# Erodibility of Bank Materials on the Lower American and Sacramento Rivers, adjacent to the City of Sacramento, California

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# Erodibility of Bank Materials on the Lower American and Sacramento Rivers, adjacent to the City of Sacramento, California

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# EXECUTIVE SUMMARY

The Water Resources Development Act (WRDA) of 2016 provides for engineering and design activities associated with implementing projects to reduce the flood risk on the Lower American and Sacramento Rivers near Sacramento, California. The integrity of levees that protect Sacramento could be adversely affected by bank erosion. The rate of bank erosion depends, among others, on the resistance-to-erosion properties and grain-size distribution of the bank soils. At the request of the U.S. Army Corps of Engineers, Sacramento District, the US Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, Mississippi characterized soil texture and conducted jet-erosion testing (JET) for resistance-to-erosion properties (critical shear stress and erodibility coefficient) of the bank material along the Lower American and Sacramento Rivers.

Ten study sites on the Lower American River and eight study sites on the Sacramento River were selected by the U.S. Army Corps of Engineers, Sacramento District. At these sites bank soil stratigraphy was characterized, and soil samples were collected for grain-size and bulk density analysis in the laboratory facilities of the National Sedimentation Laboratory. JETs were conducted using a mini-jet testing device on soils that were cohesive.

Based on the Unified Soil Classification System the bank soils at the study sites were classified as: poorly graded sand (SP), poorly graded sand with silt (SP-SM), silty sand (SM), and silt (ML). The median grain size ranged from 0.032 mm (0.00126 in) to 0.285 mm (0.0112 in) with an average value of 0.121 mm (0.00476 in). Dry bulk density varied between 0.95 g $cm^{-3}$ (59.3 lb $ft^{-3}$) and 1.39 g $cm^{-3}$ (86.8 lb $ft^{-3}$).

At higher applied shear stresses, that is for the mass erosion regime, measured critical shear stresses of the bank soils varied between 0.408 and 24.7 Pa (0.00852 and 0.516 lbf $ft^{-2}$). The corresponding erodibility coefficients varied between 0.835 and 27.2 cm $hr^{-1}$ $Pa^{-1}$ (1.31 and 42.7 $ft^{3}$ $lbf^{-1}$ $hr^{-1}$). These bank soils are therefore classified as erodible to very erodible.

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# List of Abbreviations and Units

| | |
|---|---|
| ARS | Agricultural Research Service |
| ASTM | American Society of Testing Materials |
| BSTEM | Bank Stability and Toe Erosion Model |
| $C_d$ | diffusion coefficient; dimensionless |
| $C_f$ | friction coefficient; dimensionless |
| CONCEPTS | CONservational Channel Evolution and Transport System |
| $d$ | nozzle diameter; m |
| $D$ | particle diameter; mm |
| $E$ | erosion rate; m $s^{-1}$ |
| GPS | Global Positioning System |
| $g$ | acceleration due to gravity; 9.81 m $s^{-2}$ |
| $H$ | pressure head at nozzle; m |
| HEC-RAS | Hydrologic Engineering Center River Analysis System |
| JET | Jet Erosion Test |
| $k_d$ | soil detachment coefficient; m $s^{-1}$ $Pa^{-1}$ |
| $L$ | distance between nozzle and scour hole bottom; m |
| LAR | Lower American River |
| MASL | Meters Above mean Sea Level |
| NRCS | Natural Resources Conservation Service |
| NGS | National Geodetic Survey |
| NSL | National Sedimentation Laboratory |
| OPUS | Online Position User Service |
| OSHA | Occupational Safety and Health Administration |
| RTK GPS | Real-Time Kinematic Global Positioning System |
| SAC | Sacramento River |
| SPK | U.S. Army Corps of Engineers, Sacramento District |
| SRH-2D | Sedimentation and River Hydraulics Two-Dimensional model |
| $t$ | time; s |
| TBM | Temporary BenchMark |
| $U_0$ | jet centerline velocity at the nozzle; m $s^{-1}$ |
| USACE | U.S. Army Corps of Engineers |
| USCS | Unified Soil Classification System |
| USDA | U.S. Department of Agriculture |
| WRDA | Water Resources Development Act |
| $\rho$ | density of water; kg $m^{-3}$ |
| $\tau$ | boundary (bed or bank) shear stress; Pa. |
| $\tau_c$ | critical shear stress; Pa |
| $\phi$ | Negative base 2 logarithm of particle diameter; dimensionless |

# Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| | **Length** | |
| millimeter (mm) | 0.03937 | inch (in) |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| | **Area** | |
| square meter ($m^2$) | 10.764 | square foot ($ft^2$) |
| square kilometer ($km^2$) | 0.3861 | square mile ($mi^2$) |
| | **Volume** | |
| cubic meter ($m^3$) | 35.31 | cubic foot ($ft^3$) |
| | **Flow** | |
| meter per second ($m\ s^{-1}$) | 3.281 | foot per second ($ft\ s^{-1}$) |
| cubic meter per second ($m^3\ s^{-1}$) | 35.31 | cubic foot per second ($ft^3\ s^{-1}$) |
| | **Erosion rate** | |
| meter per second ($m\ s^{-1}$) | 11,811 | foot per hour ($ft\ hr^{-1}$) |
| millimeter per minute ($mm\ min^{-1}$) | 0.1969 | foot per hour ($ft\ hr^{-1}$) |
| | **Mass** | |
| gram (g) | 0.03527 | ounce (oz) |
| kilogram (kg) | 2.205 | pound (lb) |
| tonne, metric | 1.102 | ton (short) |
| metric tonne per square kilometer per year (ton $km^{-1} yr^{-1}$) | 2.855 | ton (short) per square mile per year (ton $mi^{-2}\ yr^{-1}$) |
| | **Force per unit length** | |
| kilonewton per meter ($kN\ m^{-1}$) | 5.710 | pound-force per inch ($lbf\ in^{-1}$) |
| kilonewton per meter ($kN\ m^{-1}$) | 68.52 | pound-force per foot ($lbf\ ft^{-1}$) |
| | **Stress** | |
| pascal (Pa)<br>(= newton per square meter, N $m^{-2}$) | 0.02089 | pound-force per square foot ($lbf\ ft^{-2}$) |
| kilopascal (kPa) | 0.145 | pound-force per square inch ($lbf\ in^{-2}$) |
| kilopascal (kPa) | 20.89 | pound-force per square foot ($lbf\ ft^{-2}$) |
| | **Density** | |
| gram per cubic centimeter ($g\ cm^{-3}$) | 62.43 | pound per cubic foot ($lb\ ft^{-3}$) |
| | **Unit weight** | |
| kilonewton per cubic meter ($kN\ m^{-3}$) | 6.366 | pound-force per cubic foot ($lbf\ ft^{-3}$) |
| | **Erodibility** | |
| cubic centimeter per newton second ($cm^3\ N^{-1}\ s^{-1}$) | 0.5655 | cubic foot per pound-force hour ($ft^3\ lbf^{-1}\ hr^{-1}$) |
| centimeter per pascal hour ($cm\ Pa^{-1}\ hr^{-1}$) | 1.571 | cubic foot per pound-force hour ($ft^3\ lbf^{-1}\ hr^{-1}$) |
| meter per pascal second ($m\ Pa^{-1}\ s^{-1}$) | 157.1 | cubic foot per pound-force second ($ft^3\ lbf^{-1}\ s^{-1}$) |

# INTRODUCTION

## Problem statement

The Lower American River (LAR) below Folsom Dam consists of approximately 30 miles of alluvial channel that meanders through Sacramento and other communities in northern California. Bank erosion has been a documented concern through 11 miles of this reach due to the proximity of the fluvial system to the engineered levees and the high population densities that live on the landside of the levees. There are also about 25 miles of levees (river left) along the Sacramento River (SAC) that could be adversely affected by bank erosion. The Water Resources Development Act (WRDA) of 2016 provides for engineering and design activities associated with implementing projects to reduce the flood risk on the LAR and the SAC (USACE, 2016). Quantification of bank erosion extent and erosion potential on the LAR and SAC is an important task, both to ensure that the designed bank protection is adequate and for prioritizing the bank protection work. Isolating areas prone to erosion will ensure that areas of higher risk for bank erosion are addressed first.

Bank erosion occurs as a result of the interaction of two processes, hydraulic and geotechnical (Langendoen & Simon, 2008). The hydraulic process involves the ability of the applied erosive forces from the water to erode the bank material, or fluvial erosion. This requires knowing hydraulic properties such as water depth, energy slope, and the hydraulic radius and bank material properties, such as soil composition (layers and type), the critical shear stress, and erodibility coefficient. The geotechnical process requires insight into the strength of the soil to resist mass instabilities, or mass wasting. This requires knowing groundwater elevations and bank material properties, such as effective cohesion, friction angle, pore water pressure, soil gradations, water content, and bulk density. Of these parameters, knowledge of the soil composition (layers and type) and bank erosion resistance properties (critical shear stress and the erodibility coefficient) have been determined to be the most important parameters in estimating long term bank erosion risk on the LAR and SAC.

The United States Army Corps of Engineers (USACE) has requested the United States Department of Agriculture (USDA), Agriculture Research Service (ARS), National Sedimentation Laboratory (NSL), Oxford, Mississippi to characterize the resistance-to-fluvial-erosion properties of LAR and SAC bank soils to better evaluate the range of these parameters and the associated uncertainty in their measurements.

## Objective

This study's objective is to determine:

1. Bank geometry and soil stratigraphy at up to 10 sites (20 total) on both the Lower American and Sacramento Rivers.
2. The resistance-to-fluvial-erosion of the soils located on these sites using jet-erosion-test (JET) technology developed by ARS.

These data will be used to derive probability density functions of erosion-resistance properties by USACE for input into the BSTEM Dynamic v3 stochastic bank erosion model.

## Study area

The geographic scope of the reported work is a 10-mi long reach on the American River and a 15-mi long reach on the Sacramento River adjacent to the City of Sacramento, California (Figure 1). The U.S. Army Corps of Engineers, Sacramento District (SPK), selected 10 study sites on the Lower American River (LAR1, LAR2, LAR3, LAR4, LAR5, LAR7, LAR8, LAR9, LAR10, and LAR11) and 8 study sites on the Sacramento River (SAC1, SAC3, SAC5, SAC6, SAC7, SAC8, SAC9, and SAC10). At each site the goal was to: (1) survey the bank profile; (2) identify the bank soil stratigraphy; and (3) measure the bank-soil properties resistance-to-fluvial-erosion, bulk density, and grain-size distribution. Note, abundant vegetation, bank protection measures, or steep banks prevented the measurement of bank-soil properties at several sites. In addition to the above-mentioned study sites, bank-material samples were collected at site SAC55 for grain-size and soil density analysis only.

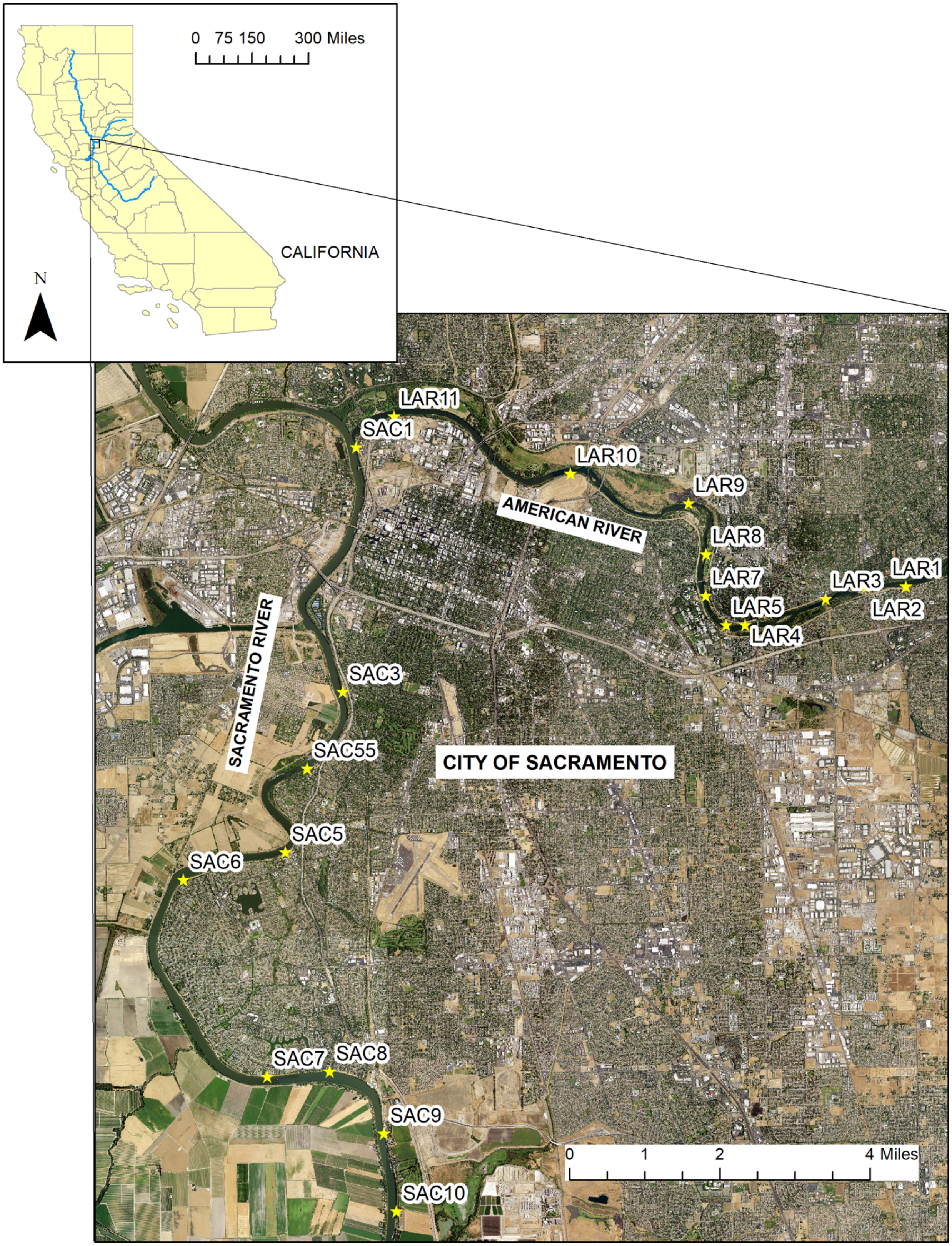

FIGURE 1 – STUDY SITES ON THE AMERICAN AND SACRAMENTO RIVERS, CALIFORNIA.

# METHODS AND MATERIALS

## Overview

Erosion of fine-grained (cohesive) bank materials is a combination of scour by the flowing water and bank collapse. Fluvial erosion of fine-grained materials is controlled by the hydraulic shear acting on the bank soils and the erodibility of these soils. The soil erodibility itself depends on various soil chemical, hydrologic, and physical properties. The bank soil erodibility in this study was determined using Jet Erosion Test (JET) methodology. In addition to bank soil erodibility measurements, bank soil samples were collected to determine soil texture (grain size distribution) and dry density. Bank collapse occurs when gravitational forces (weight of the bank soils) exceed the shear strength of the bank soils. The weight of a potential failure block is, among others, controlled by the bank profile. At each study site, the bank profile was surveyed using a combination of real-time kinematic global positioning system (RTK GPS) and total station survey methods. The following sections describe the measurement and data collection methods.

## Soil erodibility

The detachment of particles (that is, grains and aggregates of different sizes) from cohesive bank materials is extremely complex because of electro-chemical bonds between such particles. Ariathurai & Arulanandan (1978) showed that the rate of erosion, $E$, of cohesive materials can be predicted by an excess shear stress equation:

$$E = \begin{cases} k_d(\tau - \tau_c) & \tau > \tau_c \\ 0 & \tau \le \tau_c \end{cases} \tag{1}$$

where $E$ is erosion rate (m s$^{-1}$ or ft hr$^{-1}$), $\tau$ is boundary shear stress exerted by flowing water (Pa or lbf ft$^{-2}$), $\tau_c$ is critical shear stress (Pa or lbf ft$^{-2}$), and $k_d$ is soil detachment coefficient (m s$^{-1}$ Pa$^{-1}$ or ft$^3$ lbf$^{-1}$ hr$^{-1}$) representing the volume of material eroded per unit force and per unit time.

The bank erosion modules of the ARS CONservational Channel Evolution and Pollutant Transport System (CONCEPTS; Langendoen & Alonso, 2008; Langendoen & Simon, 2008) and Bank Stability and Toe Erosion Model (BSTEM; Simon, Pollen-Bankhead, & Thomas, 2011) use Eq. (1) to calculate the rate of fluvial erosion. These modules are also used by river morphologic models such as RVR Meander (Motta, Abad, Langendoen, & Garcia, 2012), HEC-RAS v5 (Brunner, 2016), and SRH-2D (Lai, et al., 2015).

Eq. (1) requires the soil parameters critical shear stress and detachment coefficient as input. ARS has developed a submerged jet erosion test device for testing the *in situ* erodibility of surface materials in the laboratory and in the field (Hanson G. , 1990).

## Jet erosion test (JET)

The JETs were performed in situ using a mini jet-test device (Figure 2). The mini-jet apparatus consists of an electric submersible 1050 GPH pump powered by a portable A/C generator that provides a head of water ($H$) measured by a pressure gage, a scaled-down 0.15 m-diameter submergence tank with an integrated, rotatable 3.18 mm-diameter nozzle and depth gauge, and delivery hoses. A sample is centered under the nozzle, where the jet originates, and submerged within the cylindrical tank. The initial height of the nozzle above the sample is noted and can be adjusted prior to initiating a test. Changes in maximum scour are measured using a point gauge at specific time increments and an asymptotic regression fitted to the erosion curve to calculate an initial point of entrainment, or material critical shear stress. The head and the initial height of the nozzle above the sample determine the applied shear stress during the test.

The device and procedure have been developed based on knowledge of the hydraulic characteristics of a submerged jet and the corresponding scour produced by the jet. The maximum shear stress acting on the sample surface for a given distance to the nozzle ($L$) is:

$$\tau = \rho C_f \left(\frac{C_d U_0 d}{L}\right)^2 \tag{2}$$

where $\rho$ is fluid density (kg m$^{-3}$), $C_f$ is friction coefficient, $C_d$ is diffusion coefficient, $U_0$ is jet centerline velocity at the nozzle (m s$^{-1}$), and $d$ is nozzle diameter (m). The coefficients $C_f = 0.00416$ and $C_d = 6.3$ were experimentally determined (Hanson, Robinson, & Temple, 1990). The velocity $U_0 = \sqrt{2gH}$, where $g$ is gravitational acceleration (m s$^{-2}$) and $H$ is pressure head (m) at the nozzle. The nozzle diameter of the JET test device used was 3.18 mm.

Fitting the measured scour depth evolution to the logarithmic-hyperbolic method to determine equilibrium (final) scour depth described in Hanson & Cook (2004) establishes $\tau_c$. The soil detachment coefficient $k_d$ is then determined by curve fitting measured values of scour depth versus time to the parametrized scour depth function. This procedure to determine $\tau_c$ and $k_d$ is known as the Blaisdell method. Two additional methods were used to determine $\tau_c$ and $k_d$: Iterative method and Linear regression method. The Iterative method initially uses the Blaisdell method to estimate $\tau_c$ and $k_d$, but then iteratively updates $\tau_c$ and $k_d$ to minimize the error of the parametrized scour depth function (Simon, Thomas, & Klimetz, 2010). The Linear regression method fits a linear trendline through the measured pairs of ($\tau$,$E$) points, where $E = \Delta L/\Delta t$ with $\Delta L$ the increase in scour depth over a time increment $\Delta t$.

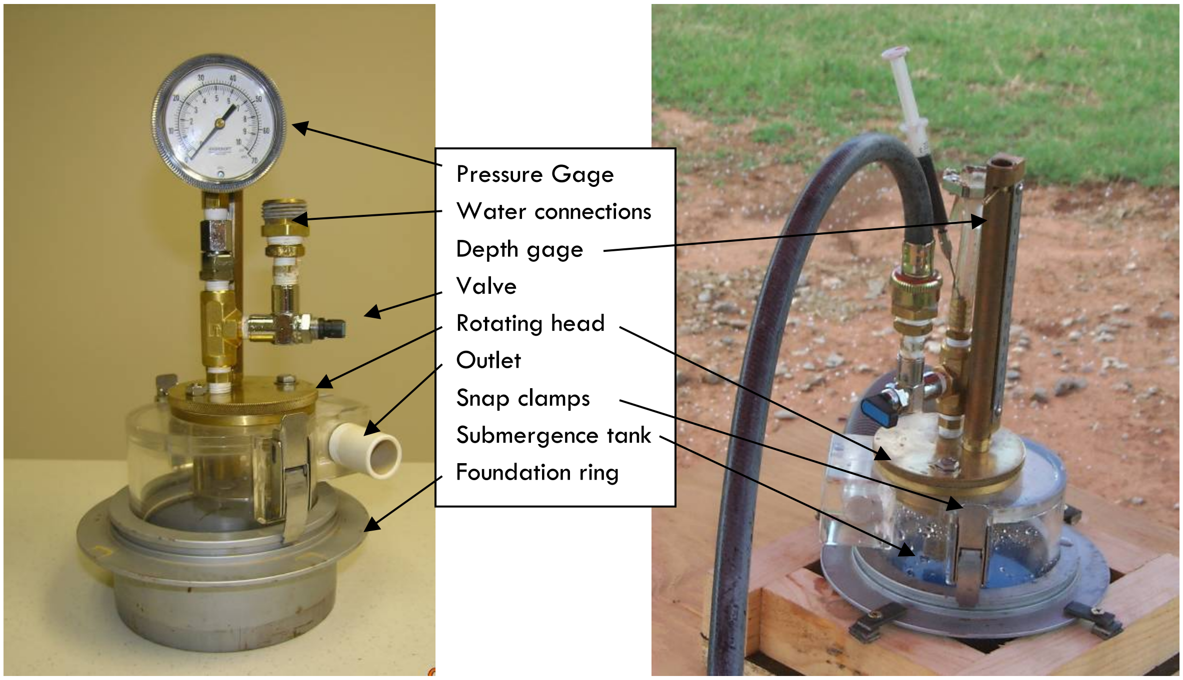

FIGURE 2 – PHOTOGRAPHS OF MINI-JET DEVICE USED TO MEASURE SOIL ERODIBILITY.

## Soil grain size distribution, bulk density, and type

The procedure for grain size analysis at NSL combines American Society of Testing Materials (ASTM) Standard D6913 (ASTM, 2017c) for coarse materials (> 2 mm) and USDA, NRCS Soil Survey Method 3A1a1 (Soil Survey Staff, 2014) for fine materials (< 2 mm). Sediment samples for particle size distributions were oven dried at 105 °C for 24 hrs. The total mass of the sample was then passed through a 2 mm sieve to remove gravels from the sand and finer fractions. The gravel sample mass was sieved separately with sieves at half-$\phi$ scale, that is with sizes (in mm): 64, 45.3, 32, 22.6, 16, 11.3, 8, 5.66, 4, 2.83, and 2. Sample mass finer than 2 mm was subsampled to a target mass of 10 g, dispersed, and wet sieved through a 0.063 mm sieve to separate sands from silts and clays. The sand fraction was dried, disaggregated with mortar and pestle, and sieved using sieve sizes (in mm): 1.41, 0.5, 0.354, 0.25, 0.178, 0.125, 0.088, and 0.063. The pan remains (< 0.063 mm) were combined with the fines from wet sieving, pipetted to determine size breaks for fine silt (< 0.025 mm), coarse silt (> 0.025 mm), and clay (< 0.002 mm). Bulk density samples were collected in aluminum rings pressed normal to the surface, excavated, cleaned, weighed, oven dried at 105 °C for 24 hrs, then reweighed. Unified Soil Classification System (USCS) soil types were determined according to ASTM Standard D2487 (ASTM, 2017a) by using MATLAB code 'Soil Classification Based on Unified Soil Classification System' (Dedement, 2020). USCS classification results from the MATLAB code were spot checked for accuracy. Atterberg Limits were determined only for samples with greater than 50% silt and clay (< 0.063 mm) according to ASTM Standard D4318 (ASTM, 2017b) utilizing the dry preparation method.

## Bank profile geometry

Surveys were conducted with a Topcon GR3 survey grade RTK GPS and/or a Topcon GPT 7500 total station. Methodology for surveying efforts were site specific due to tree cover, RTK interference, and the presence or lack thereof previously established control pins. Surveys were georeferenced or corrected through GPS static sessions since pin coordinates for previously established control points were mostly unavailable. Static sessions are used to determine a corrected base location utilizing the Online Position User Service (OPUS) by the National Geodetic Survey (NGS). Accuracy of the static session is determined by the length of time data is collected and the amount of data that is used to determine the OPUS solution. Each static session conducted for surveying efforts was collected for a minimum of 30 minutes. Ideally, static sessions would have been collected for at least two hours but given time constraints and difficulties encountered in the field, 30-minute static sessions were deemed most prudent. Two pins (0.5 inch x 2 ft rebar) or temporary benchmarks (TBMs) were placed and surveyed at each site. Coordinate accuracy of surveys could possibly be improved beyond OPUS solutions with better TBM coordinates determined by other survey methods. If previously established control points were found at a location, and were in the line of sight of the cross section, then the control point was used in lieu of the placement of a TBM. OSHA approved rebar covers were put on all pins placed by the NSL.

Upon site arrival, a TBM was hammered into the ground at a location where line of sight to the required cross section profile was available and where minimum tree cover was present. The RTK GPS base station was then aligned over the TBM with the instrument height determined from the top of the rebar to the Antenna Reference Point. A static session was then initiated for the base location. Once the base location was collecting data, efforts were made to test for RTK interference. If no interference was present, the complete survey was conducted with the RTK GPS only. The second TBM was surveyed at these locations and corrected coordinates determined from the one static session. Sites where no interference existed and the complete survey was conducted using RTK GPS were as follows: LAR5, LAR8, LAR9, LAR10, LAR11, SAC3, SAC5, SAC6, SAC7, SAC8, and SAC10. If RTK interference was present at a given site, then a total station survey was required to determine bank profiles. Total station surveys were collected in an arbitrary coordinate system and later transformed to the reference coordinate system based on static sessions collected over each TBM. Site locations where RTK interference existed and total station surveys were required were as follows: LAR1, LAR2, LAR3, LAR4, LAR7, and SAC1. A total station survey was also conducted at SAC9 but two static sessions were not collected at this site. A pin was found at SAC9 that was thought to correspond to a benchmark established by the City of Sacramento and was used in lieu of a second TBM static session. It was later determined that the pin was not in the Sacramento database and efforts were made in post processing to generalize the direction of this cross section. Vertical control at SAC9 was established using the OPUS solution for the one TBM placed at this site. All survey post processing was conducted with the Topcon software Magnet Tools.

# MEASURED DATA

## Overview

This section presents the results by study site of the surveying, soil sampling, and JET test analysis on select stream banks of the Lower American and Sacramento Rivers at the City of Sacramento, California. Tables summarizing the measured data are found in appendix 'Appendix 1 Data Tables.' At each study site notes were taken describing the bank conditions and bank profile. Appendix 'Appendix 2 Notes' presents scanned copies of the notes. Appendix 'Appendix 3 Jet Erosion Test data sheets' presents scanned copies of the JET data sheets.

## Study site LAR1

Study site LAR1 is located at latitude 38.57° N and longitude 121.37° W, on the left bank of the American River (Figure 3). Notes describing the study site are found on page 80. Figure 4 shows photos of the bank face and upstream and downstream views. Two JETs were conducted at this site on a relatively flat area about 2.5 meters above the water line. Soil samples were collected at the JET location after completion of the JETs for grain-size and bulk density analyses.

The surveyed bank profile is shown in Figure 5. Bank stratigraphy comprises two soils. The bottom soil consists of a sandy gravel (Figure 6B), which is overlain by a sandy soil (Figure 6A). The bank soil transition is located at about 7.8 meter above mean sea level (MASL). Table 1 lists the grain-size distribution of the sandy soil sample. The texture of the soil is 7.79% clay, 10.9% silt, and 81.3% sand, and has a USCS classification of SM (silty sand). The measured dry density and saturated unit weight of the sandy soil are 1.06 g cm$^{-3}$ and 16.3 kN m$^{-3}$, respectively.

The two JETs were conducted at a pressure head of 0.39 m and 0.25 m, which resulted in maximum initial applied shear stresses of 16.3 Pa and 9.8 Pa, respectively. Table 2 lists the measured erosion rate and shear stress time series during the two tests. Figure 7 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 3 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

**TABLE 1 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR1 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 7.79 | 12.6 | 18.7 | 42.3 | 88.0 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

## Study site LAR2

Study site LAR2 is located at latitude 38.57° N and longitude 121.38° W, on the right bank of the American River (Figure 8). Notes describing the study site are found on page 81. Figure 9 shows photos of the bank face and upstream and downstream views. One JET was conducted at this site on a relatively flat area about 2.3 meters above the water line. Soil samples were collected at the JET location after completion of the JET for grain-size and bulk density analyses.

The surveyed bank profile is shown in Figure 10. Bank stratigraphy comprises two soils. The bottom soil consists of a sandy gravel (Figure 11B), which is overlain by a sandy soil (Figure 6A). The bank soil transition is located at about 8.3 MASL. Table 4 lists the grain-size distribution of the sandy soil sample. The texture of the soil is 9.54% clay, 13.3% silt, and 77.2% sand, and has a USCS classification of SM (silty sand). The measured dry density and saturated unit weight of the sandy soil are 1.18 g cm$^{-3}$ and 17.1 kN m$^{-3}$, respectively.

The JET was conducted at a pressure head of 0.35 m, which resulted in a maximum initial applied shear stress of 10.3 Pa. Table 5 lists the measured erosion rate and shear stress time series during the test. Figure 12 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 6 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

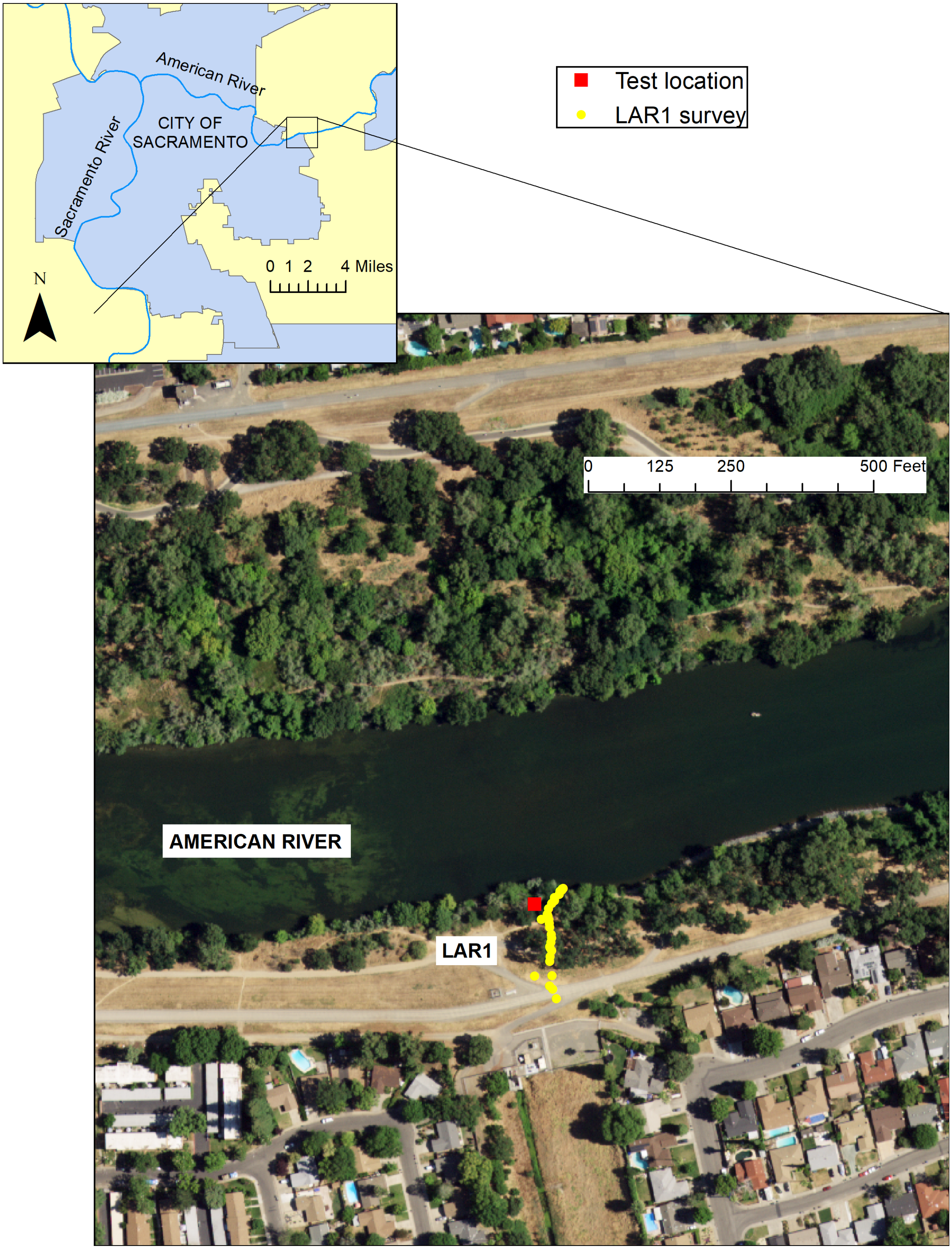

FIGURE 3 – MAP OF STUDY SITE LAR1 ON THE AMERICAN RIVER.

FIGURE 4 – PHOTOS OF STUDY SITE LAR1 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

## Study site LAR3

Study site LAR3 is located at latitude 38.57° N and longitude 121.39° W, on the right bank of the American River (Figure 13). Notes describing the study site are found on page 82. Figure 14 shows photos of the bank face and upstream and downstream views. Figure 14C shows the presence of toe protection consisting of cobbles at this site. JETs could not be carried out at this site because of the steepness of the bank and the bank material comprised of cobbly sand (Figure 14A). The bank material was too loose to collect a soil sample for bulk density analysis. A soil sample for grain-size analysis was collected from the upper bank face.

The surveyed bank profile is shown in Figure 15. As far as could be observed visually, bank stratigraphy comprises a single soil, which is a mixture of sand and cobbles. Cobble density is approximately 15 cobbles per square meter. Table 7 lists the largest and smallest diameters of 10 randomly selected cobbles. Table 8 lists the grain-size distribution of the sandy soil sample. The texture of the soil is 10.3% clay, 30.2% silt, and 59.5% sand, and has a USCS classification of SM (silty sand).

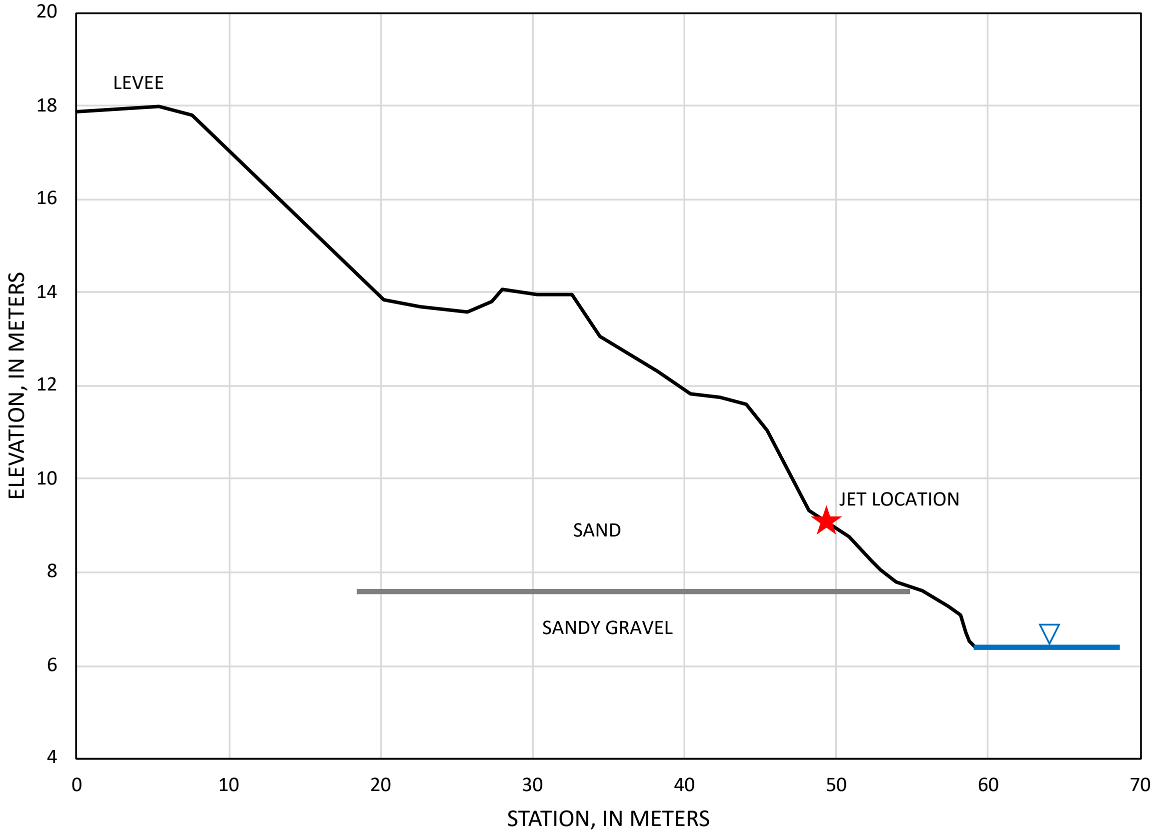

FIGURE 5 – SURVEYED BANK PROFILE OF STUDY SITE LAR1 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JET, WATER SURFACE, AND BANK STRATIGRAPHY.

TABLE 2 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT AT STUDY SITE LAR1 ON THE AMERICAN RIVER.

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 4.0 | 16.3 | 8.0 |
| | 1 | 5.0 | 14.2 | 0.67 |
| | 2 | 5.0 | 12.3 | 0 |
| | 4 | 8.0 | 11.4 | 0.4 |
| | 6 | 8.5 | 10.4 | 0.037 |
| | 10 | 9.0 | 10.2 | 0.0213 |
| **2** | 0 | 0 | - | - |
| | 0.5 | 7.0 | 9.8 | 14.0 |
| | 1 | 12.0 | 7.3 | 10.0 |
| | 1.5 | 16.0 | 5.1 | 8.0 |
| | 2 | 17.0 | 4.6 | 2.0 |
| | 3 | 17.0 | 4.6 | 0.0 |
| | 5 | 26.0 | 3.85 | 4.5 |
| | 7 | 28.0 | 3.2 | 1.0 |
| | 10 | 32.0 | 2.9 | 1.33 |

**FIGURE 6 – PHOTOS OF BANK SOILS AT STUDY SITE LAR1 ON THE AMERICAN RIVER: (A) SANDY SOIL AT JET LOCATION AND (B) SANDY GRAVEL AT BANK TOE.**

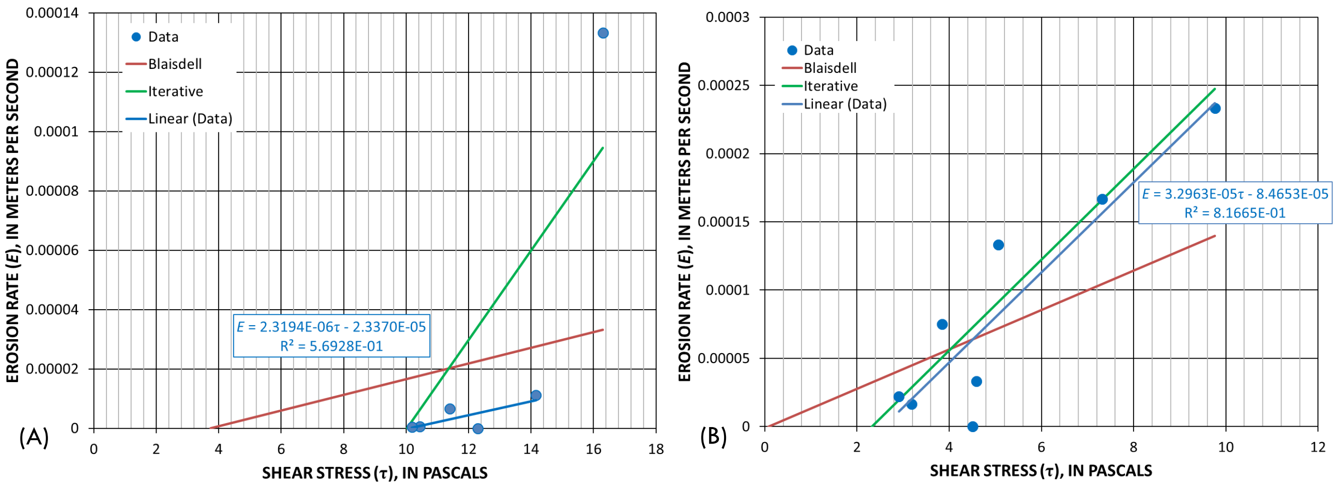

**FIGURE 7 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR1 ON THE AMERICAN RIVER: (A) TEST ONE AND (B) TEST TWO. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

**TABLE 3 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR1 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.**

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 3.74 | 10.0 | 10.1 | 0.951 | 5.42 | 0.835 |
| **2** | 0.075 | 2.33 | 2.57 | 5.19 | 12.0 | 11.9 |

**TABLE 4 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR2 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 9.54 | 16.7 | 22.8 | 40.7 | 81.6 | 98.6 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 |

**TABLE 5 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JET CARRIED OUT AT STUDY SITE LAR2 ON THE AMERICAN RIVER.**

| **Test** | **Time (min)** | **Scour depth (mm)** | **Shear stress (Pa)** | **Erosion rate (mm min$^{-1}$)** |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 18.0 | 10.3 | 36.0 |
| | 1 | 20.5 | 6.81 | 5.0 |
| | 2 | 25.0 | 4.20 | 4.5 |
| | 3 | 26.5 | 3.82 | 1.5 |
| | 5 | 36.0 | 3.27 | 4.75 |
| | 7 | 38.0 | 2.78 | 1.0 |
| | 12 | 45.0 | 2.49 | 1.4 |

**TABLE 6 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR2 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.**

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 0.139 | 2.05 | 2.05 | 7.42 | 18.0 | 8.73 |

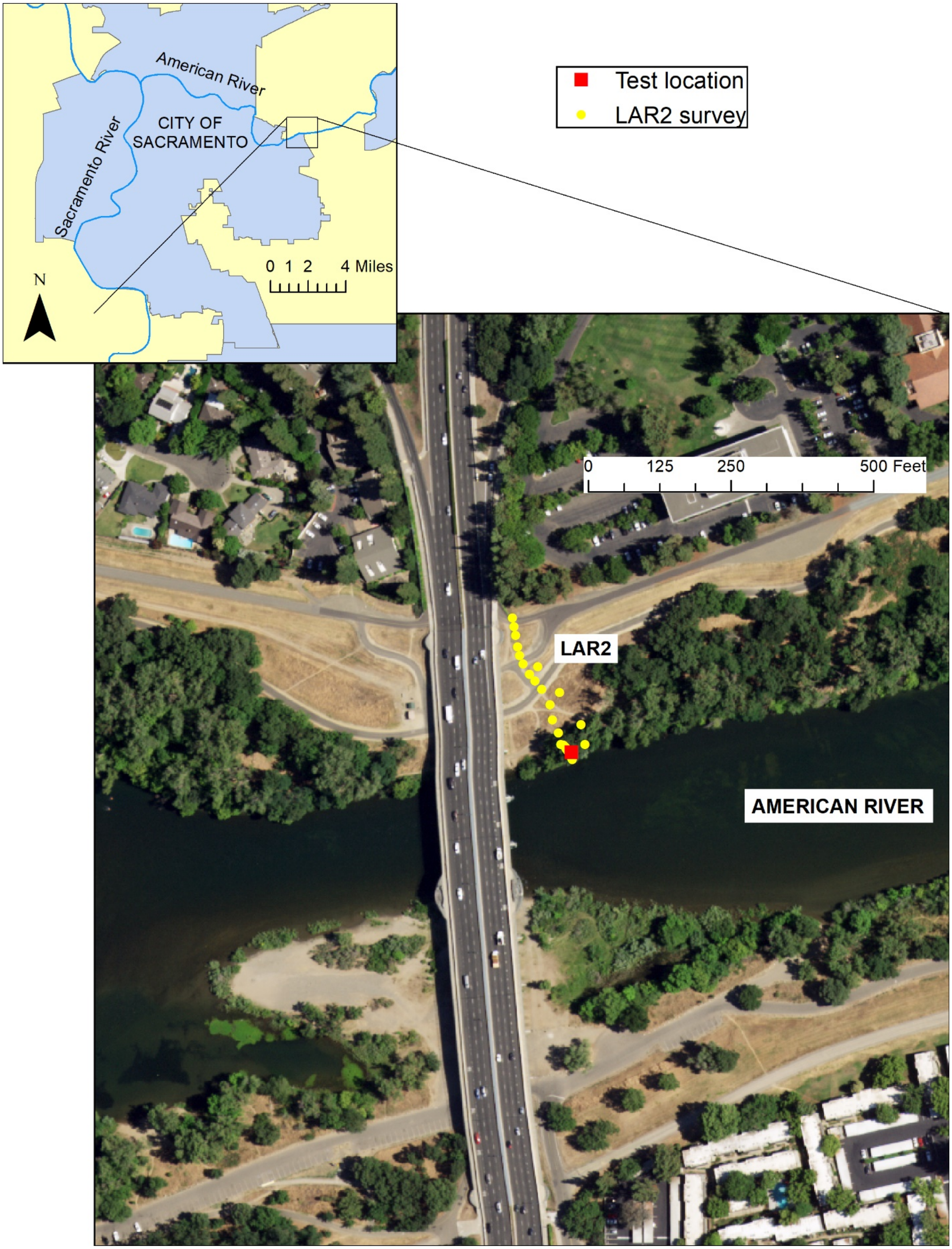

FIGURE 8 – MAP OF STUDY SITE LAR2 ON THE AMERICAN RIVER.

FIGURE 9 – PHOTOS OF STUDY SITE LAR2 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

TABLE 7 – MEASURED DIAMETERS OF TEN RANDOMLY SELECTED COBBLES FROM THE BANK FACE AT STUDY SITE LAR3 ON THE AMERICAN RIVER.

| Cobble | Smallest diameter (cm) | Largest diameter (cm) |
|---|---|---|
| **1** | 7 | 16 |
| **2** | 7 | 15 |
| **3** | 10 | 18 |
| **4** | 6 | 20 |
| **5** | 10 | 18 |
| **6** | 4.5 | 12 |
| **7** | 9 | 22 |
| **8** | 11 | 21 |
| **9** | 4 | 11 |
| **10** | 12 | 25 |

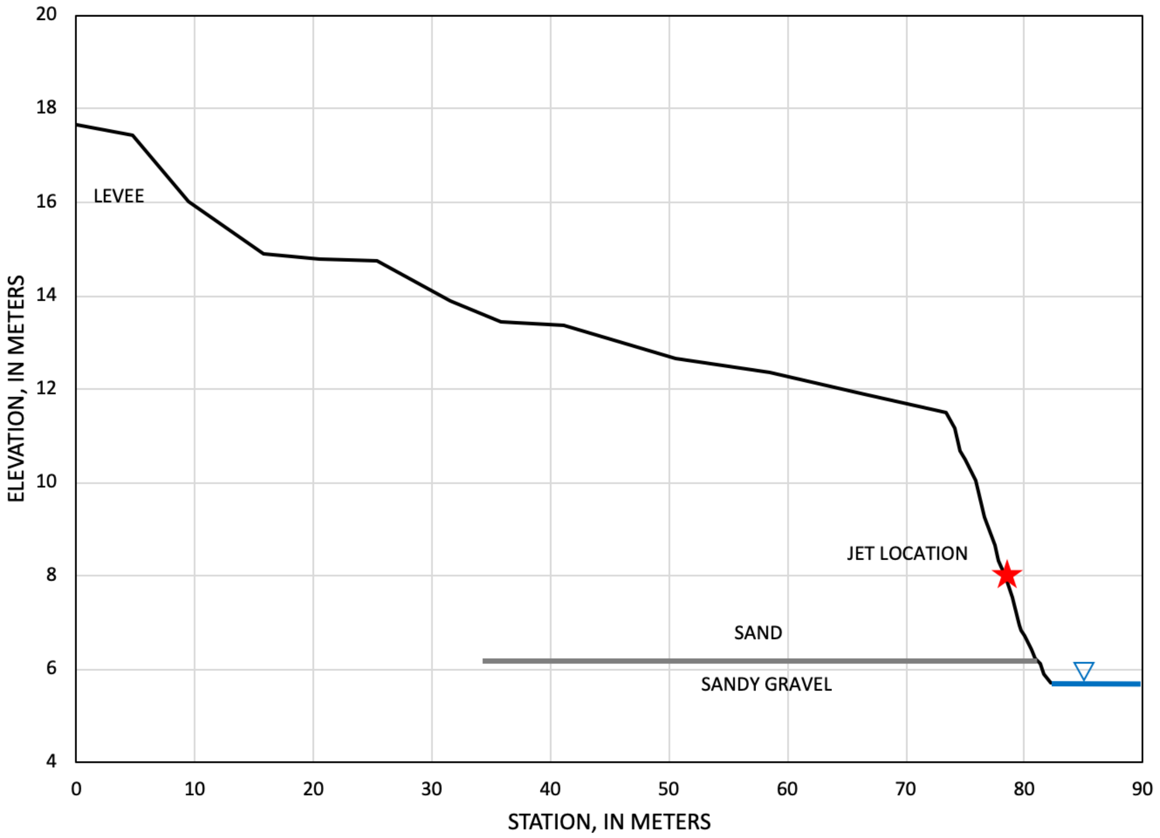

**FIGURE 10 – SURVEYED BANK PROFILE OF STUDY SITE LAR2 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JET, WATER SURFACE, AND BANK STRATIGRAPHY.**

## Study site LAR4

Study site LAR4 is located at latitude 38.56° N and longitude 121.41° W, on the right bank of the American River (Figure 16). Notes describing the study site are found on page 83. Figure 17 shows photos of the bank face and upstream and downstream views. At this site one JET was conducted on a relatively flat area about 2.3 meters above the water line. Soil samples were collected at the JET location after completion of the JET for grain-size and bulk density analyses.

The surveyed bank profile is shown in Figure 18. The bank material comprises a single soil (Figure 17B). Table 9 lists the grain-size distribution of the sandy soil sample. The texture of the soil is 8.8% clay, 14.2% silt, and 77.0% sand, and has a USCS classification of SM (silty sand). On opening of the bulk density sample, the soil fell apart preventing an accurate measurement of dry density and saturated unit weight (0.76 g $cm^{-3}$ and 14.5 kN $m^{-3}$, respectively).

The JET was conducted at a pressure head of 0.35 m, which resulted in a maximum initial applied shear stress of 12.1 Pa. Table 10 lists the measured erosion rate and shear stress time series during the test. Figure 19 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 11 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

**FIGURE 11 – PHOTOS OF BANK SOILS AT STUDY SITE LAR2 ON THE AMERICAN RIVER: (A) SANDY SOIL AT JET LOCATION AND (B) SANDY GRAVEL AT BANK TOE.**

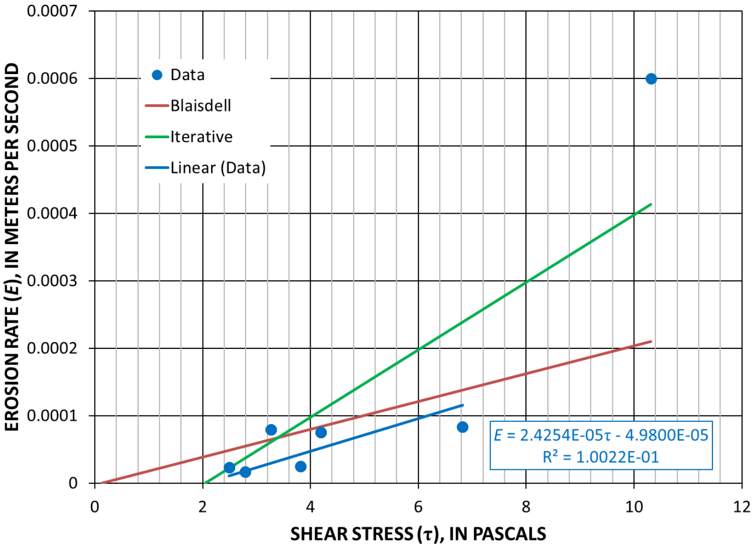

**FIGURE 12 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR2 ON THE AMERICAN RIVER. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPH.**

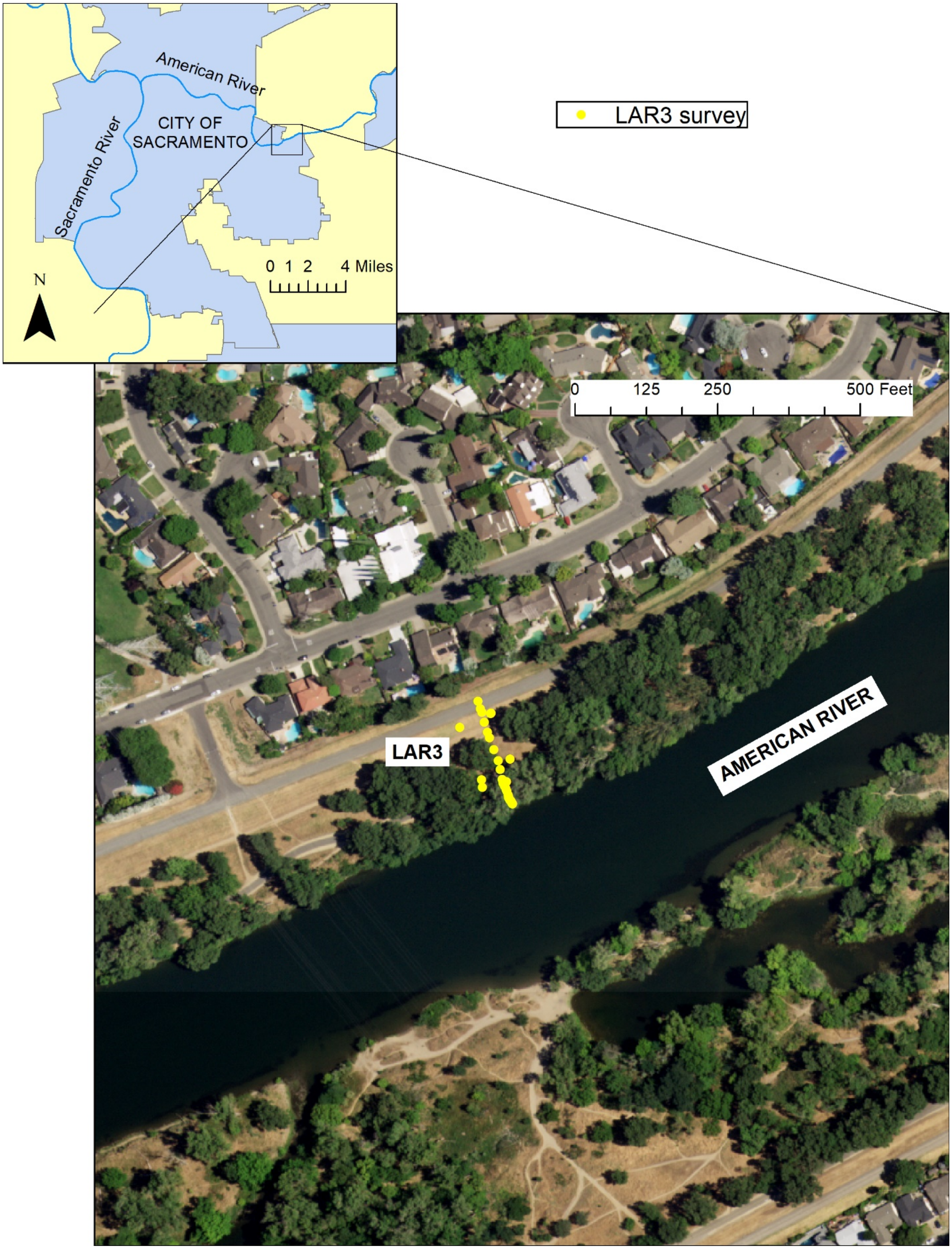

FIGURE 13 – MAP OF STUDY SITE LAR3 ON THE AMERICAN RIVER.

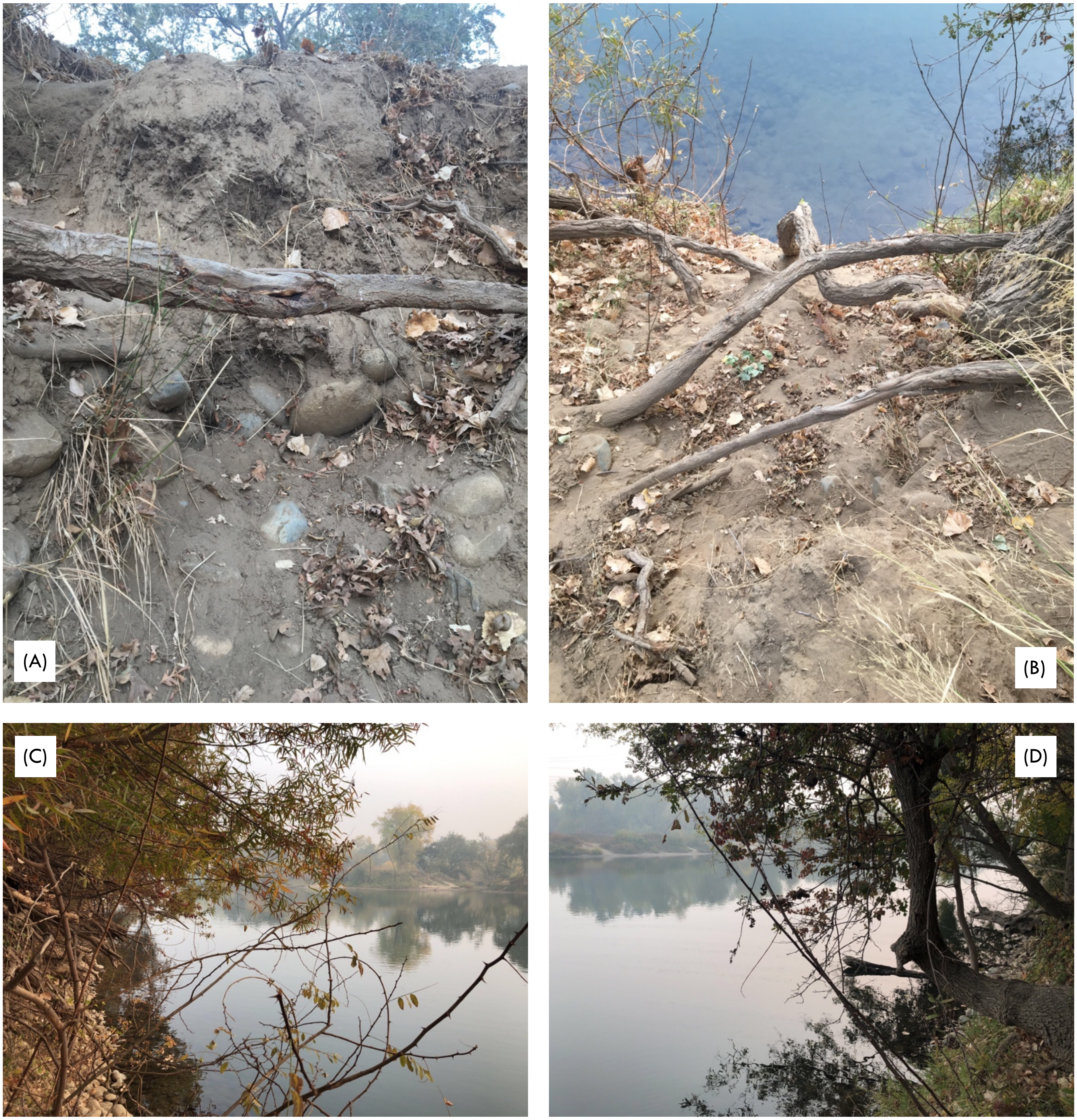

**FIGURE 14 – PHOTOS OF STUDY SITE LAR3 ON THE AMERICAN RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) TOP VIEW OF BANK SURFACE, (C) VIEW UPSTREAM, AND (D) VIEW DOWNSTREAM.**

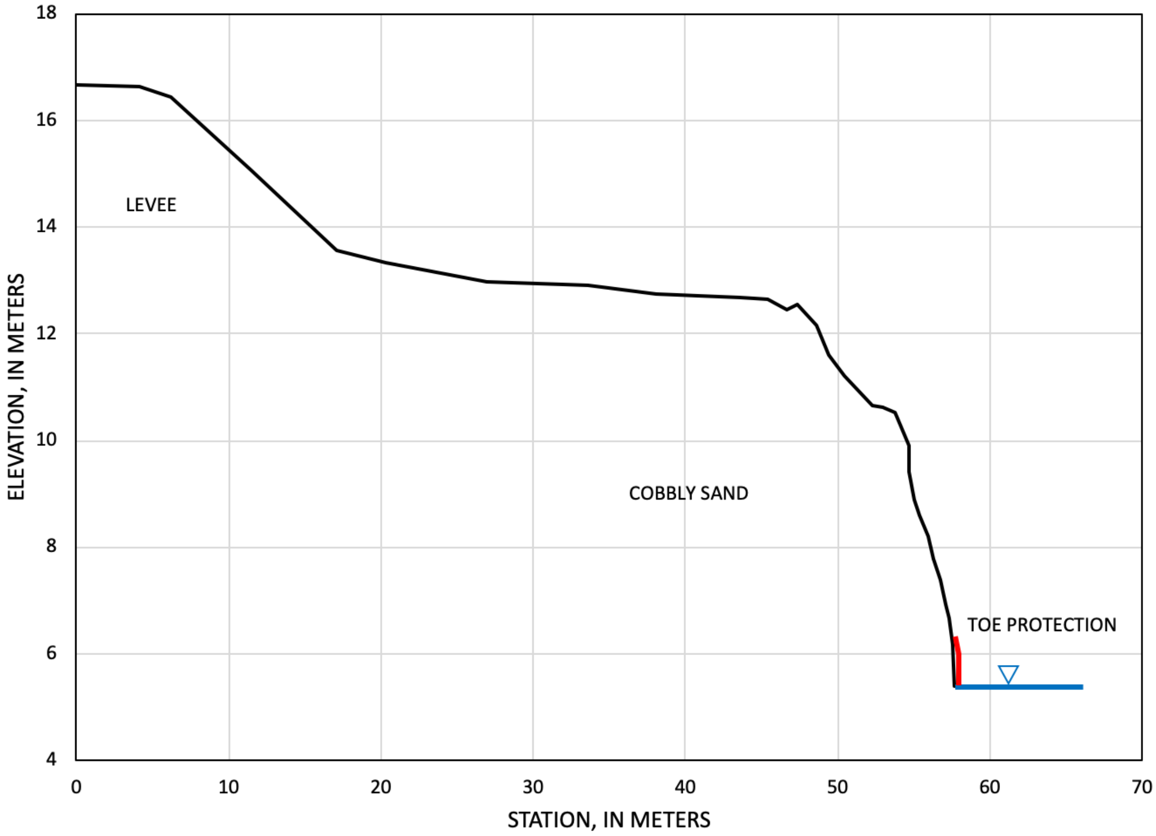

**FIGURE 15 – SURVEYED BANK PROFILE OF STUDY SITE LAR3 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF TOE PROTECTION, WATER SURFACE, AND BANK MATERIAL.**

**TABLE 8 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR3 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 10.3 | 23.9 | 40.5 | 72.0 | 96.1 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**TABLE 9 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR4 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 8.80 | 15.2 | 23.0 | 47.4 | 86.9 | 99.1 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 |

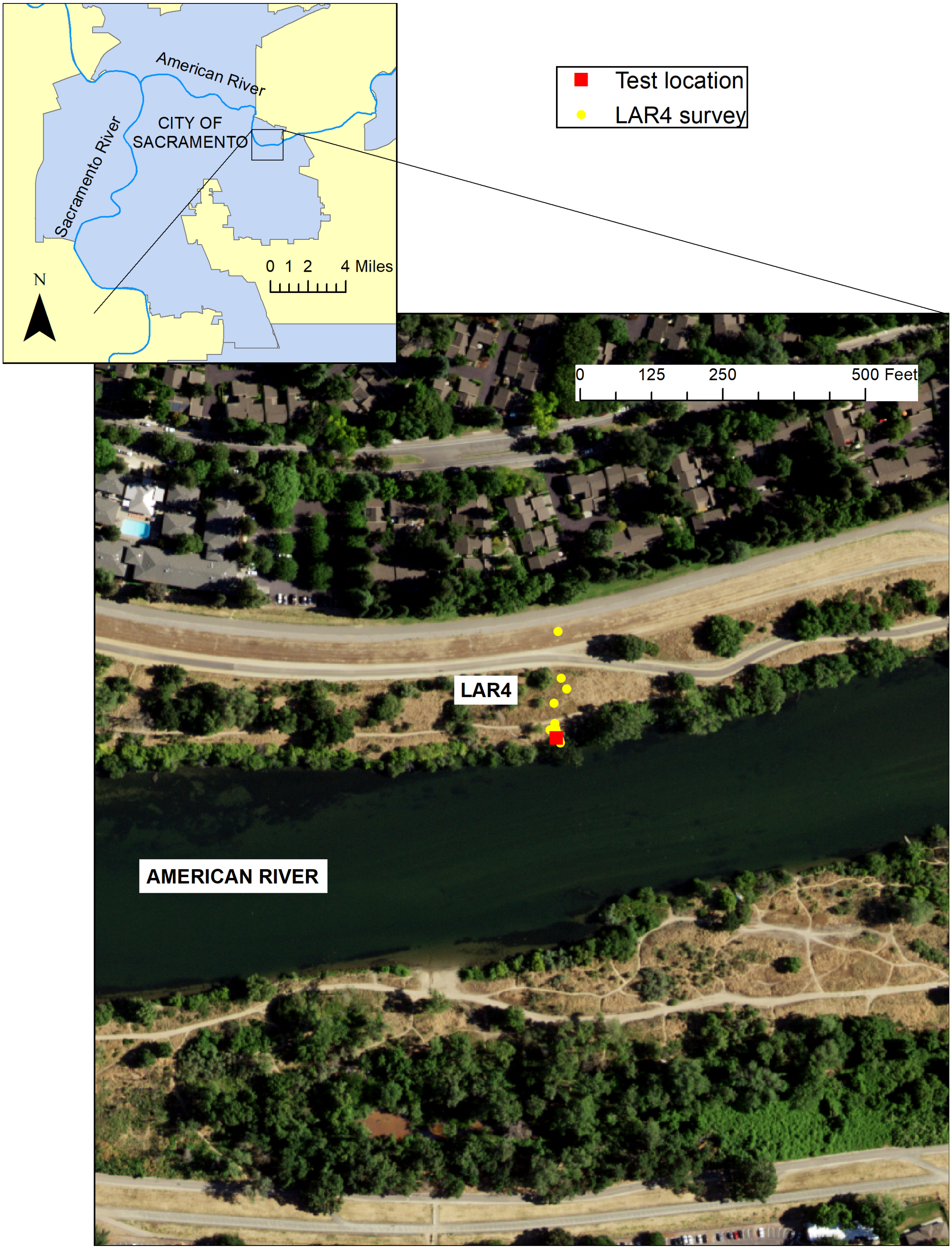

FIGURE 16 – MAP OF STUDY SITE LAR4 ON THE AMERICAN RIVER.

**FIGURE 17 – PHOTOS OF STUDY SITE LAR4 ON THE AMERICAN RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) SANDY SOIL AT JET LOCATION, (C) VIEW UPSTREAM, AND (D) VIEW DOWNSTREAM.**

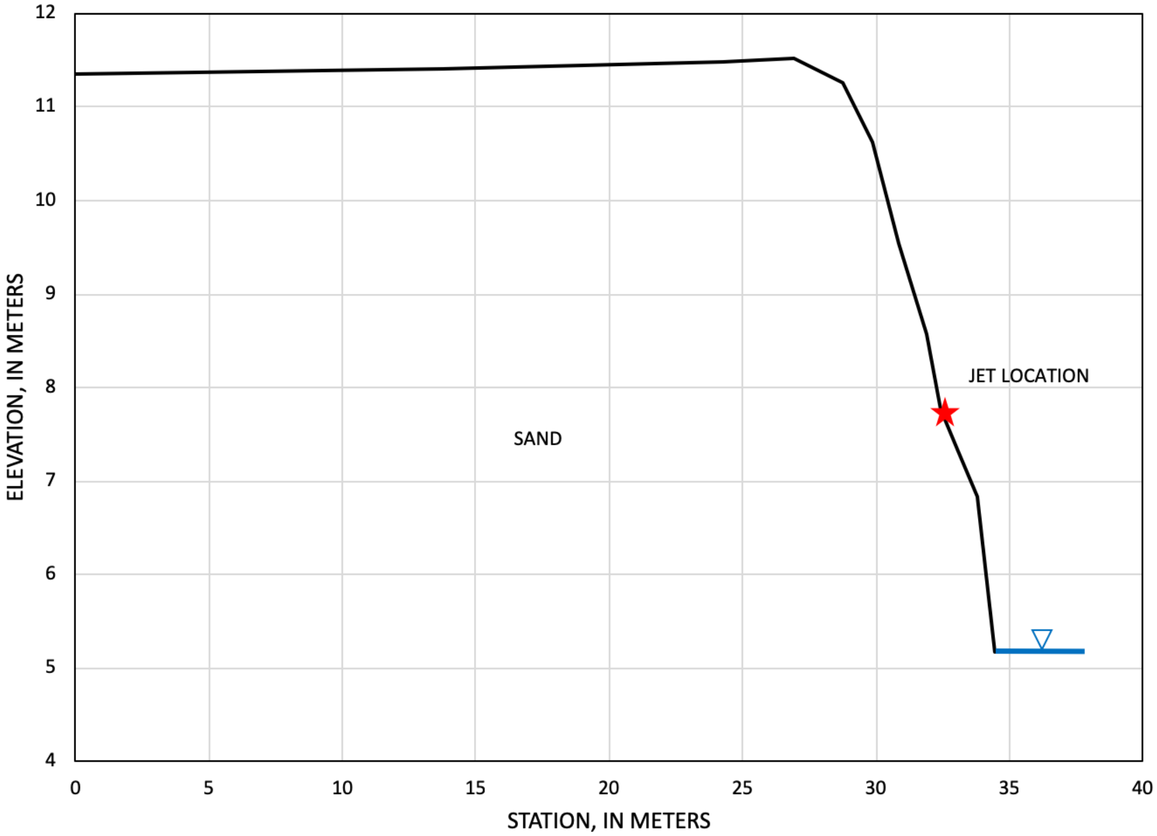

FIGURE 18 – SURVEYED BANK PROFILE OF STUDY SITE LAR4 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JET, WATER SURFACE, AND BANK MATERIAL.

TABLE 10 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JET CARRIED OUT AT STUDY SITE LAR4 ON THE AMERICAN RIVER.

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm $min^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 2.5 | 12.1 | 5.0 |
| | 1 | 4.0 | 10.9 | 3.0 |
| | 2 | 6.0 | 9.36 | 2.0 |
| | 4 | 9.0 | 8.34 | 1.5 |
| | 8 | 11.0 | 7.47 | 0.5 |
| | 12 | 12.5 | 6.95 | 0.375 |
| | 20 | 14.0 | 6.54 | 0.188 |

TABLE 11 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR4 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM $HR^{-1}$ $PA^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M $S^{-1}$ $PA^{-1}$: 1 M $S^{-1}$ $PA^{-1}$ = 360,000 CM $HR^{-1}$ $PA^{-1}$.

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm $hr^{-1}$ $Pa^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 1.28 | 6.21 | 6.38 | 0.822 | 3.53 | 4.03 |

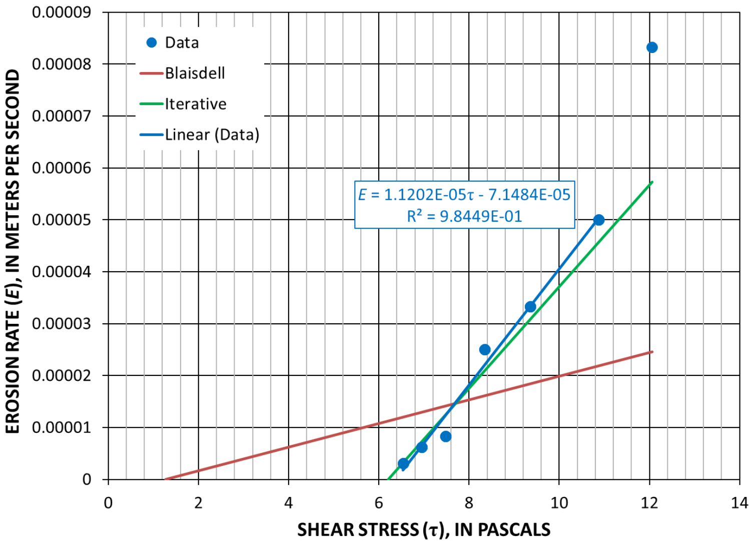

**FIGURE 19 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR4 ON THE AMERICAN RIVER. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPH.**

## Study site LAR5

Study site LAR5 is located at latitude 38.56° N and longitude 121.42° W, on the right bank of the American River (Figure 20). Notes describing the study site are found on page 84. Figure 21 shows photos of the bank face and upstream and downstream views. Three JETs were conducted at this site on a relatively flat toe near the water line. Soil samples were collected from the lower portion of the bank face (above flat toe area) and at the JET location after completion of the JETs for grain-size and bulk density analyses.

The surveyed bank profile is shown in Figure 22. The bank material comprises a single soil (Figure 21B). Table 12 lists the grain-size distribution of the sandy soil samples collected at the bank toe near the water line and at the bank face. The texture of the soil is on average 6.64% clay, 5.81% silt, and 87.6% sand, and has a USCS classification of SM (silty sand). The measured dry density and saturated unit weight of the sandy soil on the bank face are 1.24 g $cm^{-3}$ and 17.5 kN $m^{-3}$, respectively. The measured dry density and saturated unit weight of the sandy soil on the bank toe are 1.23 g $cm^{-3}$ and 17.4 kN $m^{-3}$, respectively.

The three JETs were conducted at a pressure head of 0.70 m, 0.18 m and 0.18 m, which resulted in maximum initial applied shear stresses of 26.2 Pa, 9.73 Pa, and 9.73 Pa, respectively. Table 13 lists the measured erosion rate and shear stress time series during the three tests. Figure 23 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 14 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

**TABLE 12 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR5 ON THE AMERICAN RIVER. THE BANK FACE SAMPLE IS LISTED ON THE TOP ROW, WHEREAS THE BANK TOE SAMPLE IS LISTED ON THE BOTTOM ROW.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 6.75 | 9.32 | 11.8 | 25.1 | 83.6 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 6.53 | 9.91 | 13.1 | 31.3 | 80.4 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

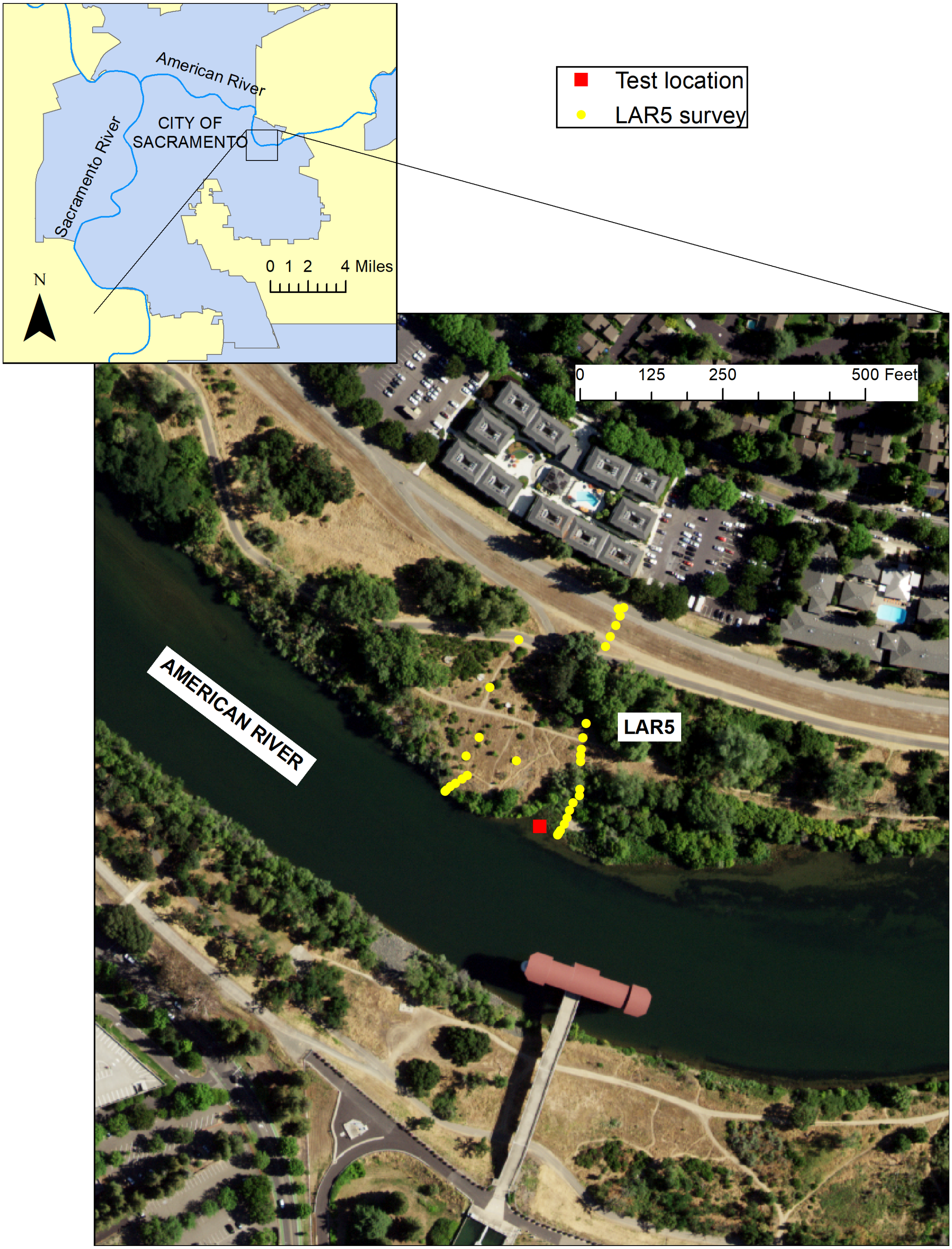

FIGURE 20 – MAP OF STUDY SITE LAR5 ON THE AMERICAN RIVER.

**FIGURE 21 – PHOTOS OF STUDY SITE LAR5 ON THE AMERICAN RIVER: (A) FRONTAL VIEW OF WELL-VEGETATED TOE AND BANK SURFACES, (B) SANDY SOIL AT JET LOCATIONS, (C) VIEW UPSTREAM, AND (D) VIEW DOWNSTREAM.**

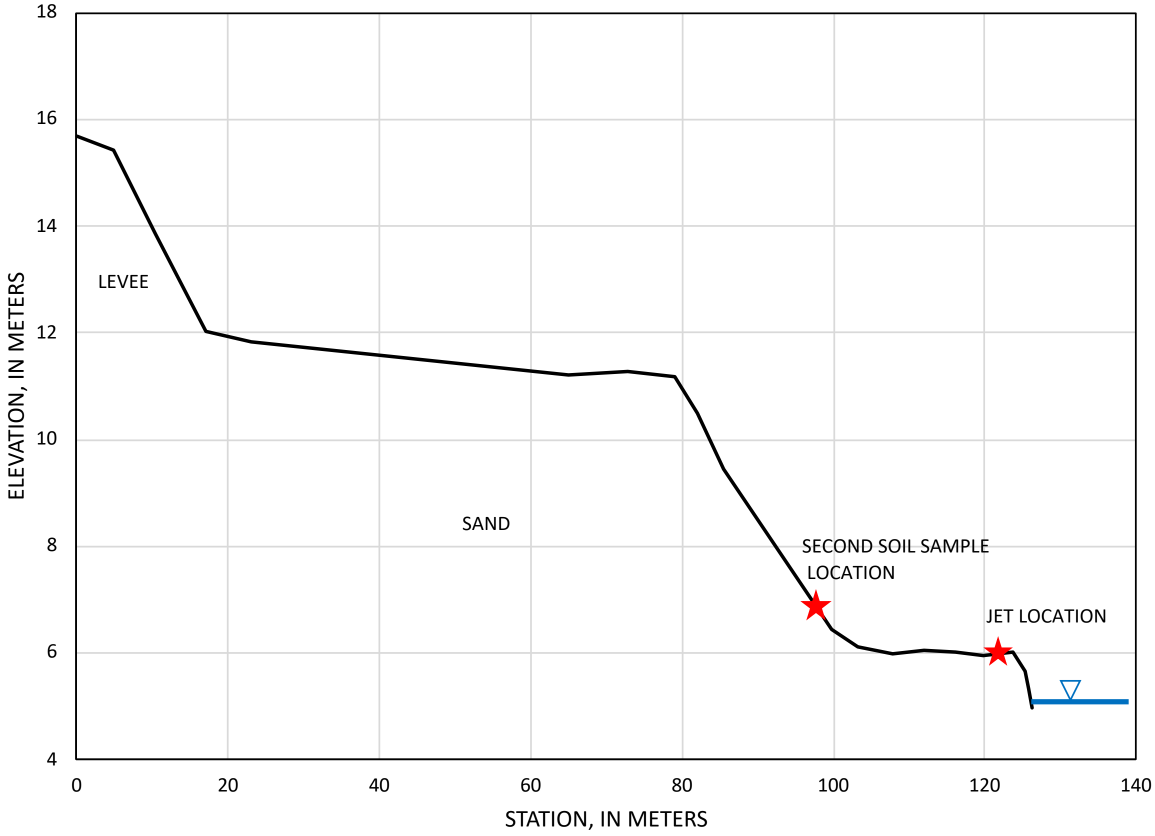

**FIGURE 22 – SURVEYED BANK PROFILE OF STUDY SITE LAR5 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JET AND SOIL SAMPLING, WATER SURFACE, AND BANK MATERIAL.**

**TABLE 13 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT AT STUDY SITE LAR5 ON THE AMERICAN RIVER.**

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 12.0 | 26.2 | 24.0 |
| | 1 | 25.0 | 14.9 | 26.0 |
| | 1.5 | 27.0 | 8.21 | 4.0 |
| | 2.5 | 28.0 | 7.80 | 1.0 |
| | 4 | 28.0 | 7.68 | 0 |
| **2** | 0 | 0 | - | - |
| | 0.5 | 8.0 | 9.73 | 16.0 |
| | 1 | 8.0 | 7.78 | 0 |
| | 2 | 8.5 | 6.15 | 0.5 |
| | 4 | 8.5 | 6.07 | 0 |
| **3** | 0 | 0 | - | - |
| | 0.5 | 22.0 | 9.73 | 44.0 |
| | 1 | 30.0 | 5.02 | 16.0 |
| | 2 | 43.0 | 2.14 | 13.0 |
| | 3 | 46.0 | 1.70 | 3.0 |
| | 5 | 57.0 | 1.44 | 5.5 |

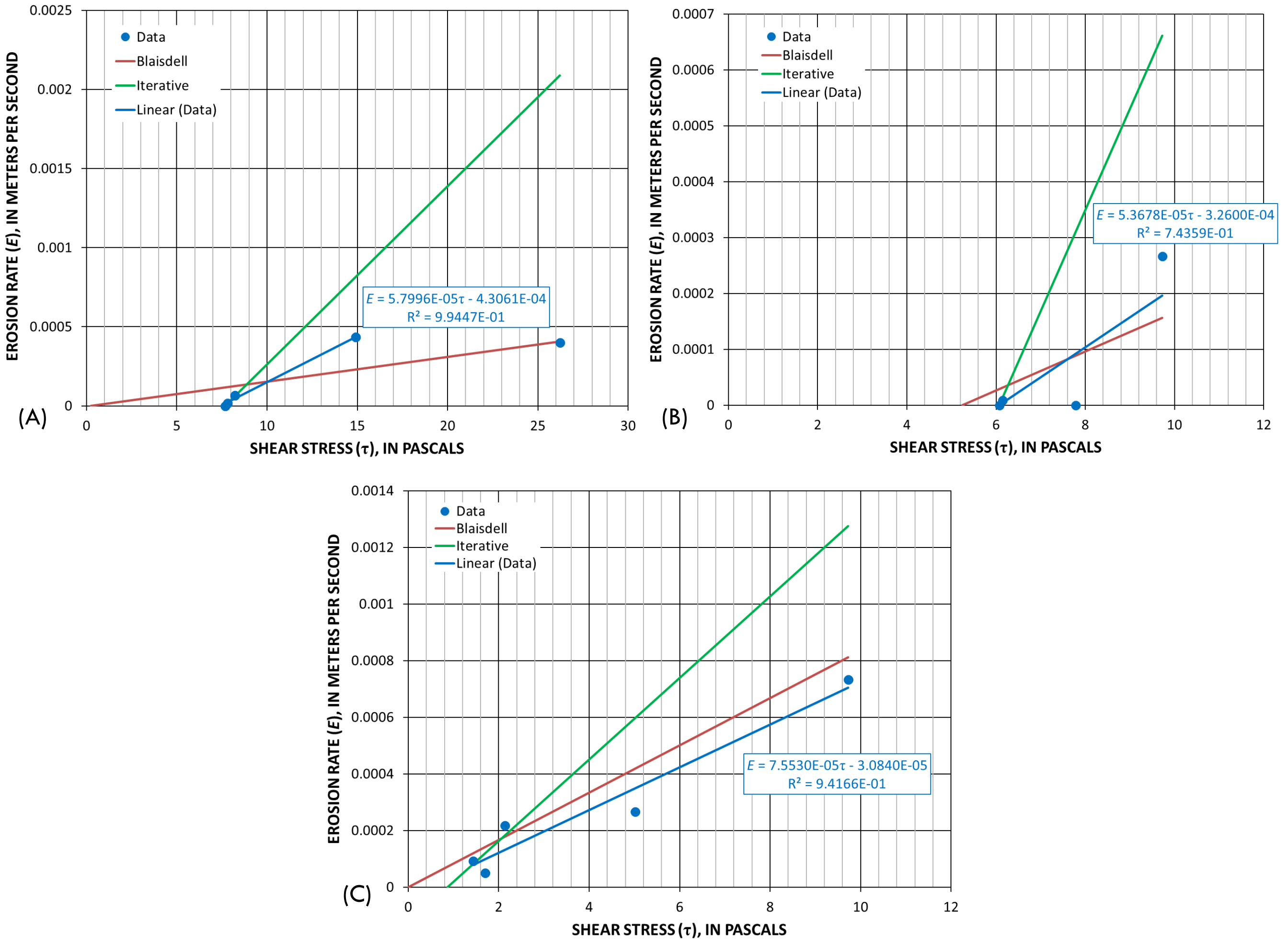

**FIGURE 23 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR5 ON THE AMERICAN RIVER: (A) TEST ONE, (B) TEST TWO, AND (C) TEST THREE. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

**TABLE 14 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR5 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.**

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 0.256 | 7.66 | 7.42 | 5.64 | 40.5 | 20.9 |
| **2** | 5.25 | 6.07 | 6.07 | 12.5 | 65.2 | 19.3 |
| **3** | 0.004 | 0.871 | 0.408 | 30.1 | 51.8 | 27.2 |

## Study site LAR7

Study site LAR7 is located at latitude 38.57° N and longitude 121.42° W, on the right bank of the American River (Figure 24). Notes describing the study site are found on page 86. Figure 25 shows photos of the bank face and upstream and downstream views. Figure 14C shows the presence of toe protection consisting of cobbles at this site. JETs could not be carried out at this site because of the steepness of the bank, presence of abundant vegetation, or loose bank material. The bank material was too loose to collect a soil sample for bulk density analysis. A soil sample for grain-size analysis was collected from the upper bank face.

The surveyed bank profile is shown in Figure 26. The bottom two meters of the profile could not be surveyed using the total station as the prism reflector could not be observed by the total station due to the topography of the bank and the presence of abundant vegetation on the lower bank face. Bank stratigraphy comprises a single sandy soil. Table 15 lists the grain-size distribution of the sandy soil sample. The texture of the soil is 8.86% clay, 26.7% silt, and 64.4% sand, and has a USCS classification of SM (silty sand).

## Study site LAR8

Study site LAR8 is located at latitude 38.57° N and longitude 121.42° W, on the right bank of the American River (Figure 27). Notes describing the study site are found on page 87. Figure 28 shows photos of the bank face and upstream and downstream views. Three JETs were conducted at this site on the upper, more cohesive portion of the bank face. Soil samples were collected at the JET location after completion of the JETs for grain-size and bulk density analyses. Soil samples for grain-size and bulk density analyses were also collected from the lower sandy portion of the streambank.

The surveyed bank profile is shown in Figure 29. Bank stratigraphy comprises two soils. The bottom soil consists primarily of sandy material, which is overlain by a silty sand (Figure 28B). The bank soil transition is located at about 6.25 MASL. Table 16 lists the grain-size distributions of the silty sand and sand soil samples. The texture of the silty sand is 14.4% clay, 30.9% silt, 51.3% sand, and 3.4% gravel, and has a USCS classification of SM (silty sand). The measured dry density and saturated unit weight of the silty sand are 1.39 g cm$^{-3}$ and 18.4 kN m$^{-3}$, respectively. The texture of the sand is 5.03% clay, 2.71% silt, and 92.3% sand, and has a USCS classification of SP-SM (poorly graded sand with silt). The measured dry density and saturated unit weight of the sandy soil are 1.22 g cm$^{-3}$ and 17.3 kN m$^{-3}$, respectively.

The three JETs were conducted at a pressure head of 0.70 m, 0.32 m, and 1.55 m, which resulted in maximum initial applied shear stresses of 23.4 Pa, 13.2 Pa, and 15.2 Pa, respectively. Table 17 lists the measured erosion rate and shear stress time series during the three tests. Figure 30 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 18 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

**TABLE 15 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SOIL AT STUDY SITE LAR7 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 8.86 | 20.4 | 35.6 | 66.2 | 92.7 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**TABLE 16 – GRAIN-SIZE DISTRIBUTION OF THE SILTY SAND (UPPER SOIL LAYER) AND SAND (LOWER SOIL LAYER) SOILS AT STUDY SITE LAR8 ON THE AMERICAN RIVER. THE SILTY SAND SAMPLE IS LISTED ON THE TOP ROW, WHEREAS THE SAND SAMPLE IS LISTED ON THE BOTTOM ROW.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 14.4 | 29.3 | 45.3 | 58.4 | 73.6 | 90.1 | 96.6 | 96.6 | 97.2 | 97.7 | 98.5 | 99.8 | 100 |
| **%Finer** | 5.03 | 6.94 | 7.74 | 16.6 | 52.3 | 84.9 | 99.2 | 100 | 100 | 100 | 100 | 100 | 100 |

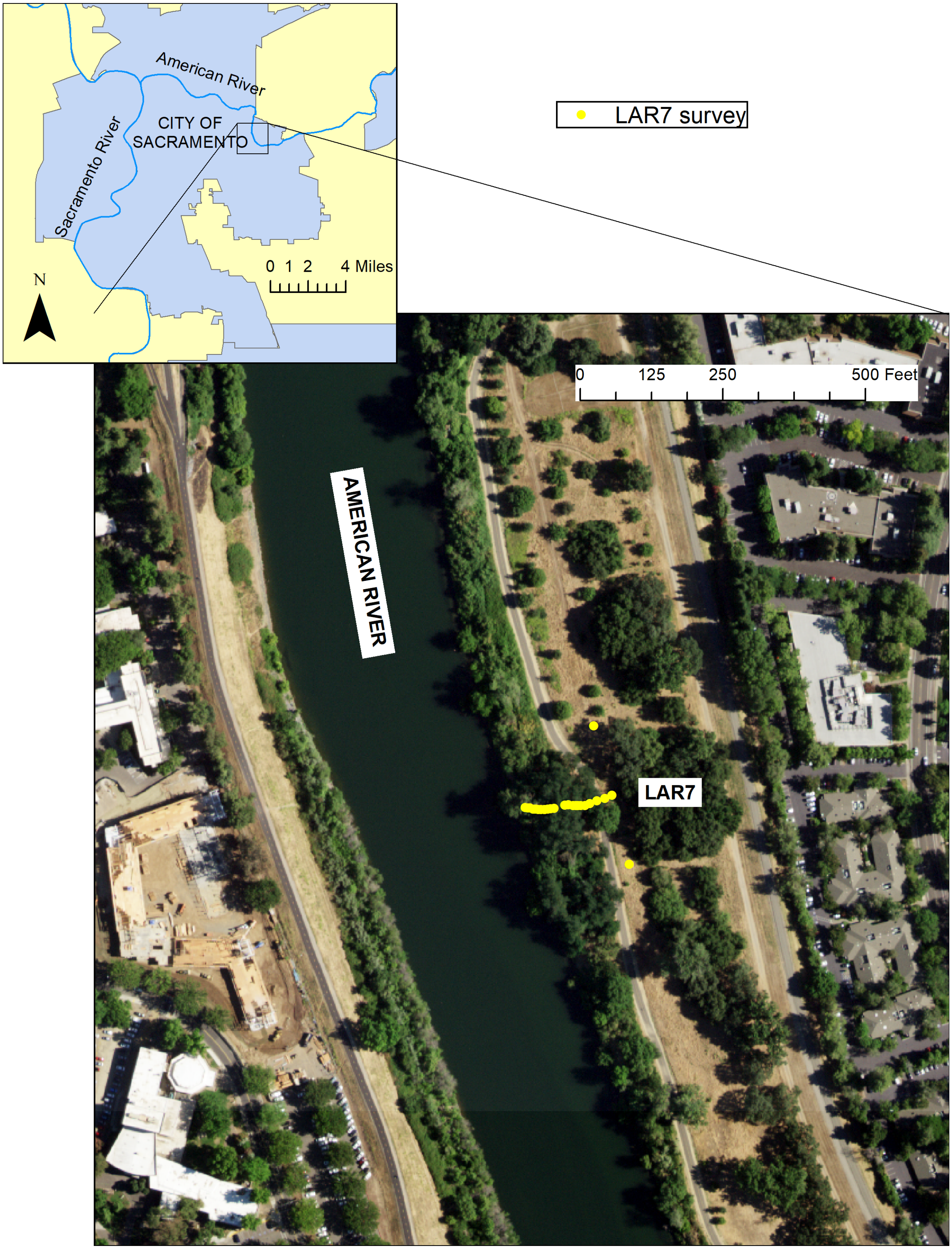

FIGURE 24 – MAP OF STUDY SITE LAR7 ON THE AMERICAN RIVER.

FIGURE 25 – PHOTOS OF STUDY SITE LAR7 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

TABLE 17 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT AT STUDY SITE LAR8 ON THE AMERICAN RIVER.

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 19.0 | 23.4 | 38.0 |
| | 1 | 23.0 | 14.3 | 8.0 |
| | 1.5 | 30.0 | 7.77 | 14.0 |
| | 3 | 39.0 | 6.12 | 6.0 |
| | 4 | 39.0 | 5.38 | 0 |
| | 6 | 41.0 | 5.24 | 1 |
| | 10 | 42.0 | 5.04 | 0.25 |

| Test | Time<br>(min) | Scour depth<br>(mm) | Shear stress<br>(Pa) | Erosion rate<br>(mm min$^{-1}$) |
|---|---|---|---|---|
| **2** | 0 | 0 | - | - |
| | 0.5 | 5.0 | 13.2 | 10.0 |
| | 1 | 7.0 | 11.0 | 4.0 |
| | 2.5 | 11.0 | 8.44 | 2.67 |
| | 4 | 14.0 | 7.26 | 2.0 |
| | 6 | 36.0 | 4.74 | 11.0 |
| | 8 | 41.0 | 3.08 | 2.5 |
| | 10 | 44.0 | 2.77 | 1.5 |
| | 12 | 45.0 | 2.63 | 0.5 |
| **3** | 0 | 0 | - | - |
| | 5.0 | 19.0 | 15.2 | 3.8 |
| | 10.0 | 25.0 | 10.2 | 1.2 |
| | 15.0 | 28.0 | 9.23 | 0.6 |

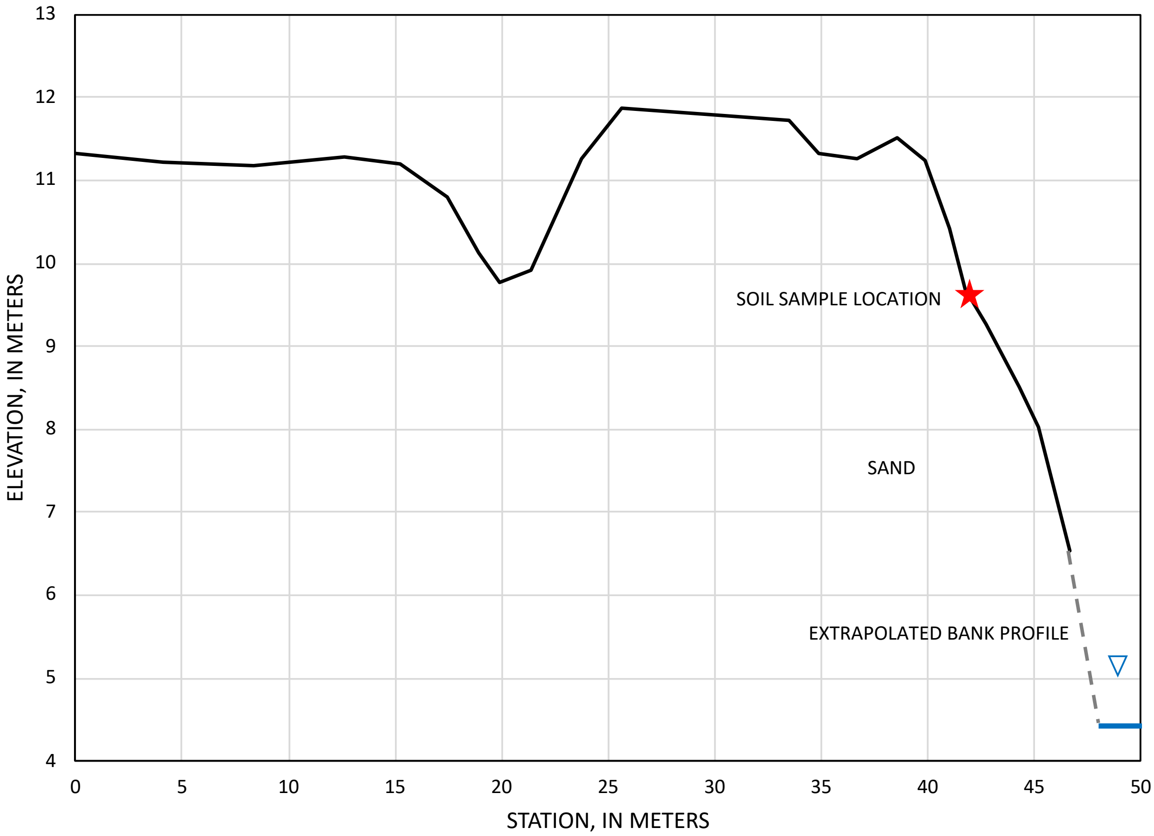

FIGURE 26 – SURVEYED BANK PROFILE OF STUDY SITE LAR7 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE SOIL SAMPLING, WATER SURFACE, AND BANK MATERIAL.

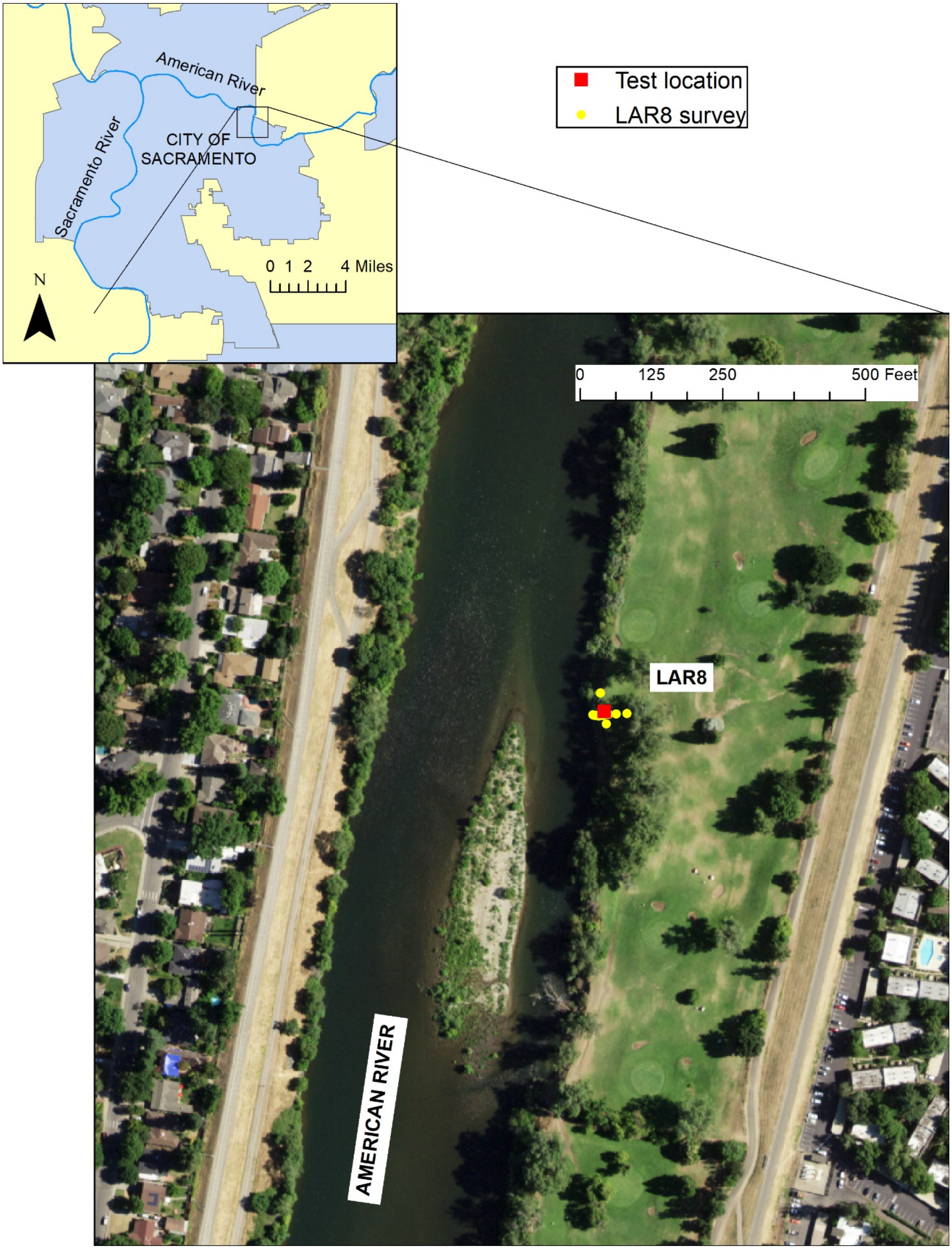

FIGURE 27 – MAP OF STUDY SITE LAR8 ON THE AMERICAN RIVER.

FIGURE 28 – PHOTOS OF STUDY SITE LAR8 ON THE AMERICAN RIVER: (A) OBLIQUE VIEW OF BANK SURFACE, (B) FRONTAL VIEW OF BANK SURFACE SHOWING SANDY SOIL OVERLAIN BY A SILTY SAND, (C) VIEW UPSTREAM, AND (D) VIEW DOWNSTREAM.

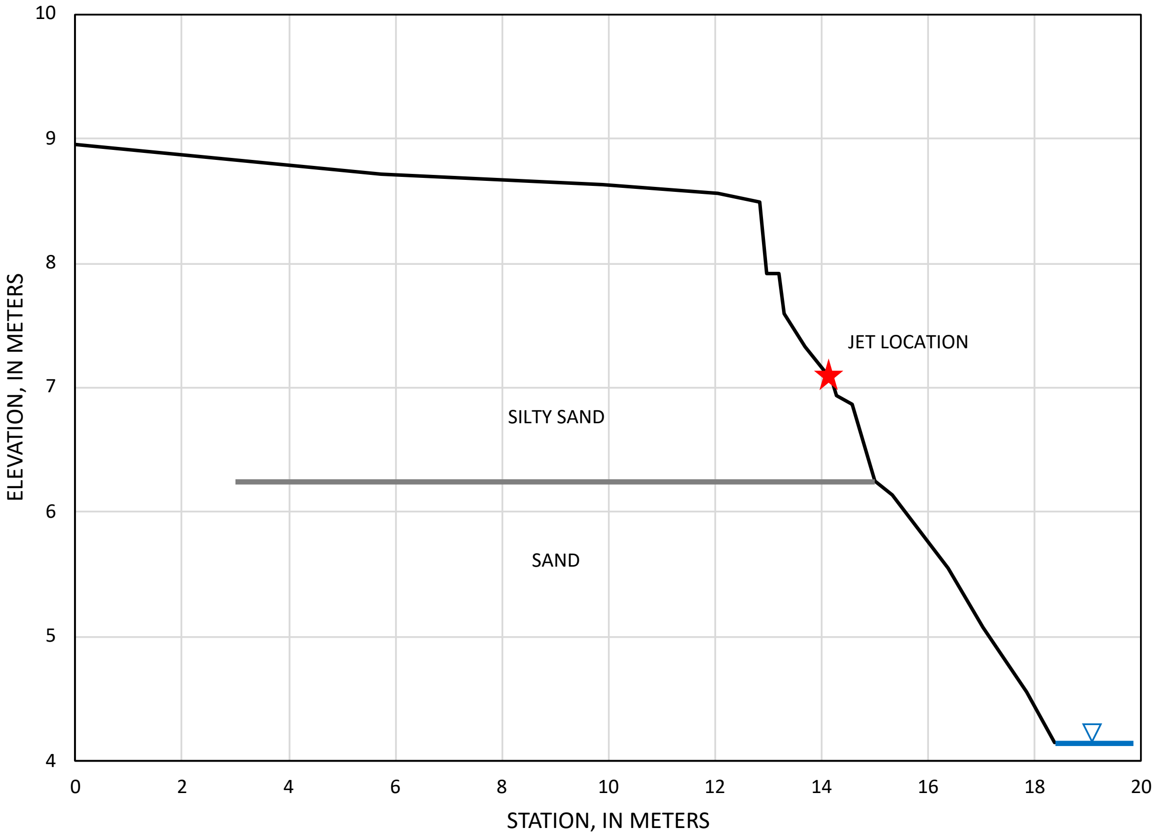

**FIGURE 29 – SURVEYED BANK PROFILE OF STUDY SITE LAR8 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JET, WATER SURFACE, AND BANK STRATIGRAPHY.**

**TABLE 18 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR8 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.**

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 0.186 | 4.96 | 4.23 | 4.96 | 23.9 | 10.7 |
| **2** | 0.007 | 0.00 | 1.45 | 5.34 | 5.34 | 3.64 |
| **3** | 0.349 | 6.76 | 8.03 | 0.836 | 1.86 | 3.17 |

## Study site LAR9

Study site LAR9 is located at latitude 38.58° N and longitude 121.43° W, on the right bank of the American River (Figure 31). Notes describing the study site are found on page 89. Figure 32 shows photos of the bank face and upstream and downstream views. Three JETs were conducted at this site on the lower middle portion of the bank face (one JET) and on the horizontal bank toe (two JETs). Soil samples were collected at the JET locations after completion of the JETs for grain-size and bulk density analyses. A soil sample for grain-size analysis was also collected from the upper bank face.

The surveyed bank profile is shown in Figure 33. Bank stratigraphy comprises two soils. The bottom soil is a silty sand (Figure 34), which is overlain by a sandy silt. The bank soil transition is located at about 6.75 MASL. Table 19 lists the grain-size distributions of the silty sand and sandy silt soil samples. The texture of the sandy silt is 10.5% clay, 51.5% silt, and 38.0%

sand, and has a USCS classification of ML (silt). The texture of the silty sand is on average 12.0% clay, 30.0% silt, and 58.0% sand. The soil collected at the higher JET location (lower middle portion of bank face) has a USCS classification of SM (silty sand), whereas the sample collected at the lower JET location (bank toe) has a USCS classification of ML (silt). The measured dry density and saturated unit weight of the silty sand are on average 1.29 g cm$^{-3}$ and 17.8 kN m$^{-3}$, respectively.

The three JETs were conducted at a pressure head of 0.70 m, 1.41 m, and 1.41 m, which resulted in maximum initial applied shear stresses of 20.9 Pa, 39.5 Pa, and 37.4 Pa, respectively. Table 20 lists the measured erosion rate and shear stress time series during the three tests. Figure 35 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 21 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

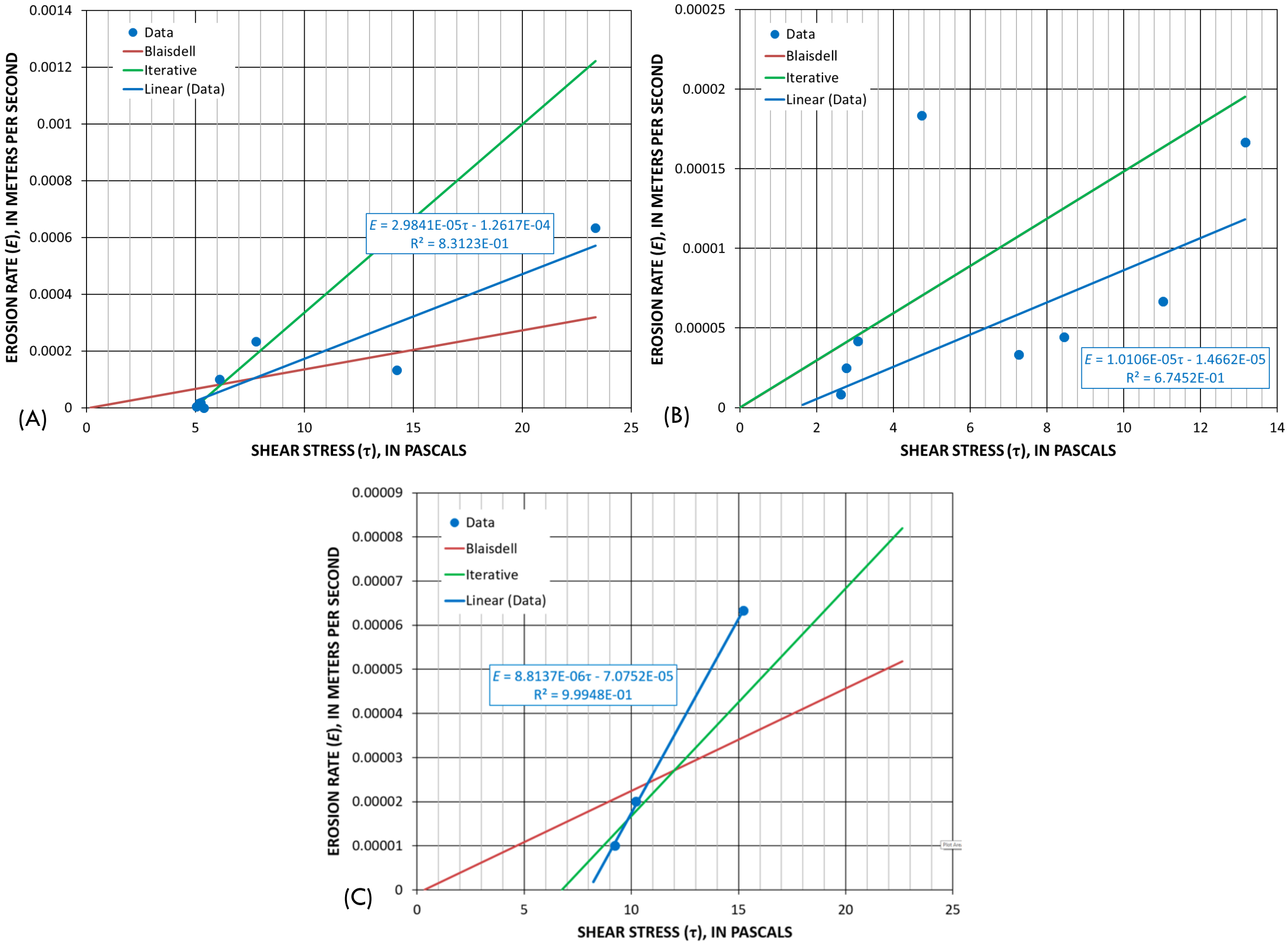

**FIGURE 30 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR8 ON THE AMERICAN RIVER: (A) TEST ONE, (B) TEST TWO, AND (C) TEST THREE. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION (R²) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

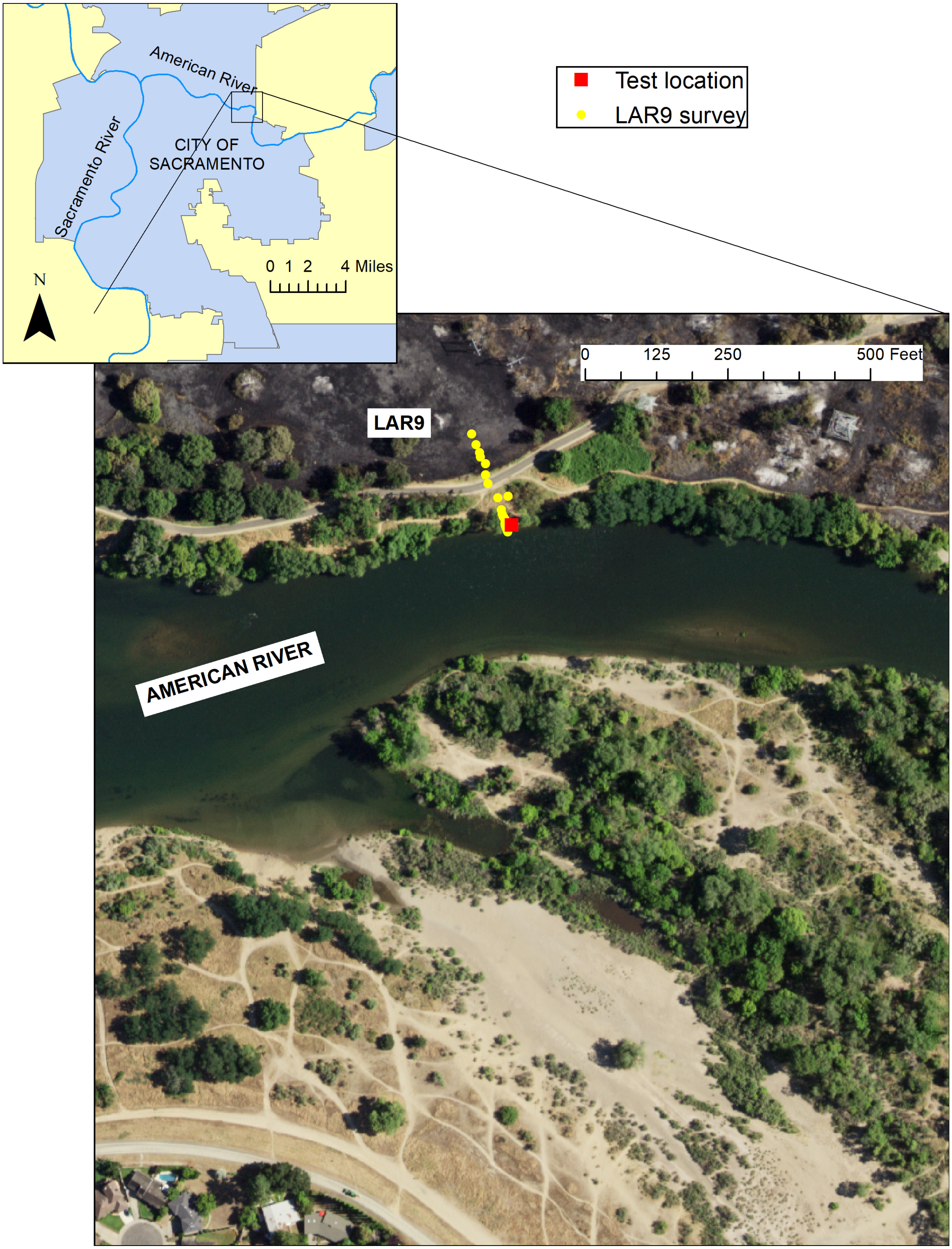

FIGURE 31 – MAP OF STUDY SITE LAR9 ON THE AMERICAN RIVER.

FIGURE 32 – PHOTOS OF STUDY SITE LAR9 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

TABLE 19 – GRAIN-SIZE DISTRIBUTION OF THE SANDY SILT (UPPER SOIL LAYER) AND SILTY SAND (LOWER SOIL LAYER/BANK TOE) SOILS AT STUDY SITE LAR9 ON THE AMERICAN RIVER. THE SANDY SILT SAMPLE IS LISTED ON THE TOP ROW, WHEREAS THE TWO SILTY SAND SAMPLES ARE LISTED ON THE BOTTOM TWO ROWS.

| | **Diameter ($D$) in millimeters** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | **Phi scale, $\phi = -\log_2 D$** | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 10.5 | 32.1 | 62.0 | 88.4 | 97.3 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 12.4 | 26.5 | 38.7 | 56.1 | 80.2 | 96.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 11.6 | 28.1 | 45.2 | 73.6 | 97.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

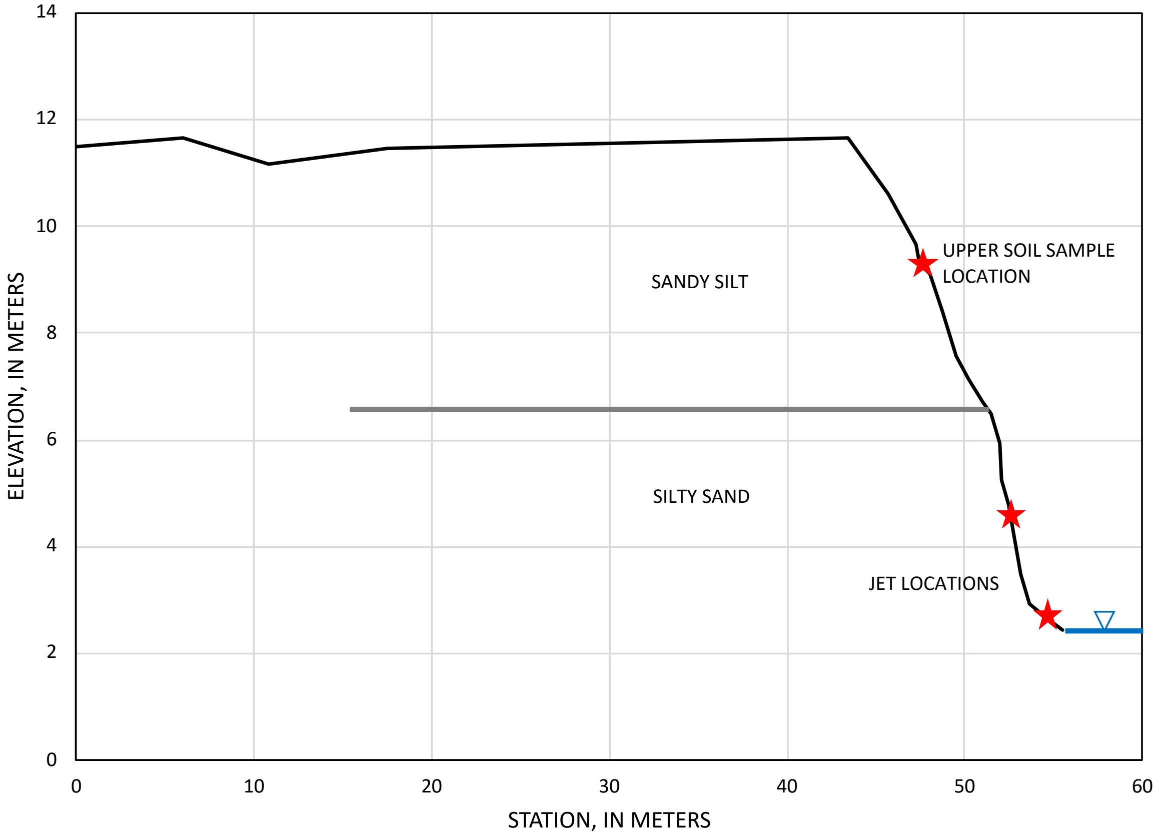

FIGURE 33 – SURVEYED BANK PROFILE OF STUDY SITE LAR9 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE JETS, WATER SURFACE, AND BANK STRATIGRAPHY.

TABLE 20 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT AT STUDY SITE LAR9 ON THE AMERICAN RIVER.

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 12.0 | 20.9 | 24.0 |
| | 1 | 16.0 | 14.6 | 8.0 |
| | 2 | 31.0 | 7.93 | 15.0 |
| | 3 | 32.0 | 6.09 | 1.0 |
| | 5 | 38.0 | 5.52 | 3.0 |
| | 7 | 41.0 | 4.88 | 1.5 |
| | 11 | 43.0 | 4.58 | 0.5 |
| **2** | 0 | 0 | - | - |
| | 0.5 | 3.5 | 39.5 | 7.0 |
| | 1 | 4.5 | 35.1 | 2.0 |
| | 2 | 7.5 | 29.1 | 3.0 |
| | 3 | 9.0 | 26.2 | 1.5 |
| | 5 | 12.0 | 23.7 | 1.5 |
| | 7 | 13.0 | 21.8 | 0.5 |
| | 11 | 13.0 | 21.3 | 0 |

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **3** | 0 | 0 | - | - |
| | 0.5 | 5.0 | 37.4 | 10.0 |
| | 1 | 6.0 | 32.2 | 2.0 |
| | 2 | 9.0 | 25.9 | 3.0 |
| | 3 | 10.0 | 23.7 | 1.0 |
| | 5 | 11.0 | 22.7 | 0.5 |
| | 7 | 12.0 | 21.8 | 0.5 |
| | 11 | 13.0 | 20.9 | 0.25 |

TABLE 21 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR9 ON THE AMERICAN RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 0.048 | 4.35 | 4.27 | 4.28 | 15.4 | 8.42 |
| **2** | 3.10 | 21.0 | 20.5 | 0.432 | 2.44 | 1.75 |
| **3** | 5.15 | 20.3 | 20.2 | 0.509 | 2.34 | 2.51 |

FIGURE 34 – PHOTOS OF THE LOWER BANK SOIL AT STUDY SITE LAR9 ON THE AMERICAN RIVER ON WHICH JETS WERE CONDUCTED: (A) ABOUT 2 M ABOVE WATER LINE, AND (B) NEAR THE WATER LINE.

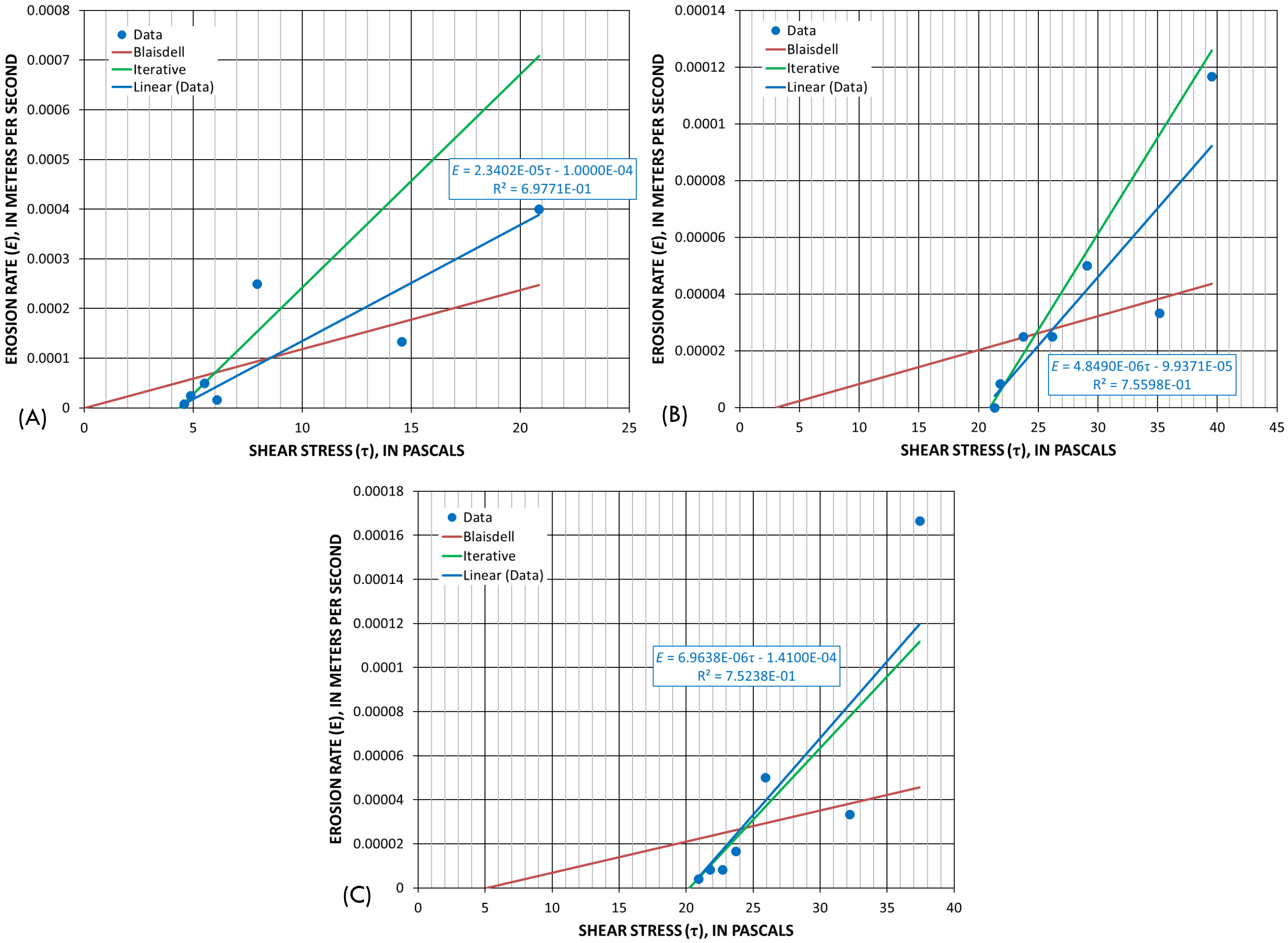

**FIGURE 35 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE LAR9 ON THE AMERICAN RIVER: (A) TEST ONE, (B) TEST TWO, AND (C) TEST THREE. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

## Study site LAR10

Study site LAR10 is located at latitude 38.59° N and longitude 121.45° W, on the left bank of the American River (Figure 36). Notes describing the study site are found on page 90. Figure 37 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because of the loose bank material. The bank material was too loose to collect a soil sample for bulk density analysis. Soil samples for grain-size analysis were collected at the bank toe and mid-bank.

The surveyed bank profile is shown in Figure 38. Bank material comprises primarily sands, and fines upward with increasing silt content. Table 22 lists the grain-size distribution of the bank toe and mid-bank soil samples. The texture of the bank toe soil is 4.87% clay, 0.65% silt, and 94.5% sand, and has a USCS classification of SP-SM (poorly graded sand with silt). The texture of the mid-bank soil is 7.84% clay, 24.4% silt, and 67.8% sand, and has a USCS classification of SM (silty sand).

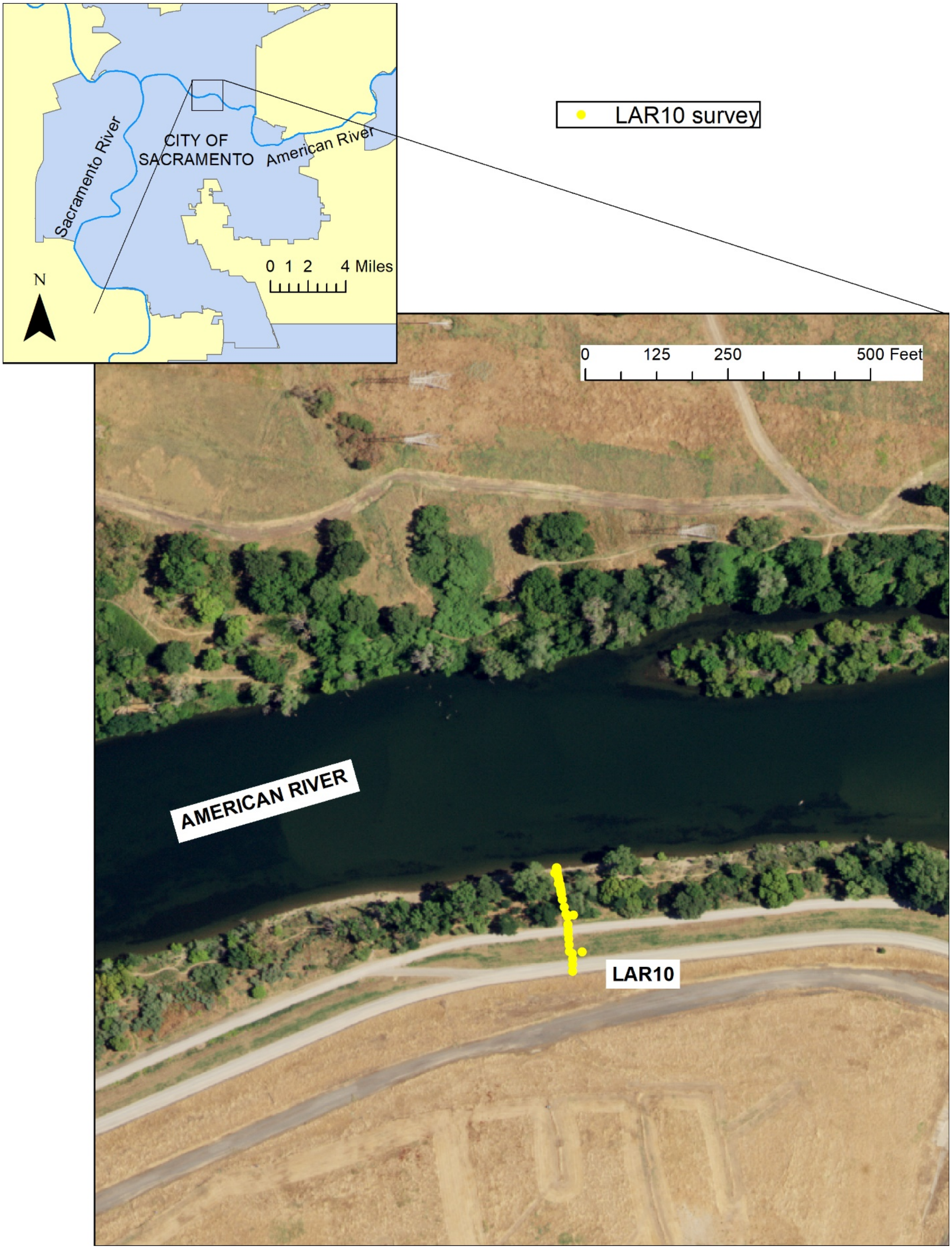

FIGURE 36 – MAP OF STUDY SITE LAR10 ON THE AMERICAN RIVER.

**FIGURE 37 – PHOTOS OF STUDY SITE LAR10 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.**

**TABLE 22 – GRAIN-SIZE DISTRIBUTIONS OF THE MID-BANK (TOP ROW) AND BANK TOE (BOTTOM ROW) SOILS AT STUDY SITE LAR10 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 7.84 | 16.9 | 32.2 | 58.0 | 85.3 | 95.7 | 98.7 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 4.87 | 5.19 | 5.52 | 11.1 | 38.8 | 90.4 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 |

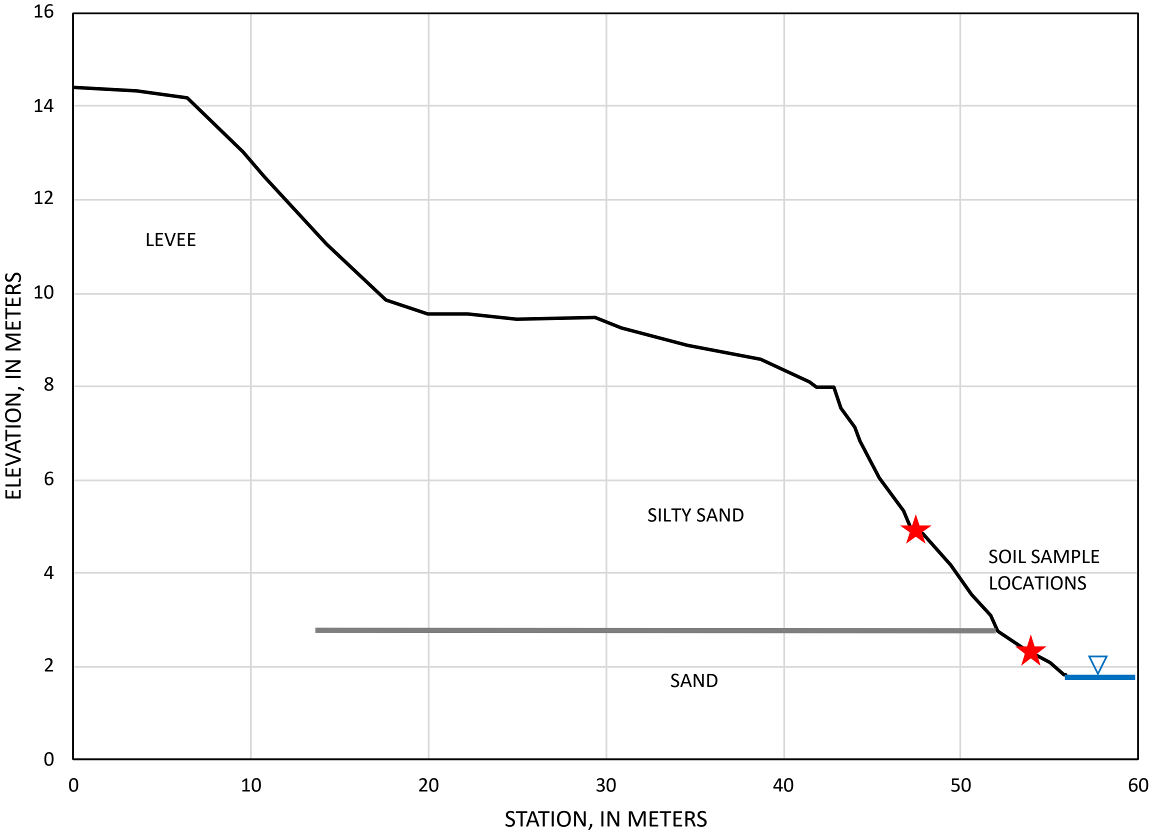

**FIGURE 38 – SURVEYED BANK PROFILE OF STUDY SITE LAR10 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE COLLECTED SOIL SAMPLES, WATER SURFACE, AND BANK STRATIGRAPHY.**

## Study site LAR11

Study site LAR11 is located at latitude 38.60° N and longitude 121.50° W, on the left bank of the American River immediately upstream of the confluence with the Sacramento River (Figure 39). Notes describing the study site are found on page 91. Figure 40 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because riprap and grasses covering the bank face. A soil sample for grain-size analysis was collected from the sandy berm (deposit) on the upper edge of the denser riprap cover. The bank material was too loose to collect a soil sample for bulk density analysis.

The surveyed bank profile is shown in Figure 41. Bank material is primarily comprised of sands. Table 23 lists the grain-size distribution of the bank material. The texture of the bank soil is 6.78% clay, 4.42% silt, and 88.8% sand, and has a USCS classification of SM (silty sand).

**TABLE 23 – GRAIN-SIZE DISTRIBUTION OF THE BANK MATERIAL AT STUDY SITE LAR11 ON THE AMERICAN RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 6.78 | 8.78 | 11.2 | 25.7 | 85.6 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

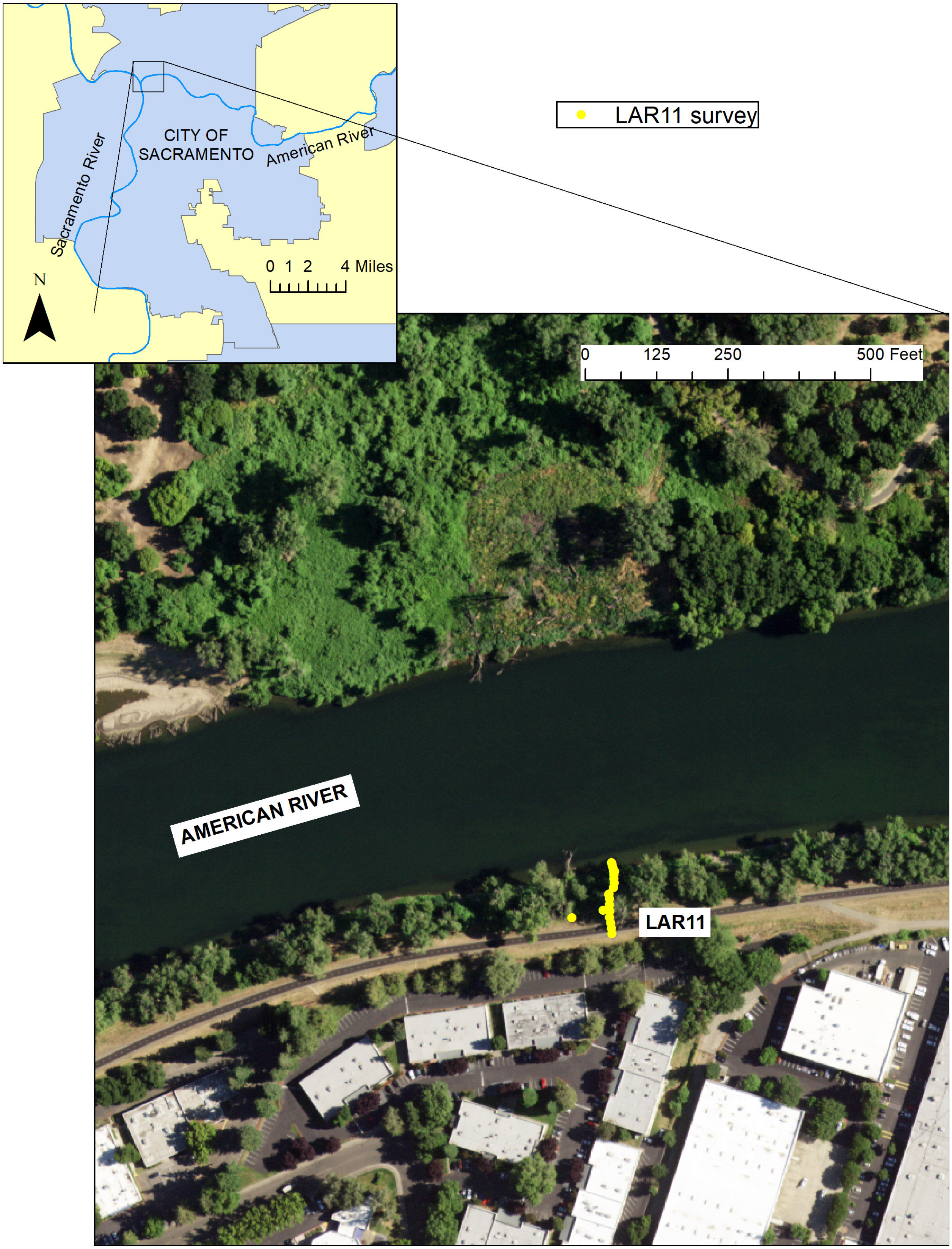

FIGURE 39 – MAP OF STUDY SITE LAR11 ON THE AMERICAN RIVER.

FIGURE 40 – PHOTOS OF STUDY SITE LAR11 ON THE AMERICAN RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

## Study site SAC1

Study site SAC1 is located at latitude 38.60° N and longitude 121.51° W on the left bank of the Sacramento River immediately downstream of the confluence with the American River (Figure 42). Notes describing the study site are found on page 92. Figure 43 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because riprap covering the bank face. A soil sample for grain-size analysis was collected at the top of the riprap. The bank material was too loose to collect a soil sample for bulk density analysis.

The surveyed bank profile is shown in Figure 44. Bank material is a sandy soil, which is protected at the toe by a mix of cobble and riprap, and scattered riprap and grasses along the upper portion of the bank. Table 24 lists the grain-size distribution of the deposited bank material on the upper end of the riprap-cobble toe protection. The texture of the deposit is 8.43% clay, 5.47% silt, and 86.1% sand, and has a USCS classification of SM (silty sand).

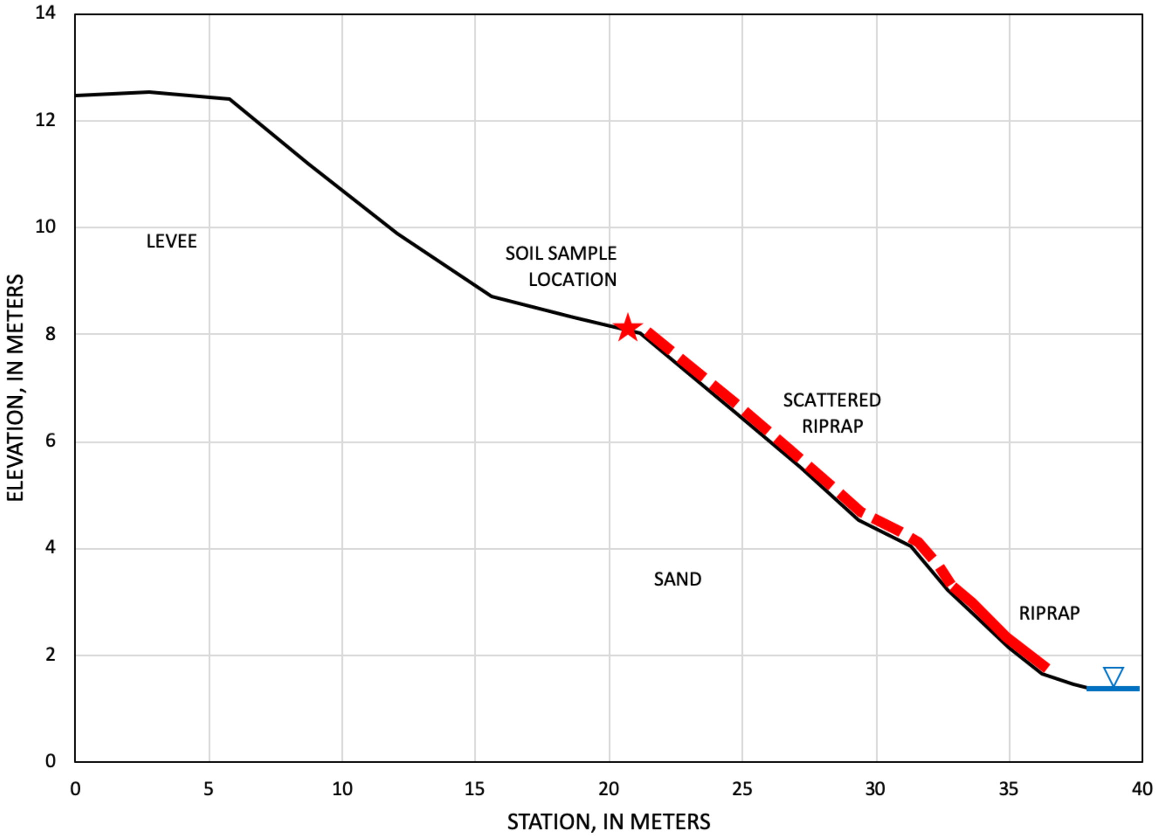

FIGURE 41 – SURVEYED BANK PROFILE OF STUDY SITE LAR11 ON THE AMERICAN RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE COLLECTED SOIL SAMPLE, WATER SURFACE, BANK MATERIAL, AND RIPRAP.

TABLE 24 – GRAIN-SIZE DISTRIBUTION OF THE DEPOSITED BANK MATERIAL AT STUDY SITE SAC1 ON THE SACRAMENTO RIVER.

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 8.43 | 12.1 | 13.9 | 31.9 | 87.5 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

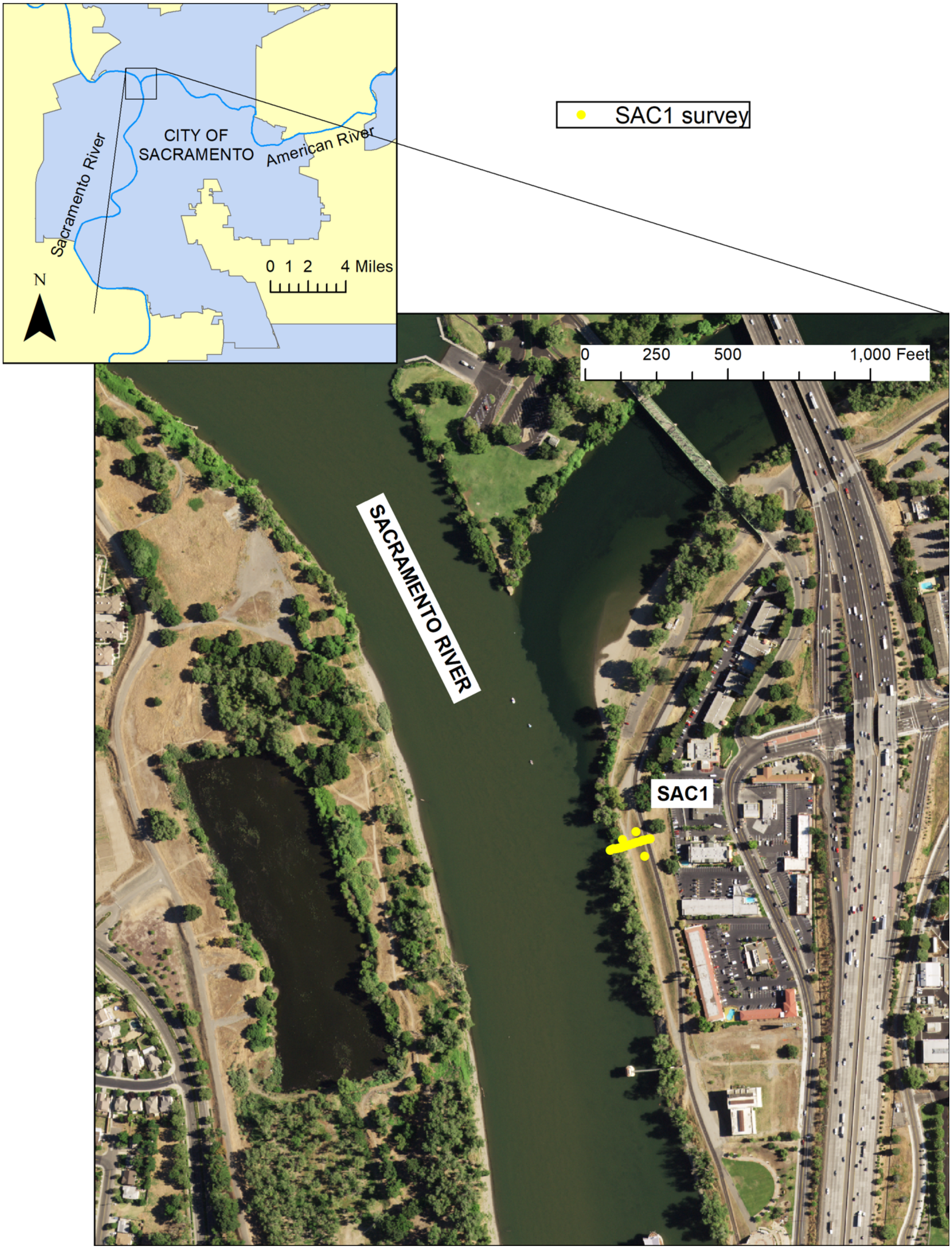

FIGURE 42 – MAP OF STUDY SITE SAC1 ON THE SACRAMENTO RIVER.

FIGURE 43 – PHOTOS OF STUDY SITE SAC1 ON THE SACRAMENTO RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

## Study site SAC3

Study site SAC3 is located at latitude 38.55° N and longitude 121.51° W, on the left bank of the Sacramento River (Figure 45). Notes describing the study site are found on page 93. Figure 46 shows photos of the bank face and upstream and downstream views. Six JETs were conducted at this site on the lower (three JETs) and upper middle (three JETs) portions of the bank face. Soil samples were collected at the JET locations after completion of the JETs for grain-size and bulk density analyses. A soil sample was also collected at the bank toe.

The surveyed bank profile is shown in Figure 47. Bank stratigraphy comprises three soils. The bottom soil at the bank toe is a sand, which is overlain by a sandy silt material. The upper most bank material is a silty sand. The bank soil transitions are located at about 2.3 and 3.6 MASL. Table 25 lists the grain-size distributions of the bank toe and bank face soil samples. The texture of the bank toe sample is 2.24% clay, 0.07% silt, and 97.7% sand, and has a USCS classification of SP (poorly graded sand). The texture of the middle bank material is 12.5% clay, 47.3% silt, and 40.2% sand, and has a USCS classification of ML (silt). The texture of the upper bank material is 10.8% clay, 36.2% silt, and 53.0% sand, and has a USCS classification of ML (silt). The measured dry density and saturated unit weight of the sandy silt at the lower JET location are 0.95 g cm$^{-3}$ and 15.7 kN m$^{-3}$, respectively. The measured dry density and saturated unit weight of the silty sand at the upper JET location are 1.00 g cm$^{-3}$ and 16.0 kN m$^{-3}$, respectively.

Three JETs were conducted at each, lower and upper, location. The three JETs at the lower location (JET 1 through 3) were conducted at pressure heads of 1.41 m, 0.70 m, and 1.05 m, which resulted in maximum initial applied shear stresses of 37.4 Pa, 23.3 Pa, and 32.7 Pa, respectively. Table 26 lists the measured erosion rate and shear stress time series during the three tests. Figure 48 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 27 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$. The three JETs at the upper location (JET 4 through 6) were conducted at pressure heads of 0.77 m, 0.70 m, and 0.70 m, which resulted in maximum initial applied shear stresses of 29.6 Pa, 24.7 Pa, and 23.3 Pa, respectively. Table 28 lists the measured erosion rate and shear stress time series during the three tests. Figure 49 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 27 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

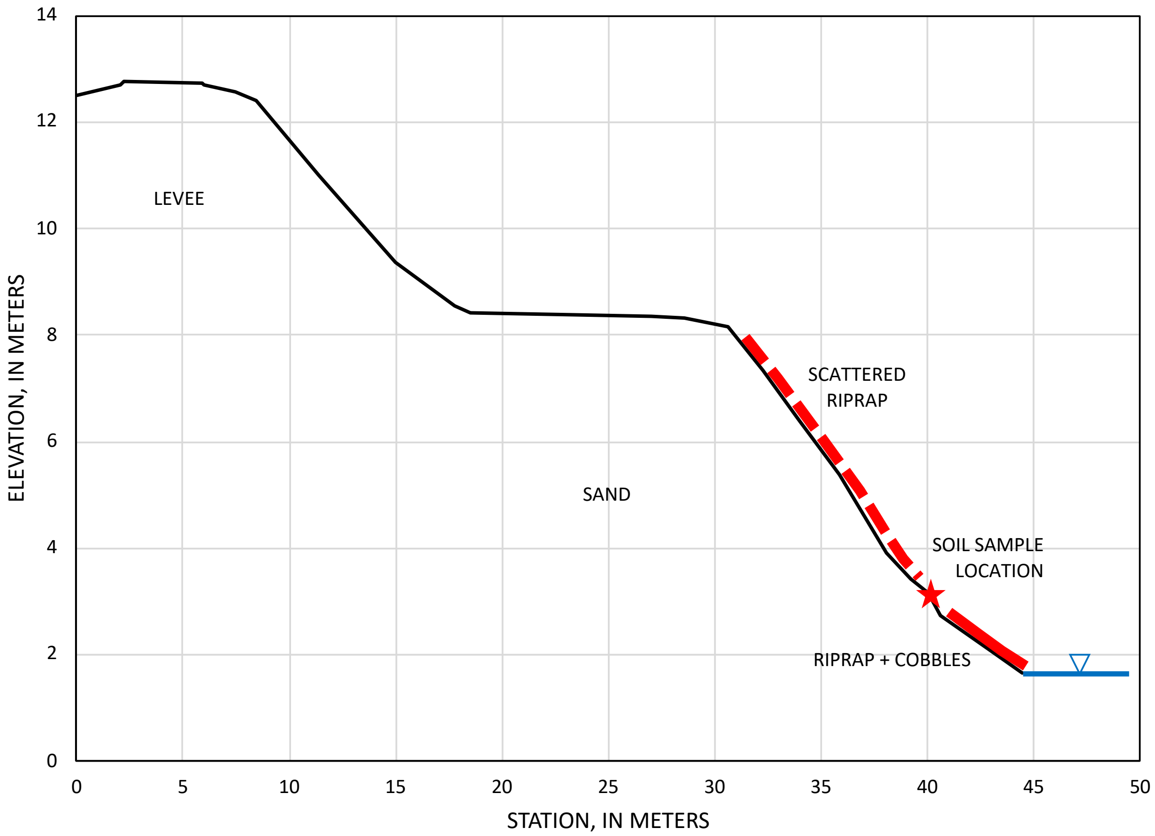

**FIGURE 44 – SURVEYED BANK PROFILE OF STUDY SITE SAC1 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATION OF THE COLLECTED SOIL SAMPLE, WATER SURFACE, BANK MATERIAL, AND RIPRAP.**

**TABLE 25 – GRAIN-SIZE DISTRIBUTIONS OF THE SILTY SAND (UPPER BANK FACE, TOP ROW), SANDY SILT (LOWER BANK FACE, MIDDLE ROW), AND SANDY (BANK TOE, BOTTOM ROW) SOILS AT STUDY SITE SAC3 ON THE SACRAMENTO RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 10.8 | 25.5 | 47.0 | 81.0 | 97.8 | 99.6 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 12.5 | 32.6 | 59.8 | 95.6 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 2.22 | 2.29 | 2.29 | 7.24 | 63.7 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

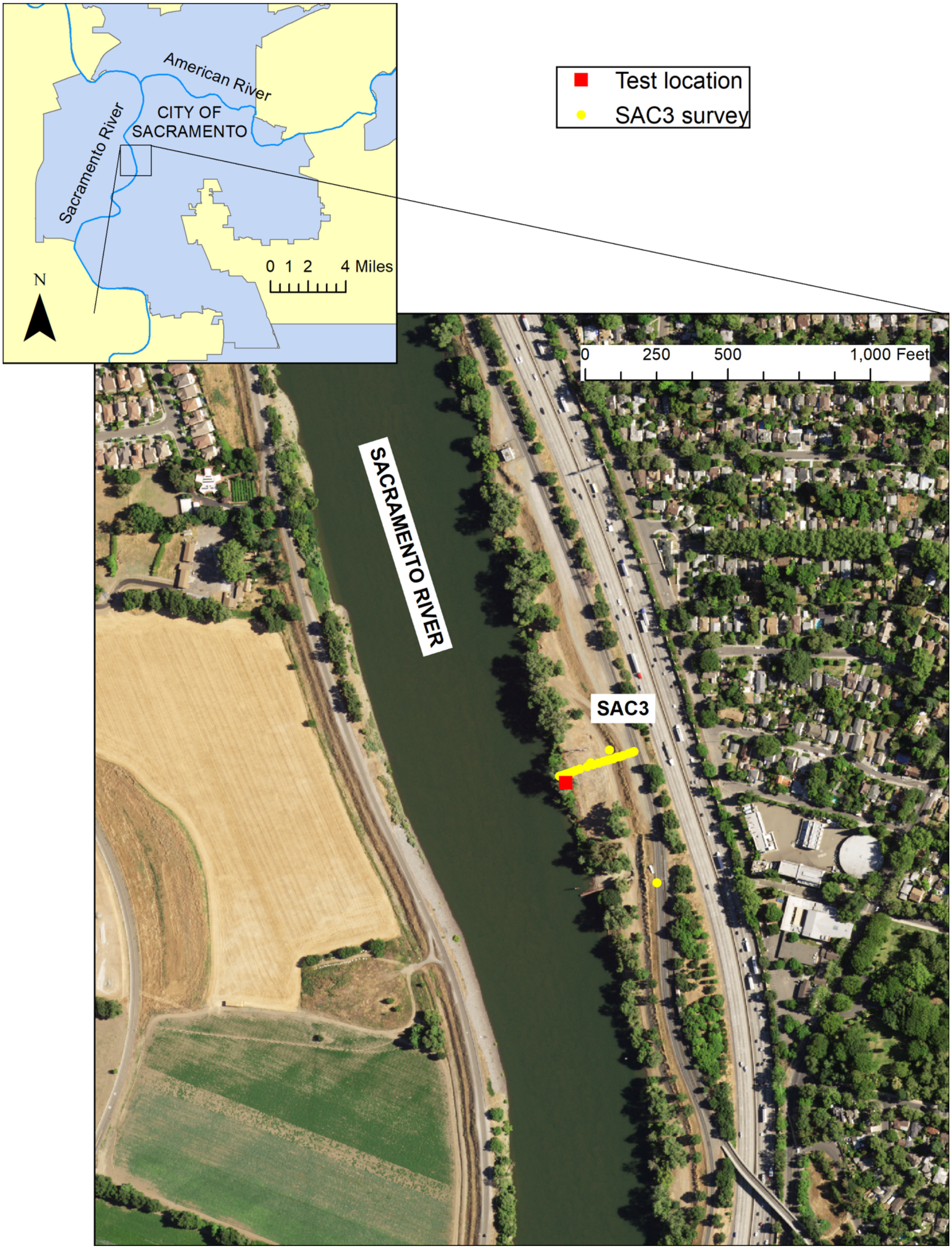

FIGURE 45 – MAP OF STUDY SITE SAC3 ON THE SACRAMENTO RIVER.

FIGURE 46 – PHOTOS OF STUDY SITE SAC3 ON THE SACRAMENTO RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

TABLE 26 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT ON THE LOWER JET LOCATION AT STUDY SITE SAC3 ON THE SACRAMENTO RIVER.

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 13.0 | 37.4 | 26.0 |
| | 1 | 14.0 | 27.1 | 2.0 |
| | 2 | 24.5 | 16.3 | 10.5 |
| | 3 | 25.0 | 13.4 | 0.5 |
| | 5 | 31.5 | 12.1 | 3.25 |
| | 7 | 33.0 | 10.7 | 0.75 |
| | 12 | 33.5 | 10.4 | 0.1 |

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **2** | 0 | 0 | - | - |
| | 0.5 | 6.5 | 23.3 | 13.0 |
| | 1 | 7.5 | 19.2 | 2.0 |
| | 2 | 8.0 | 15.6 | 0.5 |
| | 4 | 8.0 | 15.4 | 0 |
| | 8 | 8.0 | 15.4 | 0 |
| **3** | 0 | 0 | - | - |
| | 0.5 | 1.0 | 32.7 | 2.0 |
| | 1 | 3.5 | 29.7 | 5.0 |
| | 2 | 13.0 | 21.7 | 9.5 |
| | 3 | 20.0 | 15.2 | 7.0 |
| | 4 | 27.0 | 11.7 | 7.0 |
| | 5 | 27.5 | 10.3 | 0.5 |
| | 7 | 28.0 | 10.2 | 0.25 |
| | 11 | 28.0 | 10.1 | 0 |

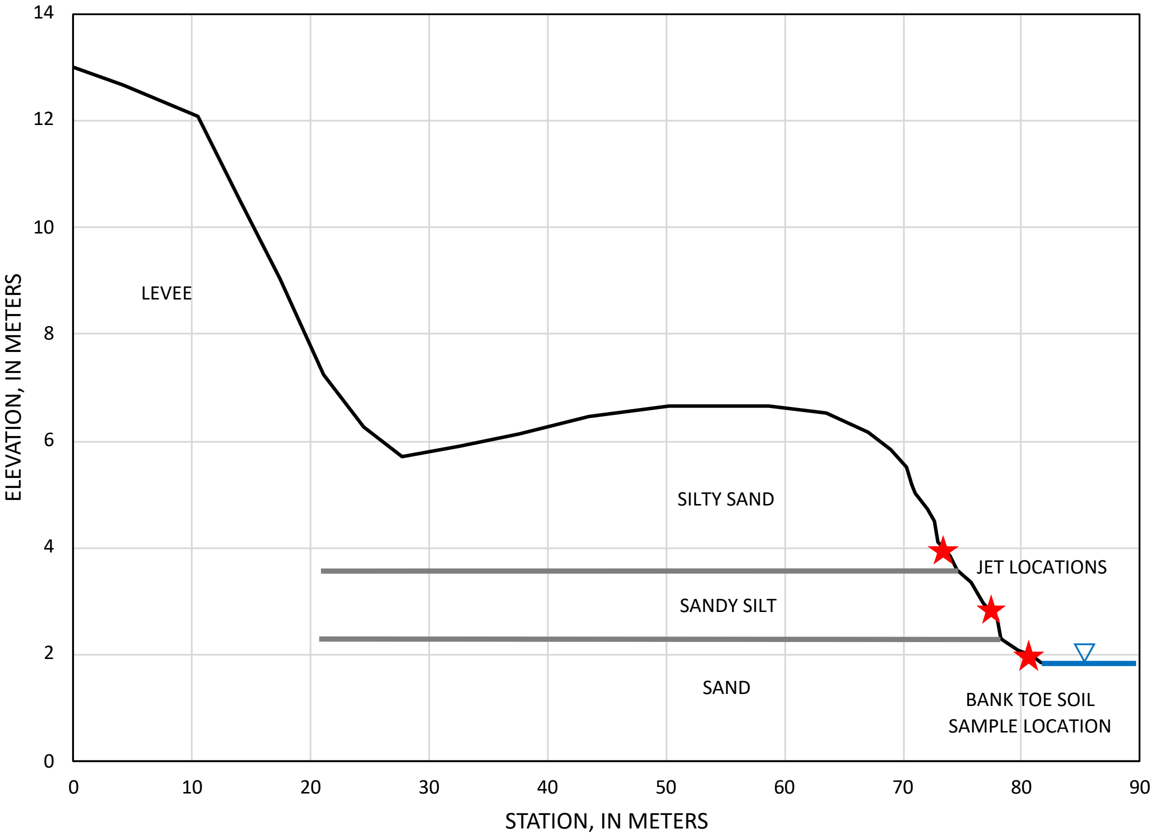

**FIGURE 47 – SURVEYED BANK PROFILE OF STUDY SITE SAC3 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF JETS, WATER SURFACE, AND BANK STRATIGRAPHY.**

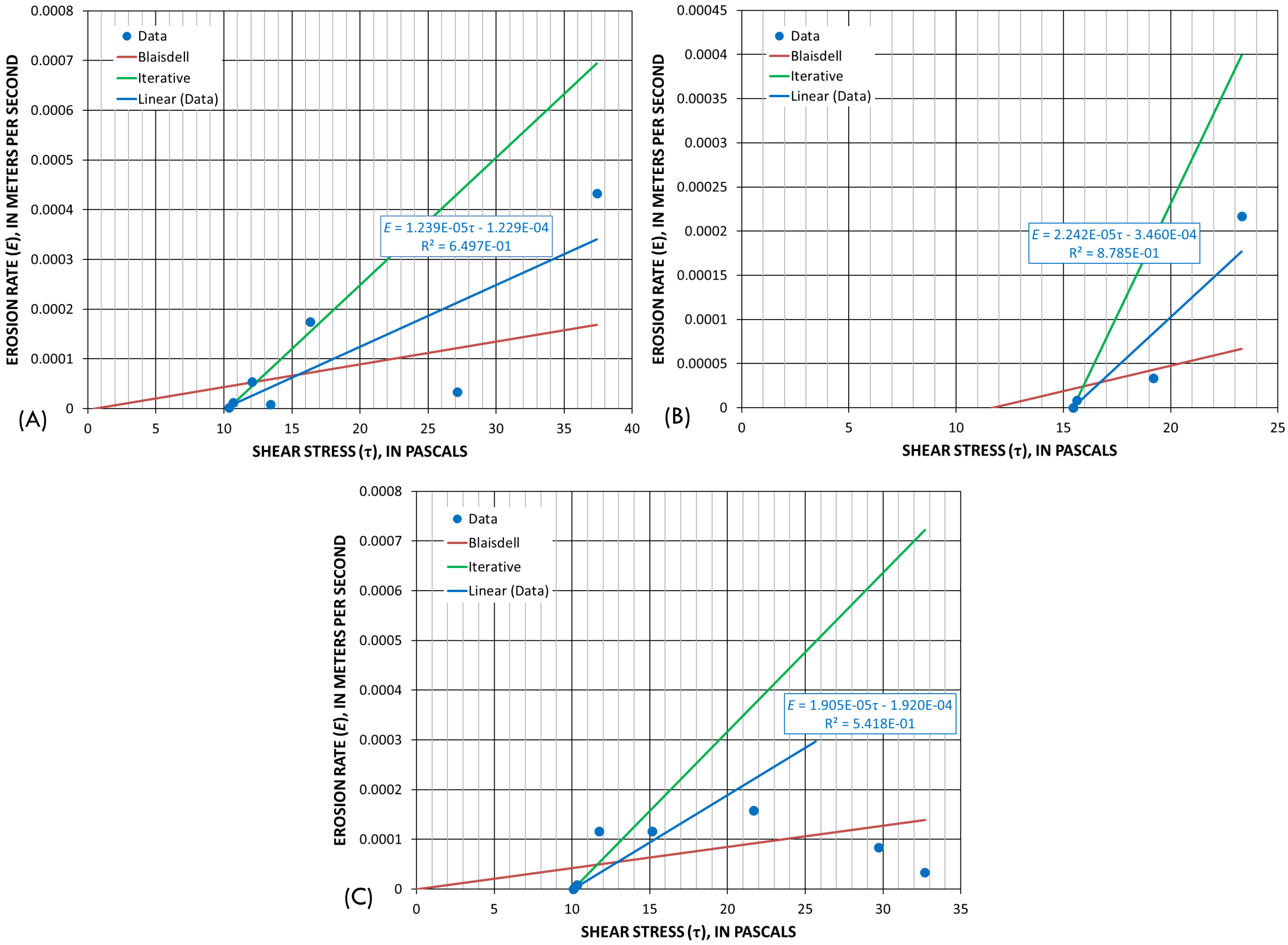

**FIGURE 48 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR THE LOWER JET LOCATION AT STUDY SITE SAC3 ON THE SACRAMENTO RIVER: (A) TEST ONE, (B) TEST TWO, AND (C) TEST THREE. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

**TABLE 27 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE SAC3 ON THE SACRAMENTO RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM $HR^{-1}$ $PA^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M $S^{-1}$ $PA^{-1}$: 1 M $S^{-1}$ $PA^{-1}$ = 360,000 CM $HR^{-1}$ $PA^{-1}$.**

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm $hr^{-1}$ $Pa^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 0.417 | 10.3 | 9.92 | 1.64 | 9.21 | 4.46 |
| **2** | 11.7 | 15.4 | 15.4 | 2.06 | 18.3 | 8.07 |
| **3** | 0.021 | 10.1 | 10.1 | 1.53 | 11.5 | 6.86 |
| **4** | 4.15 | 13.3 | 14.2 | 0.439 | 2.37 | 7.78 |
| **5** | 0.451 | 7.57 | 7.65 | 0.912 | 3.24 | 3.52 |
| **6** | 2.68 | 12.1 | 12.3 | 0.331 | 1.20 | 1.62 |

**TABLE 28 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT ON THE UPPER JET LOCATION AT STUDY SITE SAC3 ON THE SACRAMENTO RIVER.**

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm $\text{min}^{-1}$) |
|---|---|---|---|---|
| **4** | 0 | 0 | - | - |
| | 0.25 | 5.0 | 29.6 | 20.0 |
| | 0.5 | 8.0 | 23.6 | 12.0 |
| | 0.75 | 10.0 | 18.0 | 8.0 |
| | 1 | 11.0 | 17.4 | 4.0 |
| | 1.5 | 12.0 | 17.2 | 2.0 |
| | 2.5 | 14.0 | 16.1 | 2.0 |
| | 3.5 | 14.0 | 15.4 | 0 |
| | 5.5 | 15.0 | 15.1 | 0.5 |
| | 7.5 | 15.0 | 14.7 | 0 |
| | 12.5 | 16.0 | 14.4 | 0.2 |
| | 17.5 | 16.0 | 14.1 | 0 |
| | 22.5 | 17.0 | 13.8 | 0.2 |
| | 27.5 | 17.0 | 13.6 | 0 |
| | 32.5 | 17.0 | 13.6 | 0 |
| **5** | 0 | 0 | - | - |
| | 0.5 | 4.5 | 24.7 | 9.0 |
| | 1 | 7.0 | 20.5 | 5.0 |
| | 2 | 18.5 | 13.3 | 11.5 |
| | 3 | 19.0 | 10.3 | 0.5 |
| | 5 | 19.5 | 10.1 | 0.25 |
| | 9 | 20.5 | 9.80 | 0.25 |
| | 13 | 23.0 | 9.19 | 0.625 |
| | 17 | 26.0 | 8.35 | 0.75 |
| | 21 | 26.5 | 7.87 | 0.125 |
| **6** | 0 | 0 | - | - |
| | 0.5 | 2.0 | 23.3 | 4.0 |
| | 1 | 2.5 | 21.8 | 1.0 |
| | 2 | 5.0 | 19.0 | 2.5 |
| | 3 | 7.0 | 17.0 | 2.0 |
| | 5 | 8.0 | 15.8 | 0.5 |
| | 9 | 9.0 | 15.1 | 0.25 |
| | 13 | 10.0 | 14.4 | 0.25 |
| | 17 | 12.0 | 13.5 | 0.5 |
| | 21 | 12.5 | 12.8 | 0.125 |

## Study site SAC5

Study site SAC5 is located at latitude 38.51° N and longitude 121.53° W on the left bank of the Sacramento River (Figure 50). Notes describing the study site are found on page 94. Figure 51 shows photos of the bank face and upstream and downstream views. JETs and soil sampling for bulk density and grain-size analyses could not be carried out at this site because riprap and dense grasses covering the bank face.

The surveyed bank profile is shown in Figure 52. Based on visual observation, bank material is a sandy soil. The entire bank face, up to the toe of the levee, is protected by riprap. The levee face is covered by grasses.

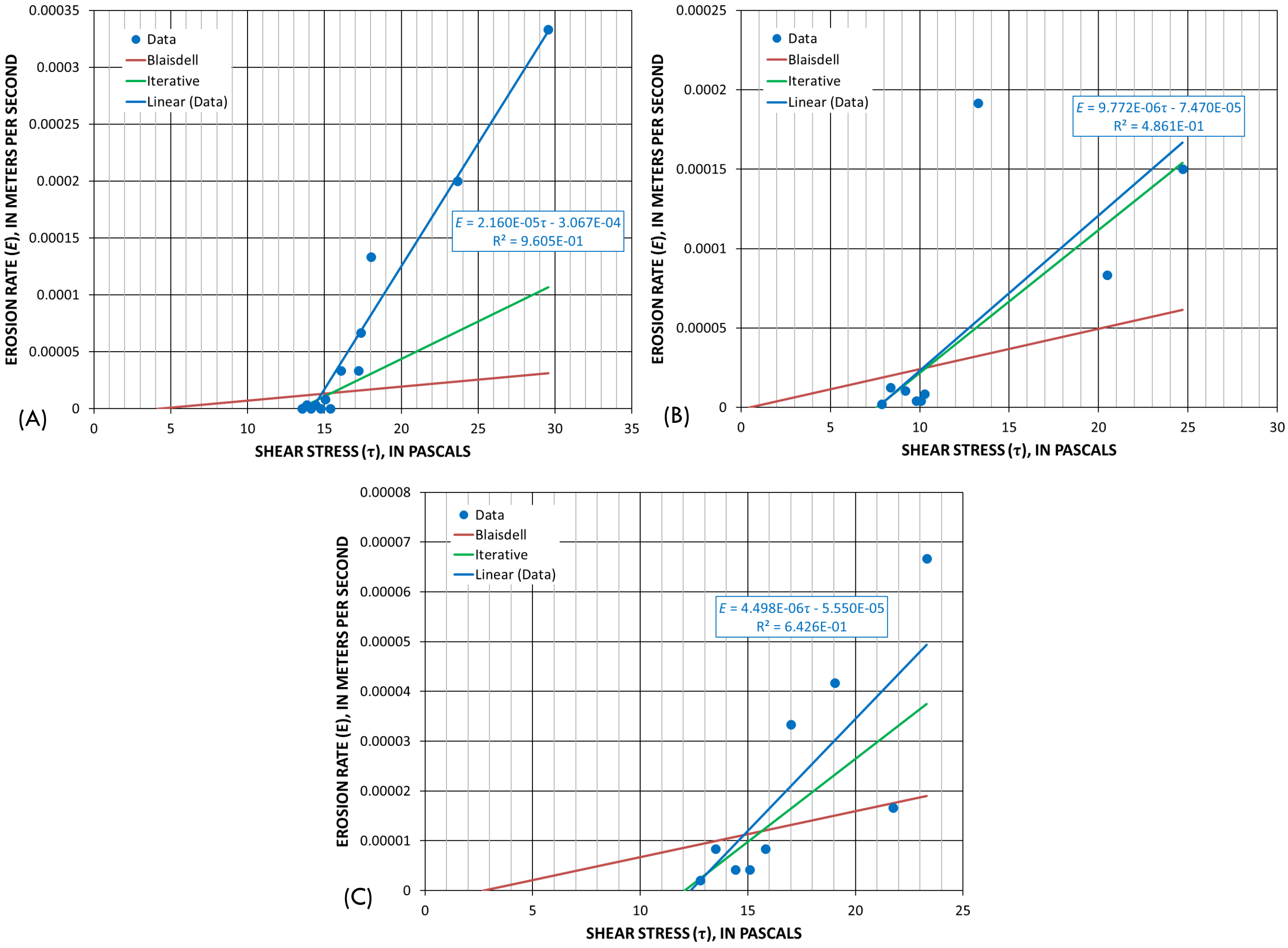

**FIGURE 49 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR THE UPPER JET LOCATION AT STUDY SITE SAC3 ON THE SACRAMENTO RIVER: (A) TEST FOUR, (B) TEST FIVE, AND (C) TEST SIX. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

## Study site SAC6

Study site SAC6 is located at latitude 38.51° N and longitude 121.55° W on the left bank of the Sacramento River (Figure 53). Notes describing the study site are found on page 95. Figure 54 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because riprap and abundant vegetation covering the bank face. Soil samples for grain-size and bulk density analyses were collected above the riprap at about 6 MASL.

The surveyed bank profile is shown in Figure 55. Bank material is a silty sand, which is protected at the toe by riprap, and riprap and vegetation along the upper portion of the bank. Table 29 lists the grain-size distribution of the bank material. The texture of the bank material sample is 10.8% clay, 24.2% silt, and 65.0% sand, and has a USCS classification of SM (silty sand). The measured dry density and saturated unit weight of the silty sand are 1.26 g $cm^{-3}$ and 17.6 kN $m^{-3}$, respectively.

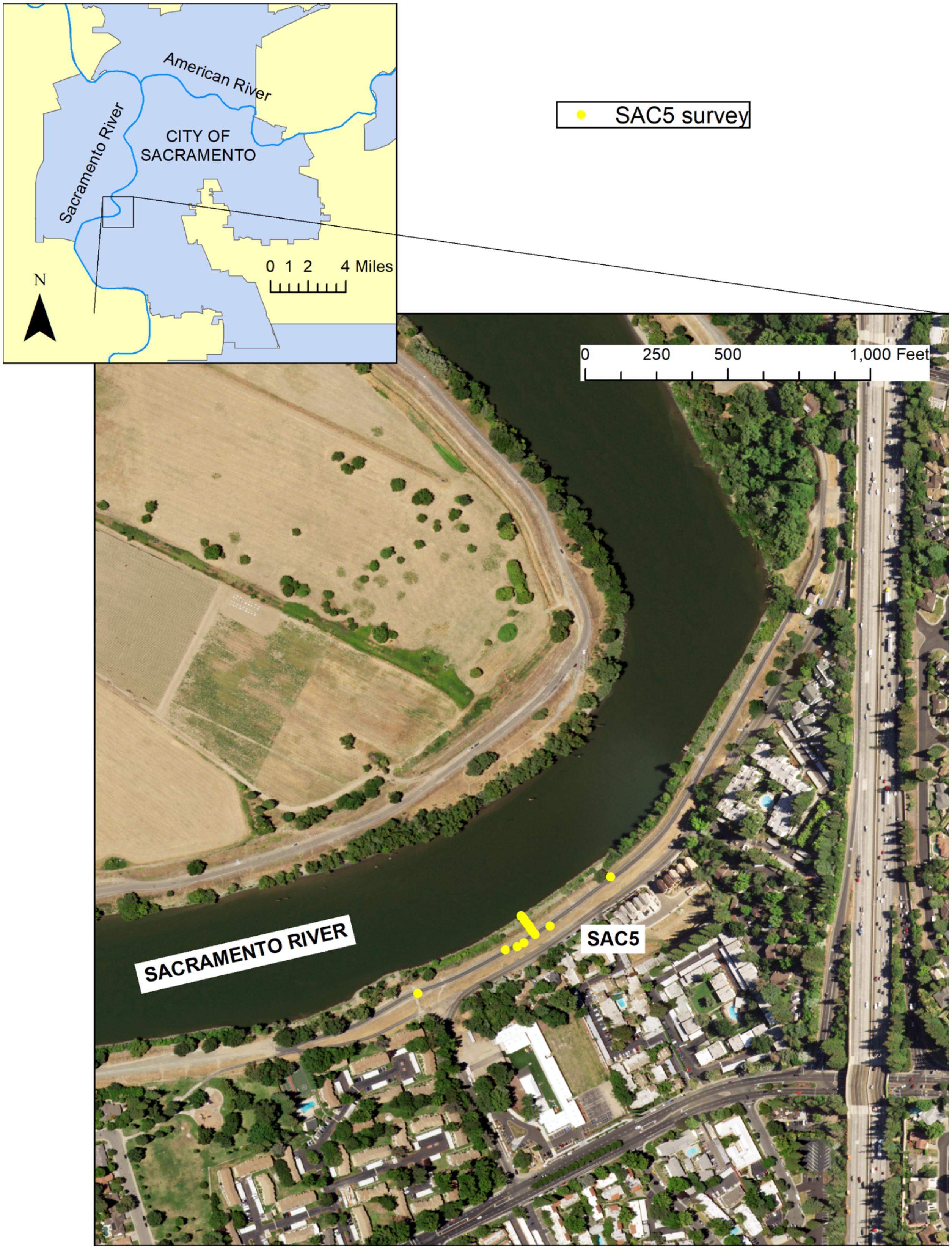

FIGURE 50 – MAP OF STUDY SITE SAC5 ON THE SACRAMENTO RIVER.

FIGURE 51 – PHOTOS OF STUDY SITE SAC5 ON THE SACRAMENTO RIVER: (A) BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

TABLE 29 – GRAIN-SIZE DISTRIBUTION OF BANK MATERIAL AT STUDY SITE SAC6 ON THE SACRAMENTO RIVER.

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | **Phi scale, $\phi = -\log_2 D$** | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 10.8 | 21.5 | 35.0 | 64.1 | 81.3 | 94.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

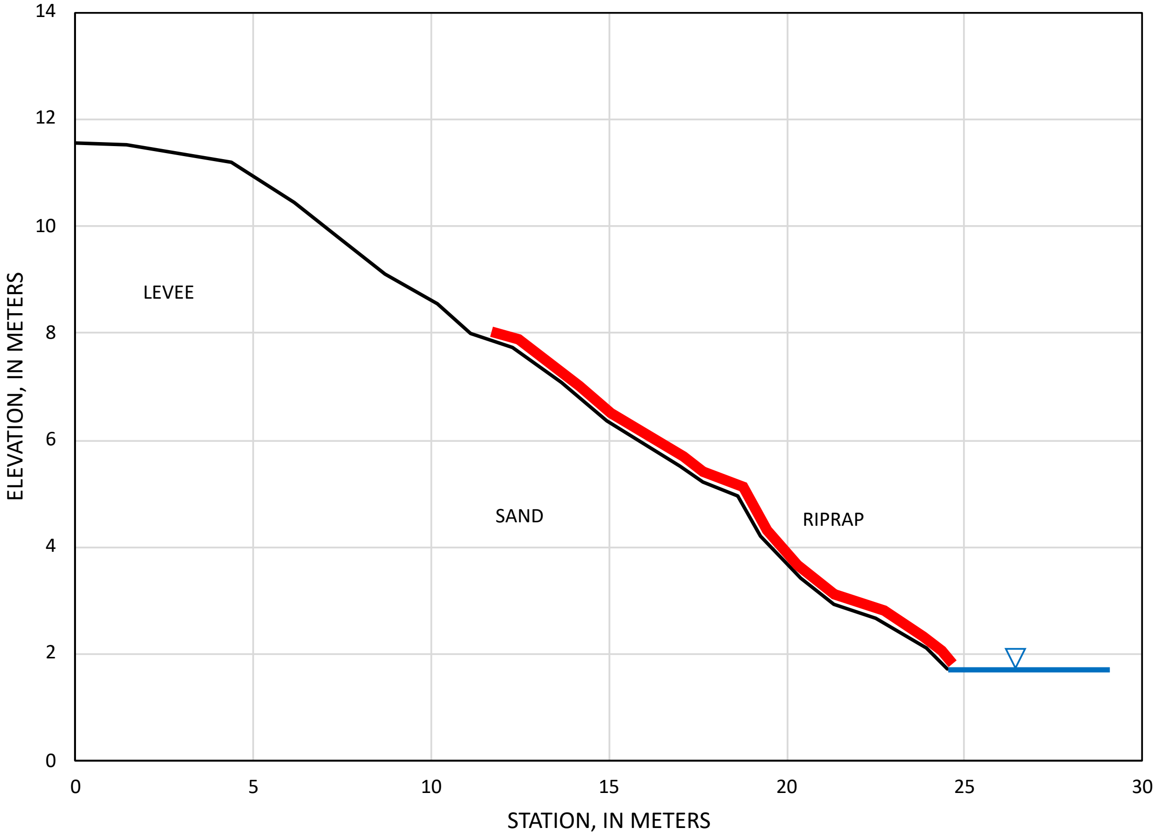

**FIGURE 52 – SURVEYED BANK PROFILE OF STUDY SITE SAC5 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF WATER SURFACE AND RIPRAP BANK PROTECTION.**

## Study site SAC7

Study site SAC7 is located at latitude 38.47° N and longitude 121.53° W, on the left bank of the Sacramento River (Figure 56). Notes describing the study site are found on page 96. Figure 57 shows photos of the bank face and upstream and downstream views. Three JETs were conducted at this site about 2 m above the water line. Soil samples were collected at the JET locations after completion of the JETs for grain-size and bulk density analyses. An additional sample of point bar/channel bed sediment was collected at the water line.

The surveyed bank profile is shown in Figure 58. Bank material is a silty sand. Table 30 lists the grain-size distributions of the silty sand and point-bar materials. The point-bar material was collected near the water line. The texture of the silty sand bank material is 10.7% clay, 35.6% silt, and 53.7% sand, and has a USCS classification of ML (silt). The measured dry density and saturated unit weight of the silty sand are: sample 1, 1.07 g cm$^{-3}$ and 16.4 kN m$^{-3}$, respectively; and sample 2, 1.03 g cm$^{-3}$ and 16.2 kN m$^{-3}$, respectively. The texture of the point-bar sample is 5.76% clay, 0.60% silt, and 93.6% sand, and has a USCS classification of SP-SM (poorly graded sand with silt).

The three JETs were conducted at a pressure head of 1.41 m, 1.76 m, and 2.11 m, which resulted in maximum initial applied shear stresses of 44.3 Pa, 48.4 Pa, and 59.7 Pa, respectively. Table 31 lists the measured erosion rate and shear stress time series during the three tests. Figure 59 presents the fitted excess shear stress relationships, Eq. (1), obtained using the Blaisdell, Iterative, and Linear Regression methods. Table 32 lists the derived fluvial erosion-resistance parameters $\tau_c$ and $k_d$.

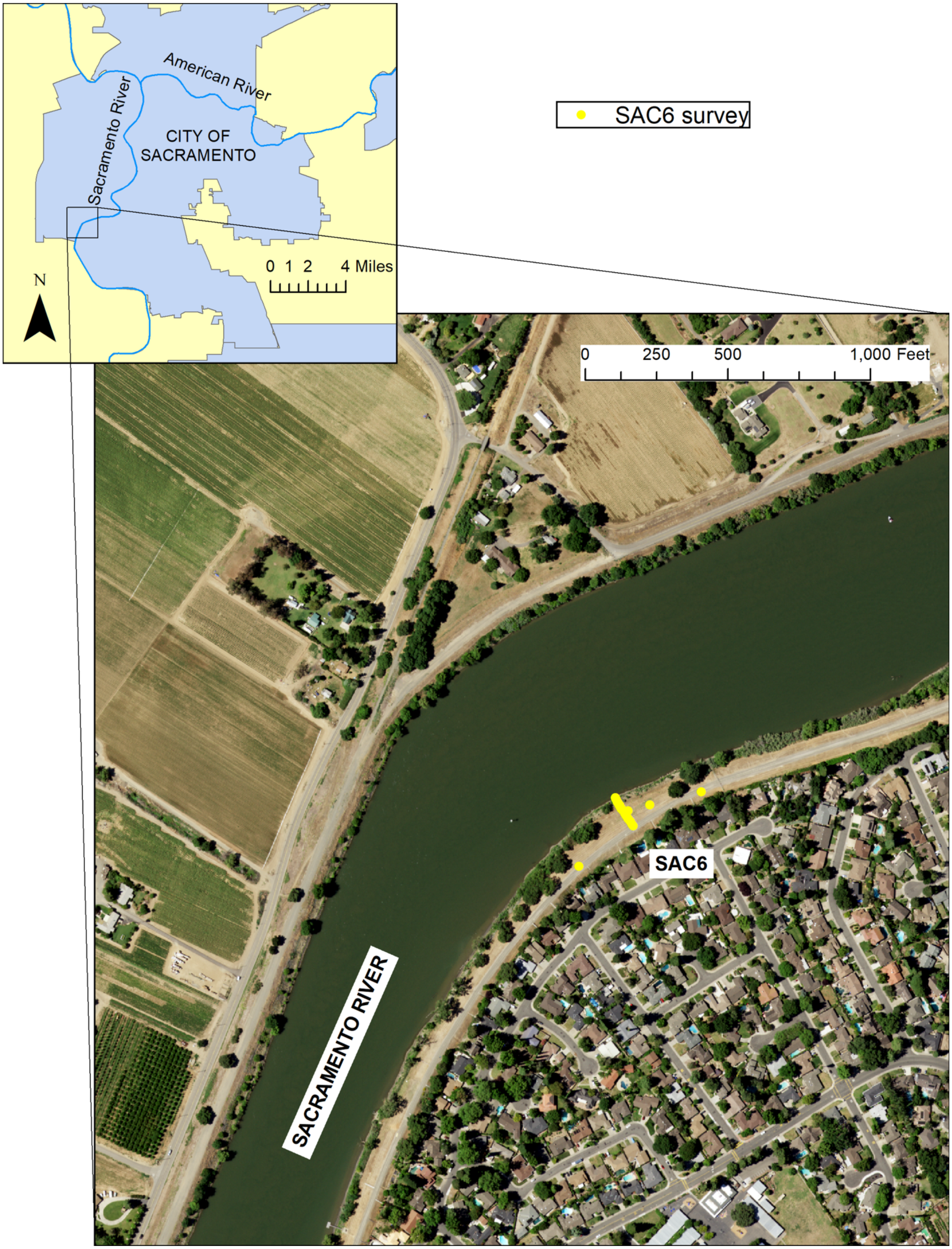

FIGURE 53 – MAP OF STUDY SITE SAC6 ON THE SACRAMENTO RIVER.

**FIGURE 54 – PHOTOS OF STUDY SITE SAC6 ON THE SACRAMENTO RIVER: (A) BANK SURFACE SEEN FROM BANK TOP, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.**

**TABLE 30 – GRAIN-SIZE DISTRIBUTIONS OF BANK (TOP ROW) AND POINT-BAR (BOTTOM ROW) MATERIALS AT STUDY SITE SAC7 ON THE SACRAMENTO RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 10.7 | 24.3 | 46.3 | 86.4 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **%Finer** | 5.76 | 6.24 | 6.36 | 31.0 | 98.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

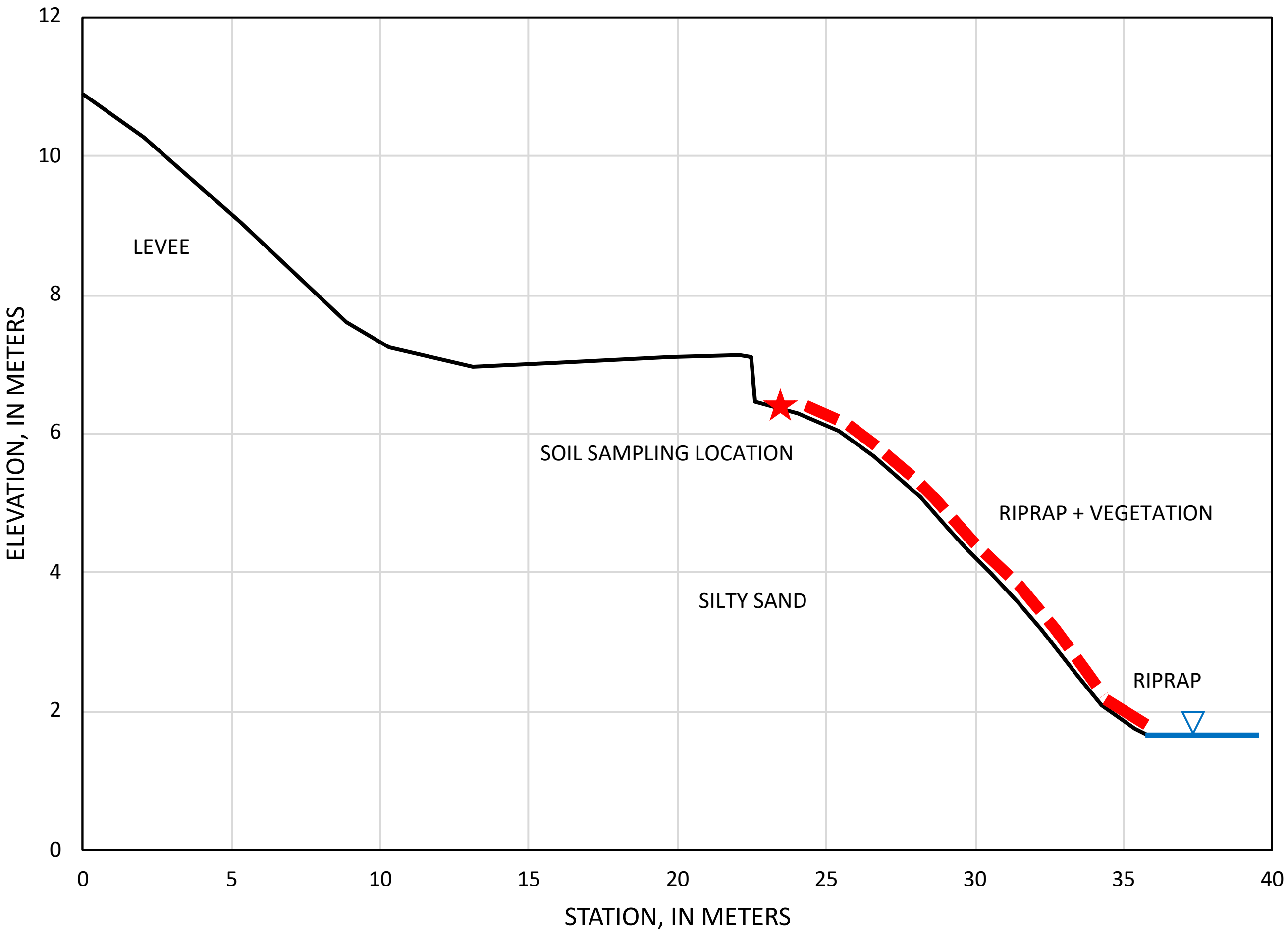

**FIGURE 55 – SURVEYED BANK PROFILE OF STUDY SITE SAC6 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF SOIL SAMPLING, WATER SURFACE, AND RIPRAP BANK PROTECTION.**

## Study site SAC8

Study site SAC8 is located at latitude 38.48° N and longitude 121.52° W on the left bank of the Sacramento River (Figure 60). Notes describing the study site are found on page 97. Figure 61 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because riprap and abundant vegetation covering the bank face. Soil samples for grain-size and bulk density analyses were collected from sediments deposited on the riprap.

The surveyed bank profile is shown in Figure 62. The bank face is completely protected by riprap and vegetation. The soil deposited between elevations of about 3 to 5 MASL is a silty sand. Table 33 lists the grain-size distribution of the deposited bank material. The texture of the deposit is 12.2% clay, 31.6% silt, and 56.2% sand, and has a USCS classification of ML (silt). The measured dry density and saturated unit weight of the deposited material are 1.04 g cm$^{-3}$ and 16.2 kN m$^{-3}$, respectively.

FIGURE 56 – MAP OF STUDY SITE SAC7 ON THE SACRAMENTO RIVER.

**FIGURE 57 – PHOTOS OF STUDY SITE SAC7 ON THE SACRAMENTO RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.**

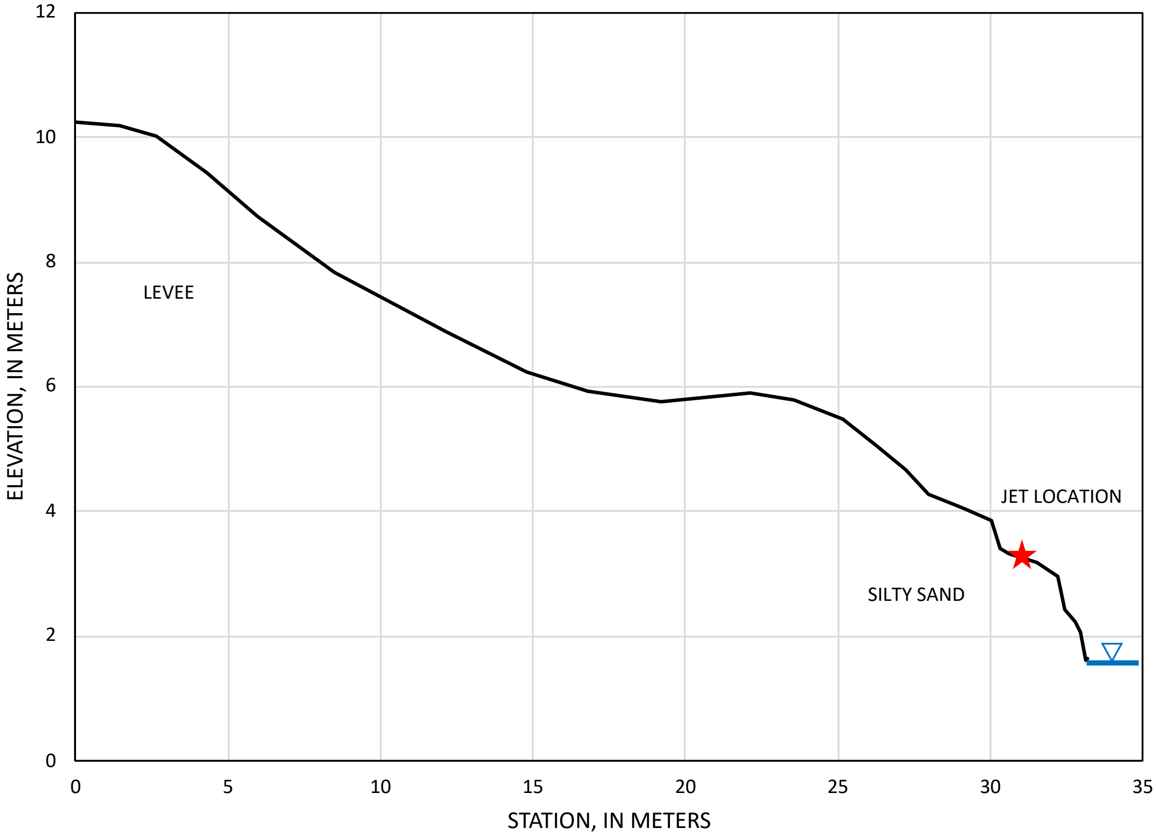

**FIGURE 58 – SURVEYED BANK PROFILE OF STUDY SITE SAC7 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF JETS, WATER SURFACE, AND BANK SOIL.**

**TABLE 31 – MEASURED EROSION RATE AND APPLIED SHEAR STRESS FOR JETS CARRIED OUT ON THE LOWER JET LOCATION AT STUDY SITE SAC7 ON THE SACRAMENTO RIVER.**

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **1** | 0 | 0 | - | - |
| | 0.5 | 3.5 | 44.3 | 7.0 |
| | 1 | 7.5 | 36.3 | 8.0 |
| | 1.5 | 8.0 | 29.4 | 1.0 |
| | 2.5 | 9.0 | 28.4 | 1.0 |
| | 5 | 9.5 | 27.4 | 0.2 |
| | 10 | 11.0 | 26.2 | 0.3 |
| | 15 | 12.5 | 24.5 | 0.3 |
| | 20 | 13.0 | 23.4 | 0.1 |

| Test | Time (min) | Scour depth (mm) | Shear stress (Pa) | Erosion rate (mm min$^{-1}$) |
|---|---|---|---|---|
| **2** | 0 | 0 | - | - |
| | 0.25 | 7.0 | 48.4 | 28.0 |
| | 0.5 | 11.0 | 37.1 | 16.0 |
| | 0.75 | 12.0 | 27.8 | 4.0 |
| | 1.25 | 17.0 | 24.7 | 10.0 |
| | 2 | 19.0 | 21.5 | 2.67 |
| | 3 | 19.0 | 20.8 | 0 |
| | 5 | 20.0 | 20.4 | 0.5 |
| | 7 | 20.0 | 20.0 | 0 |
| | 12 | 20.0 | 20.0 | 0 |
| | 22 | 21.0 | 19.7 | 0.1 |
| | 32 | 33.0 | 16.0 | 1.2 |
| | 42 | 38.0 | 12.3 | 0.5 |
| | 52 | 38.0 | 11.5 | 0 |
| **3** | 0 | 0 | - | - |
| | 0.5 | 8.5 | 59.7 | 17.0 |
| | 1 | 17.0 | 40.1 | 17.0 |
| | 2 | 20.0 | 25.5 | 3.0 |
| | 3 | 25.0 | 22.1 | 5.0 |
| | 4 | 27.5 | 19.5 | 2.5 |
| | 6 | 32.0 | 17.5 | 2.25 |
| | 8 | 36.5 | 15.3 | 2.25 |
| | 10 | 37.0 | 14.2 | 0.25 |
| | 14 | 37.0 | 14.1 | 0 |

TABLE 32 – JET TEST RESULTS USING BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE SAC7 ON THE SACRAMENTO RIVER. THE UNITS OF THE SOIL DETACHMENT COEFFICIENT ARE CM HR$^{-1}$ PA$^{-1}$ FOR DISPLAY PURPOSES. TO CONVERT TO M S$^{-1}$ PA$^{-1}$: 1 M S$^{-1}$ PA$^{-1}$ = 360,000 CM HR$^{-1}$ PA$^{-1}$.

| | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Test** | **Blaisdell** | **Iterative** | **Regression** | **Blaisdell** | **Iterative** | **Regression** |
| **1** | 6.84 | 23.0 | 24.7 | 0.260 | 1.15 | 2.53 |
| **2** | 1.85 | 10.1 | 16.9 | 0.320 | 0.740 | 4.7 |
| **3** | 0.201 | 13.3 | 14.0 | 0.975 | 3.33 | 2.72 |

TABLE 33 – GRAIN-SIZE DISTRIBUTION OF DEPOSITED BANK MATERIAL AT STUDY SITE SAC8 ON THE SACRAMENTO RIVER.

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 12.2 | 25.5 | 43.8 | 81.1 | 99.6 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

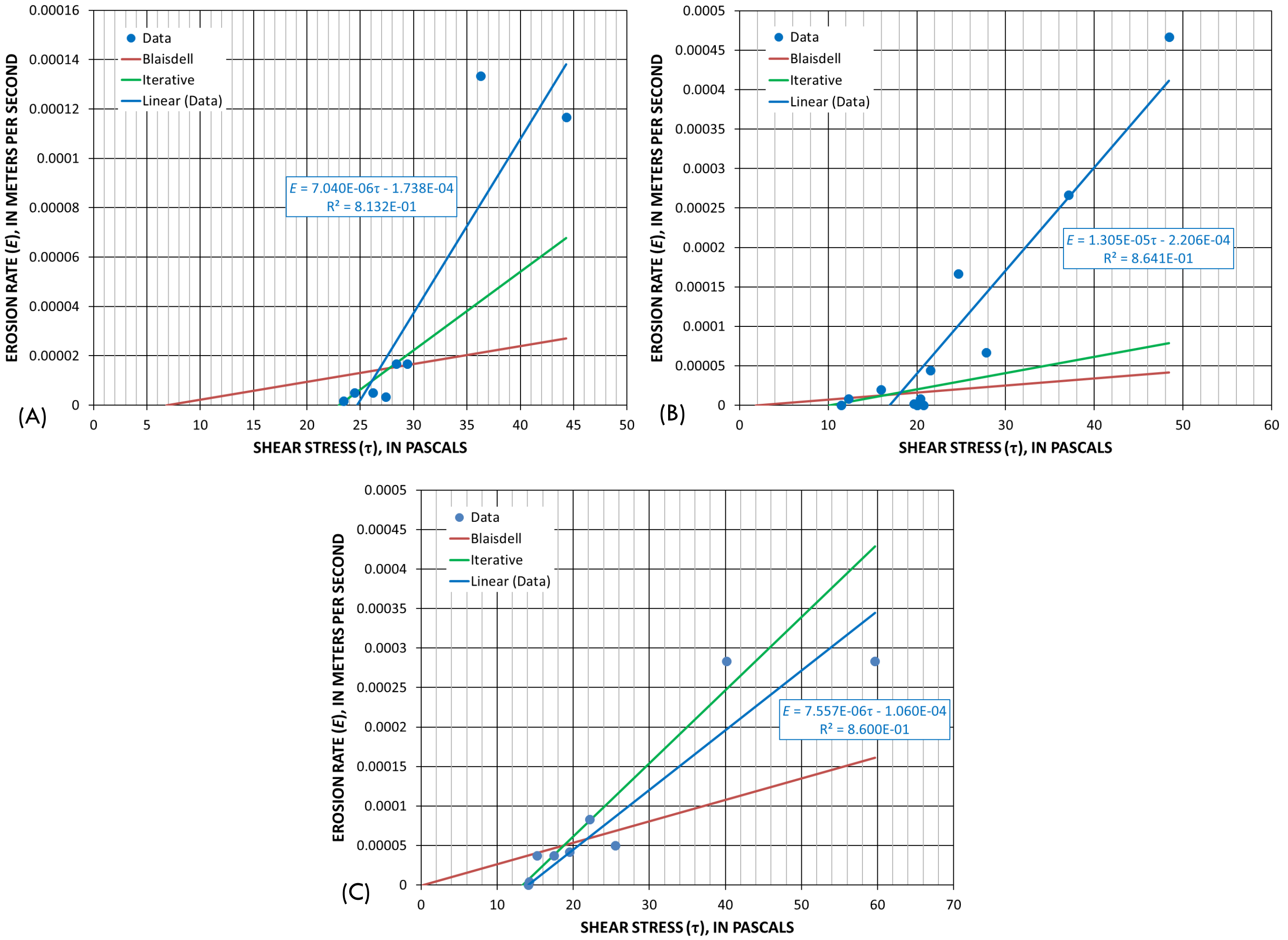

**FIGURE 59 – JET ANALYSIS USING THE BLAISDELL, ITERATIVE AND LINEAR REGRESSION METHODS FOR STUDY SITE SAC7 ON THE SACRAMENTO RIVER: (A) TEST ONE, (B) TEST TWO, AND (C) TEST THREE. THE REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION ($R^2$) FOR THE LINEAR REGRESSION METHOD ARE DISPLAYED ON THE GRAPHS.**

## Study site SAC9

Study site SAC9 is located at latitude 38.46° N and longitude 121.50° W on the left bank of the Sacramento River (Figure 63). Notes describing the study site are found on page 98. Figure 64 shows photos of the bank face and upstream and downstream views. JETs and soil sampling for bulk density and grain-size analyses could not be carried out at this site because riprap and vegetation covering the bank face.

The surveyed bank profile is shown in Figure 65. Based on visual observation, bank material is a silty sand. The entire bank face, up to the toe of the levee, is protected by a mix of cobble and riprap. The levee face is covered by grasses.

FIGURE 60 – MAP OF STUDY SITE SAC8 ON THE SACRAMENTO RIVER.

FIGURE 61 – PHOTOS OF STUDY SITE SAC8 ON THE SACRAMENTO RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

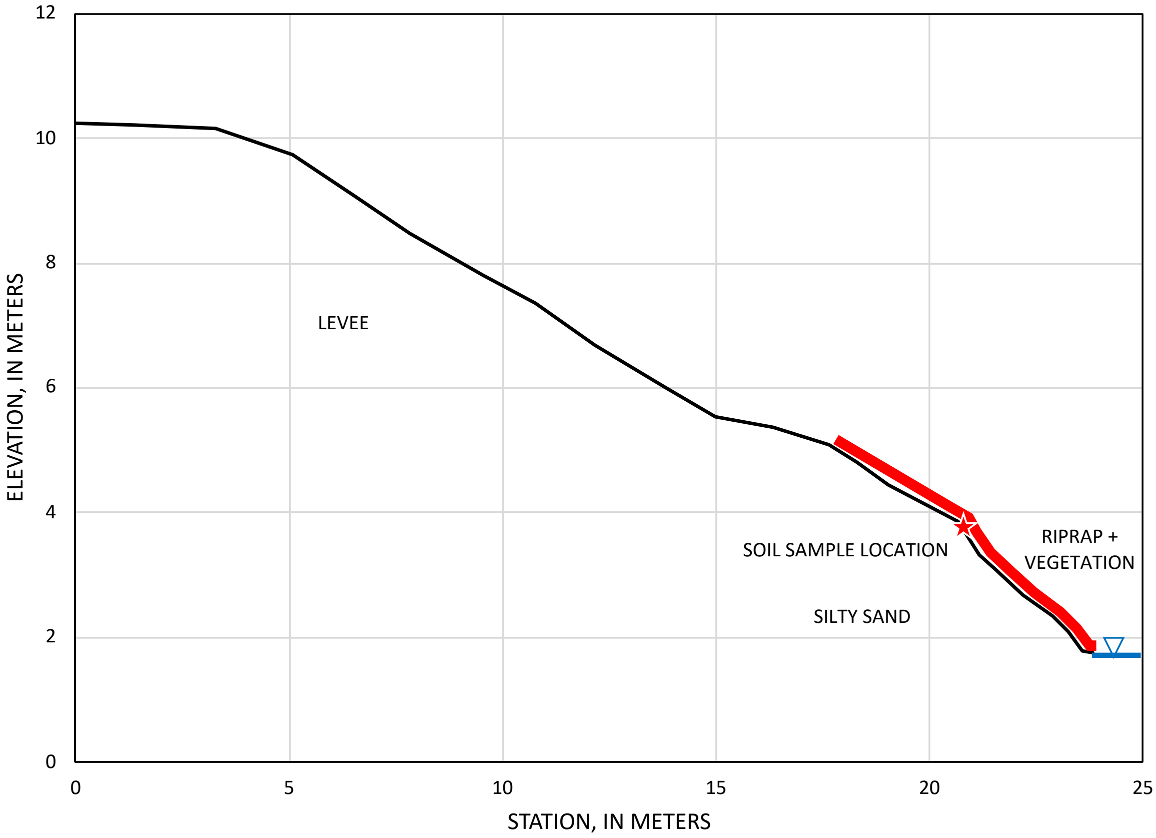

**FIGURE 62 – SURVEYED BANK PROFILE OF STUDY SITE SAC8 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF SOIL SAMPLE COLLECTION, WATER SURFACE, AND BANK PROTECTION.**

## Study site SAC10

Study site SAC10 is located at latitude 38.45° N and longitude 121.50° W on the left bank of the Sacramento River (Figure 66). Notes describing the study site are found on page 99. Figure 67 shows photos of the bank face and upstream and downstream views. JETs could not be carried out at this site because riprap/cobble mix and abundant vegetation covered the bank face. A soil sample for grain-size analysis was collected from sediments deposited on the riprap/cobble mix.

The surveyed bank profile is shown in Figure 68. The bank face is completely protected by riprap and vegetation. The soil deposited between elevations of about 2.5 to 4 MASL is a sandy silt. Table 34 lists the grain-size distribution of the deposited bank material. The texture of the deposit is 19.0% clay, 48.4% silt, and 32.6% sand, and has a USCS classification of ML (silt).

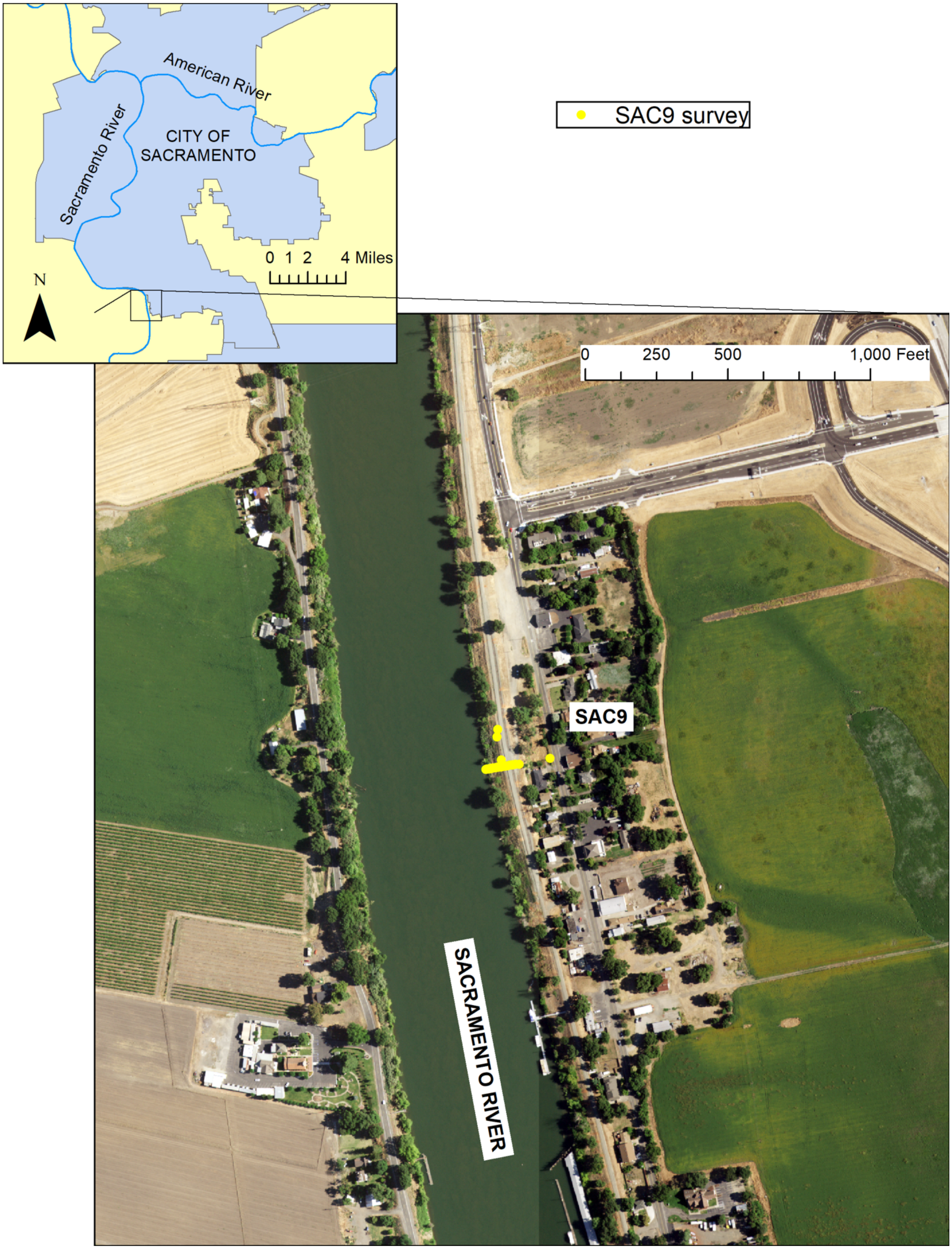

FIGURE 63 – MAP OF STUDY SITE SAC9 ON THE SACRAMENTO RIVER.

**FIGURE 64 – PHOTOS OF STUDY SITE SAC9 ON THE SACRAMENTO RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.**

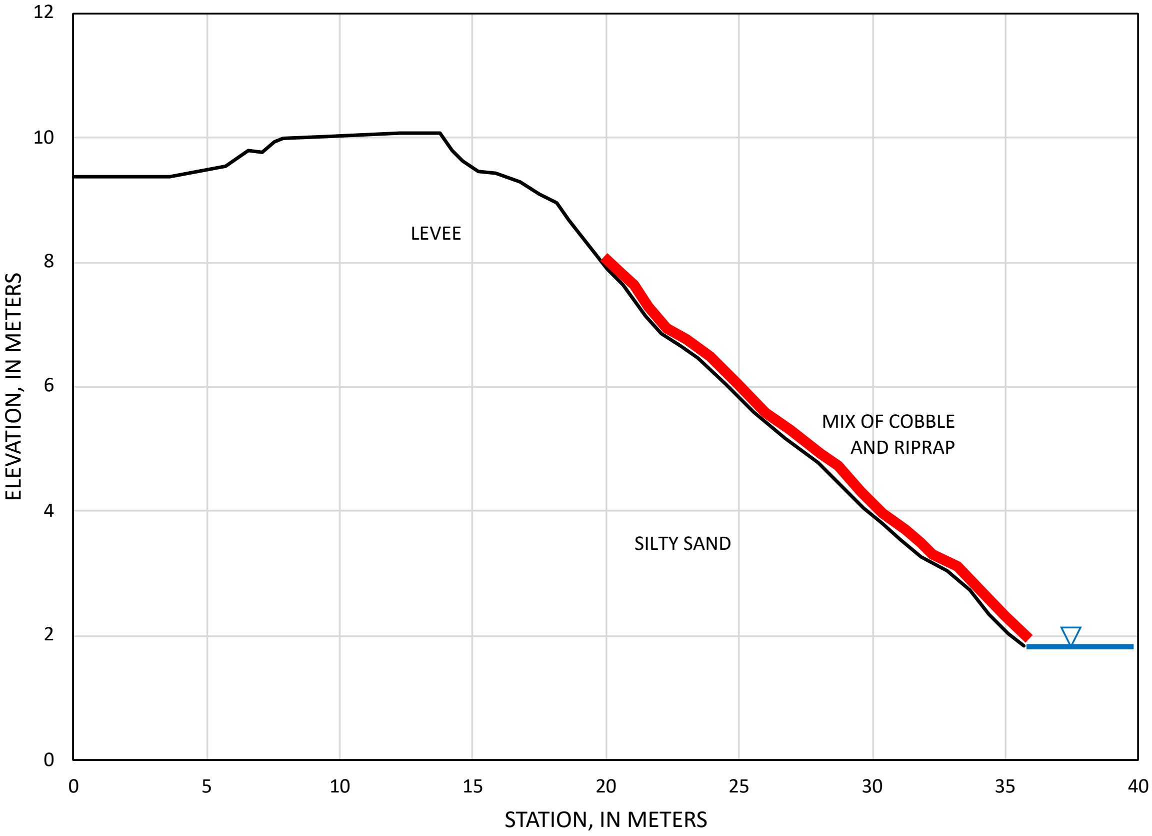

**FIGURE 65 – SURVEYED BANK PROFILE OF STUDY SITE SAC9 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF WATER SURFACE AND BANK PROTECTION.**

**TABLE 34 – GRAIN-SIZE DISTRIBUTION OF DEPOSITED BANK MATERIAL AT STUDY SITE SAC10 ON THE SACRAMENTO RIVER.**

| | Diameter ($D$) in millimeters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0.002** | **0.025** | **0.063** | **0.125** | **0.25** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | Phi scale, $\phi = -\log_2 D$ | | | | | | | | | | | | |
| | **9** | **5.3** | **4** | **3** | **2** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **%Finer** | 19.0 | 43.4 | 67.4 | 96.3 | 99.6 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

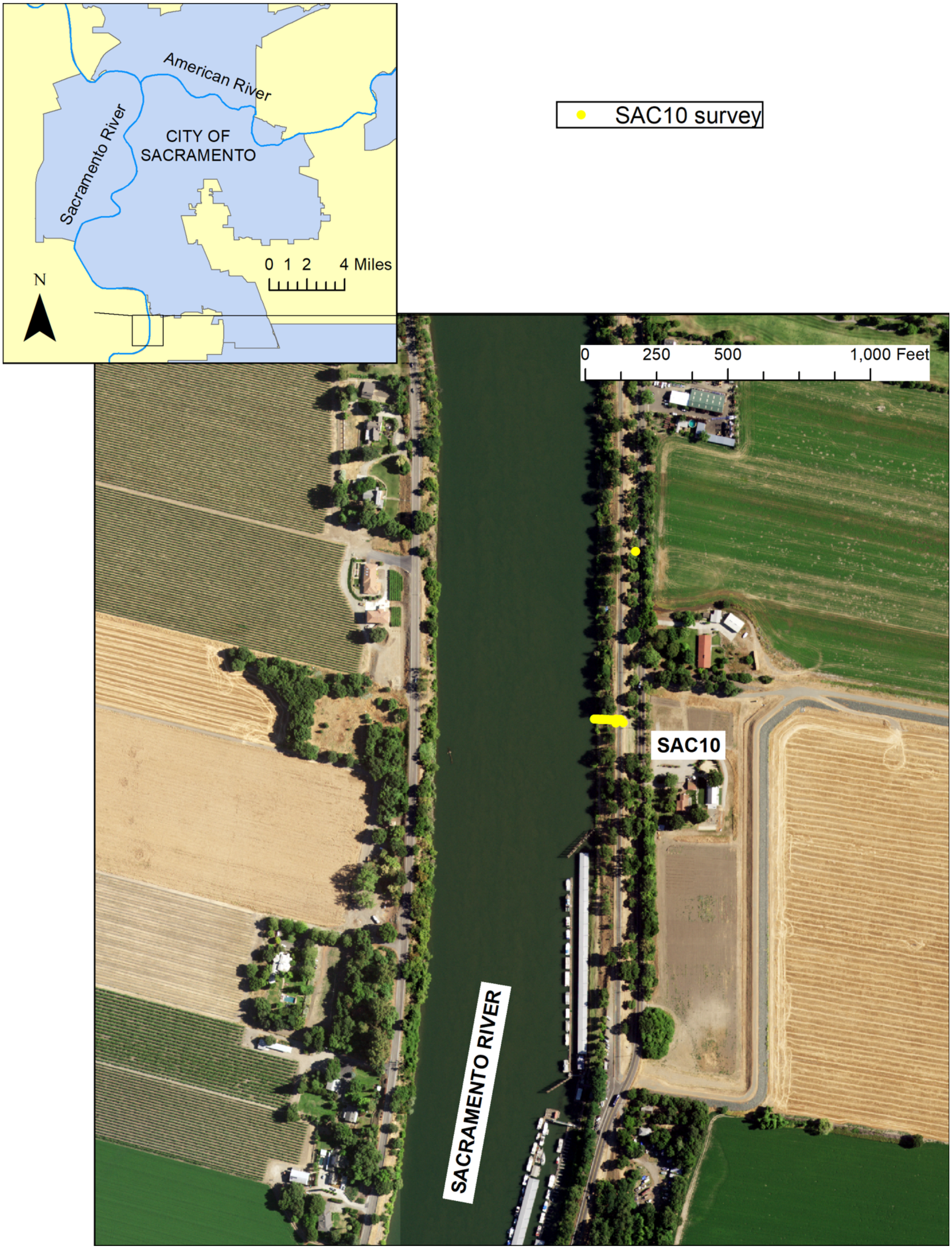

FIGURE 66 – MAP OF STUDY SITE SAC10 ON THE SACRAMENTO RIVER.

FIGURE 67 – PHOTOS OF STUDY SITE SAC10 ON THE SACRAMENTO RIVER: (A) FRONTAL VIEW OF BANK SURFACE, (B) VIEW UPSTREAM, AND (C) VIEW DOWNSTREAM.

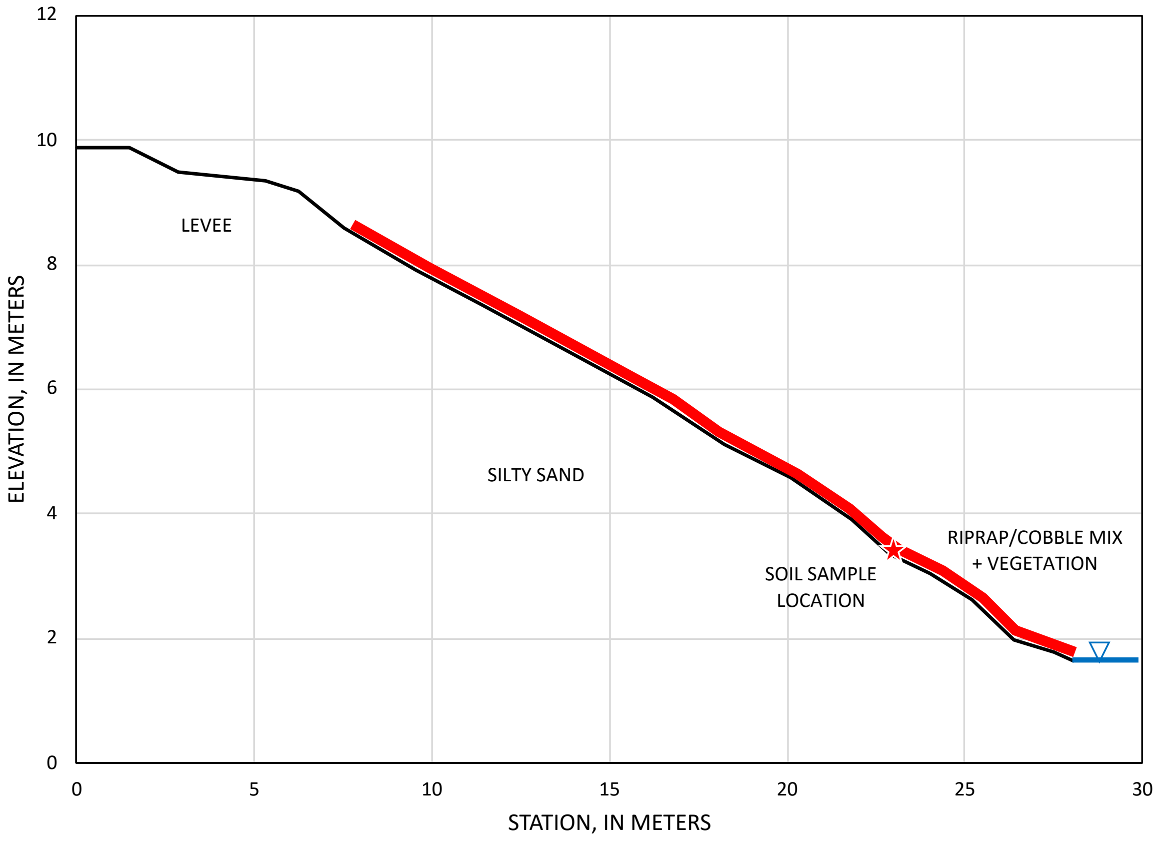

**FIGURE 68 – SURVEYED BANK PROFILE OF STUDY SITE SAC10 ON THE SACRAMENTO RIVER. GRAPH INDICATES APPROXIMATE LOCATIONS OF SOIL SAMPLE COLLECTION, WATER SURFACE, AND BANK PROTECTION.**

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# APPENDIX 1 DATA TABLES

## Bank soil density

| Site | Sample volume (cm$^3$) | Wet weight (g) | Dry weight (g) | Water weight (g) | Moisture content (-) | Solid volume (cm$^3$) | Void volume (cm$^3$) | Void ratio (-) | Saturation (-) | Dry density (g cm$^{-3}$) | Ambient density (g cm$^{-3}$) | Dry unit weight (kN m$^{-3}$) | Ambient unit weight (kN m$^{-3}$) | Saturated unit weight (kN m$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LAR1** | 103 | 133.95 | 108.94 | 25.01 | 0.23 | 40.35 | 62.65 | 1.55 | 0.40 | 1.06 | 1.30 | 10.38 | 12.76 | 16.34 |
| **LAR2** | 103 | 152.66 | 121.51 | 31.15 | 0.26 | 45.00 | 58.00 | 1.29 | 0.54 | 1.18 | 1.48 | 11.57 | 14.54 | 17.10 |
| **LAR4†** | 103 | 88.19 | 78.42 | 9.77 | 0.12 | 29.04 | 73.96 | 2.55 | 0.13 | 0.76 | 0.86 | 7.47 | 8.40 | 14.51 |
| **LAR5-1** | 103 | 169.14 | 127.73 | 41.41 | 0.32 | 47.31 | 55.69 | 1.18 | 0.74 | 1.24 | 1.64 | 12.17 | 16.11 | 17.47 |
| **LAR5-2** | 103 | 167.86 | 126.95 | 40.91 | 0.32 | 47.02 | 55.98 | 1.19 | 0.73 | 1.23 | 1.63 | 12.09 | 15.99 | 17.42 |
| **LAR8-1** | 103 | 148.43 | 125.65 | 22.78 | 0.18 | 46.54 | 56.46 | 1.21 | 0.40 | 1.22 | 1.44 | 11.97 | 14.14 | 17.34 |
| **LAR8-2** | 103 | 159.52 | 142.67 | 16.85 | 0.12 | 52.84 | 50.16 | 0.95 | 0.34 | 1.39 | 1.55 | 13.59 | 15.19 | 18.37 |
| **LAR9-1** | 103 | 172.31 | 129.41 | 42.90 | 0.33 | 47.93 | 55.07 | 1.15 | 0.78 | 1.26 | 1.67 | 12.33 | 16.41 | 17.57 |
| **LAR9-2** | 103 | 162.76 | 135.75 | 27.01 | 0.20 | 50.28 | 52.72 | 1.05 | 0.51 | 1.32 | 1.58 | 12.93 | 15.50 | 17.95 |
| **SAC3-1** | 103 | 117.53 | 103.39 | 14.14 | 0.14 | 38.29 | 64.71 | 1.69 | 0.22 | 1.00 | 1.14 | 9.85 | 11.19 | 16.01 |
| **SAC3-2** | 103 | 128.95 | 98.18 | 30.77 | 0.31 | 36.36 | 66.64 | 1.83 | 0.46 | 0.95 | 1.25 | 9.35 | 12.28 | 15.70 |
| **SAC6** | 103 | 143.39 | 129.95 | 13.44 | 0.10 | 48.13 | 54.87 | 1.14 | 0.24 | 1.26 | 1.39 | 12.38 | 13.66 | 17.60 |
| **SAC7-1** | 103 | 127.78 | 110.59 | 17.19 | 0.16 | 40.96 | 62.04 | 1.51 | 0.28 | 1.07 | 1.24 | 10.53 | 12.17 | 16.44 |
| **SAC7-2** | 103 | 121.70 | 106.03 | 15.67 | 0.15 | 39.27 | 63.73 | 1.62 | 0.25 | 1.03 | 1.18 | 10.10 | 11.59 | 16.17 |
| **SAC8** | 103 | 123.79 | 106.82 | 16.97 | 0.16 | 39.56 | 63.44 | 1.60 | 0.27 | 1.04 | 1.20 | 10.17 | 11.79 | 16.22 |
| **SAC55-1** | 103 | 140.12 | 115.90 | 24.22 | 0.21 | 42.93 | 60.07 | 1.40 | 0.40 | 1.13 | 1.36 | 11.04 | 13.35 | 16.76 |
| **SAC55-2** | 103 | 128.10 | 109.18 | 18.92 | 0.17 | 40.44 | 62.56 | 1.55 | 0.30 | 1.06 | 1.24 | 10.40 | 12.20 | 16.36 |

† Part of the sample fell out of its sleeve. The dry density value may therefore be too low.

## Grain size distribution and soil type

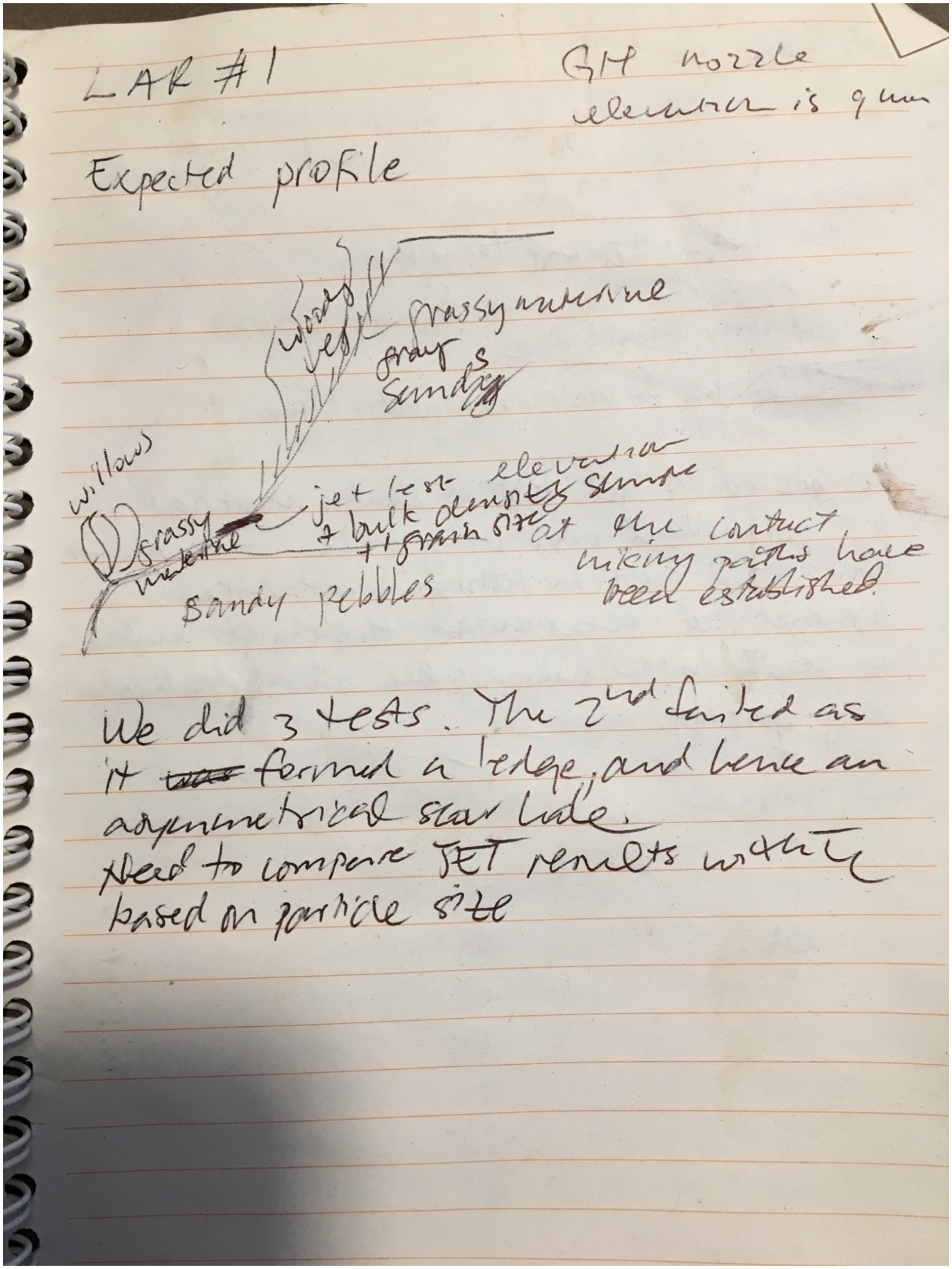
| | | | %Finer | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Diameter (D) in millimeters** | **0.002** | **0.025** | **0.063** | **0.088** | **0.125** | **0.177** | **0.25** | **0.354** | **0.5** | **1.41** | **2.0** | **2.83** | **4.0** | **5.66** | **8.0** | **11.3** |
| | **USCS** | **Phi scale, $\phi = -\log_2 D$** | **9** | **5.3** | **4** | **3.5** | **3** | **2.5** | **2** | **1.5** | **1** | **-0.5** | **-1** | **-1.5** | **-2** | **-2.5** | **-3** | **-3.5** |
| **Study site** | **type** | **Location** | | | | | | | | | | | | | | | | |
| **LAR1** | SM | Mid bank | 7.79 | 12.6 | 18.7 | 26.3 | 42.3 | 67.8 | 88.0 | 98.1 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR2** | SM | Mid bank | 9.54 | 16.7 | 22.8 | 29.9 | 40.7 | 61.6 | 81.6 | 95.8 | 98.6 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR3** | SM | Upper bank | 10.3 | 23.9 | 40.5 | 54.9 | 72.2 | 88.6 | 96.1 | 99.2 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR4** | SM | Mid bank | 8.80 | 15.2 | 23.0 | 31.8 | 47.4 | 70.3 | 86.9 | 97.0 | 99.1 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR5** | SM | Lower bank | 6.75 | 9.32 | 11.8 | 16.0 | 25.1 | 54.4 | 83.6 | 98.0 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR5** | SM | Toe | 6.53 | 9.91 | 13.1 | 19.0 | 31.3 | 57.8 | 80.4 | 97.0 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR7** | SM | Lower bank | 8.86 | 20.4 | 35.6 | 48.2 | 66.2 | 83.6 | 92.7 | 98.4 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR8** | SM | Upper bank | 14.4 | 29.3 | 45.3 | 51.7 | 58.4 | 66.4 | 73.6 | 83.4 | 90.1 | 96.6 | 96.6 | 97.2 | 97.7 | 98.5 | 99.8 | 100 |
| **LAR8** | SP-SM | Lower bank | 5.03 | 6.94 | 7.74 | 10.7 | 16.6 | 33.2 | 52.3 | 69.7 | 84.9 | 99.2 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR9** | ML | Upper bank | 10.5 | 32.1 | 62.0 | 78.9 | 88.4 | 94.4 | 97.3 | 99.0 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR9** | SM | Lower bank | 12.4 | 26.5 | 38.7 | 46.5 | 56.1 | 69.2 | 80.2 | 91.4 | 96.5 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR9** | ML | Toe | 11.6 | 28.1 | 45.2 | 57.7 | 73.6 | 90.4 | 97.7 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR10** | SM | Mid bank | 7.84 | 16.9 | 32.2 | 43.6 | 58.0 | 74.6 | 85.3 | 92.9 | 95.7 | 98.7 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR10** | SP-SM | Toe | 4.87 | 5.19 | 5.52 | 7.07 | 11.1 | 21.8 | 38.8 | 68.7 | 90.4 | 99.7 | 100 | 100 | 100 | 100 | 100 | 100 |
| **LAR11** | SM | Mid bank | 6.78 | 8.78 | 11.2 | 15.6 | 25.7 | 51.4 | 85.6 | 98.8 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC1** | SM | Lower bank | 8.43 | 12.1 | 13.9 | 19.3 | 31.9 | 59.8 | 87.5 | 98.8 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC3** | ML | Mid bank | 10.8 | 25.5 | 47.0 | 61.5 | 81.0 | 93.8 | 97.8 | 99.2 | 99.6 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC3** | ML | Lower bank | 12.5 | 32.6 | 59.8 | 82.0 | 95.6 | 99.4 | 99.8 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC3** | SP | Toe | 2.22 | 2.29 | 2.29 | 3.07 | 7.24 | 25.5 | 63.7 | 98.5 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC6** | SM | Upper bank | 10.8 | 21.5 | 35.0 | 48.2 | 64.1 | 76.8 | 81.3 | 87.8 | 94.7 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC7** | ML | Mid bank | 10.7 | 24.3 | 46.3 | 61.7 | 86.4 | 98.8 | 99.8 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC7** | SP-SM | Toe/Bed | 5.76 | 6.24 | 6.36 | 11.7 | 31.0 | 84.2 | 98.9 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC8** | ML | Mid bank | 12.2 | 25.5 | 43.8 | 57.8 | 81.1 | 97.3 | 99.6 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC10** | ML | Lower bank | 19.0 | 43.4 | 67.4 | 85.1 | 96.3 | 99.3 | 99.6 | 99.8 | 99.9 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **SAC55** | ML | Upper bank | 27.7 | 77.4 | 94.8 | 96.5 | 97.6 | 98.5 | 99.0 | 99.5 | 99.8 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

# Bank soil resistance to fluvial erosion

| | | Metric units | | | | | | English units | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Critical shear stress (Pa) | | | Soil detachment coefficient (cm hr$^{-1}$ Pa$^{-1}$) | | | Critical shear stress (psf) | | | Soil detachment coefficient (ft$^{3}$ lb-f$^{-1}$ hr$^{-1}$) | | |
| Study site | Test | Blaisdell | Iterative | Regression | Blaisdell | Iterative | Regression | Blaisdell | Iterative | Regression | Blaisdell | Iterative | Regression |
| **LAR1** | 1 | 3.74 | 10.0 | 10.1 | 0.951 | 5.42 | 0.835 | 0.0781 | 0.209 | 0.211 | 1.49 | 8.51 | 1.31 |
| | 2 | 0.075 | 2.33 | 2.57 | 5.19 | 12.0 | 11.9 | 0.00157 | 0.0487 | 0.0537 | 8.15 | 18.9 | 18.7 |
| **LAR2** | 1 | 0.139 | 2.05 | 2.05 | 7.42 | 18.0 | 8.73 | 0.00290 | 0.0428 | 0.0428 | 11.7 | 28.3 | 13.7 |
| **LAR4** | 1 | 1.28 | 6.21 | 6.38 | 0.822 | 3.53 | 4.03 | 0.0267 | 0.130 | 0.133 | 1.29 | 5.55 | 6.33 |
| **LAR5** | 1 | 0.256 | 7.66 | 7.42 | 5.64 | 40.5 | 20.9 | 0.00535 | 0.160 | 0.155 | 8.86 | 63.6 | 32.8 |
| | 2 | 5.25 | 6.07 | 6.07 | 12.5 | 65.2 | 19.3 | 0.110 | 0.127 | 0.127 | 19.6 | 102.4 | 30.3 |
| | 3 | 0.004 | 0.871 | 0.408 | 30.1 | 51.8 | 27.2 | 8.36 x 10$^{-5}$ | 0.0182 | 0.00852 | 47.3 | 81.4 | 42.7 |
| **LAR8** | 1 | 0.186 | 4.96 | 4.23 | 4.96 | 23.9 | 10.7 | 0.00389 | 0.104 | 0.0884 | 7.79 | 37.5 | 16.8 |
| | 2 | 0.007 | 0.00 | 1.45 | 5.34 | 5.34 | 3.64 | 1.46 x 10$^{-4}$ | 0 | 0.0303 | 8.39 | 8.39 | 5.72 |
| | 3 | 0.349 | 6.76 | 8.03 | 0.836 | 1.86 | 3.17 | 0.00729 | 0.141 | 0.168 | 1.31 | 2.92 | 4.98 |
| **LAR9** | 1 | 0.048 | 4.35 | 4.27 | 4.28 | 15.4 | 8.42 | 0.00100 | 0.0909 | 0.0892 | 6.72 | 24.2 | 13.2 |
| | 2 | 3.10 | 21.0 | 20.5 | 0.432 | 2.44 | 1.75 | 0.0648 | 0.439 | 0.428 | 0.679 | 3.83 | 2.75 |
| | 3 | 5.15 | 20.3 | 20.2 | 0.509 | 2.34 | 2.51 | 0.108 | 0.424 | 0.422 | 0.800 | 3.68 | 3.94 |
| **SAC3** | 1 | 0.417 | 10.3 | 9.92 | 1.64 | 9.21 | 4.46 | 0.00871 | 0.215 | 0.207 | 2.58 | 14.5 | 7.01 |
| | 2 | 11.7 | 15.4 | 15.4 | 2.06 | 18.3 | 8.07 | 0.244 | 0.322 | 0.322 | 3.24 | 28.7 | 12.7 |
| | 3 | 0.021 | 10.1 | 10.1 | 1.53 | 11.5 | 6.86 | 4.39 x 10$^{-4}$ | 0.211 | 0.211 | 2.40 | 18.1 | 10.8 |
| | 4 | 4.15 | 13.3 | 14.2 | 0.439 | 2.37 | 7.78 | 0.0867 | 0.278 | 0.297 | 0.690 | 3.72 | 12.2 |
| | 5 | 0.451 | 7.57 | 7.65 | 0.912 | 3.24 | 3.52 | 0.00942 | 0.158 | 0.160 | 1.43 | 5.09 | 5.53 |
| | 6 | 2.68 | 12.1 | 12.3 | 0.331 | 1.20 | 1.62 | 0.0560 | 0.253 | 0.257 | 0.520 | 1.89 | 2.54 |
| **SAC7** | 1 | 6.84 | 23.0 | 24.7 | 0.260 | 1.15 | 2.53 | 0.143 | 0.480 | 0.516 | 0.408 | 1.81 | 3.97 |
| | 2 | 1.85 | 10.1 | 16.9 | 0.320 | 0.740 | 4.70 | 0.0386 | 0.211 | 0.353 | 0.503 | 1.16 | 7.38 |
| | 3 | 0.201 | 13.3 | 14.0 | 0.975 | 3.33 | 2.72 | 0.00420 | 0.278 | 0.292 | 1.53 | 5.23 | 4.27 |

# APPENDIX 2 NOTES

## LAR1



LAR #1

GH nozzle elevation is 9 mm

Expected profile

woody veg

grassy waterline

gray sandy s

willows

grassy waterline

jet test elevation

+ bulk density sample

+ grain size at the contact

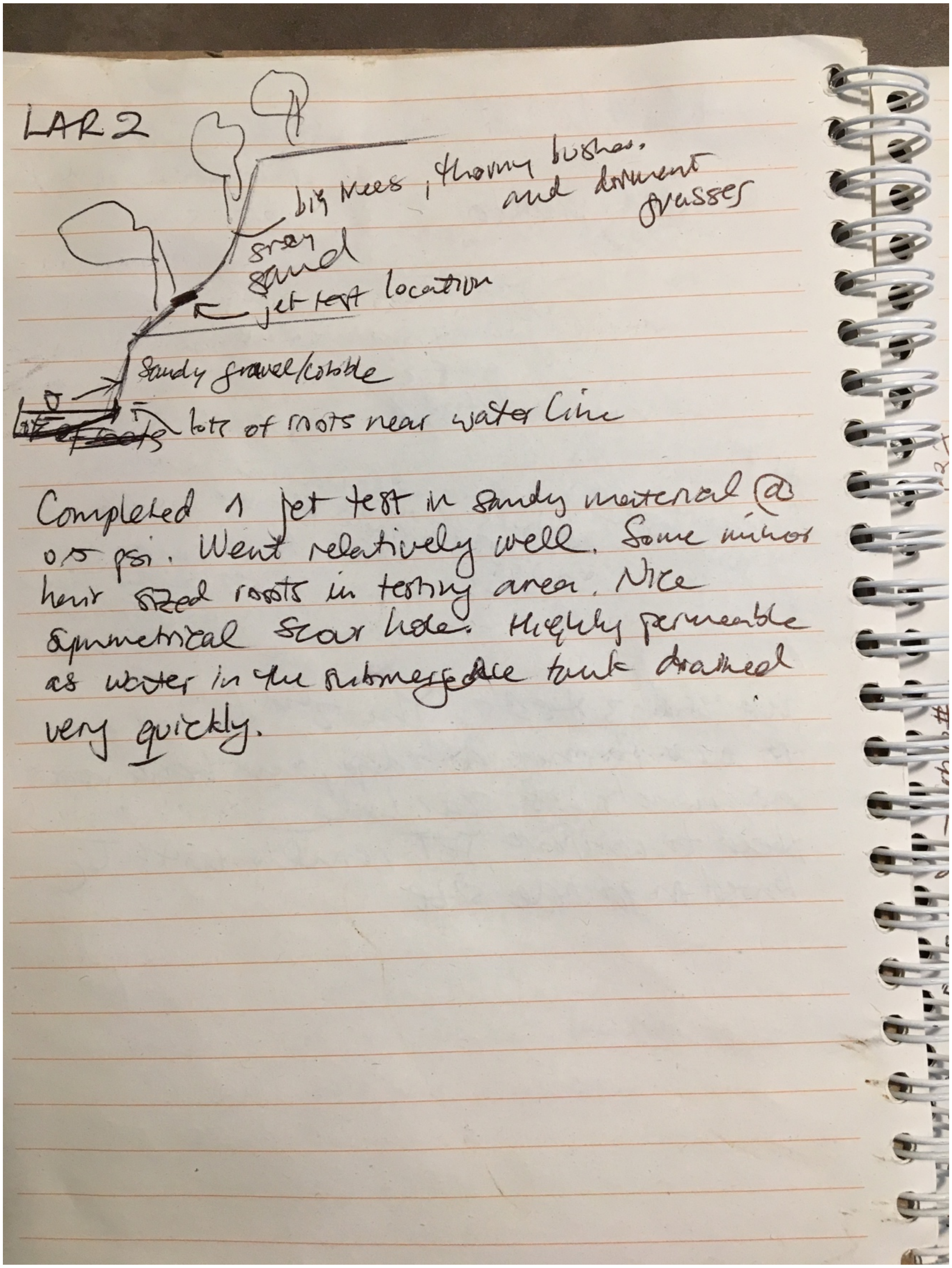
sandy pebbles

hiking paths have been established.

We did 3 tests. The 2nd failed as it ~~was~~ formed a 'edge', and hence an asymmetrical scar hole.

Need to compare JET results with $\tau_c$ based on particle size

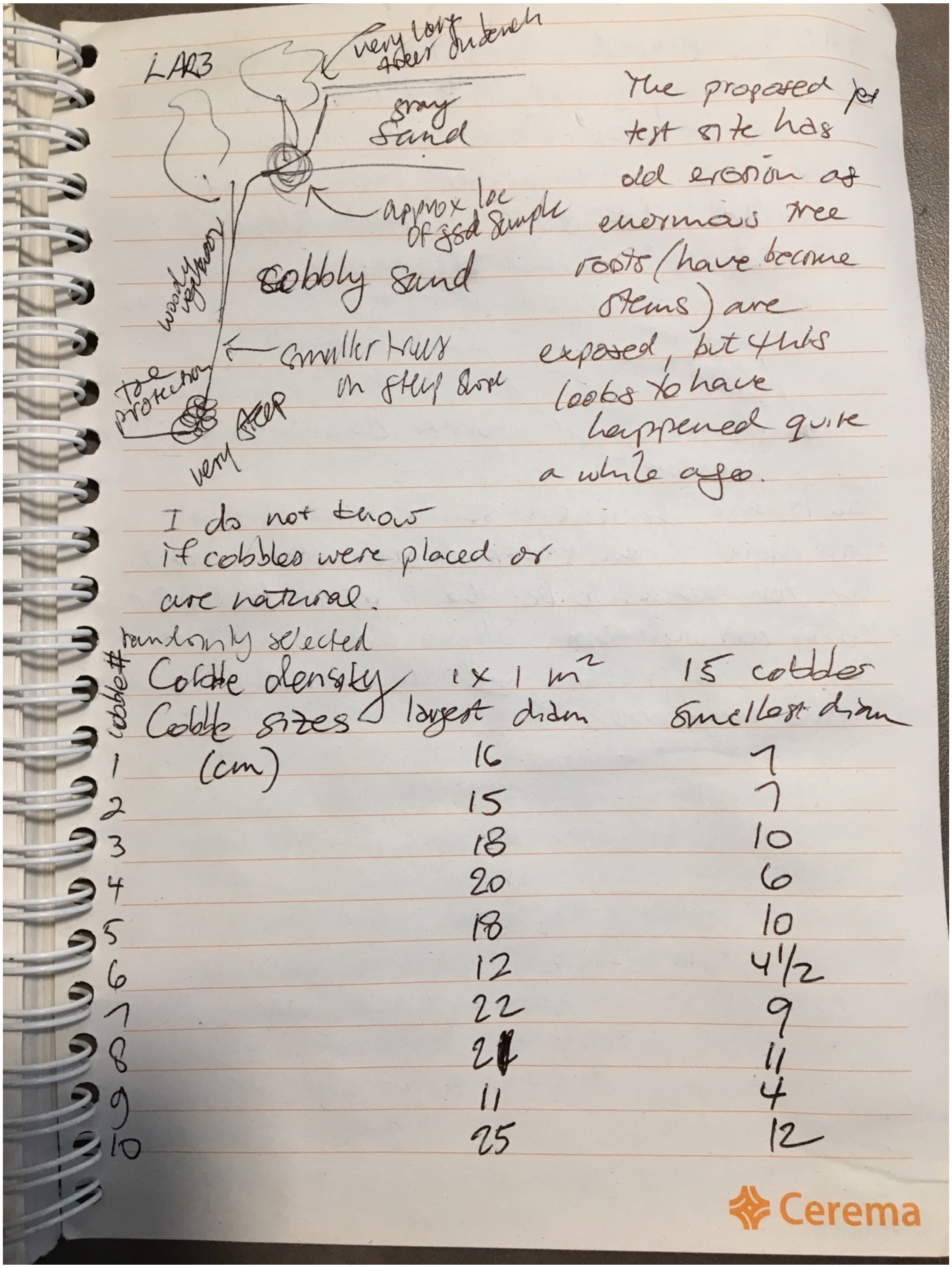
# LAR2



LAR2

Completed 1 jet test in sandy material @ 0.5 psi. Went relatively well. Some minor hair sized roots in testing area. Nice symmetrical scour hole. Highly permeable as water in the submergence tank drained very quickly.

## LAR3



LAR3

very large tree overhang

gray sand

approx loc of gsd sample

woody vegetation

cobbly sand

smaller trees on steep slope

toe protection

very steep

The proposed jet test site has old erosion as enormous tree roots (have become stems) are exposed, but this looks to have happened quite a while ago.

I do not know if cobbles were placed or are natural.

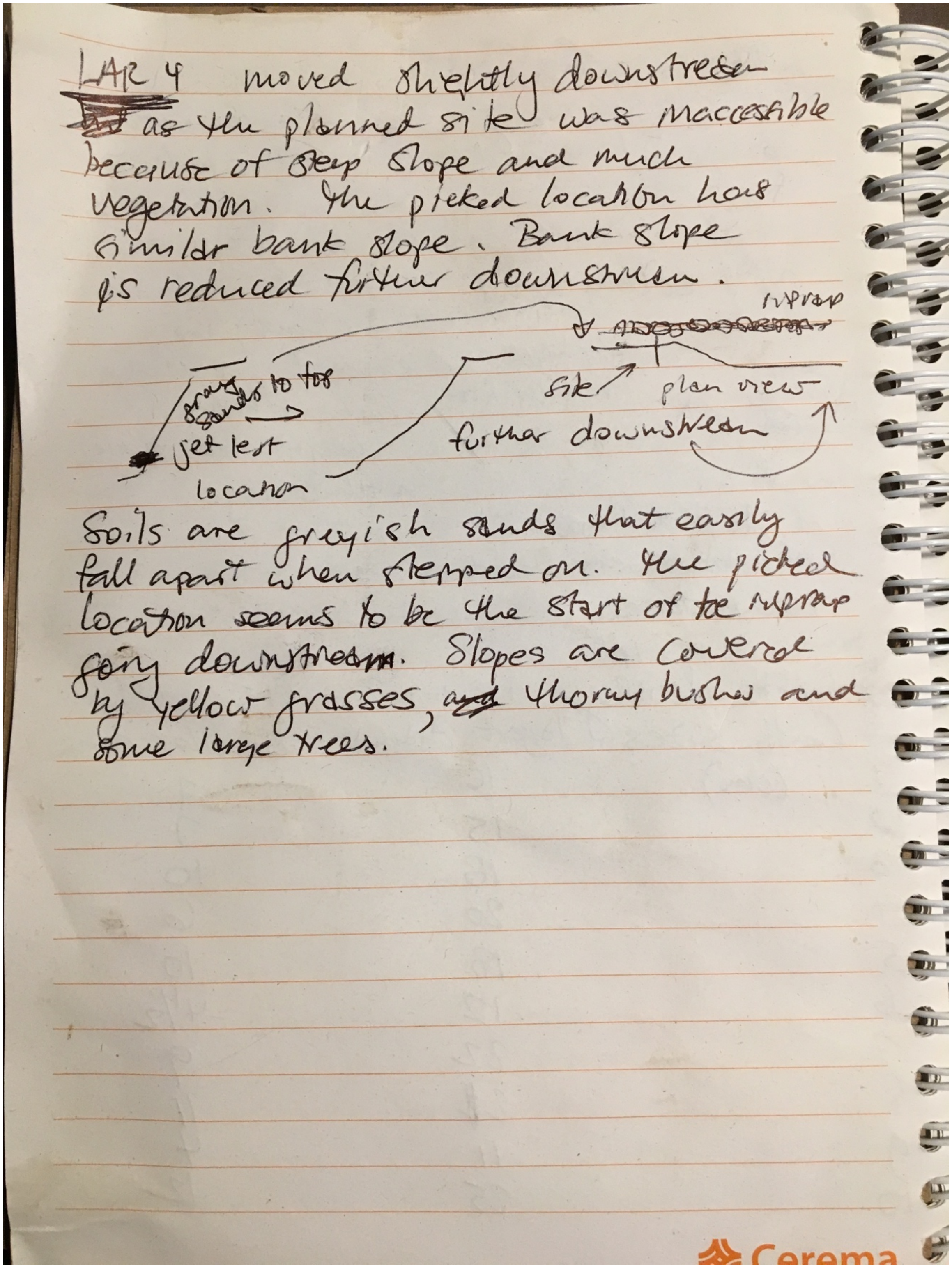
randomly selected

Cobble density 1 x 1 m² 15 cobbles

Cobble sizes (cm)

| cobble # | largest diam | smallest diam |
|---|---|---|
| 1 | 16 | 7 |
| 2 | 15 | 7 |
| 3 | 18 | 10 |
| 4 | 20 | 6 |
| 5 | 18 | 10 |
| 6 | 12 | 4 1/2 |
| 7 | 22 | 9 |
| 8 | 21 | 11 |
| 9 | 11 | 4 |
| 10 | 25 | 12 |

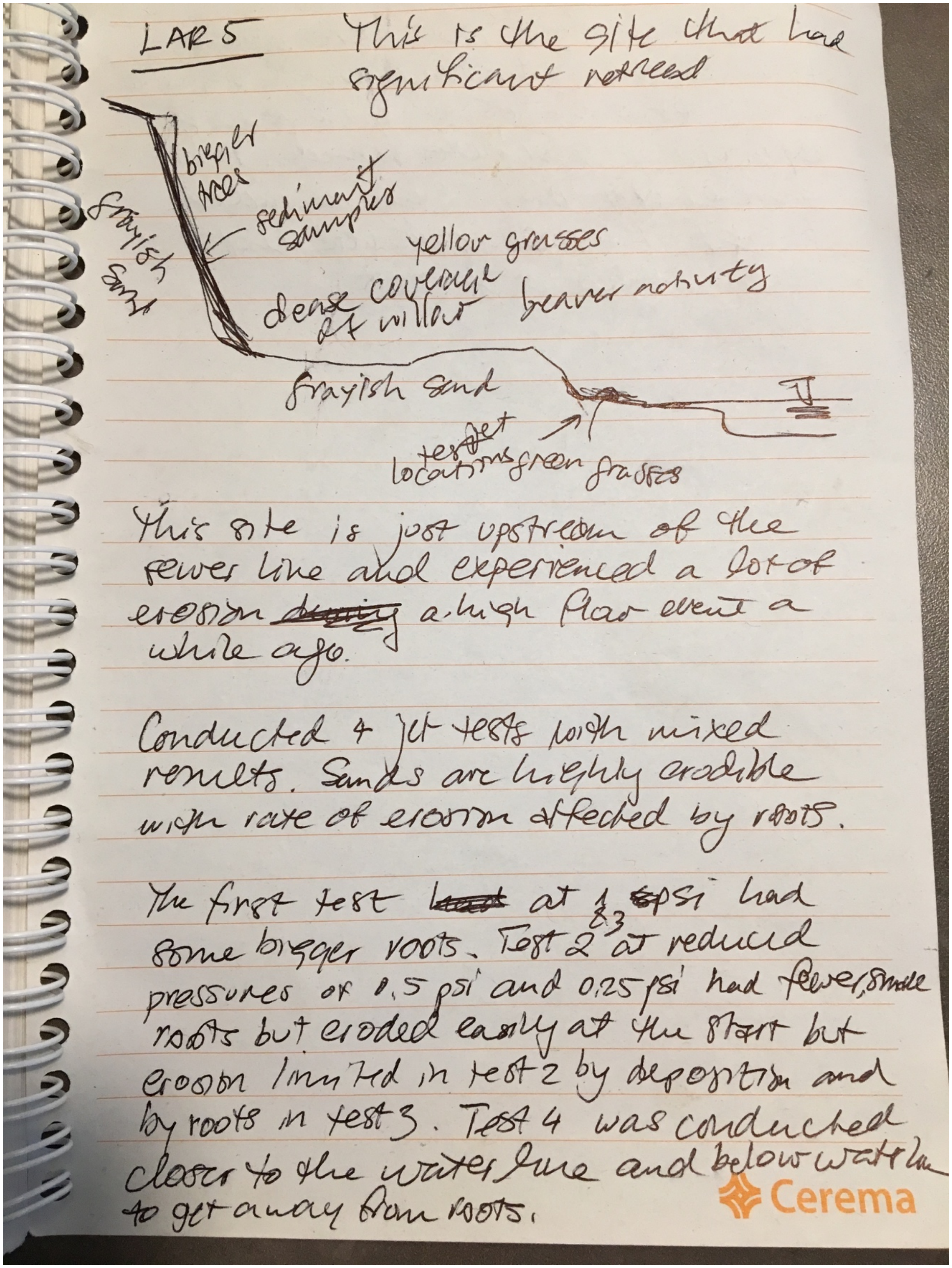
## LAR4



LAR 4 moved slightly downstream as the planned site was inaccessible because of steep slope and much vegetation. The picked location has similar bank slope. Bank slope is reduced further downstream.

Soils are greyish sands that easily fall apart when stepped on. The picked location seems to be the start of the riprap going downstream. Slopes are covered by yellow grasses, ~~and~~ thorny bushes and some large trees.

## LAR5



LAR5

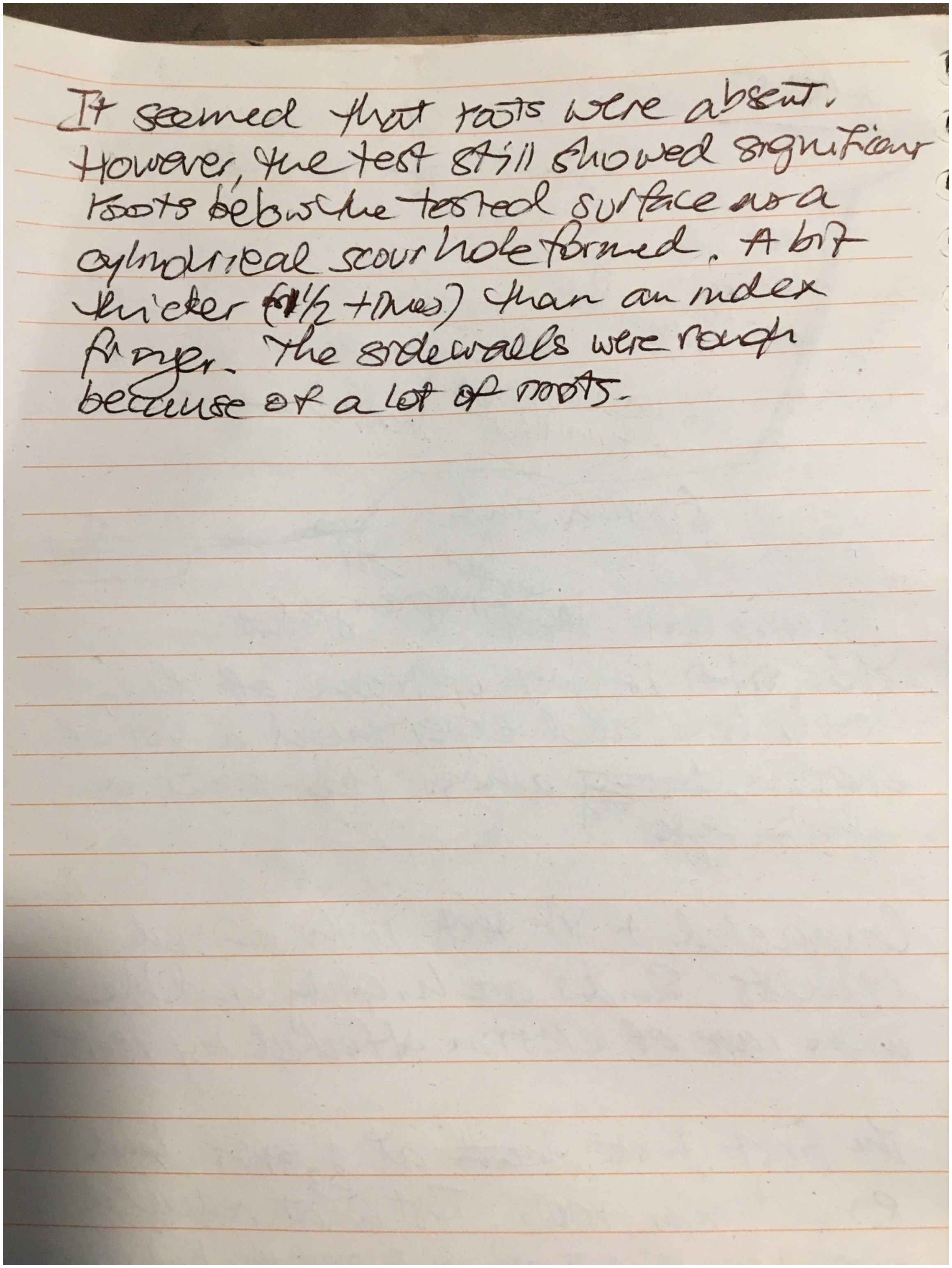
This is the site that had significant retreat

This site is just upstream of the sewer line and experienced a lot of erosion ~~during~~ a high flow event a while ago.

Conducted 4 jet tests with mixed results. Sands are highly erodible with rate of erosion affected by roots.

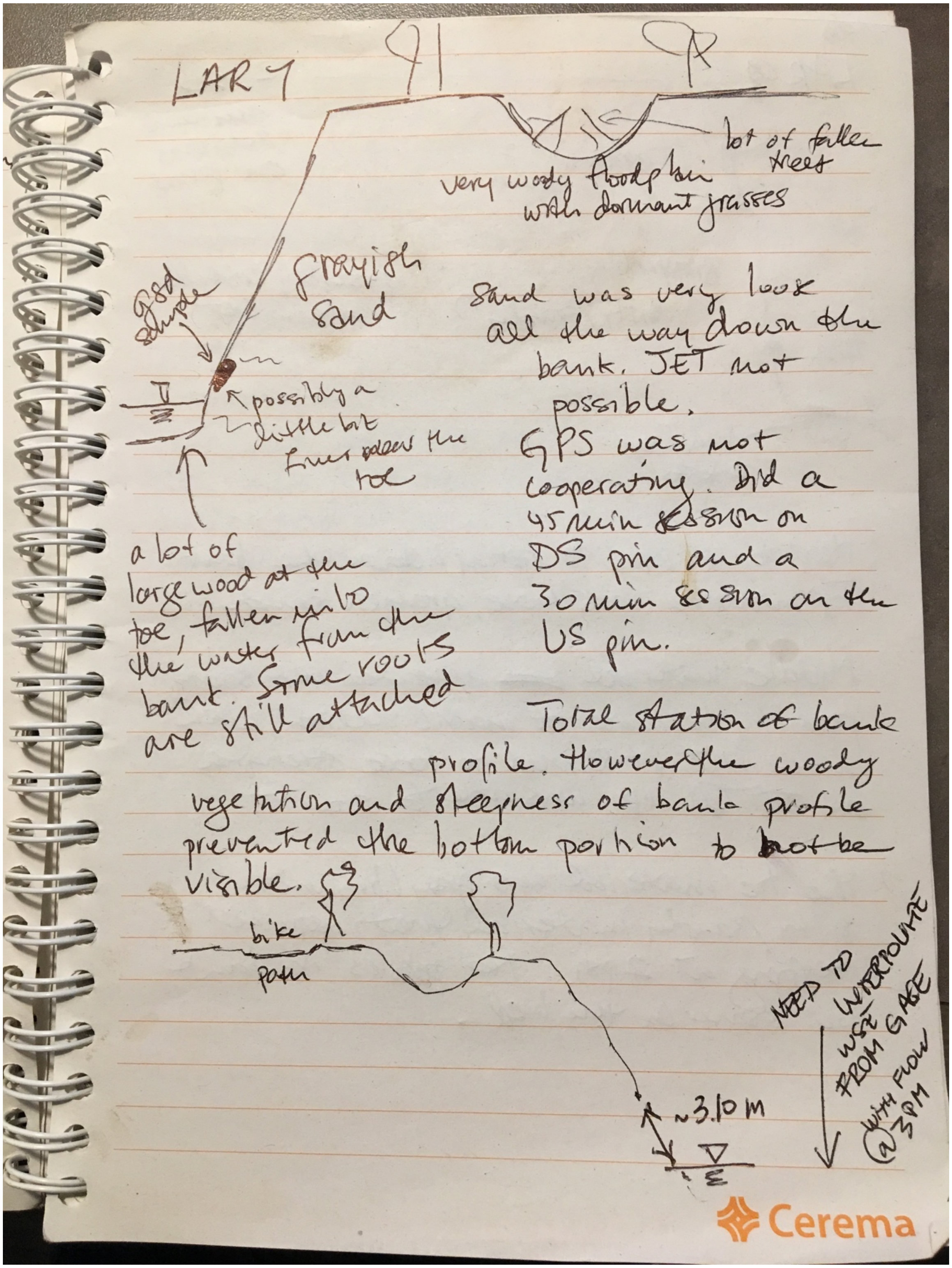
The first test at 1 83 psi had some bigger roots. Test 2 at reduced pressures of 0.5 psi and 0.25 psi had fewer, smaller roots but eroded easily at the start but erosion limited in test 2 by deposition and by roots in test 3. Test 4 was conducted closer to the water line and below water line to get away from roots.

Cerema



It seemed that roots were absent. However, the test still showed significant roots below the tested surface as a cylindrical scour hole formed. A bit thicker (1½ times) than an index finger. The sidewalls were rough because of a lot of roots.

## LAR7



LAR 7

lot of fallen trees

very woody floodplain with dormant grasses

grayish sand

grab sample

possibly a little bit finer near the toe

Sand was very loose all the way down the bank. JET not possible.

GPS was not cooperating. Did a 45 min session on DS pin and a 30 min session on the US pin.

a lot of large wood at the toe, fallen into the water from the bank. Some roots are still attached

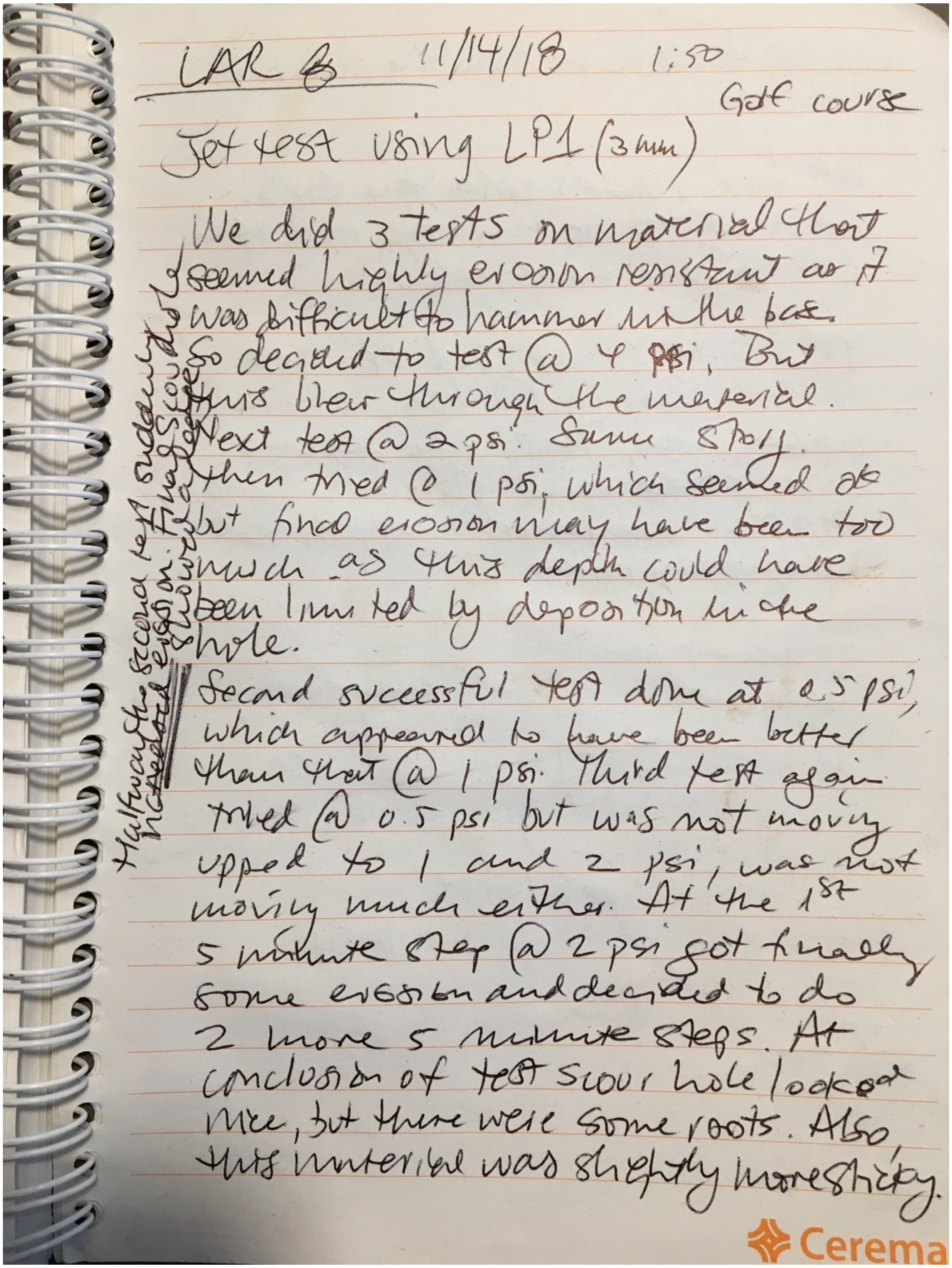
Total station of bank profile. However the woody vegetation and steepness of bank profile prevented the bottom portion to not be visible.

bike path

~3.10 m

NEED TO INTERPOLATE WSE FROM GAGE with FLOW @ 3PM

## LAR8



LAR 8 11/14/18 1:50

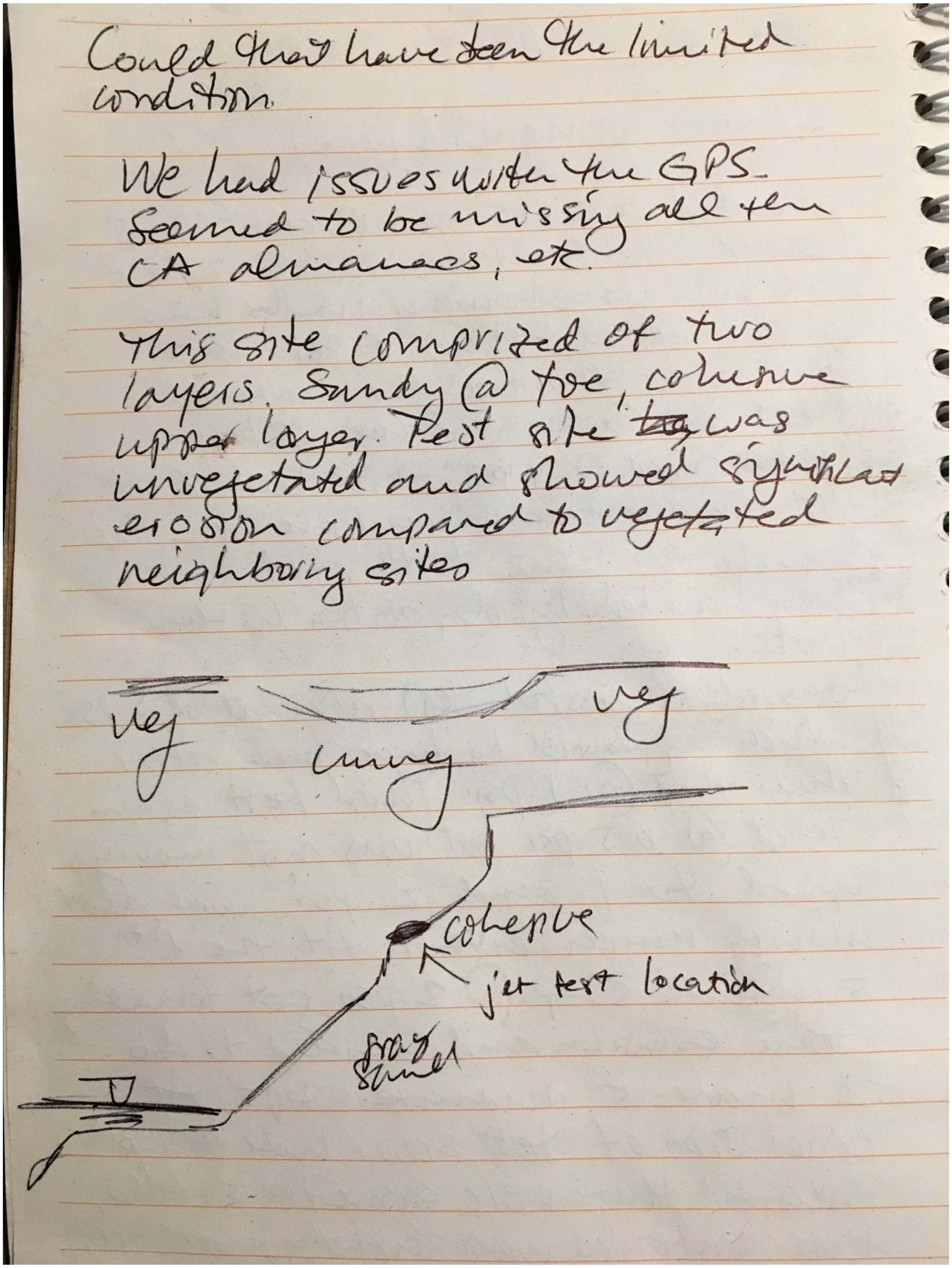
Golf course

Jet test using LP1 (3mm)

We did 3 tests on material that seemed highly erosion resistant as it was difficult to hammer in the base. So decided to test @ 4 psi. But this blew through the material. Next test @ 2 psi. Same story. then tried @ 1 psi, which seemed ok but final erosion may have been too much as this depth could have been limited by deposition in the hole.

Second successful test done at 0.5 psi, which appeared to have been better than that @ 1 psi. Third test again tried @ 0.5 psi but was not moving upped to 1 and 2 psi, was not moving much either. At the 1st 5 minute step @ 2 psi got finally some erosion and decided to do 2 more 5 minute steps. At conclusion of test scour hole looked nice, but there were some roots. Also this material was slightly more sticky.

Halfway the second test suddenly increased erosion. Final scour hole showed a ledge.

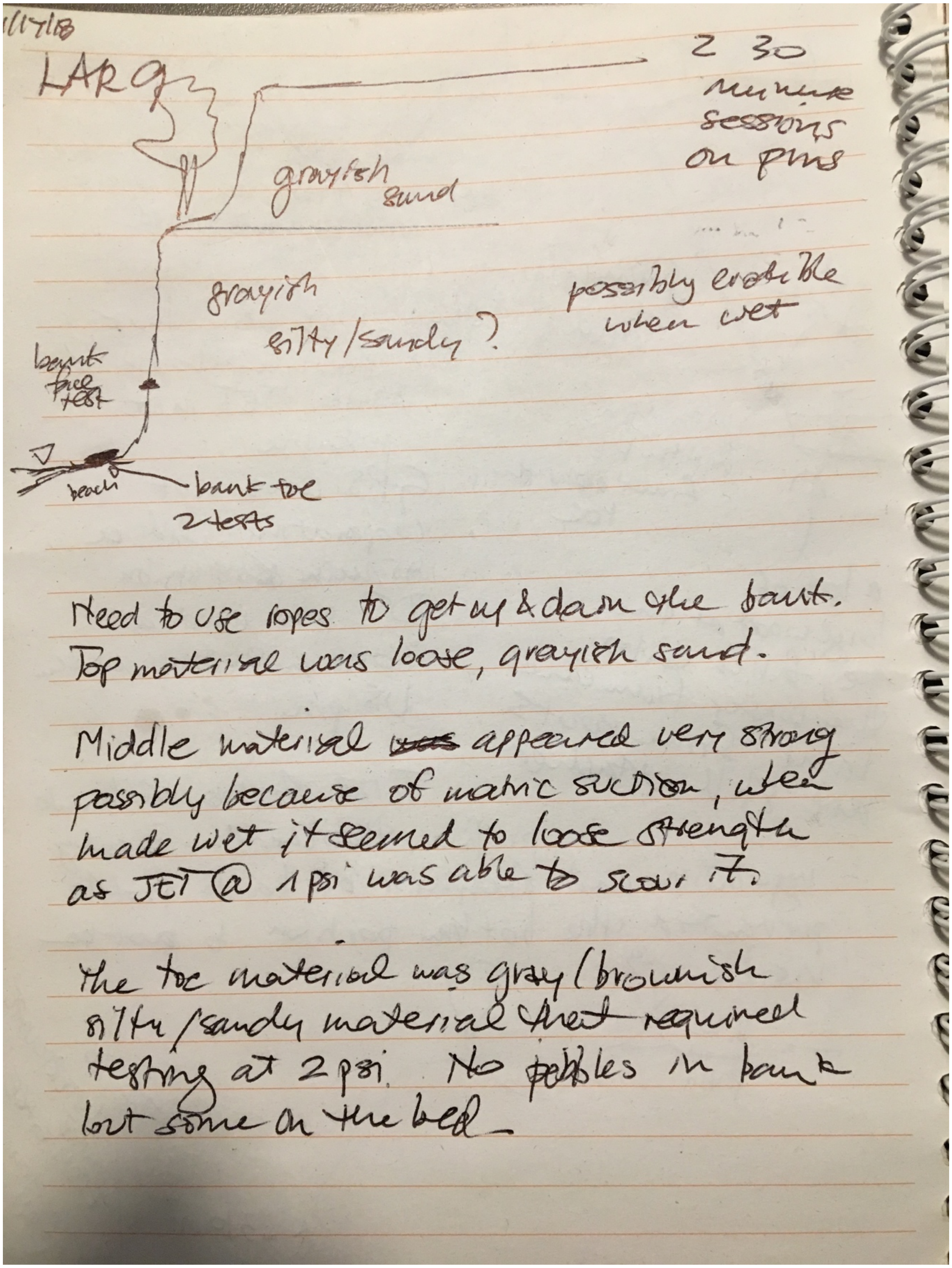


Could that have been the limited condition.

We had issues with the GPS. Seemed to be missing all the CA almanacs, etc.

This site comprized of two layers. Sandy @ toe, cohesive upper layer. Test site ~~to~~ was unvegetated and showed significant erosion compared to vegetated neighboring sites

# LAR9



1/17/18

LAR9

2 30 minute sessions on pins

grayish sand

grayish silty/sandy?

possibly erodible when wet

bank face test

beach

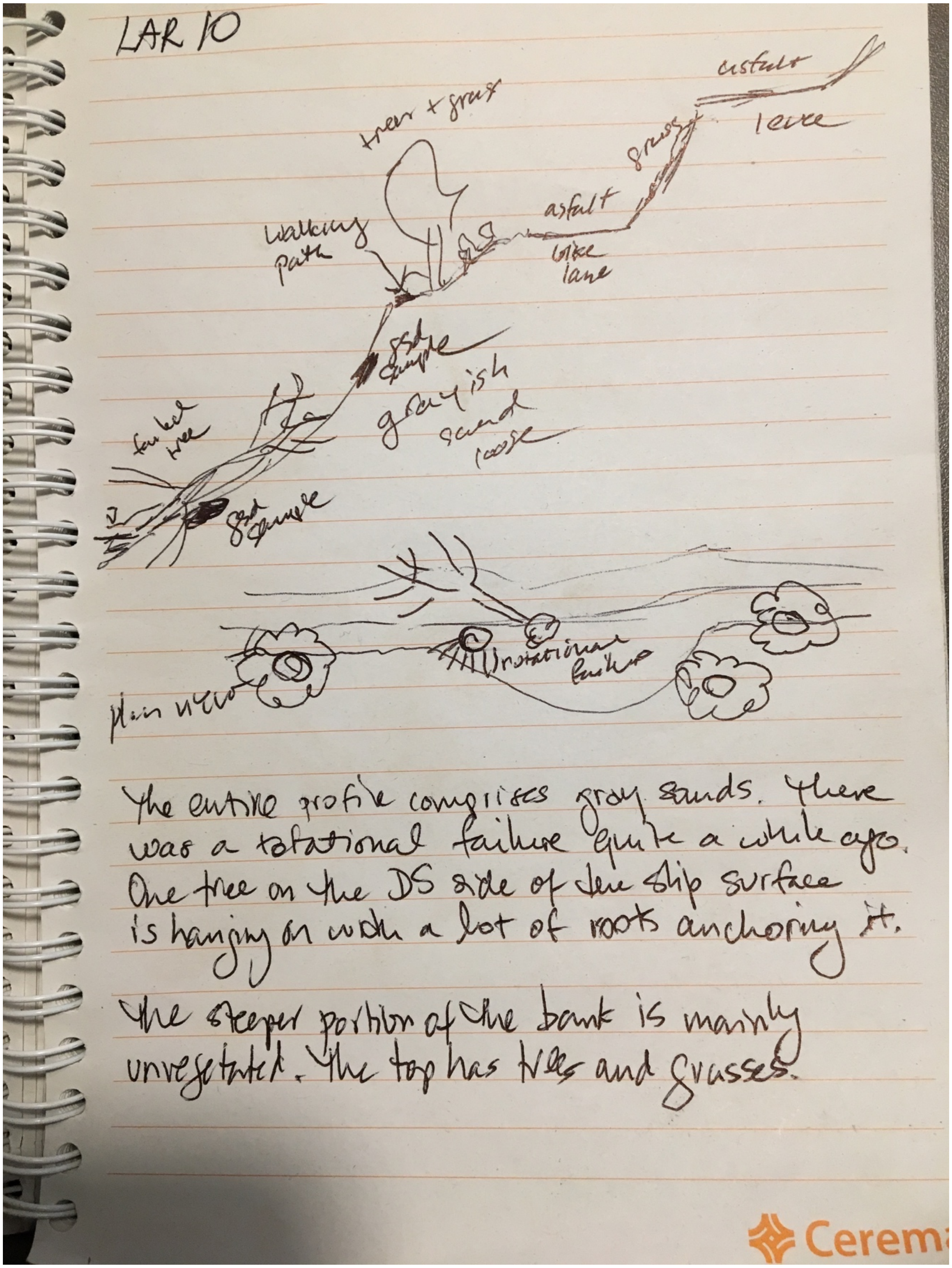
bank toe 2 tests

Need to use ropes to get up & down the bank. Top material was loose, grayish sand.

Middle material ~~was~~ appeared very strong possibly because of matric suction, when made wet it seemed to loose strength as JET @ 1 psi was able to scour it.

The toe material was gray/brownish silty/sandy material that required testing at 2 psi. No pebbles in bank but some on the bed.

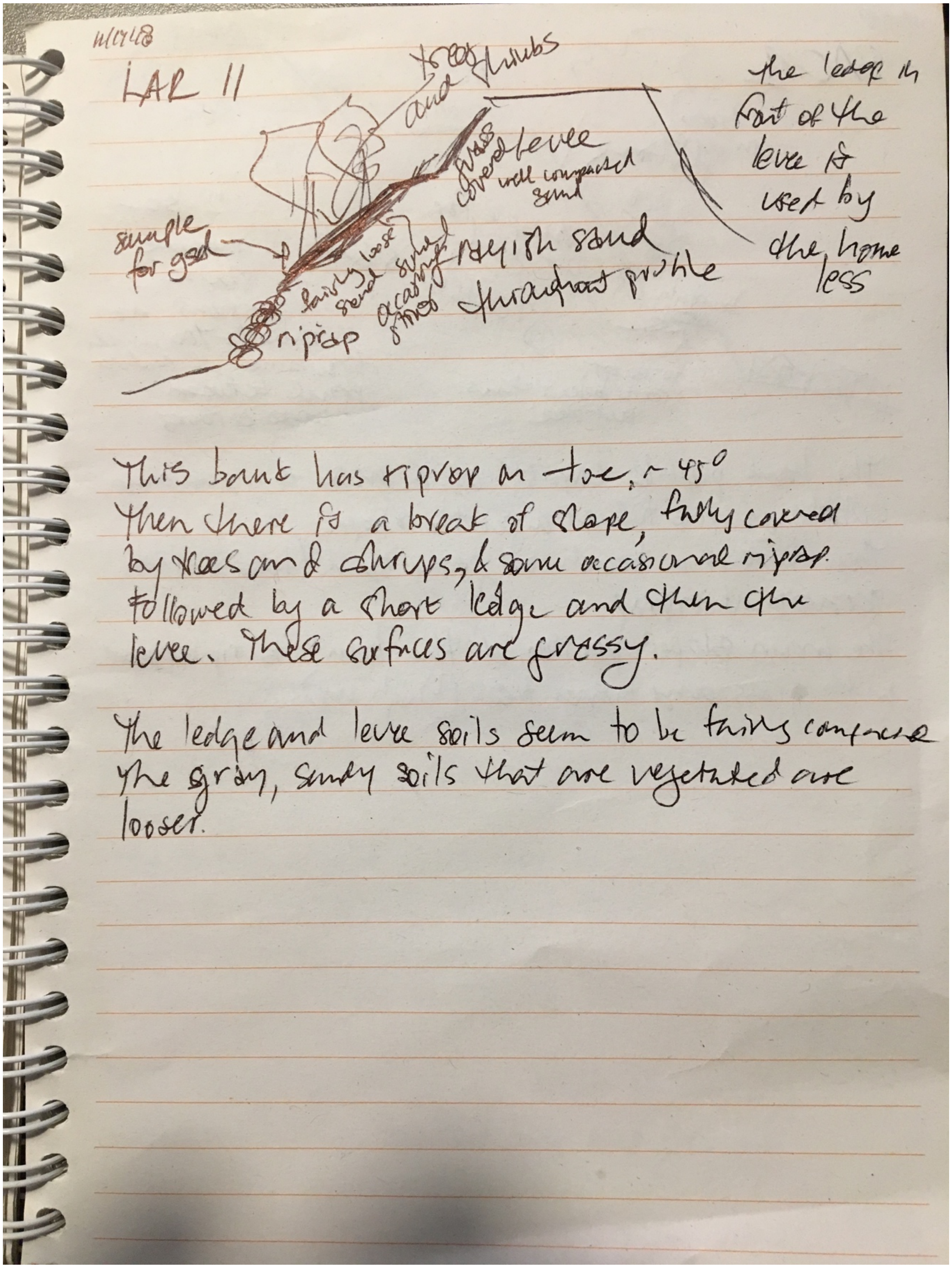
## LAR10



The entire profile comprises gray sands. There was a rotational failure quite a while ago. One tree on the DS side of the slip surface is hanging on with a lot of roots anchoring it.

The steeper portion of the bank is mainly unvegetated. The top has trees and grasses.

## LAR11



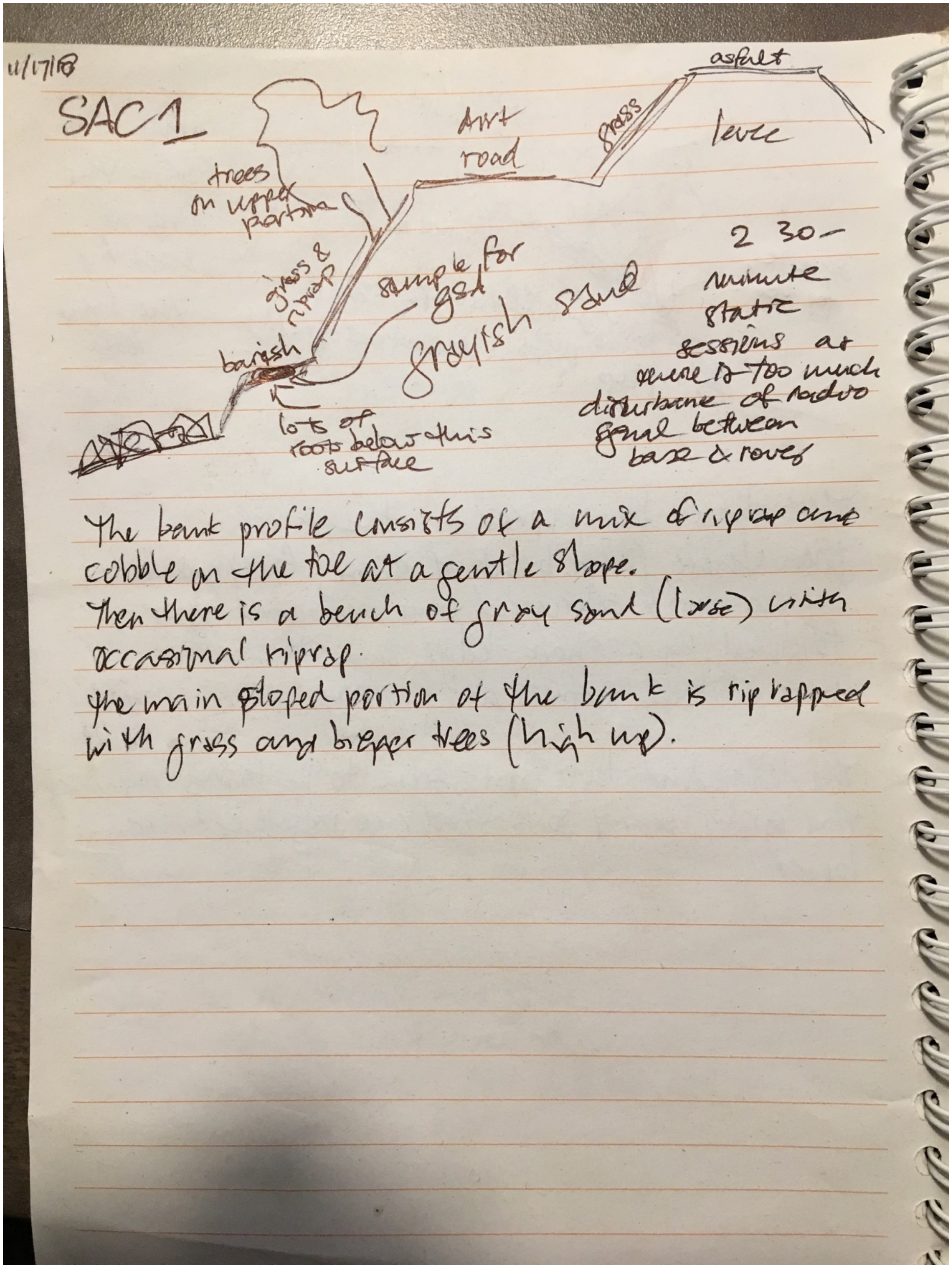
11/17/18

LAR 11

This bank has riprap on toe, ~ 45°
Then there is a break of slope, fully covered by trees and shrubs, & some occasional riprap. followed by a short ledge and then the levee. These surfaces are grassy.

The ledge and levee soils seem to be fairly compacted the gray, sandy soils that are vegetated are looser.

## SAC1



11/17/18

SAC1

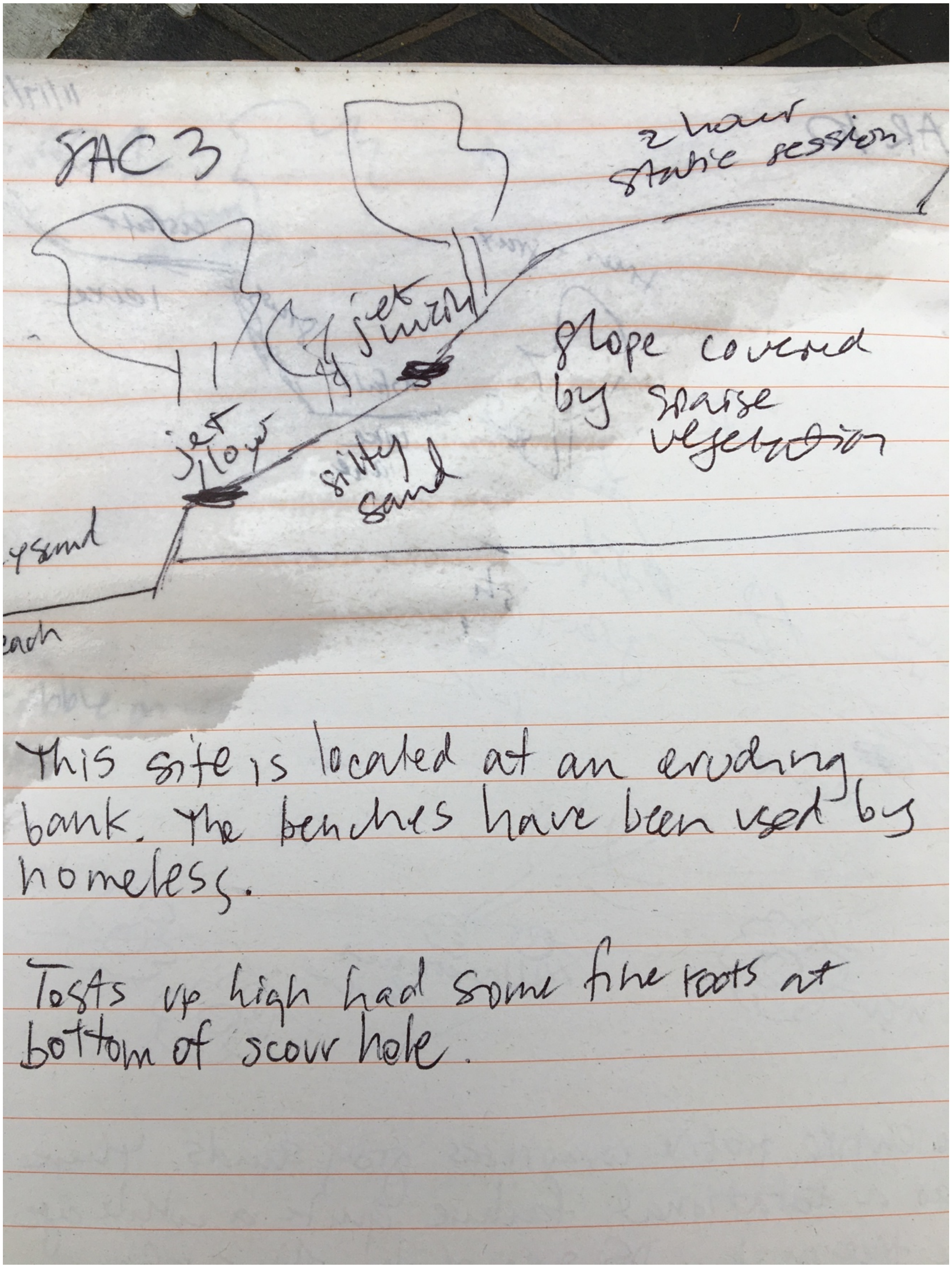
2 30-minute static sessions as there is too much disturbance of radio signal between base & rover

The bank profile consists of a mix of riprap and cobble on the toe at a gentle slope.

Then there is a bench of gray sand (loose) with occasional riprap.

The main sloped portion of the bank is rip rapped with grass and bigger trees (high up).

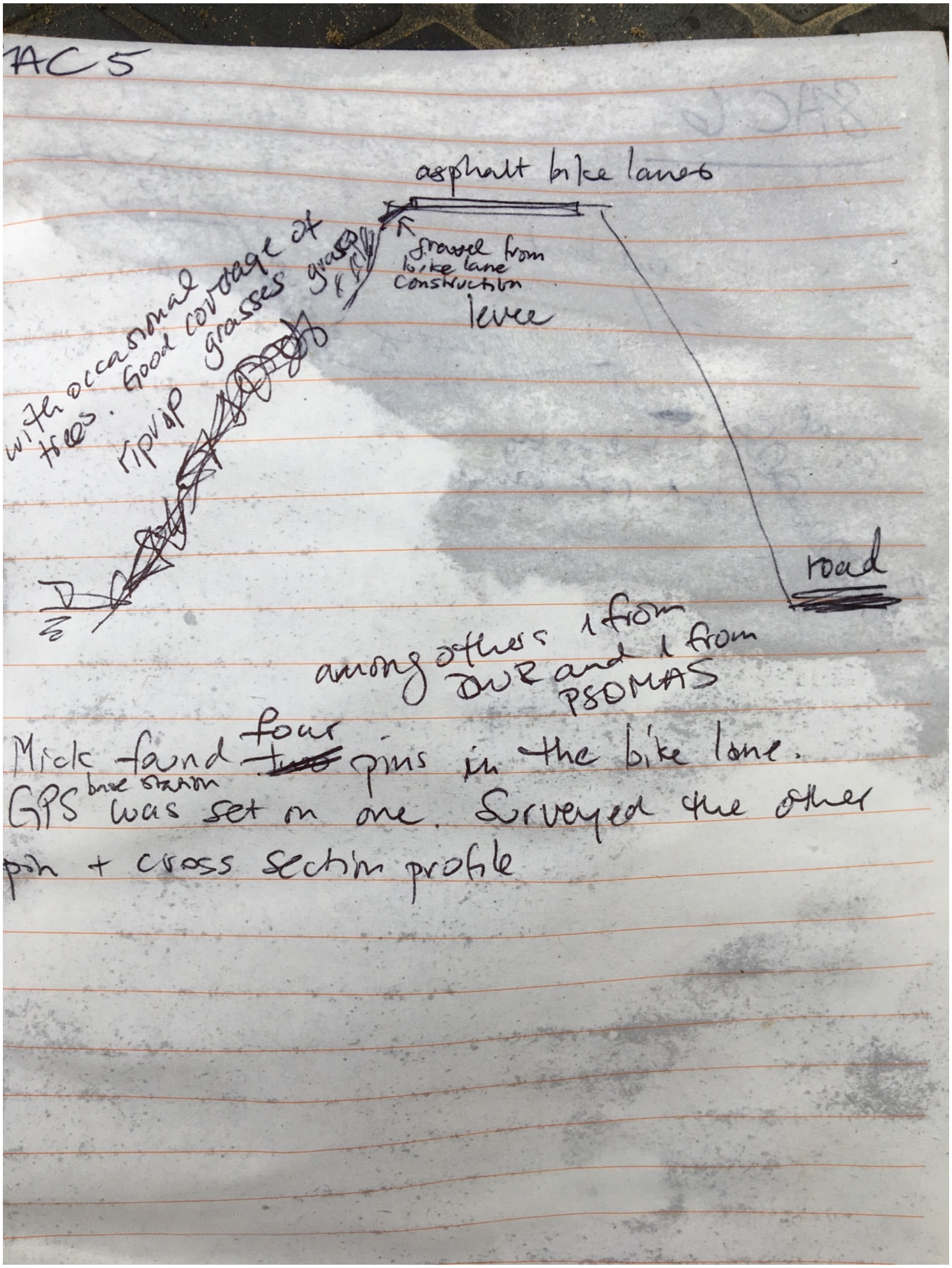
## SAC3



This site is located at an eroding bank. The benches have been used by homeless.

Tests up high had some fine roots at bottom of scour hole.

## SAC5



AC5

asphalt bike lanes

gravel from bike lane construction

levee

riprap

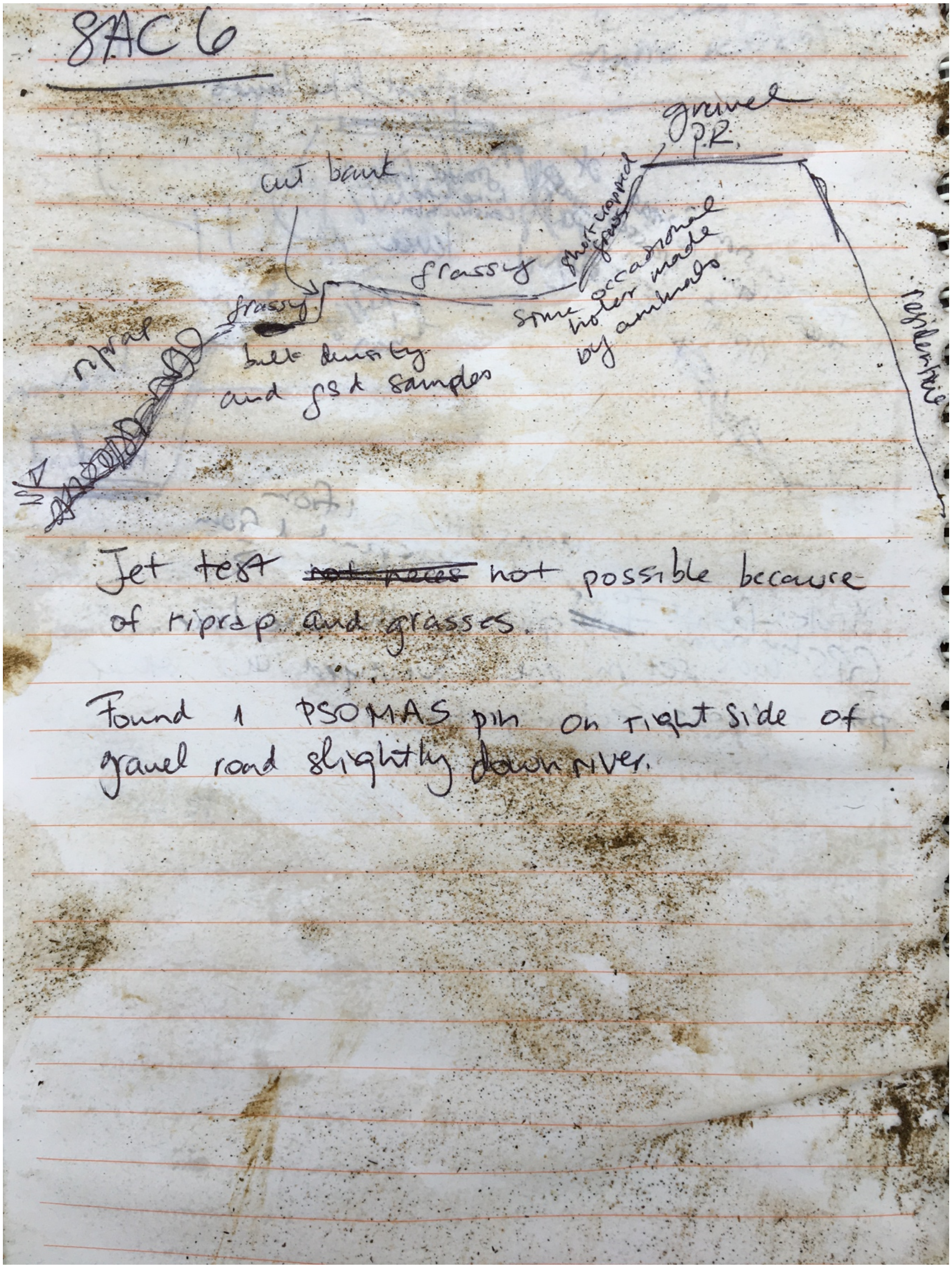
with occasional
trees. Good coverage of
grasses grass

road

among others 1 from DWR and 1 from PSOMAS

Mick found ~~two~~ four pins in the bike lane.
GPS base station was set on one. Surveyed the other
pin + cross section profile

## SAC6

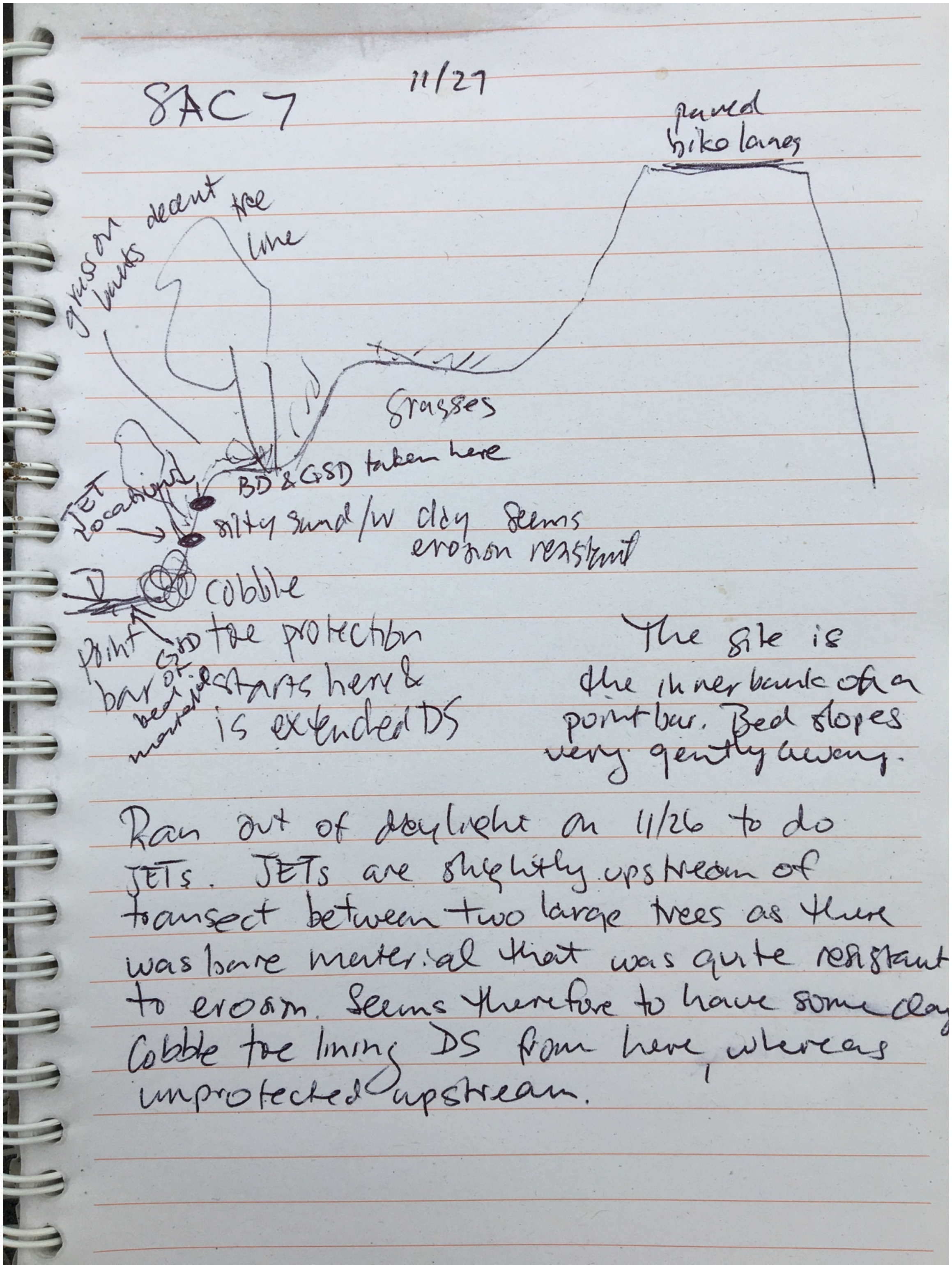


SAC6

Jet test ~~not neces~~ not possible because of riprap and grasses.

Found 1 PSOMAS pin on right side of gravel road slightly down river.

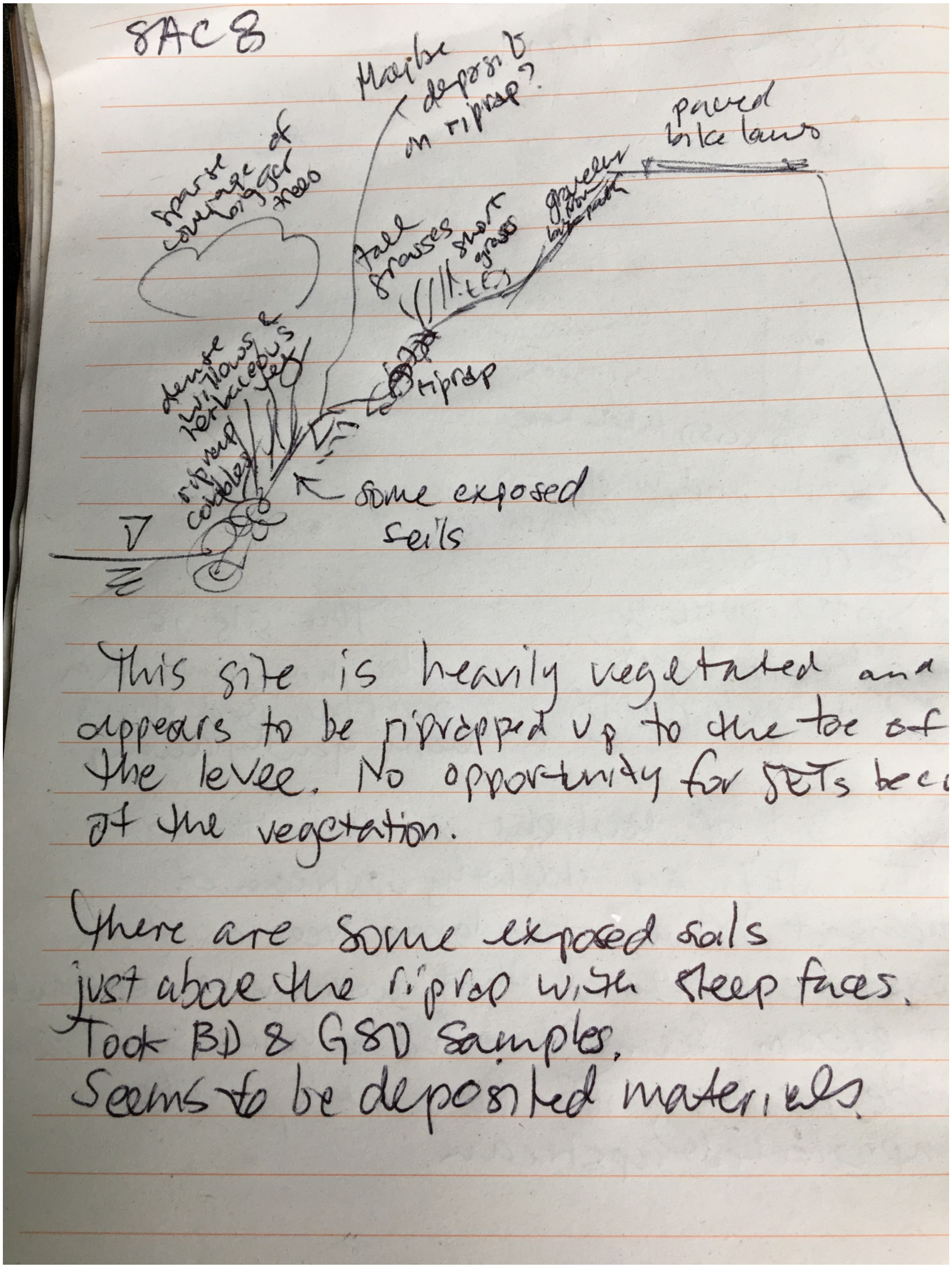
## SAC7



The site is the inner bank of a point bar. Bed slopes very gently away.

Ran out of daylight on 11/26 to do JETs. JETs are slightly upstream of transect between two large trees as there was bare material that was quite resistant to erosion. Seems therefore to have some clay. Cobble toe lining DS from here, whereas unprotected upstream.

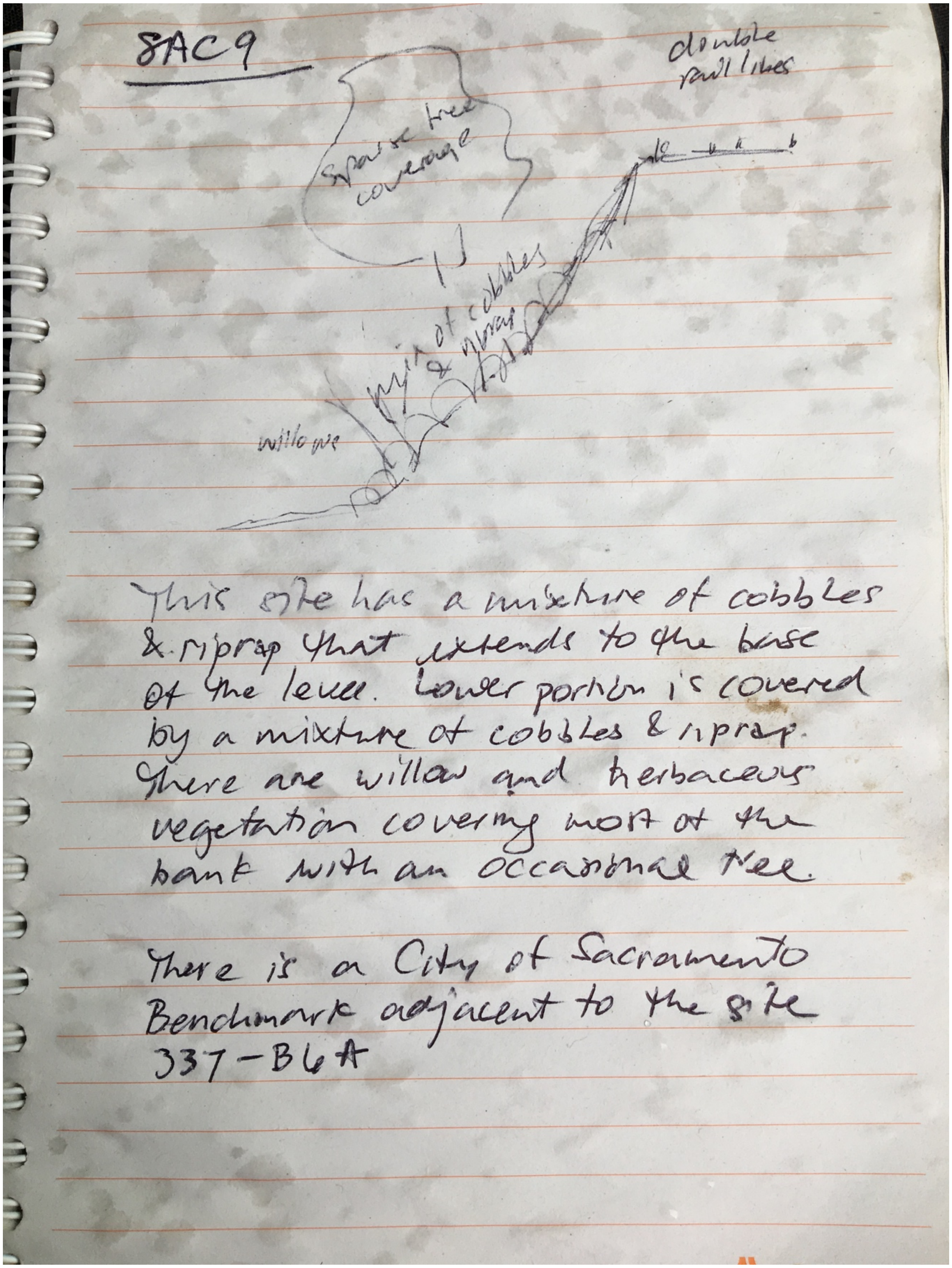
## SAC8



This site is heavily vegetated and appears to be riprapped up to the toe of the levee. No opportunity for SETs bec of the vegetation.

There are some exposed soils just above the riprap with steep faces.
Took BD & GSD samples.
Seems to be deposited materials.

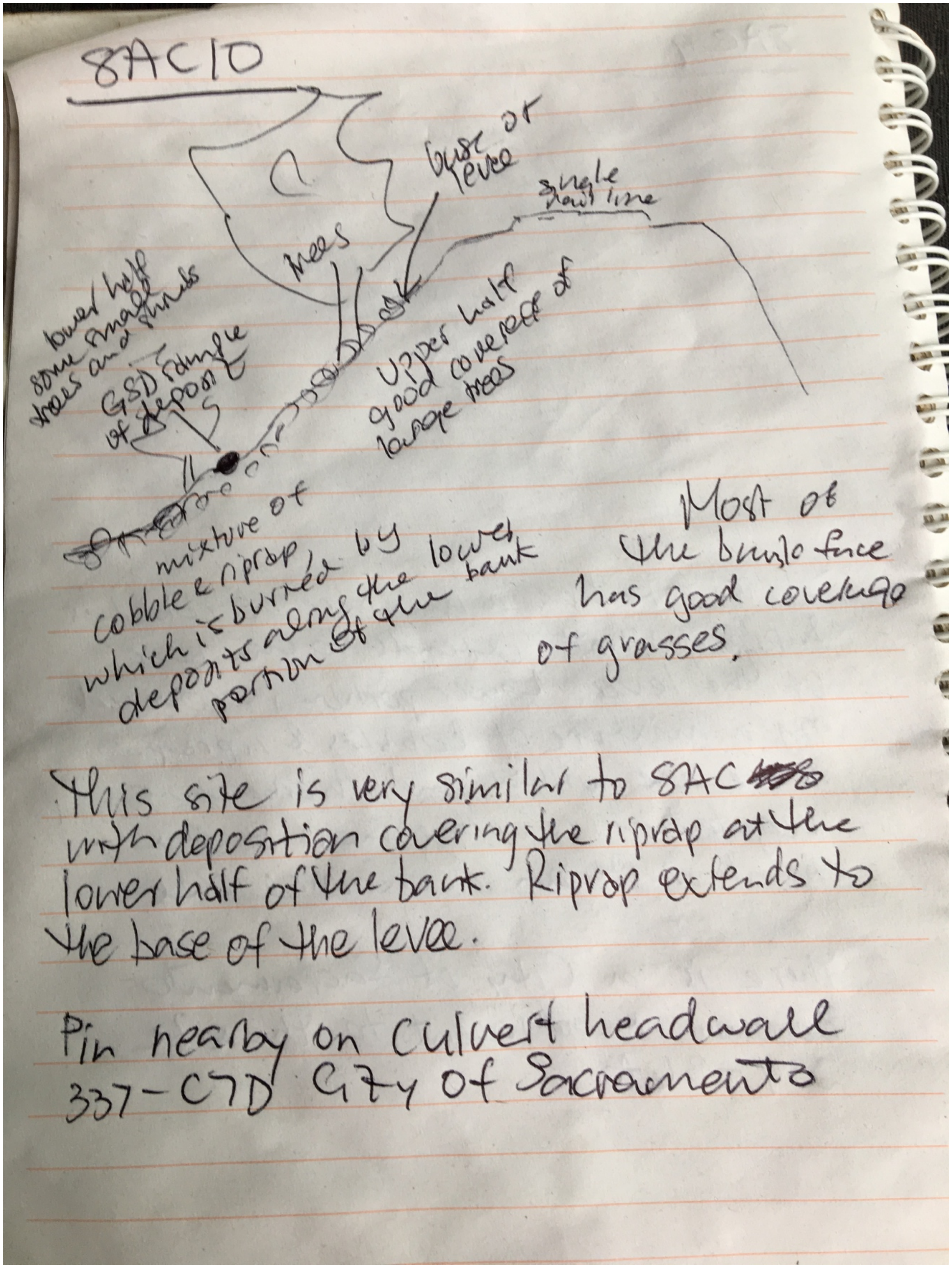
## SAC9



This site has a mixture of cobbles & riprap that extends to the base of the levee. Lower portion is covered by a mixture of cobbles & riprap. There are willow and herbaceous vegetation covering most of the bank with an occasional tree.

There is a City of Sacramento Benchmark adjacent to the site 337-B6A

## SAC10



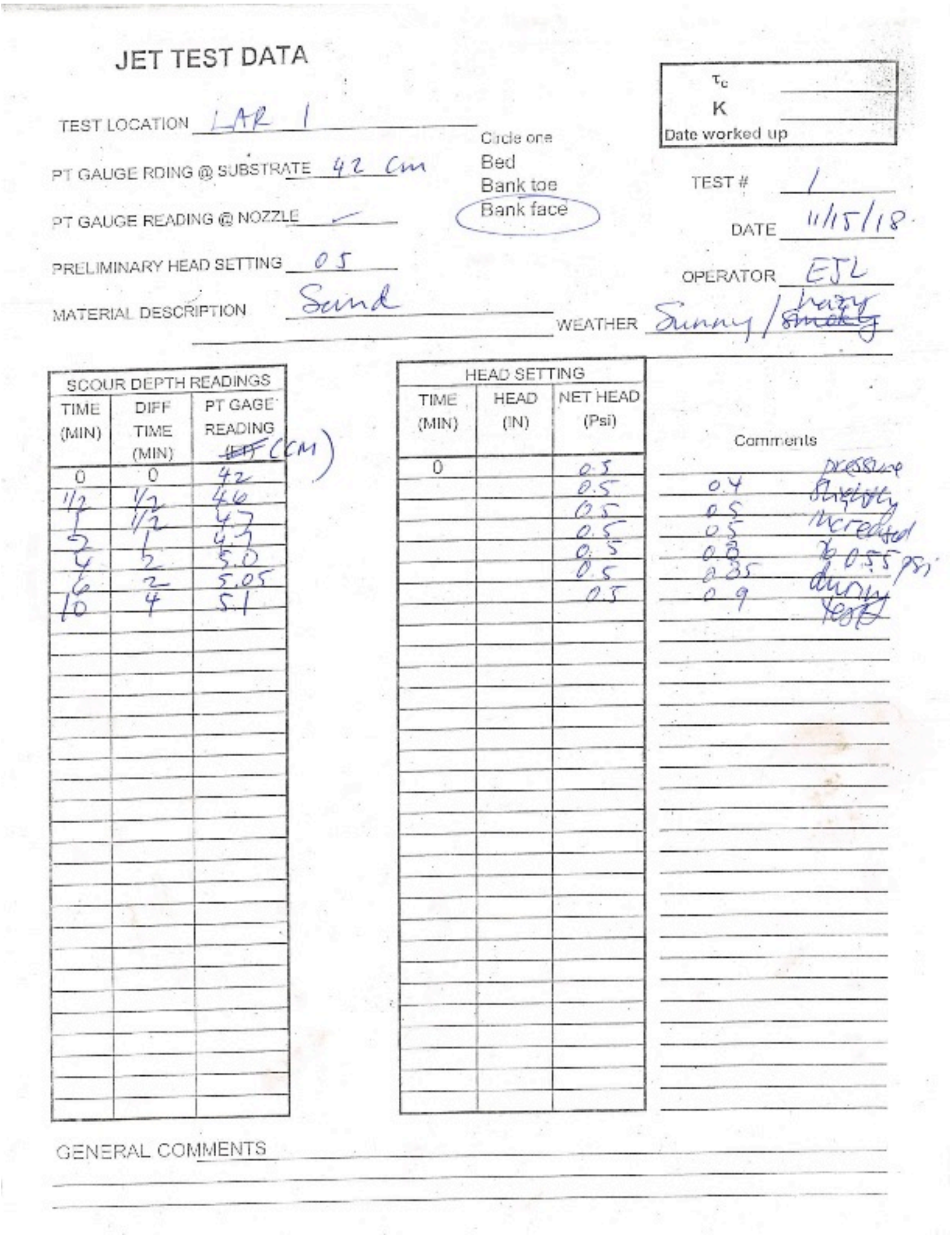
Most of the bank face has good coverage of grasses.

This site is very similar to SAC~~[illegible]~~ with deposition covering the riprap at the lower half of the bank. Riprap extends to the base of the levee.

Pin nearby on culvert headwall 337-C7D City of Sacramento

# APPENDIX 3 JET EROSION TEST DATA SHEETS

## LAR1 – test 1



JET TEST DATA

$\tau_c$ ______
K ______
Date worked up

TEST LOCATION LAR 1

PT GAUGE RDING @ SUBSTRATE 42 Cm

PT GAUGE READING @ NOZZLE ✓

PRELIMINARY HEAD SETTING 0 5

MATERIAL DESCRIPTION Sand

Circle one: Bed Bank toe [✓ Bank face]

TEST # 1

DATE 11/15/18

OPERATOR EJL

WEATHER Sunny/~~smoky~~ hazy

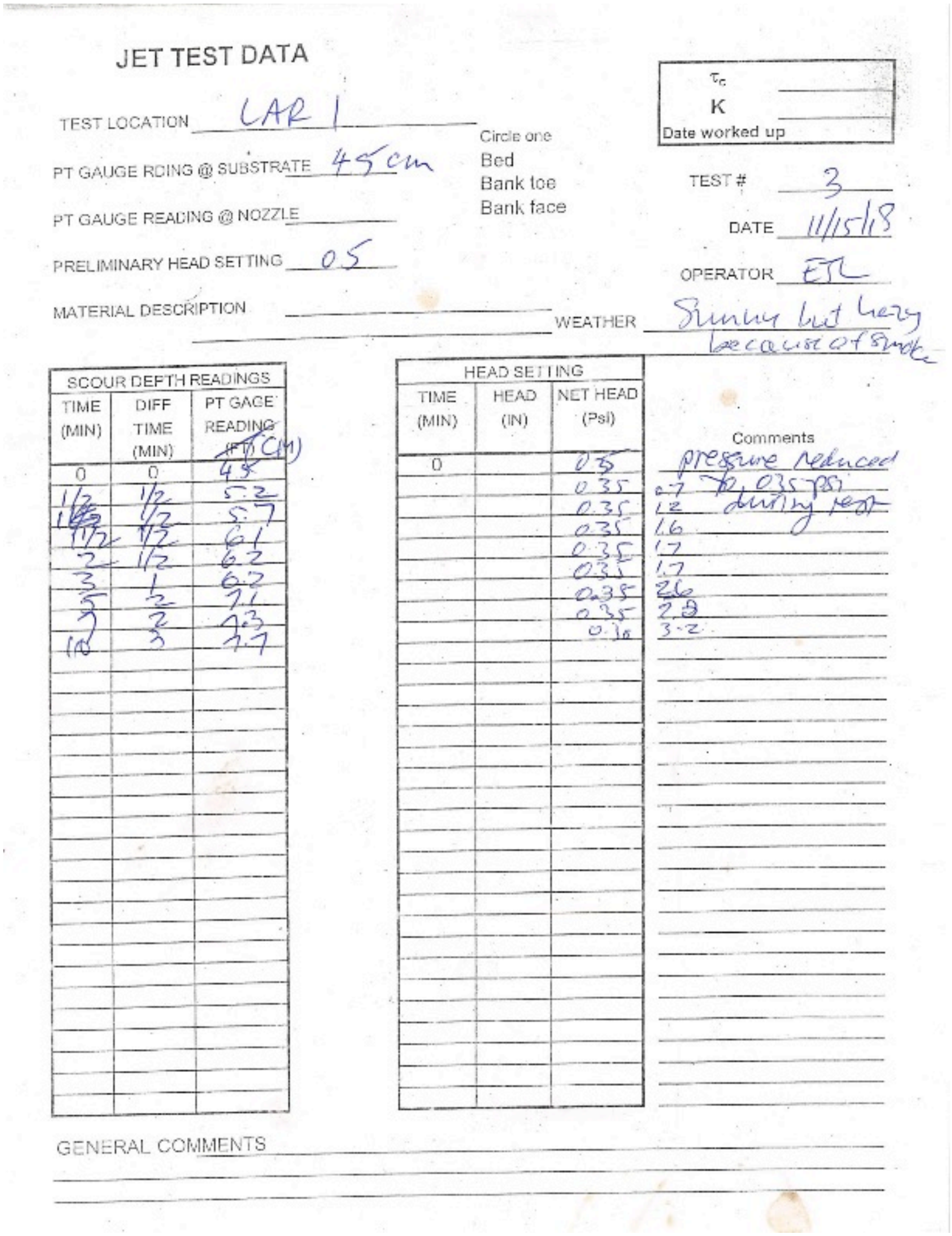
| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (CM) |
| 0 | 0 | 42 |
| 1/2 | 1/2 | 46 |
| 1 | 1/2 | 47 |
| 2 | 1 | 4.7 |
| 4 | 2 | 5.0 |
| 6 | 2 | 5.05 |
| 10 | 4 | 5.1 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 0.5 | |
| | | 0.5 | 0.4 |
| | | 0.5 | 0.5 |
| | | 0.5 | 0.5 |
| | | 0.5 | 0.8 |
| | | 0.5 | 0.85 |
| | | 0.5 | 0.9 |

pressure slightly increased to 0.55 psi during test

GENERAL COMMENTS

## LAR1 – test 2



### JET TEST DATA

TEST LOCATION LAR 1

PT GAUGE RDING @ SUBSTRATE 45cm

PT GAUGE READING @ NOZZLE

PRELIMINARY HEAD SETTING 0.5

MATERIAL DESCRIPTION

Circle one
Bed
Bank toe
Bank face

$\tau_c$
K
Date worked up

TEST # 3

DATE 11/15/18

OPERATOR ETL

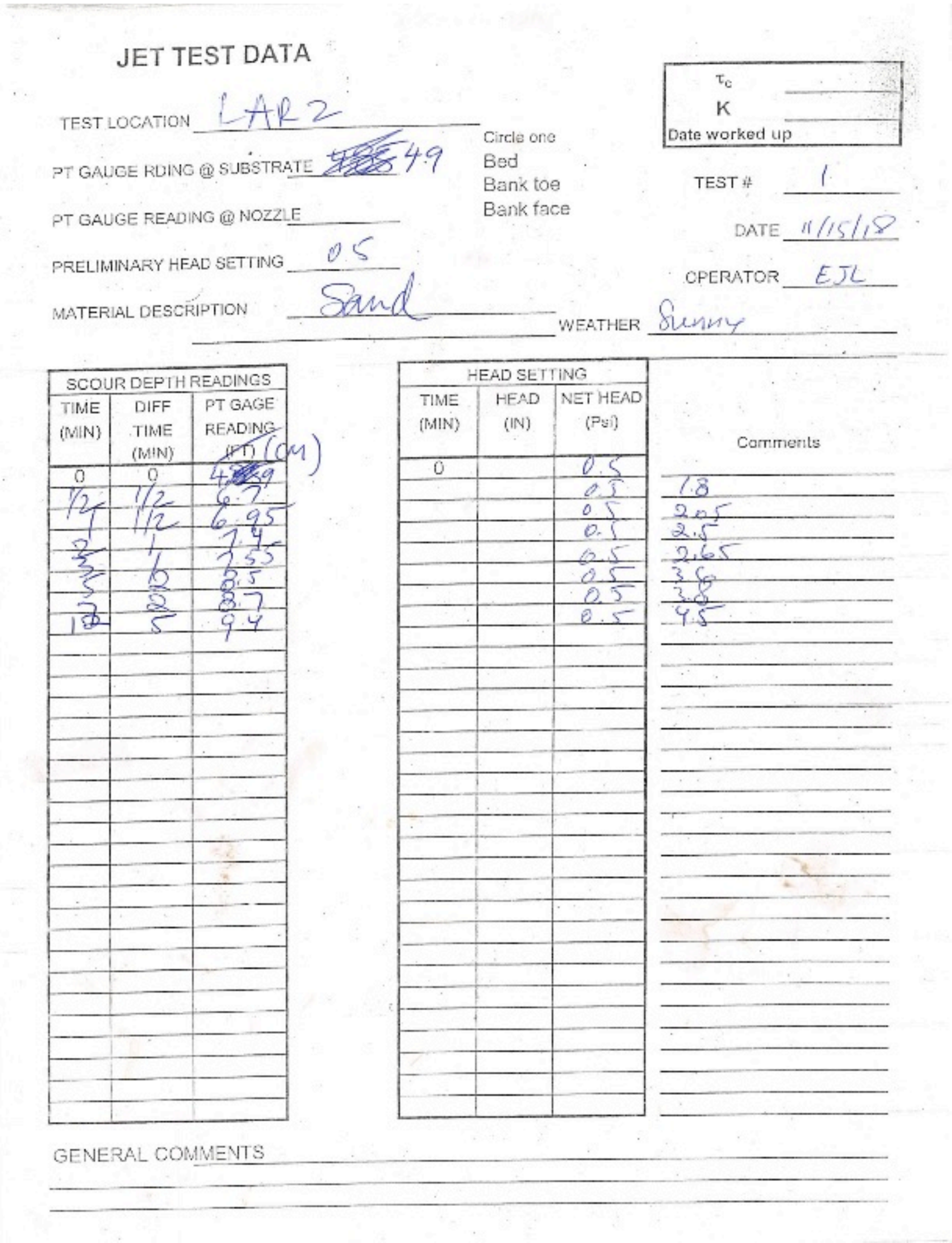
WEATHER Sunny but hazy because of smoke

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (CM) |
| 0 | 0 | 4.5 |
| 1/2 | 1/2 | 5.2 |
| 1 | 1/2 | 5.7 |
| 1 1/2 | 1/2 | 6.1 |
| 2 | 1/2 | 6.2 |
| 3 | 1 | 6.7 |
| 5 | 2 | 7.1 |
| 7 | 2 | 7.3 |
| 10 | 3 | 7.7 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 0.35 | pressure reduced |
| | | 0.35 | 0.7 to 0.35 psi |
| | | 0.35 | 1.2 during test |
| | | 0.35 | 1.6 |
| | | 0.35 | 1.7 |
| | | 0.35 | 1.7 |
| | | 0.35 | 2.6 |
| | | 0.35 | 2.9 |
| | | 0.36 | 3.2 |

GENERAL COMMENTS

## LAR2



JET TEST DATA

$\tau_c$ ____

K ____

Date worked up

TEST LOCATION LAR2

PT GAUGE RDING @ SUBSTRATE ~~4.85~~ 4.9

PT GAUGE READING @ NOZZLE

PRELIMINARY HEAD SETTING 0.5

MATERIAL DESCRIPTION Sand

Circle one
Bed
Bank toe
Bank face

TEST # 1

DATE 11/15/18

OPERATOR EJL

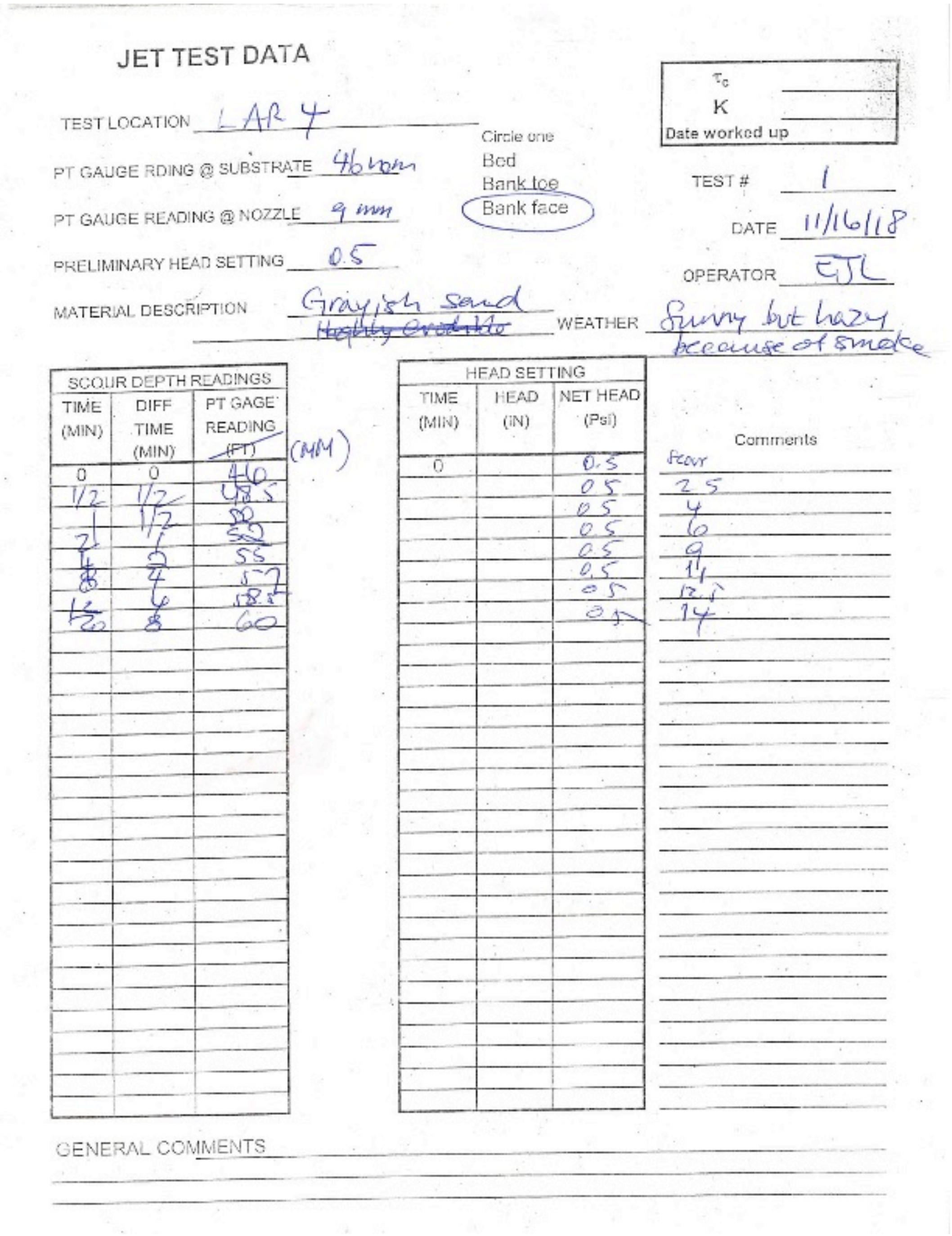
WEATHER Sunny

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (CM) |
| 0 | 0 | 4.9 |
| 1/2 | 1/2 | 6.7 |
| 1 | 1/2 | 6.95 |
| 2 | 1 | 7.4 |
| 3 | 1 | 7.55 |
| 5 | 2 | 8.5 |
| 7 | 2 | 8.7 |
| 12 | 5 | 9.4 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 0.5 | |
| | | 0.5 | 1.8 |
| | | 0.5 | 2.05 |
| | | 0.5 | 2.5 |
| | | 0.5 | 2.65 |
| | | 0.5 | 3.6 |
| | | 0.5 | 3.8 |
| | | 0.5 | 4.5 |

GENERAL COMMENTS

## LAR4



### JET TEST DATA

$\tau_c$ ______
K ______
Date worked up ______

TEST LOCATION LAR 4

PT GAUGE RDING @ SUBSTRATE 46 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 0.5

Circle one
Bed
Bank toe
[✓ Bank face]

TEST # 1

DATE 11/16/18

OPERATOR EJL

MATERIAL DESCRIPTION Grayish sand ~~Highly Erodible~~

WEATHER Sunny but hazy because of smoke

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
|---|---|---|
| 0 | 0 | 46 |
| 1/2 | 1/2 | 48.5 |
| 1 | 1/2 | 50 |
| 2 | 1 | 52 |
| 4 | 2 | 55 |
| 8 | 4 | 57 |
| 12 | 6 | 58.5 |
| 20 | 8 | 60 |

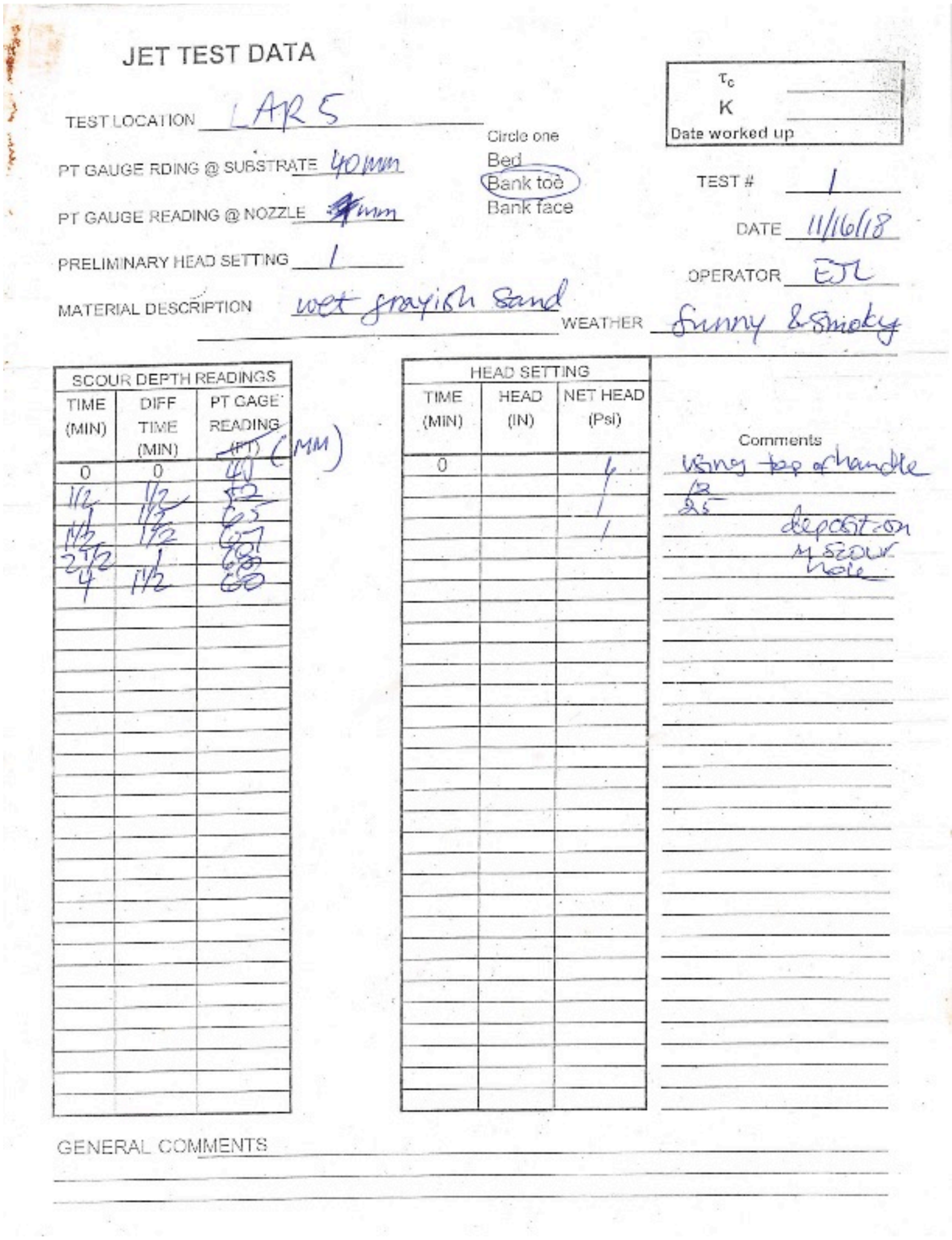
HEAD SETTING

| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
|---|---|---|---|
| | | | Scour |
| 0 | | 0.5 | 2.5 |
| | | 0.5 | 4 |
| | | 0.5 | 6 |
| | | 0.5 | 9 |
| | | 0.5 | 11 |
| | | 0.5 | 12.5 |
| | | 0.5 | 14 |
| | | 0.5 | |

GENERAL COMMENTS

)

## LAR5 – test 1



JET TEST DATA

$\tau_c$ ______
K ______
Date worked up

TEST LOCATION LAR5

PT GAUGE RDING @ SUBSTRATE 40mm

PT GAUGE READING @ NOZZLE 4mm

PRELIMINARY HEAD SETTING 1

MATERIAL DESCRIPTION wet grayish sand

Circle one
Bed
[✓ Bank toe]
Bank face

TEST # 1

DATE 11/16/18

OPERATOR EJL

WEATHER sunny & smoky

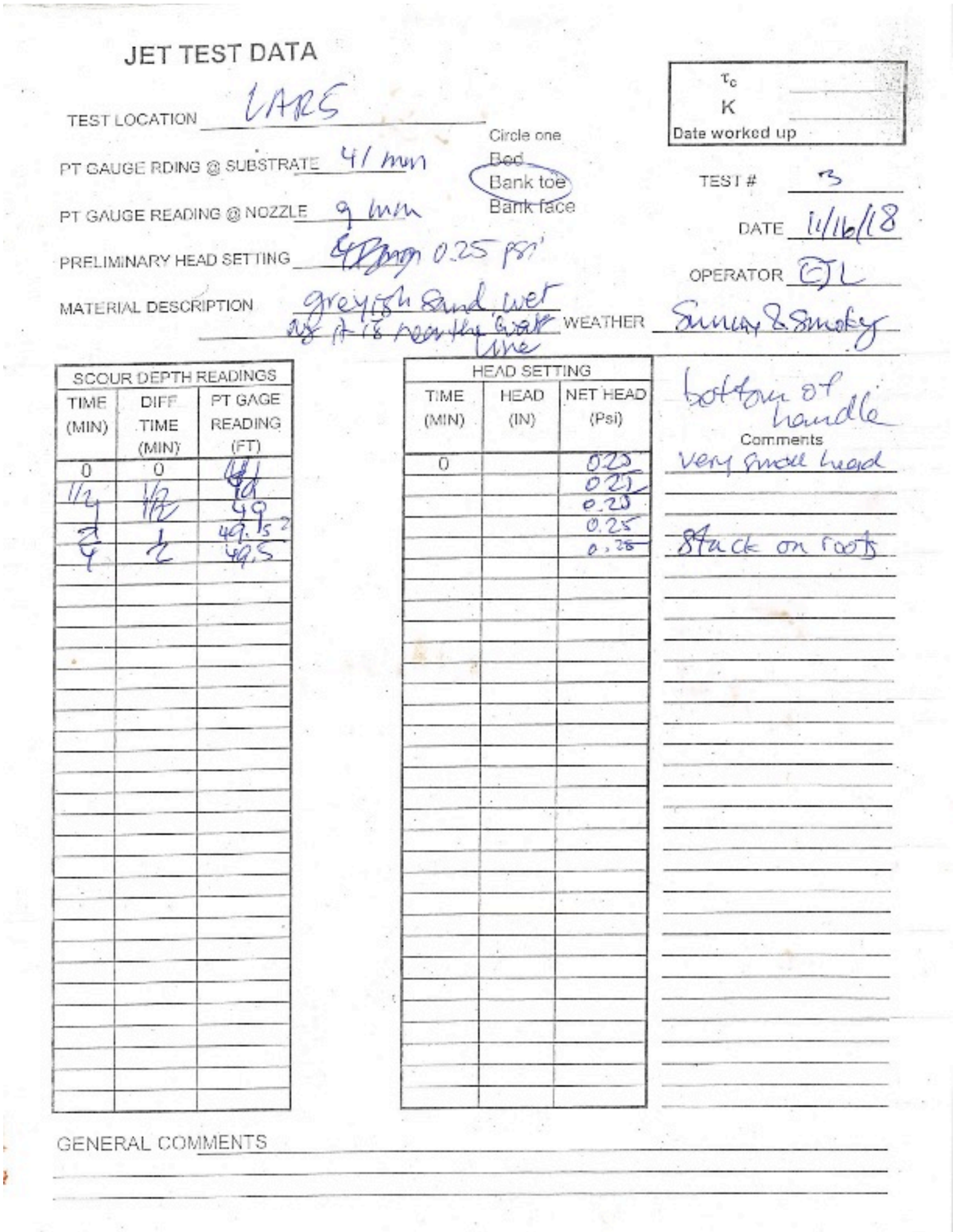
| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 40 |
| 1/2 | 1/2 | 52 |
| 1 | 1/2 | 65 |
| 1 1/2 | 1/2 | 67 |
| 2 1/2 | 1 | 68 |
| 4 | 1 1/2 | 68 |

| HEAD SETTING | | |
|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
| 0 | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |

Comments
using top of handle
12
25
deposit on
in scour
hole

GENERAL COMMENTS

## LAR5 – test 2



### JET TEST DATA

$\tau_c$ ____
K ____
Date worked up

TEST LOCATION LAR5

PT GAUGE RDING @ SUBSTRATE 41 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING ~~48mm~~ 0.25 psi

MATERIAL DESCRIPTION greyish sand, wet as it is near the water line

Circle one
Bed
[✓ Bank toe]
Bank face

TEST # 3

DATE 11/16/18

OPERATOR CJL

WEATHER Sunny & Smoky

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING (FT) |
| 0 | 0 | 48 |
| 1/2 | 1/2 | 49 |
| | | 49 |
| 2 | 1 | 49.5 ? |
| 4 | 2 | 49.5 |

| HEAD SETTING | | |
|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
| 0 | | 0.25 |
| | | 0.25 |
| | | 0.25 |
| | | 0.25 |
| | | 0.25 |

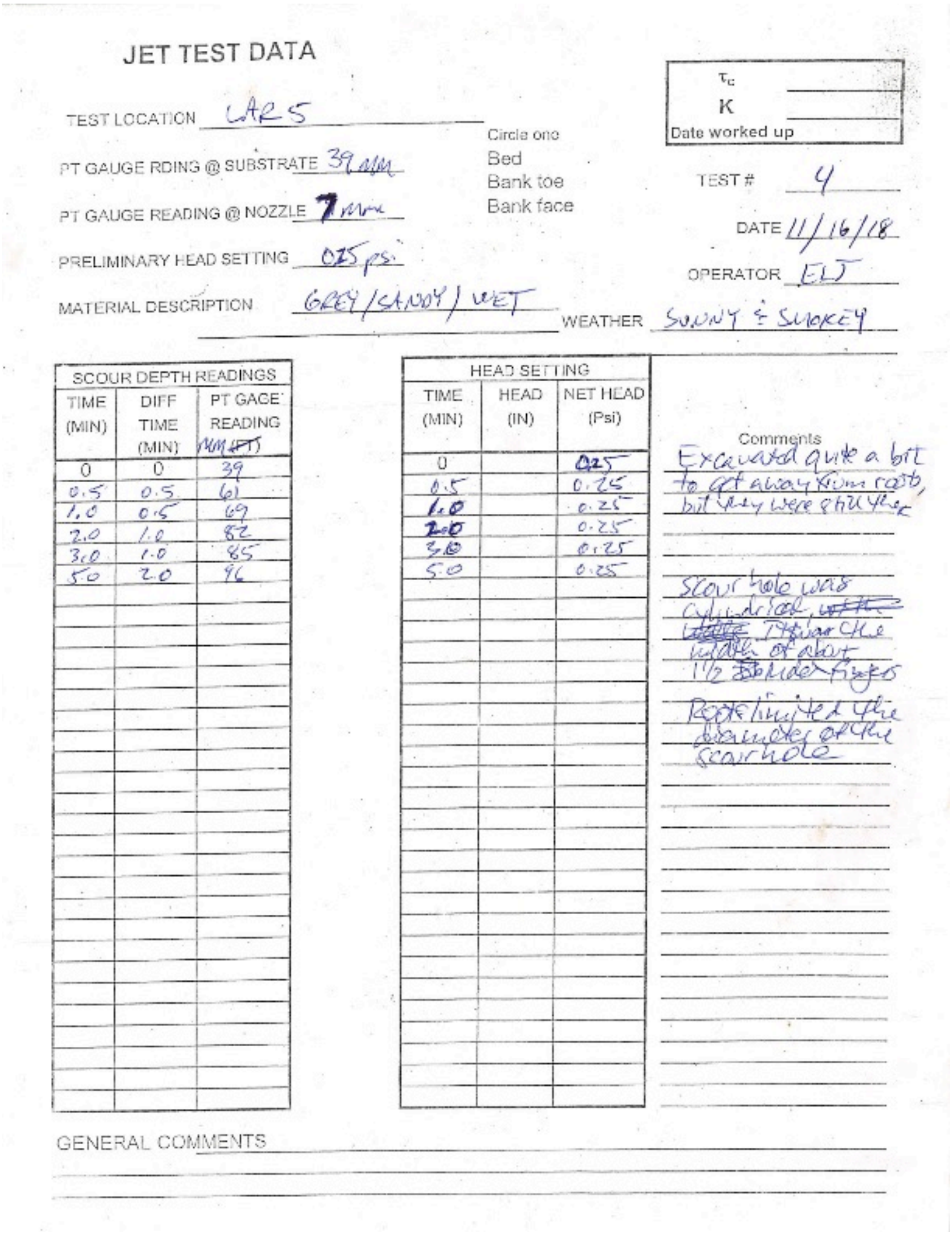
bottom of handle

Comments
very small head

stuck on roots

GENERAL COMMENTS

## LAR5 – test 3



JET TEST DATA

TEST LOCATION LAR 5

PT GAUGE RDING @ SUBSTRATE 39 mm

PT GAUGE READING @ NOZZLE 7 mm

PRELIMINARY HEAD SETTING 0.25 psi

MATERIAL DESCRIPTION GREY / SANDY / WET

Circle one
Bed
Bank toe
Bank face

τc
K
Date worked up

TEST # 4

DATE 11/16/18

OPERATOR ELJ

WEATHER SUNNY & SMOKEY

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING MM ~~(FT)~~ |
| 0 | 0 | 39 |
| 0.5 | 0.5 | 61 |
| 1.0 | 0.5 | 69 |
| 2.0 | 1.0 | 82 |
| 3.0 | 1.0 | 85 |
| 5.0 | 2.0 | 96 |

| HEAD SETTING | | |
|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
| 0 | | 0.25 |
| 0.5 | | 0.25 |
| 1.0 | | 0.25 |
| 2.0 | | 0.25 |
| 3.0 | | 0.25 |
| 5.0 | | 0.25 |

Comments

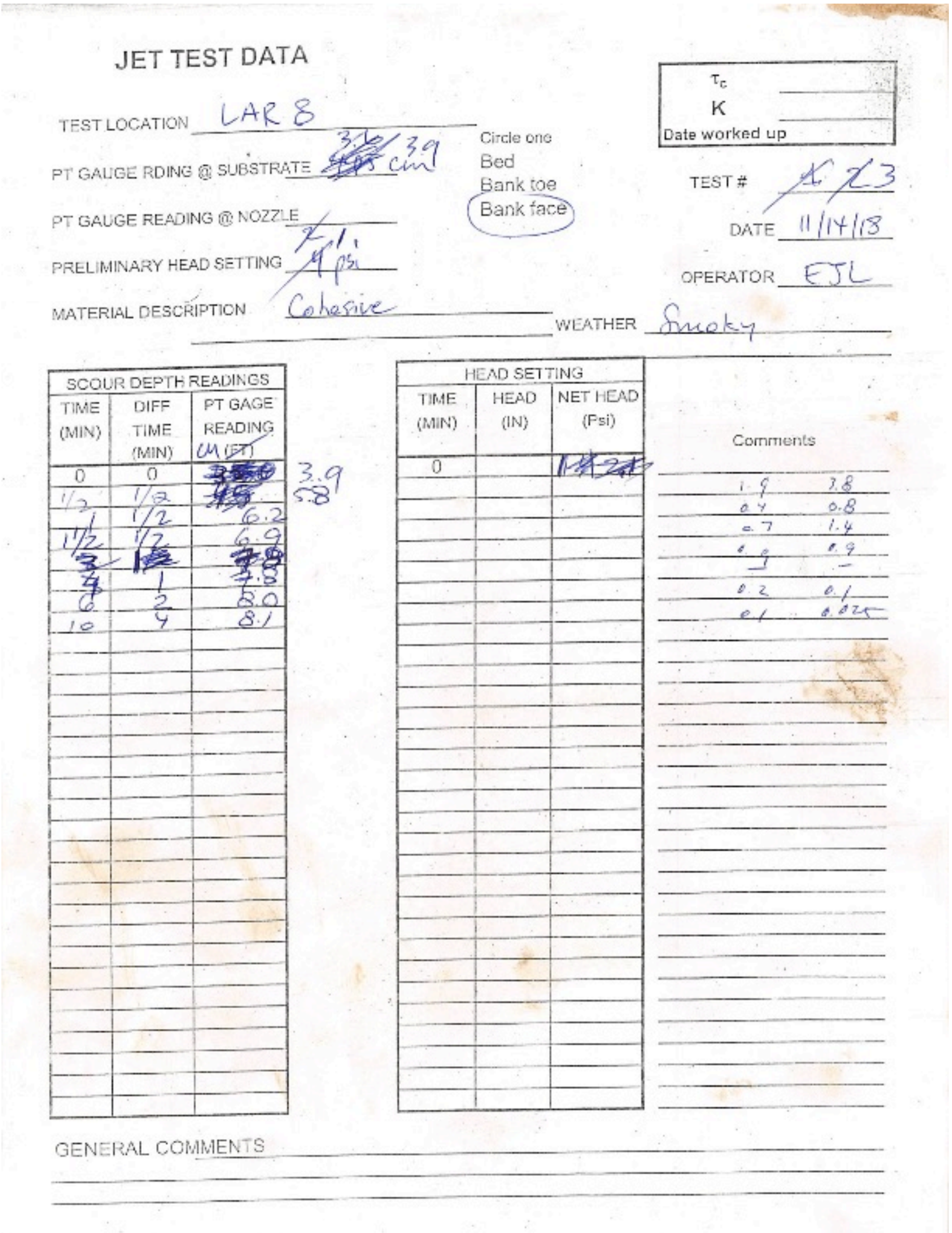
Excavated quite a bit to get away from roots, but they were still there

Scour hole was cylindrical, ~~with the~~ ~~[illegible]~~ It was the width of about 1½ ~~[illegible]~~ wider fingers

Roots limited the diameter of the scour hole

GENERAL COMMENTS

## LAR8 – test 1



JET TEST DATA

| | |
|---|---|
| $\tau_c$ | |
| K | |
| Date worked up | |

TEST LOCATION LAR 8

PT GAUGE RDING @ SUBSTRATE ~~4.5~~ 3.6/3.9 cm

PT GAUGE READING @ NOZZLE

PRELIMINARY HEAD SETTING ~~2~~ 1 ~~4~~ psi

MATERIAL DESCRIPTION Cohesive

Circle one: Bed / Bank toe / [✓ Bank face]

TEST # ~~1~~ ~~2~~ 3

DATE 11/14/18

OPERATOR EJL

WEATHER Smoky

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING cm ~~(FT)~~ | |
|---|---|---|---|
| 0 | 0 | [illegible] | 3.9 |
| 1/2 | 1/2 | [illegible] | 5.8 |
| 1 | 1/2 | 6.2 | |
| 1 1/2 | 1/2 | 6.9 | |
| 3 | 1 1/2 | [illegible] | |
| 4 | 1 | 7.8 | |
| 6 | 2 | 8.0 | |
| 10 | 4 | 8.1 | |

HEAD SETTING

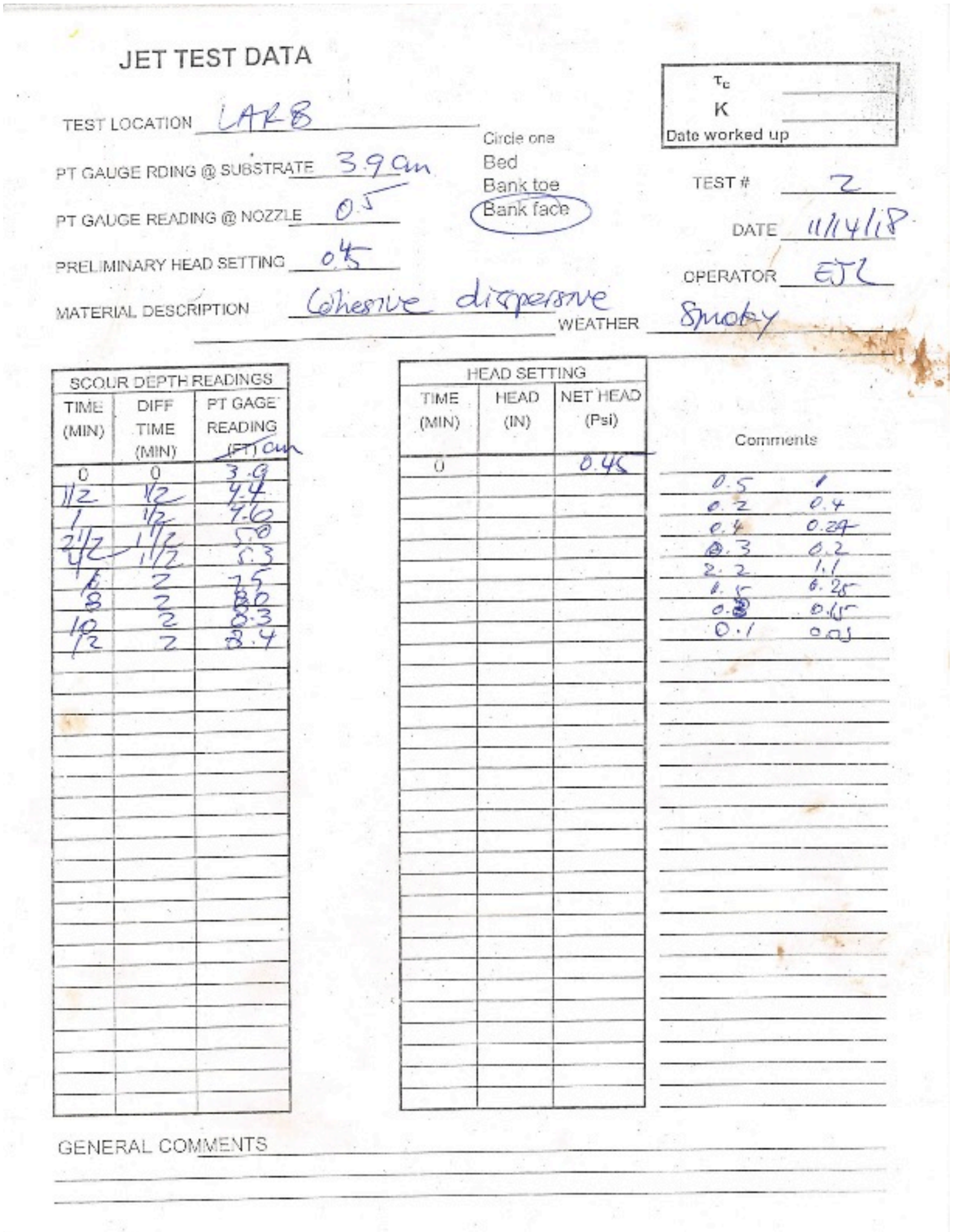
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
|---|---|---|
| 0 | | [illegible] |

Comments

| | |
|---|---|
| 1.9 | 7.8 |
| 0.4 | 0.8 |
| 0.7 | 1.4 |
| 0.9 | 0.9 |
| 0.2 | 0.1 |
| 0.1 | 0.025 |

GENERAL COMMENTS

## LAR8 – test 2



JET TEST DATA

$\tau_c$ ____
K ____
Date worked up

TEST LOCATION LAR8

PT GAUGE RDING @ SUBSTRATE 3.9 cm

PT GAUGE READING @ NOZZLE 0.5

PRELIMINARY HEAD SETTING 0.45

Circle one
Bed
Bank toe
[✓ Bank face]

TEST # 2

DATE 11/14/18

OPERATOR EJL

MATERIAL DESCRIPTION Cohesive dispersive

WEATHER Smoky

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ cm |
|---|---|---|
| 0 | 0 | 3.9 |
| 1/2 | 1/2 | 4.4 |
| 1 | 1/2 | 4.6 |
| 2 1/2 | 1 1/2 | 5.0 |
| 4 | 1 1/2 | 5.3 |
| 6 | 2 | 7.5 |
| 8 | 2 | 8.0 |
| 10 | 2 | 8.3 |
| 12 | 2 | 8.4 |

HEAD SETTING

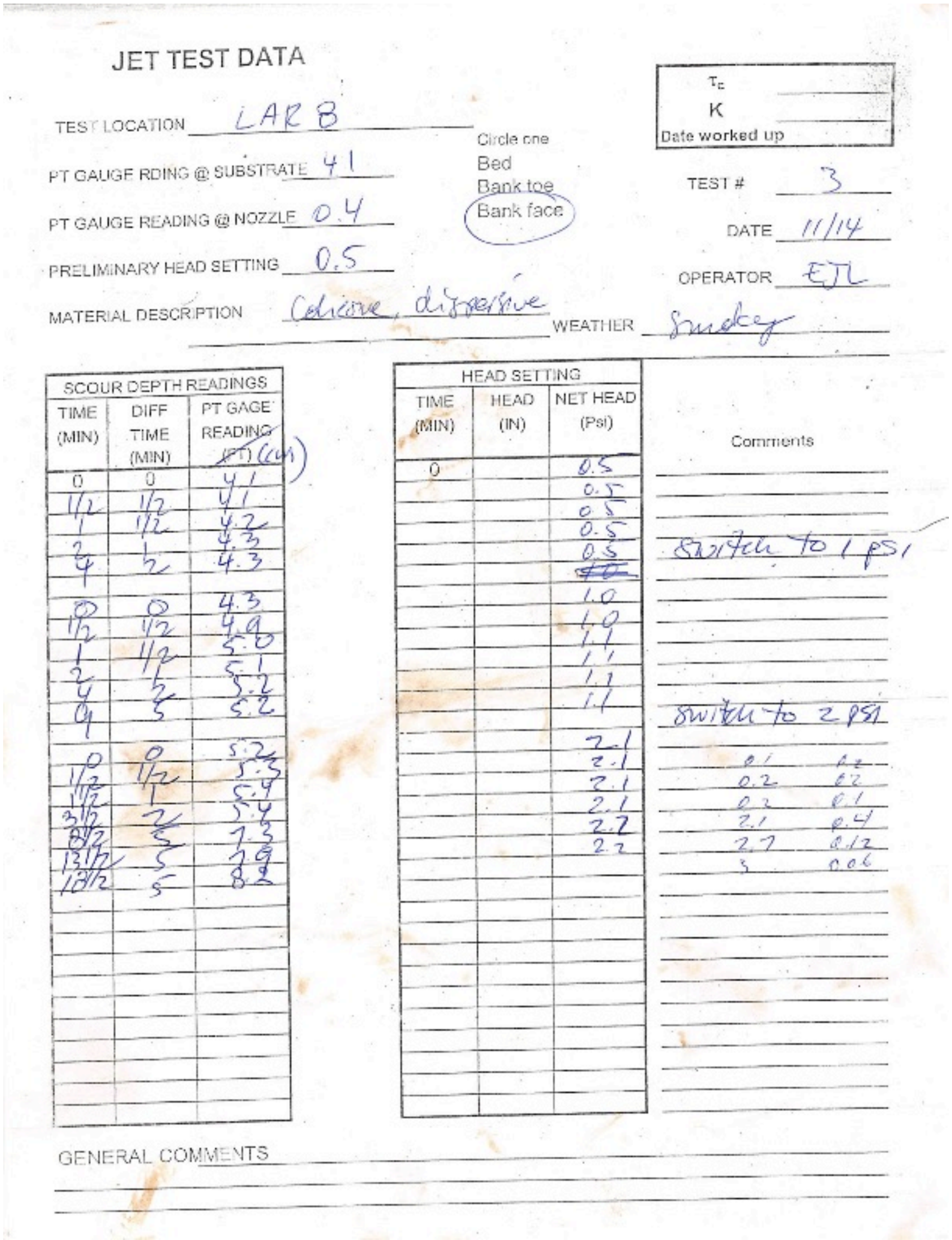
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
|---|---|---|
| 0 | | 0.45 |

Comments

| | |
|---|---|
| 0.5 | 1 |
| 0.2 | 0.4 |
| 0.4 | 0.24 |
| 0.3 | 0.2 |
| 2.2 | 1.1 |
| 1.5 | 0.25 |
| 0.3 | 0.15 |
| 0.1 | 0.05 |

GENERAL COMMENTS

## LAR8 – test 3



### JET TEST DATA

$\tau_c$ ______
K ______
Date worked up ______

TEST LOCATION LAR 8

PT GAUGE RDING @ SUBSTRATE 4.1

PT GAUGE READING @ NOZZLE 0.4

PRELIMINARY HEAD SETTING 0.5

Circle one
Bed
Bank toe
[✓ Bank face]

TEST # 3

DATE 11/14

OPERATOR EJL

MATERIAL DESCRIPTION Cohesive, dispersive

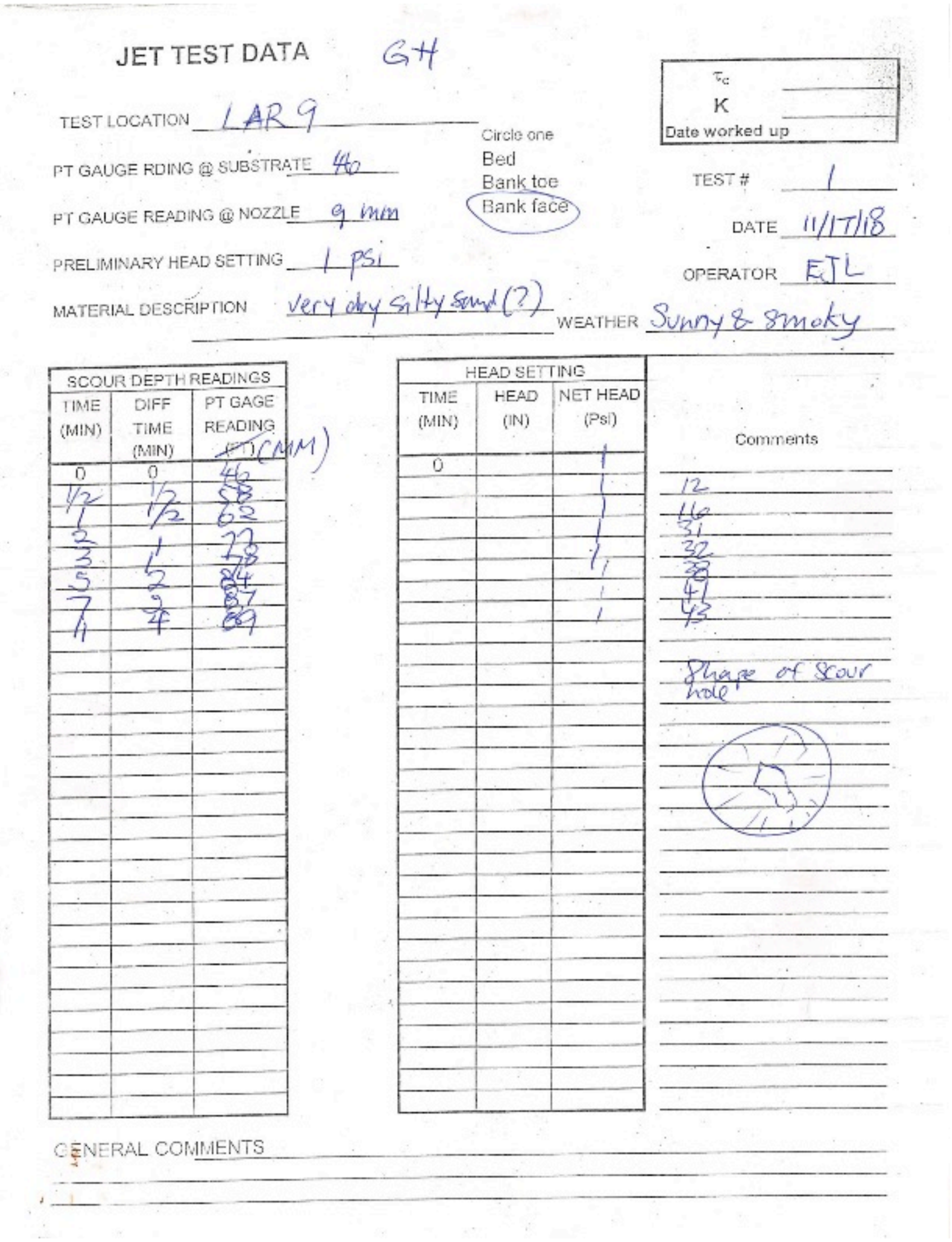
WEATHER Smokey

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (cm) |
| 0 | 0 | 4.1 |
| 1/2 | 1/2 | 4.1 |
| 1 | 1/2 | 4.2 |
| 2 | 1 | 4.3 |
| 4 | 2 | 4.3 |
| | | |
| 0 | 0 | 4.3 |
| 1/2 | 1/2 | 4.9 |
| 1 | 1/2 | 5.0 |
| 2 | 1 | 5.1 |
| 4 | 2 | 5.2 |
| 9 | 5 | 5.2 |
| | | |
| 0 | 0 | 5.2 |
| 1/2 | 1/2 | 5.3 |
| 1 1/2 | 1 | 5.4 |
| 3 1/2 | 2 | 5.4 |
| 8 1/2 | 5 | 7.3 |
| 13 1/2 | 5 | 7.9 |
| 18 1/2 | 5 | 8.2 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 0.5 | |
| | | 0.5 | |
| | | 0.5 | |
| | | 0.5 | |
| | | 0.5 | switch to 1 psi |
| | | ~~1.0~~ | |
| | | 1.0 | |
| | | 1.0 | |
| | | 1.1 | |
| | | 1.1 | |
| | | 1.1 | |
| | | 1.1 | switch to 2 psi |
| | | 2.1 | |
| | | 2.1 | 0.1 0.2 |
| | | 2.1 | 0.2 0.2 |
| | | 2.1 | 0.2 0.1 |
| | | 2.2 | 2.1 0.4 |
| | | 2.2 | 2.7 0.12 |
| | | | 3 0.06 |

GENERAL COMMENTS ______

## LAR9 – test 1



JET TEST DATA GH

$\tau_c$

K

Date worked up

TEST LOCATION LAR 9

PT GAUGE RDING @ SUBSTRATE 46

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 1 psi

MATERIAL DESCRIPTION very dry silty sand (?)

Circle one
Bed
Bank toe
[✓ Bank face]

TEST # 1

DATE 11/17/18

OPERATOR EJL

WEATHER Sunny & smoky

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 46 |
| 1/2 | 1/2 | 58 |
| 1 | 1/2 | 62 |
| 2 | 1 | 77 |
| 3 | 1 | 78 |
| 5 | 2 | 84 |
| 7 | 2 | 87 |
| 11 | 4 | 89 |

| HEAD SETTING | | |
|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
| 0 | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |

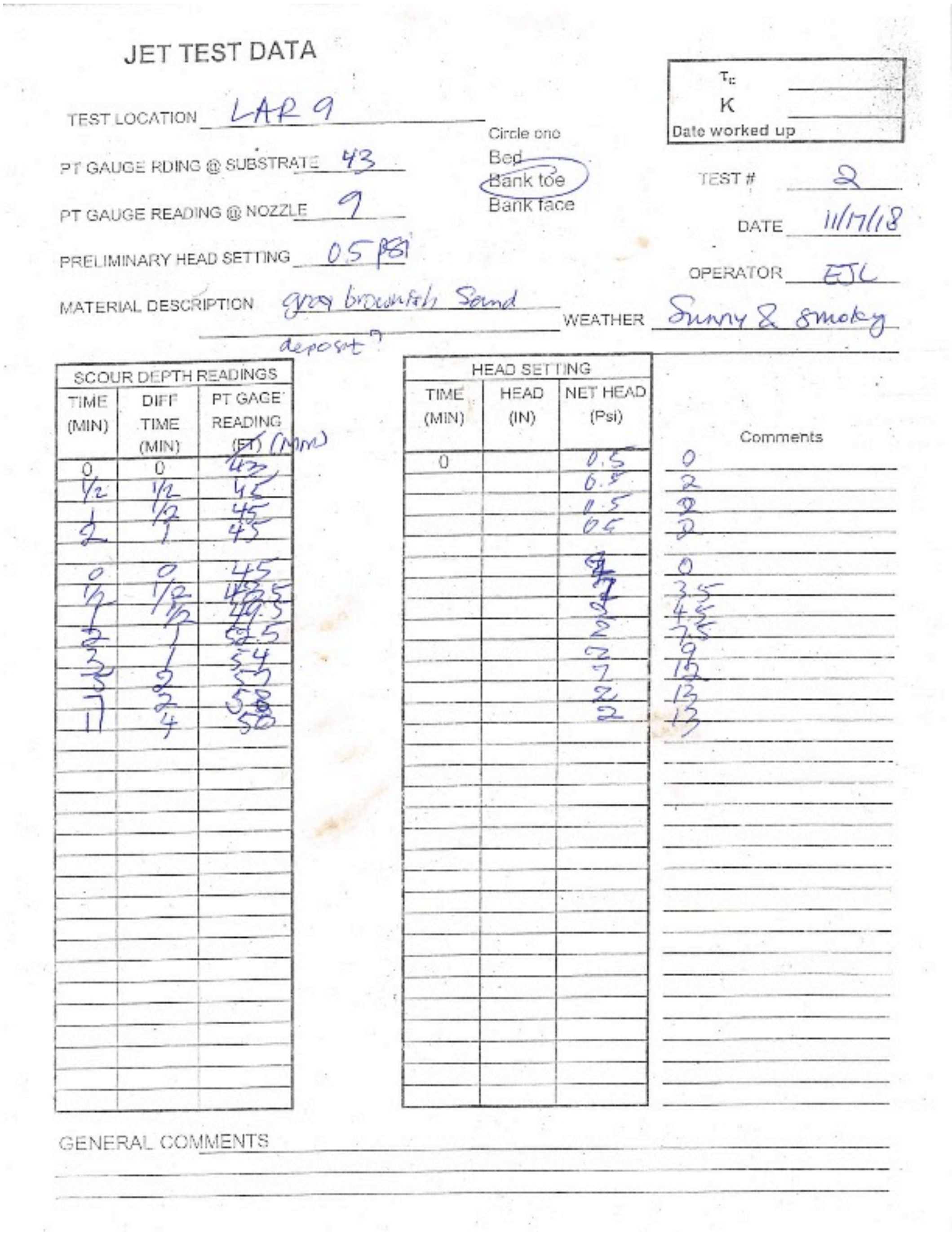
Comments

12
16
31
32
38
41
43

Shape of Scour hole

GENERAL COMMENTS

## LAR9 – test 2



### JET TEST DATA

$\tau_c$ ____

K ____

Date worked up ____

TEST LOCATION LAR 9

PT GAUGE RDING @ SUBSTRATE 43

PT GAUGE READING @ NOZZLE 9

PRELIMINARY HEAD SETTING 0.5 PSI

MATERIAL DESCRIPTION gray brownish Sand deposit?

Circle one: Bed [✓ Bank toe] Bank face

TEST # 2

DATE 11/17/18

OPERATOR EJL

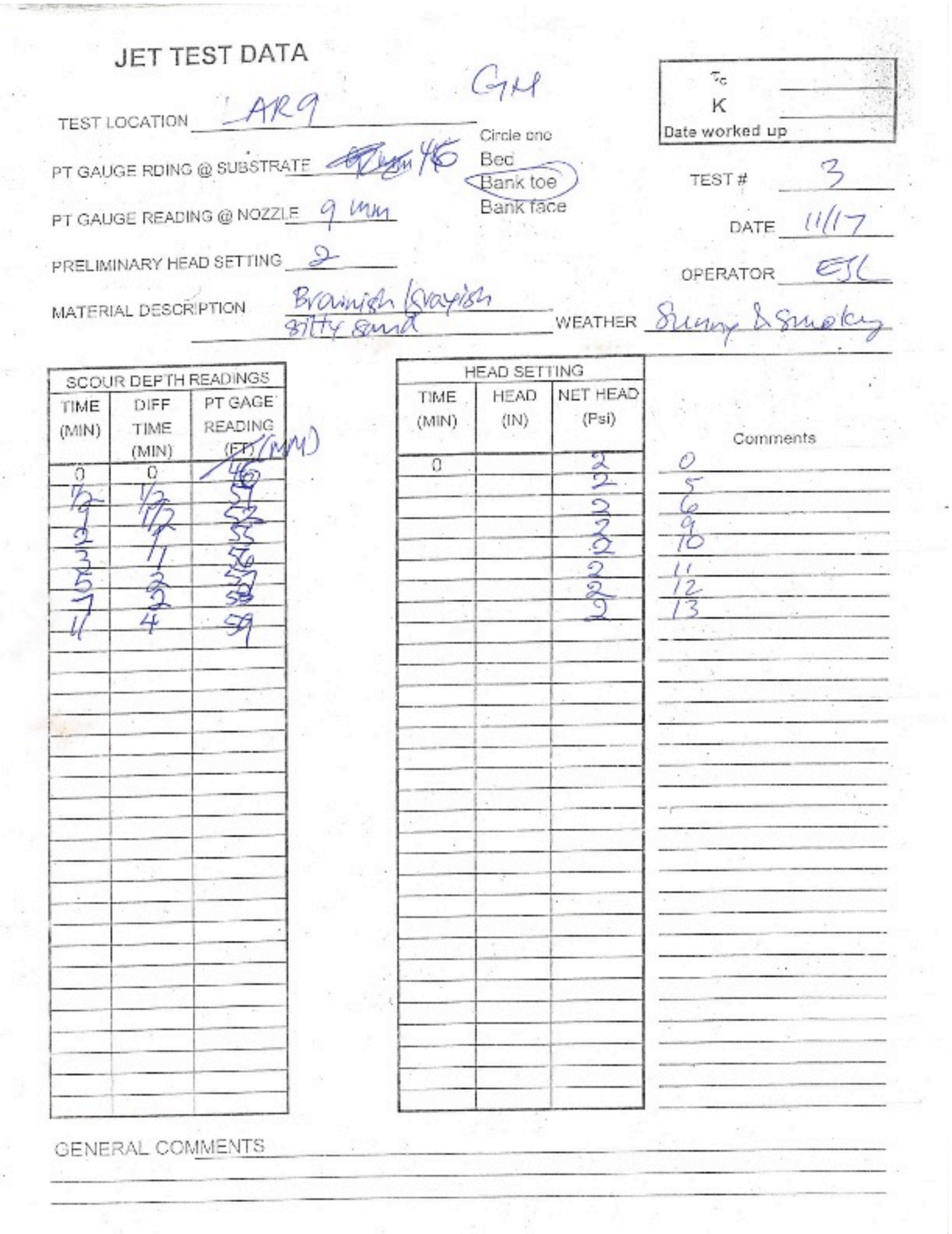
WEATHER Sunny & smoky

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 43 |
| 1/2 | 1/2 | 45 |
| 1 | 1/2 | 45 |
| 2 | 1 | 45 |
| | | |
| 0 | 0 | 45 |
| 1/2 | 1/2 | 48.5 |
| 1 | 1/2 | 49.5 |
| 2 | 1 | 52.5 |
| 3 | 1 | 54 |
| 5 | 2 | 57 |
| 7 | 2 | 58 |
| 11 | 4 | 58 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 0.5 | 0 |
| | | 0.5 | 2 |
| | | 0.5 | 2 |
| | | 0.5 | 2 |
| | | | |
| | | 2 | 0 |
| | | 2 | 3.5 |
| | | 2 | 4.5 |
| | | 2 | 7.5 |
| | | 2 | 9 |
| | | 2 | 12 |
| | | 2 | 13 |
| | | 2 | 13 |

GENERAL COMMENTS ____

## LAR9 – test 3



### JET TEST DATA

TEST LOCATION LAR9 GM

PT GAUGE RDING @ SUBSTRATE 46

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 2

MATERIAL DESCRIPTION Brownish/grayish silty sand

Circle one: Bed [✓ Bank toe] Bank face

$\tau_c$ ____

K ____

Date worked up

TEST # 3

DATE 11/17

OPERATOR EJC

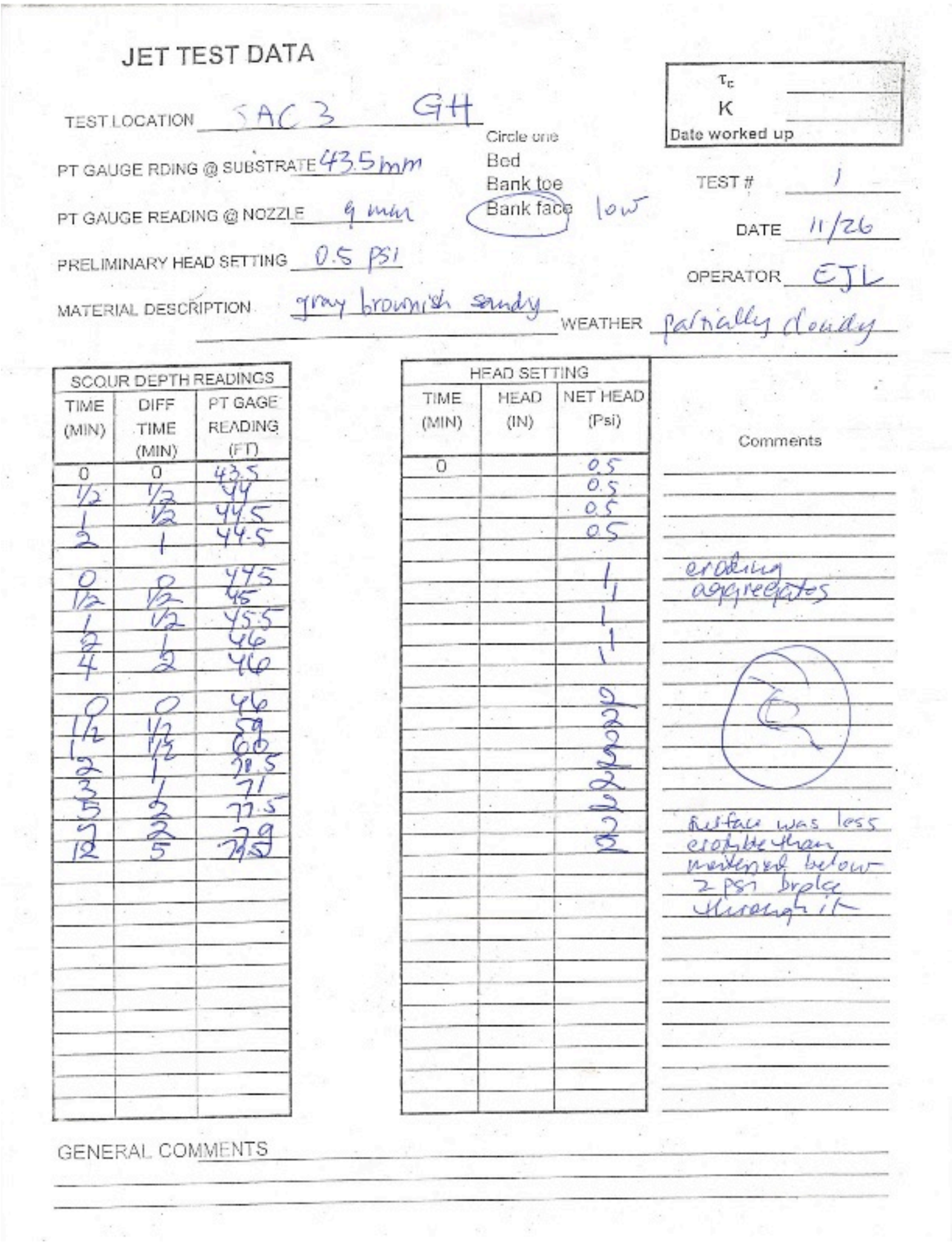
WEATHER Sunny & smoky

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 46 |
| 1/2 | 1/2 | 51 |
| 1 | 1/2 | 52 |
| 2 | 1 | 55 |
| 3 | 1 | 56 |
| 5 | 2 | 57 |
| 7 | 2 | 58 |
| 11 | 4 | 59 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 2 | 0 |
| | | 2 | 5 |
| | | 2 | 6 |
| | | 2 | 9 |
| | | 2 | 10 |
| | | 2 | 11 |
| | | 2 | 12 |
| | | 2 | 13 |

GENERAL COMMENTS

## SAC3 – test 1



**JET TEST DATA**

$\tau_c$ ______

K ______

Date worked up

TEST LOCATION SAC3 GH

PT GAUGE RDING @ SUBSTRATE 43.5 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 0.5 PSI

MATERIAL DESCRIPTION gray brownish sandy

Circle one: Bed / Bank toe / [✓ Bank face] low

TEST # 1

DATE 11/26

OPERATOR EJL

WEATHER partially cloudy

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING (FT) |
| 0 | 0 | 43.5 |
| 1/2 | 1/2 | 44 |
| 1 | 1/2 | 44.5 |
| 2 | 1 | 44.5 |
| | | |
| 0 | 0 | 44.5 |
| 1/2 | 1/2 | 45 |
| 1 | 1/2 | 45.5 |
| 2 | 1 | 46 |
| 4 | 2 | 46 |
| | | |
| 0 | 0 | 46 |
| 1/2 | 1/2 | 59 |
| 1 | 1/2 | 60 |
| 2 | 1 | 70.5 |
| 3 | 1 | 71 |
| 5 | 2 | 77.5 |
| 7 | 2 | 79 |
| 12 | 5 | 79.5 |

| HEAD SETTING | | |
|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
| 0 | | 0.5 |
| | | 0.5 |
| | | 0.5 |
| | | 0.5 |
| | | |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | |
| | | 2 |
| | | 2 |
| | | 2 |
| | | 2 |
| | | 2 |
| | | 2 |
| | | 2 |
| | | 2 |

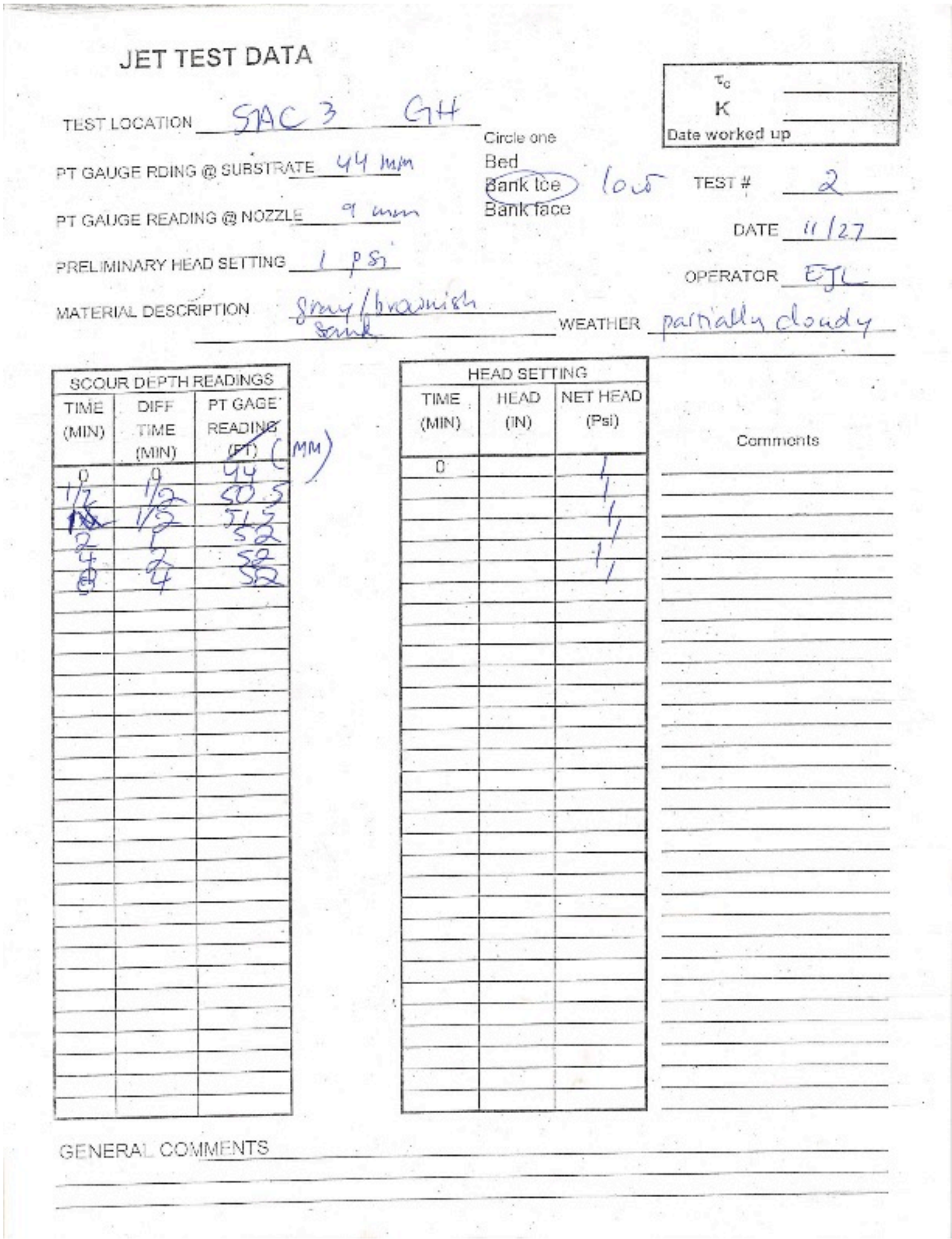
Comments

eroding aggregates

surface was less erodible than material below 2 psi broke through it

GENERAL COMMENTS

## SAC3 – test 2



### JET TEST DATA

$\tau_c$ ______
K ______
Date worked up

TEST LOCATION SAC 3 GH
PT GAUGE RDING @ SUBSTRATE 44 mm
PT GAUGE READING @ NOZZLE 9 mm
PRELIMINARY HEAD SETTING 1 psi
MATERIAL DESCRIPTION gray/brownish sand

Circle one
Bed [✓ Bank toe] low
Bank face

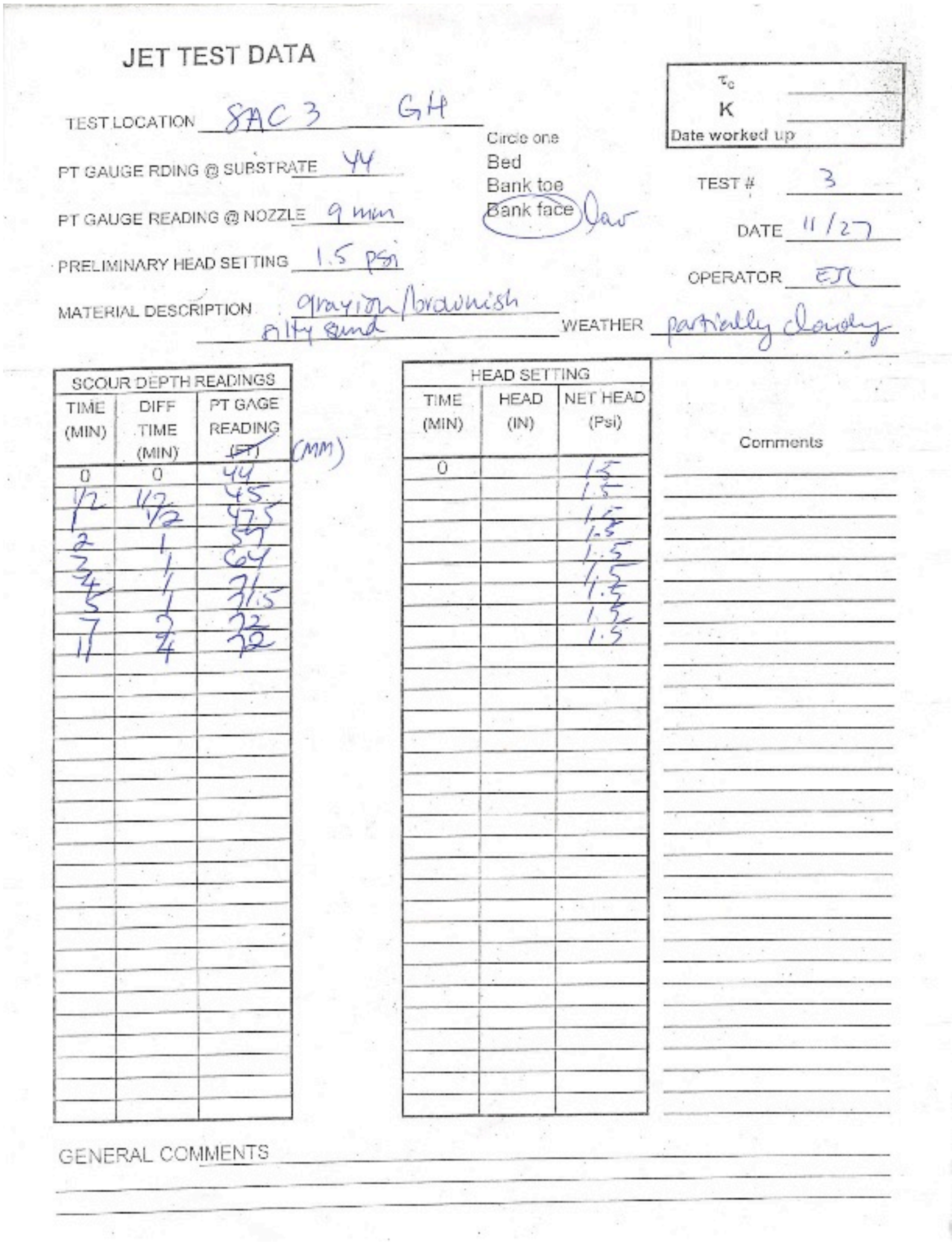
TEST # 2
DATE 11/27
OPERATOR EJL
WEATHER partially cloudy

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 44 |
| 1/2 | 1/2 | 50.5 |
| 1 | 1/2 | 51.5 |
| 2 | 1 | 52 |
| 4 | 2 | 52 |
| 8 | 4 | 52 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 1 | |
| | | 1 | |
| | | 1 | |
| | | 1 | |
| | | 1 | |
| | | 1 | |

GENERAL COMMENTS

## SAC3 – test 3



### JET TEST DATA

| | |
|---|---|
| $\tau_c$ | |
| K | |
| Date worked up | |

TEST LOCATION SAC 3 GH

PT GAUGE RDING @ SUBSTRATE 44

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 1.5 psi

MATERIAL DESCRIPTION grayish/brownish silty sand

Circle one
Bed
Bank toe
[✓ Bank face] Clay

TEST # 3

DATE 11/27

OPERATOR EJC

WEATHER partially cloudy

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
|---|---|---|
| 0 | 0 | 44 |
| 1/2 | 1/2 | 45 |
| 1 | 1/2 | 47.5 |
| 2 | 1 | 54 |
| 3 | 1 | 64 |
| 4 | 1 | 71 |
| 5 | 1 | 71.5 |
| 7 | 2 | 72 |
| 11 | 4 | 72 |

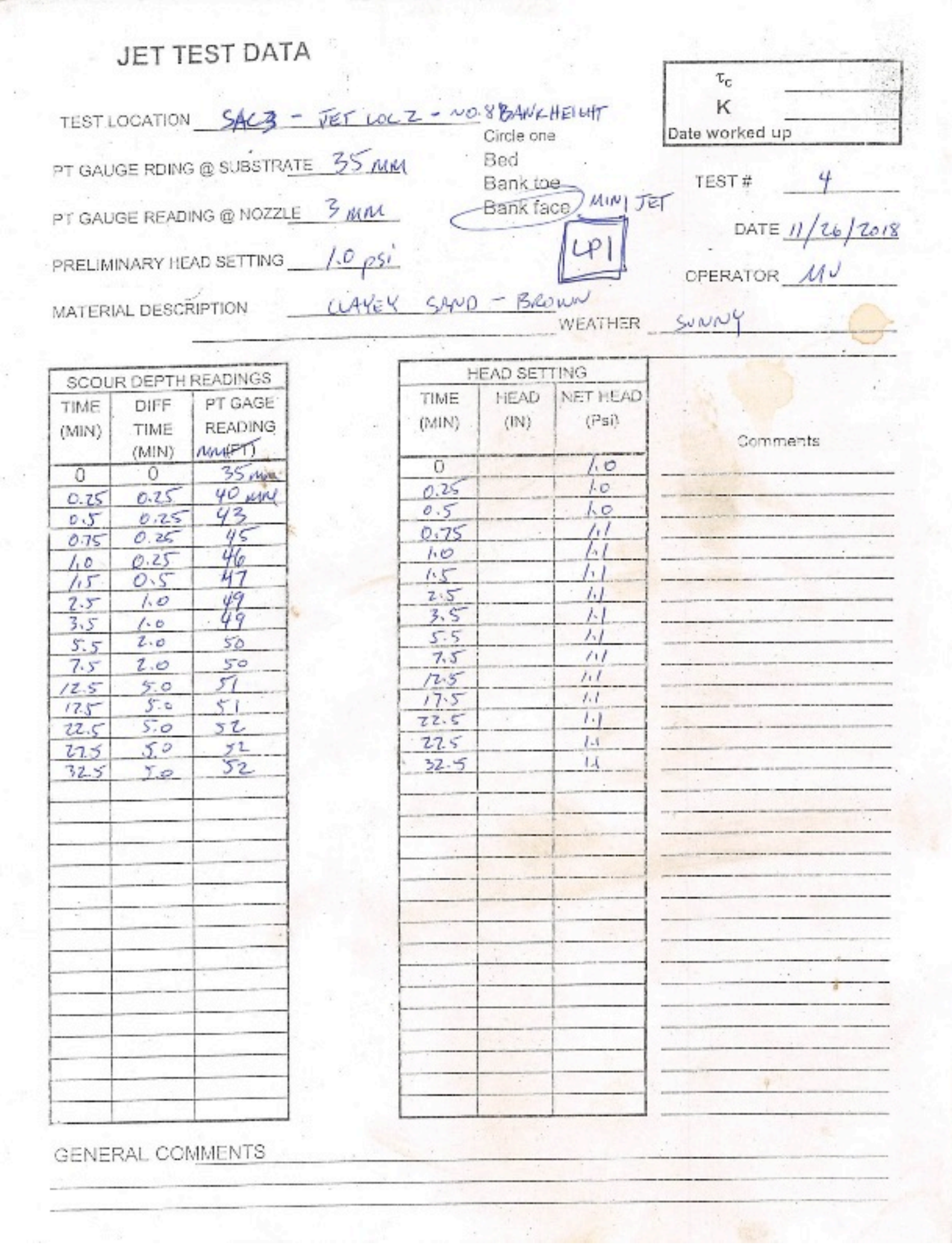
HEAD SETTING

| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
|---|---|---|
| 0 | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |
| | | 1.5 |

Comments

GENERAL COMMENTS

## SAC3 – test 4



JET TEST DATA

| | |
|---|---|
| $\tau_c$ | |
| K | |
| Date worked up | |

TEST LOCATION SAC3 - JET LOC 2 - NO.8 BANK HEIGHT

PT GAUGE RDING @ SUBSTRATE 35 MM

PT GAUGE READING @ NOZZLE 3 MM

PRELIMINARY HEAD SETTING 1.0 psi

MATERIAL DESCRIPTION CLAYEY SAND - BROWN

Circle one
Bed
Bank toe
[✓ Bank face] MINI JET

LP1

TEST # 4

DATE 11/26/2018

OPERATOR MJ

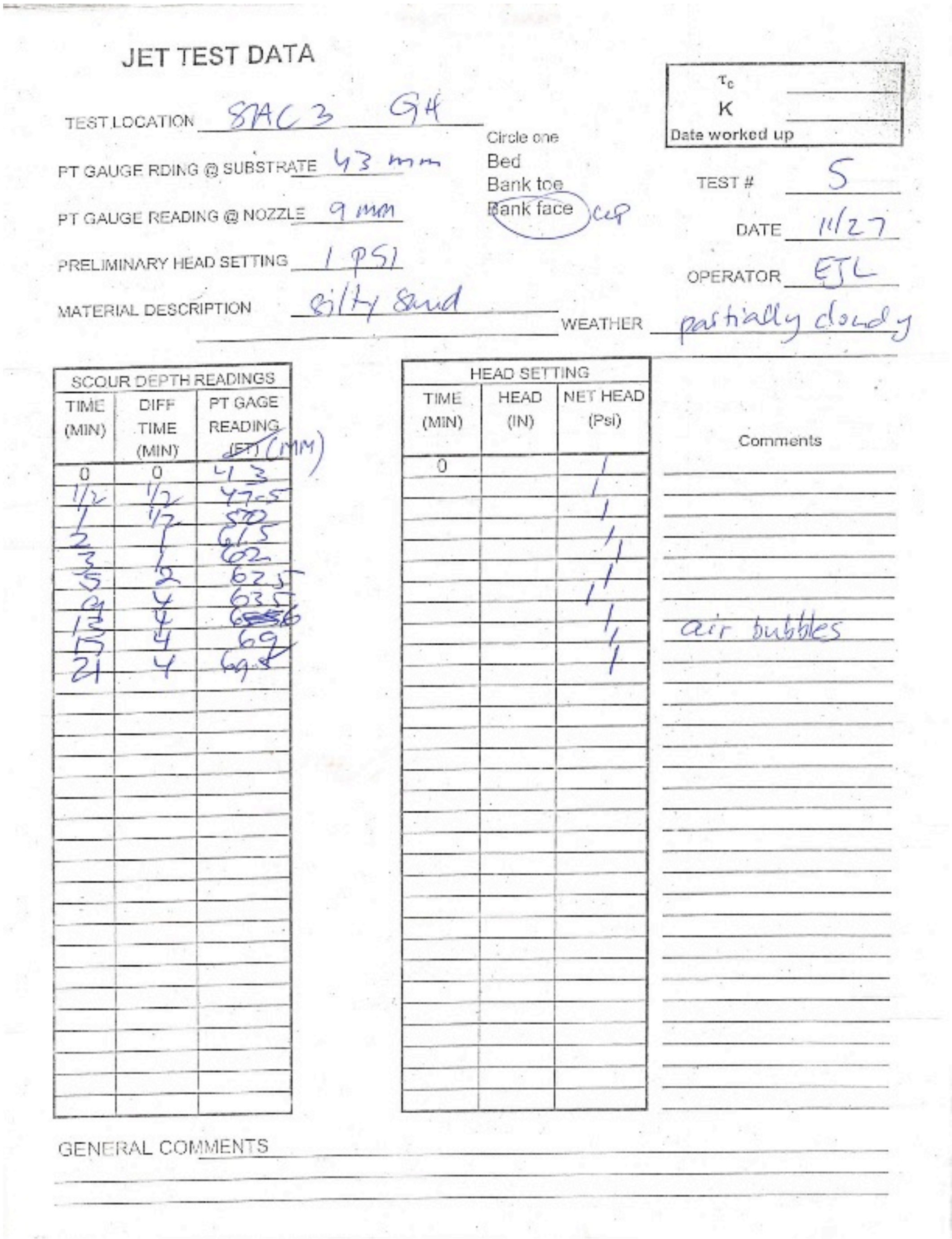
WEATHER SUNNY

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING MM ~~(FT)~~ |
| 0 | 0 | 35 MM |
| 0.25 | 0.25 | 40 MM |
| 0.5 | 0.25 | 43 |
| 0.75 | 0.25 | 45 |
| 1.0 | 0.25 | 46 |
| 1.5 | 0.5 | 47 |
| 2.5 | 1.0 | 49 |
| 3.5 | 1.0 | 49 |
| 5.5 | 2.0 | 50 |
| 7.5 | 2.0 | 50 |
| 12.5 | 5.0 | 51 |
| 17.5 | 5.0 | 51 |
| 22.5 | 5.0 | 52 |
| 27.5 | 5.0 | 52 |
| 32.5 | 5.0 | 52 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 1.0 | |
| 0.25 | | 1.0 | |
| 0.5 | | 1.0 | |
| 0.75 | | 1.1 | |
| 1.0 | | 1.1 | |
| 1.5 | | 1.1 | |
| 2.5 | | 1.1 | |
| 3.5 | | 1.1 | |
| 5.5 | | 1.1 | |
| 7.5 | | 1.1 | |
| 12.5 | | 1.1 | |
| 17.5 | | 1.1 | |
| 22.5 | | 1.1 | |
| 22.5 | | 1.1 | |
| 32.5 | | 1.1 | |

GENERAL COMMENTS

## SAC3 – test 5



JET TEST DATA

$\tau_c$ ______
K ______
Date worked up

TEST LOCATION SAC3 G4

PT GAUGE RDING @ SUBSTRATE 43 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 1 PSI

MATERIAL DESCRIPTION Silty Sand

Circle one
Bed
Bank toe
[✓ Bank face] CCP

TEST # 5

DATE 11/27

OPERATOR EJL

WEATHER partially cloudy

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
|---|---|---|
| 0 | 0 | 43 |
| 1/2 | 1/2 | 47.5 |
| 1 | 1/2 | 50 |
| 2 | 1 | 61.5 |
| 3 | 1 | 62 |
| 5 | 2 | 62.5 |
| 9 | 4 | 63.5 |
| 13 | 4 | 66 |
| 17 | 4 | 69 |
| 21 | 4 | 69.8 |

HEAD SETTING

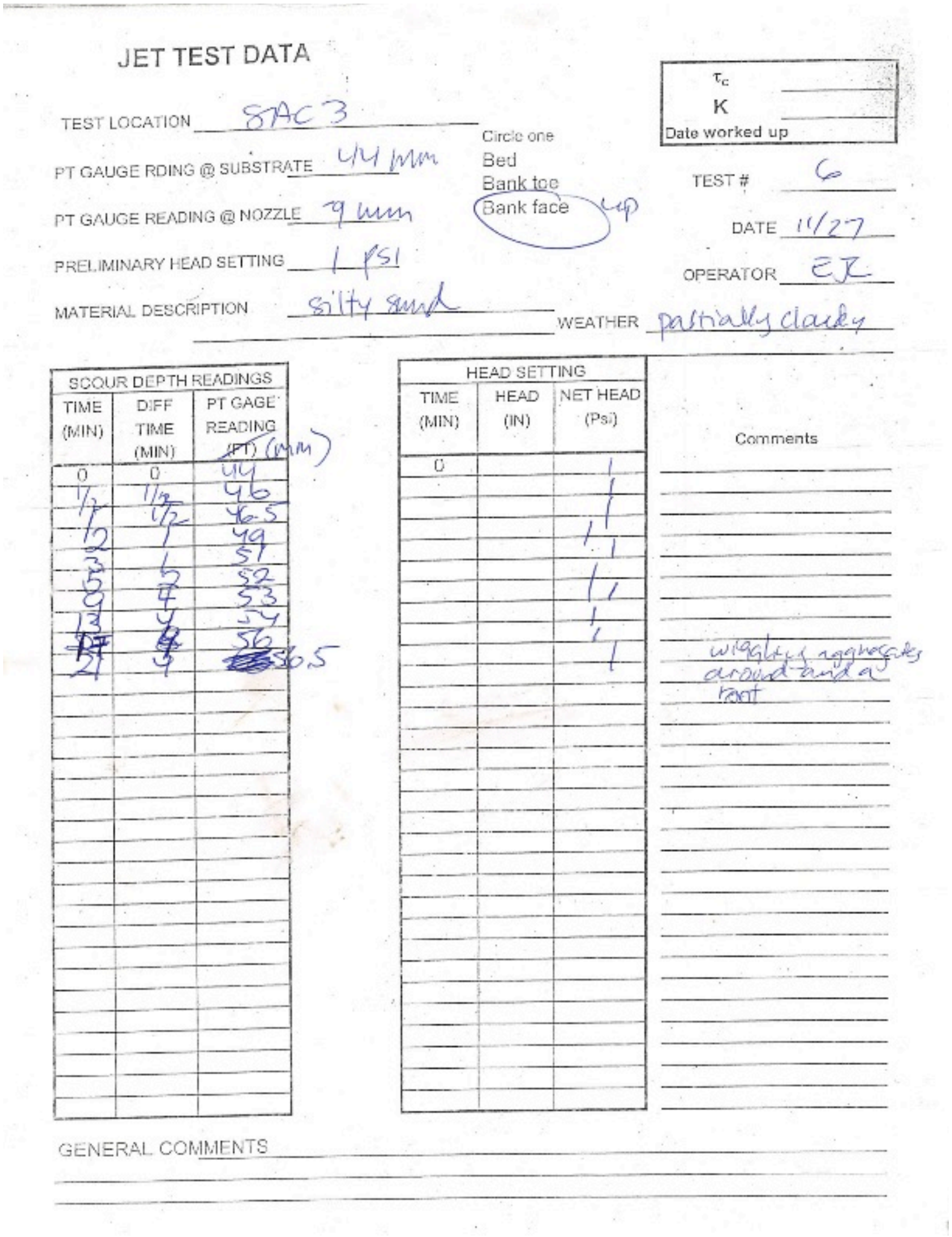
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
|---|---|---|
| 0 | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |
| | | 1 |

Comments

air bubbles

GENERAL COMMENTS

## SAC3 – test 6



### JET TEST DATA

$\tau_c$ 
K 
Date worked up

TEST LOCATION SAC3

PT GAUGE RDING @ SUBSTRATE 44 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 1 PSI

MATERIAL DESCRIPTION silty sand

Circle one
Bed
Bank toe
[✓ Bank face] up

TEST # 6

DATE 11/27

OPERATOR EK

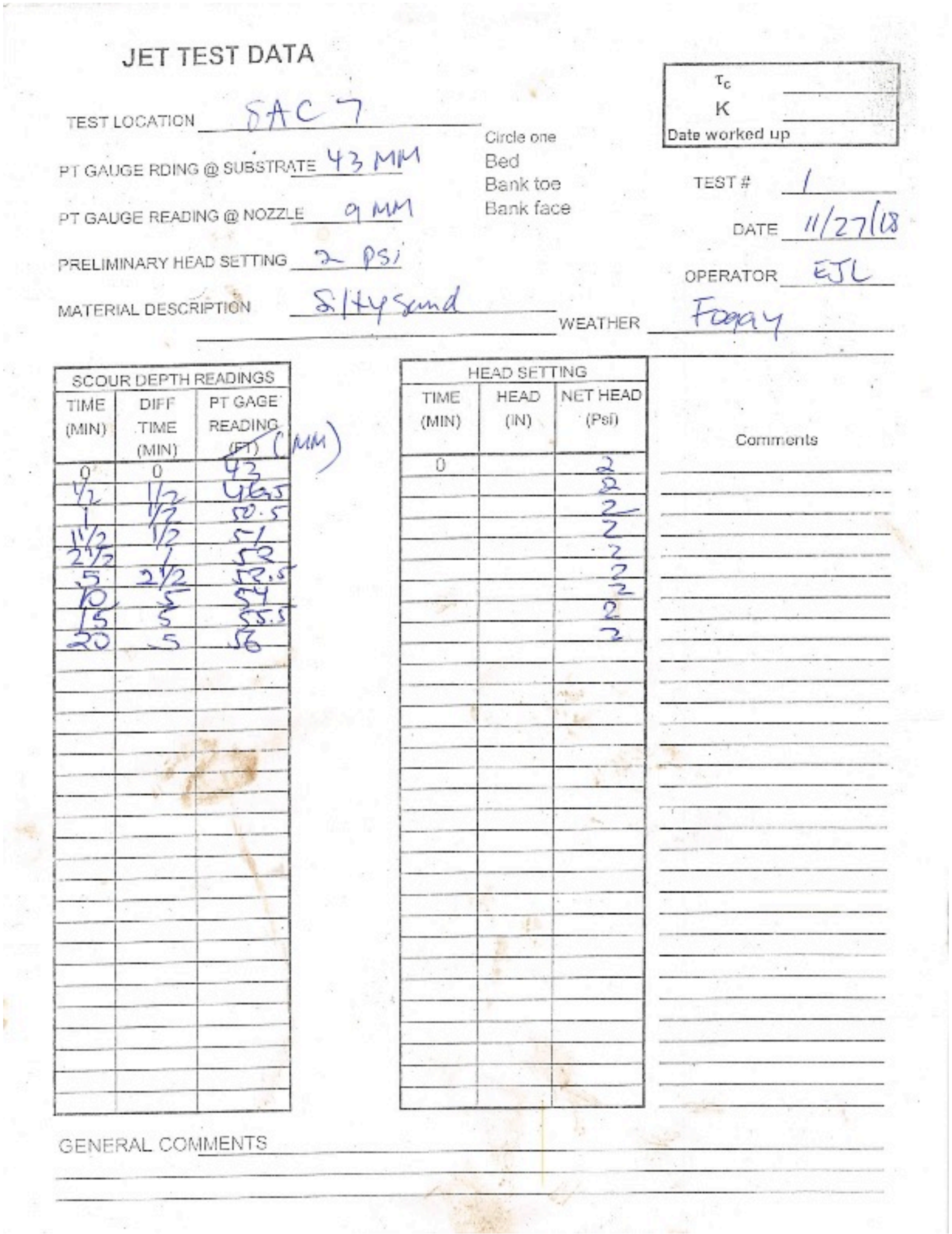
WEATHER partially cloudy

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 44 |
| 1/2 | 1/2 | 46 |
| 1 | 1/2 | 46.5 |
| 2 | 1 | 49 |
| 3 | 1 | 51 |
| 5 | 2 | 52 |
| 9 | 4 | 53 |
| 13 | 4 | 54 |
| 17 | 4 | 56 |
| 21 | 4 | 56.5 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 1 | |
| | | 1 | |
| | | 1 | |
| | | 1 1 | |
| | | 1 | |
| | | 1 1 | |
| | | 1 | |
| | | 1 | |
| | | 1 | wiggling aggregates around and a root |

GENERAL COMMENTS

## SAC7 – test 1



### JET TEST DATA

$\tau_c$ ______

K ______

Date worked up

TEST LOCATION SAC 7

PT GAUGE RDING @ SUBSTRATE 43 MM

PT GAUGE READING @ NOZZLE 9 MM

PRELIMINARY HEAD SETTING 2 psi

MATERIAL DESCRIPTION Siltysand

Circle one
Bed
Bank toe
Bank face

TEST # 1

DATE 11/27/18

OPERATOR EJL

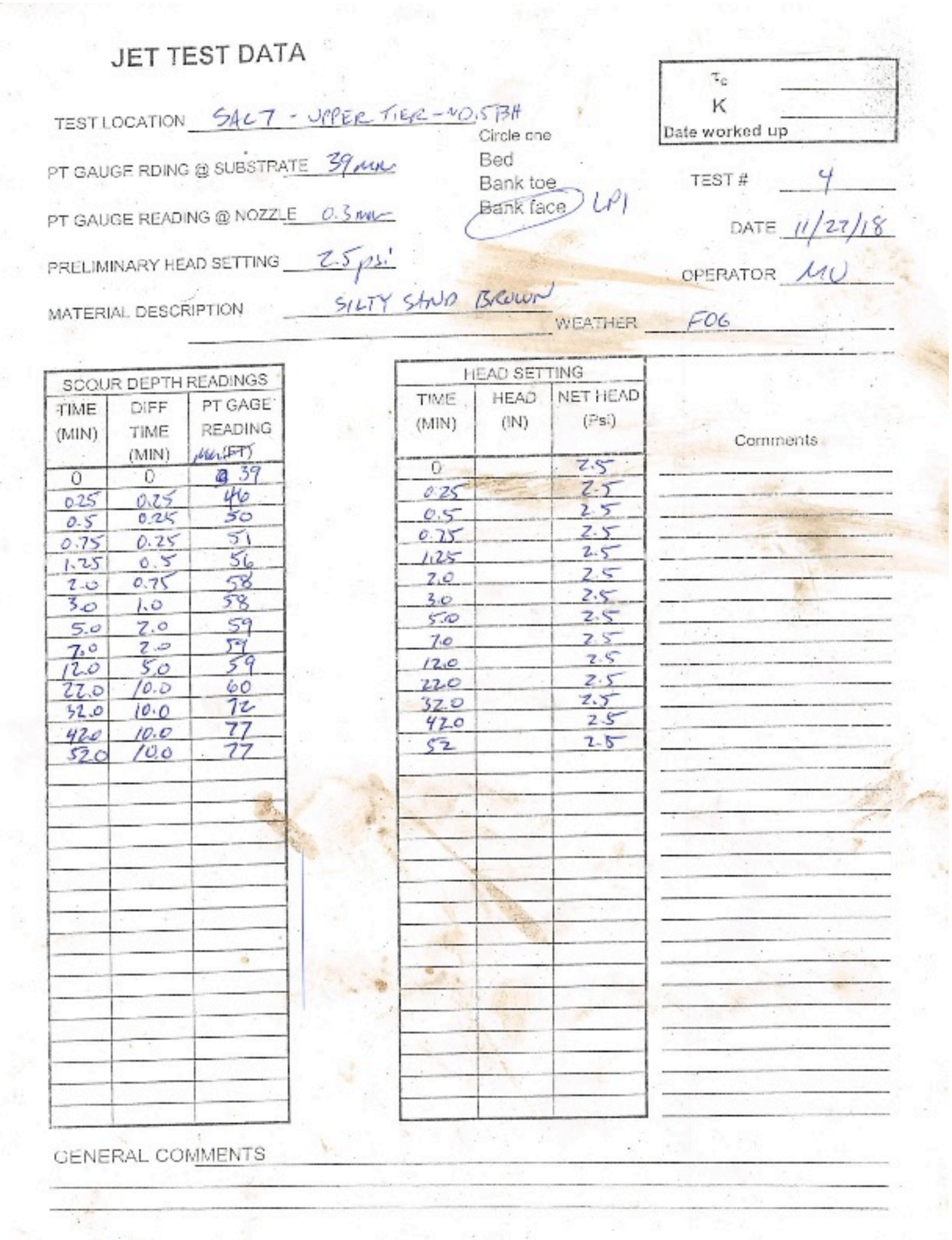
WEATHER Foggy

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (MM) |
| 0 | 0 | 43 |
| 1/2 | 1/2 | 46.5 |
| 1 | 1/2 | 50.5 |
| 1 1/2 | 1/2 | 51 |
| 2 1/2 | 1 | 52 |
| 5 | 2 1/2 | 52.5 |
| 10 | 5 | 54 |
| 15 | 5 | 55.5 |
| 20 | 5 | 56 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |
| | | 2 | |

GENERAL COMMENTS

## SAC7 – test 2



JET TEST DATA

$\tau_c$ ______

K ______

Date worked up

TEST LOCATION SAC7 - UPPER TIER - NO.5BH

Circle one
Bed
Bank toe
[✓ Bank face] LP1

PT GAUGE RDING @ SUBSTRATE 39mm

PT GAUGE READING @ NOZZLE 0.3mm

PRELIMINARY HEAD SETTING 2.5psi

MATERIAL DESCRIPTION SILTY SAND BROWN

TEST # 4

DATE 11/27/18

OPERATOR MU

WEATHER FOG

SCOUR DEPTH READINGS

| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING mm ~~(FT)~~ |
|---|---|---|
| 0 | 0 | 39 |
| 0.25 | 0.25 | 46 |
| 0.5 | 0.25 | 50 |
| 0.75 | 0.25 | 51 |
| 1.25 | 0.5 | 56 |
| 2.0 | 0.75 | 58 |
| 3.0 | 1.0 | 58 |
| 5.0 | 2.0 | 59 |
| 7.0 | 2.0 | 59 |
| 12.0 | 5.0 | 59 |
| 22.0 | 10.0 | 60 |
| 32.0 | 10.0 | 72 |
| 42.0 | 10.0 | 77 |
| 52.0 | 10.0 | 77 |

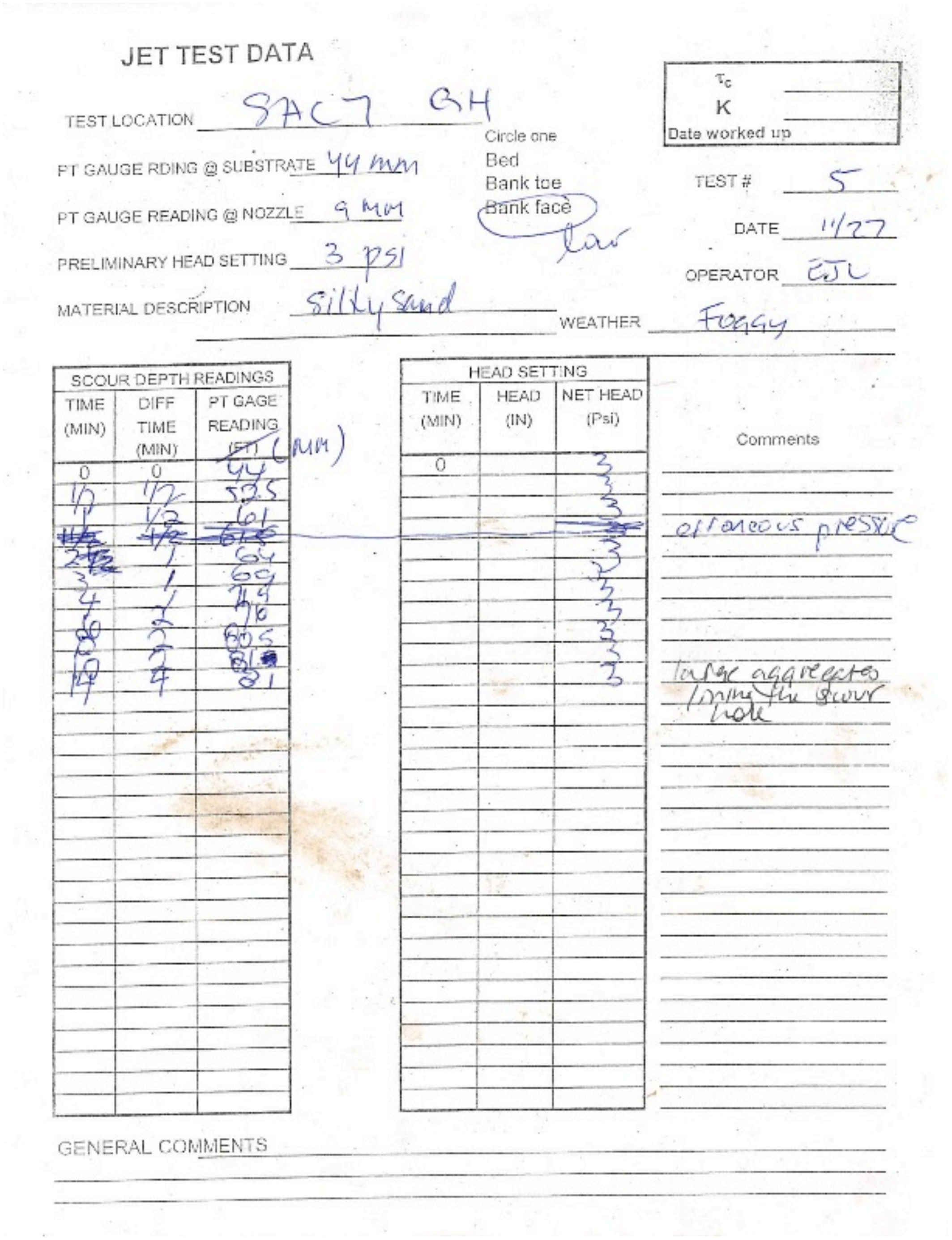
HEAD SETTING

| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) |
|---|---|---|
| 0 | | 2.5 |
| 0.25 | | 2.5 |
| 0.5 | | 2.5 |
| 0.75 | | 2.5 |
| 1.25 | | 2.5 |
| 2.0 | | 2.5 |
| 3.0 | | 2.5 |
| 5.0 | | 2.5 |
| 7.0 | | 2.5 |
| 12.0 | | 2.5 |
| 22.0 | | 2.5 |
| 32.0 | | 2.5 |
| 42.0 | | 2.5 |
| 52 | | 2.5 |

Comments

GENERAL COMMENTS

## SAC7 – test 3



JET TEST DATA

TEST LOCATION SAC7 GH

PT GAUGE RDING @ SUBSTRATE 44 mm

PT GAUGE READING @ NOZZLE 9 mm

PRELIMINARY HEAD SETTING 3 psi

MATERIAL DESCRIPTION silty sand

Circle one
Bed
Bank toe
[✓ Bank face] low

$\tau_c$
K
Date worked up

TEST # 5

DATE 11/27

OPERATOR EJL

WEATHER Foggy

| SCOUR DEPTH READINGS | | |
|---|---|---|
| TIME (MIN) | DIFF TIME (MIN) | PT GAGE READING ~~(FT)~~ (mm) |
| 0 | 0 | 44 |
| 1/2 | 1/2 | 52.5 |
| 1 | 1/2 | 61 |
| ~~1 1/2~~ | ~~1/2~~ | ~~61.5~~ |
| 2 | 1 | 64 |
| 3 | 1 | 69 |
| 4 | 1 | 74 |
| 6 | 2 | 76 |
| 8 | 2 | 80.5 |
| 10 | 2 | 81.[illegible] |
| 14 | 4 | 81 |

| HEAD SETTING | | | |
|---|---|---|---|
| TIME (MIN) | HEAD (IN) | NET HEAD (Psi) | Comments |
| 0 | | 3 | |
| | | 3 | |
| | | 3 | |
| | | ~~3~~ | erroneous pressure |
| | | 3 | |
| | | 3 | |
| | | 3 | |
| | | 3 | |
| | | 3 | |
| | | 3 | |
| | | 3 | large aggregates forming the scour hole |

GENERAL COMMENTS