Title

Hydrogeologic Assessment of the East Bear Creek Unit, San Luis National Wildlife Refuge

Permalink

https://escholarship.org/uc/item/3sg4k226

Author

Quinn, Nigel W.T.

Publication Date

2007-07-15

HydroGeologic Assessment of the East Bear Creek Unit, San Luis National Wildlife Refuge

Prepared for : US Bureau of Reclamation

Nigel W.T. Quinn PhD, P.E.
Berkeley National Laboratory
1 Cyclotron Road, Bld,. 70A-3317H
Berkeley, CA 94720

July 15, 2007

This work was supported by the U.S. Bureau of Reclamation under US Department of Interior Interagency Agreement No. 3-AA-20-10970 through U.S. Department of Energy Contract No. DE-AC03-76SF00098

ACKNOWLEDGEMENTS

This report was prepared for the US Bureau of Reclamation to assist the agency make planning decisions with respect to groundwater conjunctive use planning for the East Bear Creek Unit of the San Luis National Wildlife Refuge. The author gratefully acknowledges the financial support provided by Dan Meier, MP-410, US Bureau of Reclamation who initiated the project and to staff at the San Luis National Wildlife Refuge for well log data. Dr Grace Su and Paul Cook (Lawrence Berkeley National Laboratory) assisted with the groundwater water quality logging and geophysical logging in the East Bear Creek Unit. Tony Shanahan (US Bureau of Reclamation) operated the Geoprobe which was used to make the geophysical logs and bulk salinity depth profiles that were interpreted by Jeff Farrar at the Technical Services Center (US Bureau of Reclamation) and are included in this report. Steve Sherer (US Bureau of Reclamation) provided useful data, reports and analysis that were used in the preparation of this report. Dr Kenneth Schmidt (Kenneth Schmidt and Associates) provided invaluable access to reports and data as well as advice based on his many years of groundwater consulting in the Valley. Thanks to Dr. Grace Su, Dr. Kenneth Schmidt, Dan Meier and Georgiana Gregory (US Bureau of Reclamation) for their review and helpful comments on the report.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The East Bear Creek Unit is currently being evaluated as a potential source of supplemental water supply for the San Luis National Wildlife Refuge Complex to meet Reclamation's obligations for Level 4 water supply under the Central Valley Project Improvement Act. Hydrogeological assessment of the East Bear Creek Unit of the San Luis National Wildlife Refuge was conducted using a combination of field investigations and a survey of available literature from past US Geological Survey Reports and reports by local geological consultants. Conservative safe yield estimates made using the available data show that the East Bear Creek Unit may have sufficient groundwater resources in the shallow groundwater aquifer to meet about between 25% and 52% of its current Level II and between 17% and 35% of its level IV water supply needs . The rate of surface and lateral recharge to the Unit and the design of the well field and the layout and capacity of pumped wells will decide both the percentage of annual needs that the shallow aquifer can supply and whether this yield is sustainable without affecting long-term aquifer quality. In order to further investigate the merits of pumping the near surface aquifer, which appears to have reasonable water quality for use within the East Bear Creek Unit – monitoring of the potential sources of aquifer recharge and the installation of a pilot shallow well would be warranted. Simple monitoring stations could be installed both upstream and downstream of both the San Joaquin River and Bear Creek and be instrumented to measure river stage, flow and electrical conductivity. Ideally this would be done in conjunction with a shallow pilot well, pumped to supply a portion of the Unit's needs for the wetland inundation period.

2. HYDROGEOLOGICAL ASSESSMENT

2.1 Introduction

The goal of this hydrogeological report is to provide an assessment of the groundwater resource conditions within the East Bear Creek Unit of the San Luis National Wildlife Refuge (NWR) Complex in western Merced County. The US Department of Interior purchased the 4,000 acres that comprise the property in 1993 from the Gallo family for the purpose of meeting wildlife habitat needs. Potential refuge water supply sources include a combination of onsite and offsite surface and groundwater resources. Three groundwater production wells existed at one time on the East Bear Creek Unit – these have all been abandoned. The purpose of this report is to report on the condition of these wells, evaluate water quality conditions that exist or may exist within the groundwater aquifer and to suggest options based on current analysis of data.

2.2 Location

The 4,000 acre East Bear Creek Unit of the San Luis NWR Complex is bounded by the San Joaquin River on its western and southern borders. Bear Creek/Bravel Slough from the northern boundary of the refuge. The refuge is contained within Township 8S-11E.

2.3 Basin description and water resources

The East Bear Creek Unit of the San Luis NWR Complex lies within the Merced Groundwater Basin of western Merced County southwest of the City of Merced and to the east of the San Joaquin River (Figure 1). The Merced Groundwater Basin is bounded by the Merced river on the north, the San Joaquin River to the west and the Chowchilla River to the south and contains over a great number of municipal, industrial, agricultural and domestic wells (Schmidt, 2005). The proximity of these watercourses suggests that shallow wells in this region will have an opportunity for recharge. Active production wells in the groundwater basin have been reported as having capacities ranging from 100 to 4,500 gallons per minute (DWR, 2003). The safe pumping yield of the aquifer beneath the East Bear Creek Unit will be addressed in a qualitative fashion in this report based on current data and limited aquifer testing that was performed as part of this project. The location of the East-Bear Creek Unit adjacent to the San Joaquin River Basin trough and its position at the distal end of the east-side Merced River alluvial fan (Figure 2) would suggest that limitations for groundwater conjunctive use are more likely to be water quality related given the interfingering of alluvial clays, derived from the west-side of the Basin in this subarea. These clay lenses reduce connectivity between shallow and deep subsurface aquifers and can hinder drainage – allowing evaporative concentration of salts in the near-surface aquifer.

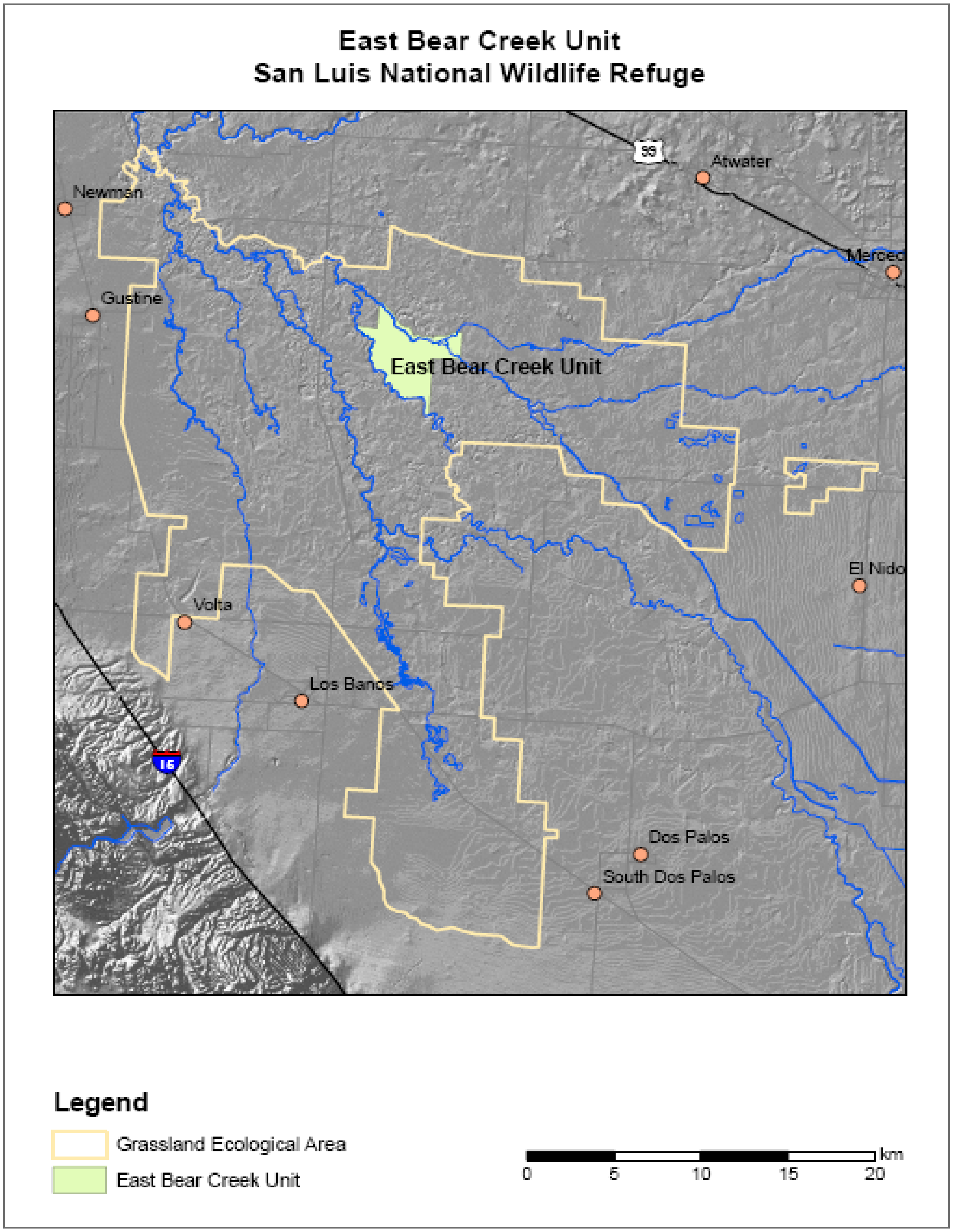


Figure 1. Location of East Bear Creek Unit within the San Luis National Wildlife Refuge Complex.

2.4 Regional geology

The San Joaquin River Basin is a large structural trough filled with approximately 16,000 feet of eroded sediments from the granitic Sierra Nevada and the marine shales and siltstones of the Coast Range. These sediments derived from alluvial fans, rivers and shallow lakes that formed complex layered beds of various geologic materials that were later folded by landforming stresses in the earth's mantle. A generalized regional San Joaquin Valley cross-section is provided in Figure 2 (Bookman-Edmonston, 2003).

The preponderance of flow from east-side streams has given the San Joaquin Basin an asymmetric form with distances from the rim of the basin to the valley axis almost as wide on the east side compared to the west side. This produces steeper topographic gradients of between 20 and 40 ft per mile on the west side compared to shallow gradients of 6 to 8 ft per mile on the east-side (Mendenhall, 1908). Groundwater flow along the valley axis is slow, allowing time for capillarity and evaporation to concentrate salts in the shallow aquifer – especially in proximity to the valley trough.

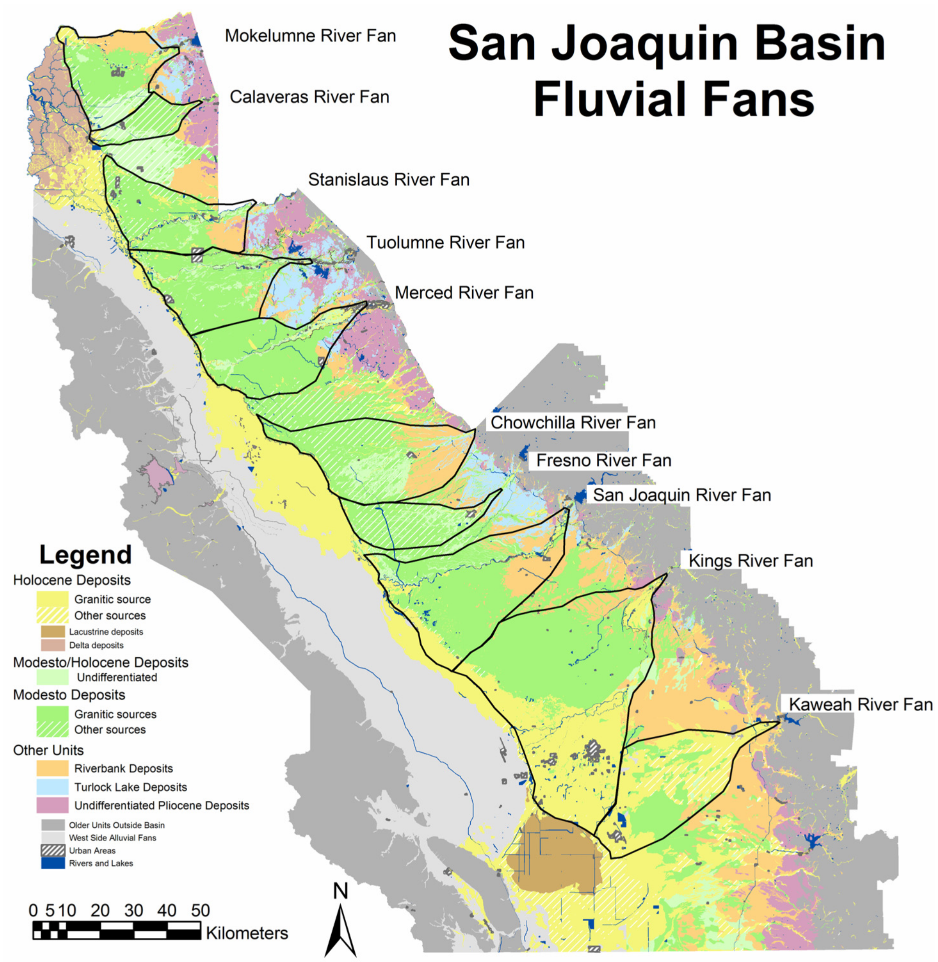


Figure 2. San Joaquin Basin Fluvial Fans. (Weissman G. et al. 2006. Presentation on : "Coarse-Grained Incised Valley Fill Deposits in the Tuolumne River Fluvial Fan: Implications for Artificial Recharge").

The chemical character of the groundwater aquifers are related to their geology. Valley alluvium, derived from Cretaceous and Tertiary Coast Range formations are rich in soluble gypsum, sulfates and carbonates which leach large quantities of salt as they deep percolate to the water table. Waters derived from the east-side Sierran granites and metamorphic rocks contain potassium, sodium and calcium mineral species – but these are in the form of less soluble silicate minerals which dissolve less readily (Mendenhall, 1908). In the Valley trough the groundwater aquifers show characteristics of both east and west-side influences with interfingering layers of sands and silty-clays that correspond to the dominant erosional environment at the time of formation.

The upper 1,500 ft of sediments is comprised of both young and old alluvium, continental deposits and the Mehrten Formation (USGS, 1973). The Younger Alluvium consists of narrow bands of fine sand, sand and gravel with little or no hardpan and typically is found along river courses. This alluvial material ranges in thickness from 0 – 100 feet (USGS, 1973). The Older Alluvium is the more pervasive exposed structural unit in the vicinity of the East Bear Creek Unit.. This structural unit comprises interbedded sand, silt, clay and gravel with some hardpan at shallower depths, and ranges in thickness from 400 to 700 ft below the land surface (Bookman-Edmonston, 2003). The bottom of the Older Alluvium is typically between 400 ft and 600 ft below sea level and is apparent in driller's logs as a transition from coarse grained to fine grained sediments (USGS, 1971, 1973).

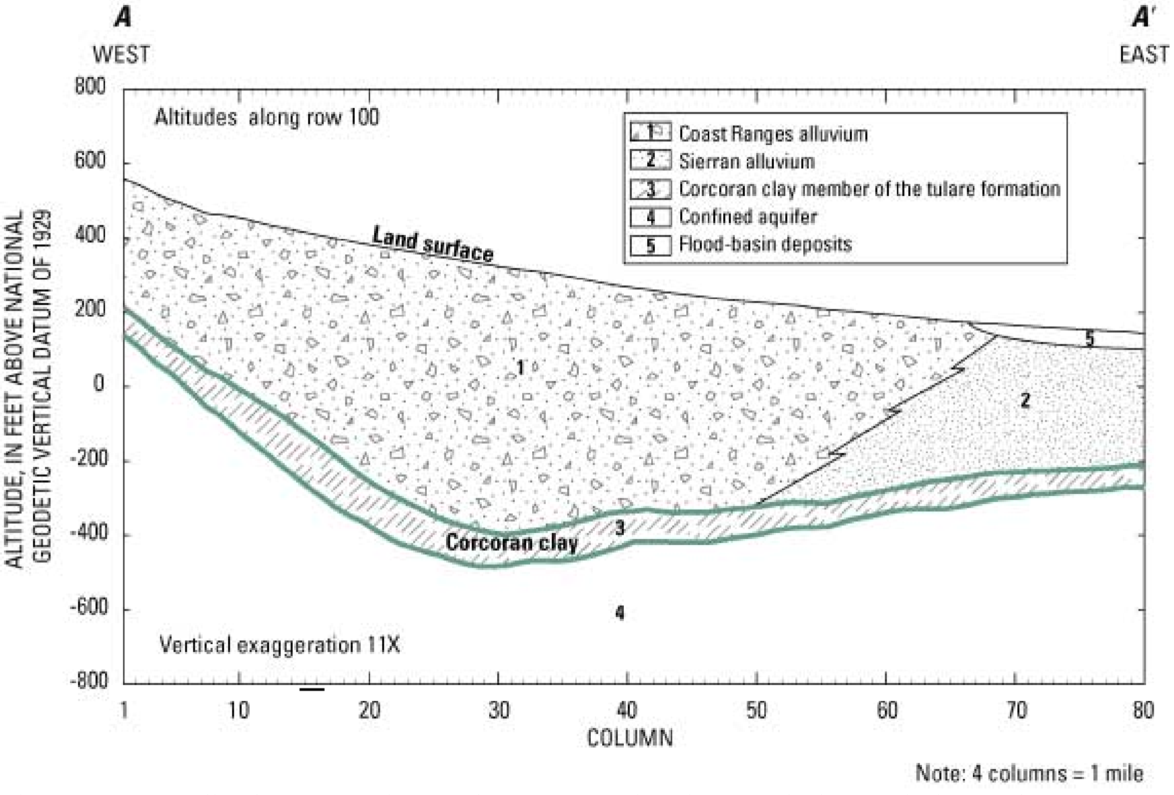


Figure 3. Generalized cross-section of the San Joaquin River Basin in proximity of the East Bear Creek Unit of the San Luis NWR Complex. (Brush et al., 2005)).

Embedded within the Older Alluvium are a number of continuous lacustrine deposits of gray and blue silts, silty clays and clays that display low permeability and act as impermeable barriers to vertical groundwater movement (Figure 3). The most significant of these deposits is the Corcoran "E" Clay which is regionally extensive in the Valley trough between Tracy and Kern County and which pinches out close to the alignment of Highway 99 in the eastern San Joaquin Valley, north of Chowchilla and in the vicinity

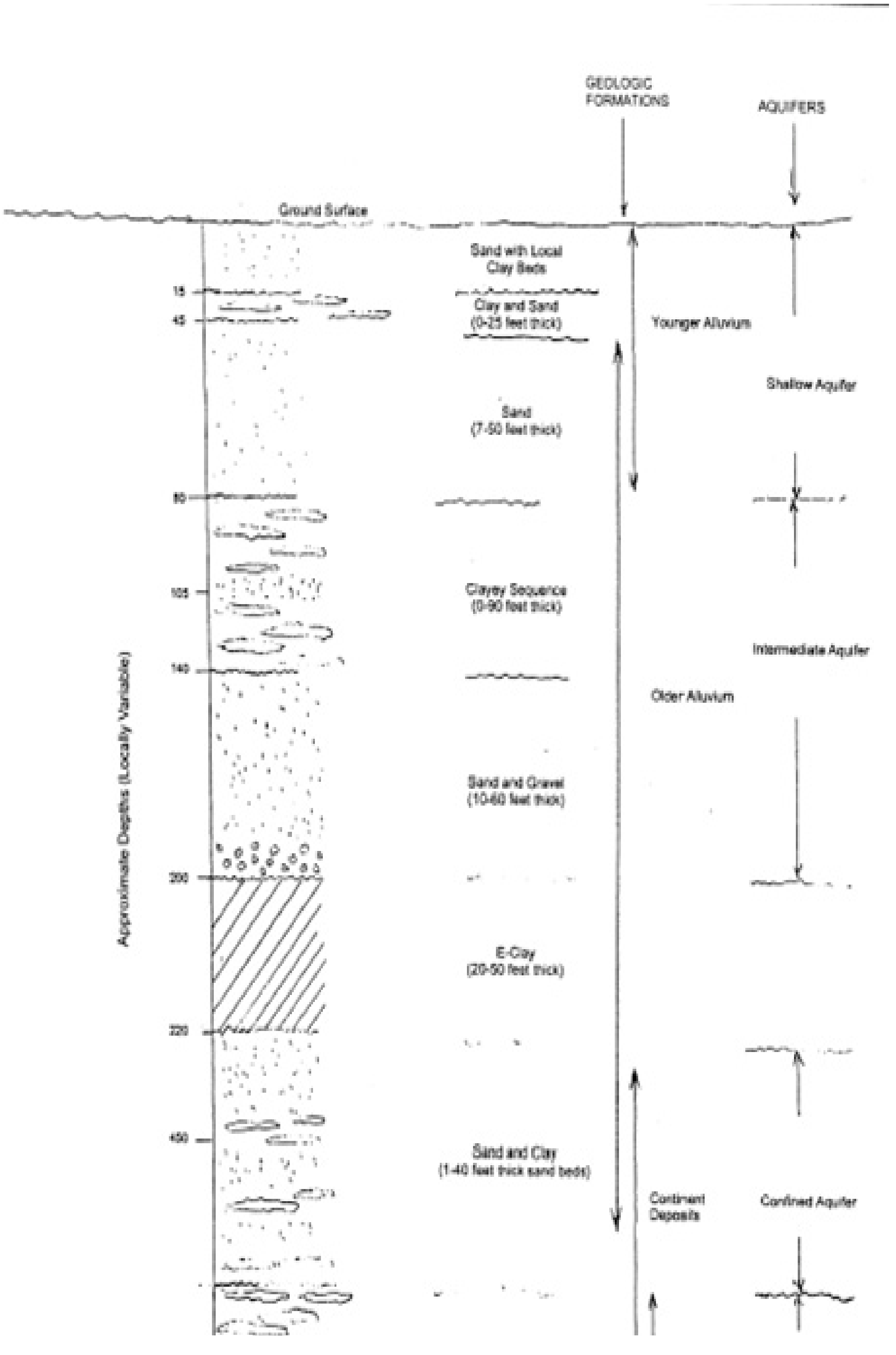


Figure 4. Generalized structural profile of sedimentary deposits and groundwater aquifers in the vicinity of East Bear Creek Unit in the San Luis NWR Complex. (Source : Bookman-Edmonston, 2003).

of Highway I-5 in the western San Joaquin Valley. In western Merced County the Corcoran Clay extends to Merced and Atwater and hence underlies the extent of the East Bear Creek Unit. The Corcoran Clay is at its thickest in the Valley trough reaching thicknesses of 80-100 ft (Bookman-Edmonston, 2003). It is approximately 60 ft thick in the vicinity of the East Bear Creek Unit.

The Continental Deposits are to be found beneath the Older Alluvium – the base of the Deposits extend to between 400 ft and 800 ft below sea level (Bookman-Edmonston, 2003). Water quality in the upper sections of the Continental Deposits is acceptable for many uses with an average electrical conductivity (EC) below 3,000 umhos/cm. The "base" of this fresh water – typically defined as the interface between water with an EC below 3000 uS/cm and poorer quality water – is not well defined and has been mapped by the USGS to be approximately 500 ft below mean sea level. Beneath the Continental Deposits lies the Mehrten Formation which is comprised of deposits of sandstone, tuff, siltstone, breccia, claystone and conglomerate often referred to by local drillers and "black sand and gravel" (Bookman-Edmonston, 2003; USGS, 1973). Although the depth of this formation is generally unknown because no wells have been sunk this deep, largely on account of abundant shallow water resources, it is an important aquifer in both the Sacramento and San Joaquin Valleys and has permitted well production between 1,500 and 3,500 gpm (Bookman-Edmonston, 2003).

2.5 Local hydrogeology

The local geology dictates the nature of the local groundwater system and can be derived from well driller's reports, geophysical logs, consultant reports and agency hydrogeological studies in the vicinity of the East Bear Creek Unit. The distal end of the sedimentary deposits within and between major alluvial fans are characterized by having finer sediment texture and are often discharge zones where water originating from higher elevations on the east side of the San Joaquin Valley is forced under pressure upward through the near surface formations to discharge into sloughs and other surface drainages into the San Joaquin River.

Surface soils within the East Bear Creek Unit boundary are predominantly classified as Raynor clay, Temple loam, Merced clay loam, Fresno loam, Hilmar loamy sand (both well drained and poorly drained types), Kesterson sandy loam and Waukena loam soil associations. Soils investigated by Reclamation (Sherer, 2003) from drill holes SPT-OW/PW-02-1 through 3, SPT-OW-02-4 through 11, SPT-OW-02-11 through 15 and SPT-OW-02-25 through 26 suggested an area characterized by fine grained soils between 5 and 20 feet thick that overlie sands typical of those in the vicinity of the San Joaquin River (Figure 4, Figure 7). The fine grained deposits contain various combinations of fat and lean clays, sands and silts.

Figure 5 shows the local relief in the East Bear Creek Unit, which is flat between the levees to the north and west associated with Bear Creek and the San Joaquin River. In the north-eastern corner of the East Bear Creek Unit, Deep Slough bifurcates from East Bear Creek at the location of a small impoundment. The locations of the known groundwater wells are shown in Figure 4. Wells labeled EB-IW-01 and EB-IW-02 are both inactive wells with intact well casing. Well EB-IW-03 is a non-functional well in poorer physical condition than the first two. Well EB-IW-04 has been destroyed and cannot be rehabilitated.

Figure 6 is a Landsat image that shows the moisture status of surface soils within the East Bear Creek Unit suggesting that the surface vegetation is more abundant and of higher moisture status in the north-eastern sector of the Unit than in the remainder. This might be attributed to higher water tables in this sector or possibly the presence of a groundwater discharge area adjacent to the San Joaquin River levee. Discharge areas are associated with coarse textured soils (Figure 7), high near surface soil salinity and high concentrations of salt within the near-surface groundwater system.

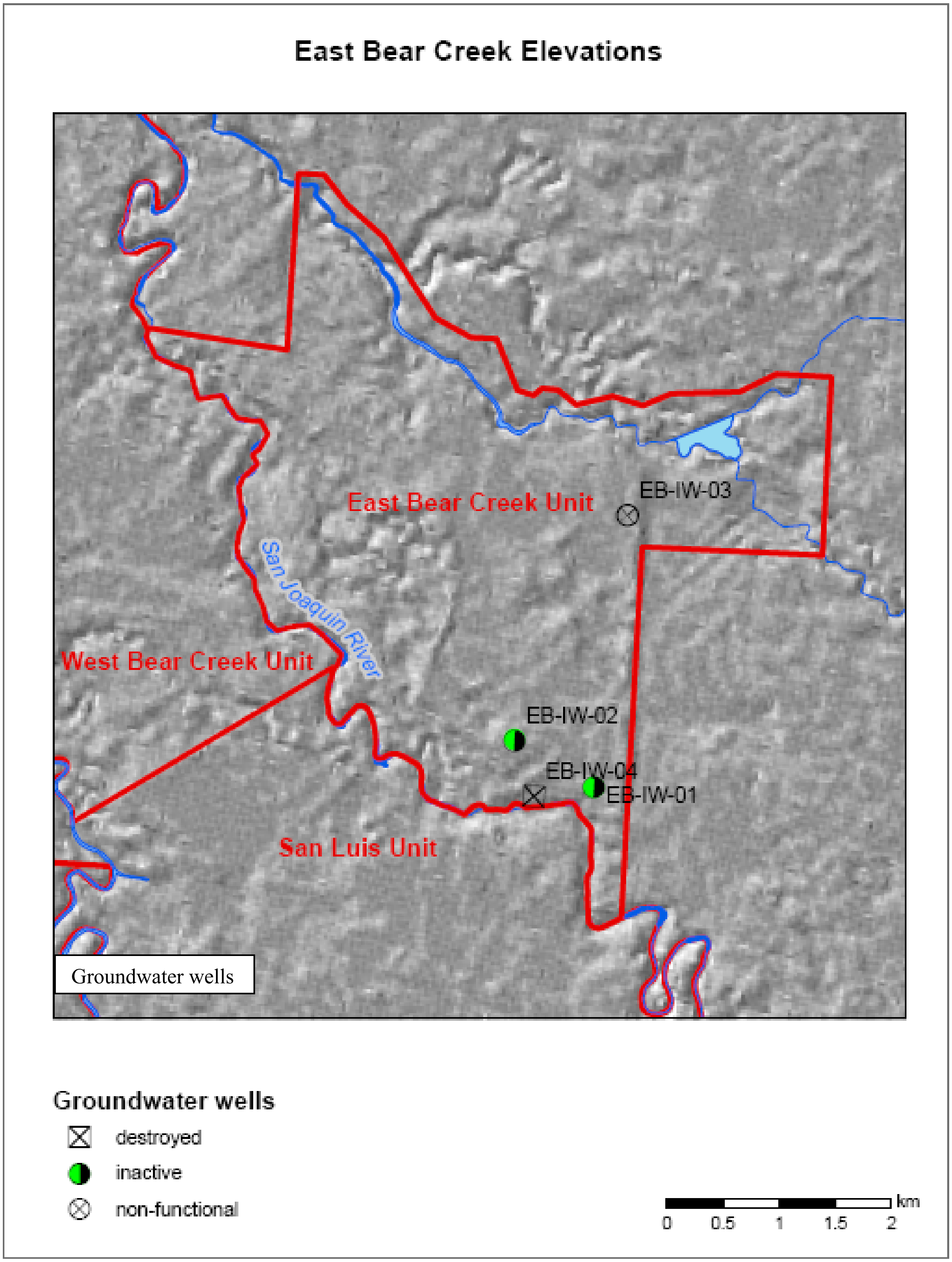


Figure 5. Surface relief on the East Bear Creek Unit within the San Luis NWR Complex showing the location of former production wells and their current status.

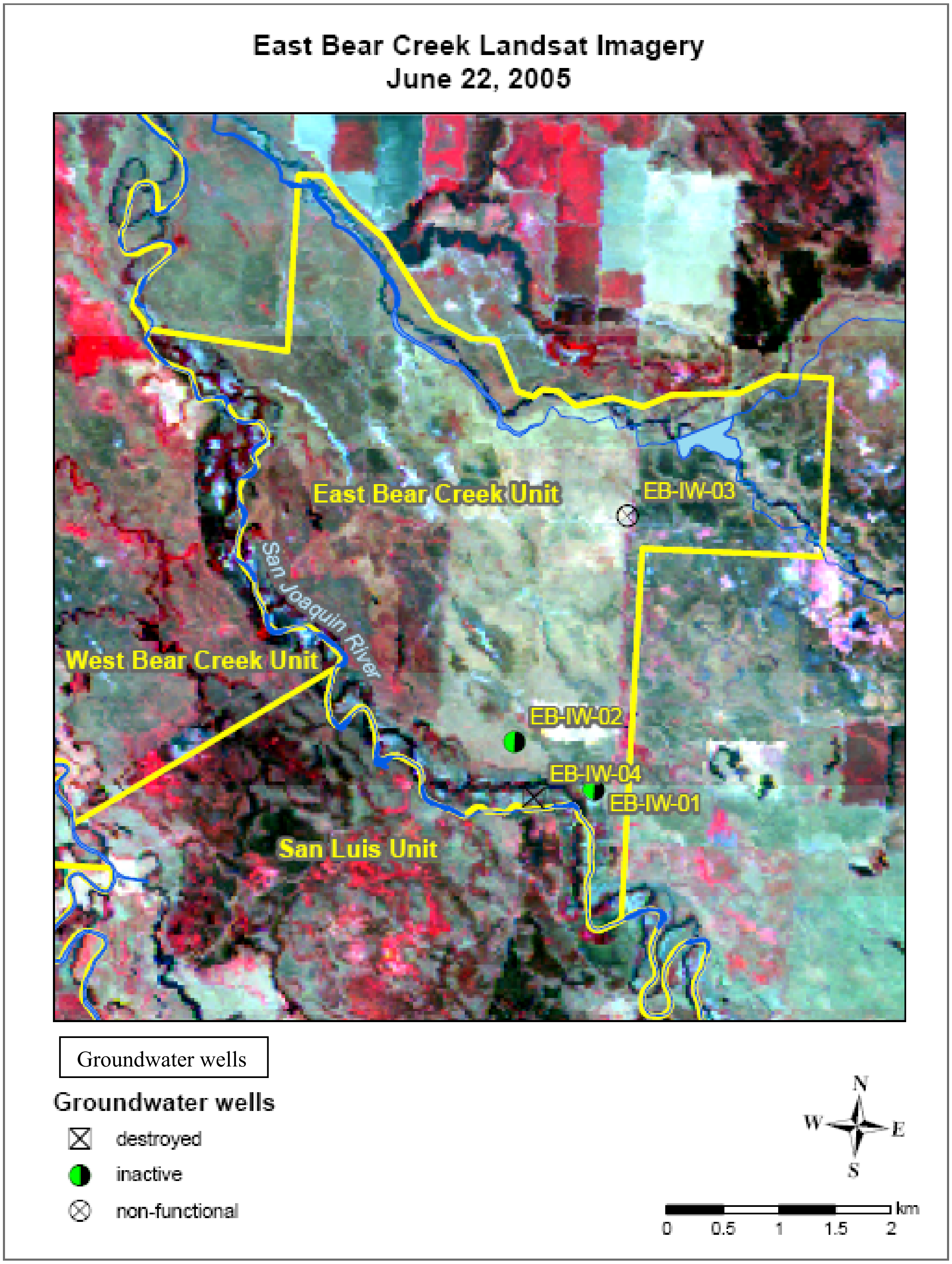


Figure 6. Satellite imagery of the East Bear Creek Unit within the San Luis NWR Complex showing the moisture status of soils and predominance of surface vegetation. Interpretation of the Landsat image suggests a higher moisture status in the north-east sector of the Unit closest to the San Joaquin River where water tables may be closer to the land surface.

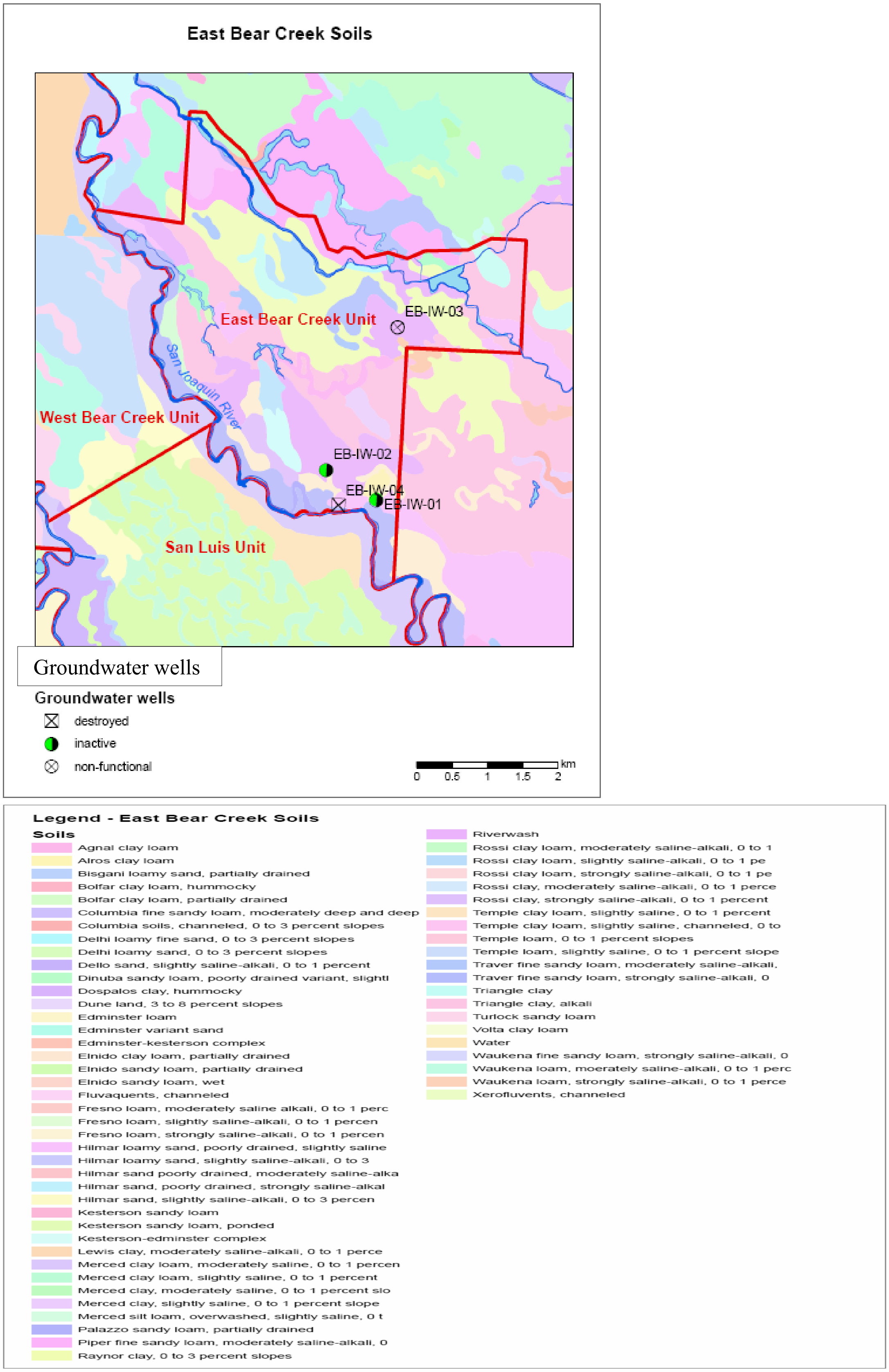


Figure 7. East Bear Creek Unit soil associations.

2.6 Cone penetrometer (CPT) logging

Cone Penetrometer Logging (CPT) was conducted at the East Bear Creek Unit to develop a better understanding of the sedimentary geology of the semi-confined groundwater. During the CPT logging experiments, a conical-shaped probe instrumented with sensors was pushed into the ground up to depths of 120 feet. The cone penetrometer used at the East Bear Creek Unit contained sensors that continuously measured the friction sleeve, tip resistance, and electrical conductivity. A calibration curve was developed to convert bulk soil salinity measurements made with the CPT sensor to an equivalent soil solution salinity. Both Myron Inc. and YSI Inc. soil salinity sensors were used to develop this calibration curve. During the experiments it was noted that saturation occurred in the CPT electrode at bulk salinity concentrations above 600 mS/m – above this threshold the relationship between bulk salinity and EC became highly non-linear. Since the groundwater underlying much of the managed wetland area in the San Joaquin Valley has an EC below 9000 uS/cm – the non-linear portion of the calibration curve was eliminated and a best fit least squares calibration curve fitted (Figure 8).

The best-fit equation was shown to be :

EC (uS/cm) = 13.567 * bulk salinity (mS/m)

This equation has a regression coefficient of 0.9983 (mg/l)

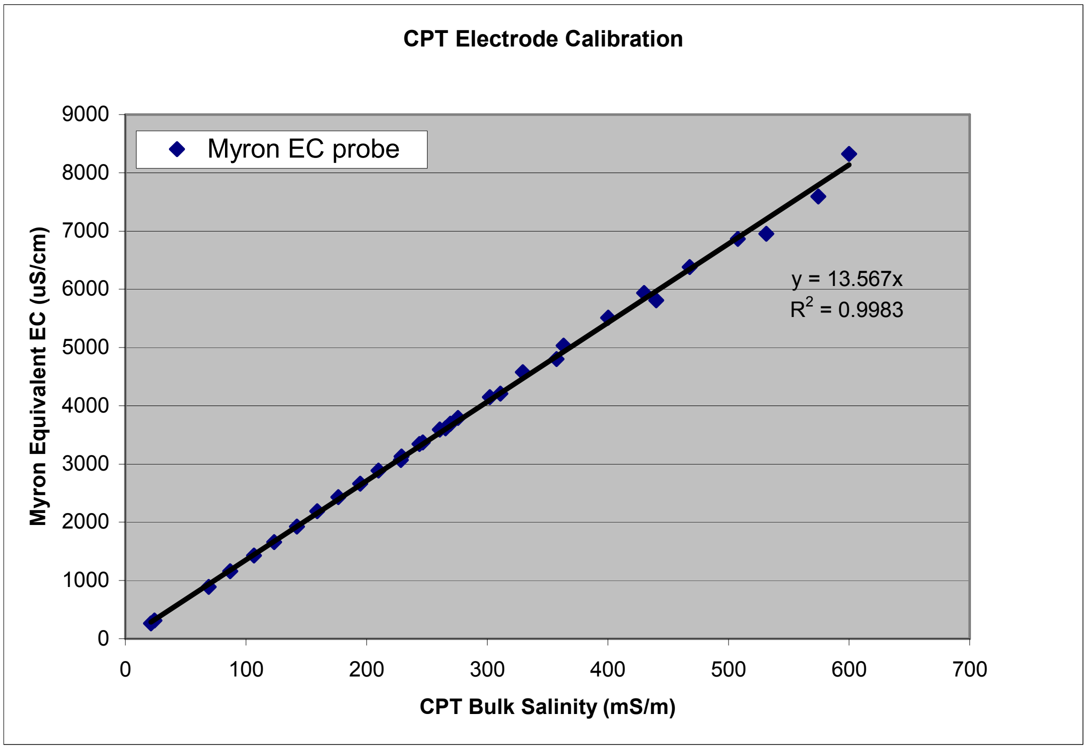
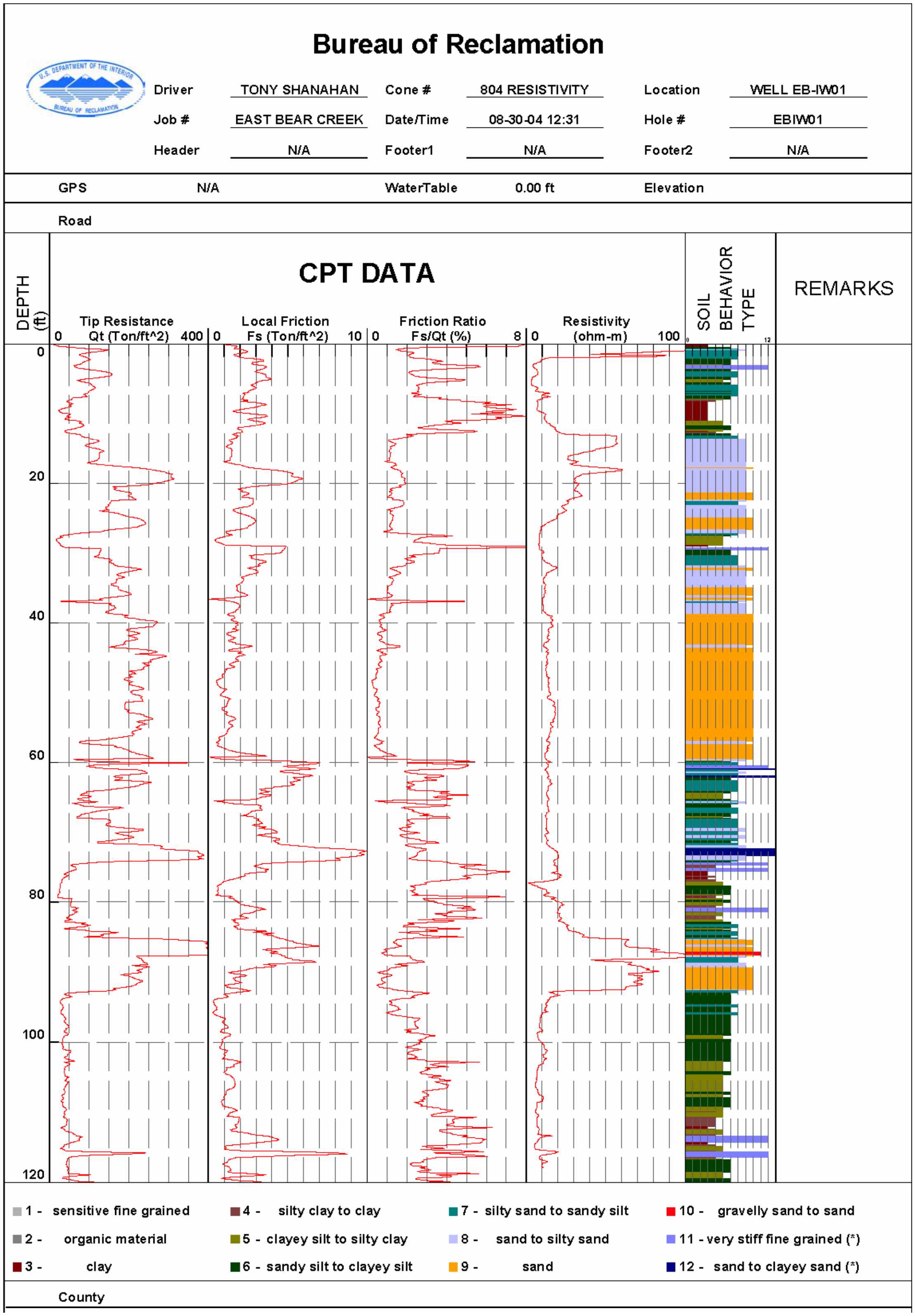


Figure 8. Calibration curve for converting CPT bulk salinity measurements (mS/m) to an equivalent groundwater EC (uS/cm).

Plots of the CPT sensor data with depth are shown in Figures 9 and 10 for two locations at the East Bear Creek Unit. The maximum depths of the CPT logs ranged from 110 ft to 120 ft in the two locations.



Bureau of Reclamation

Driver TONY SHANAHAN Cone # 804 RESISTIVITY Location WELL EB-IW01

Job # EAST BEAR CREEK Date/Time 08-30-04 12:31 Hole # EBIW01

Header N/A Footer1 N/A Footer2 N/A

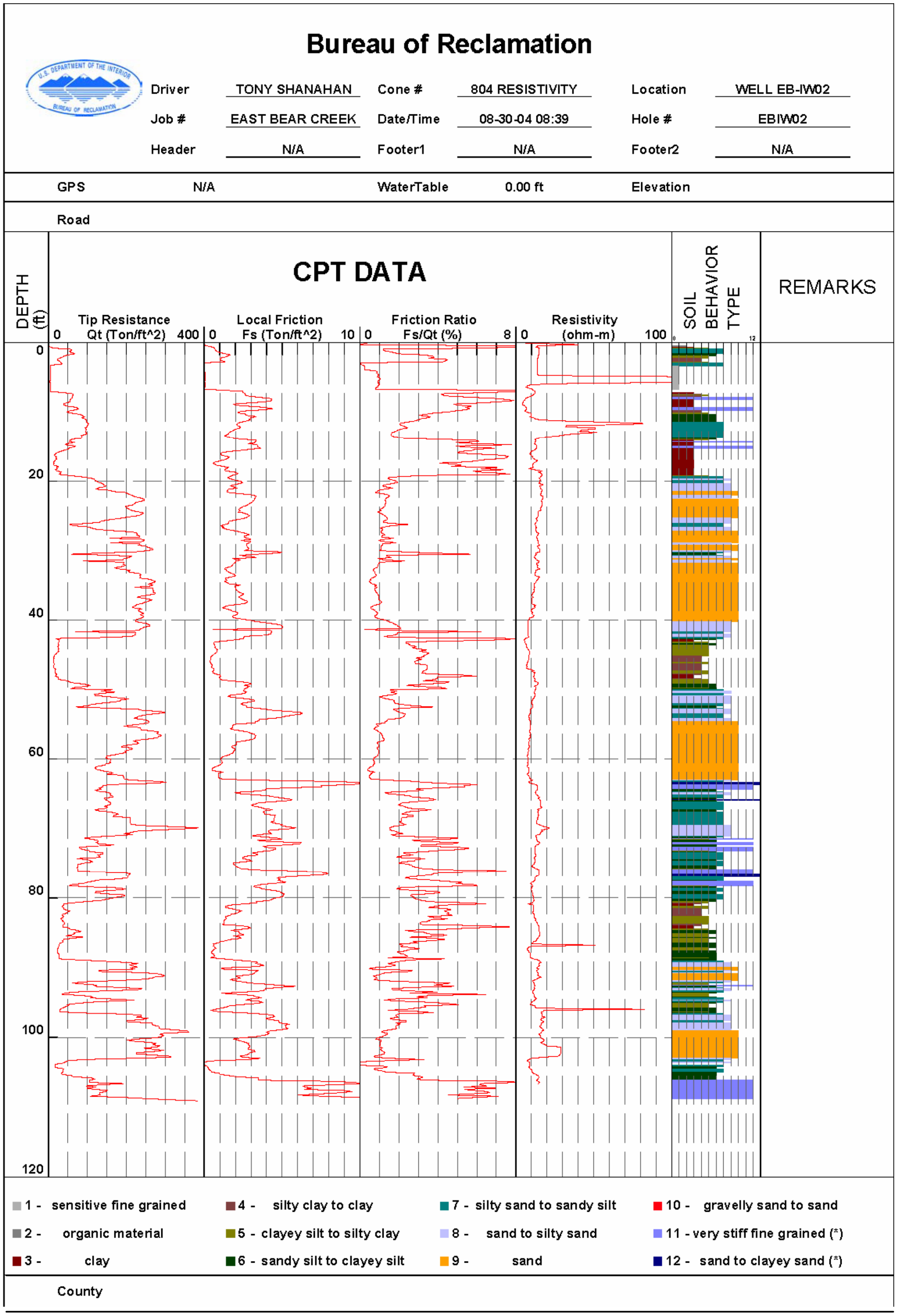
GPS N/A WaterTable 0.00 ft Elevation

Road

- ■ 1 - sensitive fine grained
- ■ 2 - organic material
- ■ 3 - clay
- ■ 4 - silty clay to clay
- ■ 5 - clayey silt to silty clay
- ■ 6 - sandy silt to clayey silt
- ■ 7 - silty sand to sandy silt
- ■ 8 - sand to silty sand
- ■ 9 - sand
- ■ 10 - gravelly sand to sand
- ■ 11 - very stiff fine grained (*)
- ■ 12 - sand to clayey sand (*)

County

Figure 9. CPT log for well EB-01 in the East Bear Creek Unit of the San Luis NWR Complex.



Bureau of Reclamation

Driver TONY SHANAHAN
Cone # 804 RESISTIVITY
Location WELL EB-IW02
Job # EAST BEAR CREEK
Date/Time 08-30-04 08:39
Hole # EBIW02
Header N/A
Footer1 N/A
Footer2 N/A

GPS N/A
WaterTable 0.00 ft
Elevation

Road

County

Figure 10. CPT log for well EB-02 in the East Bear Creek Unit of the San Luis NWR Complex

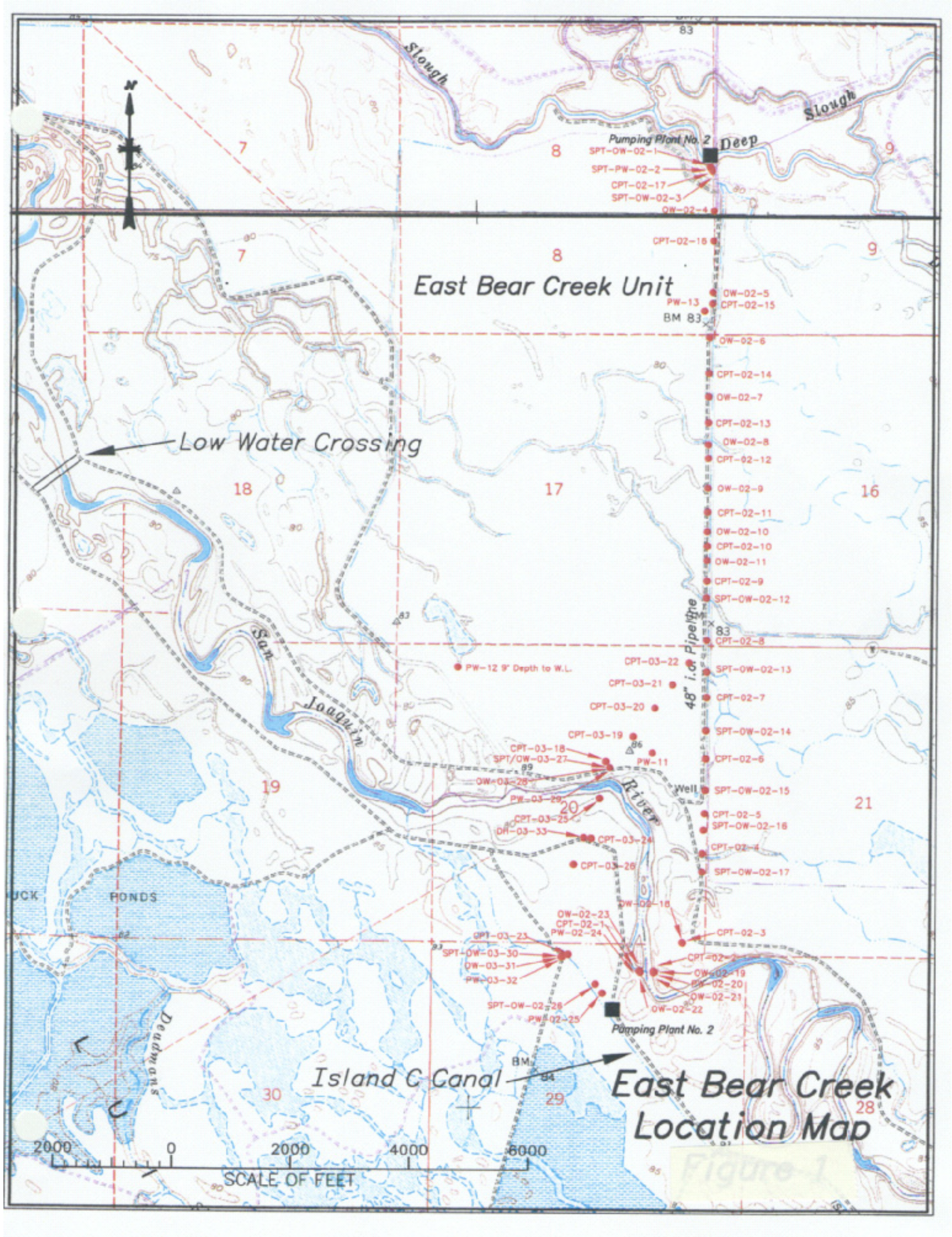


Figure 11. Location of CPT logs taken within the East Bear Creek and West Bear Creek Units for analysis of water supply conveyance options (Sherer, 2003).

In Figure 9, sand layers are found at about 20 ft below the surface and extend down to about 92 ft in this deep abandoned well (EB-01/EB-IB-01). The highest permeability continuous sand layer occurs in a depth interval of 40 ft to 60 ft below the surface. A second smaller sand layer appears between 86 ft and 92 ft below the surface. Provided these sand layers are laterally continuous they may provide a sufficiently extensive shallow aquifer for exploitation. Bulk pore water salinity derived from the resistivity cone data is elevated at the near surface (vadose zone) with readings in excess of 1,000 ms/cm (out of range but likely in excess of 10,000 uS/cm) diminishing to a concentration of about 100 – 200 mS/m (1300 – 2600 uS/cm) below a depth of about 17 ft. Groundwater quality is mostly in this range except for two depth intervals; between 17 ft and 25 ft where the EC equivalent rises to 600 mS/cm – about 8,000 uS/cm; and between 85 ft and 94 ft where the EC climbs as high as 1,000 mS/cm – again out of the instrument range, but likely in excess of 10,000 uS/cm. This high concentration occurs adjacent to the lower sand layer – suggesting that water may be migrating in to this area.

In Figure 10 the aquifer stratigraphy observed at the abandoned well (EB-02/EB-IW-02) is similar to the stratigraphy at well EB1 although the test wells were more than 1 mile apart. The CPT log shows a larger fraction of finer grade material. Silty sands and intermediate sand-silty sands predominate over an aquifer that lies between 22 ft and 63 ft below the surface. The porosity and the specific yield of these aquifer materials are lower than that of sand. A clay aquitard, probably the "C" Clay, that is approximately 15 ft thick, lies immediately below the sand-silty sand aquifer. The water quality profile near production well 7 is similar to that at the abandoned well. Bulk salinity concentrations are high in the vadose zone but diminishes to under 50 mS/m (680 uS/cm equivalent groundwater EC) until a depth of 62 ft below where the concentration increases to 150 mS/m (2,035 uS/cm equivalent groundwater EC).

During 2003 Reclamation completed a series of groundwater studies related to the alignment of a water supply pipeline for two pumping plants designed to convey Level 4 water to the East Bear Creek Unit. CPT logs and a series of aquifer tests were conducted at test sites within both East and West Bear Creek Units. Figure 11 shows the locations of the CPT tests as well as the pumped wells and observation wells that were used in the aquifer tests. Figures 12 - 16 show the aquifer stratigraphy that was derived from the CPT logs that were conducted during these investigations. The CPT logs CPT-03-18 through CPT-03-03-22 were made within the south-west sector of the refuge whereas logs CPT-03-23 and CPT-03-03-26 were made within the west Bear Creek Unit west of the San Joaquin River. Unlike the previous logs in Figures 9 and 10 these CPT logs only reported on the top 35 – 50 ft of the groundwater aquifer. Bulk salinity was not logged during these tests.

Analysis of the plots shows a consistent lens of porous sands and silty sands beginning between 6 ft and 15 ft below ground surface and of thickness between 20 and 40 ft. In most instances the depth of sand exceeds the depth of silty sand – both aquifer materials are capable of high vertical and horizontal transmissivities. Wells located in this porous strata, if hydraulically connected to streams such as Bear Creek or unlined conveyance structures, can show good water quality.

2.7 Groundwater quality logging

A significant obstacle to assessment of conjunctive use of water is inadequate data on the depth distribution of groundwater quality in the regional aquifer. In regions where the salinity of the groundwater varies considerably with depth, such as the Central Valley of California, an understanding of both the hydraulic properties of the aquifer and the depth distribution of salts is critical for evaluating the potential of aquifers for conjunctive water use. The electrical conductivity profiles recorded in a well using the flowing fluid electric conductivity logging (FEC logging) method can be analyzed to estimate interval specific hydraulic conductivity and estimates of the salinity concentration with depth (Su et al., 2006).

As described by Tsang and Doughty (2003), the flowing FEC logging method involves first replacing the well bore water by de-ionized water or water of a constant salinity distinctly different from that of the formation water. This is done by injecting de-ionized water down a tube to the bottom of the well, while simultaneously pumping from the top of the well, until the EC of the water pumped out of the well stabilizes at a low value. Next, the pumps are turned off and the well is pumped only from the top at a constant low flow rate, while an electrical conductivity probe is lowered into the borehole to record the EC as a function of depth and time.

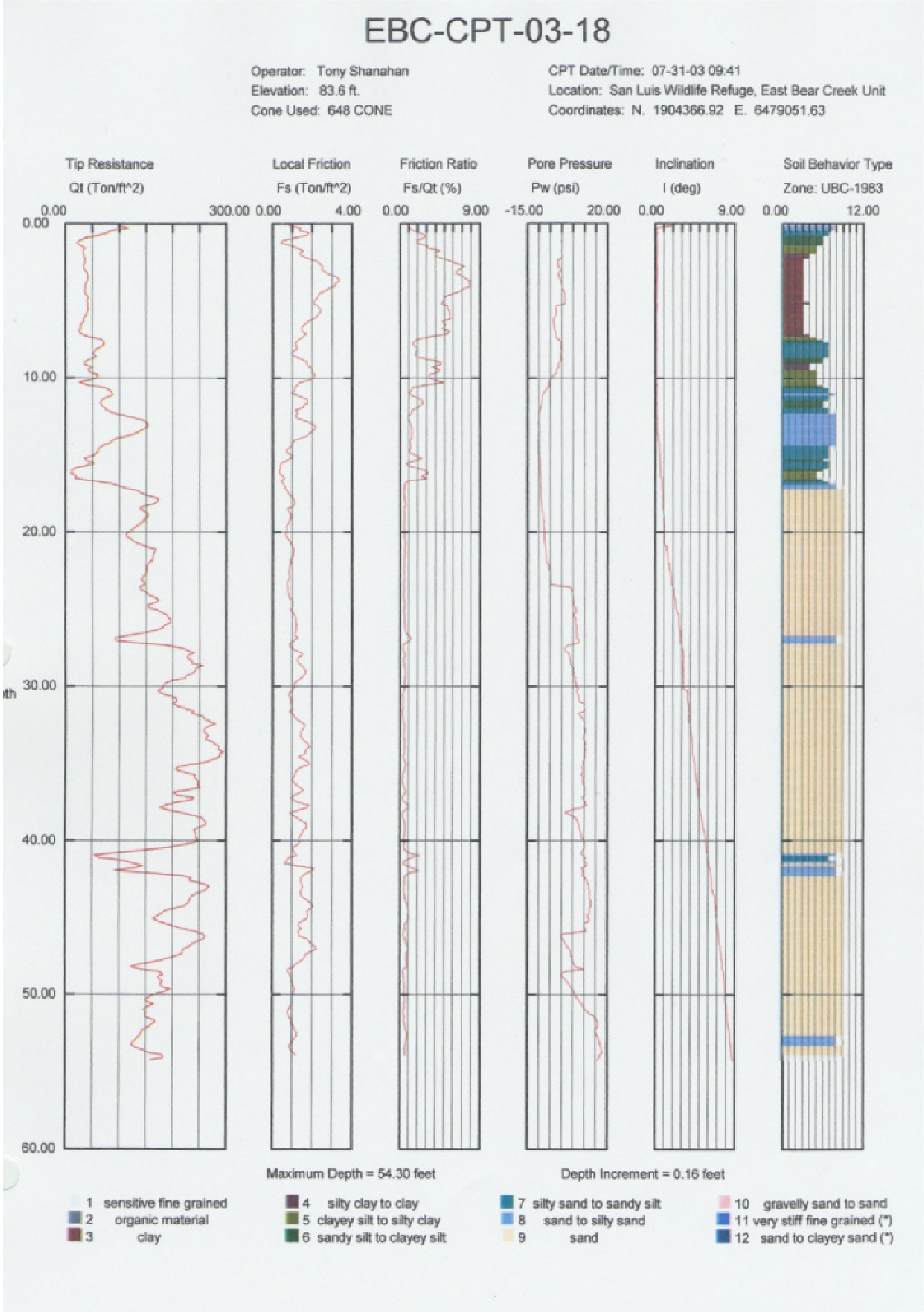


Figure 12. CPT Log CPT-03-18 in the East Bear Creek Unit of the San Luis NWR Complex

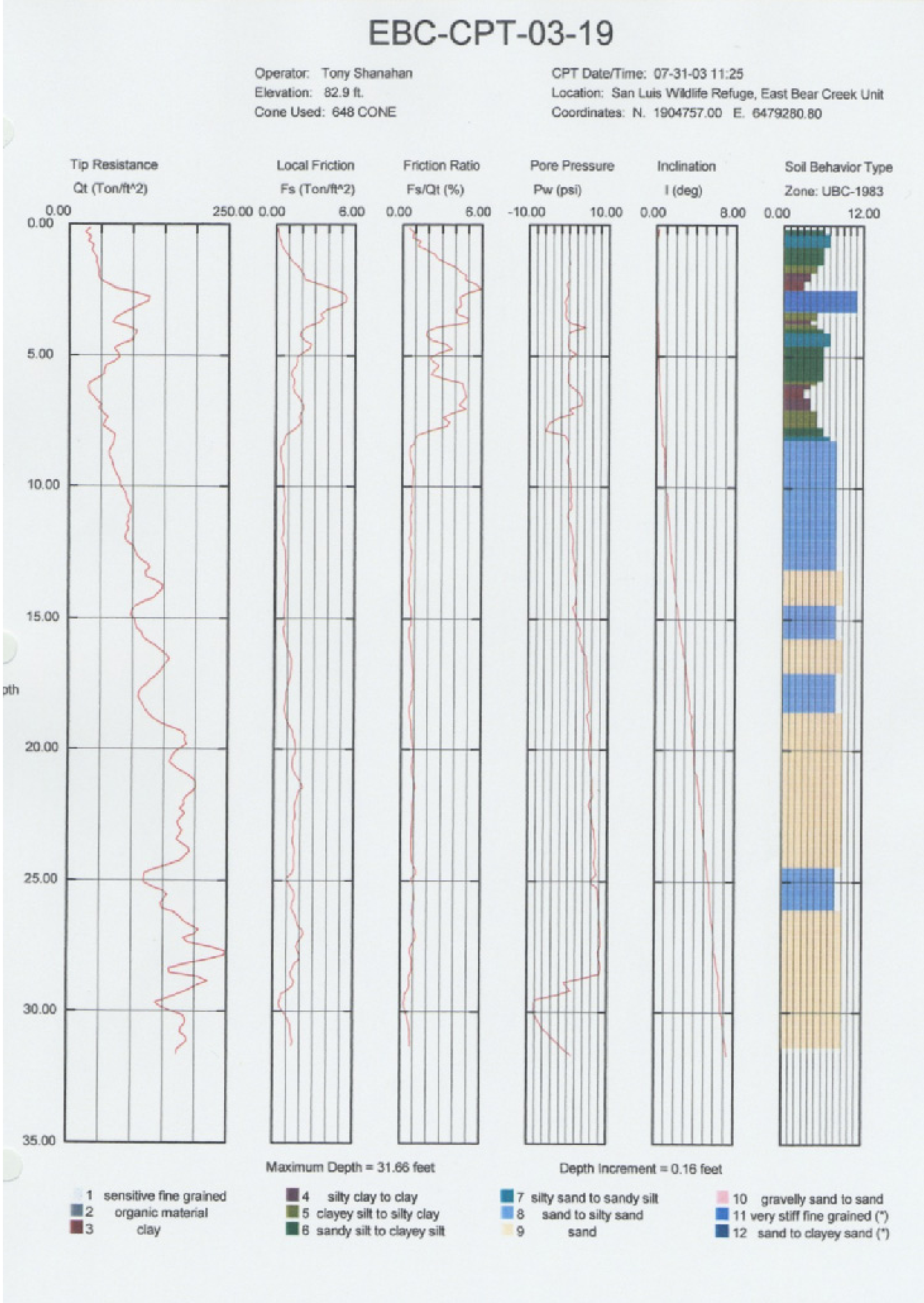


Figure 13. CPT Log CPT-03-19 in the East Bear Creek Unit of the San Luis NWR Complex

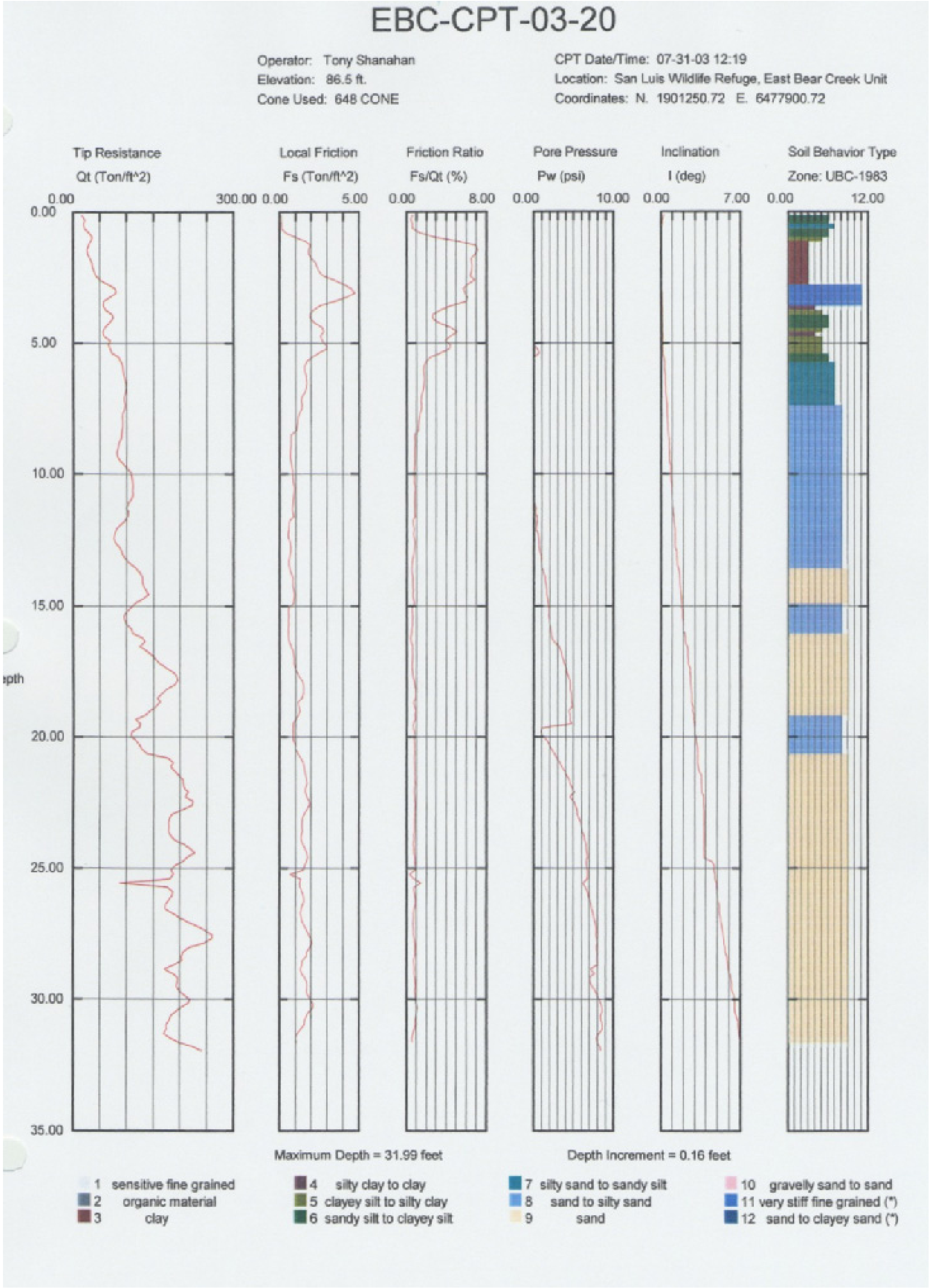


Figure 14. CPT Log CPT-03-20 in the East Bear Creek Unit of the San Luis NWR Complex.

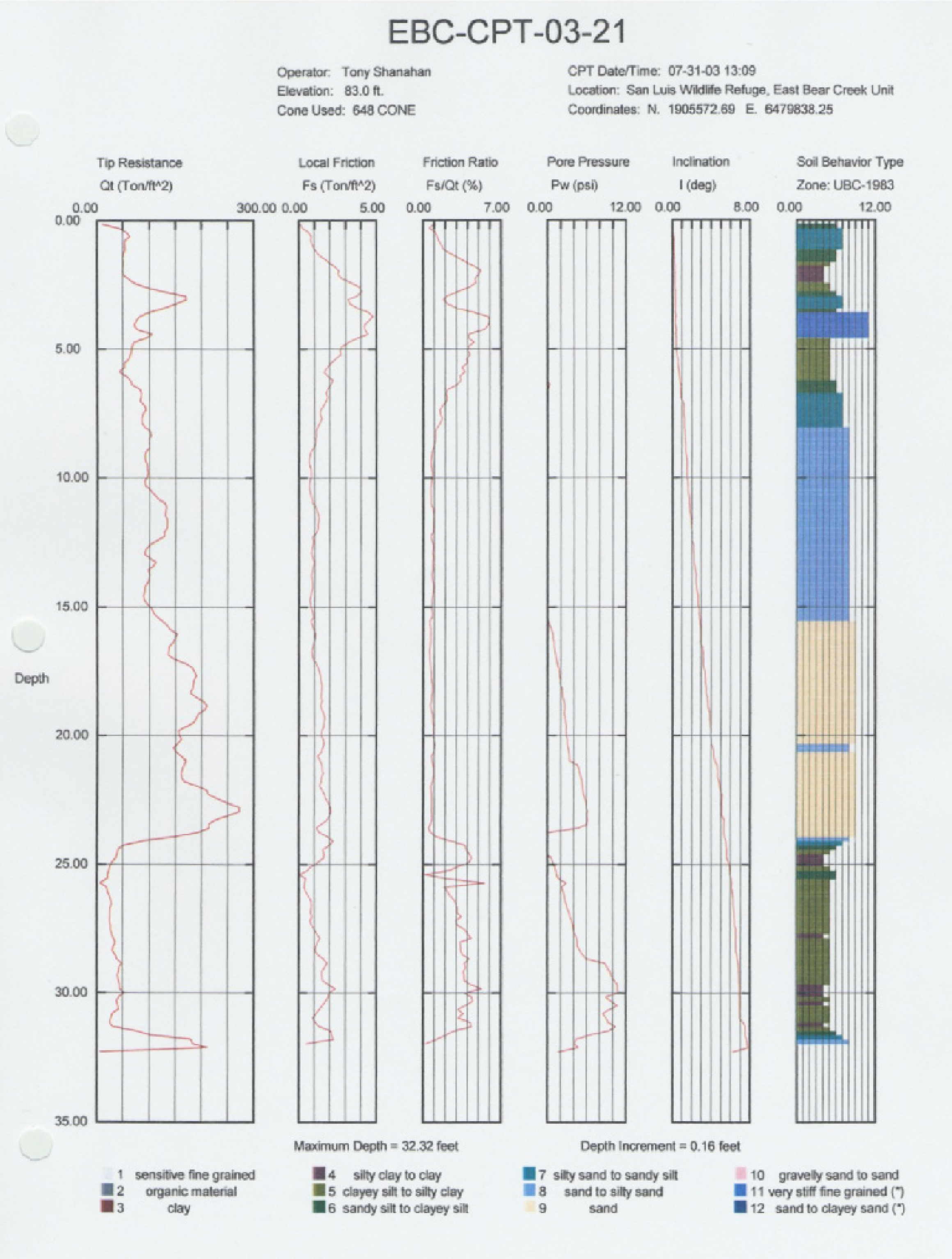


Figure 15. CPT Log CPT-03-21 in the East Bear Creek Unit of the San Luis NWR Complex

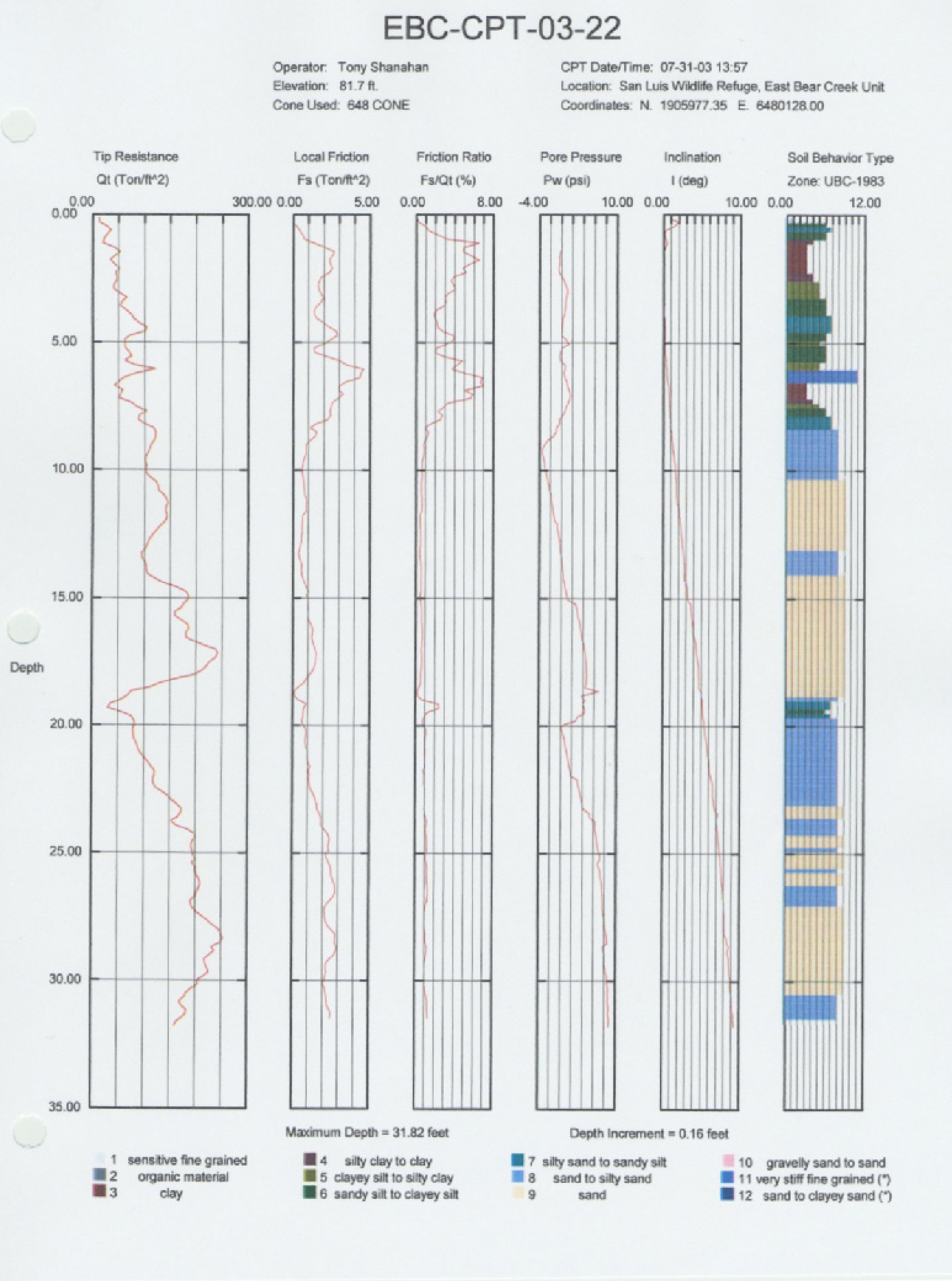
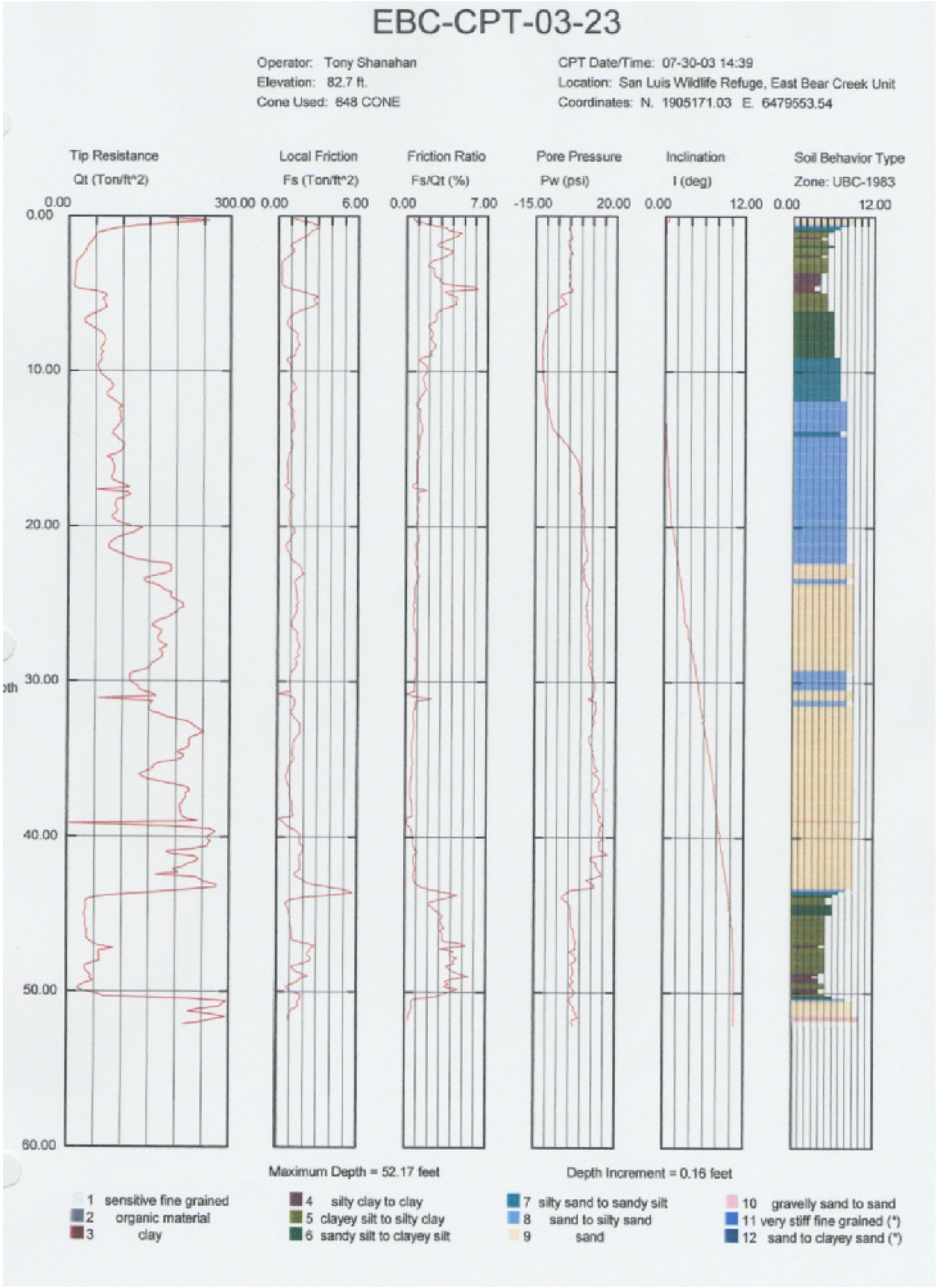


Figure 16. CPT Log CPT-03-22 in the East Bear Creek Unit of the San Luis NWR Complex.



EBC-CPT-03-23

Operator: Tony Shanahan
Elevation: 82.7 ft.
Cone Used: 648 CONE

CPT Date/Time: 07-30-03 14:39
Location: San Luis Wildlife Refuge, East Bear Creek Unit
Coordinates: N. 1905171.03 E. 6479553.54

Figure 17. CPT Log CPT-03-23 in the East Bear Creek Unit of the San Luis NWR Complex.

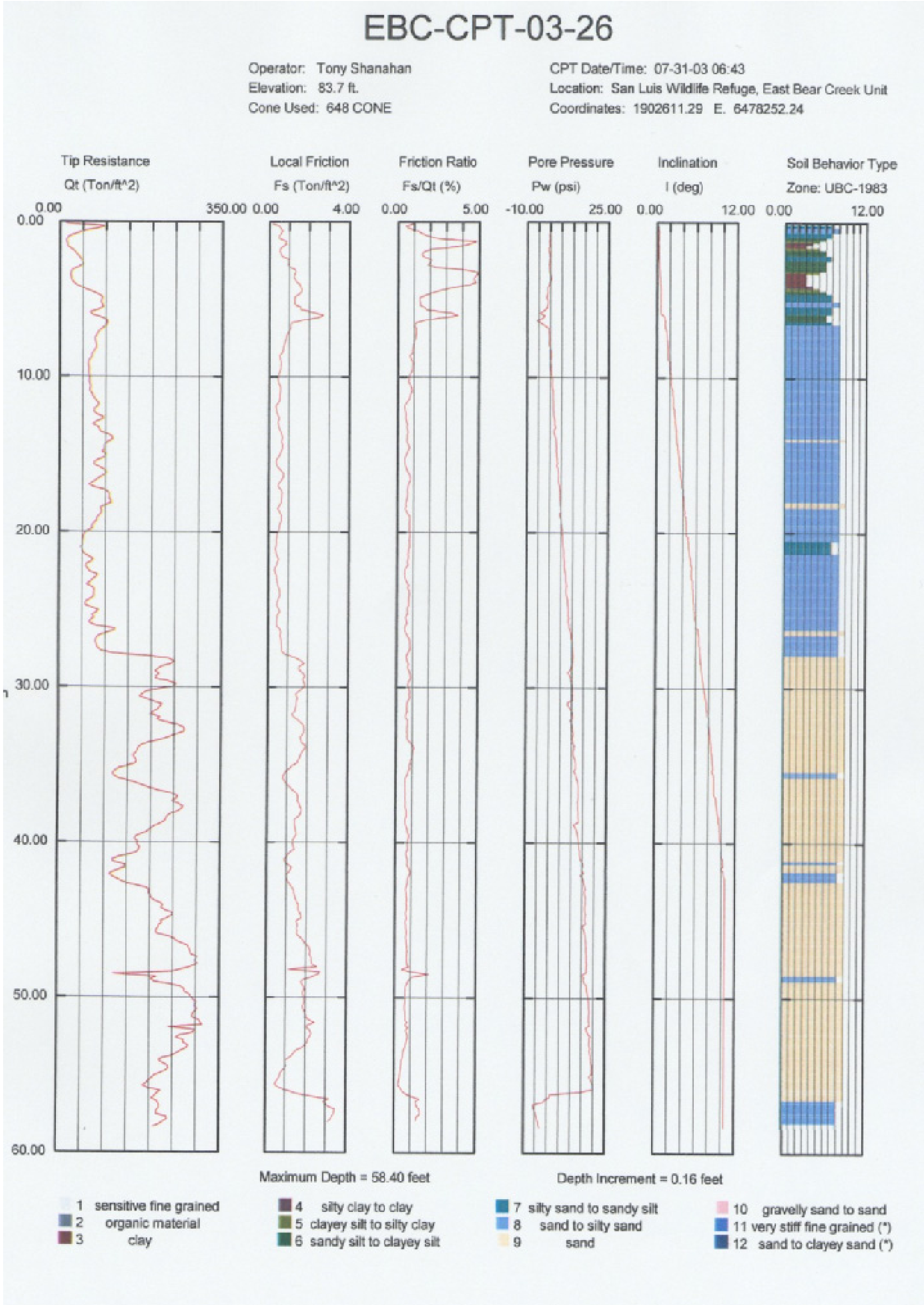


Figure 18. CPT Log CPT-03-26 in the East Bear Creek Unit of the San Luis NWR Complex.

2.7.1 *Fluid Electrical Conductivity Logging in Limited Access Wells*

During traditional FEC logging, constant salinity water with salinity lower than the existing well bore water is injected at the bottom of the well screen simultaneously as the well bore water is extracted from the top of the well bore (Figure 19). The less dense, lower salinity water should theoretically move up the well bore as it displaces the existing water. In an unconsolidated formation, some of the injected water is likely to enter the formation over time, with more water entering the bottom of the formation where the water is injected. Injection of water into the irrigation wells with limited access is a challenge since the small diameter access pipe (11/2 in) limits the diameter of tubing that can be used in the well. In addition, both the injection and extraction hose must simultaneously fit through the pipe opening. FEC logging is typically performed in wells with diameters in range from 2 – 6 ins. The diameter of the irrigation well casing used in this study is nearly 18 ins, so it would take a long time to replace the borehole water using tubing with a small diameter and a single injection point.

Because replacing the existing well water using a small diameter tube is difficult in these large diameter wells with limited access, we developed a new technique of injecting water using tubing with emitters to provide nearly uniform injection over the length of the well screen. Emitters were originally developed for drip irrigation in agricultural fields, but they have not been used to inject water into wells. Because of the pressure drop along the length of the tubing, pressure-compensating emitters were used to provide a uniform injection rate. The emitters were inserted into ¾ in diameter reinforced PVC tubing every foot m over a length of 75 ft beginning at the bottom of the hose. Above the 75 ft interval, the emitters were spaced at 2 ft intervals for a total of nearly 125 ft m of hose with emitters. The total length of the hose was around 300 ft. The emitters are rated at 3.2 gals/hr for pressures between 10-50 psi, and we verified that the flow rate remained nearly constant as the pressure changed. The emitters maintain a constant flow rate with a flexible membrane that becomes compressed as the pressure increases. A constant flow rate is maintained because the permeability of the membrane decreases with increasing pressure. Our new injection method reduces the time of well water replacement compared to the traditional, single point injection method since the injection occurs over the screened interval and mixes with the existing water over that interval. The existing well water does not have to be entirely replaced as with the single point injection method because FEC logging still works as long as the low salinity water becomes well-mixed with the existing well water and the resulting water salinity has enough contrast with the formation EC (Su et al., 2006).

During the water-replacement part of our well logging tests, constant salinity water with an electrical conductivity between 0 - 500 mS/cm was injected into the well bore via emitters while the well bore water was simultaneously extracted from the top. Centrifugal pumps were used to inject and extract water, and the extraction and injection hose had a ¾ in diameter. A schematic of the experimental set-up is shown in Figure 12.

The electrical conductivity probes typically used to perform FEC logging have a 11/2 in diameter and have an inflexible 3 ft – 6 ft long section. A probe of this size would not fit into most well access pipes and could not bend around the lip where the well casing and access pipe intersect. A small electrical conductivity probe manufactured by Campbell Scientific (Logan, UT) was used that had a cross-sectional area of 1 in x ¾ in and was 3.6 in long. The probe was made heavier using five stainless steel weights that had a 1 in diameter and were 2 in long to reduce the buoyancy of the probe. The probe depth was measured using a depth encoder, which is a device that detects depth measurements and converts them to electrical signals for input into data acquisition systems.

2.7.2 *Open, Abandoned Well EB-01*

The FEC logging conducted in the open, abandoned irrigation well in the East Bear Creek Unit was perforated from a depth of 170 ft below ground surface to the bottom of the well. The well depth was estimated to be approximately 265 ft (Figure 20). The water in this well was around 18 ft below ground surface. Deionizing filters were used to reduce the salinity of the well water that was extracted. The extracted water was run through the filters and then the de-ionized water was injected into the well. The water was extracted/injected at a rate of 3.6 gal/min over a period of 5 hours.

After the 5 hour period of replacing the well bore water, the injection pump was shut off and only the extraction pump was maintained at a rate of 5 gal/min, and the EC profile in the well was logged for the next 3 hours. The initial EC profile in the well before water was extracted/injected and the subsequent hourly EC profiles after the water replacement had ceased and water was only extracted are presented in Figure 20.

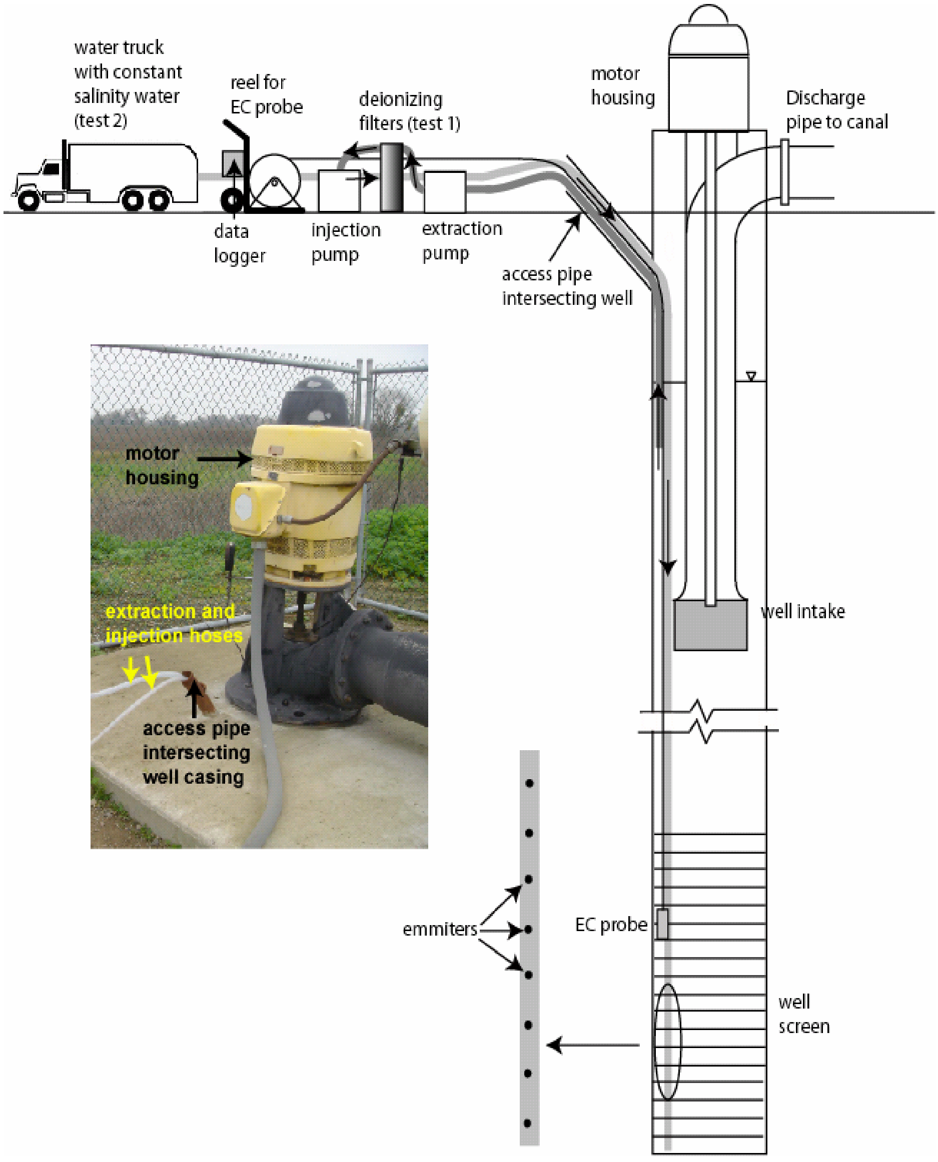


Figure 19. Schematic and photograph of a limited-access well that FEC logging was conducted in using our modified technique.

The shallow aquifer from the water table down to 150 ft shows an initial EC profile of approximately 1,000 uS/cm with a spike in concentration at about 75 ft where the EC reaches 1,400 uS/cm. Continued pumping of the well caused the EC in the top 150 ft of the well to improve over time as some of the deionized water moves upward from the screened interval of the well where deionized water was injected. Over the screened interval, the initial EC profile is nearly uniform at 2650 uS/cm. Continued pumping of the formation causes the EC to increase over time as formation water displaces the lower concentration water in the well bore. The EC stablilizes at about 2900 uS/cm.

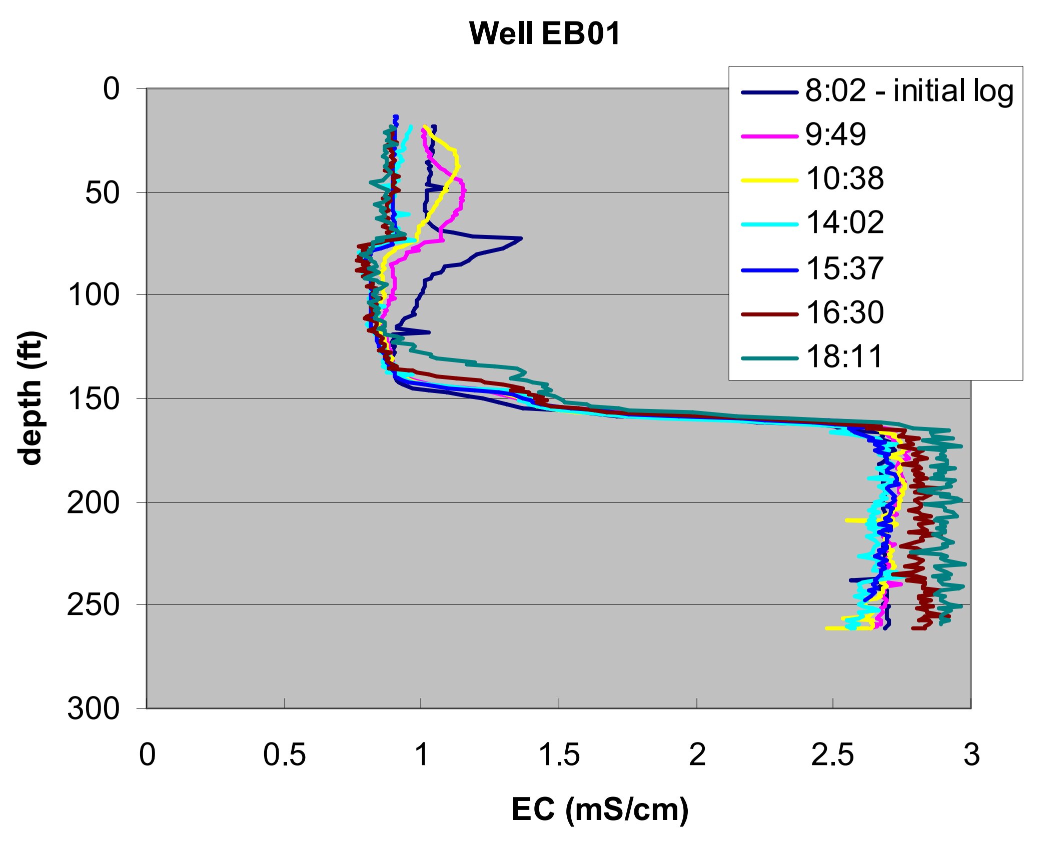
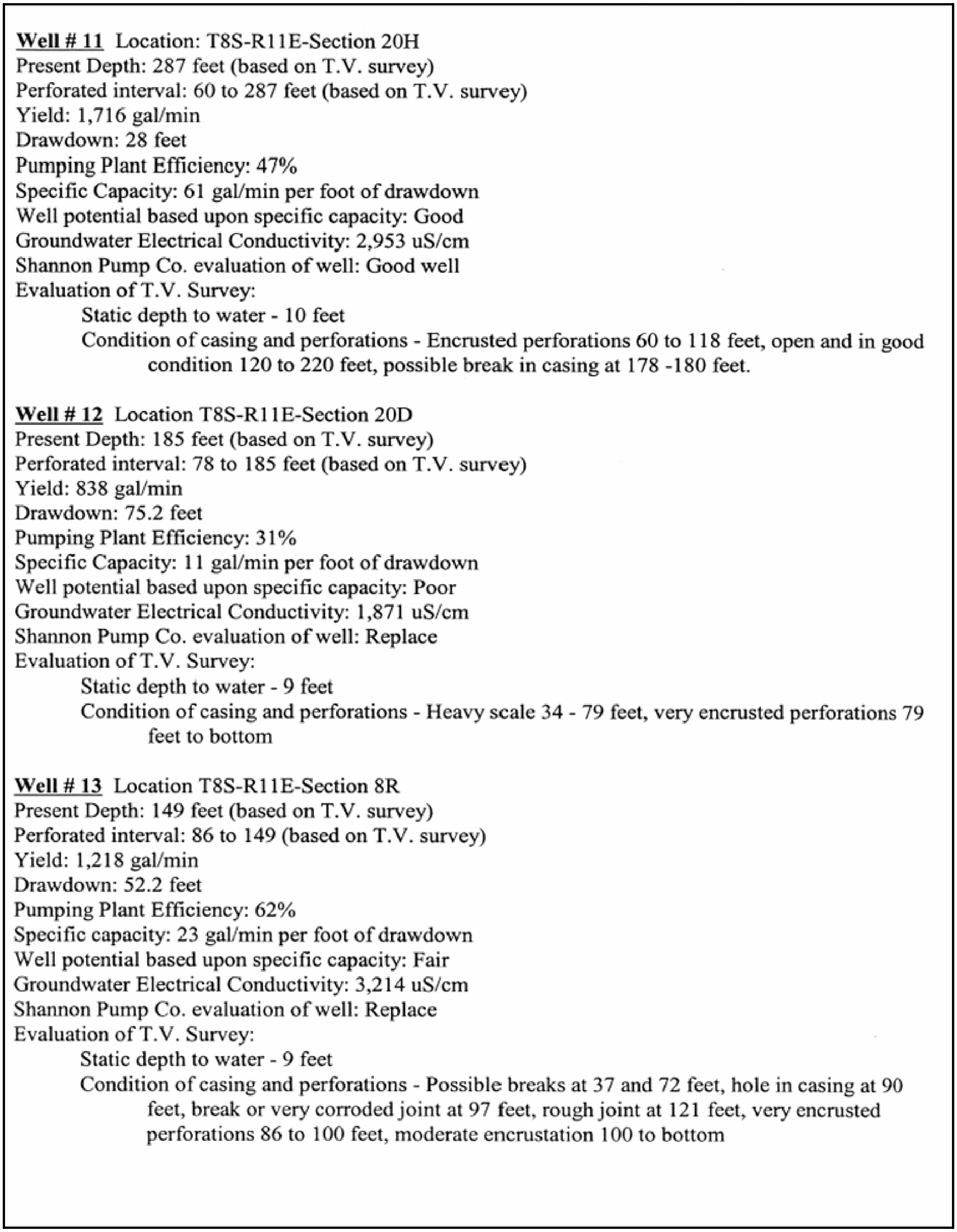


Figure 20. FEC logging profiles at open abandoned well EB-01 in East Bear Creek Unit. The times during which the logging took place are indicated in the legend. The water level in this well was initially at 18 ft below the ground surface.

2.8 Groundwater quality

Regional groundwater quality is highly variable on lands to the east of the San Joaquin River with the best water quality being reported in areas served by shallow wells associated with recharge areas supplied by east-side tributaries such as the Merced River and Bear Creek with poorer water quality reported from deeper wells closer to the San Joaquin River. Bookman-Edmonston (2003, 2005), Schmidt (2005) and Quinn (2006) have published reports on groundwater quality that support this generalization. Water quality in the above- Corcoran semi-confined aquifer is affected by the regional flow system that is

Table 1. Specifications for abandoned production wells (inactive, non-functional): well 11 (EB-01), well 12 (EB-02) and well 13 (EB-03) within the East Bear Creek Unit of the San Luis NWR.



Well # 11 Location: T8S-R11E-Section 20H
Present Depth: 287 feet (based on T.V. survey)
Perforated interval: 60 to 287 feet (based on T.V. survey)
Yield: 1,716 gal/min
Drawdown: 28 feet
Pumping Plant Efficiency: 47%
Specific Capacity: 61 gal/min per foot of drawdown
Well potential based upon specific capacity: Good
Groundwater Electrical Conductivity: 2,953 uS/cm
Shannon Pump Co. evaluation of well: Good well
Evaluation of T.V. Survey:
Static depth to water - 10 feet
Condition of casing and perforations - Encrusted perforations 60 to 118 feet, open and in good condition 120 to 220 feet, possible break in casing at 178 -180 feet.

Well # 12 Location T8S-R11E-Section 20D
Present Depth: 185 feet (based on T.V. survey)
Perforated interval: 78 to 185 feet (based on T.V. survey)
Yield: 838 gal/min
Drawdown: 75.2 feet
Pumping Plant Efficiency: 31%
Specific Capacity: 11 gal/min per foot of drawdown
Well potential based upon specific capacity: Poor
Groundwater Electrical Conductivity: 1,871 uS/cm
Shannon Pump Co. evaluation of well: Replace
Evaluation of T.V. Survey:
Static depth to water - 9 feet
Condition of casing and perforations - Heavy scale 34 - 79 feet, very encrusted perforations 79 feet to bottom

Well # 13 Location T8S-R11E-Section 8R
Present Depth: 149 feet (based on T.V. survey)
Perforated interval: 86 to 149 (based on T.V. survey)
Yield: 1,218 gal/min
Drawdown: 52.2 feet
Pumping Plant Efficiency: 62%
Specific capacity: 23 gal/min per foot of drawdown
Well potential based upon specific capacity: Fair
Groundwater Electrical Conductivity: 3,214 uS/cm
Shannon Pump Co. evaluation of well: Replace
Evaluation of T.V. Survey:
Static depth to water - 9 feet
Condition of casing and perforations - Possible breaks at 37 and 72 feet, hole in casing at 90 feet, break or very corroded joint at 97 feet, rough joint at 121 feet, very encrusted perforations 86 to 100 feet, moderate encrustation 100 to bottom

influenced by recharge from local streams and surface water conveyances and drainage into the San Joaquin River to the west. Newer man-made channels which cut through sandy formations within the shallow groundwater aquifer may experience high rates of seepage. Older natural channels may seal over time as fine grained materials plug the interstices between sand grains and hence experience low rates of seepage. In the latter case, the rate of seepage is dictated by the permeability of the streambed rather than the permeability of the shallow aquifer.

Table 2 Comprehensive chemical analysis performed on the well water from the abandoned production wells 11 (EB-01), 12 (EB-02) and 13 (EB-03). The reported EC of 2,953 uS/cm in well 11 (EB-01) is consistent with the water quality obtained from FEC logging experiments. Ag and Aquatic STD – refers to water quality objectives for either agriculture or State of California receiving waters (Turner, 2001).

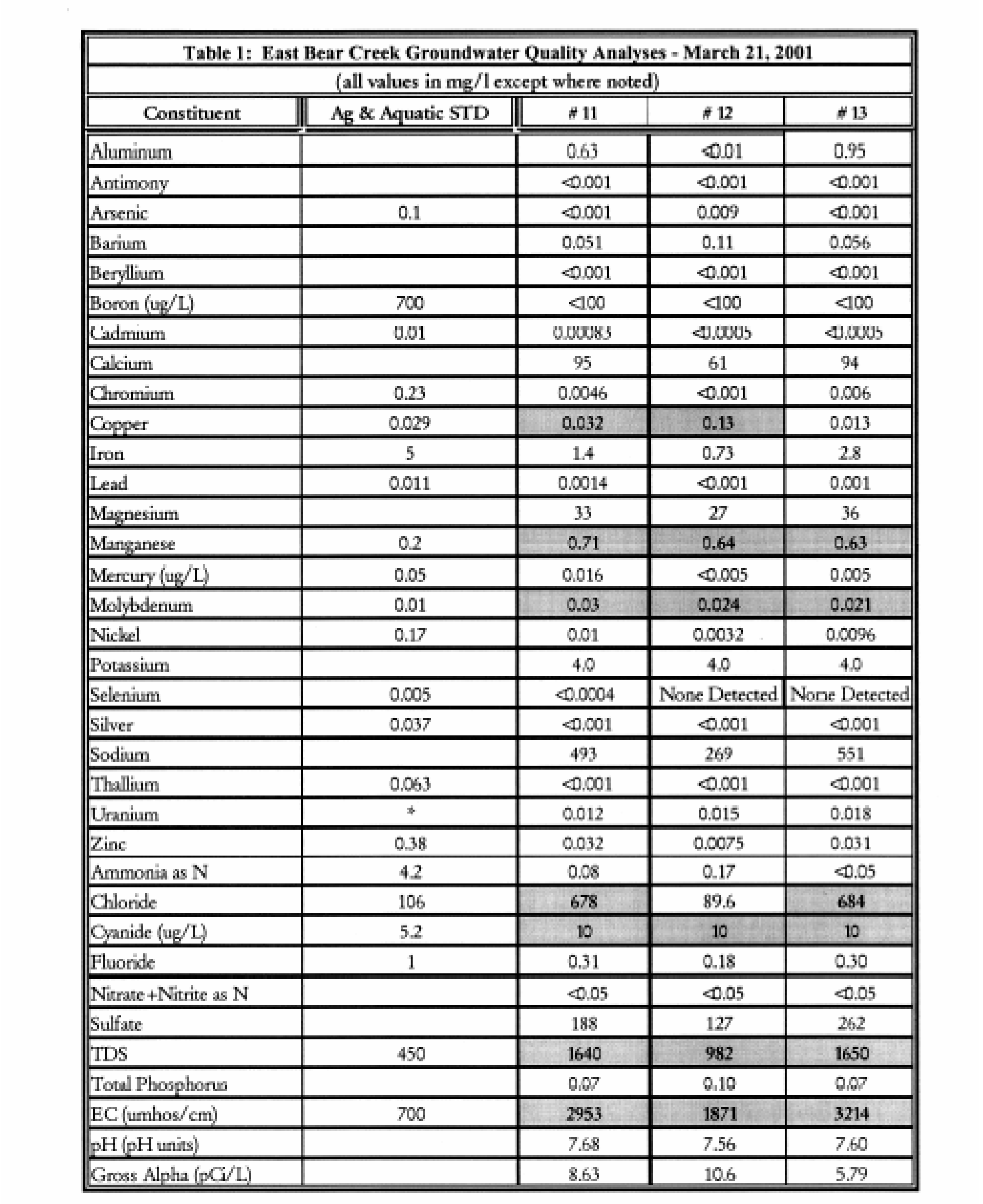
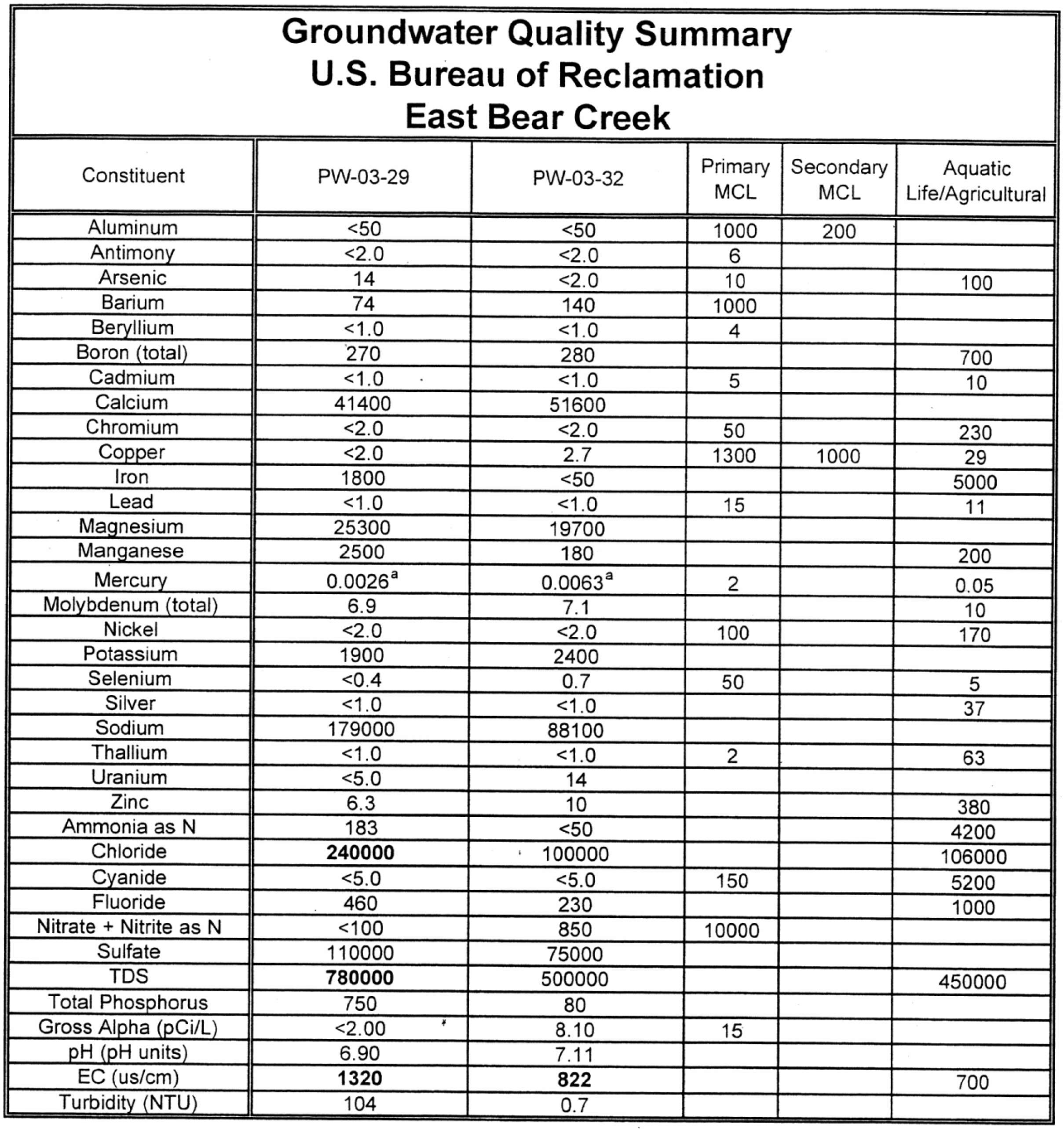


Table 1: East Bear Creek Groundwater Quality Analyses - March 21, 2001

(all values in mg/l except where noted)

Constituent	Ag & Aquatic STD	# 11	# 12	# 13
Aluminum		0.63	<0.01	0.95
Antimony		<0.001	<0.001	<0.001
Arsenic	0.1	<0.001	0.009	<0.001
Barium		0.051	0.11	0.056
Beryllium		<0.001	<0.001	<0.001
Boron (ug/L)	700	<100	<100	<100
Cadmium	0.01	0.00083	<0.0005	<0.0005
Calcium		95	61	94
Chromium	0.23	0.0046	<0.001	0.006
Copper	0.029	**0.032**	**0.13**	0.013
Iron	5	1.4	0.73	2.8
Lead	0.011	0.0014	<0.001	0.001
Magnesium		33	27	36
Manganese	0.2	**0.71**	**0.64**	**0.63**
Mercury (ug/L)	0.05	0.016	<0.005	0.005
Molybdenum	0.01	**0.03**	**0.024**	**0.021**
Nickel	0.17	0.01	0.0032	0.0096
Potassium		4.0	4.0	4.0
Selenium	0.005	<0.0004	None Detected	None Detected
Silver	0.037	<0.001	<0.001	<0.001
Sodium		493	269	551
Thallium	0.063	<0.001	<0.001	<0.001
Uranium	*	0.012	0.015	0.018
Zinc	0.38	0.032	0.0075	0.031
Ammonia as N	4.2	0.08	0.17	<0.05
Chloride	106	**678**	89.6	**684**
Cyanide (ug/L)	5.2	**10**	**10**	**10**
Fluoride	1	0.31	0.18	0.30
Nitrate+Nitrite as N		<0.05	<0.05	<0.05
Sulfate		188	127	262
TDS	450	**1640**	**982**	**1650**
Total Phosphorus		0.07	0.10	0.07
EC (umhos/cm)	700	**2953**	**1871**	**3214**
pH (pH units)		7.68	7.56	7.60
Gross Alpha (pCi/L)		8.63	10.6	5.79

Table 3 Comprehensive chemical analysis performed on the well water from shallow production wells PW-03-29 within the East Bear Creek Unit and PW-03-32 within the West Bear Creek Unit during 2003. The wells are ¾ mile apart. The reported ECs of 1,320 uS/cm and 822 uS/cm respectively are representative of the near surface aquifer. Agricultural and Aquatic Life – refer to water quality objectives for either agriculture or State of California receiving waters (Sherer, 2003).



Groundwater Quality Summary
U.S. Bureau of Reclamation
East Bear Creek

Constituent	PW-03-29	PW-03-32	Primary MCL	Secondary MCL	Aquatic Life/Agricultural
Aluminum	<50	<50	1000	200	
Antimony	<2.0	<2.0	6		
Arsenic	14	<2.0	10		100
Barium	74	140	1000		
Beryllium	<1.0	<1.0	4		
Boron (total)	270	280			700
Cadmium	<1.0	<1.0	5		10
Calcium	41400	51600			
Chromium	<2.0	<2.0	50		230
Copper	<2.0	2.7	1300	1000	29
Iron	1800	<50			5000
Lead	<1.0	<1.0	15		11
Magnesium	25300	19700			
Manganese	2500	180			200
Mercury	0.0026[a]	0.0063[a]	2		0.05
Molybdenum (total)	6.9	7.1			10
Nickel	<2.0	<2.0	100		170
Potassium	1900	2400			
Selenium	<0.4	0.7	50		5
Silver	<1.0	<1.0			37
Sodium	179000	88100			
Thallium	<1.0	<1.0	2		63
Uranium	<5.0	14			
Zinc	6.3	10			380
Ammonia as N	183	<50			4200
Chloride	**240000**	100000			106000
Cyanide	<5.0	<5.0	150		5200
Fluoride	460	230			1000
Nitrate + Nitrite as N	<100	850	10000		
Sulfate	110000	75000			
TDS	**780000**	500000			450000
Total Phosphorus	750	80			
Gross Alpha (pCi/L)	<2.00	8.10	15		
pH (pH units)	6.90	7.11			
EC (us/cm)	**1320**	**822**			700
Turbidity (NTU)	104	0.7			

The groundwater data provided in Tables 1, 2 and 3 show that water quality in wells 11 (EB-01), 12 (EB-02) and 13 (EB-03) is generally better in the upper 50 ft of the aquifer than in the screened interval of the three wells. For well 29, which is located close to well 11 (EB-01) within the East Bear Creek Unit (tested using the FEC logging technique), the EC after 15 minutes of pumping was 980 uS/cm. As previously reported, the EC at the depth of the well screen in well 11 (EB-01) is over 2,900 uS/cm. This suggests that pumping of the shallow groundwater aquifer will yield consistently better quality water. However shallow pumping has the disadvantage of being constrained by rate of withdrawl owing to well induced drawdown and a requirement that a head of water remain above the pump bowls. Low well yield constrained by the horizontal transmissivity of the shallow aquifer would require a large well field which would significantly increase the cost of pumped water compared to fewer wells pumping from greater depths and at rates more than 10 times those of the shallow aquifer wells.

Table 4. Water quality data comparison between groundwater and surface water sources (Source : Shipp, 2004)

Groundwater Well/ Surface Water	**Pumping duration** (mins)	**Temperature** (deg C)	**Discharge** (gals)	**EC** (uS/cm)
Island C Canal (west-side)	0	25	0	550
San Joaquin River	0	24	0	1,215
Pumped well PW-03-29	41	21.7	2,624	950
	118	19.5	7,552	935
	930	19.3	59,520	980
Pumped well PW-03-32	46	18.5	2,994	1,340
	500	18.8	32,000	1,380

2.9 Groundwater Pumping

Pump tests conducted by Shipp and Sherer (Shipp, 2004) were evaluated to determine the suitability of the shallow groundwater aquifer for providing water supply to the East Bear Creek Unit. Graphs illustrating the results of the various pump tests provide information on the specific capacity of the wells, the maximum drawdown of the water level during pumping, the total pump lift, measured flow rate and allow the estimation of the cost of groundwater pumping based on the cost of power.

The pump tests were carried out using a Berkeley 7.5 hp pump operating at flow rates of between 63 and 65 gals/min for the duration of the experiment. Pumpage was measured with a totalizing meter and discharged to a canal approximately 50 ft away. Pumping continued until the rate of drawdown diminished to less than 0.01 ft/hr. The East Bear Creek Unit well PW-03-29 was pumped for 1,300 minutes whereas well PW-03-32 approximately ¾ mile away directly across the San Joaquin River in the West Bear Creek Unit, was pumped for 920 minutes (Shipp, 2004). Drawdown data was obtained from pressure transducers located in nearby observation wells reporting to a multi-channel datalogger. The data recording interval increased with time according to a logarithmic scale. Specific conductivity measurements were measured at the beginning of the pump tests and at intervals during the pump test to check if dewatering the shallow aquifer would lead to interception of poorer quality water. These results are presented in table 4. A groundwater sample was taken during the pump tests and submitted to an analytical laboratory for a full chemical analysis of dissolved constituents and turbidity. These data were presented in Table 3 and can be contrasted with the data for wells 11 (EB-01), 12 (EB-02) and 13 (EB-03) that were shown in Table 2, taken within the deep, above-Corcoran aquifer and indicative of formation water adjacent to the well screen of each abandoned well.

2.9.1 Pump test theory

Aquifer pump tests were performed on observation wells OW-03-27 and OW-03-28, located adjacent to the pumping wells PW-03-29 in the East Bear Creek Unit and on observation well OW-03-30 located adjacent to PW-03-32 in the West Bear Creek Unit (Figure 11). The saturated interval of wells OW-03-27 and OW-03-28 were 19 ft and 15 ft respectively – well OW-03-27 was 20 ft from the pumped well PW-03-29 and well OW-03-28 was 38 ft distant. The saturated interval of well OW-03-30 was 20 ft and the well was located 21 ft from the pumped well PW-03-32. A review of site hydrogeology suggested that the groundwater aquifer within which the aquifer pump test was conducted was unconfined and this assumption was used in calculating aquifer hydraulic parameters.

Aquifer hydraulic parameters were estimated using a number of common test methods using computer software AquiferTest 2000 (Shipp, 2004) and are presented in Table 5. Methods developed by Theis (1935), Cooper-Jacob (1946), Neuman (1975) and Moench (1993) all yield slightly different results. Averages of all relevant methods are usually used to determine aquifer hydraulic parameters. An overview of the theory of aquifer parameter estimation methods is provided by the User's Manual for the AquiferTest2000 computer software (Waterloo HydroGeologic, 2000) which is summarized below :

Table 5. Results of aquifer tests performed by Shipp and Sherer in July 2003 as part of a geologic assessment in support of a canal realignment project (Shipp, 2004).

Well ID	**Parameter**	**Theis**	**Cooper-Jacob**	**Neuman**	**Moench**	**Average**
East Side						
OW-03-27	T (ft^2/min)	2.830	4.500	1.910	0.639	2.50
	K (ft/min)	0.150	0.239	0.102	0.0340	0.131
	Sy	-	-	0.00010	0.0638	0.030
OW-03-28	T (ft^2/min)	4.220	2.790	2.760	0.681	2.60
	K (ft/min)	0.283	0.187	0.0185	0.0457	0.175
	Sy	-	-	0.0000053	0.0681	0.030
West side						
OW-03-30	T (ft^2/min)	5.280	4.240	1.880	0.589	3.10
	K (ft/min)	0.263	0.211	0.0935	0.0273	0.153
	Sy	-	-	0.00009	0.589	0.300
OW-03-31	T (ft^2/min)	4.060	3.890	2.310	0.691	2.90
	K (ft/min)	0.229	0.220	0.130	0.0390	0.162
	Sy	-	-	0.0010	0.069	0.040

In groundwater aquifers such as that below the East Bear Creek Unit characteristics are non-ideal, meaning they display characteristics of both unconfined and confined aquifers. The layer of silty clay that was shown from the CPT logs to be present above the first shallow aquifer acts as a leaky confining layer. It is not homogeneous hence in some areas the groundwater system behaves more like an unconfined system than a confined system. In these circumstances performing aquifer parameter estimation using a variety of methods provides a useful range of values that most likely bracket conditions in the field. Hence in Table 5 a simple average of the four aquifer methods can yield a reasonable first estimate of aquifer transmissivity, hydraulic conductivity and storativity.

The assumptions made by each of the methods for validity are as follows :

- The aquifer is confined and has an "apparent" infinite extent
- the aquifer should be homogeneous, isotropic and of uniform thickness over the area influenced by pumping
- the piezometric surface was horizontal prior to pumping
- the well is pumped at a constant rate
- the well is fully penetrating
- water removed from storage is discharged instantaneously with a decline in head
- the well diameter is small and well storage in negligible
- the values of "u" are small – typically u < 0.01

2.9.1.1 Theis Method

The Theis method (Theis, 1935) is an analytical solution for confined aquifer conditions that describes drawdown, measured as hydraulic head (h) at any radial distance (r) from the pumped well at any time (t) after the initiation of pumping.

$$s(r,t) = \frac{Q}{4\pi T}\int_{t}^{\infty} e^{-u}\,\frac{du}{u}$$

$$u = \frac{r^2 S}{4Tt}$$

Where : s = drawdown (ft)
Q = pumping well discharge (gpm)
T = coefficient of transmissivity (gpd/ft)
S = storativity (dimensionless)
u = analytical parameter

An integral, known as a well function $[W(u)]$, which relies on the definition of "u" provided above can be represented by an infinite Taylor series, which takes the following form :

$$W(u) = 0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - .....$$

Using this function W(u) the equation (above) becomes :

$$s = \frac{Q}{4\pi T} W(u)$$

If a graph is constructed of W(u) along the ordinate and the 1/u along the abscissa as a log- log plot – the result is known as a Theis curve. Field data are typically plotted as t/r^2 along the x-axis against s along the y axis. Aquifer parameters are determined by matching the observed data to the standard Theis curve. The assumptions for validity that were described above are not fully met by the field conditions in the East Bear Creek Unit. Pumping tests typically should be performed for longer than 24 hours to be valid in order to allow for removal of water around the well casing. Determination of an avcurate estimate of aquifer transmissivity depends on being able to identify any well casing storage effect and whether a recharge boundary has been encountered early on in the pump test.

Theis plots are presented in Appendix Figures A1 and A5. In both plots a match point is selected where there is maximum overlap between the observed data and the Theis curve. Recharge and impervious boundaries can cause the real data to deviate significantly from the theoretical Theis curve. This deviation is observed in neither of Figures A1 and A5 suggesting an absence of these effects for the duration of the aquifer test.

Hydraulic conductivity estimates made using curve matching and the Theis method range between 216 and 408 ft/day. Transmissivity rates estimates are 4075 and 6077 ft^2/day. Since the Theis method is relevant to ideal confined aquifers – these results suggest high transmission rates of groundwater within the near-surface aquifer layer within which the test was conducted.

2.9.1.2 Cooper and Jacob Method

The Cooper and Jacob (1946) method was developed as a simplification of the Theis technique that is valid for greater pump test periods and observation wells located closer to the pumped well. In the analytical solution the Taylor series (described above) is truncated eliminating the relevance of the measured values taken at times close to the onset of pumping. The Theis equation is therefore simplified to the following :

$$s = \left[\frac{2.3Q}{4\pi T}\right] \log_{10}\left[\frac{2.25Tt}{Sr^2}\right]$$

Where : s = drawdown (ft)

If the limiting conditions are met and sufficient time has elapsed - the equation above plots as a straight line on semi-log paper.

Transmissivity and storativity are calculated from the following equations :

$$T = \frac{2.3Q}{4\pi\Delta s}$$

$$S = \frac{2.25Tt_0}{r^2}$$

Cooper and Jacob (1946) plots are provided in Figures A2 and A6. Figure A2 for observation well OW-03-27 shows a classical example of the effect of slow drainage to the well which typically occurs whenever there is a marked difference between the vertical and horizontal hydraulic conductivity in the aquifer sediments allowing water to move more rapidly in a horizontal direction than a vertical direction. When pumping commences vertical flow is slight but increases over time as gradients increase and the cone of depression surrounding the well widens. The slope of the curve deviates approximately 10 minutes into the test – the shape of which suggests it is not caused by well casing storage. The temporary excursion below the straight time-drawdown curve converges with increased time. This condition tends to be more pronounced where the top layer of finer grained sediments is greater in thickness and contains lower permeability materials. The Cooper and Jacob (1946) method produced higher estimates of hydraulic conductivity and transmissivity than the Theis method – hydraulic conductivity was 344 ft/day and transmissivity was 6,460 ft^2/day.

In Figure A6 for well OW-03-28 the Cooper and Jacob (1946) plot deviates at approximately 3 minutes into the well test and provides evidence of recharge to the aquifer within the zone of influence of the well. The change in slope is not likely due to well casing because this effect commonly occur very soon after the onset of pumping (approximately 1/10th minute) (Driscoll, 1995). The fact that the time-drawdown plot maintains a downward trajectory suggests that the pumping rate exceeds the natural rate of recharge from the watercourses in the vicinity of the pumped well. Vertical recharge can be ruled out since the area is not irrigated. The San Joaquin River and Bear Creek both are likely sources of recharge to the pumped well. Shipp (2004) estimated the transmissivity of both portions of the curve for well OW-03-28 – the first segment of the curve provided a value of 4,016 ft^2/day (2.76 ft^2/min) and the second portion of the curve a value of 9,187 ft^2/day (6.38 ft^2/min). Shipp (2204) suggested that because the values derived from the two different slopes were not that different – the recharge boundary does not greatly influence the drawdown in the observation well. Since no significant changes in slope occurred in the later stages of the pumping test Shipp (2204) concluded that the cone of depression had not encountered the San Joaquin River. He suggested using the initial portion of the curve as the more representative of the aquifer. Hydraulic conductivity of well 28 was estimated to be 269 ft/day.

The Cooper-Jacob (1946) method produces higher values for aquifer properties for aquifer transmissivity and hydraulic conductivity for observation well OW-03-28 than for observation well OW-03-27 – the Theis method produces the opposite result. The Cooper-Jacob (1946) method is a simplification of the Theis method and therefore possibly more prone to error when conditions deviate from a strictly confined aquifer system.

2.9.1.3 Neuman Method

The Neuman (1975) method was developed specifically to analyze pumping tests in unconfined aquifers. As was previously suggested - groundwater aquifers such as that below the East Bear Creek Unit typically demonstrate both confined and unconfined aquifer characteristics. Techniques that emulate drawdown response for unconfined systems such as the Neuman method can be contrasted with the Theis and Cooper/Jacob method to determine a realistic range of aquifer parameters that better describe the likely spatial heterogeneity of the groundwater system.

Plotting drawdown against time on logarithmic paper produces and inflected curve with three district segments : (1) a steep segment at early time; (2) a flat segment at intermediate time; and (3) a somewhat steep segment at later time. Analysis of the three segments reveals storage characteristics of the aquifer. The early segment describes instantaneous release of water from storage. The intermediate segment typically suggests a secondary source of water which is released from the aquifer after a period of delay. When this secondary source has been depleted (delayed yield has been fully exploited) the time-drawdown curve becomes steep once again. Hence the Neuman method has utility in providing information on some of the surface hydrology of the landscape and how it might interact with the local groundwater system.

The equation developed by Neuman (1975) which describes drawdown in an unconfined aquifer has the following form :

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \beta)$$

Where : $W(u_A, u_B, \beta)$ = unconfined well function

$u_A = \frac{r^2 S}{4Tt}$ (Type A curve for early time)

$u_B = \frac{r^2 S}{4Tt}$ (Type B curve for later time)

$\beta = \frac{r^2 K_v}{D_2 K_h}$

D = initial saturated thickness

Two sets of curves are used : Type-A curves for early drawdown when water is released from elastic storage and Type-B curves for later drawdown when the effects of gravity drainage become more significant.

Hydraulic conductivity is determined from the relation : $K_h = T / D$

Vertical hydraulic conductivity is determined using : $Kv = \frac{\beta D^2 K_h}{r^2}$

Neuman plots are presented in Appendix Figures A3 and A7. In both plots a match point is selected where there is maximum overlap between the observed data and the Theis curves. Recharge and impervious boundaries can cause the real data to deviate significantly from the theoretical Theis curves. Hydraulic conductivity estimates made using curve matching range between 147 and 27 ft/day for the two observation wells OW-03-27 and OW-03-28 respectively. Transmissivity rates estimates are 2,750 and 3,974 ft^2/day. Since the Neuman method is suited to ideal unconfined aquifers – these results suggest somewhat lower values of hydraulic conductivity for groundwater within the near-surface aquifer layer than was determined in either the Theis (1935) or Cooper Jacob (1946) methods. The Neuman method shows a match at low values of S – close to 0.01. Aquifer specific yields computed with this method are low – especially for the observation well OW-03-28 which was assigned a value of 5.3 e^{-06} , a value that is more indicative of a confined aquifer system.

2.9.1.4 Moench Method

The Moench (1993) method is an extension of the Neuman method which permits analysis of delayed yield effects in unconfined aquifers. The technique can be extended to confined conditions where D is the thickness of the saturated zone. Previous analytical solutions assume instantaneous drainage from the unsaturated zone (Theis, 1935; Neuman, 1972, 1974) and tend to underestimate the specific yield (Moench, 1995). The assumption that drainage from the unsaturated zone declines exponentially with time, tend to overestimate drawdown at early-times and underestimate it during late times.

The general solution developed by Moench for drawdown (dimensionless drawdown h_D) is given by :

$$\mathrm{h_D}(\gamma,\beta,\sigma,z_D,t_D) = h_{DT} + \Delta h_{DH} + \Delta h_{DN}$$

Where : $h_d = \frac{4\pi KD}{Q}(h_0 - h_f)$

And : $\gamma = \alpha b S_y / K_z$ - dimensionless fitting parameter; α is an empirical constant

$\beta = (r^2 K_v)/(D^2 K_h)$

$\sigma = S / S_y$

$z_D = b / D$ - dimensionless depth of the piezometer

b = aquifer thickness (confined wells) or depth from water table to bottom of well screen (unconfined aquifers)

t_D = Tt / r^2S - dimensionless time

h_{DT} = Theis solution for a well in a confined aquifer

Δh_{DH} = deviation from the Theis solution due to a partially penetrating well in a confined aquifer

Δh_{DN} = deviation from the Theis solution due to the effects of the free surface (Neuman component)

For confined aquifers the Moench (1993) method uses the first two components of the equation above to account for the confined aquifer conditions and for a partly penetrating well. For confined conditions and fully-penetrating pumping and observation wells – the Moench method uses the same analytical solution as the Theis method. For unconfined conditions and fully-penetrating pumping and observation wells the analytical solution is the same as the Neuman method. The Moench solution uses dimensionless parameters for the type curves where log(h_d) on the ordinate is plotted against log (t_{dy}) on the abscissa. The data are plotted as log (s) on the ordinate against log (t/r^2) on the abscissa.

Moench plots are presented in Appendix Figures A4 and A8. The well time drawdown observations are bracketed by the two theoretical Theis curves for both observation wells. For observation well OW-03-27 the observed data seems to fit the confined Theis curve more closely whereas observation well OW-03-28 is closer to the Neuman curve. Recharge and impervious boundaries can cause the real data to deviate significantly from the theoretical Theis curves. Hydraulic conductivity estimates made using curve matching range between 49 and 66 ft/day for the two observation wells OW-03-27 and OW-03-28 respectively. Transmissivity rates estimates are much closer at 980 and 920 ft^2/day. Moench estimates for hydraulic conductivity and aquifer transmissivity are generally lower than the estimates for the other methods. The specific yield/storativity estimates for both observation wells are identical and equal to 0.03 – a relatively low yield for an unconfined aquifer and high number for a confined aquifer. This result is similar to that for observation well OW-03-31 in the West Bear Creek Unit.

2.10 Groundwater Resource Evaluation

The volume of groundwater in storage can be estimated using the average estimated aquifer thickness and the estimated specific yield of the aquifer (Table 5). Well logs for the deep abandoned wells were not available for the East Bear Creek Unit nor were any of the wells screened to penetrate the full extent of the above-Corcoran Clay aquifer. Well logs were developed from the CPT logging experiments – however the cone truck was only able to achieve depths of between 70 – 100ft before the truck started lifting – because of high sliding friction on the cone penetrometer. Exceeding the applied load can cause a rod to stick or, if the cone truck is pushed out of alignment, can cause bent or damaged rods.

Using the areal extent of the East Bear Creek Unit of 4,000 acres and an average aquifer depth derived by taking the average depth of both sand and sand to silty-sand layers between the surface and the 50 ft depth from the CPT plots in Figures 13 – 17. The West Bear Creek Unit CPT logs were not considered in this determination. The mean depth of sand aquifer for the CPT logs analyzed is 20 ft (for those CPT logs discontinued after 35 ft – the mean depths in the interval from 35 ft to 50 ft were derived from Figure 13) and the average depth of material described as sand to silty-sand was estimated at 15 ft. The sand to silty-sand layer was assumed to have 2/3 of the hydraulic conductivity of the sand layer – hence the total effective depth of aquifer was reduced to an estimated 30ft. Tables 1 and 2 suggest that a 50 ft depth may be the limit of good quality water.

From the analysis and assumptions provided above the amount of groundwater yield available is estimated at 3,600 acre-ft/ft of drawdown. A distributed well field pumping for 6 months per year should be able to supply sufficient water for Level 4 requirements without excessive well drawdown based on the analysis of aquifer properties. However, sustainable exploitation of this groundwater resource depends on the rate of groundwater recharge derived from deep percolation of irrigated water and seepage from canals and conveyance structures that border the East Bear Creek Unit.

2.11 Groundwater levels and aquifer safe yield

Groundwater level data have not been routinely collected within the East Bear Creek Unit hence there are no hydrographs to show trends in groundwater levels over time. The maximum rate of aquifer groundwater pumping that does not exceed the recharge is known as the safe yield. Recharge rates to the aquifer are a combination of effective rainfall, or seepage from nearby water conveyances such as Bear Creek, Bravel Slough and the San Joaquin River. Hence future shallow pumping of the groundwater aquifer below the East Bear Creek Unit will be limited by surface recharge and by lateral movement of groundwater into the Unit from these conveyances. Data analyzed in this report shows reasonable shallow aquifer transmissivity to allow the design of a functional well field. Groundwater recharge from the surface is restricted by the presence of a surface layer that is high in clay and silty materials which would limit the likely success of deliberate recharge through infiltration galleries and a program of water banking. Such a scheme might be wasteful of water given that water that percolates beyond the shallow layers will mix with the lower quality deeper within the above-Corcoran aquifer – reducing its utility. Water stored in aquifers that are subject to high water tables also can lose water through direct evaporation from the water table.

In order to estimate what portion of the potential well yield might be pumpable on an annual basis an estimate was made of potential exchange between the three conveyances Bear Creek, Bravel Slough and the San Joaquin River and the shallow groundwater aquifer. Earlier studies of groundwater accretions into the San Joaquin River in the vicinity of Salt Slough by the USGS have produced estimates of 1-2 cfs/mile. Although the gradients induced by wells pumping the aquifer in hydraulic contact with the San Joaquin River will likely compare to drainage gradients - current flow along the San Joaquin River upstream of Salt Slough is mostly the result of groundwater accretions and canal spills from agricultural and wetland operations and amounts to less than 10 cfs during the late summer months. Bear Creek is not gauged but also tends to experience seasonal low flow during the late summer months. Aquifer recharge rates from these conveyances along are assumed to be no greater than 0.25 cfs/mile. From Figure 21 – the total length of conveyance structures hydraulically connected to the East Bear Creek Unit sum to 10 miles. Using the 0.25 cfs/mile estimate this amounts to a potential recharge rate to a well field within the East Bear Creek Unit of 5 cfs. If sustained over a year this amounts to 3,613 acre-ft/year – approximately 40% of the annual Level II water requirement for the East Bear Creek Unit of 8,863 acre-ft and 27% of the annual Level IV water requirement of 13,295 acre-ft.

A different approach might be to assume all recharge to be provided upslope and to the east of the East Bear Creek Unit. The slope of the water table can be assumed to follow the land surface and would be in the vicinity of 3-5 ft/mile or a gradient of about 7%. Typical hydraulic conductivity of the aquifer material has been previously reported in the vicinity of 0.15 ft/minute or in the range of 1,000 – 1,500 gals/day-ft^2. If the shallow aquifer is, on average about 20 ft deep and the transmissivity is 20,000 – 30,000 gals/day-ft – then assuming an east-side boundary of 4 km along the north-east boundary of the East Bear Creek Unit, the previously calculated gradient of 0.07 ft/ft – this results in a recharge of 17-25 acre-ft/day or 6,200 - 9,400 acre-ft per year or between 47% and 70% of the East Bear Creek Unit water requirements. This assumes that the mean gradient of 4 ft/mile is sustained over the course of the year.

However, not all of this yield can be recovered by groundwater pumping – this depends of the configuration of the well field and the rate of pumping. It is also conceivable that groundwater gradients might decline in the winter months as water levels rise in the San Joaquin River and the other stream conveyances. If only 50% of this potential yield were recoverable – this would amount to between 24% and 35% of the annual Level IV supply requirements.

Although both analyses are based on a number of simplifying assumptions it is clear that there is likely insufficient groundwater recharge to the aquifer beneath the East Bear Creek to provide full Level IV supply. However it is highly likely that this groundwater resource might provide between 17% and 35% of the annual Level IV requirements.

Limitations to the analysis based on stream-aquifer interaction are the lack of flow data in the relevant reaches of the San Joaquin River and Bear Creek – compounded by the fact that some of the flow observed in these conveyances during summer months may in fact be river accretions from the groundwater aquifer along the same flow path. During the late summer when flows within East Bear Creek and the San Joaquin River are at their lowest level and when seasonal wetlands are flooding – pumping of the groundwater aquifer in East Bear Creek may potentially eliminate flow in either or both of these conveyances. A similar phenomenon has occurred further up the San Joaquin River at Gravelly Ford where groundwater pumping of the underlying aquifer has eliminated all flow in the River past this point. Once rainfall occurs and river and stream stage rises in response to rainfall-runoff events – however the groundwater aquifer should be able to recover during average water years. The assumptions made in this analysis can only be checked by monitoring and by the deployment of monitoring stations upstream and downstream along the San Joaquin River and East Bear Creek adjacent to the East Bear Creek Unit. If this assessment continues to a feasibility stage - it is a recommendation of this report that gauging stations be deployed at the upstream and downstream points of each reach adjacent to the East Bear Creek Unit.

Limitations to the analysis of aquifer recharge based on upslope regional groundwater gradients assumes that no water is lost to the surface water conveyances which can act like interceptor drains and may siphon off some of the potential aquifer safe yield. The analysis also assumes that an average groundwater gradients of 4 ft/mile is sustained over the year. Since groundwater flow is the product of yield and aquifer transmissivity – a reduction in effective cross-sectional area of flow due to groundwater interception can reduce sustainable yield.

If shallow groundwater pumping were chosen as an option to supply a portion of the 13,295 acre-ft of Level 4 water required for the East Bear Creek Unit annually – the well field would most likely comprise a large number of wells pumping at relatively low volumes. Management of such a system, combined with the capital cost of a large number of installations would likely make such a system somewhat expensive compared to the cost of a smaller number of high yielding production wells, pumping from deeper in the aquifer. However, poor water quality limits further exploitation of the deep, above-Corcoran, semi-confined aquifer.

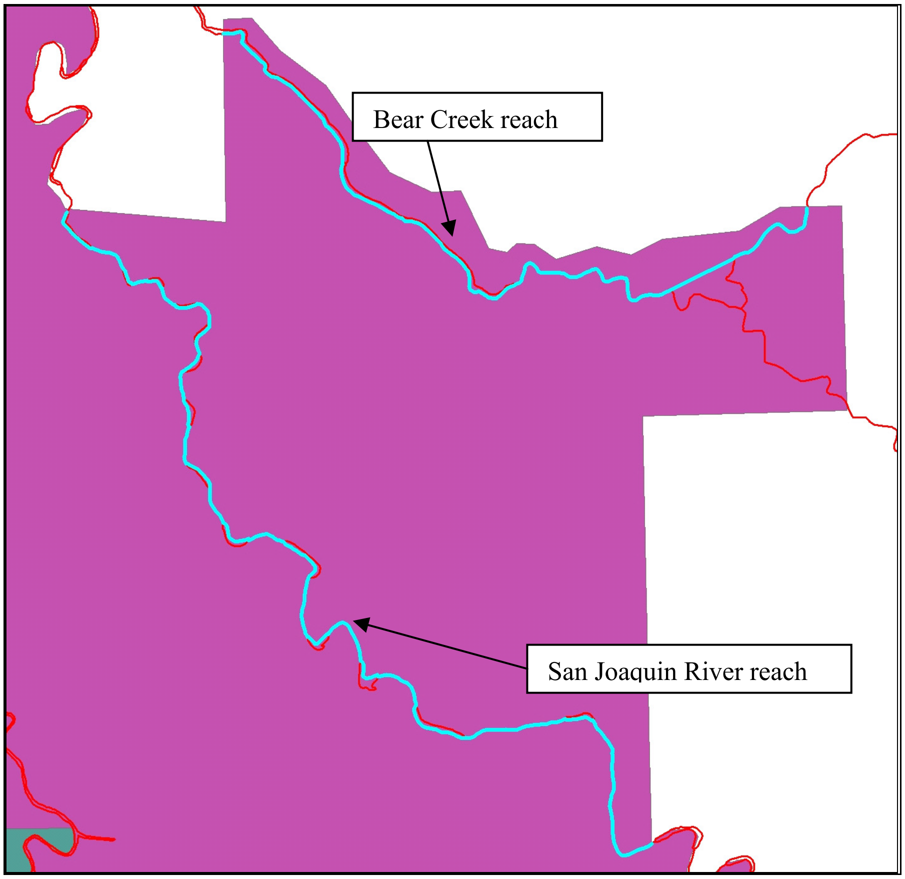


Figure 21. Arc lengths used in estimating potential shallow aquifer recharge to the East Bear Creek Unit from the San Joaquin River and Bear Creek. Upper arc is 6.476 km (4.1 mi) and the lower arc is 9.470 km (5.9 mi).

Although below-Corcoran pumping has been suggested by some groundwater hydrologists as a possible solution - there are no available data from wells developed within the sub-Corcoran aquifer to ascertain the merits of this proposal. From a long-term sustainability perspective – the presence of poor quality groundwater in the aquifer immediately above the Corcoran Clay aquitard would suggest that increased gradients might induce greater across-Corcoran flow, leading term long-term decline in water quality. The thickness of the Corcoran Clay in the vicinity of the Valley trough and the extremely low transmissivity of this aquitard suggest that this process would take decades to be have a significant impact.

3. FINDINGS AND RECOMMENDATIONS

Hydrogeological assessment of the East Bear Creek Unit was conducted using a combination of field investigations and a survey of previous aquifer investigations by US Bureau of Reclamation staff geologists. Safe yield estimates made using the available data show that the East Bear Creek Unit may have sufficient groundwater resources in the shallow groundwater aquifer to meet between 17% and 35% of current Level IV water supply needs. The rate of surface and lateral recharge to the Unit and the design of the well field and the layout and capacity of pumped wells will decide both the percentage of annual needs that the shallow aquifer can supply and whether this yield is sustainable without affecting long-term aquifer quality.

In order to further investigate the merits of pumping the near surface aquifer, which appears to have reasonable water quality for use within the East Bear Creek Unit – monitoring of the potential sources of aquifer recharge and the installation of a pilot shallow well would be warranted. Simple monitoring stations could be installed both upstream and downstream of both the San Joaquin River and Bear Creek and be instrumented to measure river stage, flow and electrical conductivity. Ideally this would be done in conjunction with a shallow pilot well that was pumped to supply part of the Unit's needs for the duration of the wetland inundation period.

4. REFERENCES

Brush, C.F., K. Belitz, S.P. Phillips, K.R. Burow and D.L. Knifong. 2005. MODGRASS: Update of a ground-water flow model for the central part of the western San Joaquin Valley, California

California Department of Water Resources. 2003. Bulletin 118: California's Groundwater, Update 2003, April 2003.

Cooper H.H. and C.E. Jacob. 1946. A Generalized Graphical Method for Evaluation Formation Constants and Summarizing Well Field History. Am. Geophys. Union Trans., Vol 27, pp 526-534.

Bookman-Edmonston, 2003. Hydrogeologic Assessment. Prepared for Stevinson Water District. December 2003. 30p.

Driscoll F.G. 1989. Groundwater and Wells. Second Edition. Johnson Filtration Systems, St. Paul, Minn.

GEI Consultants, 2004. Water Supply, Water Recycling and Storm Water management Evaluation. Prepared for Stevinson Ranch Development. 58p.

Moench A.F. 1993. Computation of Type Curves for Flow to Partially Penetrating Wells in Water table Aquifers. Ground Water. Vol. 31, No. 6, pp 966-971.

Neuman S.P. 1975. Analysis of Pumping Well Data from Anisotropic Unconfined Aquifers Considering Delayed Yield. Water Resources Research. Vol. 11, No. 2, pp 329-342.

Quinn, N.W.T. 2006. Hydrogeologic Assessment of the 4-S Land and Cattle Company Ranch, April 10, 2006. Lawrence Berkeley National Laboratory. Paper LBNL-60011; U.S. Bureau of Reclamation, MP-400. http://repositories.cdlib.org/lbnl/LBNL-60011/

Schmidt K.D. 2005. Kenneth D. Schmidt and Associates. Groundwater Conditions in the Stevinson Area. Prepared for Bates Properties, Inc., Monterey, California. August 2005. 46 p + appendices.

Su, G.W., N.W.T. Quinn, P.J. Cook, and W. Shipp. 2006. Miniaturization of the flowing fluid electrical conductivity logging technique, Ground Water, Vol. 44, No.5 pp. 754-757, Sept-Oct, 2006. LBNL-59032.

Theis C.V. 1935. The Relation Between Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage. Am. Geophys. Union Trans. Vol 16, pp 519-524.

U.S. Bureau of Reclamation. 2003. Memorandum to the Technical Files. Addendum to East Bear Creek Design Data Report, Central Valley Project, CA. Author : Steven G. Sherer, Regional Geology Section, Sacramento, CA.

U.S. Bureau of Reclamation. 2004. Memorandum to the Technical Files. Aquifer testing at proposed pumping plants of the re-aligned water supply pipeline for the East Bear Creek Unit of the San Luis NWR - Central Valley Project, CA. Author : William G. Shipp, Regional Geology Section, Sacramento, CA.

U.S. Geological Survey. 1971a. Data for Wells in the Modesto-Merced Area San Joaquin Valley, California. Prepared in cooperation with the California Department of Water Resources. Open-File Report. Menlo Park, California.

U.S. Geological Survey. 1971b. Geology, Hydrology, and Water Quality of the Tracy-Dos Palos Area, San Joaquin Valley, California. Prepared in cooperation with the California Department of Water Resources. Open-File Report. Menlo Park, California.

U.S. Geological Survey. 1973. Base of Fresh Ground Water (Approximately 3,000 Micromhos) in the San Joaquin Valley, California. Hydrologic Investigations, Atlas HA-489. Prepared in cooperation with the California Department of Water Resources. Washington D.C.

U.S. Geological Survey. 1986. Geology of the Fresh Ground-Water Basin of the Central Valley, California, with Texture Maps and Sections: Regional Aquifer-System Analysis. U.S. Geological Survey Professional Paper 1401-C.

US Geological Survey. 1983. Groundwater Conditions and Shallow test-Well Information in the Eastern Half of Merced County, California, 1977-82. Prepared in Cooperation with the City of Merced. Water Resources Investigations, report 83-4081.

U.S. Geological Survey. 1989. Ground-Water Flow in the Central Valley, California: Regional Aquifer-System Analysis. U.S. Geological Survey Professional Paper 140 1-D

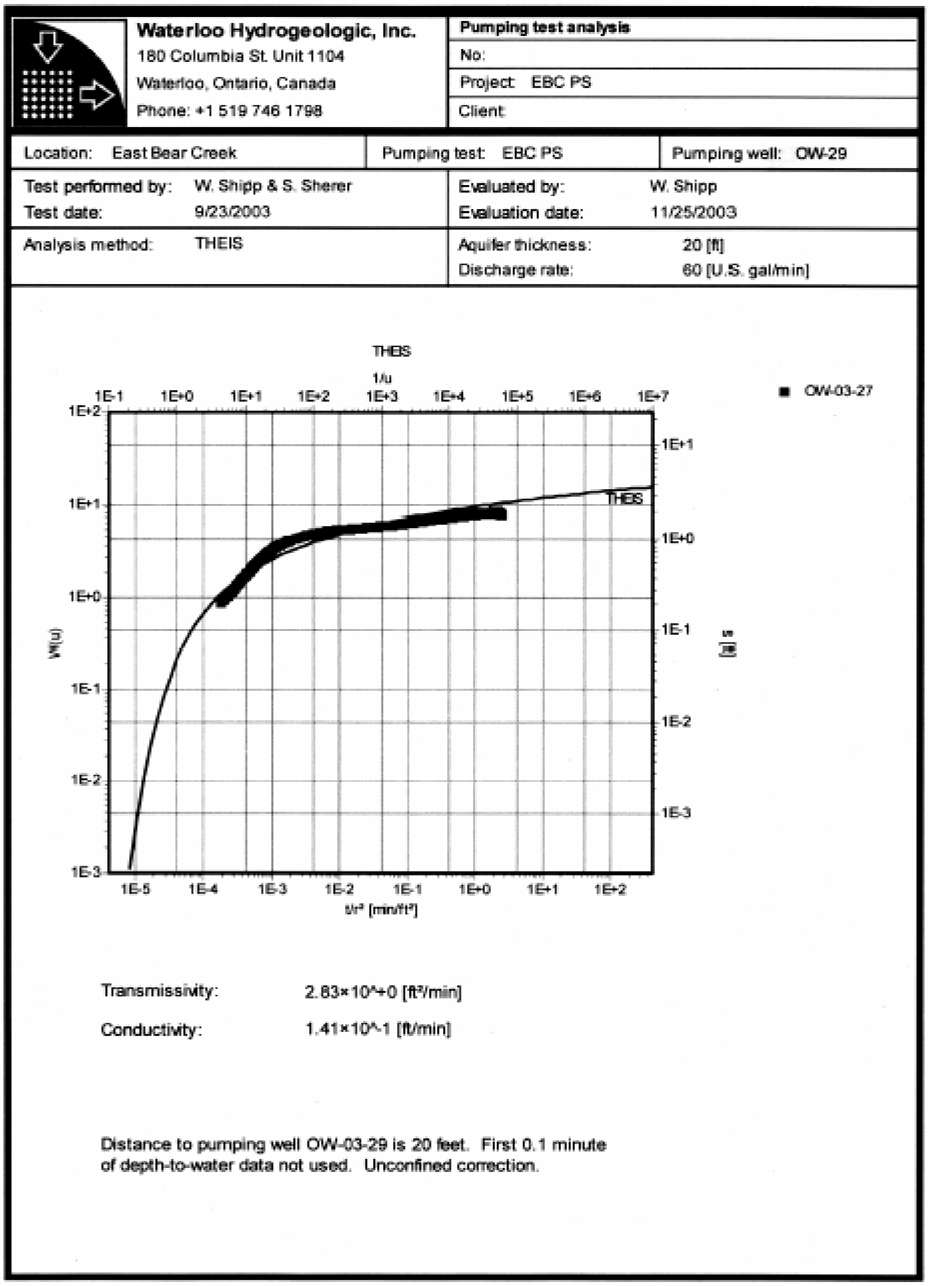
U.S. Geological Survey. 1989. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition. U.S. Geological Survey Water-Supply Paper 2254.

U.S. Geological Survey. 1991. Ground Water in the Central Valley, California-A Summary Report: Regional Aquifer-System Analysis. U.S. Geological Survey Professional Paper 140 1 -A.

Waterloo Hydrogeologic. 2000. AquiferTest User's Manual. Intuitive Analysis and Reporting of Pumping Test and Slug test Data. Waterloo, Canada.

APPENDIX A

Pumping test results from test wells in the East Bear Creek Unit. Tests conducted by Shipp and Sherer (US Bureau of Reclamation, 2003)



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS
Client:

Location: East Bear Creek
Pumping test: EBC PS
Pumping well: OW-29

Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

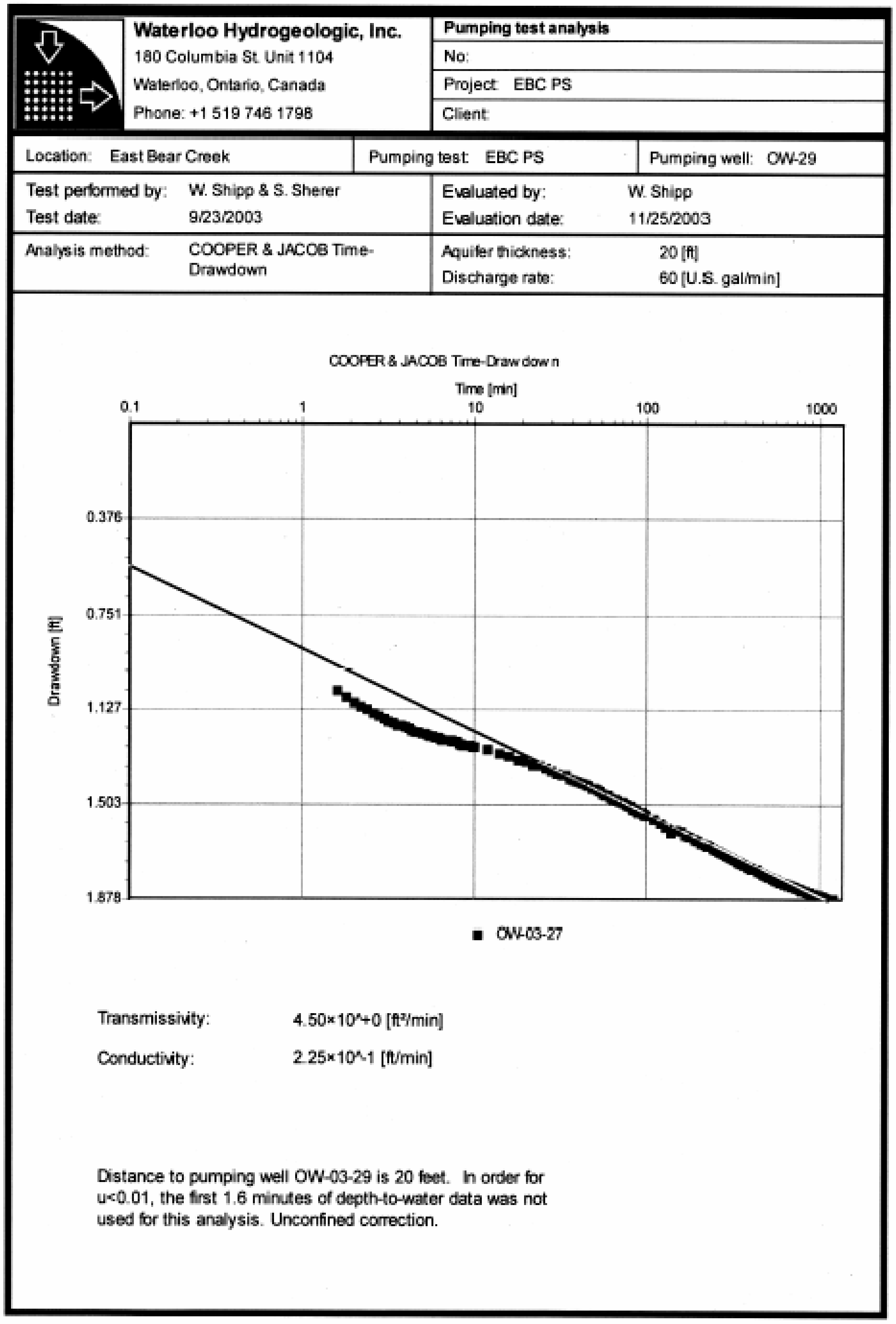
Analysis method: THEIS
Aquifer thickness: 20 [ft]
Discharge rate: 60 [U.S. gal/min]

Transmissivity: 2.83×10^+0 [ft²/min]

Conductivity: 1.41×10^-1 [ft/min]

Distance to pumping well OW-03-29 is 20 feet. First 0.1 minute of depth-to-water data not used. Unconfined correction.

Figure A1. Theis analysis from pump test data from observation well OW-03-27 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS
Client:

Location: East Bear Creek
Pumping test: EBC PS
Pumping well: OW-29

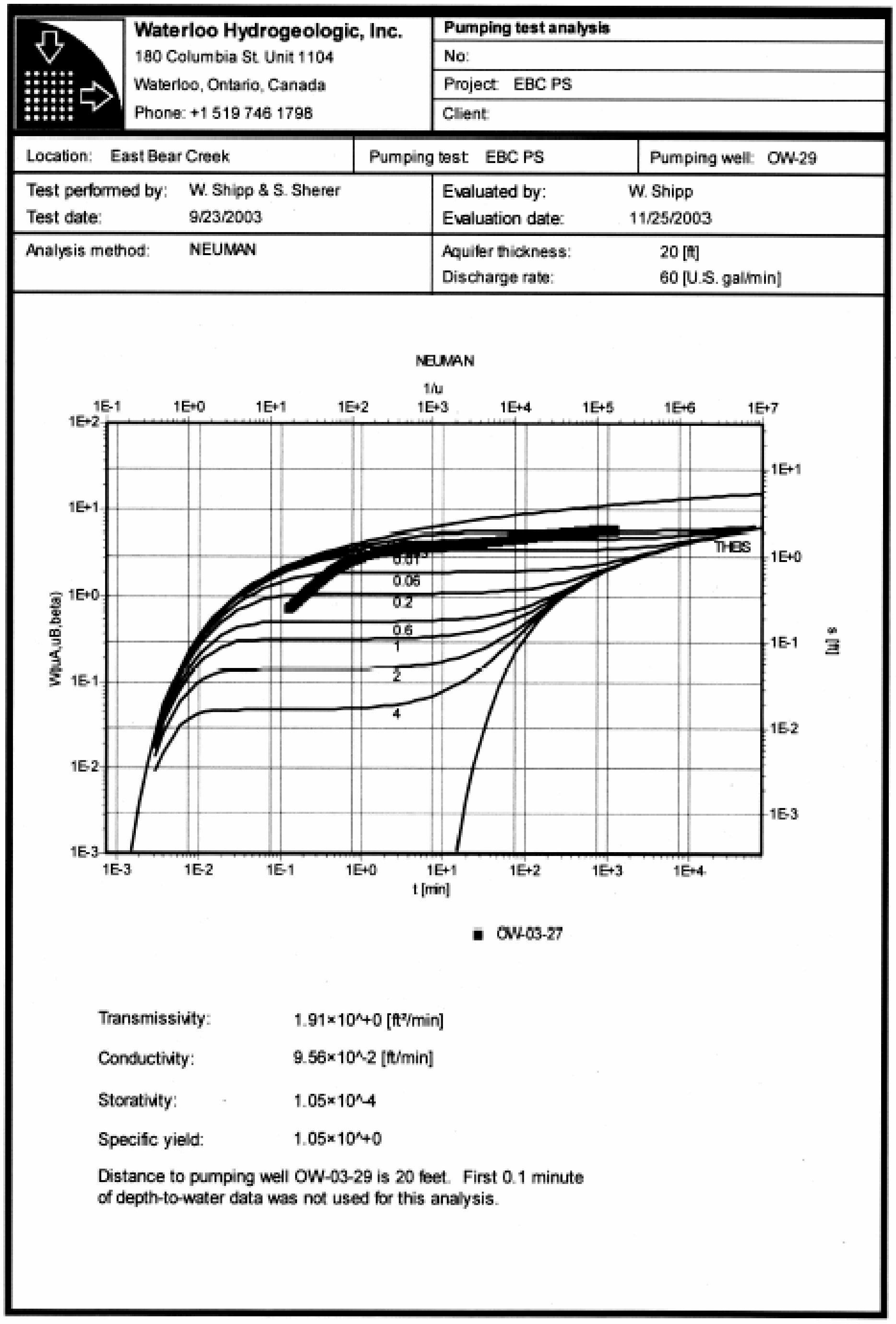
Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

Analysis method: COOPER & JACOB Time-Drawdown
Aquifer thickness: 20 [ft]
Discharge rate: 60 [U.S. gal/min]

Transmissivity: 4.50×10^+0 [ft²/min]
Conductivity: 2.25×10^-1 [ft/min]

Distance to pumping well OW-03-29 is 20 feet. In order for u<0.01, the first 1.6 minutes of depth-to-water data was not used for this analysis. Unconfined correction.

Figure A2. Cooper and Jacob analysis from pump test data from observation well OW-03-27 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS
Client:

Location: East Bear Creek
Pumping test: EBC PS
Pumping well: OW-29

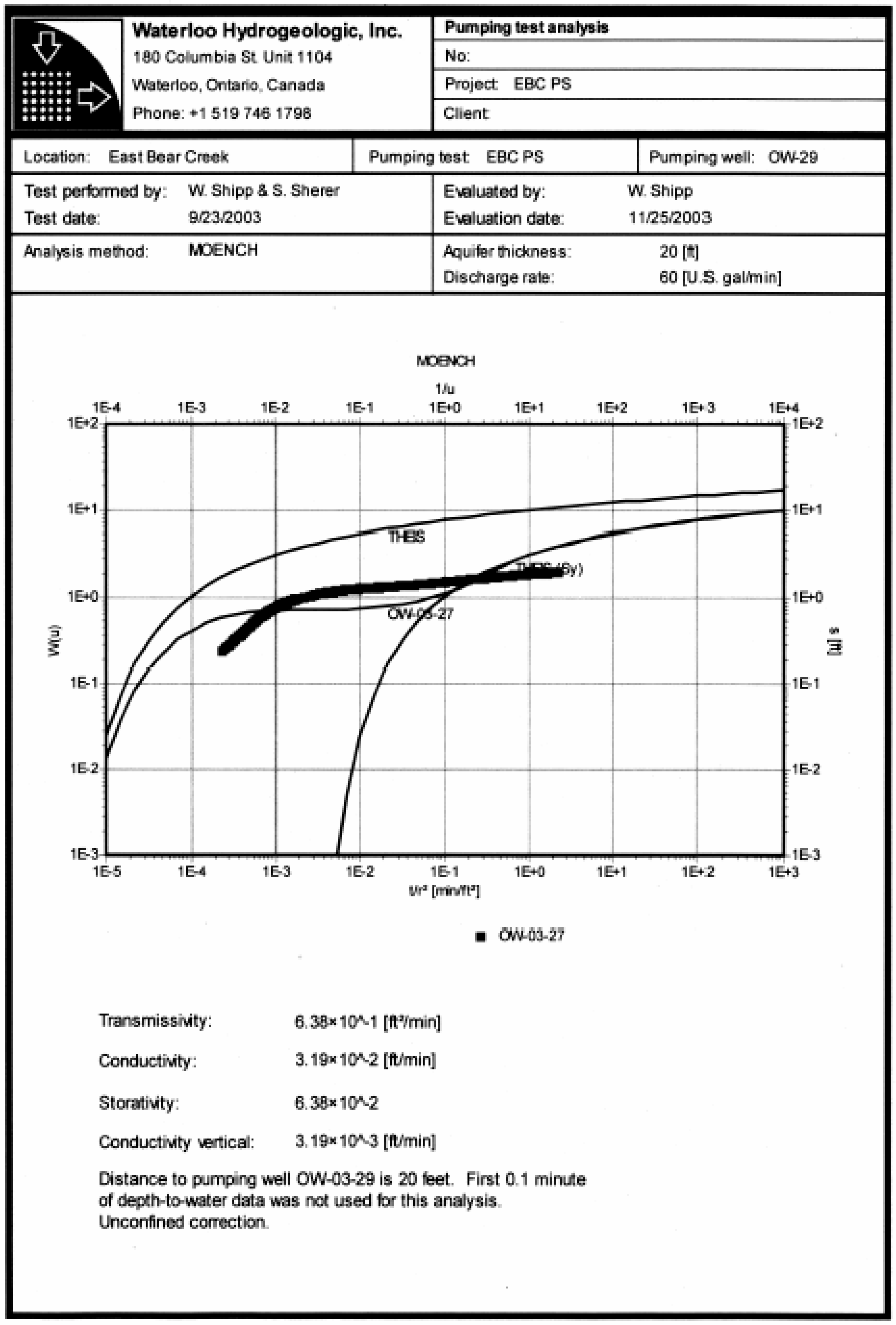
Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

Analysis method: NEUMAN
Aquifer thickness: 20 [ft]
Discharge rate: 60 [U.S. gal/min]

Transmissivity:	1.91×10^+0 [ft²/min]
Conductivity:	9.56×10^-2 [ft/min]
Storativity:	1.05×10^-4
Specific yield:	1.05×10^+0

Distance to pumping well OW-03-29 is 20 feet. First 0.1 minute of depth-to-water data was not used for this analysis.

Figure A3. Neuman analysis from pump test data from observation well OW-03-27 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS
Client:

Location: East Bear Creek
Pumping test: EBC PS
Pumping well: OW-29

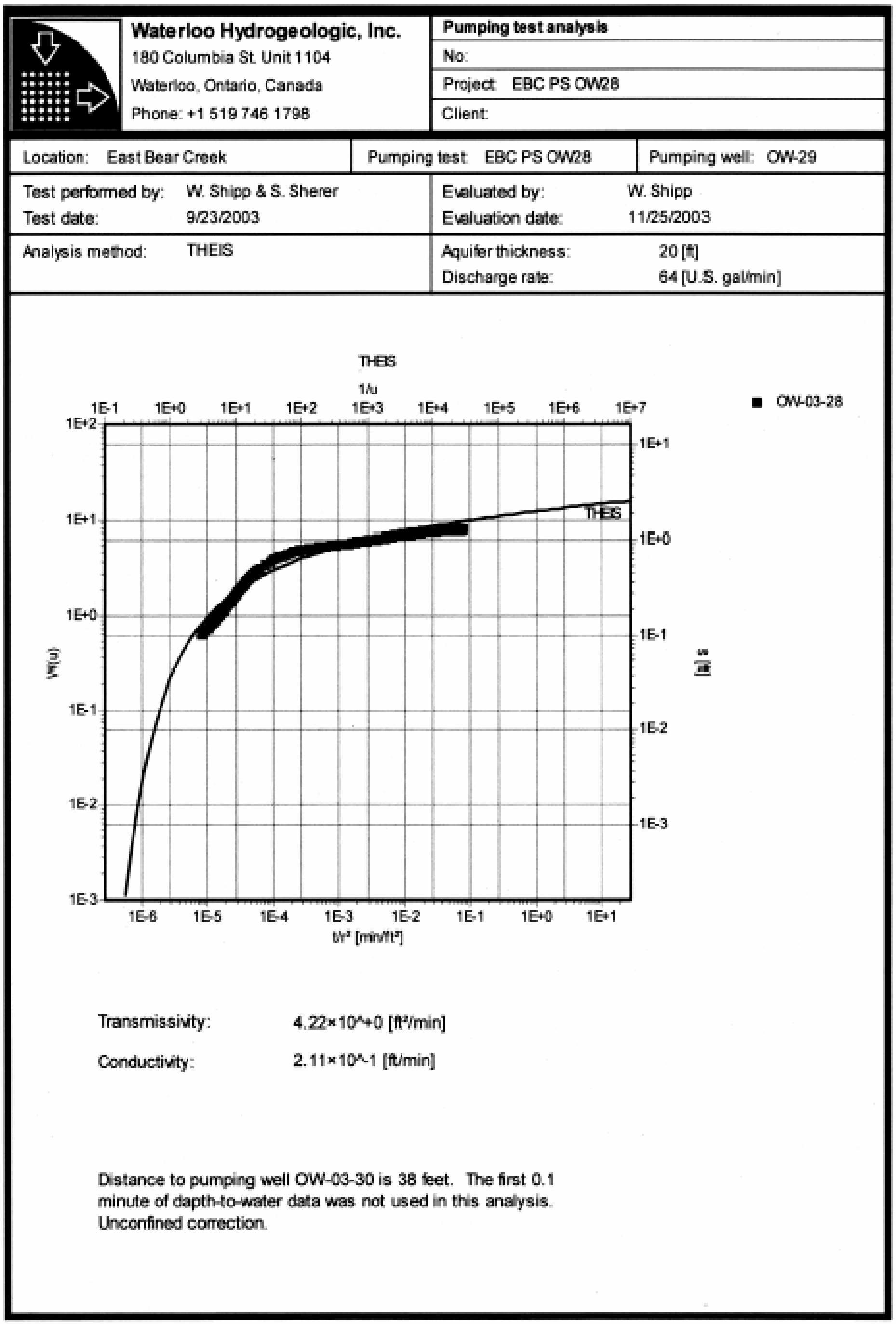
Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

Analysis method: MOENCH
Aquifer thickness: 20 [ft]
Discharge rate: 60 [U.S. gal/min]

Transmissivity:	6.38×10^-1 [ft²/min]
Conductivity:	3.19×10^-2 [ft/min]
Storativity:	6.38×10^-2
Conductivity vertical:	3.19×10^-3 [ft/min]

Distance to pumping well OW-03-29 is 20 feet. First 0.1 minute of depth-to-water data was not used for this analysis.
Unconfined correction.

Figure A4. Moench analysis from pump test data from observation well OW-03-27 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS OW28
Client:

Location: East Bear Creek
Pumping test: EBC PS OW28
Pumping well: OW-29

Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

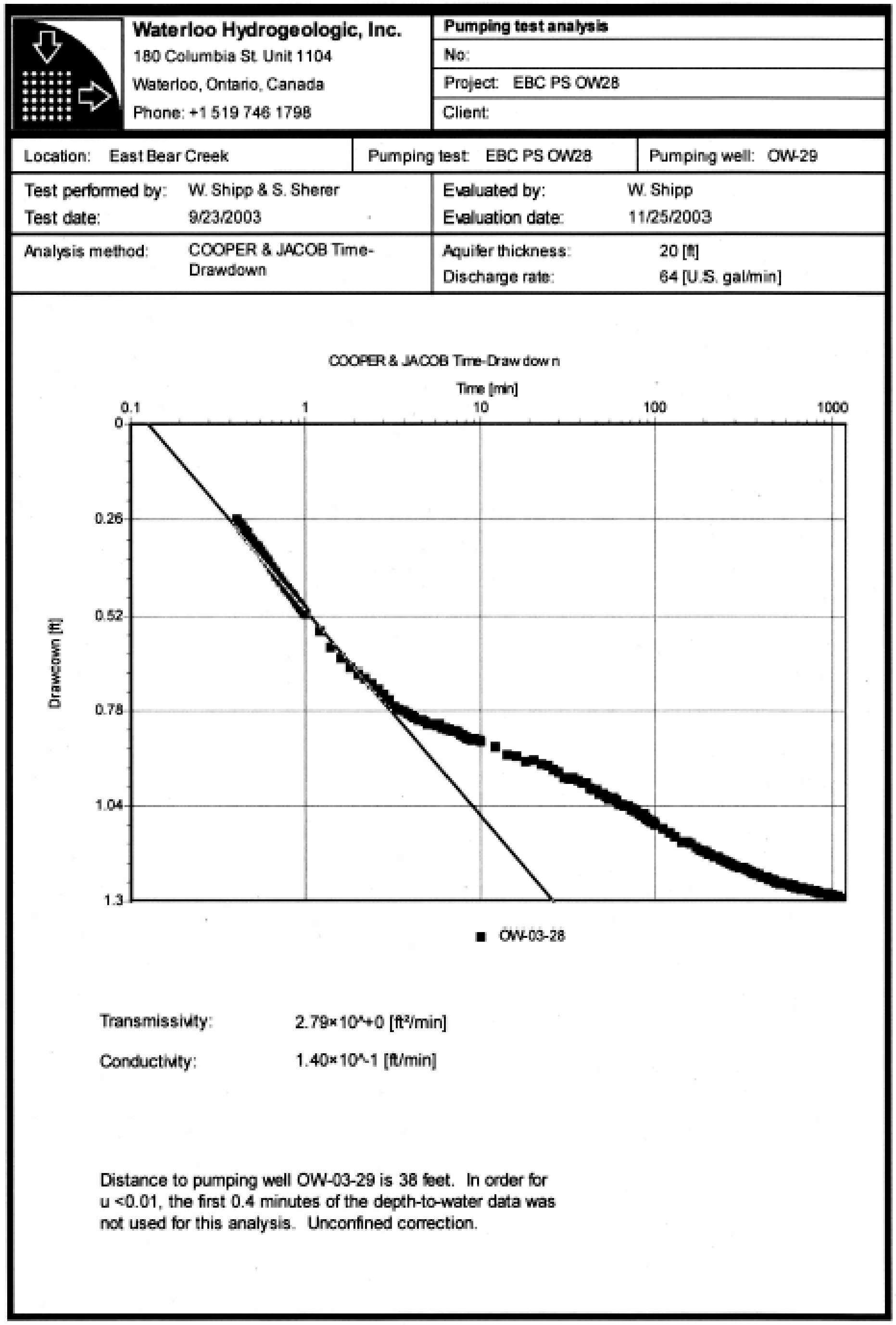
Analysis method: THEIS
Aquifer thickness: 20 [ft]
Discharge rate: 64 [U.S. gal/min]

Transmissivity: 4.22×10^+0 [ft²/min]

Conductivity: 2.11×10^-1 [ft/min]

Distance to pumping well OW-03-30 is 38 feet. The first 0.1 minute of dapth-to-water data was not used in this analysis. Unconfined correction.

Figure A5. Theis analysis from pump test data from observation well OW-03-28 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS OW28
Client:

Location: East Bear Creek
Pumping test: EBC PS OW28
Pumping well: OW-29

Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

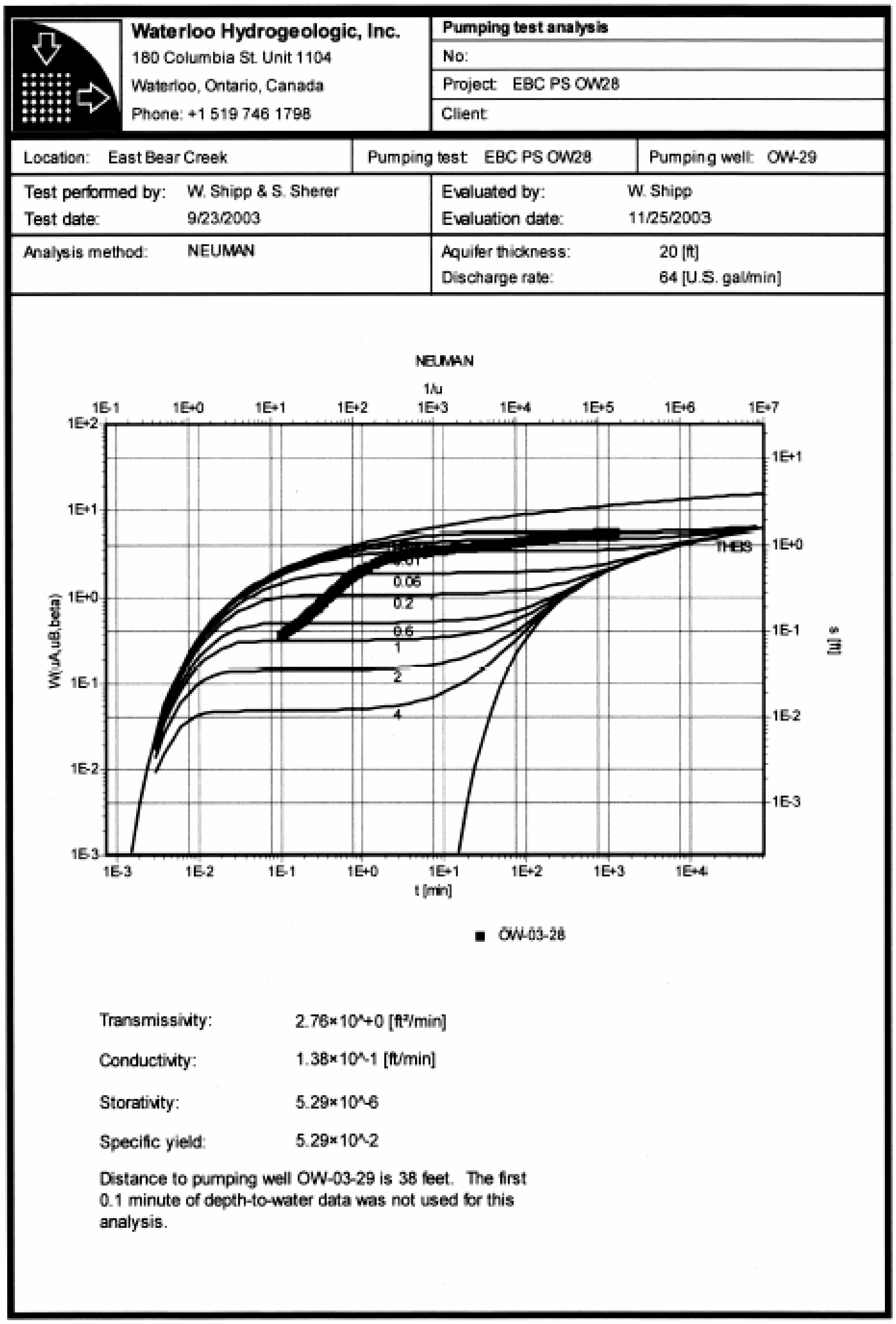
Analysis method: COOPER & JACOB Time-Drawdown
Aquifer thickness: 20 [ft]
Discharge rate: 64 [U.S. gal/min]

Transmissivity: 2.79×10^+0 [ft^2/min]

Conductivity: 1.40×10^-1 [ft/min]

Distance to pumping well OW-03-29 is 38 feet. In order for u <0.01, the first 0.4 minutes of the depth-to-water data was not used for this analysis. Unconfined correction.

Figure A6. Cooper and Jacob analysis from pump test data from observation well OW-03-28 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS OW28
Client:

Location: East Bear Creek
Pumping test: EBC PS OW28
Pumping well: OW-29

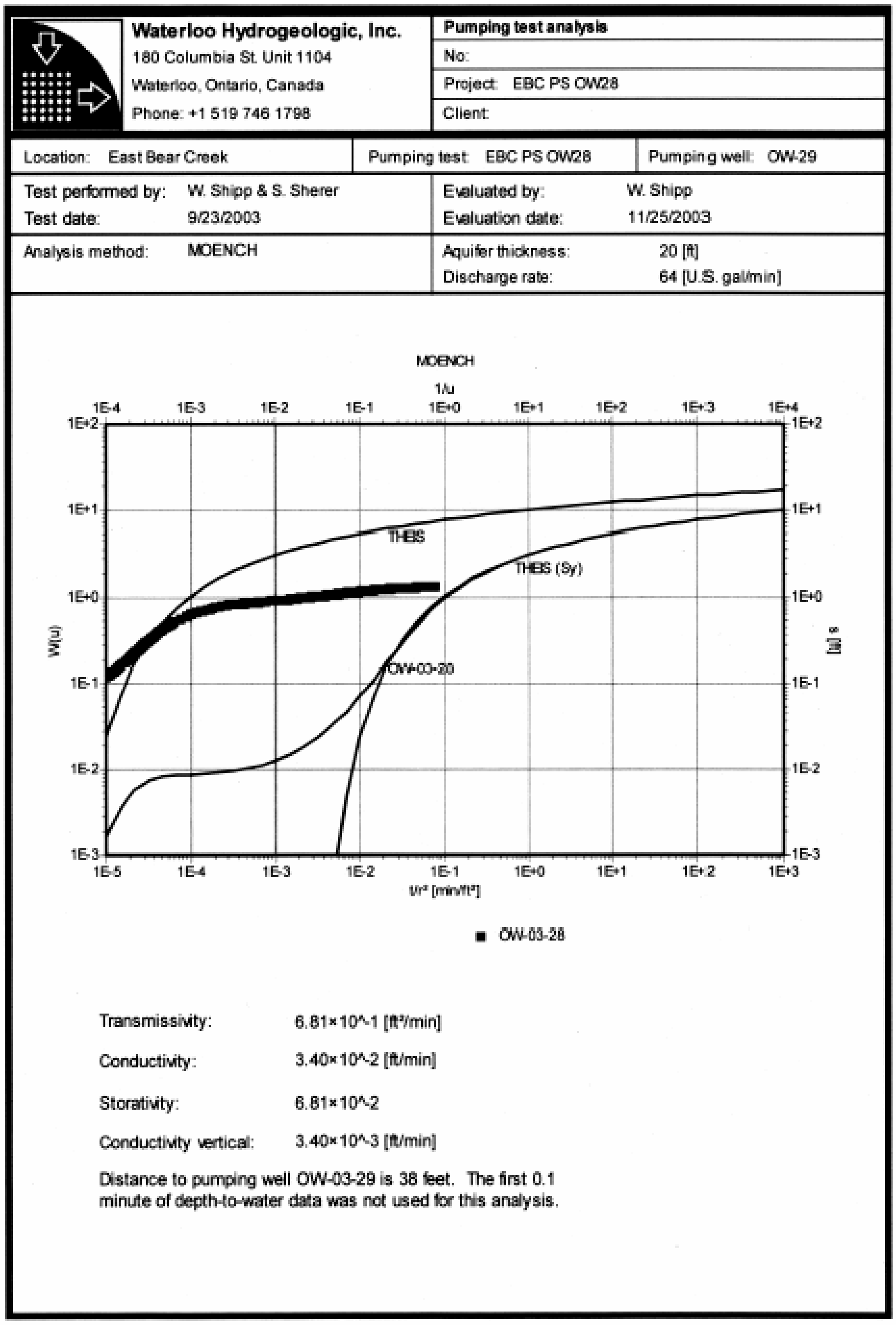
Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

Analysis method: NEUMAN
Aquifer thickness: 20 [ft]
Discharge rate: 64 [U.S. gal/min]

Transmissivity:	2.76×10^+0 [ft²/min]
Conductivity:	1.38×10^-1 [ft/min]
Storativity:	5.29×10^-6
Specific yield:	5.29×10^-2

Distance to pumping well OW-03-29 is 38 feet. The first 0.1 minute of depth-to-water data was not used for this analysis.

Figure A7. Neuman analysis from pump test data from observation well OW-03-28 during pumping test at well OW-29



Waterloo Hydrogeologic, Inc.
180 Columbia St. Unit 1104
Waterloo, Ontario, Canada
Phone: +1 519 746 1798

Pumping test analysis
No:
Project: EBC PS OW28
Client:

Location: East Bear Creek
Pumping test: EBC PS OW28
Pumping well: OW-29

Test performed by: W. Shipp & S. Sherer
Test date: 9/23/2003
Evaluated by: W. Shipp
Evaluation date: 11/25/2003

Analysis method: MOENCH
Aquifer thickness: 20 [ft]
Discharge rate: 64 [U.S. gal/min]

Transmissivity:	6.81×10^-1 [ft²/min]
Conductivity:	3.40×10^-2 [ft/min]
Storativity:	6.81×10^-2
Conductivity vertical:	3.40×10^-3 [ft/min]

Distance to pumping well OW-03-29 is 38 feet. The first 0.1 minute of depth-to-water data was not used for this analysis.

Figure A8. Moench analysis from pump test data from observation well OW-03-28 during pumping test at well OW-29

APPENDIX B

Geologic Logs from test holes (from Sherer, 2003).

GEOLOGIC LOG OF DRILL HOLE NO. SPT-OW-03-27

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/23/03 FINISHED: 7/24/03
DEPTH AND ELEVATION OF WATER LEVEL AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,359.5 E 6,479,053.7
STATION AND OFFSET:
TOTAL DEPTH: 29.9
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 84.7
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and to install an observation well to monitor groundwater levels for designing dewatering systems during construction.

LOCATION:
Proposed Pumping Plant Location north side of San Joaquin River at landside toe of river levee.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 3.2 ft.: 4-1/4 inch i.d. by 8-1/2 inch o.d. flight auger with 3-1/4 inch i.d. by 3-3/4 inch o.d. by 5-foot-long split barrel dry coring system (FADC).
3.2 to 4.7 ft.: Standard Penetration Test (SPT)
3.2 to 6.1 ft.: FADC
6.1 to 7.6 ft.: SPT
6.1 to 8.6 ft.: FADC
8.6 to 10.1 ft.: SPT
8.6 to 11.1 ft.: FADC
11.1 to 12.6 ft.: SPT
11.1 to 13.6 ft.: FADC
13.6 to 15.1 ft.: SPT
13.6 to 16.1 ft.: FADC
16.1 to 17.6 ft.: SPT
16.1 to 18.6 ft.: FADC
18.6 to 20.1 ft.: SPT
18.6 to 21.1 ft.: FADC
21.1 to 22.6 ft.: SPT
21.1 to 23.6 ft.: FADC
23.6 to 25.1 ft.: SPT
23.6 to 26.0 ft.: FADC
26.0 to 27.5 ft.: SPT
26.0 to 28.4 ft.: FADC
28.4 to 29.9 ft.: SPT

SPT EQUIPMENT:
1) CME: Automatic Hammer, Calculated Energy Efficiency Rating is 95%.

2) Pentration Sampler: Machined for liners, but no liners used.

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 29.9 ft.: 300 to 500 psi - smooth and easy.

CAVING CONDITIONS:
11.1 ft.: 0.7 ft cave
16.1 ft.: 0.9 ft. cave
18.6 ft.: 0.3 ft. cave
23.6 ft.: 0.9 ft. cave
26.0 ft.: 0.4 ft. cave

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

DEPTH	% CORE RECOVERY	LABORATORY DATA: % CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION
	80											SM/s(ML)	82.2
		39.9	41.1	81.0	19.0	0.0	43.4	23.2	12.9	(CL)s		CH	81.5
5	100	45.2	42.2	87.4	12.6	0.0	48.3	31.0	18.1	CL		(CL)s	78.7
	100	8.1	30.1	38.2	61.8	0.0	NP	NP	12.1	SM	Qb	SM	76.6
		10.0	70.8	80.8	19.2	0.0	NP	NP	20.2	(ML)s		SM/s(ML)	74.9
10	100											SM	73.0
	100	0.5	9.3	9.8	90.2	0.0	NP	NP	24.8	SP-SM		SP-SM	71.3
												SM/s(ML)	71.1
15	100											SM	

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 29.9 ft.
Quaternary Basin Deposits (Qb)

0.0 to 2.5 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 55% fine to coarse and predominantly fine sand; about 45% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, coarse sand; very soft; dry; contains roots; light brown; Strong reaction with HCl.

2.5 to 3.2 ft. **Fat Clay, CH:** About 90% fines with high plasticity, toughness and dry strength, no dilatancy; about 10% fine sand; maximum size, fine sand; soft; dry; black to dark gray mottled with light gray and orange-brown; no to weak reaction with HCl.

3.2 to 6.0 ft. **Lean Clay with Sand, (CL)s:** About 85% fines with medium to high pasticity, toughness and dry strength, no dilatancy; about 15% fine to coarse and predominantly fine sand; firm; dry to moist; dark gray with white ($CaCO_3$) mottling and nodules to 1/4-inch diameter; Strong reaction with HCl.

6.0 to 8.1 ft. **Silty Sand, SM:** About 75% to 85% fine to medium and predominantly fine sand; about 15% to 25% non-plastic fines with rapid dilatancy; maximum size, medium sand; soft; moist; brown with black spots and minor reddish-orange staining; minor, white $CaCO_3$ nodules to 1/4-inch; no reaction with HCl except on carbonate crystals.

8.1 to 9.8 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

9.8 to 11.7 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; moist to wet (water in hole and sample spoon); gray-brown with reddish-orange staining; finely laminated; micaceous; no reaction with HCl.

11.7 to 13.4 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl.

13.4 to 13.6 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

13.6 to 16.1 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; wet; gray-brown with reddish-orange staining; finely laminated; micaceous; no reaction with HCl.

COMMENTS:

FADC = Flight Auger Dry Core
NP = Nonplastic
SPT = Standard Penetration Test

EASTBEARCREEK_LABV... CRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/11/03 1:13:32 PM

GEOLOGIC LOG OF DRILL HOLE NO. SPT-OW-03-27

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/23/03 FINISHED: 7/24/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,359.5 E 6,479,053.7
STATION AND OFFSET:
TOTAL DEPTH: 29.9
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 84.7
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

HOLE COMPLETION:
Installed 30 feet of 2-inch diameter PVC pipe set at 29.0 ft. depth, with 10 feet of blank pipe above 20 feet of 0.02-inch factory slotted screen and a 2-inch cap on bottom. Backfilled hole with sand up to 7.0 foot and remainder of hole backfilled with bentonite hole-plug to surface. A 2-inch cap on top of PVC pipe to finish the observation well. Pipe stick-up is 2.7 feet above ground level.

DEPTH TO WATER:

Date	Depth to Water
07/23/03	9.8 ft.
08/19/03	10.7 ft.

DEPTH	% CORE RECOVERY	% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION
													68.6
	100	0.6	12.1	12.7	87.3	0.0	NP	NP	27.7	SM		SM	
													66.1
20	100												
												SP-SM	
	66												
													62.1
											Qb		
25	75												
												SP	
	75												
		0.0	2.5	2.5	97.5	0.0	NP	NP	18.4	SP			
													54.8

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

16.1 to 18.6 ft. **Silty Sand, SM:** About 85% fine to coarse and predominantly medium sand; about 15% non-plastic fines with rapid dilatancy; maximum size, coarse sand; wet; soft; gray with reddish-orange staining; no reaction with HCl.

18.6 to 22.6 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl.

22.6 to 29.9 ft. **Poorly Graded Sand, SP:** About 95% fine to coarse and predominantly medium sand; about 5% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; gray; no reaction with HCl.

COMMENTS:

FADC = Flight Auger Dry Core
NP = Nonplastic
SPT = Standard Penetration Test

GEOLOGIC LOG OF DRILL HOLE NO. OW-03-28

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/24/03 FINISHED: 7/25/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,327.0 E 6,479,092.9
STATION AND OFFSET:
TOTAL DEPTH: 30.0
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.3
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and to install an observation well to monitor groundwater levels for designing dewatering systems during construction.

LOCATION:
Proposed Pumping Plant Location north side of San Joaquin River at landside toe of river levee.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 30.0 ft.: 4-1/4 inch i.d. by 8-1/2 inch o.d. flight auger with pilot bit (FAPB).

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 30.0 ft.: 300 to 500 psi - smooth and easy.

CAVING CONDITIONS:
2.7 ft.: at T.D. after pilot bit pulled from hole.

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

HOLE COMPLETION:
Installed 30 feet of 2-inch diameter PVC pipe set at 27.3 ft. depth, with 10 feet of blank pipe above 20 feet of 0.02-inch factory slotted screen and a 2-inch cap on bottom. Backfilled hole with sand up to 7.0 foot and remainder of hole backfilled with bentonite hole-plug to surface. A 2-inch cap on top of PVC pipe to finish the observation well. Pipe stick-up is 2.7 feet above ground level.

DEPTH TO WATER:

Date	Depth to Water
08/19/03	13.6 ft.

DEPTH: 5, 10, 15

% CORE RECOVERY: FAPB

GEOLOGIC UNIT SYMBOL: Qb

LABORATORY DATA

% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
39.9	41.1	81.0	19.0	0.0	43.4	23.2	12.9	(CL)s
45.2	42.2	87.4	12.6	0.0	48.3	31.0	18.1	CL
8.1	30.1	38.2	61.8	0.0	NP	NP	12.1	SM
10.0	70.8	80.8	19.2	0.0	NP	NP	20.0	(ML)s
0.5	9.3	9.8	90.2	0.0	NP	NP	24.8	SP-SM

VISUAL CLASSIFICATION	ELEVATION
SM/s(ML)	83.8
CH	83.1
(CL)s	80.3
SM	78.2
SM/s(ML)	76.5
SM	74.6
SP-SM	72.9
SM/s(ML)	72.7
SM	70.2

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 30.0 ft.
Quaternary Basin Deposits (Qb)

Log based on samples obtained in SPT-OW-03-27 located 51 feet southeast of drill hole location.

0.0 to 2.5 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 55% fine to coarse and predominantly fine sand; about 545% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, coarse sand; very soft; dry; contains roots; light brown; Strong reaction with HCl.

2.5 to 3.2 ft. **Fat Clay, CH:** About 90% fines with high plasticity, toughness and dry strength, no dilatancy; about 10% fine sand; maximum size, fine sand; soft; dry; black to dark gray mottled with light gray and orange-brown; no to weak reaction with HCl.

3.2 to 6.0 ft. **Lean Clay with Sand, (CL)s:** About 85% fines with medium to high pasticity, toughness and dry strength, no dilatancy; about 15% fine to coarse and predominantly fine sand; firm; dry to moist; dark gray with white ($CaCO_3$) mottling and nodules to 1/4-inch diameter; Strong reaction with HCl.

6.0 to 8.1 ft. **Silty Sand, SM:** About 75% to 85% fine to medium and predominantly fine sand; about 15% to 25% non-plastic fines with rapid dilatancy; maximum size, medium sand; soft; moist; brown with black spots and minor reddish-orange staining; minor, white $CaCO_3$ nodules to 1/4-inch; no reaction with HCl except on carbonate crystals.

8.1 to 9.8 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

9.8 to 11.7 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; moist to wet (water in hole and sample spoon); gray-brown with reddish-orange staining; finely laminated; micaceous; no reaction with HCl.

11.7 to 13.4 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl.

13.4 to 13.6 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

13.6 to 16.1 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; wet; gray-brown with

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

EASTBEARCREEK_LABWITHCRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/11/03 1:37:49 PM

GEOLOGIC LOG OF DRILL HOLE NO. OW-03-28

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/24/03 FINISHED: 7/25/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,327.0 E 6,479,092.9
STATION AND OFFSET:
TOTAL DEPTH: 30.0
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.3
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES	DEPTH	% CORE RECOVERY	LABORATORY DATA								LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION / ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
			% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT				
			0.6	12.1	12.7	87.3	0.0	NP	NP	24.8	SM		SM	reddish-orange staining; finely laminated; micaceous; no reaction with HCl. **16.1 to 18.6 ft.** <u>**Silty Sand, SM:**</u> About 85% fine to coarse and predominantly medium sand; about 15% non-plastic fines with rapid dilatancy; maximum size, coarse sand; wet; soft; gray with reddish-orange staining; no reaction with HCl.
													67.7	
	20												SP-SM	**18.6 to 22.6 ft.** <u>**Poorly Graded to Silty Sand, SP-SM:**</u> About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl. **22.6 to 30.0 ft.** <u>**Poorly Graded Sand, SP:**</u> About 95% fine to coarse and predominantly medium sand; about 5% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; gray; no reaction with HCl.
													63.7	
		FAPB										Qb		
	25													
													SP	
			0.0	2.5	2.5	97.5	0.0	NP	NP	18.4	SP			
	30												56.3	

BOTTOM OF HOLE

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

EASTBEARCREEK_LABW...CRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/11/03 1:37:51 PM

GEOLOGIC LOG OF DRILL HOLE NO. PW-03-29

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/26/03 FINISHED: 7/27/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,359.5 E 6,479,074.0
STATION AND OFFSET:
TOTAL DEPTH: 30.0
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 85.1
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and to install a pump test well to conduct a pu,p out test to determine yield and permeability and to be used to monitor groundwater levels for designing dewatering systems during construction.

LOCATION:
Proposed Pumping Plant Location north side of San Joaquin River at landside toe of river levee.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 30.0 ft.: 14-1/2 inch o.d. by 10-1/4 inch i.d. flight auger with pilot bit (FAPB).

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 30.0 ft.: 300 to 500 psi - smooth and easy.

CAVING CONDITIONS:
0.9 ft.: at T.D. after pilot bit pulled from hole.

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

HOLE COMPLETION:
Installed 30 feet of 6-inch diameter PVC pipe set at 29.1 ft. depth, with 10 feet of blank pipe above 20 feet of 0.02-inch factory slotted screen and a 2-inch cap on bottom. Backfilled hole with sand up to 7.0 foot and remainder of hole backfilled with bentonite hole-plug to surface. A 2-inch cap on top of PVC pipe to finish the observation well. Pipe stick-up is 0.9 feet above ground level.

DEPTH TO WATER:

Date	Depth to Water
08/19/03	11.0 ft.

LABORATORY DATA

DEPTH: 5, 10, 15
% CORE RECOVERY: FAPB
GEOLOGIC UNIT SYMBOL: Qb

% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
39.9	41.1	81.0	19.0	0.0	43.4	23.2	12.9	(CL)s
45.2	42.2	87.4	12.6	0.0	48.3	31.0	18.1	CL
8.1	30.1	38.2	61.8	0.0	NP	NP	12.1	SM
10.0	70.8	80.8	19.2	0.0	NP	NP	20.2	(ML)s
0.5	9.3	9.8	90.2	0.0	NP	NP	24.8	SP-SM

VISUAL CLASSIFICATION	ELEVATION
SM/s(ML)	82.6
CH	81.9
(CL)s	79.1
SM	77.0
SM/s(ML)	75.3
SM	73.4
SP-SM	71.7
SM/s(ML)	71.5
SM	69.0

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 30.0 ft.
Quaternary Basin Deposits (Qb)

Log based on samples obtained in SPT-OW-03-27 located 20 feet west of drill hole location.

0.0 to 2.5 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 55% fine to coarse and predominantly fine sand; about 45% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, coarse sand; very soft; dry; contains roots; light brown; Strong reaction with HCl.

2.5 to 3.2 ft. **Fat Clay, CH:** About 90% fines with high plasticity, toughness and dry strength, no dilatancy; about 10% fine sand; maximum size, fine sand; soft; dry; black to dark gray mottled with light gray and orange-brown; no to weak reaction with HCl.

3.2 to 6.0 ft. **Lean Clay with Sand, (CL)s:** About 85% fines with medium to high pasticity, toughness and dry strength, no dilatancy; about 15% fine to coarse and predominantly fine sand; firm; dry to moist; dark gray with white ($CaCO_3$) mottling and nodules to 1/4-inch diameter; Strong reaction with HCl.

6.0 to 8.1 ft. **Silty Sand, SM:** About 75% to 85% fine to medium and predominantly fine sand; about 15% to 25% non-plastic fines with rapid dilatancy; maximum size, medium sand; soft; moist; brown with black spots and minor reddish-orange staining; minor, white $CaCO_3$ nodules to 1/4-inch; no reaction with HCl except on carbonate crystals.

8.1 to 9.8 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

9.8 to 11.7 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; moist to wet (water in hole and sample spoon); gray-brown with reddish-orange staining; finely laminated; micaceous; no reaction with HCl.

11.7 to 13.4 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl.

13.4 to 13.6 ft. **Silty Sand to Sandy Silt, SM/s(ML):** About 50% fine to medium and predominantly fine sand; about 50% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, medium sand; moist; soft; gray-brown with reddish-orange staining; micaceous; no reaction with HCl.

13.6 to 16.1 ft. **Silty Sand, SM:** About 70% very fine to fine sand; about 30% non-plastic fines with rapid dilatancy; maximum size, fine sand; soft; wet; gray-brown with

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

GEOLOGIC LOG OF DRILL HOLE NO. PW-03-29

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/26/03 FINISHED: 7/27/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: See Notes

PROJECT: Central Valley Project
COORDINATES: N 1,904,359.5 E 6,479,074.0
STATION AND OFFSET:
TOTAL DEPTH: 30.0
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 85.1
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES	DEPTH	% CORE RECOVERY	LABORATORY DATA % CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION / ELEVATION
			0.6	12.1	12.7	87.3	0.0	NP	NP	24.8	SM		SM
													66.5
	20												SP-SM
													62.5
		FAPB										Qb	
	25												
													SP
			0.0	2.5	2.5	97.5	0.0	NP	NP	18.4	SP		
	30												55.1

BOTTOM OF HOLE

CLASSIFICATION AND PHYSICAL CONDITION

reddish-orange staining; finely laminated; micaceous; no reaction with HCl.

16.1 to 18.6 ft. <u>Silty Sand, SM:</u> About 85% fine to coarse and predominantly medium sand; about 15% non-plastic fines with rapid dilatancy; maximum size, coarse sand; wet; soft; gray with reddish-orange staining; no reaction with HCl.

18.6 to 22.6 ft. <u>Poorly Graded to Silty Sand, SP-SM:</u> About 90% fine to coarse and predominantly medium sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark brown with 2- to 3-mm thick black sand laminae; no reaction with HCl.

22.6 to 30.0 ft. <u>Poorly Graded Sand, SP:</u> About 95% fine to coarse and predominantly medium sand; about 5% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; gray; no reaction with HCl.

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

EASTBEARCREEK_LABWITHCRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/11/03 1:38:01 PM

GEOLOGIC LOG OF DRILL HOLE NO. SPT-OW-03-30

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/29/03 FINISHED: 7/29/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 8.8 (77.7) 7/29/03

PROJECT: Central Valley Project
COORDINATES: N 1,901,246.6 E 6,477,897.0
STATION AND OFFSET:
TOTAL DEPTH: 30.2
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.5
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: MIKE McCULLA
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF THE HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and install an observation well to monitor groundwater levels for designing dewatering systems during construction. The observation well will be used in conjunction with a pump well to conduct a pump-out test.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 30.2 ft.: Drilled using 8¼ inch o.d. by 4-1/4 inch i.d. hollow stem flight augers with a 3-3/4 inch o.d. by 3-1/4 inch i.d. by 5-foot-long split barrel dry coring system (FADC) on NWJ drill rods with a combination spade and bullet auger head. SPT samples collected with a 2.0-inch o.d. by 1-1/2 inch i.d. by 24-inch long split spoon sampler (collecting a 1.5 ft. sample). FADC over cored the SPT interval and went 1 ft. deeper as a seat for the next SPT test.

Interval	Method
0.0-3.7	FADC
3.7-5.2	SPT
3.7-6.1	FADC
6.1-7.6	SPT
6.1-8.8	FADC
8.8-10.3	SPT
8.8-11.2	FADC
11.2-12.7	SPT
11.2-13.7	FADC
13.7-15.2	SPT
13.7-16.2	FADC
16.2-17.7	SPT
16.2-18.8	FADC
18.8-20.3	SPT
18.8-21.2	FADC
21.2-23.6	FADC
23.6-25.1	SPT
23.6-26.2	FADC
26.2-28.6	FADC
28.6-30.2	FADC

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

SPT EQUIPMENT:
CME Automatic Hammer, Calculated Energy Efficiency Rating is 95%.

SPT TEST SAMPLE NOTES:
8.8- to 10.3-ft. test interval rods sank 0.1 ft. into seating interval.
11.2- to 12.7-ft. test interval rods sank 0.5 ft. into seating interval.
13.7- to 15.2-ft. test interval rods sank 0.2 ft. into seating interval.
16.2- to 17.7-ft. test interval rods sank 0.2 ft. into seating interval.
18.2- to 20.3-ft. test interval started 0.1-ft. high so seating interval was 0.6-ft.
Due to the soft, cohesionless, SP-SM below 25.1-ft. the hole could not be adequately cleaned using the FADC

LABORATORY DATA

DEPTH	% CORE RECOVERY	% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
	68									
		25.4	44.1	69.5	30.5	0.0	30.7	13.7	16.9	s(CL)
5	100	25.0	36.5	61.5	38.5	0.0	27.0	11.8	15.3	s(CL)
	100									
10	92	6.7	62.5	69.2	30.8	0.0	NP	NP	25.2	s(ML)
	80									
15	64	2.6	17.4	20.0	80.0	0.0	NP	NP	23.0	SM

GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION
	SM	85.6
	SM	
	s(CL)	81.7
		79.8
Qb ▼	SM	73.6
	SP-SM	

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 0.9 ft. **Silty Sand, SM:** About 75% very fine to fine sand; about 25% nonplastic fines; maximum size, fine sand; dry; trace of mica; homogeneous; small plant roots; light gray with spotty white carbonate cement and nodules; strong reaction with HCl.

0.9 to 4.8 ft. **Silty Sand, SM:** About 80% very fine to fine sand; about 20% nonplastic fines with organics; trace mica; maximum size, fine sand; moist; homogeneous; small plant roots; dark brown with spotty white carbonate cement and nodules; strong reaction with HCl.

4.8 to 6.7 ft. **Sandy Lean Clay, s(CL):** About 65% fines with medium plasticity, high dry strength, no to slow dilatancy; about 35% very fine to fine sand; trace mica; maximum size, fine sand; moist; homogeneous; light brown with spotty white carbonate cement and nodules; strong reaction with HCl.

6.7 to 12.9 ft. **Silty Sand, SM:** About 80% very fine to fine sand; about 20% nonplastic fines; trace mica; trace brown organic nodules about 4-mm in size spaced at about 30mm; maximum size, 4mm; moist to wet; light brown, homogeneous. 9.0- to 12.9-ft.: Sand 85% and silt 15%.

12.9 to 17.7 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly fine to medium sand; about 10% nonplastic fines; trace mica; maximum size, coarse sand: wet: finely laminated; grain size increasing with depth; gray to light brown.

17.7 to 19.0 ft.: Silty Sand, SM: About 75% very fine to medium sand; about 25% nonplastic fines; trace mica; maximum size fine sand; wet; homogeneous: light brown.

19.0 - 22.7 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium sand; about 10% nonplastic fines; trace mica; maximum size, medium sand; wet; homogeneous; gray to light brown.

22.7 to 24.7 ft. **Well Graded to Silty Sand, SW-SM:** About 90% fine to coarse sand; about 10% nonplastic fines; trace fine, hard gravel; trace mica; maximum size, fine gravel (10mm); wet; finely laminated; sand size increasing with depth;
gray to gray-brown.

24.7 to 30.2 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium and predominantly medium sand; about 10% nonplastic fines; trace mica; maximum size, medium sand, wet, homogeneous; gray to gray-brown. except 26.0- to 26.2-ft.: medium to coarse sand.

COMMENTS:

FADC = Flight Auger Dry Core
SPT = Standard Penetration Test
Tr = Trace

* See SPT Test Sample Notes

GEOLOGIC LOG OF DRILL HOLE NO. SPT-OW-03-30

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/29/03 FINISHED: 7/29/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 8.8 (77.7) 7/29/03

PROJECT: Central Valley Project
COORDINATES: N 1,901,246.6 E 6,477,897.0
STATION AND OFFSET:
TOTAL DEPTH: 30.2
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.5
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: MIKE McCULLA
REVIEWED BY: STEVE SHERER

NOTES

method (1- to 2 ft. of disturbed material was left in the hole after each run) and SPT tests were discontinued. Between the surface and 25 ft. SPT tests generally resulted in 1-blow per 0.1-ft. interval in the last half foot. of each test; except from 24.6 to 25.1 ft. where a thin lens of fine to coarse sand and trace fine gravel was encountered and blow counts increased to 2-blows per 0.1 ft. interval in the last half-ft. of the test.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
Good sample recovery from 0.0 to 17.7 ft; below 17.7 ft generally poor sample recovery with at least part of each sample dropping out of core and SPT barrels; water added to augers to keep formation sand from running in. Used sand fingers with plastic bag on FADC runs from 21.2 to 30.2 ft. No SPT runs below 25.1 ft. because the hole could not be adequately cleaned of disturbed material using FADC.

CAVING CONDITIONS:
Flowing sands below 17.7 ft.

ESTIMATED DRILLING FLUID RETURN:
No Return. Water was added to the inside of augers during FADC runs to keep formation sand from running in.

HOLE COMPLETION:
Following drilling the hole was taped measured as open to a depth of 29.6 ft. The hole was completed as a water observation well with an end-capped slotted 2-inch PVC from 29.7 to 9.7 ft. and blank 2-inch PVC from 9.7 ft. to the surface.The annulus of the hole was back filled with No. 8 sand and naturally caving sand from 29.7 ft. to 7.0 ft., and hole plug (bentonite) from 7.0 ft. to the surface. A stand pipe was added to a height of about 2.7 ft. above ground level.

DEPTH TO WATER:
8.7 ft. below ground surface, 08/07/03
11.4 ft. below top of stand pipe, 08/07/03

DEPTH	% CORE RECOVERY	LABORATORY DATA								LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
		% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT					
	40												68.8	
												SM	67.5	
20	25											SP-SM		
	76												63.8	
											Qb	SW-SM		
		1.8	13.9	15.7	84.3	0.0	NP	NP	20.0	SM			61.8	
25	25													
	92											SP-SM		
		0.6	9.4	10.0	90.0	0.0	NP	NP	23.9	SP-SM				
	44													
30													56.3	

BOTTOM OF HOLE

COMMENTS:

FADC = Flight Auger Dry Core
SPT = Standard Penetration Test
Tr = Trace

* See SPT Test Sample Notes

GEOLOGIC LOG OF DRILL HOLE NO. OW-03-31

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/24/03 FINISHED: 7/25/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 11.0 (75.5) 8/19/03

PROJECT: Central Valley Project
COORDINATES: N 1,901,241.4 E 6,477,948.5
STATION AND OFFSET:
TOTAL DEPTH: 30.2
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.5
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and to install a observation well to monitor groundwater levels and to conduct a pump-out test to determine permeability and well yield for designing dewatering system for construction.

LOCATION:
At proposed intake structure site and 52.5 feet southeast of drill hole SPT-OW-03-30, at the land-side toe of the canal embankment of the Island C Canal where the canal transitions from 100 cfs to 50 cfs capacity.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 30.0 ft.: 8-1/4 inch o.d. by 4-1/4 inch i.d. flight augers with a pilot bit (FAPB).

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 30.2 ft.: smooth and easy, 300 to 600 psi.

CAVING CONDITIONS:
None

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

HOLE COMPLETION:
Installed 30.0 feet of 2-inch diameter PVC pipe into drill hole. Bottom 20.0 feet of PVC pipe is 0.02-inch diameter factory slotted screen with a cap on bottom. The upper 10 feet of PVC pipe is blank pipe. The annulus of the drill hole was backfilled with sand up to about 7 feet depth and the remainder of the drill hole annulus was backfilled with bentonite hole plug as the augers were pulled from the drill hole. The PVC pipe has a 2.7 foot stick-up above ground surface.

DEPTH TO WATER:

Date	Depth to Water
08/19/03	11.0 ft.

LABORATORY DATA

DEPTH	% CORE RECOVERY	% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
		25.4	44.1	69.5	30.5	0.0	30.7	13.7	16.9	s(CL)
5		25.0	36.5	61.5	38.5	0.0	27.0	11.8	15.3	s(CL)
	FAPB									
10		6.7	62.5	69.2	30.8	0.0	NP	NP	25.2	s(ML)
15		2.6	17.4	20.0	80.0	0.0	NP	NP	23.0	SM

GEOLOGIC UNIT SYMBOL: Qb
▼

VISUAL CLASSIFICATION / ELEVATION:
SM
85.6
SM
81.7
s(CL)
79.8
SM
73.6

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 30.2 ft.
Quaternary Basin Deposits (Qb)

Drill hole log based on soil materials encountered in drill hole SPT-OW-03-30, located 52.5 feet northwest of drill hole location.

0.0 to 0.9 ft. **Silty Sand, SM:** About 75% very fine to fine sand; about 25% nonplastic fines; maximum size, fine sand; dry; light gray; trace of mica; homogeneous; small plant roots; spotty white carbonate cement and nodules; strong reaction with HCl.

0.9 to 4.8 ft. **Silty Sand, SM:** About 80% very fine to fine sand; about 20% nonplastic fines with organics; maximum size, fine sand; moist; dark brown; trace of mica; homogeneous; small plant roots; spotty white carbonate cement and nodules; strong reaction with HCl.

4.8 to 6.7 ft. **Sandy Lean Clay, s(CL):** About 65% fines with medium plasticity and toughness, high dry strength, no to slow dilatancy; about 35% very fine to fine sand; maximum size fine sand; moist; trace of mica; light brown with spotty white carbonate nudules and cement; strong reaction with HCl.

6.7 to 12.9 ft. **Silty Sand, SM:** About 80% very fine to fine sand; about 20% nonplastic fines; trace of brown organic nodules to 4 mm in size spaced at about 30 mm apart; maximum size, 4 mm; moist to wet; homogeneous; light brown. 9.0 to 12.9 ft.: Sand 85% and silt 15%.

12.9 to 17.7 ft. **Poorly Graded Sand with Silt, SP-SM:** About 90% fine to coarse, predominantly fine to medium sand; about 10% nonplastic fines; maximum size, coarse sand; wet; trace of mica; finely laminated; grain size inceasing with depth; gray to light brown.

17.7 to 19.0 ft. **Silty Sand, SM:** About 75% very fine to medium sand; about 25% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; light brown.

19.0 to 22.7 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium sand; about 10% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; gray to light brown.

22.7 to 24.7 ft. **Well Graded to Silty Sand, SW-SM:** About 90% fine to coarse sand; about 10% nonplastic fines; trace of hard, fine gravel; maximum size, fine gravel (10 mm); wet; trace of mica; finely laminated; coarse sand increasing with depth; gray to light gray-brown.

24.7 to 30.2 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium, predominantly medium sand; about 10% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; gray to light gray-brown; except 26.0 to 26.2 ft.: medium to coarse sand.

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

GEOLOGIC LOG OF DRILL HOLE NO. OW-03-31

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 7/24/03 FINISHED: 7/25/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 11.0 (75.5) 8/19/03

PROJECT: Central Valley Project
COORDINATES: N 1,901,241.4 E 6,477,948.5
STATION AND OFFSET:
TOTAL DEPTH: 30.2
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.5
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES	DEPTH	% CORE RECOVERY	LABORATORY DATA								LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
			% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT					
														68.8	
													SM		
														67.5	
	20												SP-SM		
													SP-SM		
														64.6	
		FAPB										Qb			
													SW-SM		
			1.8	13.9	15.7	84.3	0.0	NP	NP	20.0	SM				
														61.8	
	25														
													SP-SM		
			0.6	9.4	10.0	90.0	0.0	NP	NP	23.9	SP-SM				
	30													56.3	

BOTTOM OF HOLE

EASTBEARCREEK_LAB\...CRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/12/03 1:11:31 PM

COMMENTS:

FAPB = Flight Auger Pilot Bit
NP = Nonplastic

SHEET 2 OF 2 | DRILL HOLE OW-03-31

GEOLOGIC LOG OF DRILL HOLE NO. PW-03-32

SHEET 1 OF 1

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 8/13/03 FINISHED: 8/14/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 11.0 (75.4) 8/19/03

PROJECT: Central Valley Project
COORDINATES: N 1,901,232.8 E 6,477,912.6
STATION AND OFFSET:
TOTAL DEPTH: 30.2
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 86.4
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment and to install a pump well to conduct a pump-out test to determine permeability and well yield for designing dewatering system for construction.

LOCATION:
At proposed intake structure site and 21 feet eastward from drill hole SPT-OW-03-30, at the land-side toe of the canal embankment of the Island C Canal where the canal transitions from 100 cfs to 50 cfs capacity.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 30.0 ft.: 14-1/2 inch o.d. by 10-1/4 inch i.d. flight augers with a pilot bit (FAPB).

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper.

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 30.0 ft.: smooth and easy, 300 to 600 psi.

CAVING CONDITIONS:
None

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

HOLE COMPLETION:
Installed 30.0 feet of 6-inch diameter PVC pipe into drill hole. Bottom 20.0 feet of PVC pipe is 0.02-inch diameter factory slotted screen with a cap on bottom. The upper 10 feet of PVC pipe is blank pipe. The annulus of the drill hole was backfilled with sand up to about 7.0 feet depth and the remainder of the drill hole annulus was backfilled with bentonite hole plug as the augers were pulled from the drill hole. The PVC pipe has a 0.4 foot stick-up above ground surface.

DEPTH TO WATER:

Date	Depth to Water
08/19/03	11.0 ft.

LABORATORY DATA

DEPTH	% CORE RECOVERY	% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
		25.4	44.1	69.5	30.5	0.0	30.7	13.7	16.9	s(CL)
5		25.0	36.5	61.5	38.5	0.0	27.0	11.8	15.3	s(CL)
10		6.7	62.5	69.2	30.8	0.0	NP	NP	25.2	s(ML)
15	FAPB	2.6	17.4	20.0	80.0	0.0	NP	NP	23.0	SM
20										
		1.8	13.9	15.7	84.3	0.0	NP	NP	20.0	SM
25										
		0.6	9.4	10.0	90.0	0.0	NP	NP	23.9	SP-SM
30										

BOTTOM OF HOLE

GEOLOGIC UNIT SYMBOL: Qb ▼

VISUAL CLASSIFICATION	ELEVATION
SM	85.5
SM	81.6
s(CL)	79.7
SM	73.5
	68.7
SM	67.4
SP-SM SP-SM	64.5
SW-SM	61.7
SP-SM	56.2

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 30.2 ft.
Quaternary Basin Deposits (Qb)

Drill hole log based on soil materials encountered in drill hole SPT-OW-03-30, located 21 feet southwest of drill hole location.

0.0 to 0.9 ft. **Silty Sand, SM:** About 75% very fine to fine, poorly graded sand; about 25% nonplastic fines; maximum size, fine sand; dry; light gray; trace of mica; homogeneous; small plant roots; spotty white carbonate cement and nodules; strong reaction with HCl.

0.9 to 4.8 ft. **Silty Sand, SM:** About 80% very fine to fine, poorly graded sand; about 20% nonplastic fines with organics; maximum size, fine sand; moist; dark brown; trace of mica; homogeneous; small plant roots; spotty white carbonate cement and nodules; strong reaction with HCl.

4.8 to 6.7 ft. **Sandy Lean Clay, s(CL):** About 65% fines with medium plasticity and toughness, high dry strength, no to slow dilatancy; about 35% very fine to fine sand; maximum size fine sand; moist; trace of mica; light brown with spotty white carbonate nudules and cement; strong reaction with HCl.

6.7 to 12.9 ft. **Silty Sand, SM:** About 80% very fine to fine sand; about 20% nonplastic fines; trace of brown organic nodules to 4 mm in size spaced at about 30 mm apart; maximum size, 4 mm; ; moist to wet; homogeneous; light brown. 9.0 to 12.9 ft.: Sand 85% and silt 15%.

12.9 to 17.7 ft. **Poorly Graded Sand with Silt, SP-SM:** About 90% fine to coarse, predominantly fine to medium sand; about 10% nonplastic fines; maximum size, coarse sand; wet; trace of mica; finely laminated; grain size inceasing with depth; gray to light brown.

17.7 to 19.0 ft. **Silty Sand, SM:** About 75% very fine to medium sand; about 25% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; light brown.

19.0 to 22.7 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium sand; about 10% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; gray to light brown.

22.7 to 24.7 ft. **Well Graded to Silty Sand, SW-SM:** About 90% fine to coarse sand; about 10% nonplastic fines; trace of hard, fine gravel; maximum size, fine gravel (10 mm); wet; trace of mica; finely laminated; coarse sand increasing with depth; gray to light gray-brown.

24.7 to 30.2 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium, predominantly medium sand; about 10% nonplastic fines; maximum size, medium sand; wet; trace of mica; homogeneous; gray to light gray-brown; except 26.0 to 26.2 ft.: medium to coarse sand.

COMMENTS:

FAPB = Flight Auger Pilot Bit

SHEET 1 OF 1 | DRILL HOLE PW-03-32

EASTBEARCREEK_LABV...ICRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/12/03 1:10:09 PM

GEOLOGIC LOG OF DRILL HOLE NO. DH-03-33

SHEET 1 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 8/11/03 FINISHED: 8/12/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 8.8 (80.5) 8/11/03

PROJECT: Central Valley Project
COORDINATES: N 1,903,000.0 E 6,478,459.7
STATION AND OFFSET:
TOTAL DEPTH: 63.7
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 89.3
ANGLE FROM HORIZONTAL: AZIMUTH:
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES

ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.

PURPOSE OF HOLE:
Determine stratigraphy and engineering properties of foundation materials along proposed pipeline alignment near the mid-point of the proposed horizontal direction drill pipe installation alignment.

LOCATION:
South side of San Joaquin River at riverside toe of river levee near mid-point of proposed horizontal directional drill.

DRILL RIG:
CME 75

DRILLING & SAMPLING METHODS:
0.0 to 3.9 ft.: 4-1/4 inch i.d. by 8-1/2 inch o.d. flight auger with 3-1/4 inch i.d. by 3-3/4 inch o.d. by 5-foot-long split barrel dry coring system (FADC).
3.9 to 8.8 ft.: FADC
8.8 to 13.8 ft.: FADC
13.8 to 18.8 ft.: FADC
18.8 to 23.8 ft.: FADC
23.8 to 28.8 ft.: FADC
28.8 to 33.8 ft.: FADC
33.8 to 38.7 ft.: FADC
38.7 to 43.7 ft.: FADC
43.7 to 48.7 ft.: FADC
48.7 to 53.7 ft.: FADC
53.7 to 58.7 ft.: FADC
58.7 to 63.7 ft.: FADC

DRILLED BY:
MP-Regional Drill Crew; J. Fry, Driller; S. Odom, Helper

DRILLING CONDITIONS AND DRILLER'S COMMENTS:
0.0 to 63.7 ft.: 300 to 500 psi - smooth and easy.

CAVING CONDITIONS:
none

ESTIMATED DRILLING FLUID RETURN:
None - dry drilled

HOLE COMPLETION:
Backfilled hole with bentonite hole-plug to surface. Marked location of drill hole with marked survey stake. .

DEPTH TO WATER:

Date	Depth to Water
08/11/03	8.8 ft.

DEPTH: 5, 10, 15, 20, 25, 30, 35

% CORE RECOVERY: 64, 57, 68, 0, 28, 16, 65

LABORATORY DATA

% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT	LABORATORY CLASSIFICATION
21.9	17.4	39.3	60.7	0.0	25.4	10.4	11.3	SC
2.5	4.7	7.2	92.8	0.0	NP	NP	19.8	SP-SM
4.2	25.6	29.8	70.2	0.0	NP	NP	22.5	SM

GEOLOGIC UNIT SYMBOL: ▼ Qb

VISUAL CLASSIFICATION	ELEVATION
ML	87.9
SM	87.5
(CL)s	87.2
SM	83.0
s(CL)	82.2
SC-SM	80.5
SP-SM	68.0
SM	65.5
SP-SM	51.3

CLASSIFICATION AND PHYSICAL CONDITION

0.0 to 63.7 ft.
Quaternary Basin Deposits (Qb)

0.0 to 1.4 ft. **Silt, ML:** About 90% fines with low plasticity, toughness and dry strength, rapid dilatancy; about 10% fine sand; maximum size, fine sand; soft; dry; contains roots; light gray-brown; weak reaction with HCl.

1.4 to 1.8 ft. **Silty Sand, SM:** About 70% fine sand; about 30% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, fine sand; soft; dry; brown; weak reaction with HCl.

1.8 to 2.1 ft. **Lean Clay with Sand, (CL)s:** About 80% fines with medium plasticity, toughness and dry strength, no dilatancy; about 20% fine sand; maximum size, fine sand; soft to firm; dry; organically rich; black; weak reaction with HCl.

2.1 to 6.3 ft. **Silty Sand, SM:** About 65% fine sand; about 35% fines with low plasticity, toughness and dry strength, rapid dilatancy; maximum size, fine sand; soft; dry; light gray to light brown; no reaction with HCl.

6.3 to 7.1 ft. **Sandy Lean Clay, s(CL):** About 60% fines with medium plasticity, toughness and dry strength, no dilatancy; about 40% fine to medium and predominantly fine sand; maximum size, medium sand; firm; dry to moist; brown with white CaCO3 cementation and nodules to 1/4-inch; strong reaction with HCl.

7.1 to 8.8 ft. **Silty to Clayey Sand, SM-SC:** About 60% fine to coarse and predominantly fine sand; about 40% fines with low to medium pasticity, toughness and dry strength, slow dilatancy; maximum size, coarse sand; soft; moist; micaceous; brown; no reaction with HCl.

8.8 to 21.3 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to coarse and predominantly medium to coarse sand; about 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet (water in hole); reddish-orange to brown grading downward to gray with minor reddish-orange staining; no reaction with HCl.

21.3 to 23.8 ft. **Silty Sand, SM:** About 85% fine to coarse and predominantly fine sand; about 15% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; dark gray; no reaction with HCl.

23.8 to 38.0 ft. **Poorly Graded to Silty Sand, SP-SM:** About 90% fine to medium and predominantly fine sand; about 10% non-plastic fines with rapid dilatancy; maximum size, medium sand; soft; wet; dark gray; micaceous; no reaction with HCl.

38.0 to 43.7 ft. **Poorly Graded Sand, SP:** About 90 to 95% fine to coarse and predominantly coarse sand; about 5 to 10% non-plastic fines with rapid dilatancy; maximum size, coarse sand; soft; wet; gray; slightly micaceous; no reaction with HCl.

43.7 to 48.7 ft. **Silty Sand, SM:** About 85% fine to coarse and predominantly medium sand; about 15% non-plastic fines with rapid

COMMENTS:

FADC = Flight Auger Dry Core
NP = Nonplastic
SPT = Standard Penetration Test

GEOLOGIC LOG OF DRILL HOLE NO. DH-03-33

SHEET 2 OF 2

FEATURE: East Bear Creek Unit - San Luis NWR
LOCATION: See Notes
BEGUN: 8/11/03 FINISHED: 8/12/03
DEPTH AND ELEVATION OF WATER LEVEL
AND DATE MEASURED: 8.8 (80.5) 8/11/03

PROJECT: Central Valley Project
COORDINATES: N 1,903,000.0 E 6,478,459.7
STATION AND OFFSET:
TOTAL DEPTH: 63.7
DEPTH TO BEDROCK: Not Encountered

STATE: California
GROUND ELEVATION: 89.3
ANGLE FROM HORIZONTAL: AZIMUTH
HOLE LOGGED BY: STEVE SHERER
REVIEWED BY: STEVE SHERER

NOTES	DEPTH	% CORE RECOVERY	LABORATORY DATA								LABORATORY CLASSIFICATION	GEOLOGIC UNIT SYMBOL	VISUAL CLASSIFICATION	ELEVATION	CLASSIFICATION AND PHYSICAL CONDITION
			% CLAY	% SILT	% FINES	% SAND	% GRAVEL	LIQUID LIMIT	PLASTICITY INDEX	MOISTURE CONTENT					
		65											SP	45.6	dilatancy; maximum size, coarse sand; soft; wet; gray; micaceous; no reaction with HCl. **48.7 to 63.7 ft.** <u>**Poorly Graded to Silty Sand, SP-SM:**</u> About 85 to 90% fine to coarse and predominantly coarse sand; about 10 to 15% non-plastic fines with rapid dilatancy; trace of fine, hard gravel; maximum size, fine gravel; soft; wet; gray; no reaction with HCl.
	45	40											SM	40.6	
	50	50	1.7	8.7	10.4	89.6	0.0	NP	NP	18.0	SW-SM	Qb			
	55	56											SP-SM		
	60	60												25.6	

BOTTOM OF HOLE

EASTBEARCREEK_LABWITHCRP EAST BEAR CREEK.GPJ EAST BEAR CREEK.GDT 9/12/03 10:03:35 AM

COMMENTS:

FADC = Flight Auger Dry Core
NP = Nonplastic
SPT = Standard Penetration Test

APPENDIX C

East Bear Creek Refuge Water Supply

East Bear Creek Refuge Water Supply

Bear Creek Below Eastside Canal Near Crane Ranch

Monthly Discharge in Acre Feet - Water Year Jan (partial) 1980 to Aug 2006

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total	Nov-Feb	Mar - Oct
2006	0	0	1,727	26,167	2,030	0	98,037	20,341	4,218	3,646	0	0	**156,166**	**29,924**	**126,242**
2005	3,350	4,371	8,138	65,401	20,921	34,593	9,464	2,728	4,941	681	5,457	3,296	**163,341**	**98,831**	**64,510**
2004	20	151	118	263	474	2,246	783	511	0	0	0	0	**4,567**	**1,006**	**3,561**
2003	49	499	3,710	2,192	159	50	220	80	79	79	668	7	**7,791**	**6,560**	**1,231**
2002	417	455	2,623	8,953	1,240	164	50	128	9	84	86	6	**14,215**	**13,271**	**945**
2001	1,151	887	342	260	1,612	1,906	77	774	455	153	119	89	**7,826**	**3,101**	**4,725**
2000	352	8	0	1,598	19,112	11,069	2,495	1,364	1,101	1,459	570	436	**39,565**	**20,718**	**18,847**
1999	2,038	833	90	1,920	7,831	1,276	5,557	317	420	864	1,460	863	**23,468**	**10,674**	**12,794**
1998	1,512	190	108	30,560	37,518	16,702	10,327	6,382	2,793	1,058	2,892	3,840	**113,883**	**68,376**	**45,507**
1997	784	1,570	23,506	62,040	22,553	1,868	280	69	69	120	369	237	**113,465**	**109,669**	**3,796**
1996	416	229	1,033	2,792	18,245	6,666	1,098	2,145	1,069	329	191	1,913	**36,126**	**22,299**	**13,827**
1995	95	3,079	0	12,777	3,890	16,246	3,880	3,007	2,583	4,148	4,607	5,502	**59,813**	**19,746**	**40,067**
1994	2,074	1,011	120	939	5,152	724	159	91	524	123	78	604	**11,598**	**7,222**	**4,376**
1993	8	0	190	27,952	7,940	6,420	1,864	396	959	187	78	495	**46,488**	**36,081**	**10,407**
1992	1,818	382	0	80	7,451	828	513	174	119	105	42	16	**11,527**	**7,913**	**3,614**
1991	0	0	0	36	1	8,852	26	66	23	16	77	45	**9,141**	**36**	**9,105**
1990	886	41	2	132	1,708	306	27	651	37	51	53	25	**3,918**	**1,882**	**2,036**
1989	1,155	2	491	818	1,083	2,448	210	81	29	38	96	961	**7,411**	**2,393**	**5,018**
1988	1,306	292	512	1,148	244	452	1,474	111	49	54	127	437	**6,205**	**2,195**	**4,010**
1987	8,889	19	174	570	1,565	4,271	34	410	134	51	464	2,673	**19,256**	**2,329**	**16,927**
1986	2,436	751	1,072	334	26,033	28,886	6,956	4,217	2,162	1,473	2,474	9,479	**86,274**	**28,191**	**58,083**
1985	8,957	624	1,587	649	2,216	6,656	1,298	636	997	257	381	5,388	**29,647**	**5,076**	**24,571**
1984	12,740	6,536	21,610	6,119	4,066	7,948	6,066	3,301	2,116	1,655	3,424	4,907	**80,487**	**38,331**	**42,156**
1983	16,461	7,966	18,756	39,289	51,192	84,691	19,171	14,722	11,990	9,662	10,689	13,654	**298,243**	**117,203**	**181,040**
1982	3,978	2,492	2,715	13,783	12,766	13,101	23,586	3,590	2,795	734	1,348	17,717	**98,605**	**31,756**	**66,849**
1981	7,224	599	31	1,416	2,071	8,067	1,670	1,351	159	42	136	1,745	**24,510**	**4,117**	**20,393**
1980				7,821	26,527	15,049	7,833	10,239	6,849	1,085	1,246	7,807	**84,455**	**34,348**	**50,107**
Avg	3,537	1,310	3,445	9,683	11,854	11,111	4,300	2,459	1,701	1,076	1,405	3,583	**55,087**	**26,075**	**29,012**
MAX	16,461	7,966	23,506	62,040	51,192	84,691	23,586	14,722	11,990	9,662	10,689	17,717	**298,243**	**117,203**	**181,040**
MIN	0	0	0	36	1	306	26	66	23	16	42	16	**3,918**	**36**	**2,036**
	Monthly Average cfs based on above														
Avg	**58**	**22**	**56**	**157**	**213**	**181**	**72**	**40**	**29**	**17**	**23**	**60**			
MAX	268	134	382	1,009	922	1,377	396	239	202	157	174	298			
MIN	0	0	0	1	0	5	0	1	0	0	1	0			
Avg 1980 - 87	8,669	2,712	6,564	8,748	15,805	21,084	8,327	4,808	3,400	1,870	2,520	7,921			
Avg 1988 - 06	917	737	2,248	12,949	8,377	5,938	7,186	2,075	1,025	694	893	988			
	Monthly Average cfs based on above														
Avg 1980 - 87	**141**	**46**	**107**	**142**	**285**	**343**	**140**	**78**	**57**	**30**	**41**	**133**			
Avg 1988 - 01	15	12	37	211	151	97	121	34	17	11	15	17			