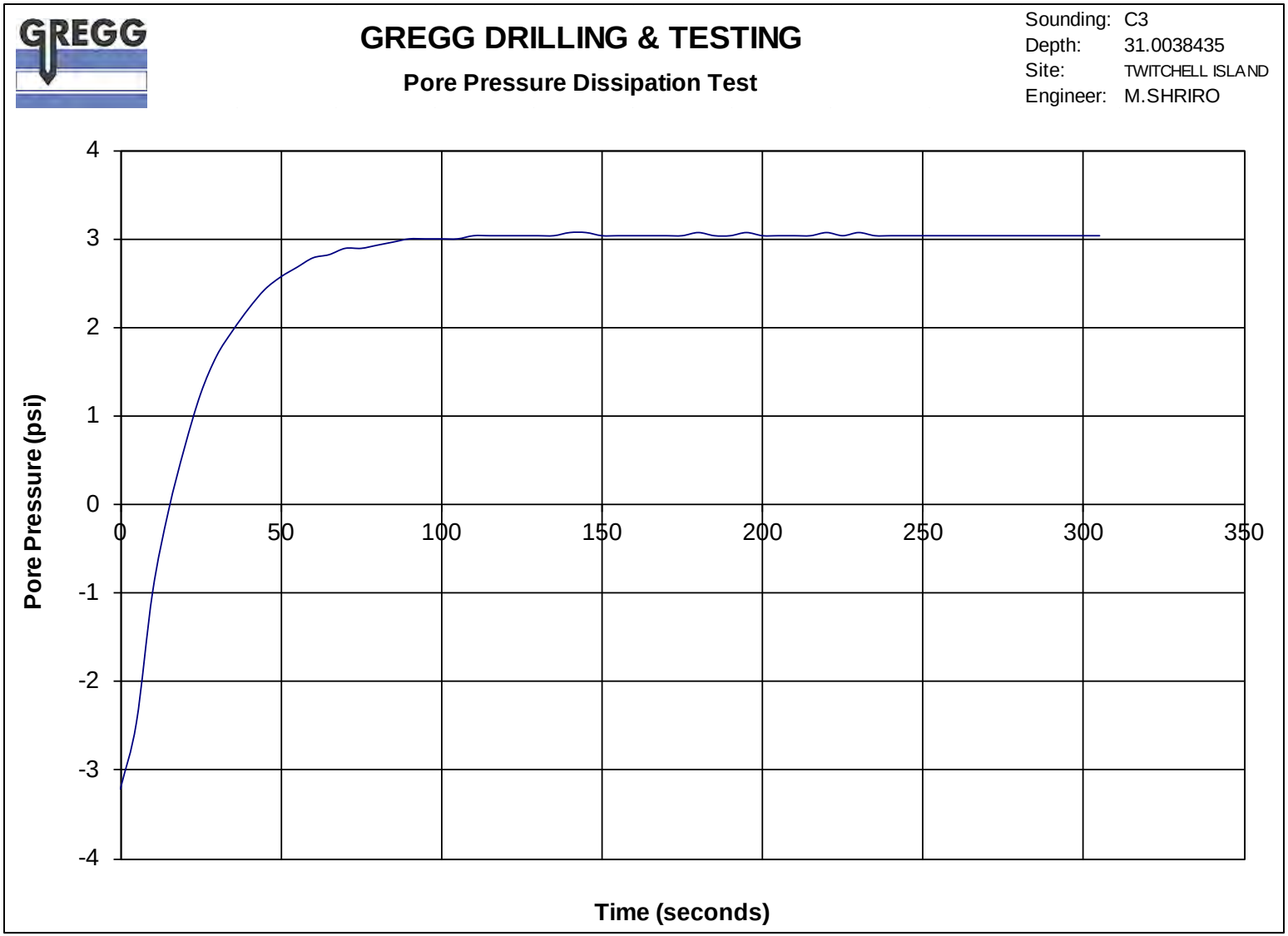


Figure C- 16. Pore pressure dissipation test at CPT location C3 at instrument line C, depth = 31ft

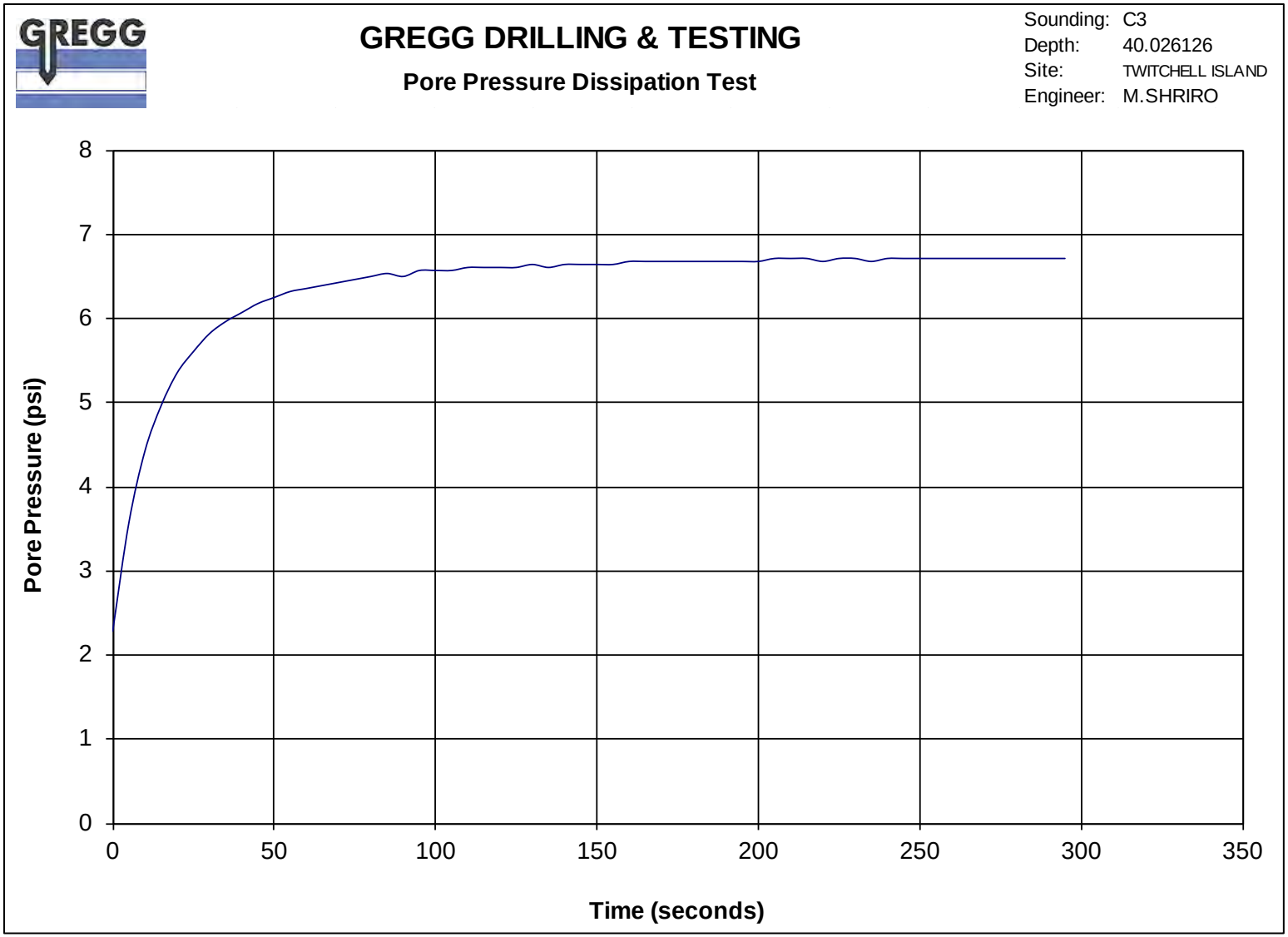


Figure C- 17. Pore pressure dissipation test at CPT location C3 at instrument line C, depth = 40ft

APPENDIX D: REGIONAL SOIL DATA

Appendix D

The study site is located on the south bank of the Sevenmile Slough along the northern levee of Twitchell Island within the Sacramento San Joaquin River Delta. The site is owned by the California Department of Water Resources and maintained by Reclamation District 1601. The section of levee under study was bypassed in 2008 with construction of a new levee just south of the site. As part of our review of available documents, the document titled "Reclamation District 1601 Twitchell Island Five Year Plan" (KSN, 2010) was reviewed. The document provides a comprehensive review of site history and available civil and geotechnical data for the island. The data found to be most proximal and relevant to our site was performed as part of a study by Neil O. Anderson and Associates titled "Geotechnical Services Report: Sevenmile Slough Sites 1, 2, and 3 – Levee Improvements" and dated August 8, 2007. The study included three soil borings and three test pits within the foundation soils of the new levee that bypassed our study site. Additionally, borings and test pits were performed for two other sites along the northern levee to the north and south of our study site. A total of 9 test borings and 6 test pits were reviewed and are attached herein.

GEOTECHNICAL SERVICES REPORT

SEVENMILE SLOUGH SITES 1, 2, & 3 LEVEE IMPROVEMENTS

TWITCHELL ISLAND

SACRAMENTO COUNTY, CALIFORNIA

REPORT PREPARED FOR:

RECLAMATION DISTRICT 1601

OUR PROJECT NUMBER: LFG-0229

AUGUST 8, 2007

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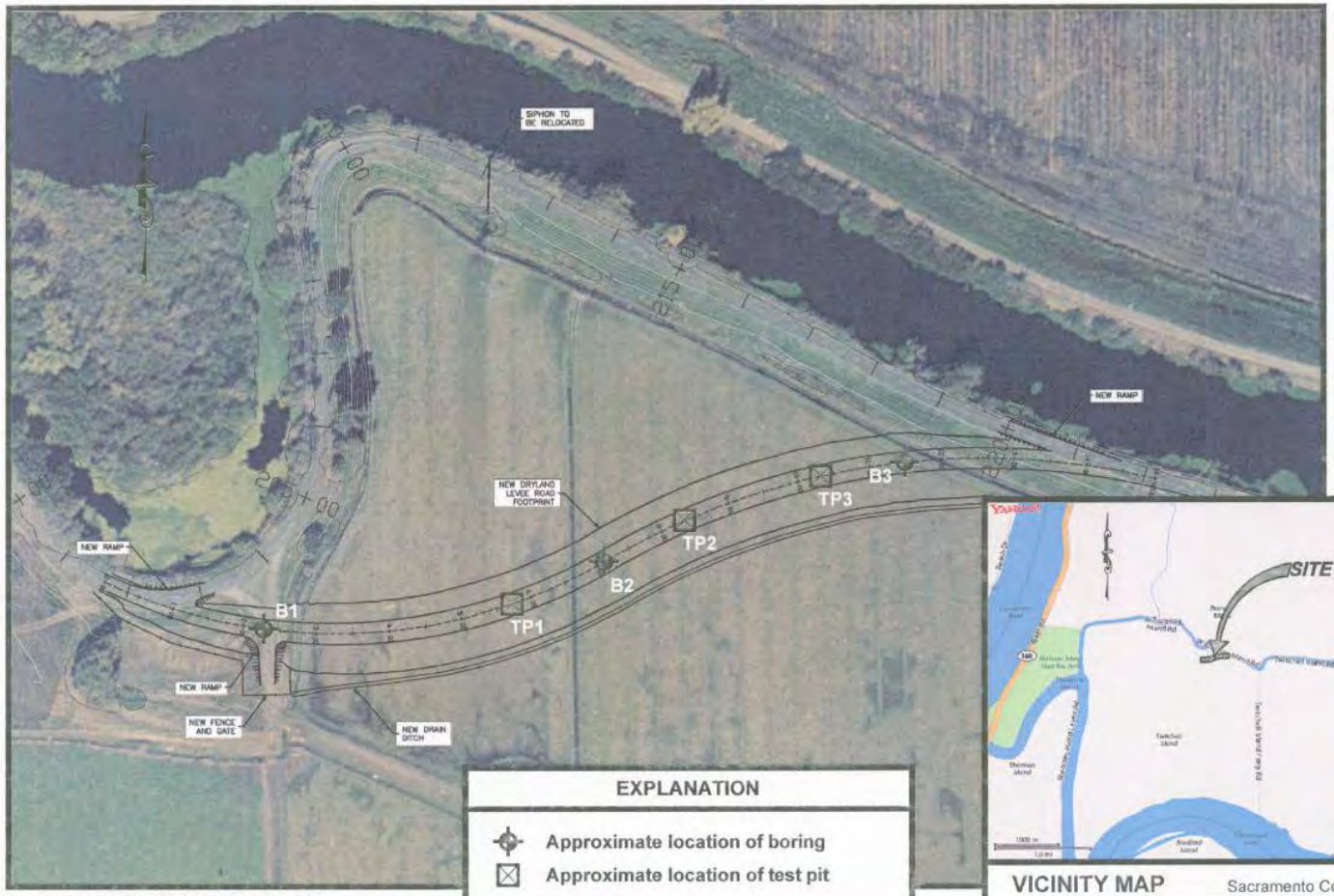

VICINITY MAP Sacramento County, CA

EXPLANATION

- Approximate location of boring
- Approximate location of test pit

Base plan provided by KSN, Inc. Stockton, CA .

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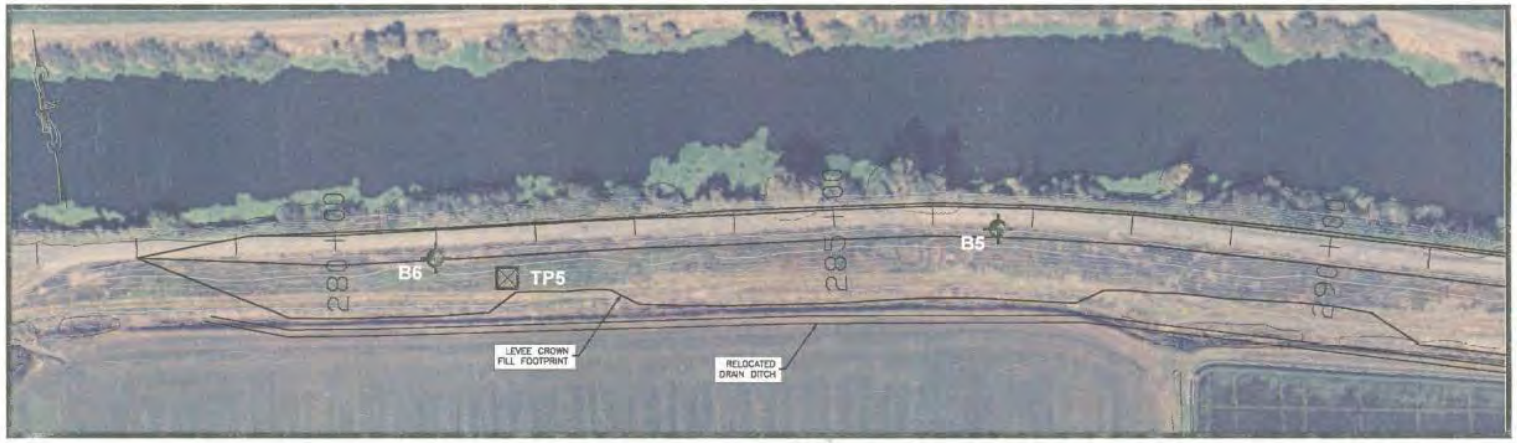
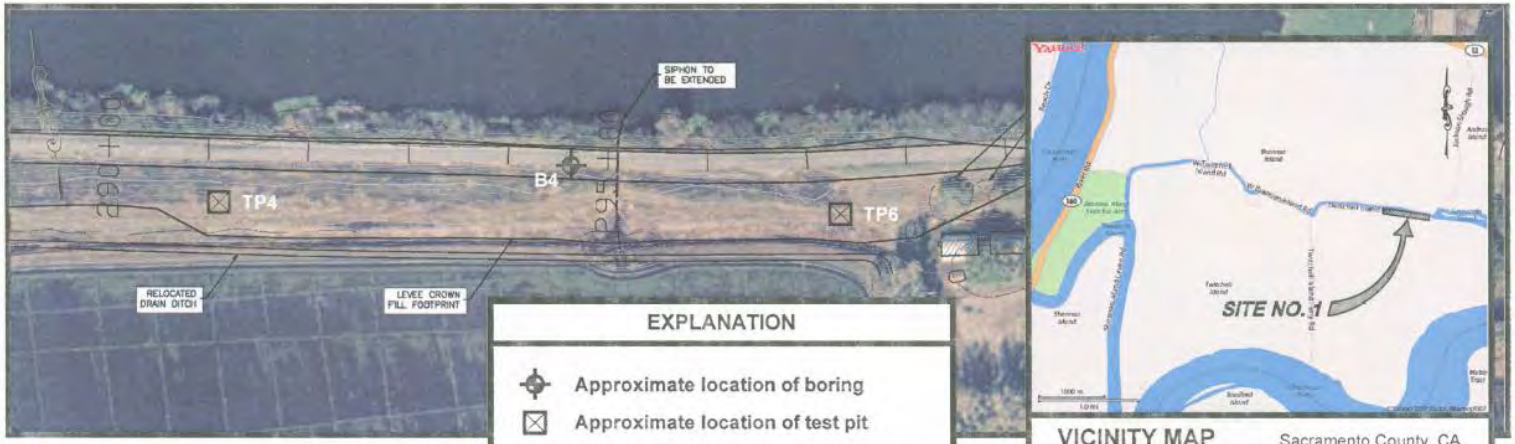
BORING LOCATION MAP
SITE No. 2

TWITCHELL ISLAND
7 MILE SLOUGH LEVEE IMPROVEMENTS
RECLAMATION DISTRICT NO. 1601
SACRAMENTO COUNTY, CA

DATE:	6/25/07
JOB NUMBER:	LFG-0229
SCALE:	NTS
DRAWN BY:	RC
CHECKED BY:	PD
PLATE:	1b





VICINITY MAP Sacramento County, CA

EXPLANATION

- Approximate location of boring
- Approximate location of test pit

Base plan provided by KSN, Inc. Stockton, CA .

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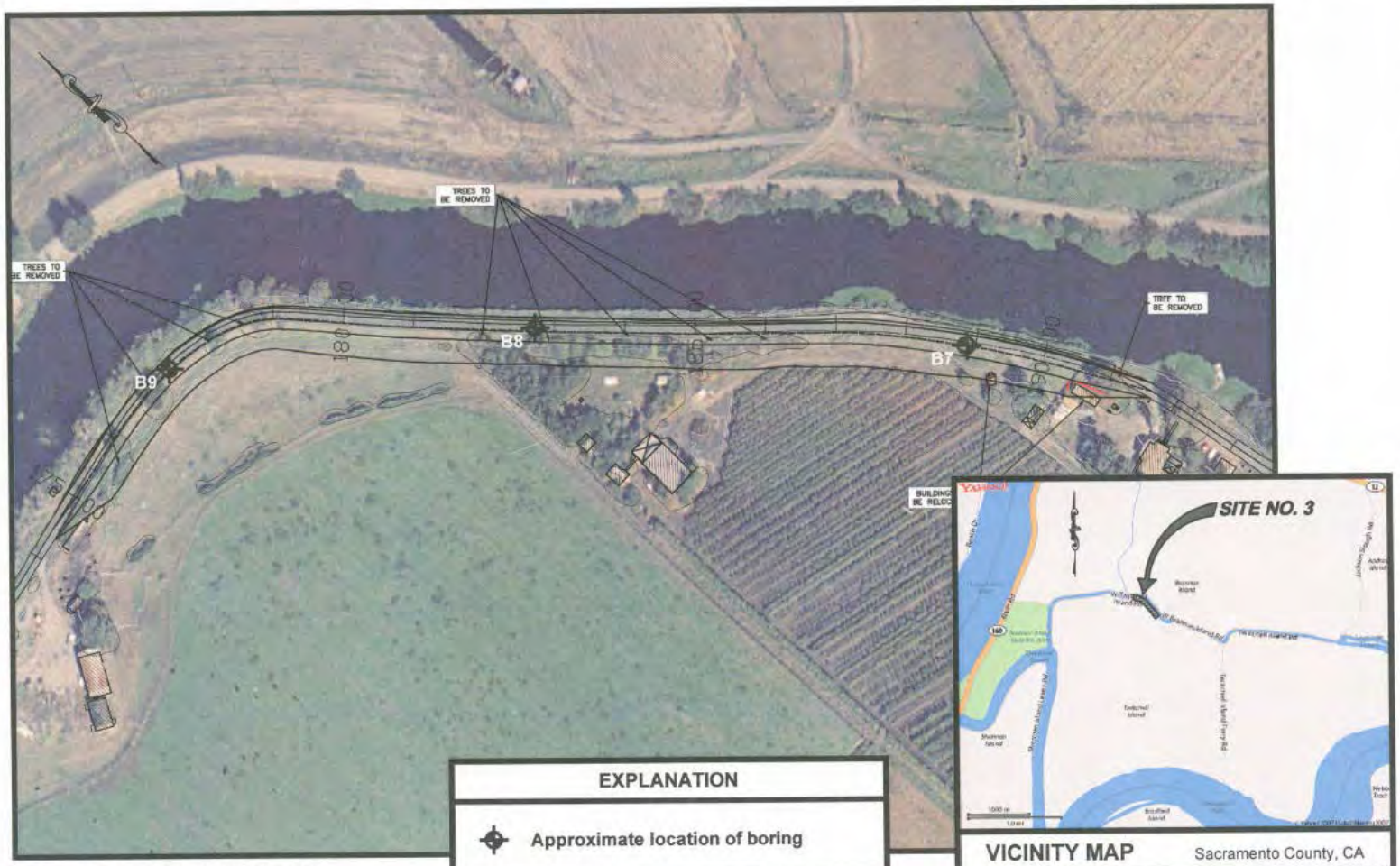
BORING LOCATION MAP
SITE No. 1

TWITCHELL ISLAND
7 MILE SLOUGH LEVEE IMPROVEMENTS
RECLAMATION DISTRICT NO. 1601
SACRAMENTO COUNTY, CA

DATE:	6/25/07
JOB NUMBER:	LFG-0229
SCALE:	NTS
DRAWN BY:	RC
CHECKED BY:	PD
PLATE:	1a



Base plan provided by KSN, Inc. Stockton, CA.

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BORING LOCATION MAP
SITE No. 3

TWITCHELL ISLAND
7 MILE SLOUGH LEVEE IMPROVEMENTS
RECLAMATION DISTRICT NO. 1601
SACRAMENTO COUNTY, CA

DATE:	6/25/07
JOB NUMBER:	LFG-0224
SCALE:	NTS
DRAWN BY:	RC
CHECKED BY:	PD
PLATE:	1c

UNIFIED SOIL CLASSIFICATION SYSTEM AND BORING LOG SYMBOLS

	DESCRIPTION	MAJOR DIVISIONS		
GW	Well-graded gravels, gravel sand mixtures, little or no fines.	Clean gravels (little or no fines)	Gravel and gravelly soils More than 50% of coarse fraction retained on No. 4 sieve	Coarse grained soils more than 50% larger than No. 200 sieve
GP	Poorly-graded gravels, gravel sand mixtures, little or no fines			
GM	Silty gravels, gravel-sand-clay mixtures	Sands with appreciable amount of fines		
GC	Clayey gravels, gravel-sand-clay mixtures			
SW	Well-graded sands, gravelly sands, little or no fines	Clean sand (little or no fines)	Sands and sandy soils More than 50% of coarse fraction passing No. 4 sieve	
SP	Poorly-graded sands, gravelly sands, little or no fines			
SM	Silty sands, sand-silt mixtures	Sands with appreciable amount of fines		
SC	Clayey sands, sand-silt mixtures			
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Liquid limit less than 50	Silts and clays	Fine grained soils more than 50% smaller than No. 200 sieve
CL	Inorganic clays of low to medium plasticity, gravelly clays, lean clays			
OL	Organic silts and organic silty clays of low plasticity			
MH	Inorganic silts, micacious or diatomaceous fine sand or silty soils	Liquid limit greater than 50	Silts and clays	
CH	Inorganic clays of high plasticity, fat clays			
OH	Organic clays of medium to high plasticity, organic silts			
PT	Peat, humas swamp scils with high organic content	Highly organic soils		

DEPTH (FEET)	SAMPLE	SAMPLE TYPE	TEST TYPE	NOTES
	PS	**Push Sample**	Plasticity	pi
	SPT	**Drive Sample**, 2.0" o.d., 1.38" i.d., sampler driven with 140 lb. hammer, 30" drop (Standard Penetration Test, SPT).	Grain Size Analysis Uniformity Coefficient Coefficient of Gradation	gr Cu Cc
	CM	**Drive Sample**, 2.5" o.d., 1.92" i.d., sampler driven with 140 lb. hammer, 30" drop, with 6" tube liners (California Modified, CM).	Coefficient of Consolidation Specific Gravity Shrink/Swell	Cv sg s/s
	ES	**Ely Sample**, Used to determine unit weight	Direct Shear Unconfined Compression	ds uc
	HS	**Hand Sampler**, 2.0" o.d. sampler driven with 10 lb. hammer, 18" drop, with 4" tube liners.	Triaxial Compression Pocket Penetrometer	tx p
	GS	**Grab Sample**, disturbed sample taken from auger tailings and sealed in plastic bag.	Torvane Shear Consolidations	ts c

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LOG OF TEST BORING

BOREHOLE NUMBER

B1

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1,2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer**

DATE DRILLED: **12-7-06**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 2

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									FILL: Brown, silty sand and gravel, medium dense, moist	Gravel Road Station 2+20
-1										
-2										
-3										
-4										
-5										
-6		CM	17	101	11					
-7									CL: Brown, silty clay, medium stiff to stiff, moist	
-8										
-9										
-10									SM: Brown, silty fine sand, very loose to loose, moist	
-11		CM	35		4					
-12										
-13										
-14										
-15									ML: Green, fine sandy silt, soft to medium stiff, wet	
-16		SPT	53	85	4					Passing No.200 = 71%
-17										
-18										
-19										
-20									SM-SP: Green/brown mottled, fine sand with silt, medium dense, wet	
-21		SPT	31	102	12					
-22										
-23										
-24										
-25										
-26		SPT	30	97	22					Passing No.200 = 11%
-27										
-28										
-29										
-30										
-31		SPT	27	103	19				SP: Green, fine sand, medium dense, wet	
-32										
-33										
-34										
-35										
-36		SPT	26	84	16					
-37										
-38										
-39										
-40										
-41		SPT	26	101	16					Boring Terminated at 41.5 feet.

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LOG OF TEST BORING

BOREHOLE NUMBER

B2

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1,2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer**

DATE DRILLED: **12-8-06**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 3

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									SM: Brown, silty fine sand, medium dense, moist	Open Field Station 7+10
-1										
-2										
-3										
-4										
-5										
-6		CM	14	81	14					
-7										
-8										
-9										
-10									SM: Dark brown, silty fine sand, medium dense, moist to wet	
-11		CM			14					
-12										
-13										
-14									SM: Gray, silty fine sand, medium dense, wet	
-15										
-16		SPT	31	78	14					Passing No.200 = 26%
-17										
-18										
-19										
-20										
-21		SPT	30	91	14					
-22										
-23										
-24										
-25										
-26		SPT	32	86	18					
-27										
-28										
-29									SM-SP: Green/gray, fine sand with some silt, medium dense to dense, wet	
-30										
-31		SPT	20	104	30					Passing No.200 = 9%
-32										
-33										
-34										
-35										
-36		SPT	17	110	21					
-37										
-38										
-39										
-40										
-41		SPT	18	111	37					Boring Terminated at 41.5 feet.

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LOG OF TEST BORING

BOREHOLE NUMBER

B3

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1,2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer**

DATE DRILLED: **12-18-06**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 4

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									ML: Black, fine sandy silt with organics, stiff to very stiff, moist	Open Field Station 11+50
-2		CM	48	66	19					
-5									SM: Gray, silty fine sand, medium dense, moist to wet	
-6		CM	17	88	21					
-11		CM	43		10					
-16		SPT	35	90	12					Passing No.200 = 15%
-21		SPT	31	103	14					
-26		SPT	27	103	24					
-29									SM-SP: Gray, fine sand with silt, medium dense, wet	
-31		SPT	19	115	23					Passing No.200 = 9%
-36		SPT	21	113	12					
-41		SPT	21	110	30					Boring Terminated at 41.5 feet

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LOG OF TEST BORING

BOREHOLE NUMBER

B4

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-13-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 5

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0										
-1										
-2		CM	28	56	15				FILL: Brown, fine sandy silt, stiff to very stiff, moist	Asphalt Levee Road Station 294+75
-3										
-4										
-5										
-6		CM	28	59	6				FILL: Brown, fine sandy silt, medium stiff, non plastic, moist	
-7										
-8										
-9										
-10										
-11		CM	51	67	6				ML: Dark brown, clayey silt with organics, medium stiff, medium to high plasticity, very moist	pp = 1.0tsf
-12										
-13										
-14										
-15										
-16		CM	75	51	8				ML: Dark brown, clayey silt with some organics, medium stiff to stiff, medium to high plasticity, very moist	pp = 1.0tsf
-17										
-18										
-19										
-20										
-21		CM	39	68	9				SM: Blue gray, silty fine sand, loose, wet	Passing No.200 = 42%
-22										
-23										
-24										
-25										
-26		SPT	53		2				SM: Blue gray, silty clayey fine sand, very loose, wet	
-27										
-28										
-29										
-30										
-31		SPT	52		4				ML: Blue gray, fine sandy silt, very soft to medium stiff, wet	
-32										
-33										
-34										
-35										
-36		SPT	56		2					
-37										
-38										
-39										
-40										
-41		SPT	50		3					Boring Terminated at 41.5 feet

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LOG OF TEST BORING

BOREHOLE NUMBER

B5

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-13-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 6

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0										
-1										
-2		CM	20		13				FILL: Brown, fine sandy silt, medium stiff to stiff, low plasticity, moist	Asphalt Levee Road Station 286+50
-3										
-4										
-5										
-6		CM	41	65	6					pp = 1.0tsf
-7										
-8										
-9									FILL: Black, organic fine sandy silt with trace of clay, medium stiff, low to medium plasticity, moist	
-10										
-11		CM	18		5					
-12										
-13										
-14										
-15									ML: Black, organic silt with peat, medium stiff to stiff, moist	
-16		CM			6					UC = 2.1ksf pp = 1.25tsf
-17										
-18										
-19										
-20									ML: Blue gray, fine sandy silt, soft, moist	
-21		SPT	44		3					Passing No.200 = 66% Caving Depth at 20.5'
-22										
-23										
-24										
-25										
-26		SPT	64		2				ML: Black, fine sandy silt with peat, soft, moist	
-27										
-28										
-29										
-30										
-31		SPT	49		2					
-32										
-33									ML: Blue gray, fine sandy silt, soft, low plasticity, moist	
-34										
-35										
-36		SPT	43		2					Passing No.200 = 62%
-37										
-38										
-39									SM: Blue gray, silty fine sand, very loose, moist	
-40										
-41		SPT	42		2					Boring Terminated at 41.5 feet

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LOG OF TEST BORING

BOREHOLE NUMBER

B6

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-14-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 7

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0										
-1										
-2		CM			14				FILL: Brown, fine sandy silt, medium stiff to stiff, low plasticity, moist	Asphalt Levee Road Station 281+00 pp = 1.0tsf
-3										
-4										
-5										
-6		CM	34	68	5				FILL: Brown, silty fine sand, loose, moist	
-7									CL: Dark gray, silty clay with trace of peat, soft to medium stiff, moist	
-8										
-9										
-10										
-11		CM	61	52	4					pp = 1.0tsf
-12										
-13										
-14										
-15										
-16		CM	41	70	3					UC = 1.2ksf pp = 0.75tsf
-17										
-18										
-19									ML: Blue gray, fine sandy silt, soft, moist	
-20										
-21		SPT	43		2					Passing No.200 = 54% Caving Depth at 20.5'
-22										
-23										
-24										
-25										
-26		SPT	49		2				ML: Blue gray, fine sandy silt with slight organics, soft, moist	
-27										
-28										
-29										
-30										
-31		SPT	50		2					Passing No.200 = 63%
-32										
-33										
-34										
-35										
-36		SPT	48		2					
-37										
-38										
-39										
-40										
-41		SPT	45		3					Boring Terminated at 41.5 feet.

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LOG OF TEST BORING

BOREHOLE NUMBER

B7

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-15-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 8

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0										
-1										
-2		CM	46		10				FILL: Brown, silty fine sand, loose to medium dense, moist	Asphalt Levee Road Station 189+00
-3										
-4										
-5									ML: Brown, fine sandy silt, medium stiff to stiff, moist	
-6		CM	29		6					
-7										
-8										
-9										
-10										
-11		CM	36	67	11					UC = 2.0ksf pp = 0.75tsf
-12										
-13										
-14										
-15										
-16		SPT	52		4				ML: Olive brown/brown gray, fine sandy silt, soft, wet	
-17										
-18										
-19										
-20										
-21		SPT	65		2				ML: Brown gray, fine sandy silt, soft, wet	Caving Depth at 20' Passing No.200 = 87% LL = 41, PI = 6
-22										
-23										
-24										
-25										
-26		SPT	49		3					
-27										
-28										
-29										
-30										
-31		SPT	49		6				SM: Blue gray, silty fine sand, very loose, wet	Passing No.200 = 33%
-32										
-33										
-34										
-35										
-36		SPT	26		16				SP: Blue gray, fine sand with silt, loose to medium dense, wet	
-37										
-38										
-39										
-40										
-41		SPT			9					Boring Terminated at 41.5 feet.

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LOG OF TEST BORING

BOREHOLE NUMBER

B8

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-15-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 9

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									FILL: Brown, silty fine sand, medium dense, moist	Asphalt Levee Road Station 183+50
-1										
-2										
-3		CM	9	96	26					
-4									ML: Brown, fine sandy silt, moist	
-5										
-6										
-7										
-8										
-9										
-10		PS								
-11										
-12										
-13										
-14										
-15										
-16		SPT	42		2				ML: Blue gray, fine sandy silt with rust mottling, soft, moist	
-17										
-18										
-19										
-20										
-21		SPT	41		2				ML: Gray, fine sandy silt, soft, moist	Passing No.200 = 79%
-22										
-23										
-24										
-25										
-26		SPT	40		3				SP: Blue gray, fine sand with some silt, very loose, moist	Caving Depth at 25'
-27										
-28										
-29										
-30										
-31		SPT	34		10				SM-SP: Gray, fine sand with silt, loose to medium dense, wet	Passing No.200 = 8%
-32										
-33										
-34										
-35										
-36		SPT	47		14					
-37										
-38										
-39										
-40										
-41		SPT			12					Boring Terminated at 41.5 feet

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LOG OF TEST BORING

BOREHOLE NUMBER

B9

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Seven Mile Slough Site 1, 2, & 3 Levee**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Mobile B53 Explorer Mud Rotary**

DATE DRILLED: **3-16-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 10

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0–2		CM	29	69	10				FILL: Brown, silty fine sand/fine sandy silt, loose to medium dense/stiff, moist	Asphalt Levee Road Station 177+50
5–6		CM	25		12				FILL: Brown, silty fine sand, medium dense, moist	
10–11		CM	39	66	13				OL/OH: Olive brown, organic silty clay with rust mottling, medium stiff to stiff, medium to high plasticity, moist	UC = 1.1ksf pp = 1.0tsf
15–16		CM	34	76	10					pp = 2.0tsf
20–21		SPT	44		11				ML: Olive, fine sandy silt, stiff, medium plasticity, moist	
25–26		SPT	50		3				ML: Blue gray, fine sandy silt, soft, medium plasticity, moist	Caving Depth at 25' Passing No.200 = 93% LL = 44, PI = 14
30–31		SPT	52		5				ML: Blue gray, fine sandy silt with organics, medium stiff, medium to high plasticity, wet	Passing No.200 = 87%
35–36		SPT	47		6				ML: Blue gray, fine sandy silt, medium stiff, medium to high plasticity, wet	
40–41		SPT			3				SP: Blue gray, fine sand, very loose, wet	Boring Terminated at 41.5 feet

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LOG OF TEST PIT

TEST PIT NUMBER

TP-1

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 2

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									CL: Brown, silty clay with fine sand, dry	Station 6+00
-1										
-2										
-3										
-4									SM: Brown, silty fine sand, moist	
-5										
-6										
-7										
-8										
-9										Test Pit Terminated at 9.5 feet.

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LOG OF TEST PIT

TEST PIT NUMBER

TP-2

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 3

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									ML: Brown, clayey silt with fine sand, dry	Station 8+50
-1										
-2										
-3										
-4									SM: Brown, silty fine sand, dry to moist	
-5										
-6										
-7										
-8										
-9										Test Pit Terminated at 9 feet.

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LOG OF TEST PIT

TEST PIT NUMBER

TP-3

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 4

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									CL: Brown, silty clay with fine sand, dry	Station 10+50
-1										
-2										
-3										
-4										
-5										
-6									SM: Brown, silty fine sand, dry to moist	
-7										
-8										
-9										Test Pit Terminated at 9 feet.

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LOG OF TEST PIT

TEST PIT NUMBER

TP-4

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 5

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									ML: Brown, clayey silt with fine sand, very stiff, dry	Station 291+00
-1										
-2										
-3									ML: Gray, clayey silt with slight organics, dry to moist	
-4									ML: Brown, fine sandy silt with rust mottling, moist	
-5										
-6									SM: Blue gray, silty fine sand, very moist	
-7										Water Seepage @ 7 feet. Test Pit Terminated at 7.5

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LOG OF TEST PIT

TEST PIT NUMBER

TP-5

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 6

Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									ML: Brown, fine sandy silt, very stiff, dry	Station 282+50
-1										
-2										
-3										
-4									ML: Dark brown, clayey silt, moist	
-5									ML: Gray, clayey silt with rust mottling, very moist	
-6									ML: Brown/gray, fine sandy silt, soft, very moist	
-7									SM: Blue gray, silty fine sand, very moist	
-8										Test Pit Terminated at 8.5 feet.

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LOG OF TEST PIT

TEST PIT NUMBER

TP-6

PROJECT NUMBER: **LFG-0229**
PROJECT NAME: **Twitchell Island**
LOCATION: **Sacramento County, CA**
DRILLING EQUIP.: **Case Backhoe with 30 inch Bucket**

DATE EXCAVATED: **8-8-07**
GROUND SURFACE ELEVATION: **0.0** Feet

PLATE NO. 7

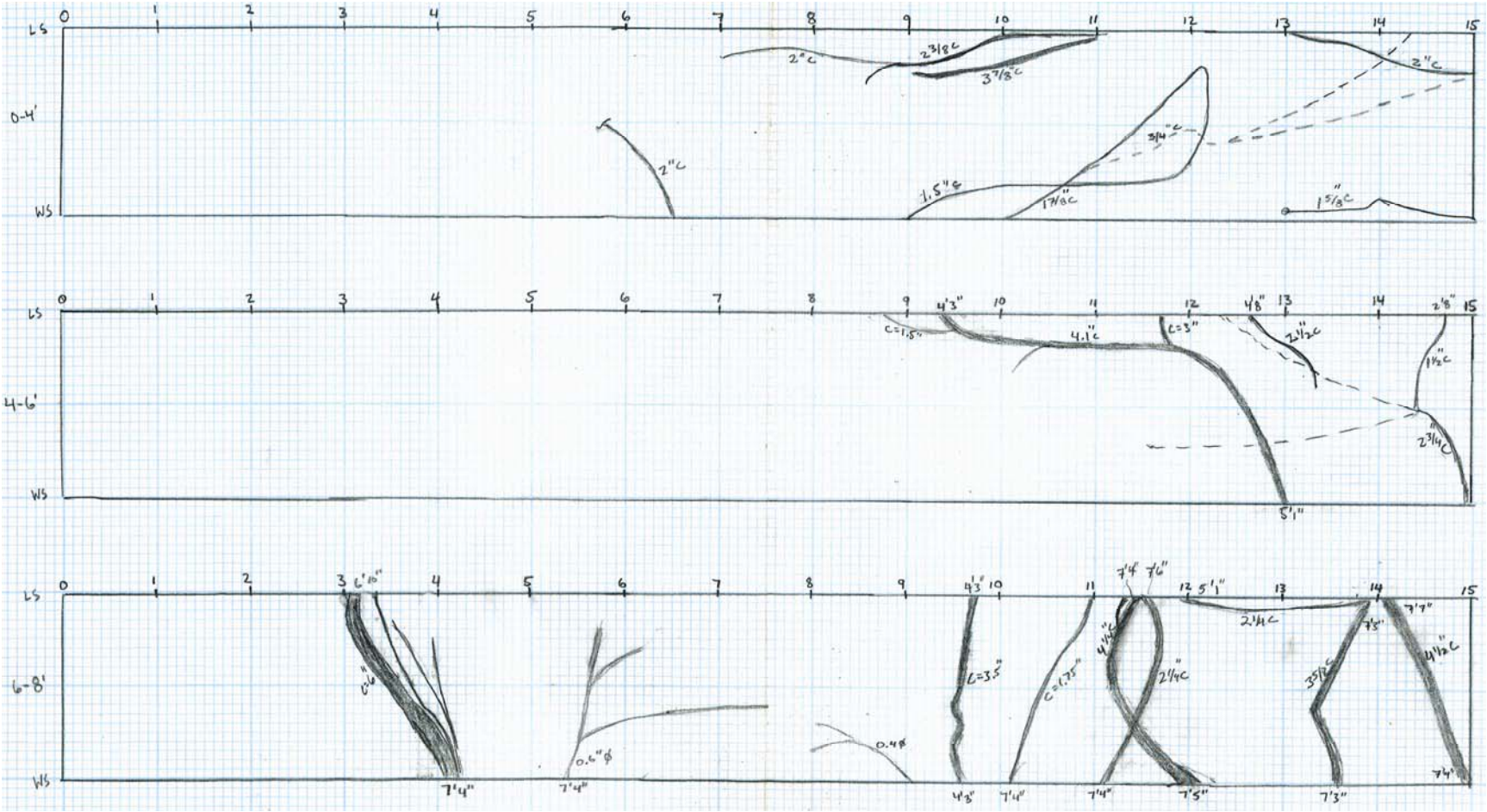
Depth, ft.	Sample	Sampling Method	Moisture, %	Dry Density, pcf	Blow Counts	Blow Count Histogram	Ground Water	Soil Lithology	Soil Lithology Description	Notes
0									ML: Brown, fine sandy silt, very stiff, dry	Station 296+50
-1										
-2										
-3										
-4									ML: Dark brown/brown, clayey silt, dry to moist	
-5										
-6									ML/SM: Blue gray, fine sandy silt/silty fine sand, very soft, very moist	
-7									SM: Blue gray, silty fine sand with rust mottling, wet	
-8										Test Pit Terminated at 8 feet.

APPENDIX E: TRENCH LOGS

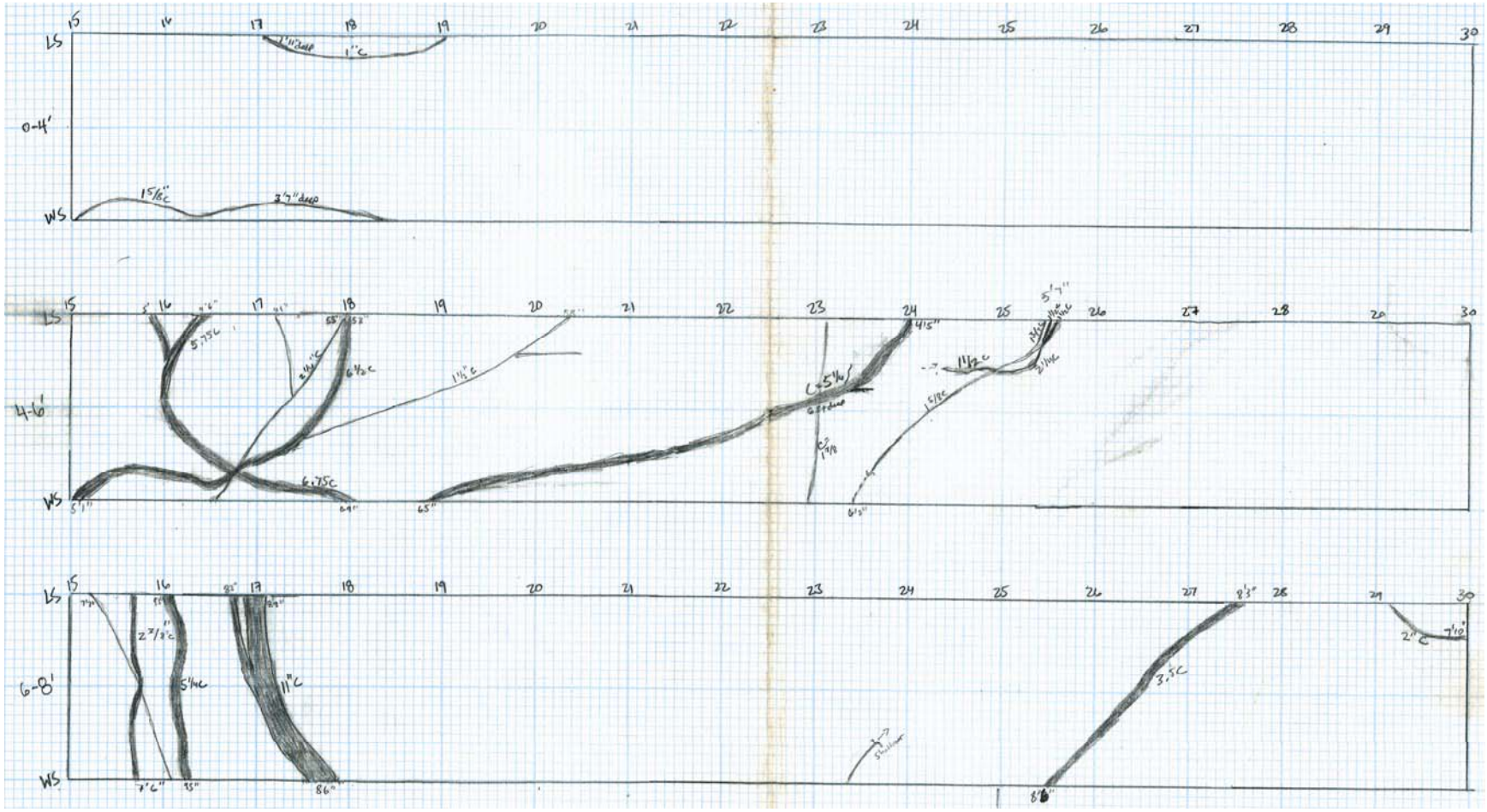
Appendix E

Partial plan view trench logs with photographs as well as complete wall logs are provided with discussion within Section 2.5.2 of the primary report. Complete field plan view logs are provided herein unedited. Where measured, root circumference is provided adjacent to the root (ex – 2.5 C means 2.5 inch circumference) with a depth in feet and inches noted at the location where the root intersected the wall. Roots are shown shaded and approximately to scale with solid lines, while burrows are lightly hatched. Diameters, where measured are noted with the ∅ symbol.

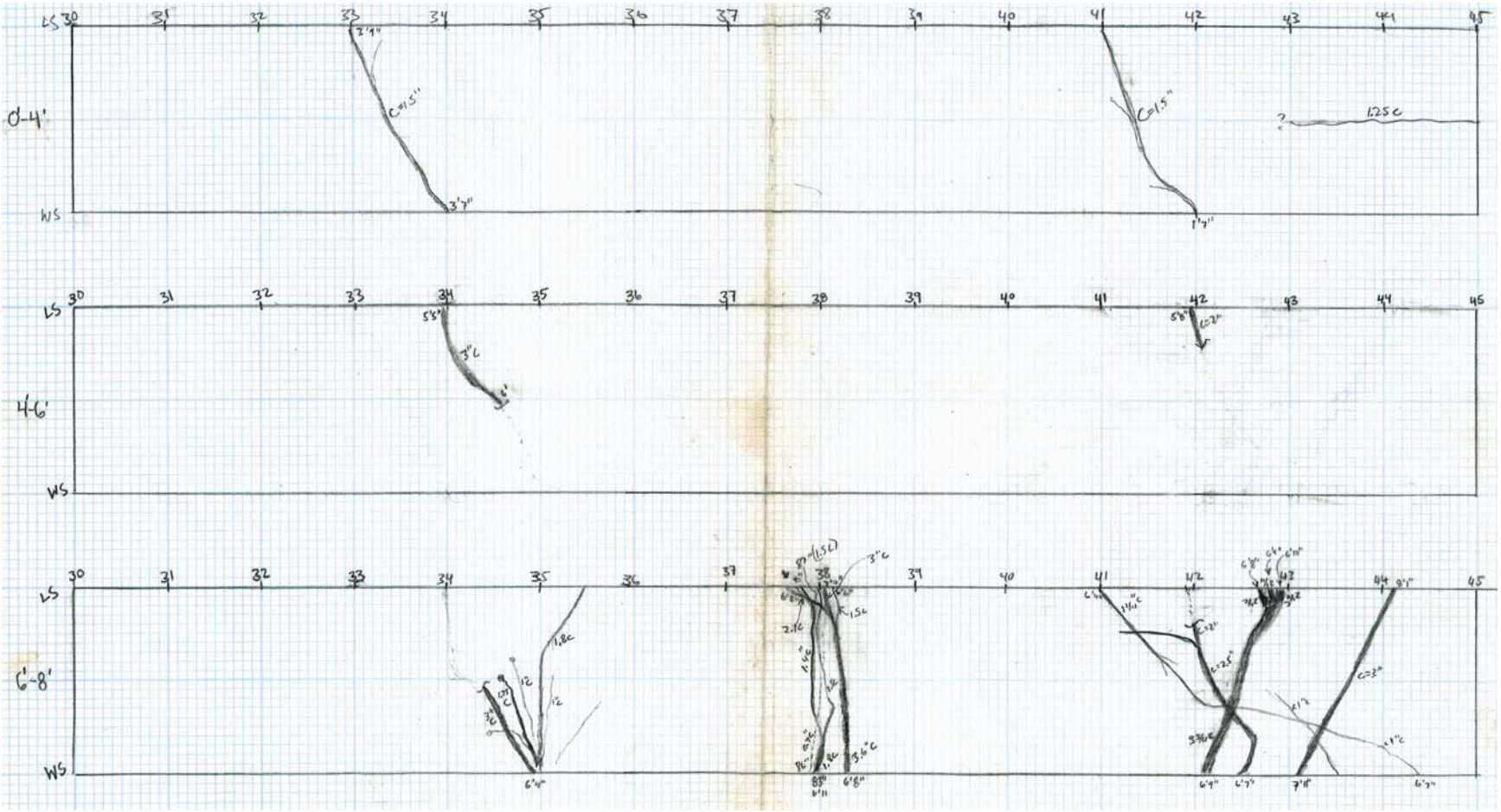
Tree Trench (Sta TT 0 to TT 15):



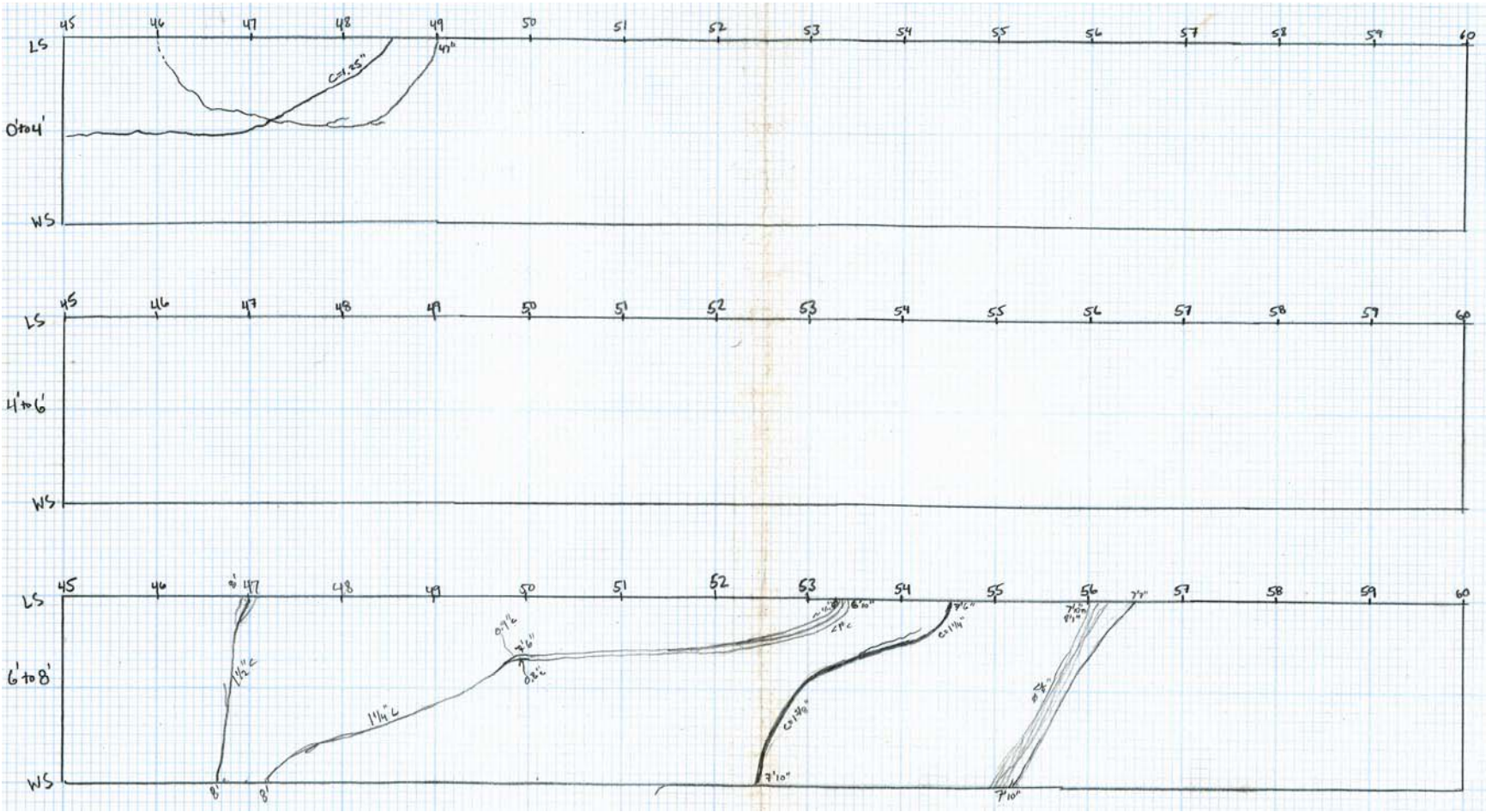
Tree Trench (Sta TT 15 to TT 30):



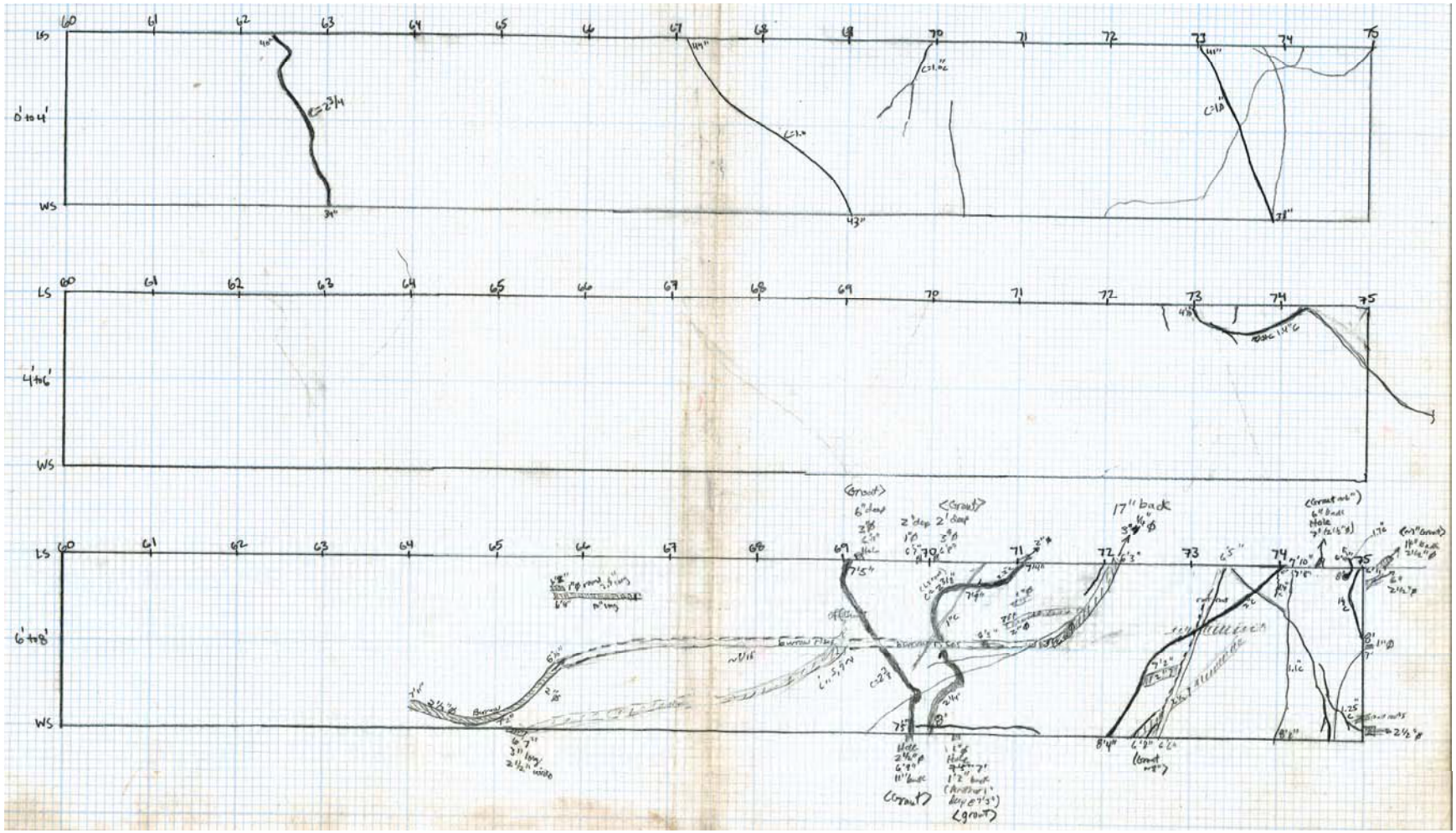
Tree Trench (Sta TT 30 to TT 45):



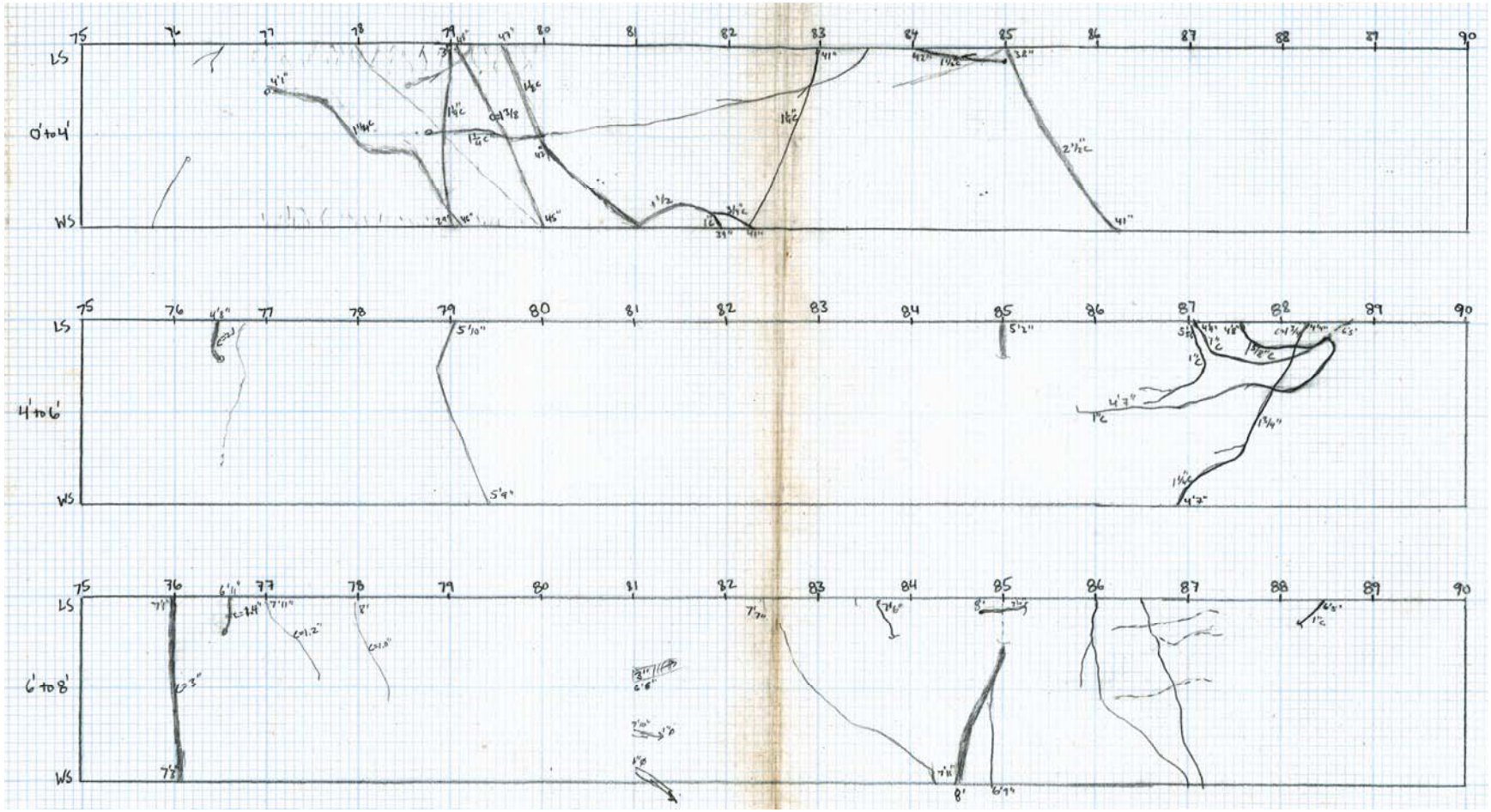
Tree Trench (Sta TT 45 to TT 60):



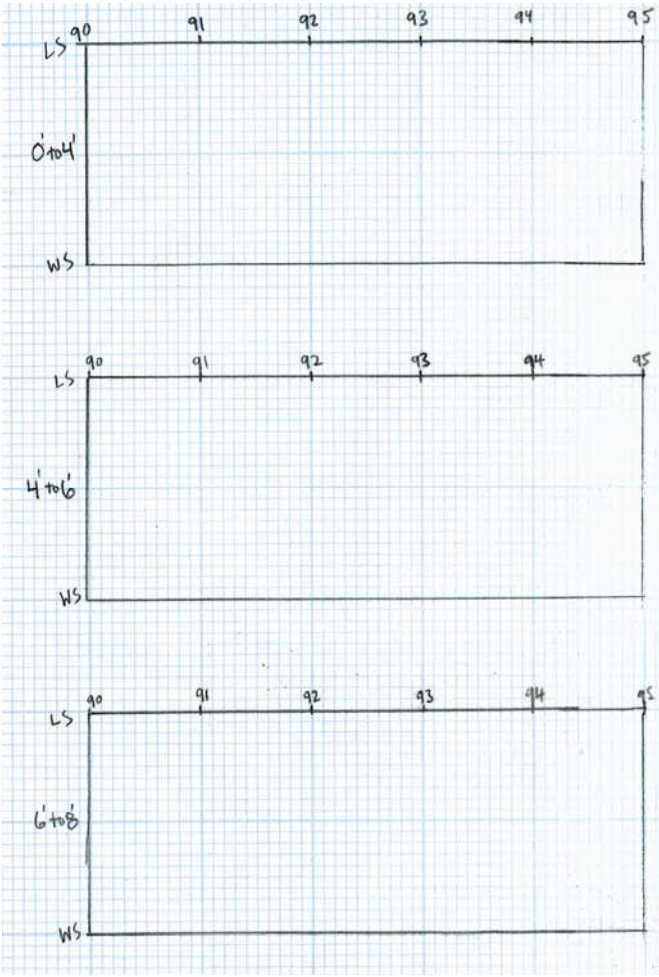
Tree Trench (Sta TT 60 to TT 75):



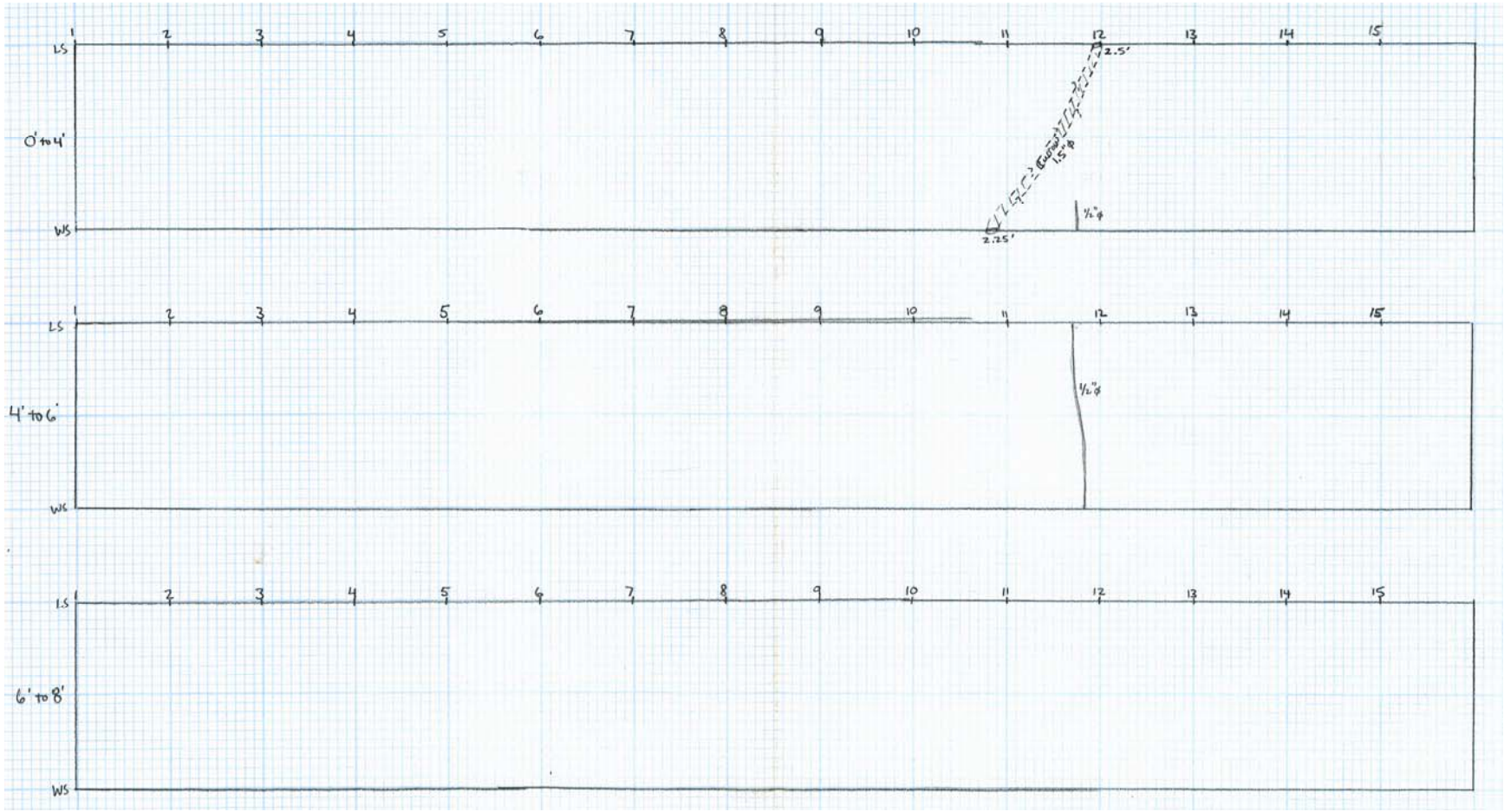
Tree Trench (Sta TT 75 to TT 90):



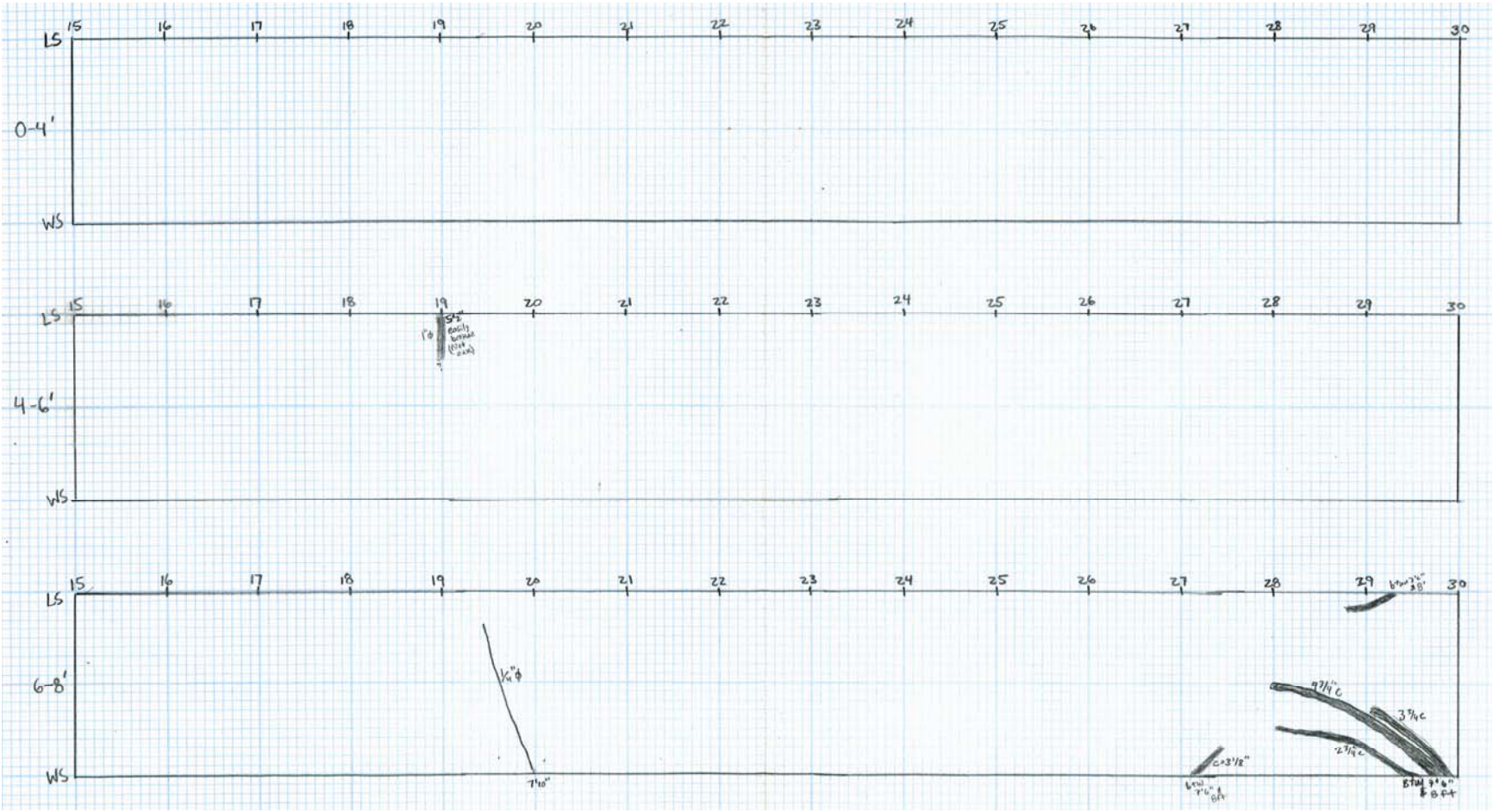
Tree Trench (Sta TT 90 to TT 95):



Control Trench (Sta CT 0 to CT 15):



Control Trench (Sta CT 15 to CT 30):



APPENDIX F: INSTRUMENT DATA

Appendix F

Tensiometer data is presented first, followed by piezometer data. Tensiometer data collection began with a dry run equilibration phase. During the dry run equilibration phase, tensiometers were assembled, leak checked, and installed in the ground. Soil Moisture tensiometers of 24, 48, and 60 inches in length were installed to depths of 24, 36 and 60 inches, respectively. The instruments were assembled with brass 'T' adaptors to allow for connection of both a mechanical gauge and a Model 5301 current transducer by Soil Moisture. The current transducer was wired to a Campbell Scientific CR3000 datalogger in order to continuously read the instruments. The current output from each transducer was converted to voltage using a 249 ohm resister with a resistor error of 1 percent. Based on manufacturer's specifications, currents of 4 and 20 mA correspond to soil suction values of 0 and 100 kpa, respectively. The values can be scaled linearly between these values. With a resistance of 249 ohms, using Ohms Law (which states that voltage is equal to current multiplied by resistance) voltages of 996 ohms and 4980 ohms correspond to soil suction values of 0 and 100 kpa, respectively, sharing the same linear relationship.

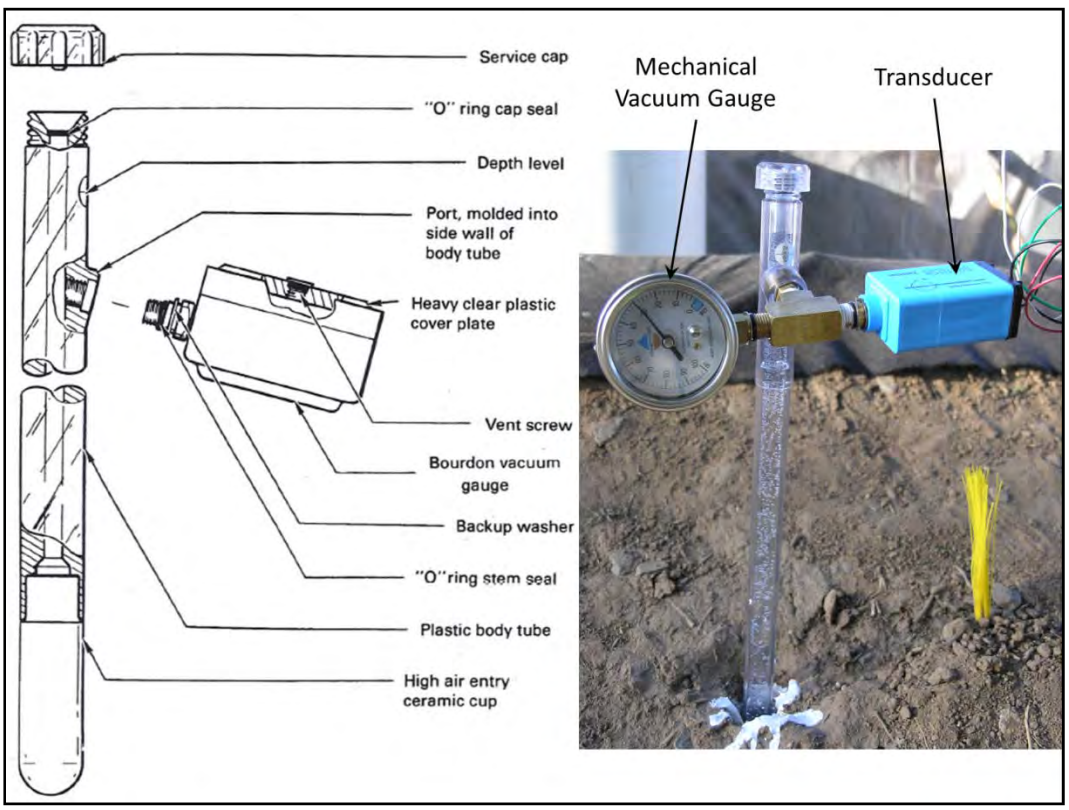


Figure F -1. Components of a tensiometer broken down by Fredlund and Rahardjo, 2005 (left) as compared with our tensiometer equipped with both vacuum gauge and transducer (right).

Tensiometers were installed ahead of the flow test and were connected to a continuously reading datalogger for a few days prior to the inundation of the trenches to establish baseline values in the instruments and to check functionality. Initial moisture contents of surficial soils are presented in Appendix B and results of initial testing are presented in Figure F -2 through Figure F -6. These moisture contents resulted in observed initial suction values of approximately 0 to 64 kPa. Results during the flow test are presented in Section 2.6.4. Values reported are not corrected for barometric pressure, though this parameter was recorded at the surface and values are presented on Figure F -7.

Piezometers were installed into 4 to 8-inch diameter auger holes and grouted in place with a mix of Portland cement and bentonite in accordance with the specifications of the manufacturers, Geokon and Slope Indicator. A grout mix compatible with soft soils as discussed in Mikkelsen (2002) and Mikkelsen and Green (2003). Due to initially unsaturated conditions and the likelihood of low measured pressures throughout the test, the Geokon 4500 AL (70 kPa) and the Slope Indicator Low Pressure (10 psi) Vibrating Wire models were selected. The constant head in the trench is held a maximum of 9 feet above the porous stone of the deepest piezometer (84 inches from surface grade, installed at mid-slope) resulting in a maximum possible pressure of 3.9 psi. The 10 psi low-pressure instrument was the most sensitive available for this application. The instruments were pre-saturated in a water bath and grouted into the hole upside down in order to minimize loss of saturation in the porous element due to the unsaturated conditions.

Figure F -8 includes data from piezometer during the dry run equilibration period prior to the flow test. Instruments show steady pressures, typically near zero. Waterside instruments in Row 6, nearest the water, show small initial pressures of less than 5 kPa, as do the deeper instruments near the landside toe in Row 3. Initial suction values are recorded in several instruments within Rows 1 and 2 on the waterside and landside of the levee crown road, respectively. Gray and Leiser (1982) discuss the ability of trees to deplete soil moisture due to transpiration through their leaves. The extent to which the presence of roots has contributed to increased initial suction values in these instruments is unclear. Suction in these instruments was lost upon inundation of the site with water.

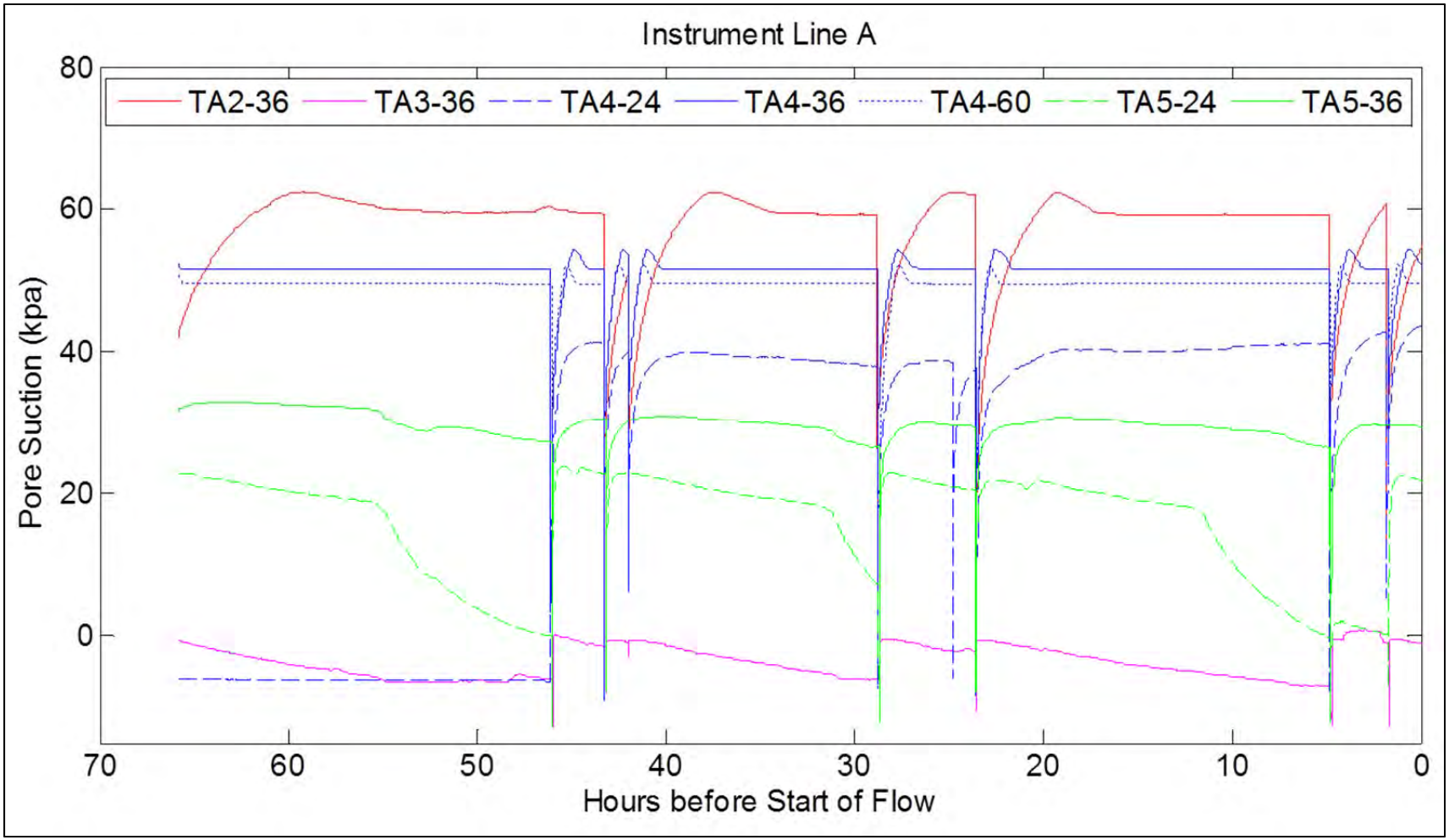


Figure F -2. Initial values of soil suction at instrument line A, measured in the days just prior to the flow test

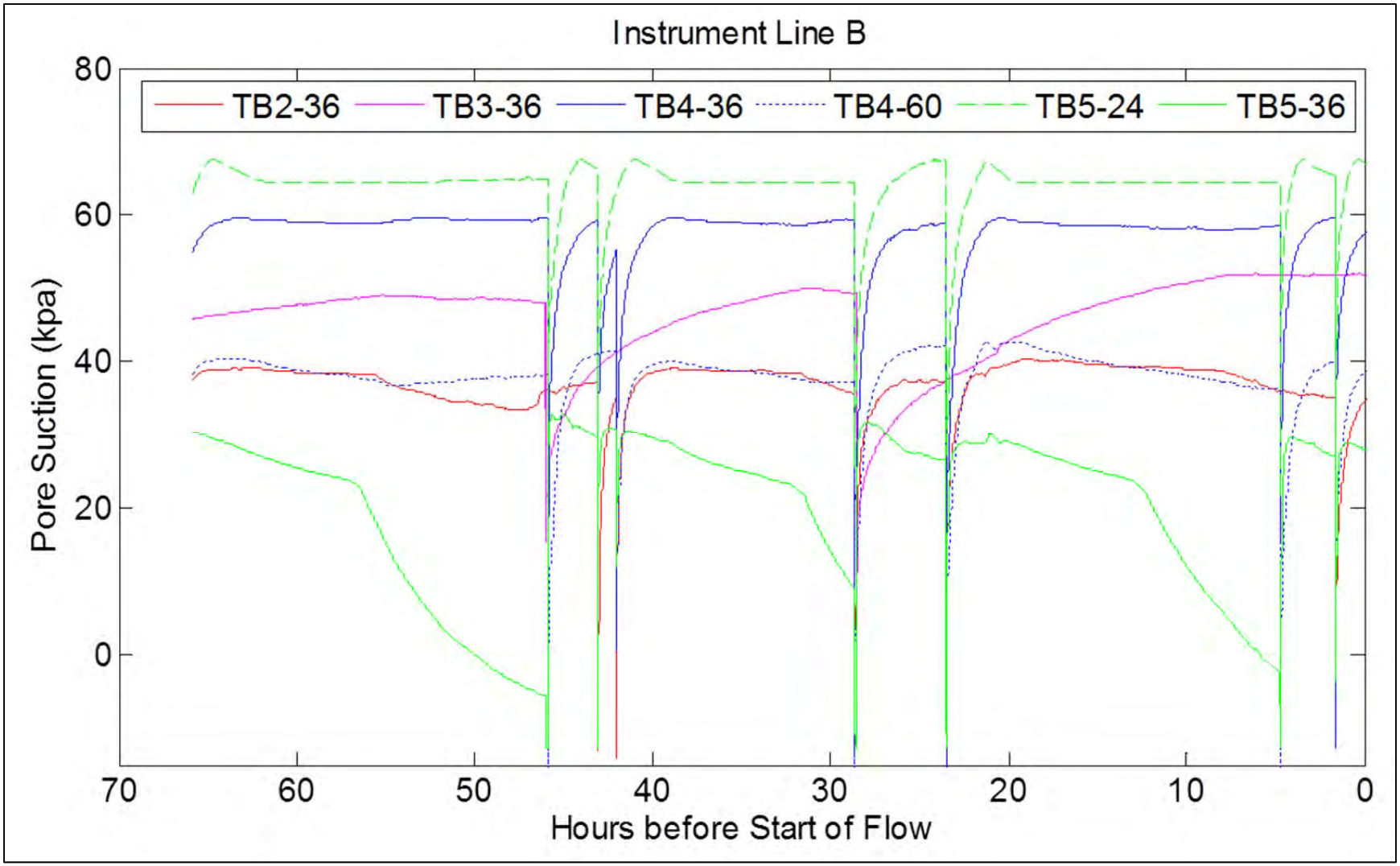


Figure F -3. Initial values of soil suction at instrument line B, measured in the days just prior to the flow test

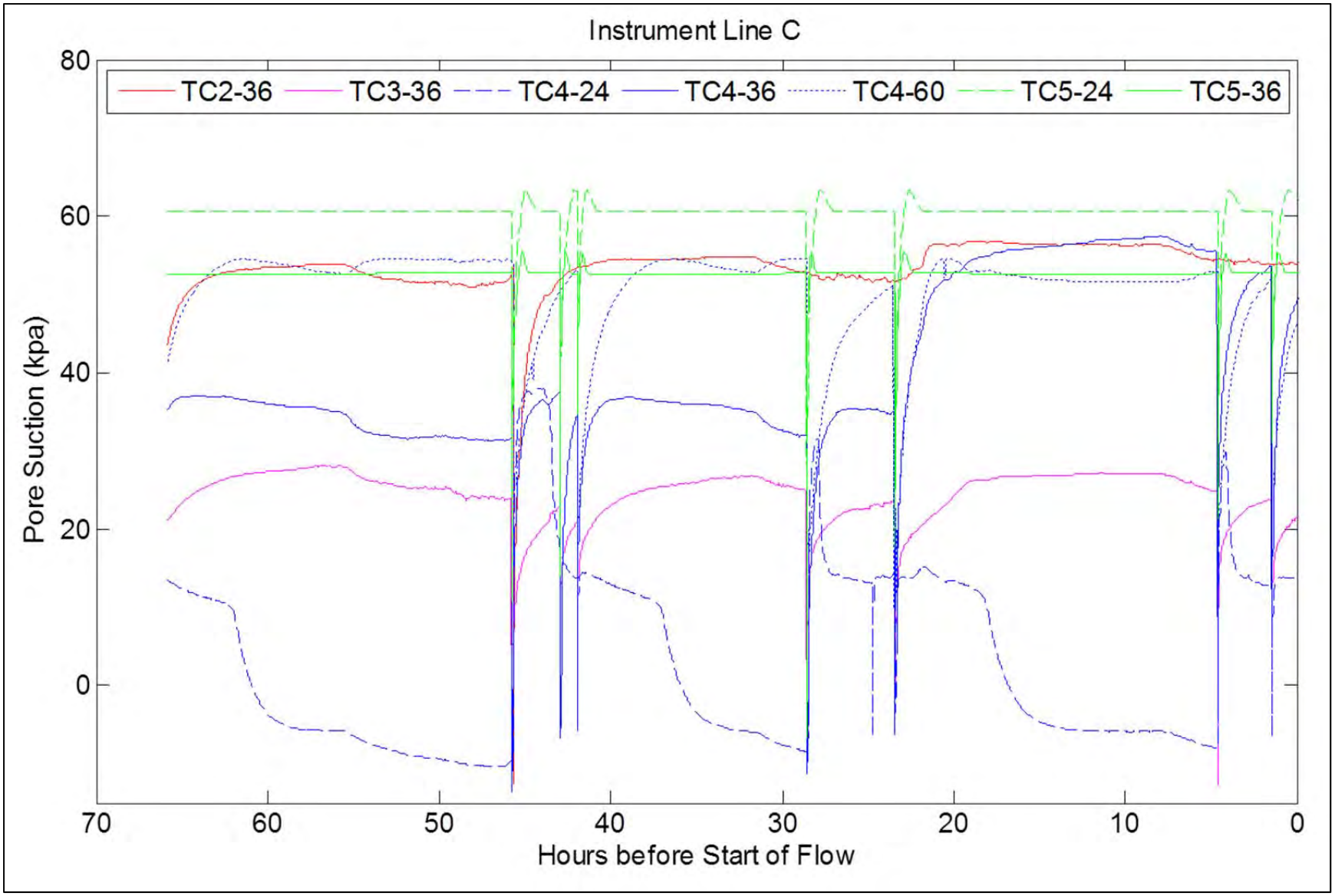


Figure F -4. Initial values of soil suction at instrument line C, measured in the days just prior to the flow test

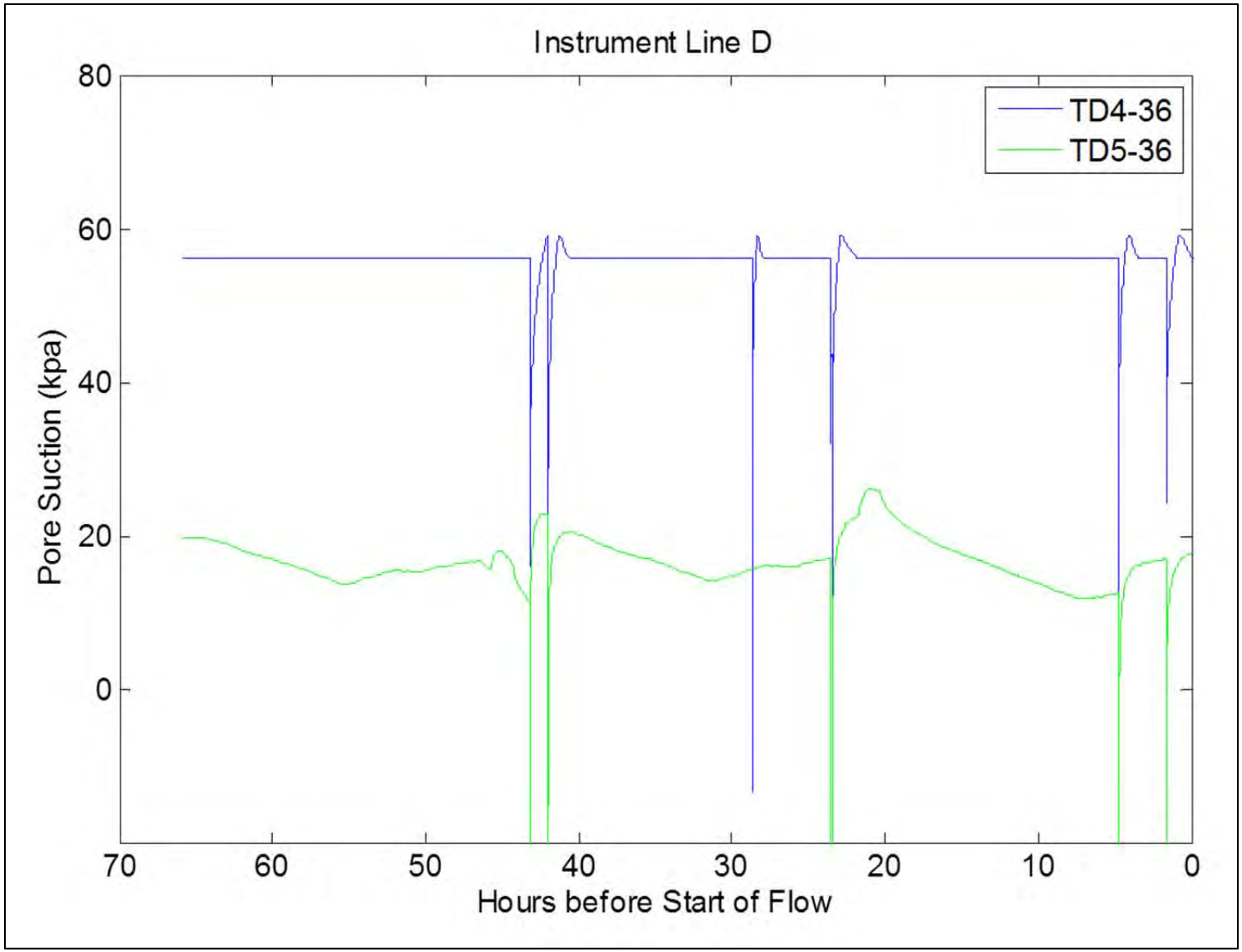


Figure F -5. Initial values of soil suction at instrument line D, measured in the days just prior to the flow test

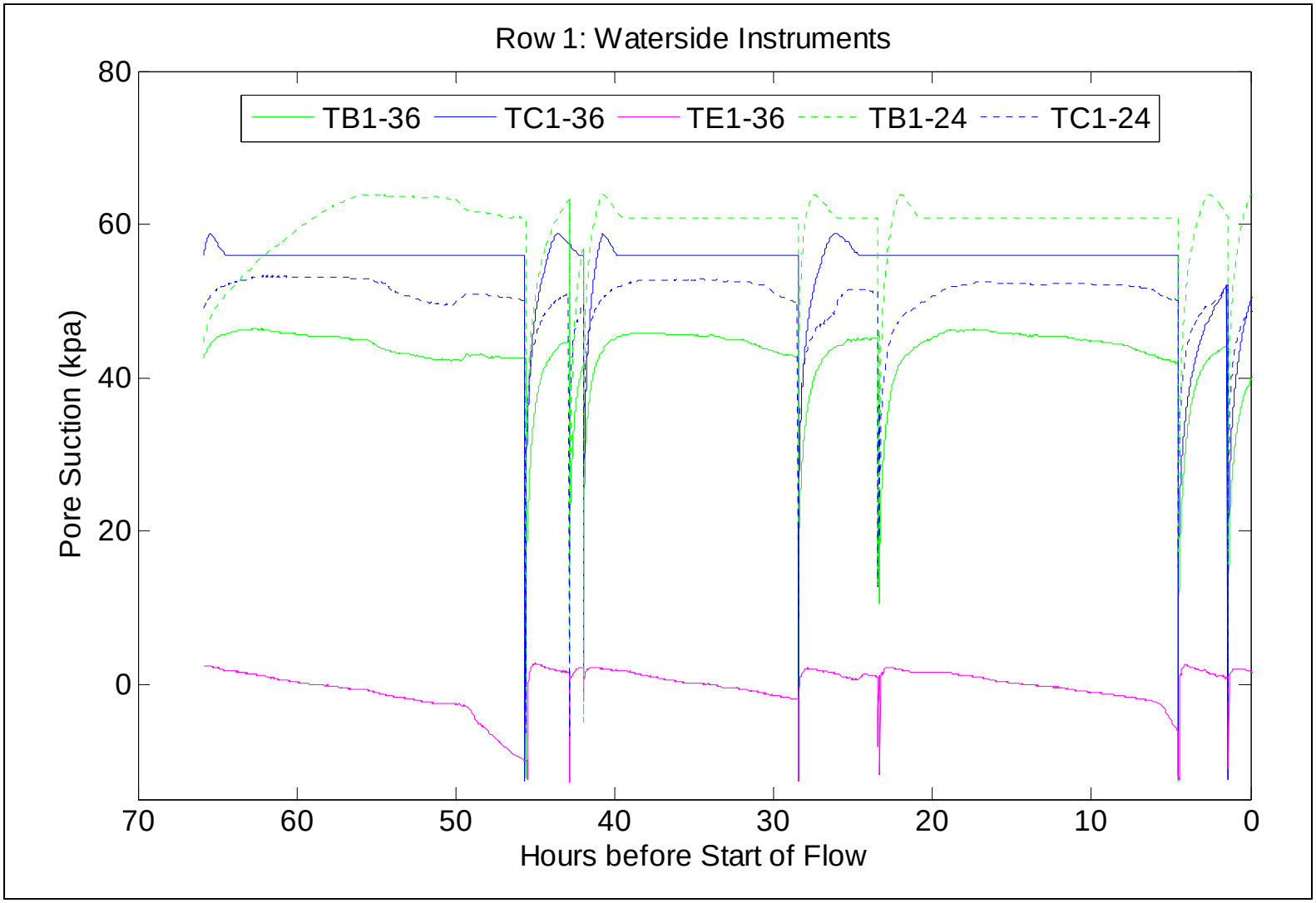


Figure F -6. Initial values of soil suction at waterside instruments (Row 1), measured in the days just prior to the flow test

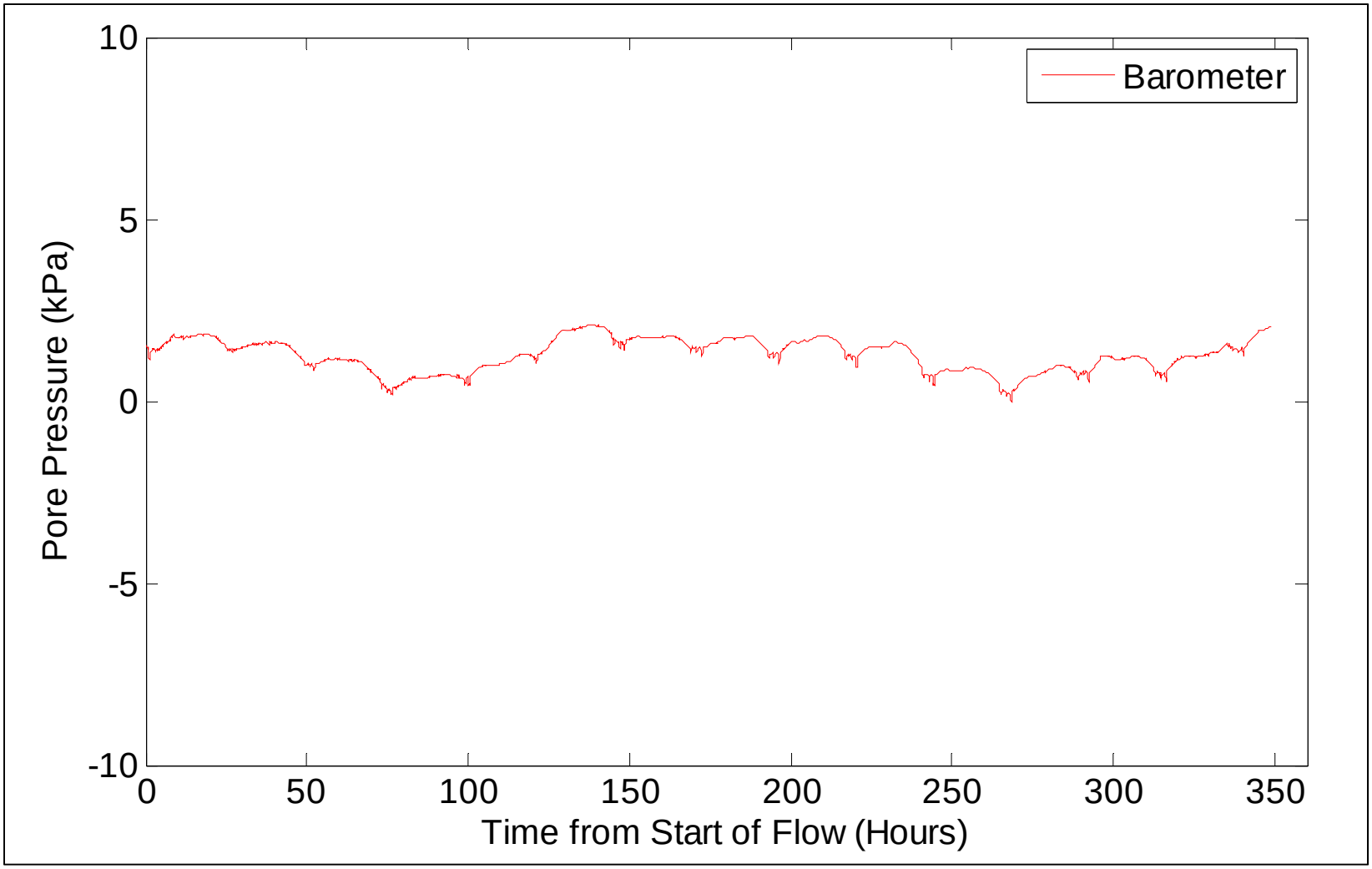


Figure F -7. Barometric pressures at the surface of the levee during the 10 day flow test and for 5 days afterward

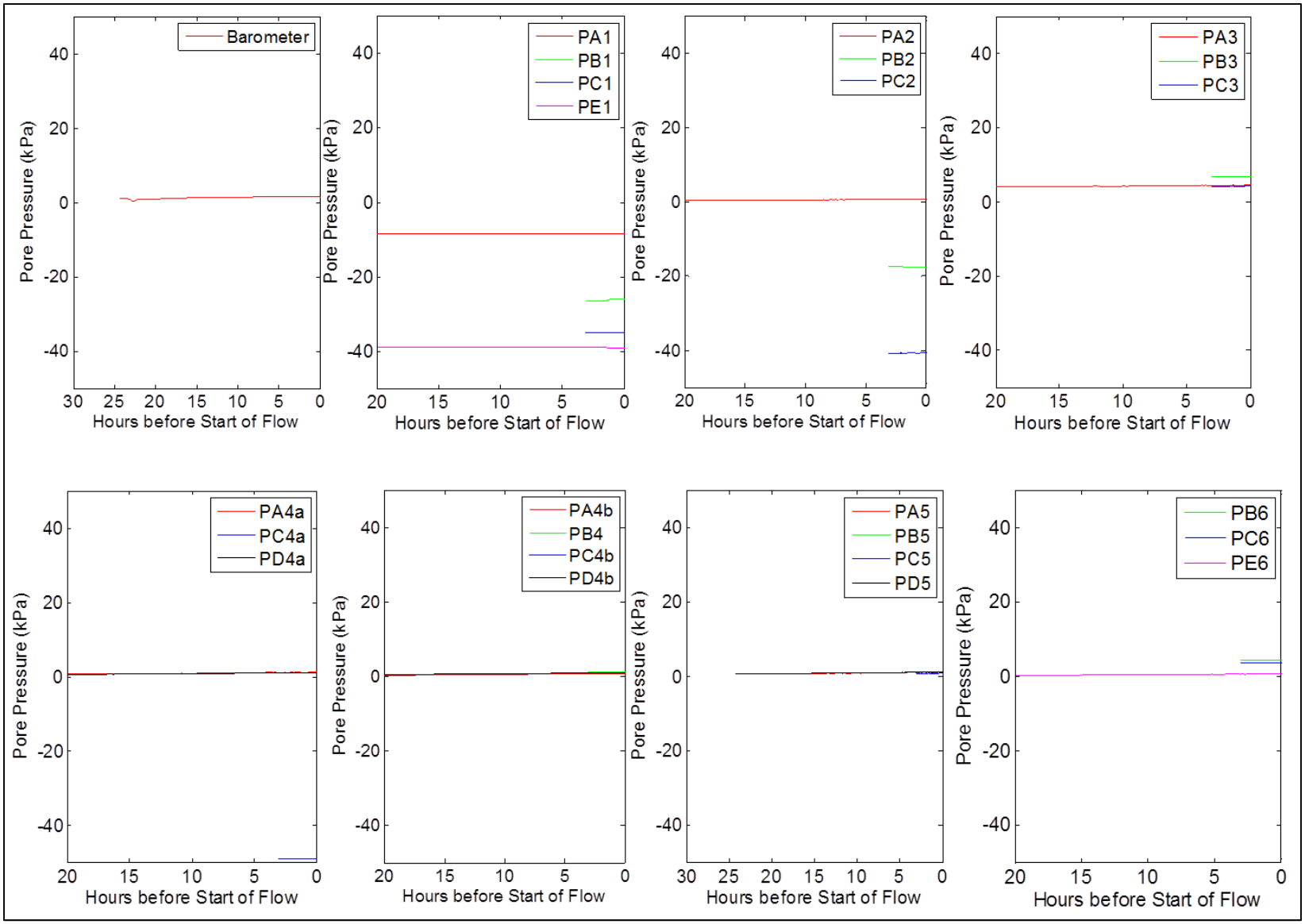


Figure F -8. Initial values of pore water pressure at all piezometers, measured just prior to the flow test

APPENDIX G: TREE LOAD ANALYSIS

Appendix G

G.1 ANALYSIS OF TREE LOADING

To understand the potential effects of the studied trees on the integrity of the levee, the existing conditions of the waterside and landside oak trees are important. Table G-1 shows the tree types, sizes, ages, and lean angles for the studied trees at the Twitchell Island test site. Peterson (2012) estimated critical overturning moments and pit sizes for trees of various types and plots this information with the parameter 'dbh', or diameter at breast height. Valley Oak was one of the studied species, while Coast live oak was not. Cooper (1926) describes the root system of the Valley oak to be "characterized by a well-developed tap root, with large, comparatively numerous laterals, these penetrating to a considerable depth. It also possesses numerous superficial roots of great size-up to 70 feet in length." Comparatively, the live oak is well adapted to acquiring water from shallow sources and has "habitually shallow root systems." The critical turning moment was estimated based on dbh for the waterside oak using a correlation presented in Peterson (2012). Based on the information provided in Cooper (1926), this curve shown for the Valley Oak is likely an overestimate for a more superficial root system such as that of the live oak. The range of trees within Peterson's study show a range of critical overturning moment from 350 to 1500 kN-m (260 to 1100 kip-ft) for trees with similar dbh values to those studied herein. Values are not reported for the landside oak. Tree weights were estimated for the landside and waterside trees using relationships by Myers et al. (1980) developed for red oak trees and white oak trees, respectively.

Table G-1. Estimated properties of landside and waterside oak trees

Position	Common Name	Section	Estimated Age (yrs)	Approximate Canopy Diameter (ft)	Approximate dbh (in)	Lean Angle (deg)	Estimated Pit Size* (ft^2)	Estimated Critical Turning Moment* (kip-ft)	Estimated Weight** (kips)
landside	Coastal Live Oak	Red Oak	25-30	40	33	6	60	-	11
waterside	Valley Oak	White Oak	60	60x80 (ave 70)	40	44	70	960-1,200	26

* Estimated from Peterson (2012); ** Estimated from Myers et al. (1980)

G.1.1 Tree Lean and Dynamic Wind Loading

Tree lean and wind loading are key factors in the analysis of a root system. Figure G-1 shows a diagram by Coutts (1983) explaining the mechanism of tree uprooting under a horizontal force. The leeward side, or 'L, in Figure G-1, of the root-soil system is subject to bending with the position of the fulcrum determined by the branching of roots (Coutts, 1983) and their reduced ability to resist bending. The windward side, or 'W' in Figure G-1 is able to stiffen soil more efficiently as roots are able to deform and develop tension without significant overburden to restrict uplift.

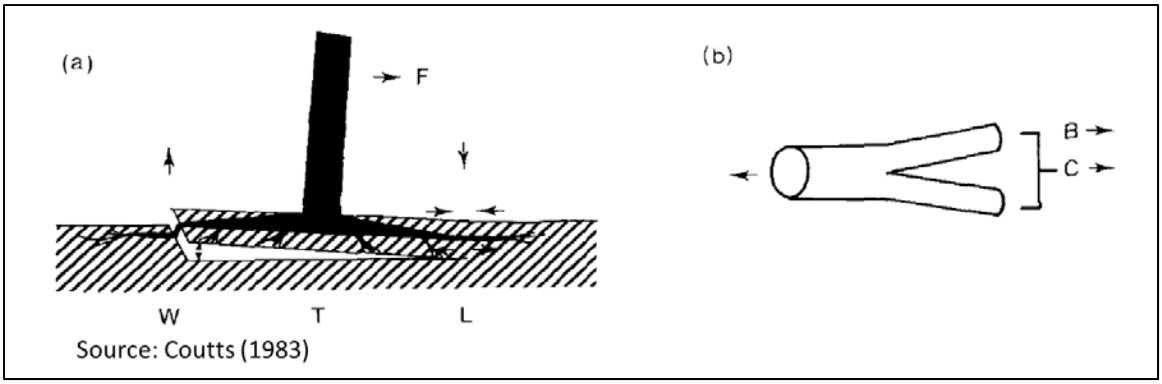


Figure G-1. Diagram showing (a) the mechanism of overturning and (b) branching. According to Coutts (1983), branching on the leeward side can determine the position of the fulcrum on which the root plate is hinged in overturning.

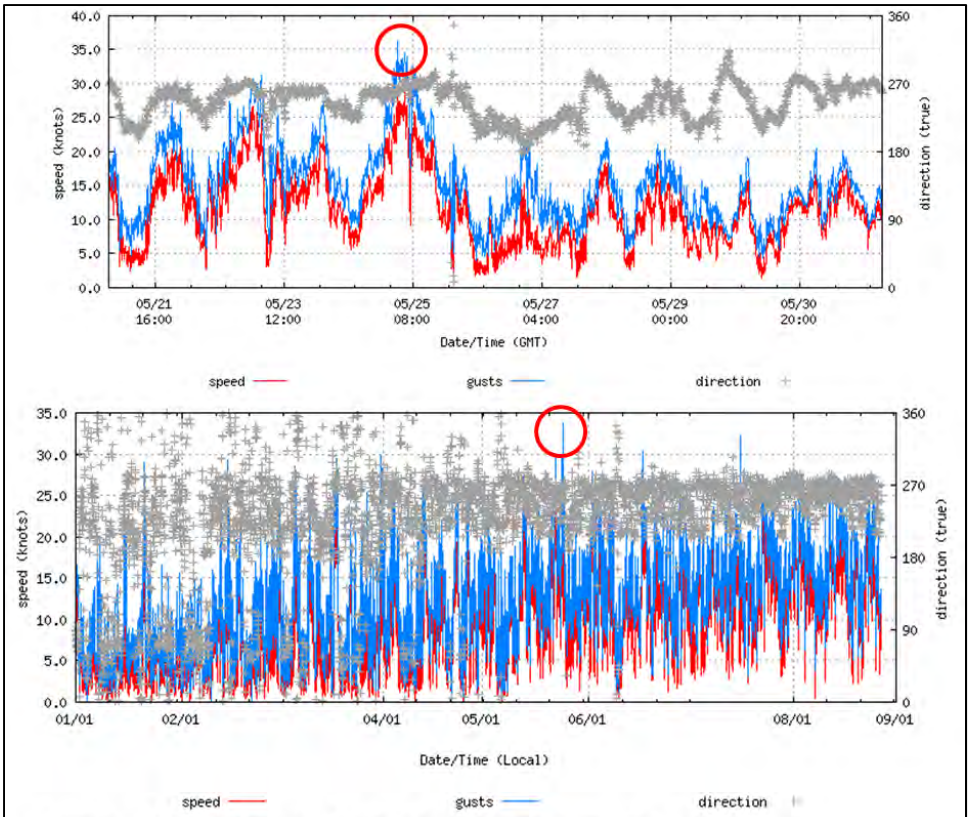
The destabilizing moment due to the static loading associated with the lean angle of the waterside tree is estimated from the weight and geometry. Wind forces can add to this destabilization. Peterson (2012) estimates wind force as follows:

$$Force\ (N) = 0.5\ C_d(air\ density)\ (crown\ area)(velocity)^2$$

Where: C_d = drag coefficient, 0.4 recommended value for critical moment calculation;

air density = 1.2 $\frac{Kg}{m^3}$;
crown area = cross sectional area of tree in m^2;
velocity = wind speed in meters per second

Wind speed in the vicinity of the San Joaquin Delta during the Twitchell Island field test is shown on Figure G-2.

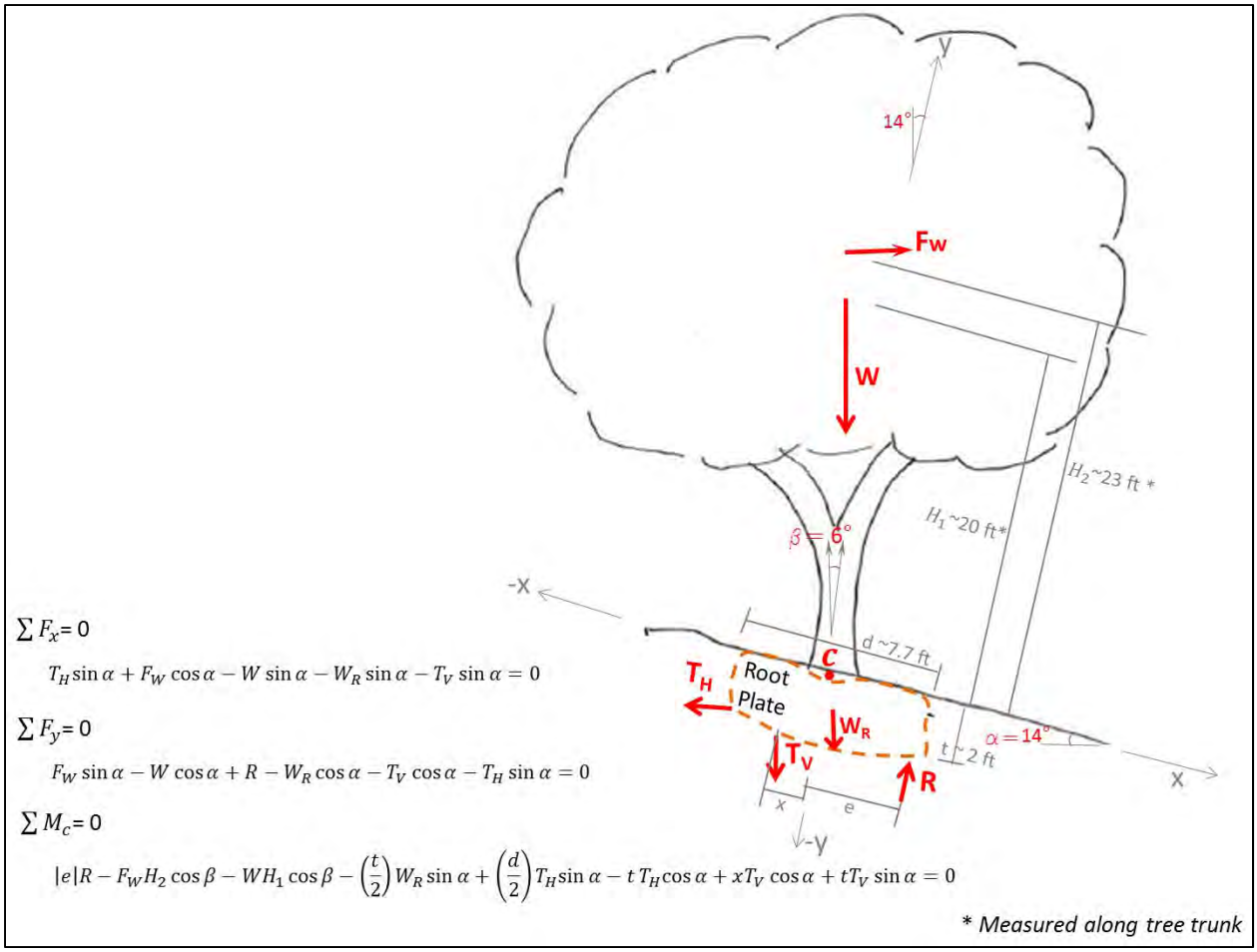


Source: NOAA Tides and Currents: Port Costa Weather Station

Figure G-2. Wind speeds during the week of the field test showing peak velocities of 31 to 37 knots (16 to 19 m/s).

G.1.2 Loading for Landside Oak Tree

A free body diagram detailing the loading on the landside oak tree is presented as Figure G-3. Based on T-LiDAR scans of the tree shape performed by Gerald Bawden of the USGS, the tree exhibited a slight lean (about 6 degrees). The diagram details wind forces, gravitational forces, a reaction force, and root tensile forces extending from a root plate. As discussed above, the landside oak tree, a Coast live oak, is expected to have a relatively shallow root system without a well-developed tap root (Cooper, 1926). The position of the resultant vertical tensile force was applied at a distance of about a third of the root plate diameter, d, to account for the decreasing number of roots with distance from the tree center. The size of the root plate was estimated from the empirically derived data associated with windthrow studies (e.g., Peterson, 2012). Table G-1 solves equations presented on Figure G-3 based on assumed values of key input parameters (highlighted in green) to arrive at horizontal and vertical loading of the tree based on an assumption that the tree and root plate act as a rigid body.



$$\sum F_x = 0$$

$$T_H \sin\alpha + F_W \cos\alpha - W \sin\alpha - W_R \sin\alpha - T_V \sin\alpha = 0$$

$$\sum F_y = 0$$

$$F_W \sin\alpha - W \cos\alpha + R - W_R \cos\alpha - T_V \cos\alpha - T_H \sin\alpha = 0$$

$$\sum M_c = 0$$

$$|e|R - F_W H_2 \cos\beta - W H_1 \cos\beta - \left(\frac{t}{2}\right) W_R \sin\alpha + \left(\frac{d}{2}\right) T_H \sin\alpha - t\, T_H \cos\alpha + x T_V \cos\alpha + t T_V \sin\alpha = 0$$

Figure G-3. Free body diagram representing the force balance on the landside oak tree at Twitchell Island.

Table G-2.Calculated force balance for landside oak tree.

Canopy Width	**40**	ft
Canopy height	**30**	ft
Wind Speed	**39**	mph
Tree height	**41**	ft
Diameter at breast height, dbh	**33**	in
Angle of slope (from horizontal), Alpha	**14.0**	degrees
Angle of tree lean (from vertical), Beta	**6**	degrees
Thickness of root plate, t	**2**	ft
Unit weight of root plate	**80**	pcf
Height*, wind force, H_2	**23**	ft
Height*, center of mass, H_1	**20**	ft
Tap (or vertical) root offset from trunk, x	**2.5**	ft
Eccentricity of reaction force, e	**-3.9**	ft
Tree Weight (white oak), W	11,100	lbs
Wind Load, Fw	1,470	lbs
Weight of Root Plate, W_R	9,570	lbs
Size of root plate (assumed square), d	7.7	ft
Angle of X-axis (from horizontal)	14	degrees
Vertical Root Tension, T_V	**10,200**	lbs
Horizontal Root Tension, T_H	**9,170**	lbs
Reaction Force, R	**31,800**	lbs
**measured along the alignment of the tree trunk*		

G.1.3 Loading for Waterside Oak Tree

A free body diagram detailing the loading associated with the waterside oak tree is presented as Figure G-4. Based on estimates from pre-test photographs, the waterside oak tree leaned at an angle of approximately 46 degrees from vertical prior to testing. The diagram details wind forces, gravitational forces, a reaction force, and root tensile forces extending from a root plate. As discussed for the landside oak tree, the size of the root plate was estimated from the empirically derived data associated with windthrow studies (e.g., Peterson, 2012). Table G-3 provides input parameters (highlighted in green) and solutions to equations presented on Figure G-4 to arrive at horizontal and vertical loading of the tree based on an assumption that the tree and root plate act as a rigid body.

Horizontal and vertical root tension loads are intended to represent total horizontal and total vertical loading associated with the anchoring demand on the root system based on the configuration of the leaning tree and wind loading. The waterside oak tree, a valley oak, is expected to have a well-developed tap root (Cooper, 1926); however, the vertical component of the root tension force includes all roots acting in the vertical direction. Roots on the windward side of the tree are expected to contribute more to resisting overturning. On this basis, the vertical tension force was assumed to act midway between the trunk center and the edge of the root plate (i.e., a value of $x = \frac{d}{4}$ as shown on Figure G-4). This distance is closer than that assumed for the landside

tree to account for the presence of the tap root in the valley oak tree. The vertical loading delivered to the root system is expected to be 25 percent smaller if the vertical root tension force, T_V, acts at the windward edge of the root plate, and 50 percent larger if the vertical root tension force acts at the center of the tree trunk (assumes a 27 degree slope angle). Similarly, the horizontal force, T_H, is also impacted by the assumed position of the vertical force. The horizontal force is reduced by 16 percent when the vertical root tension force acts at the windward edge of the root plate ($x = \frac{d}{4}$) and increased by 32 percent when the vertical root resists tree topple from the trunk center.

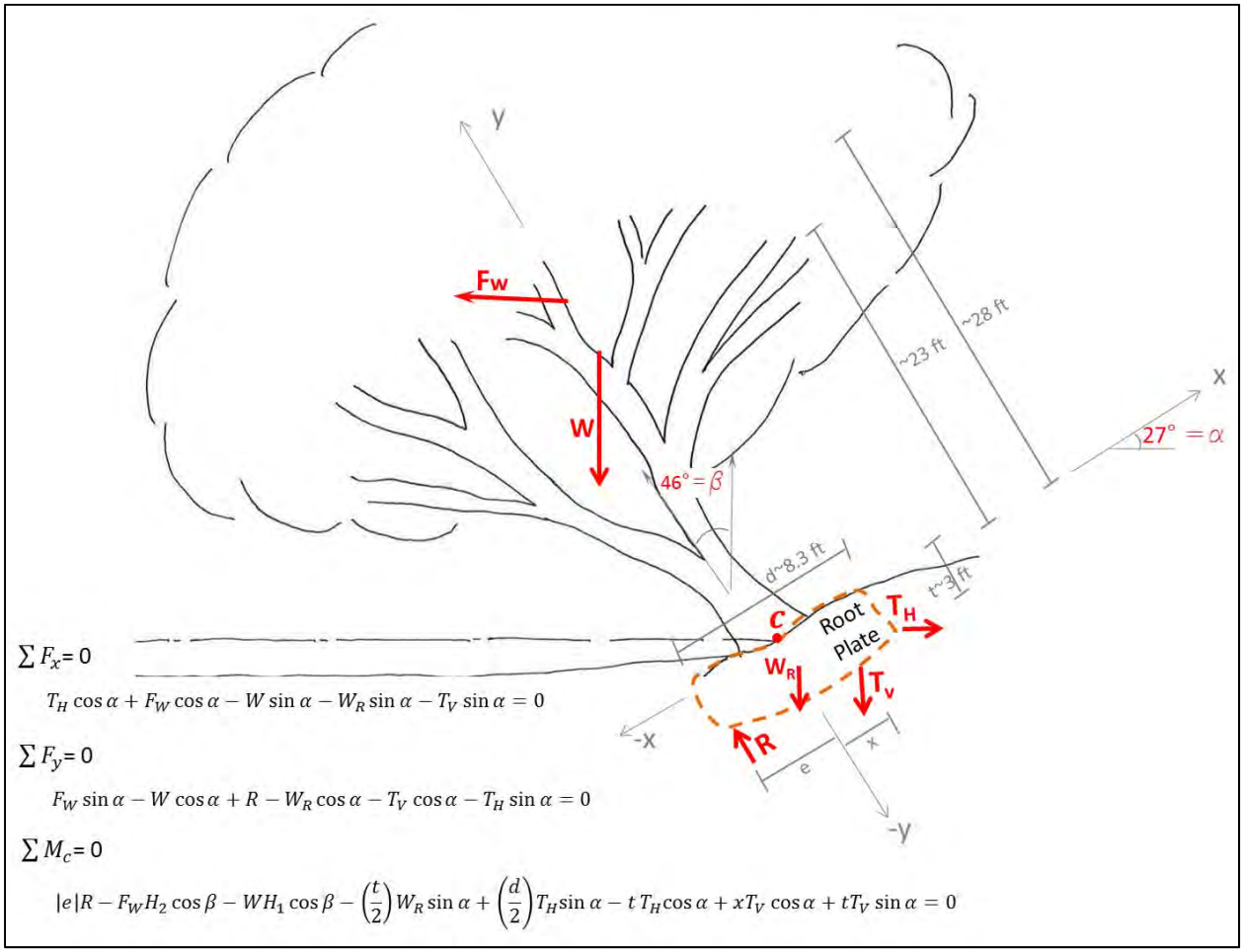


Figure G-4. Free body diagram representing the force balance on the waterside oak tree at Twitchell Island.

Table G-3. Calculated force balance for waterside oak tree

Canopy Width	**70**	ft
Canopy height	**35**	ft
Wind Speed	**39**	mph
Tree height	**47**	ft
Diameter at breast height, dbh	**40**	in
Angle of slope (from horizontal), Alpha	**27**	degrees
Angle of tree lean (from vertical), Beta	**46**	degrees
Thickness of root plate, t	**3**	ft
Unit weight of root plate	**80**	pcf
Height*, wind force, H_2	**28**	ft
Height*, center of mass, H_1	**23**	ft
Tap (or vertical) root offset from trunk, x	**2.0**	ft
Eccentricity of reaction force, e	**-4**	ft
Tree Weight (white oak), W	26,100	lbs
Wind Load, Fw	3,300	lbs
Weight of Root Plate, W_R	16,700	lbs
Size of root plate (assumed square), d	8.3	ft
Angle of X-axis (from horizontal)	27	degrees
Vertical Root Tension Force, T_V	**97,000**	lbs
Horizontal Root Tension Force, T_H	**74,500**	lbs
Reaction Force, R	**157,000**	lbs
**measured along the alignment of the tree trunk*		

Input parameters (highlighted in green in Table G-3) have the capacity to impact the force delivered to the root system. Understanding the forces delivered to the root system and how they may act on the levee is important in creating a representative model. To this end, a sensitivity analysis was performed examining the impact of key site conditions such as slope angle or tree lean on horizontal and vertical tree root tension loading.

Horizontal and vertical root loading associated with the waterside oak tree (estimated to weigh about 26,000 pounds) was calculated with slope angles varying from 0 to 45 degrees (measured from horizontal) and with tree lean angles of 0 to 46 degrees (measured from vertical). Root loading increases with increasing slope angle and tree lean angle. Figure G-5 shows a steep rise in horizontal root loading for slopes steeper than 27 degrees (about 2 horizontal to 1 vertical) regardless of tree lean, while vertical root loading appears to respond more strongly to tree lean. Figure G-6 shows the relationship between horizontal and vertical root loading with increasing tree lean. Loading calculations neglect deformations associated with the system and are estimated for a tree and root system considered as a rigid body.

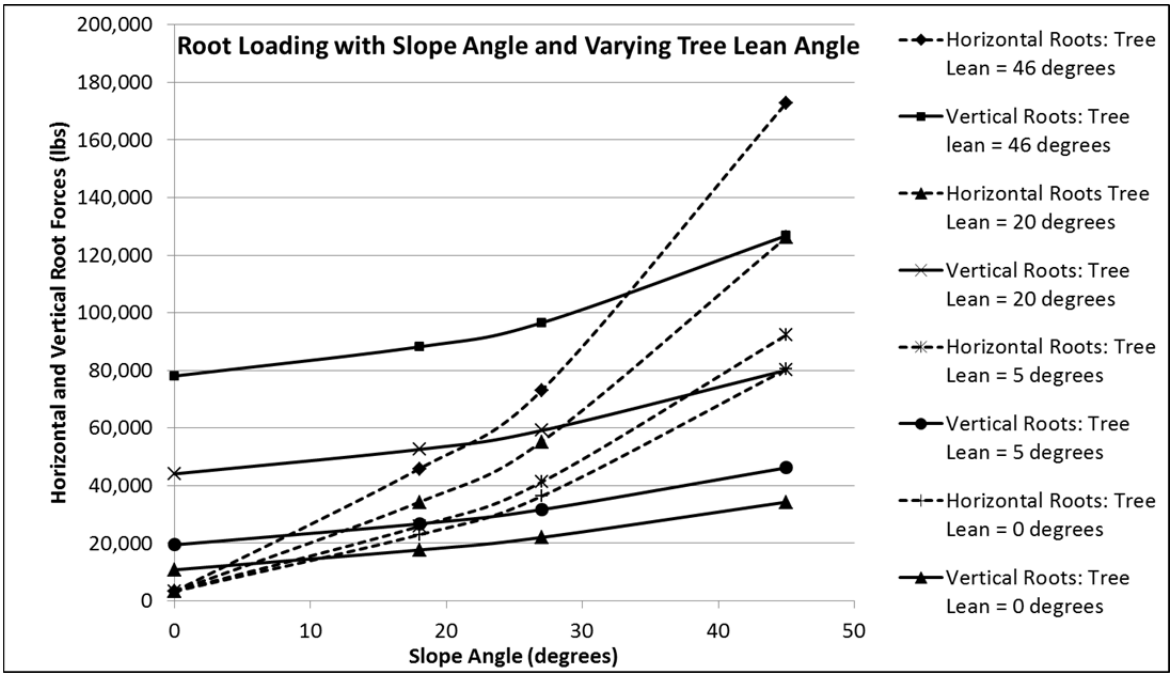


Figure G-5. Horizontal and vertical root loading plotted against slope angle for tree lean angles ranging from 0 to 46 degrees (measured from vertical). Plots assume a 26,000 pound tree similar to the waterside oak tree with a tap root and windward roots with a vertical component (resultant acting downward from 2 feet windward of the trunk center).

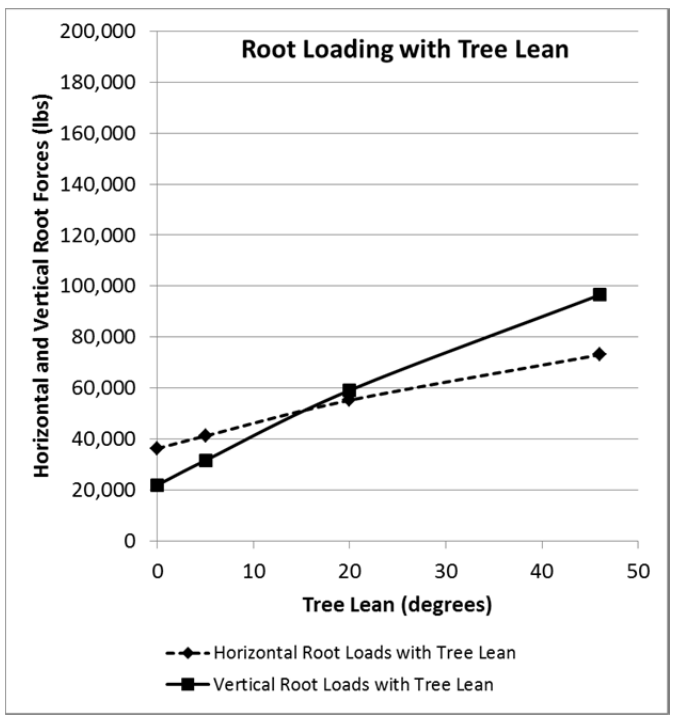


Figure G-6. Horizontal and vertical tree root loading plotted with increasing slope angle (top) and increasing tree lean angle (bottom). Assumes a tree similar to the waterside oak tree, weighing approximately 26,000 pounds with a tap root and windward roots with a vertical component (resultant acting downward from 2 feet windward of the trunk center).

G.2 ROOT REINFORCEMENT

Trench logs show that the root system of the waterside oak was significantly more extensive within the trench than the root system of the landside oak (Figure G-7). The majority of roots of the waterside oak were found at depths of 4 to 8 feet within the trench. The waterside tree was positioned at an elevation approximately 6 feet below the levee crown and the largest roots were found to extend approximately horizontal into the levee. The landside tree shows significantly lower root area ratios and a more even distribution with depth. Our observations seem to be consistent with those reported by Cooper (1926) who noted that the Coast live oak obtains water from shallow depths and is less likely to have the well-developed tap root and extensive lateral root system typical of the Valley oak. Figure G-8 provides a graphical breakdown of the root size and number of occurrences within the trench wall.

Estimates for number and size of roots at closer distances to the tree were estimated based on available root architecture data. Based on a review of raw data charts for several valley oak trees excavated and data provided to us by Dr. Alison Berry and Shih-Ming Chung of UC Davis, roots were estimated to be about 5 times more abundant at distances of 25 to 50 percent of the canopy radius and about 2.5 times larger at 25 percent of the canopy radius than at 50 to 100 percent of the canopy radius. Roots intersected by the trench extending from the waterside and landside oak trees are located at approximately 65 to 100 percent of the canopy diameter.

The critical overturning moment estimated by empirical data provided by Peterson (2012) for the waterside valley oak tree is about 1,100 kip-ft. Looking at Figure G-8, typical root sizes are on the order of 0.8 to 1.5 inches at depths of 4 to 8 feet. Smaller and shallower roots do not provide much reinforcing. Looking at an 8 foot failure zone and the primary roots extending back from this zone, assume one root of 1.5 inch diameter and one root of 0.75 inch diameter per foot across an 8 foot section. The critical overturning moment for a one foot thick slice would be 138 kip-ft. Using Gray and Sotir (1996), each root is evaluated to determine if it fails in tension or pullout. In general, roots of 0.75 to 2 inches and an assumed 25 feet in length will not break in tension. Bond strengths are estimated using equation 3-13 of Gray and Sotir (1996):

$$\tau_b = z\gamma(1 - \sin\phi) f \ tan\phi$$

Where: z = depth below ground surface ;
γ = soil unit weight;
ϕ =friction angle of soil ;
f = coefficient of friction between the soil and the root fiber

The root tensile strength was checked against equation 3-12 of Gray and Sotir:

$$T_R = \frac{4\tau_b L}{D}$$

Where: T_R = root tensile strength;
L = root length;
D = root diameter

Root load estimates are summarized in Shriro (2014) as a series of general tables based on calculations using the above equations by Gray and Sotir. A tensile strength of 20 MPa (418 ksf) for

oak was selected based on Table 3-5 of Gray and Sotir (1996). Roots are highlighted in red and capped at their tensile strength if tension is limiting. Root capacity for an oak can be estimated given root diameter, length, and effective stress. Effective stress was averaged over the bonded portion of the root zone. For roots modeled in subsequent sections, the embedment was estimated from the crown as this was the primary bonded zone. For shorter roots, an approximated average embedment was considered to arrive at the appropriate effective overburden stress.

The destabilizing moment of the waterside tree due to the static loading associated with the lean angle is estimated at about 480 kip-ft based on a weight of 26,000 lbs and a wind speed of 17.5 mph. Based on Table G-1, the empirically derived critical turning moment based on Peterson (2012) is on the order of 960 kip-ft to 1,200 kip-ft. In this study, trees were pulled to failure with a winch under non-flood conditions. Under pre-flood conditions, it is estimated that the initial factor of safety against overturning was on the order of 2.

Based on tables of root load capacity with effective stress provided for various root lengths in Appendix 4A, an estimate of root strength loss can be made with pore water pressure rise. The tables assume a unit weight of soil of 120 pounds per cubic foot (pcf) and no groundwater. Effective stress is equal to the total stress minus the pore water pressure. Consider the effect of pore water pressure increase on effective stress and the subsequent effect on root bond stress and load capacity. If pore water pressures rise by two (2) feet of head, the effective stress is reduced by 125 psf. When pore water pressure rises by six (6) feet of head, the effective stress decreases by about 375 psf. A reduction in bond stress on the order of 40 percent is expected. The critical overturning moment measured empirically may be expected to be reduced by 40 percent based on pore water pressure accumulation, reducing the factor of safety against tree overturning to approximately 1.2.

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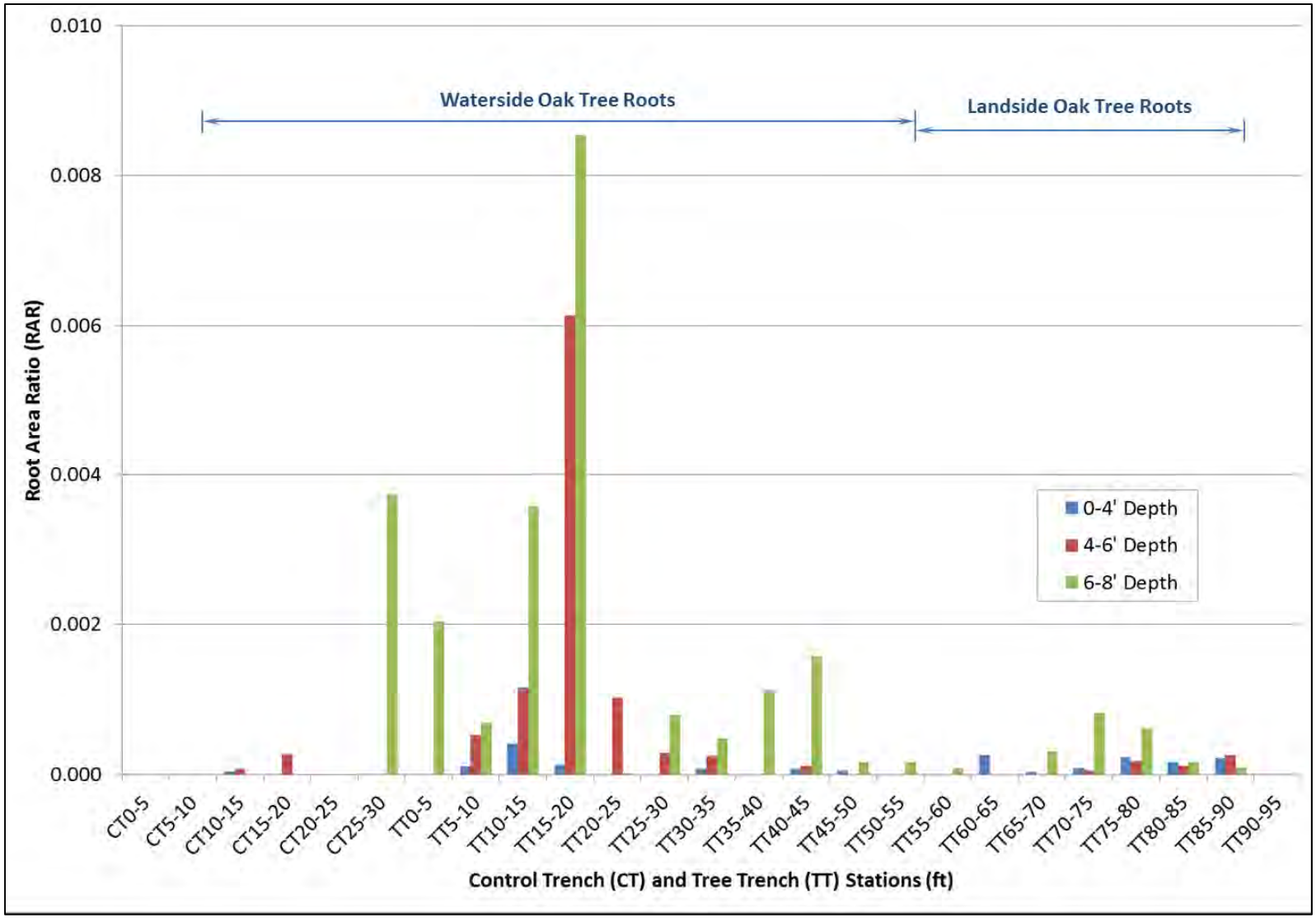

Figure G-7. Root area ratio along the length of the control and tree trenches. Ratios are broken out for three depth categories within each 5 foot segment of trench. The waterside oak root system spans from Station CT25 to TT55, while landside oak roots were encountered between Station TT60 and TT90.

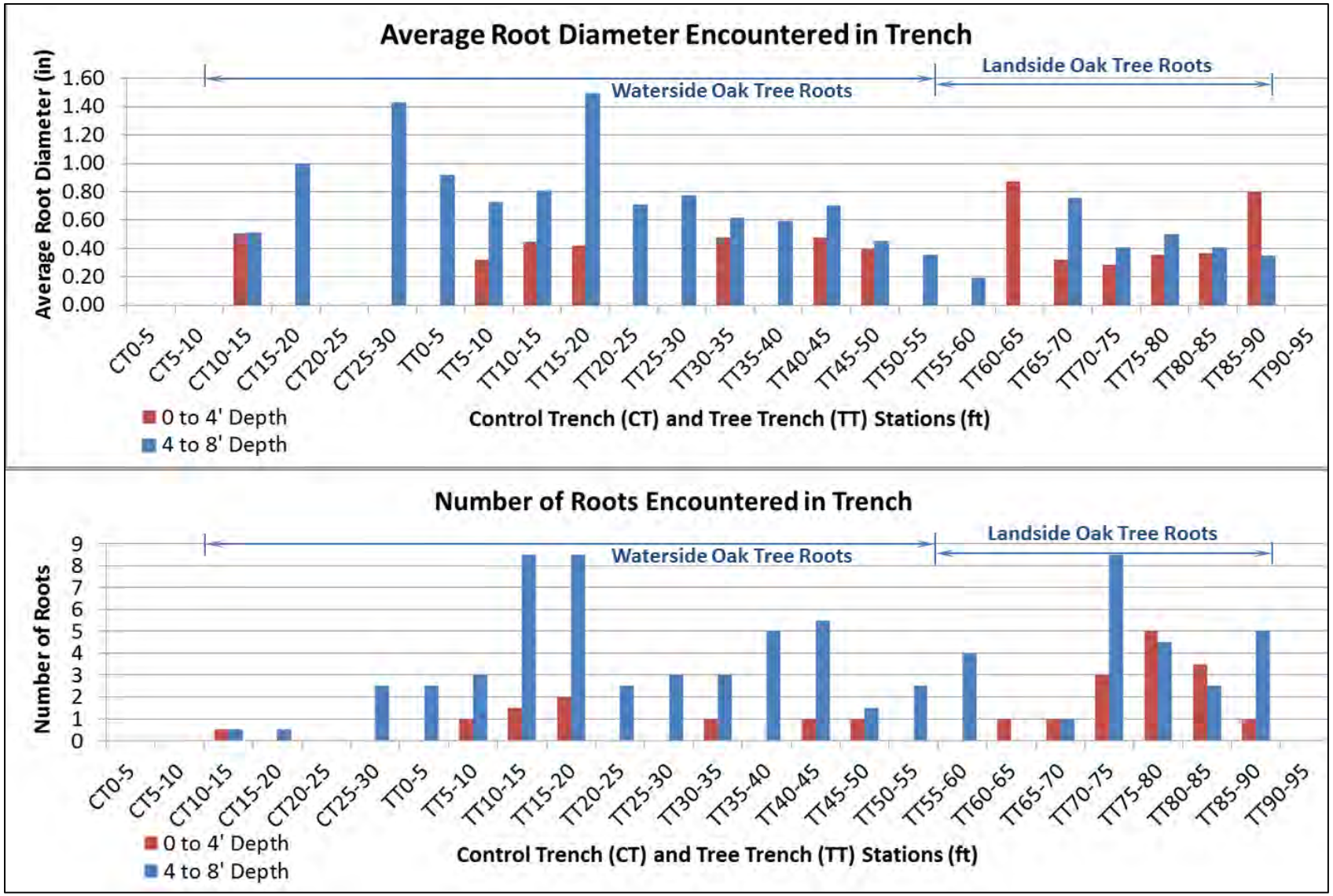

Figure G-8. Average root diameter and number of roots encountered along the walls of the control and tree trenches. Ratios are broken out for two depth categories within each 5 foot segment of trench. Results are averaged from waterside and landside walls.