AP Area Down and Up Flushing Treatability Study Results Report

Nevada Environmental Response Trust Site
Henderson, Nevada

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
amsl	above mean sea level
AP Area	ammonium perchlorate manufacturing area
AP	ammonium perchlorate
ASTM	American Society for Testing and Materials
AWF	Athens Road Well Field
bgs	below ground surface
CPS	calcium polysulfide
CRB	Central Retention Basin
DVSR	Data Validation Summary Report
ETI	Envirogen Technologies, Inc.
EVS	Earth Volumetric Studio
FBR	Fluidized Bed Reactor
ft^2	square feet
ft/day	feet per day
gpm	gallons per minute
GWETS	Groundwater Extraction and Treatment System
GWTP	Groundwater Treatment Plant
in/hr	inches per hour
IWF	Interceptor Well Field
LSI	Logistical Solutions, LLC
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliters
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NERT or Trust	Nevada Environmental Response Trust
OM&M	operation, maintenance, and monitoring
psi	pounds per square inch
psig	pounds per square inch gauge
PVC	polyvinyl chloride
Qal	Quaternary alluvium
QAPP	quality assurance project plan
Site	Nevada Environmental Response Trust Site

Acronyms/Abbreviations	Definition
SLMW	stabilized Lake Mead water
TestAmerica	TestAmerica Laboratories, Inc.
Tetra Tech	Tetra Tech, Inc.
UMCf	Upper Muddy Creek formation
USEPA	United States Environmental Protection Agency

CERTIFICATION

AP Area Down and Up Flushing Treatability Study Results Report

Nevada Environmental Response Trust Site
(Former Tronox LLC Site)
Henderson, Nevada

Nevada Environmental Response Trust (NERT) Representative Certification
I certify that this document and all attachments submitted to the Division were prepared at the request of, or under the direction or supervision of NERT. Based on my own involvement and/or my inquiry of the person or persons who manage the systems(s) or those directly responsible for gathering the information or preparing the document, or the immediate supervisor of such person(s), the information submitted and provided herein is, to the best of my knowledge and belief, true, accurate, and complete in all material respects.

Office of the Nevada Environmental Response Trust

Le Petomane XXVII, not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

not individually, but solely as President

Signature: ______________________, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

Name: Jay A. Steinberg, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

Title: Solely as President and not individually

Company: Le Petomane XXVII, Inc., not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

Date: 12/21/18

CERTIFICATION

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been prepared in a manner consistent with the current standards of the profession, and to the best of my knowledge, comply with all applicable federal, state, and local statutes, regulations, and ordinances. I hereby certify that all laboratory analytical data was generated by a laboratory certified by the NDEP for each constituent and media presented herein.

Description of Services Provided: AP Area Down and Up Flushing Treatability Study Results Report, Nevada Environmental Response Trust Site, Henderson, Nevada

Kyle S. Hansen

December 21, 2018

Kyle Hansen, CEM
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Tetra Tech, Inc.

Date

Nevada CEM Certificate Number: 2167
Nevada CEM Expiration Date: September 18, 2018

EXECUTIVE SUMMARY

This report summarizes the technical approach and findings for the Ammonium Perchlorate (AP) Area Down and Up Flushing Treatability Study conducted at the Nevada Environmental Response Trust (NERT or Trust) site (Site) in Henderson, Nevada. This treatability study was implemented in accordance with the *AP Area Down and Up Flushing Treatability Study Work Plan*, approved by the Nevada Division of Environmental Protection (NDEP) on March 5, 2018 (Tetra Tech, Inc., 2018a). Soil flushing was selected to release and transport perchlorate for extraction and treatment at the AP Area. Two variants of the soil flushing technology, down flushing and up flushing, were included as part of this Treatability Study.

The objectives of the AP Area Down and Up Flushing Treatability Study were to evaluate the effectiveness of down flushing and up flushing, while building on the results of the Soil Flushing Treatability Study conducted in the Central Retention Basin (CRB) (Tetra Tech, Inc., 2017) by testing a different water delivery system at a larger scale and testing the viability of up flushing to remove perchlorate from the lower permeability Upper Muddy Creek formation (UMCf). The AP Area Down and Up Flushing Treatability Study utilized drip irrigation, while the previous Soil Flushing Treatability Study maintained standing water as its soil flushing water delivery system. The use of this alternate water delivery system allows NERT to evaluate options for improving water efficiency and cost implications of implementing a large-scale soil flushing system at source areas at the Site. This information will be critical for use during remedial options evaluations performed as part of the Feasibility Study. The previous soil flushing treatability study focused on an area with moderate concentrations of perchlorate in the alluvial soils whereas this study focused on a source area with significantly higher concentrations of perchlorate in the vadose zone.

Down Flushing Program

Prior to performing down flushing, soil samples were collected from soil borings drilled within the down flushing area, and baseline perchlorate mass estimates were calculated using the analytical results. Down flushing was applied to two 90-foot by 90-foot plots (Plots 1 and 2), located respectively 250 feet and 420 feet upgradient (south) of the Interceptor Well Field (IWF) using drip irrigation systems. These plot locations were selected due to the presence of high perchlorate concentrations in the vadose zone.

Down flushing was conducted in five separate phases that targeted specific zones within Plot 1 and Plot 2. Stabilized Lake Mead water (SLMW) was applied to the soil surface through conveyance piping, and later tubing, placed on the ground surface. The down flushing program was implemented with SLMW, without carbon substrate to enhance in-situ bioremediation. This approach allowed for separate evaluation of the performance of SLMW, with the understanding that carbon substrate could be added in the future to further enhance down flushing applied elsewhere at the Site. At least two pore volumes were flushed in both Plots 1 and 2. In total, approximately 2,700,000 gallons of SLMW were applied to Plot 1, and approximately 1,900,000 gallons of SLMW were applied to Plot 2.

Following down flushing activities, post-treatment perchlorate mass estimates were calculated using analytical results from confirmation soil samples collected from soil borings drilled within the down flushing area. Perchlorate concentration data from the down flushing baseline and confirmation soil borings were used to develop three-dimensional models of the spatial distribution of perchlorate beneath Plots 1 and 2 before and after down flushing. In addition to modeling perchlorate concentrations, Earth Volumetric Studio (EVS) software was used to model the geometry of the contact between the Quaternary alluvium (Qal) and UMCf based on data from the soil boring logs, and the water table surface was modeled using groundwater elevation data from the shallow monitoring wells, injection wells, and extraction wells collected during the baseline groundwater monitoring round. The EVS models were then used to estimate the mass of perchlorate in the unsaturated zone (i.e., between the ground surface and water table), the saturated Qal aquifer (between the water table and the Qal/UMCf contact), and the upper portion of the UMCf (to approximately 15 feet below the Qal/UMCf contact) beneath Plots 1 and 2. The procedure used for estimating mass was similar to that used in the *RI Study Area Mass Estimate and Expanded Performance Metrics Technical Approach* (Ramboll Environ, Inc., 2017a).

Up Flushing Program

The original objective of the up flushing program as outlined in the work plan was to convey perchlorate-bearing groundwater toward the IWF and supplemental extraction wells by injecting SLMW into and directly below the Qal aquifer where high perchlorate concentrations were anticipated, based on data from previous borings and wells in the vicinity of the AP Area. SLMW without carbon substrate to enhance in-situ bioremediation was planned.

The installation of soil borings, monitoring wells, and injection wells for the up flushing program revealed that high perchlorate concentrations were deeper in the AP Area than had previously been identified on Site. The highest perchlorate concentrations were found in soil samples at 60 feet below ground surface (bgs), the deepest extent explored in the present study. As a result, the scope of the up flushing program was significantly reduced due to concerns of pushing contamination deeper into the UMCf.

The up flushing scope was subsequently removed after consultation with NDEP and thus focused on providing information about the ability to inject water into and extract water out of the Qal and UMCf. Slug testing was periodically performed in select wells during the treatability study. The objective of the slug testing was to estimate aquifer hydraulic conductivity in the treatability study area before and after injection activities to evaluate changes in the hydraulic conductivity. Slug testing could not be conducted at the shallow wells due to insufficient saturated thickness in those wells. Specific capacity tests were conducted in select shallow and intermediate wells to estimate location-specific hydraulic conductivity in the Qal, as well as provide a comparison of specific capacity hydraulic conductivity values with corresponding slug test hydraulic conductivity estimates.

Several injection tests were performed in the shallow and intermediate injection wells for Plot 1 and Plot 2. The deep set of injection wells were not used for injection tests to reduce the potential for pushing contamination deeper into the UMCf. However, they were used to monitor water levels and concentrations during and after the injection tests in the shallow and intermediate wells. Preliminary injection testing was performed by injecting SLMW into the shallow and intermediate injection wells at various pressures to assess the varying injection rates that could be achieved at each well.

Three additional injection events were performed using tracer dyes, calcium polysulfide (CPS), and SLMW. The tracer dye Rhodamine WT was injected into the shallow injection wells and the tracer dye fluorescein was injected into the intermediate injection wells to evaluate the vertical and horizontal distribution of the injections as well as the groundwater flow rate within the study area. To evaluate various injection methodologies, injections were performed using both an injection trailer and a direct injection system using the pressurized SLMW line located northwest of Plot 1. The CPS injections were conducted as part of the chemical reduction field study in the In-Situ Chromium Treatability Study and the results of the CPS injections are presented in the *In-Situ Chromium Treatability Study Results Report* (Tetra Tech, Inc., 2018b).

Groundwater Extraction System

The AP Area Down and Up Flushing Treatability Study included the installation of a groundwater extraction system to capture a large percentage of the water being flushed through Plots 1 and 2 and convey the extracted water to the Groundwater Treatment Plant (GWTP) and Groundwater Extraction and Treatment System (GWETS) for treatment. Three groundwater extraction wells were installed approximately 30 feet downgradient of Plot 1 and five groundwater extraction wells were installed approximately 30 feet downgradient of Plot 2. After the initial startup period, routine system operation, maintenance, and monitoring (OM&M) was performed for the groundwater extraction system from October 2016 through January 2018, the designated end date for the Treatability Study. OM&M consisted of daily system inspections, weekly sample collection and groundwater gauging, and bimonthly groundwater monitoring. After the conclusion of the treatability study period on January 31, 2018, the extraction system continued to operate at the request of the Trust due to its effectiveness at removing perchlorate mass from the groundwater. On April 1, 2018, responsibility for operation of the AP Area extraction system was transferred to Envirogen Technologies, Inc. (ETI), which continues to operate the extraction system and conduct all appropriate OM&M activities.

Treatability Study Findings

The main findings of the AP Area Down and Up Flushing Treatability Study are as follows:

- During the initial well installation and groundwater monitoring events, it was discovered that perchlorate concentrations in the AP Area increased with depth up to 60 feet bgs, the maximum depth investigated. The highest perchlorate concentration in soil was 4,900 milligrams per kilogram (mg/kg), from a soil sample collected at 60 feet bgs. The groundwater concentrations in the deep screened interval (maximum concentration of 2,900 milligrams per liter [mg/L]) exceeded the perchlorate concentrations in the shallow screened interval (maximum concentration of 1,500 mg/L) and the intermediate screened interval (maximum concentration of 1,900 mg/L).
- Perchlorate mass reductions in soil of 97 percent and 99 percent were achieved by down flushing in the unsaturated zone beneath Plot 1 and Plot 2, respectively, with the application of as little as two pore volumes of water.
- Perchlorate mass reductions in soil of 51 percent and 44 percent were observed in the UMCf beneath Plot 1 and Plot 2 during the Treatability Study. The reductions in perchlorate concentrations are attributed to flushing from water drawn downward from the saturated Qal through the UMCf in response to groundwater extraction. The estimated perchlorate mass reduction in each hydrostratigraphic unit is presented in the following summary table:

Hydrostratigraphic Unit[1]	Baseline Mass (pounds)	Post-Treatment Mass (pounds)	Mass Reduction	
			Pounds	Percent
Plot 1				
Unsaturated Qal	1,827	48	1,779	97%
Saturated Qal	210	22	188	90%
Entire Qal	2,037	70	1,967	97%
UMCf	8,089	3,940	4,149	51%
Plot 2				
Unsaturated Qal	2,415	22	2,393	99%
Saturated Qal	196	81	115	59%
Entire Qal	2,611	103	2,508	96%
UMCf	2,260	1,266	994	44%

Notes:

[1] The depths of the defined hydrostratigraphic units varied based on the lithology and moisture content observed in the field and are generally defined based on the following elevations:

- Unsaturated Qal: Ground surface to 1727 - 1732 feet above mean sea level (amsl)
- Saturated Qal: 1727 - 1732 feet amsl to 1724 - 1733 feet amsl
- UMCf: 1724 – 1733 feet amsl to approximately 1712 feet amsl

[2] Calculation for Saturated Qal assumes water table elevation from baseline groundwater sampling event.

- The extraction wells in the AP Area removed an estimated total of 36,395 pounds of perchlorate and a total volume of approximately 4,600,000 gallons of groundwater during the Treatability Study operational period (October 2016 to January 2018).
- Multiple rounds of injections were successfully performed using SLMW, tracer dyes, and CPS within the saturated Qal and UMCf.

Conclusions

The treatability study results indicate that application of down flushing at the Site would require fewer pore volumes of water to remove perchlorate impacts from the unsaturated zone, allowing for a potentially quicker, more cost-effective remedial program than what was indicated by the previous Soil Flushing Treatability Study in the CRB, which was an area that had previously underwent extensive excavation and backfill/compaction. In addition, perchlorate mass reductions were observed in the UMCf. These results suggest that down flushing coupled with longer term groundwater extraction in the UMCf could be an effective means for reducing contaminant concentrations in both the Qal and UMCf. The previous Soil Flushing Treatability Study results indicated that amending the flushing water with carbon donor to enhance in-situ bioremediation may offer the potential to further improve performance and cost effectiveness of down flushing. The operation of the groundwater extraction wells and aquifer testing in the AP Area provided useful information for future studies and the Feasibility Study with respect to the ability to inject into and extract from the UMCf. The concept of Up Flushing soil contamination to extraction wells will be further considered, if appropriate, during the Feasibility Study.

1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this *Ammonium Perchlorate (AP) Area Down and Up Flushing Treatability Study Report* for the AP Area at the NERT site (Site), located in Clark County, Nevada (Figure 1). This report is being submitted to the Nevada Division of Environmental Protection (NDEP) pursuant to the Interim Consent Agreement effective February 14, 2011. This report presents a summary of the technical approach, field activities, evaluation of results, key findings, and recommendations for the AP Area Down and Up Flushing Treatability Study. The treatability study was implemented in general accordance with the *AP Area Down and Up Flu*shing Treatabilit*y Study Work Plan* (Tetra Tech, Inc., 2018a), which was approved by the NDEP on March 5, 2018.

1.1 OBJECTIVES

The objective of this treatability study was to demonstrate and evaluate the effectiveness of down and up flushing, while building on the results of the recently completed Soil Flushing Treatability Study conducted in the Central Retention Basin (Tetra Tech, Inc., 2017). Soil flushing was selected to release and transport perchlorate for extraction and treatment. Two variants of the soil flushing technology, down flushing and up flushing, were evaluated as part of this treatability study. This treatability study also tested a different water delivery system at a larger scale and the viability of up flushing to remove perchlorate from the lower permeability Upper Muddy Creek Formation (UMCf). The use of an alternate water delivery system was intended to enable future evaluation of the cost implications for implementing a large-scale soil flushing system at source areas onsite, which will be critical during remedial option evaluations performed as part of the Feasibility Study.

1.2 REPORT ORGANIZATION

This Report is organized as follows:

- **Introduction (Section 1.0):** Provides the primary objectives of this treatability study and relevant background information.
- **Background (Section 2.0):** Provides relevant background information, including the regional and local setting, existing groundwater extraction and treatment system, and historical operations within the treatability study location.
- **Treatability Study Description (Section 3.0):** Provides a description of the down flushing and up flushing technology, the design and results of the previous Soil Flushing Treatability Study, and an overview of the AP Area Down and Up Flushing Treatability Study.
- **Treatability Study Activities (Section 4.0):** Describes the various activities conducted during the treatability study to implement and evaluate the effectiveness of down and up flushing. This section also describes data validation procedures.
- **Analysis of Results (Section 5.0):** Summarizes the results for analytical and field testing data in addition to parameters measured as part of system operation for implementation of the treatability study.
- **Summary of Key Findings (Section 6.0):** Presents the overall findings of the treatability study and provides considerations for future implementation of down and up flushing at the NERT site.
- **References (Section 7.0):** Lists the documents referenced in this report.

2.0 BACKGROUND

2.1 SITE HISTORY

The Site has been used for industrial purposes since 1942, when it was initially developed by the United States government as a magnesium plant to support World War II operations. Since that time, the Site and the surrounding properties have been used for chemical manufacturing, including the production of various chlorate and perchlorate compounds. Entities that operated at the Site include Western Electrochemical Company, American Potash and Chemical Company, Kerr-McGee Chemical Corporation, and Tronox Incorporated. On February 14, 2011, NERT took title to the Site as part of the settlement of the Tronox Incorporated Chapter 11 bankruptcy proceedings. As part of a long-term lease, Tronox Limited operates a manufacturing facility on 114 acres of the Site to produce manganese and boron products. Historical industrial production and related waste management activities conducted at the Site and on adjacent properties have resulted in the contamination of various environmental media, including soil, groundwater, and surface water. The most notable site-related contaminants of potential concern are hexavalent chromium and perchlorate (Tetra Tech, Inc., 2015).

2.2 REGIONAL GEOLOGY

The Site is located near the southeast end of the Las Vegas Valley, a structural basin that also includes the metropolitan areas of North Las Vegas, Las Vegas, and Henderson. Las Vegas Valley is bounded on the west by the Spring Mountains, on the north by the southern ends of the Sheep and Las Vegas Ranges, on the east by Frenchman and Sunrise Mountains, and on the south by the River Mountains and McCullough Range. The northwest-southeast trending structural basin that underlies Las Vegas Valley is composed of Precambrian crystalline rocks; Precambrian and Paleozoic carbonate rocks; Permian, Triassic, and Jurassic clastic rocks; and Miocene igneous rocks. Gravity data indicate that the deeper parts of the basin are filled with approximately 3,000 to 5,000 feet of clastic sedimentary deposits that range in age from Miocene through Holocene (Plume, 1989).

The clastic sedimentary valley-fill deposits of Las Vegas Valley are generally believed to consist of Muddy Creek Formation and younger deposits. The Muddy Creek Formation also includes thick beds of gypsum and salt and basalt flows, though these are not exposed in the Las Vegas Valley. The thickness of the valley fill deposits in the vicinity of the Site is approximately 4,000 feet. Extraction of groundwater from the valley fill since the early 1900s has resulted in over two feet of subsidence centered on the areas with the heaviest groundwater pumping, such as downtown Las Vegas (Plume, 1989).

2.3 LOCAL GEOLOGY AND HYDROGEOLOGY

At and near the NERT Site, soil borings have encountered valley fill deposits including Quaternary alluvium (Qal), transitional Muddy Creek Formation, and the Pleistocene UMCf. The Qal is generally described as reddish-brown discontinuous layers of sand and gravel with minor amounts of silt, clay, and caliche. The thickness of the Qal ranges from less than one foot to more than 50 feet beneath the Site (ENVIRON, 2014b). Thick deposits of alluvium that are structurally narrow and linear have been interpreted as stream-deposited sands and gravels that were deposited within paleochannels during flooding events. The paleochannel sand and gravel deposits often exhibit significantly greater permeability than the alluvium outside the paleochannels.

At the base of the alluvium, the transitional Muddy Creek Formation is sometimes encountered. The transitional Muddy Creek formation consists of reworked sediments derived from the Muddy Creek formation.

The UMCf underlies the transitional Muddy Creek formation (if present) or alluvium and consists of interbedded coarse-grained and fine-grained sediments that become progressively finer-grained to the north towards the central portion of the valley. The UMCf subcrops beneath a thin veneer of Qal near the Site. In that area, the contact between the Qal and UMCf is typically marked by the appearance of a well-compacted, moderate brown silt/sandy silt or stiff clay/sandy clay (ENVIRON, 2014b).

The depth to water at the AP Area is approximately 30 feet. The groundwater flow direction is generally to the north toward the Interceptor Well Field (IWF). The water table is typically in the upper portion of the UMCf due to pumping at the IWF since 1987. However, in areas where paleochannels or depressions in the Qal/UMCf contact exist, saturated alluvium may be encountered. Monitoring wells in the vicinity of the AP Area suggest that vertical hydraulic gradients are small. Both upward and downward gradients were found in the UMCf (ENVIRON, 2014b).

2.4 GROUNDWATER EXTRACTION AND TREATMENT SYSTEM

Groundwater extraction has been implemented at the Site to address impacts to groundwater resulting from releases of perchlorate and hexavalent chromium. Collectively, the entire system of extraction wells, water conveyances, and treatment plants is referred to as the Groundwater Extraction and Treatment System (GWETS). The GWETS treats water from three groundwater extraction well fields: the IWF; Athens Road Well Field (AWF); and Seep Well Field. Pipelines and lift stations convey groundwater from the well fields to the Site to be treated by the onsite treatment plant. This treatment plant is comprised of the following components: the Groundwater Treatment Plant (GWTP) which treats hexavalent chromium from the IWF; the Fluidized Bed Reactor (FBR), which treats perchlorate in groundwater from all of the well fields; the GW-11 Pond, which is used for water storage and equalization; the Equalization Area, which includes equalization tanks and a granular activated carbon pretreatment system; and the effluent pump station and pipeline, which convey treated effluent from the FBR treatment plant to an outfall at the Las Vegas Wash (Tetra Tech, Inc., 2015).

2.5 TREATABILITY STUDY LOCATION

The treatability study area generally consists of two 90- by 90-foot plots (Plots 1 and 2) located within the AP Area (Figure 2). Plots 1 and 2 are located approximately 250 feet and 420 feet upgradient (south) of IWF wells, which discharge to the western manifold of the GWTP. Historical operations in the AP Area consisted of ammonium perchlorate manufacturing by Western Electrochemical Company and American Potash and Chemical Company from approximately 1950 to 1967 and by Kerr-McGee from 1967 to 1998 (Ramboll Environ, Inc., 2016). Plot locations were selected for their known high perchlorate concentrations in the vadose zone (e.g., historical soil boring SA179 had a perchlorate concentration of 8,810 milligrams per kilogram [mg/kg]) (Ramboll Environ, Inc., 2015a).

3.0 TREATABILITY STUDY DESCRIPTION

This section provides an overview of the AP Area Down and Up Flushing Treatability Study, including a discussion of the down flushing and up flushing technology and the design and results of the previous Soil Flushing Treatability Study.

3.1 TECHNOLOGY OVERVIEW

The following sections provide a brief overview of the remedial technologies utilized in the treatability study.

3.1.1 Down Flushing

Perchlorate is the anionic component of ammonium and sodium perchlorate, the two highest production perchlorate salts formerly manufactured at the NERT Site. Perchlorate salts are very soluble in water (solubility limit is approximately 200,000 milligrams per liter [mg/L] for ammonium perchlorate; approximately 2,100,000 mg/L for sodium perchlorate) and do not adsorb very strongly to most soils. The high aqueous solubility of perchlorate compounds suggests that flushing the unsaturated zone with water applied at the surface (down flushing) could be a viable means of removing perchlorate from soil. In concept, water infiltrated from the surface would mobilize and transport perchlorate compounds from the unsaturated zone to groundwater. Once in groundwater, the perchlorate can be collected by groundwater extraction and then treated. This remediation process could be enhanced by amending the flush water with an organic carbon substrate to induce perchlorate biodegradation in the vadose zone and saturated zone. This enhancement can potentially increase perchlorate removal efficiency and reduce perchlorate loading to groundwater and, ultimately, to the GWETS.

3.1.2 Up Flushing

Because perchlorate does not adsorb appreciably to soils, continuous injection of water into the saturated zone (up flushing) also has the potential to be a useful remedial technology. For example, water can be injected below a highly contaminated interval of the saturated UMCf, causing the contaminated water to be displaced upward into the Qal aquifer where it can be collected by groundwater extraction and then treated. This process could also be enhanced through the addition of amendments to the flush water to induce perchlorate biodegradation or hexavalent chromium reduction. Water injection can also be used to reduce contaminant concentrations by dilution, which could improve biodegradation kinetics in highly contaminated zones.

3.2 PREVIOUS SOIL FLUSHING TREATABILITY STUDY

A treatability study was previously conducted at the NERT site to evaluate the effectiveness of down flushing. The *Soil Flushing Treatability Study Report* (Tetra Tech, Inc., 2017) was performed in the Central Retention Basin (CRB) area of the Site (Figure 2). The treatability consisted of constructing and operating four 30- by 30-foot test plots, each of which represented different variations of water application rates and use of a carbon substrate added to enhance perchlorate biodegradation. The test plots were set up as follows:

Test Plot	Water Application Rate	Carbon Substrate
1	Reduced (~5% of maximum)	Yes
2	Maximum	Yes
3	Maximum	No
4	Reduced (~13% of maximum)	No

The two maximum flow test plots consisted of infiltration galleries that were operated to maintain standing water throughout the study. By maintaining saturated conditions at the surface, the water applied to these test plots infiltrated at the maximum rate allowed by local soil conditions. Water was applied to the reduced flow test plots using drip irrigation systems that were operated so that the soil was uniformly moistened, but not to the point where standing water was observed.

Approximately 2.5 weeks before water application was terminated, the water applied to one maximum flow test plot (Test Plot 2) and one reduced flow test plot (Test Plot 1) was amended with glycerol, an organic carbon substrate. Glycerol was added near the end of the study to minimize potential reductions in infiltration rate caused by biomass buildup, which was observed during a similar treatability study performed at another site (Tetra Tech, Inc., 2013).

The treatability study was monitored using several techniques, including the following:

- Measuring flow to each test plot to determine the water application rate.
- Measuring groundwater levels in nearby monitoring wells to evaluate groundwater mounding in response to water application.
- Collecting and analyzing:
    - Pore water samples from lysimeters installed in each test plot to monitor changes in the perchlorate and total dissolved solids concentrations in pore water.
    - Groundwater samples from monitoring wells installed downgradient of the test plots to evaluate the effects of down flushing on perchlorate and total dissolved solids concentrations in groundwater.
    - Soil samples from each test plot before and after the treatability study to estimate the initial and final perchlorate mass in the unsaturated zone as a measure of treatment effectiveness.

The treatability study found that perchlorate mass reductions ranging from 73 percent to 98 percent were obtained in Test Plots 2 and 3, where water was applied at the maximum rate. Approximately six pore volumes of water (at an assumed porosity of 30 percent) were required to achieve a 90 percent reduction in pore water perchlorate concentrations at Test Plot 2. The highest mass reduction was observed in Test Plot 2, where glycerol was also added to enhance biodegradation. Lower mass reduction was observed in Test Plots 1 and 4 (5% and 43%, respectively), where water was applied at rates substantially lower than the maximum.

3.3 AP AREA TREATABILITY STUDY OVERVIEW

3.3.1 Work Plan Deviations

The objectives and approach for the up flushing program were adjusted from what was presented in the *AP Area Down and Up Flu*shing Treatabilit*y Study Work Plan* (Tetra Tech, Inc., 2018a), which was approved by the NDEP on March 5, 2018. The adjustments were made in response to the new soil and groundwater investigation data from the AP Area. Due to the discovery of high perchlorate concentrations at 60 feet below ground surface (bgs) (Section 5.3.1), the amount of water injected into the UMCf was limited to avoid potentially displacing the high perchlorate concentrations downward. Given the unknown depth of perchlorate in this area and after consultation with NDEP given the concerns with potentially driving contaminations downwards, the up flushing program was limited to short-term injection testing in the UMCf. This limited testing allowed for the collection of injection information for the UMCf for the potential future use of the technology and allowed for the evaluation of the effectiveness of calcium polysulfide (CPS) as part of the chemical reduction field study for the In-Situ Chromium Treatability Study (Tetra Tech, Inc., 2018b). Vertical delineation of soil and groundwater contamination is being addressed during the Remedial Investigation such that the concept of Up Flushing to extraction wells can be considered, if appropriate, during the Feasibility Study.

3.3.2 Down Flushing Program

The down flushing program implemented for the AP Area Treatability Study expands on the prior Soil Flushing Treatability Study in several ways by testing a different method for applying water, increasing the size of the treatment areas, and reducing the number of pore volumes of water used for treatment in the later part of the study. The most significant of these differences is in the water application method. The prior Soil Flushing Treatability Study found that down flushing is most effective when water is applied at or near the maximum infiltration rate based on soil conditions. In the prior Soil Flushing Treatability Study, the maximum infiltration rate was accomplished using water-filled infiltration galleries. Infiltration galleries have several disadvantages for full-scale implementation, which include: 1) water usage can only be adjusted by physically changing the size of the infiltration gallery; 2) a significant grading effort would be required to construct infiltration galleries over large areas of the Site; and 3) infiltration galleries cannot be readily used in areas where the ground surface has a significant slope.

For this AP Area Treatability Study, drip irrigation systems were used as an alternative to infiltration galleries. Water usage can readily be adjusted in drip irrigation systems through the selection of appropriate combinations of emitter flow rate, emitter spacing, and tubing length and layout. Furthermore, these systems can be designed to apply water at rates which result in minor pooling of water at the ground surface, a physical indication that the water application rate is comparable to the infiltration rate. Installation of these systems also does not require significant construction effort, and they can be used in areas with a sloping ground surface. Drip irrigation systems are portable and reusable, both of which are advantages for large scale implementation.

As explained in Section 2.5, down flushing was applied to two 90- by 90-foot plots (Plots 1 and 2), located approximately 250 feet and 420 feet upgradient (south) of the IWF (Figure 2). These plot locations were selected for their known high perchlorate concentrations in the vadose zone (e.g., historical soil boring SA179 had a perchlorate concentration of 8,810 milligrams per kilogram) (Ramboll Environ, Inc., 2015a). Plots 1 and 2 were further subdivided into nine 30- by 30-foot zones. The zones for Plot 1 were identified as Zones 1 through 9 and the zones for Plot 2 were identified as Zones 10 through 18 (Figure 3).

3.3.3 Up Flushing Program

The purpose of the up flushing program was to push perchlorate-bearing groundwater toward the IWF and supplemental extraction wells by injecting stabilized Lake Mead water (SLMW) into and directly below the Qal aquifer. Due to the presence of high perchlorate concentrations in the UMCf at depths greater than initially expected (Section 5.3.1), the up flushing program was modified to only consist of 1) installing injection and monitoring wells to characterize the subsurface, 2) assessing perchlorate impacts within the Qal and UMCf, 3) performing aquifer testing, and 4) performing limited injection testing. The injection testing consisted of injecting tracer dyes, CPS, and SLMW (Section 4.4.6). The scope of the up flushing program was significantly reduced, after consultation with NDEP, due to concerns of pushing contaminants deeper into the UMCf.

Four triple-cluster completion injection wells were installed at the north end of each down flushing plot, with the shallow well screened within the Qal, the intermediate well screened approximately 5 feet below the Qal/UMCf contact, and the deep well screened in the UMCf approximately 15 feet below the Qal/UMCf interface. Three triple-completion groundwater monitoring wells were installed downgradient of each plot, generally screened at the same depths as the injection wells, to evaluate the effects of the up flushing and down flushing activities.

3.3.4 Groundwater Extraction

Extraction wells were installed immediately downgradient of the flushing plots to capture a large percentage of the water being flushed through Plots 1 and 2. The extraction well network was designed based on expected groundwater travel time, taking into consideration access constraints associated with installing wells within a street, so that the majority of the water being flushed through Plots 1 and 2 would be captured within the project schedule outlined in the *AP Area Down and Up Flu*shing Treatabilit*y Study Work Plan* (Tetra Tech, Inc., 2018a).

Three groundwater extraction wells were initially installed approximately 30 feet downgradient of Plot 1 and an additional five groundwater extraction wells were installed approximately 30 feet downgradient of Plot 2. The extracted water was conveyed to the GWETS for treatment.

3.3.5 Paleochannel Investigation

Ramboll Environ, Inc. reported the presence of a paleochannel just to the east of the AP Area Down and Up Flushing Treatability Study location and south of the AP-5 Pond (Figure 2) (Ramboll Environ, Inc., 2017c). An investigation was performed to confirm the location of the paleochannel as it would have a large impact on the groundwater flow and perchlorate mass transport in the vicinity of the AP Area Down and Up Flushing Treatability Study. Two soil borings (DFS-01 and DFS-02) and four monitoring wells (DFW-03 through DFW-06) were installed in the vicinity of the former Beta Ditch, Central Retention Basin, BT tanks, and upgradient of the AP-5 Pond to confirm the location of the paleochannel. The results of this investigation are discussed in Section 5.1.

4.0 TREATABILITY STUDY ACTIVITIES

This section describes the methodology used for field activities during the AP Area Down and Up Flushing Treatability Study. All field work was conducted in general accordance with the existing *Field Sampling Plan, Revision 1* (ENVIRON, 2014c).

4.1 PERMITTING

The following permits were obtained prior to conducting the associated field activities:

- Modification of an existing Clark County dust control permit (Permit #45436 Mod 2) to include the treatability study area.
- Demolition Permit No. 16-38974 DE1 from Clark County to remove blast walls in the vicinity of Plots 1 and 2.
- Electrical Permit No. 16-50056 from Clark County for the electrical components of the groundwater extraction system.
- Underground Injection Control Long-Term Permit No. GU07RL-51056 from NDEP Bureau of Water Pollution Control for injection rates of up to 260 gallons per minute (gpm) of fluids at pressures up to 35 pounds per square inch [psi]), containing up to 354 pounds per day of CPS and 8 pounds per day of tracer dyes.
- Notice of Intent No. 37995 and 37996 and Affidavit of Abandonment to Plug a Monitoring Well from the Nevada Department of Conservation and Natural Resources, Division of Water Resources (NDWR) for the installation of injection wells, monitoring wells, and extraction wells.
- Water Appropriation Permit No. 86355E from NDWR for the installation and operation of extraction wells to extract up to 0.25 cubic feet of groundwater per second (112 gpm).

4.2 UTILITY CLEARANCE

Geophysical surveys were performed prior to intrusive field activities to identify subsurface utilities at each soil boring location. The geophysical surveys were conducted by Ground Penetrating Radar Systems, Inc. of Las Vegas, Nevada. In addition, all soil boring locations were cleared for subsurface utilities to a depth of 12 feet or to the top of a competent soil layer using a vacuum excavation rig operated in water or air mode. The vacuum excavation rig was operated by National Exploration, Wells & Pumps of Las Vegas, Nevada.

4.3 DOWN FLUSHING PROGRAM

The following subsections describe the down flushing program implemented during the AP Area Down and Up Flushing Treatability Study.

4.3.1 Baseline Soil Sampling

A total of eighteen soil borings were drilled in Plot 1 and Plot 2 between July 5 and July 14, 2016. The borings were drilled to total depths of 40 to 45 feet bgs to assess baseline (pre-treatment) perchlorate and hexavalent chromium concentrations in the unsaturated zone, saturated Qal, and the upper portion of the saturated UMCf. Nine of the borings (DFSB-1 to DFSB-9) were drilled within Plot 1; the remaining nine borings (DFSB-10 to DFSB-18) were drilled within Plot 2. The soil boring locations are shown on Figure 3; copies of the boring logs are provided in Appendix A.

Soil borings were drilled using a hollow stem auger drill rig equipped with 8-inch diameter augers. Soil samples were collected from the borings at depths of approximately 0.5 feet bgs, 5 feet bgs, and at 5-foot depth intervals thereafter using a 2.5-inch inside diameter, 18-inch long California split barrel sampler lined with three 6-inch long, 2.5-inch diameter stainless steel sleeves. Upon retrieval from the borehole, the sleeve(s) designated for laboratory analysis were removed from the sampler. The ends of the sleeve(s) were covered with Teflon sheets and tightly-fitting plastic caps, and the soil samples were then labeled, placed in resealable plastic bags, and stored in an ice chest cooled with ice pending shipment to an offsite laboratory under chain-of-custody protocols.

Soil samples collected from the borings were analyzed by TestAmerica for perchlorate using USEPA Method 314.0 and for hexavalent chromium using USEPA Method 7199. A summary of the analytical results is presented in Appendix B. Selected soil samples collected using a 2.5-inch inside diameter California sampler were also tested for physical properties by PTS Laboratories of Santa Fe Springs, California. The samples were tested for dry bulk density, moisture content, specific gravity, and total porosity. Physical property testing results are presented in Appendix C.

The remaining soil in the sampler was used for lithologic logging and field headspace screening. Lithologic logging was performed by trained geologists and engineers in general accordance with ASTM Standard D-2488-09 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) (ASTM International, 2009a). Field headspace screening was performed by placing a small amount of soil in a labeled resealable plastic bag and allowing the bag to set for at least 5 minutes. The bags were then opened and volatile organic compound concentrations in the bag headspace were measured with a calibrated portable photoionization detector. Headspace volatile organic compound concentrations were noted on the boring logs. After drilling, soil sampling, and logging were completed, the borings were either backfilled with bentonite or neat cement grout.

4.3.2 Infiltration Testing

The infiltration tests were conducted to obtain preliminary estimates of vertical infiltration rates and infiltration rate variability in Plots 1 and 2. Eighteen double-ring infiltrometer tests were performed by Geotechnical and Environmental Services, Inc. (GES), from July 27, 2016 to August 10, 2016. Nine of the infiltration tests (DFIT-1 to DFIT-9) were conducted within Plot 1 in Zones 1 through 9; the remaining nine infiltration tests (DFIT-10 to DFIT-18) were conducted within Plot 2 in Zones 10 through 18. To obtain results that were representative of the native soils, the tests were performed in small pits (1 to 2 feet in depth) excavated at a test location, generally within the center of each zone (Zones 1 through 18). The excavated soil was placed in a covered stockpile adjacent to each test location. The infiltration test locations correspond to the baseline and confirmation boring locations shown on Figure 3; for example, DFIT-10 corresponds to the location of DFSB-10.

The infiltration tests were conducted in general accordance with American Society for Testing and Materials (ASTM) Standard D3385-09: Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer (ASTM International, 2009b). The test apparatus consisted of two metal rings with diameters of 12 and 24 inches. The rings were driven into the ground in a concentric configuration at each test location. The outer ring was intended to prevent lateral spreading of the water infiltrating from the inner ring during the test. To perform a test, water was introduced into the inner and outer rings and maintained at a constant level using Mariotte tubes, which are devices that maintain a constant head within the ring. The volume of water that infiltrated into the soil from the inner and outer rings was measured at regular time intervals during the test. These data for the inner ring were used to calculate the infiltration rate in units of inches (or centimeters) per hour (in/hr).

After testing was completed, the stockpiled soil was sampled in accordance with the requirements of the *Site Management Plan, Revision 2* (Ramboll Environ, Inc., 2015a). The results indicated that all constituents were below the soil screening levels in the *Site Management Plan, Revision 2* and the soil was used to backfill the excavations.

4.3.3 Surface Preparation

To prepare Plots 1 and 2 for down flushing, a number of surface obstructions were removed (including asphalt pavement, concrete building slabs, and cinder block blast walls). After demolition was completed, the ground surface in Plots 1 and 2 was scarified to loosen compacted surface soils in preparation for down flushing. A 1- to 2-foot thick layer of chat (a crushed limestone material) had been placed over the area following remedial excavations in 2012 and 2013. Based on the coarse grain size of the chat (predominantly fine gravel), it was assumed this material would not need to be removed prior to down flushing. But when down flushing was initiated in the chat-covered area, it was found that the chat was unwashed and contained a significant fraction of fine-grained material that interfered with infiltration. Additional surface preparation, consisting of removing the chat layer and scarifying the underlying native soil, was performed prior to conducting further down flushing in the chat-covered areas.

4.3.4 Down Flushing System Components and Installation

Water for the down flushing system was obtained from an above-ground SLMW pipeline servicing the AP-5 Pond area. A tee, pressure reducing valve, and shutoff valve were installed in the pipeline to the north of Plot 1. At the beginning of the treatability study, water was conveyed from the main pipeline connection to the down flushing plots using 2-inch diameter schedule 40 PVC conveyance piping placed on the ground surface. The PVC piping was later replaced with 2-inch diameter lay-flat mill hose, which was found to be easier to reconfigure. Other components of the system included an in-line particulate filter to reduce emitter clogging, a mechanical totalizing flow meter to measure water usage, a pressure-reducing valve and pressure gauge to set water pressure at the drip system inlet, and a shutoff valve.

The combination of relatively high infiltration rates noted above suggested that water application would need to be performed sequentially in relatively small subareas of each plot. Nine 30- by 30-foot subareas, or flushing zones, were therefore targeted in each of the two plots. A reusable 30-foot-long drip irrigation manifold was constructed from 2-inch diameter schedule 40 PVC piping, and 30-foot lengths of drip tubing were attached to the manifold so that the apparatus would cover a single flushing zone. This setup allowed the tubing to be spaced closely enough to deliver the maximum flow rate allowed.

After startup of the system, it was found that actual infiltration rates were lower than indicated by the infiltration testing. The manifold system was eventually replaced with long lengths of drip tubing arranged in a zig-zag or loop pattern, which could be more easily reconfigured in the field to match the observed infiltration rates. The maximum tubing length was based on the tubing manufacturer's specifications to ensure that emitter flow was not materially affected by pressure drop along the tubing.

4.3.5 Down Flushing System Startup and Operation

Down flushing was implemented from October 20, 2016 to January 22, 2018 in five separate phases, each of which targeted specific flushing zones or areas within Plot 1 or Plot 2 (***Table 1***). For the initial phase, one flushing zone in Plot 1 (Zone 9) was targeted. The drip irrigation manifold system was placed in Zone 9 and the system was started by opening the shutoff valve. Surface runoff was observed within an hour of startup, so the system was shut down and the drip tubing was exchanged for tubing with lower-flow emitters. The reconfigured system was then restarted. Surface runoff was observed to be greatly reduced. The reconfigured system was then allowed to continue to operate with minor runoff. During the approximate 14-week operational period, Zone 9 was flushed with approximately 12 pore volumes of water. When the down flushing system was started up, an effort was made to apply enough water to Zone 9 to evaluate whether groundwater mounding could be observed in the downgradient monitoring wells. An unequivocal signal was not observed, likely due to a combination of fluctuations in the groundwater extraction rate, a brief shutdown of both the down flushing and groundwater extraction systems in late December, and possible groundwater level fluctuations over the broader area which includes the AP Area.

After completion of Phase 1 (Zone 9 down flushing), the second phase consisted of moving the flushing apparatus to Zones 3 and 6 and restarting the system. Surface runoff was again observed shortly after startup, so lower flow drip tubing was installed on the manifold and selected drip tubing lines were disabled to further reduce flow. After the system was reconfigured, minor pooling of water occurred, but there was no runoff from the flushing area. The system was then allowed to continue operation for approximately nine weeks to apply approximately two pore volumes. Two pore volumes of water were applied during down flushing in Phase 2 and subsequent phases consistent with the number of pore volumes stated in the *AP Area Down and Up Flushing Treatability Study Work Plan* (Tetra Tech, Inc., 2018a).

The third phase consisted of simultaneously flushing the remaining six zones in Plot 1. This phase used a reconfigured drip system consisting of four longer lengths of drip tubing, which were arranged in a zig-zag pattern across the flushing area. The system was restarted and adjusted by moving the tubing until water was applied to the entire flushing area in a relatively uniform manner, with minor pooling of water observed across the entire area. This system was found to be simpler to set up and configure in the field, and could be more easily adjusted to match targeted infiltration rates. This type of system was adopted for the remainder of the down flushing program, including down flushing in Plot 2.

Based on these results for Plot 1, it became evident that areas significantly larger than the 30- by 30-foot flushing zones defined at the beginning of the treatability study could be down flushed without exceeding the GWETS capacity constraints. Down flushing of Plot 2 was performed in two phases (Phase 4 and Phase 5). Phase 4 consisted of down flushing the western portion of Plot 2 and Phase 5 consisted of down flushing the eastern portion of Plot 2.

During system operation, totalizing flow meter readings, water pressure readings, and qualitative observations were collected daily. No system maintenance was necessary during the treatability study other than replacement of drip tubing when the system was moved. A summary of the down flushing activities during the five phases is provided below in ***Table 1****.*

Table 1 Down Flushing System Operational Data Summary

Phase	Zones	Application Area (ft^2)	Start Date	End Date	Applied Water Volume		Average Application Rate (gpm)
					Gallons	Pore Volumes[1]	
Plot 1							
1	9	900	10/20/16	01/25/17	1,243,218	12.3	10.0
2	3, 6	1,500	01/27/17	03/30/17	331,892	2.0	4.6
3	1, 2, 4, 5, 7, 8	4,800	03/31/17	07/31/17	1,083,663	2.0	6.2
Plot 2							
4	West Half	3,720	07/31/17	10/27/17	1,007,387	2.4	7.9
5	East Half	3,480	10/27/17	01/22/18	909,085	2.3	7.3

Notes:

ft^2 – square feet
gpm – gallons per minute

[1] Pore volumes were calculated assuming a vadose zone thickness of 30 feet and a porosity value of 0.50 based on porosity data collected during this study.

4.3.6 Confirmation Soil Sampling

A total of 18 confirmation borings were drilled in Plot 1 and Plot 2 between February 23, 2018 and March 2, 2018. The borings were drilled immediately adjacent to the baseline soil borings to assess changes in perchlorate and hexavalent chromium concentrations in the unsaturated zone, the saturated Qal aquifer, and the saturated UMCf due to the treatability study activities. Borings DFCB-1 to DFCB-9 were drilled in Plot 1; borings DFCB-10 to DFCB-18 were drilled in Plot 2. The drilling and sampling methodology for the confirmation soil sampling was the same as the baseline soil sampling as described in Section 4.3.1. The soil boring locations are shown on Figure 3; copies of the boring logs are provided in Appendix A. Analytical results for soil samples collected from the confirmation soil borings and the results of physical properties testing on selected samples appear in Appendix C and are discussed in Section 5.2.2.

4.4 UP FLUSHING PROGRAM

The following subsections describe the activities associated with the up flushing program implemented during the AP Area Down and Up Flushing Treatability Study. As noted previously, up flushing was not implemented due to the presence of high perchlorate concentrations in the UMCf up to 60 feet bgs, the maximum depth investigated under this treatability study. As a result, the up flushing program was limited to aquifer and injection testing following consultation with NDEP.

4.4.1 Well Installation

Well installation activities were conducted by National from July 12, 2016, to August 26, 2016, using the hollow stem auger method. Four triple-cluster completion injection wells (UFIW-01 through UFIW-04) and three triple-cluster completion groundwater monitoring wells (UFMW-01 through UFMW-03) were installed along the northern boundary of Plot 1 (Figure 3). Four triple-cluster completion injection wells (UFIW-05 through UFIW-08) and three triple-cluster completion groundwater monitoring wells (UFMW-04 through UFMW-06) were installed along the northern boundary of Plot 2 (Figure 3). Geologic cross-sections depicting the well screen intervals are provided in Figures 4a through 4c.

The injection and monitoring wells consisted of 2-inch inner diameter Schedule 40 polyvinyl chloride (PVC) blank casing and 0.020-inch slotted PVC screen. The shallow wells (designated “S”) were screened in the Qal at 5 feet above the Qal/UMCf contact from approximately 25 to 30 feet bgs; the intermediate wells (designated “I”) were screened in the UMCf at 5 feet below the Qal/UMCf contact from approximately 35 to 40 feet bgs; and the deep wells (designated “D”) were screened in UMCf at 15 feet below the Qal/UMCf contact from 45 to 50 feet bgs. UFIW-02I and UFIW-06I were installed with 10-feet screen intervals from 5 feet to 15 feet below the Qal/UMCf contact to evaluate the effect of a larger screen interval on injecting into the UMCf. Injection wells were installed within their own boreholes to avoid potential short circuiting during injection activities (i.e., the multiple-cluster well construction method was not used). Following completion of well installation, well locations and top of casing were surveyed by a state-licensed surveyor. Well construction logs are provided in Appendix A.

Soil samples were collected from the borings at depths of approximately 0.5 feet bgs, 5 feet bgs, and at 5-foot depth intervals thereafter using a 2.5-inch inside diameter, 18-inch long California split barrel sampler lined with three 6-inch long, 2.5-inch diameter stainless steel sleeves. Upon retrieval from the borehole, the sleeve(s) designated for laboratory analysis were removed from the sampler. The ends of the sleeve(s) were covered with Teflon sheets and tightly-fitting plastic caps, and the soil samples were then labeled, placed in resealable plastic bags, and stored in an ice chest cooled with ice pending shipment to an offsite laboratory under chain-of-custody protocols. Soil samples were collected during well drilling/installation were analyzed by TestAmerica Laboratories, Inc. (TestAmerica) of Irvine, California, a Nevada-certified environmental laboratory, for one or more of the following analytes; perchlorate using United States Environmental Protection Agency (USEPA) Method E314.0, hexavalent chromium using USEPA Method 7199, and total chromium using USEPA Method 6010B. Perchlorate and hexavalent soil concentrations from soil samples collected from the injection well borings are depicted along with the injection well screen intervals in Figures 5a and 5b. Analytical results are summarized in Appendix B. Selected samples were also analyzed for one or more physical properties (hydraulic conductivity, grain density, dry bulk density, total porosity, air-filled porosity, moisture content and total pore fluid saturation) by PTS Laboratories using methods American Petroleum Institute RP40, ASTM D2216, and EPA 9100. These selected samples were collected at various depths ranging from 25 feet bgs to 50 feet bgs using the California-modified split-spoon sampler lined with stainless steel sleeves. A copy of PTS Laboratories' report is provided in Appendix C.

4.4.2 Surveying

Once all well installation activities had been completed, a licensed land surveyor, Atkins, surveyed the horizontal coordinates of each well relative to North American Datum 83 with an accuracy of 0.1 foot. The elevations of the ground surface and top of well casing measuring point relative to North American Vertical Datum 88 were surveyed with accuracies of 0.1 foot and 0.01 foot, respectively.

4.4.3 Well Development

Following the completion of well construction, but no sooner than 24 hours after well construction was complete, the newly installed wells were developed by National using a surge block and bailer to swab and surge the filter pack and remove sediment from the wells. This process was followed by pumping with a submersible pump to purge the well of fine-grained sediment. Well development was considered complete when three to ten casing volumes of water had been removed from the well, and index parameters consisting of pH, specific conductivity, turbidity, and temperature were stable (pH within 0.1 and other parameters within 10 percent) over three consecutive measurements.

4.4.4 Groundwater Sampling

Groundwater monitoring wells were gauged and sampled following well development to obtain baseline groundwater conditions and periodically following the beginning of down flushing and groundwater extraction operations to evaluate changes in groundwater quality. Groundwater elevation gauging was performed using an electronic water level indicator with an accuracy of 0.01 feet. Groundwater sampling was performed in accordance with the Field Sampling Plan, Revision 1 (ENVIRON, 2014c) using low-flow methods with dedicated bladder-type sampling pumps and groundwater bailing, where necessary. Several alluvium wells needed to be bailed as there was very little water column. Prior to purging, the depth to groundwater was measured in each well with an electronic water level sounder. After one pump/discharge line volume of groundwater was removed from a well, water quality field parameters (temperature, pH, electrical conductivity, dissolved oxygen, oxidation-reduction potential, and turbidity) were measured at 5-minute intervals during purging using a YSI multiparameter instrument mounted in an in-line flow cell. Purging was considered complete when three consecutive sets of field parameter measurements had stabilized to within the following values: temperature ±1 degrees Celsius, pH ±0.1 pH unit, electrical conductivity ±3 percent, dissolved oxygen ±0.3 mg/L, oxidation-reduction potential ±10 millivolts, and turbidity <10 nephelometric turbidity unit or ±10 percent if >10 nephelometric turbidity unit.

After purging was complete, the flow cell was disconnected and samples were collected in laboratory-provided containers directly from the sample tubing. The sample containers were then labeled, placed in resealable plastic bags, and stored in an ice chest cooled with water ice pending shipment to TestAmerica under chain-of-custody protocols.

The groundwater samples were analyzed for perchlorate using USEPA Method E314.0, hexavalent chromium using USEPA Method 7199, and total chromium using USEPA Method 6010B. Selected samples were also analyzed for nitrate as nitrogen using USEPA Method 300.0 and total dissolved solids using USEPA SM 2540C. Groundwater monitoring field logs are provided in Appendix D.

4.4.5 Aquifer Testing

As part of the aquifer testing, slug testing was periodically performed in select wells during the treatability study. The objective was to estimate aquifer hydraulic conductivity in the treatability study area before and after injection activities to evaluate changes in hydraulic conductivity. The first round of slug testing was performed in August and September 2016 on all the intermediate injection wells, deep injection wells, intermediate monitoring wells, deep monitoring wells, extraction wells, and monitoring wells associated with the paleochannel investigation (DFW-03 through DFW-06). Additional slug testing was conducted on select intermediate injection wells and intermediate and deep monitoring wells in April 2017 and October-November 2017. Slug testing could not be conducted at the shallow wells due to insufficient saturated thickness in the shallow wells.

The slug tests were performed in general accordance with ASTM Standard D4044-96 (ASTM International, 2008). Prior to conducting each slug test, the water level in the well was measured manually with an electronic water level probe (Solinst Model 101 water level meter or Solinst Model 122 interface probe) to determine the static groundwater level. An electronic pressure transducer/data logger (Solinst Levelogger Gold M5 pressure transducer) was then suspended in the well and water levels were monitored manually until static conditions were reestablished. A falling-head test was then conducted by smoothly lowering a length of weighted and sealed PVC pipe (slug) into the well, securing it in place above the transducer, and recording the rate of water level decline. Once static conditions were reestablished, a rising-head test was conducted by removing the slug and allowing the water level to again recover to static conditions while recording the rate of recovery. At the end of each test, the pressure transducer was removed from the well and the water level displacement data were downloaded to a laptop computer. The data were interpreted using AQTESOLV (Duffield, 2014) analysis software.

Specific capacity tests were conducted in select shallow and intermediate wells (UFIW-06S, UFIW-06I, UFMW-05S, and UFMW-06S) to estimate location-specific hydraulic conductivity in the Qal, as well as provide a comparison of specific capacity hydraulic conductivity values with corresponding slug test hydraulic conductivity estimates. Baseline specific capacity testing was conducted in September 2016 on wells UFIW06S and UFIW-06I. Additional specific capacity tests were conducted on wells UFMW-05S and UFMW-06S in October 2017. The specific capacity testing conducted in October 2017 was limited to monitoring wells, located approximately 15 feet from the injection wells, because the injection wells had wellheads that inhibited access to them.

Specific capacity tests were conducted on the installed wells by utilizing a MegaMonsoon® electronic pump set at a constant flow rate. Prior to conducting each specific capacity test, the water level in the well was measured manually with an electronic water level probe (Solinst Model 101 water level meter or Solinst Model 122 interface probe) to determine the static groundwater level. The pump was then started and water levels were monitored manually to record the rate of water level decline. The pump was then stopped and water levels were again monitored manually to record the rate of water level recovery until static conditions were reestablished. The recorded specific capacity test data were interpreted using AQTESOLV (Duffield, 2014) analysis software.

Details and results obtained from the aquifer testing are provided in the *In-Situ Chromium Treatability Study Results Report* (Tetra Tech, Inc., 2018b), and are also summarized in Section 5.2.1 and in Appendix E for reference.

4.4.6 Injection Testing

Tetra Tech performed two injection events in the shallow and intermediate injection wells for Plot 1 and Plot 2. Injections were not performed in the deep injection wells as there were high perchlorate concentrations present at and directly below the depth of the screened intervals and there was concern that injections may push contamination deeper into the UMCf. The deep injection wells and monitoring wells were used to evaluate the potential for injections in the shallow and intermediate zones to push perchlorate mass deeper. Preliminary injection testing was performed on the shallow and intermediate injection wells within Plot 1 on September 20, 2016, and within Plot 2 on September 19, 2016 and on November 2, 2016. SLMW was injected into the injection wells at various pressures using an injection trailer to assess the varying injection rates that could be achieved at each well.

Two injection events were performed for each plot from September 20, 2016 through August 8, 2017. The injection events consisted of injecting tracer dyes (Rhodamine WT and fluorescein a.k.a. uranine), CPS, and SLMW. Rhodamine WT was injected into the shallow injection wells and fluorescein was injected into the intermediate injection wells to evaluate the vertical and horizontal distribution of the injections as well as the groundwater flow rate within the study area. The groundwater monitoring wells and extraction wells associated with Plot 1 and Plot 2 were checked periodically for the presence of tracer dye to monitor vertical and horizontal distribution of the injections, as well as the groundwater flow rate, within the treatability study area. Injections were performed at both Plots 1 and 2 using either an injection trailer (operated by the RF2 Group, LLC, or Cascade Technical Services) or a direct injection system designed and installed by Tetra Tech. The direct injection system used the pressurized SLMW line located northwest of Plot 1. The CPS injections were conducted as part of the chemical reduction field study for the In-Situ Chromium Treatability Study (Tetra Tech, Inc., 2018b). The as-built drawings for the injection system are provided in Appendix F and injection summary tables are provided Appendix G. Results of the injection testing are also discussed in Section 5.3.3.

4.5 GROUNDWATER EXTRACTION SYSTEM

4.5.1 Groundwater Extraction Well Installation

As explained in Section 3.3.4, the AP Area Down and Up Flushing Treatability Study included the installation of a groundwater extraction system to capture the water being flushed through Plots 1 and 2 and convey the extracted water to the GWETS for treatment. Three groundwater extraction wells, designated E1-1 through E1-3, were installed approximately 30 feet downgradient of Plot 1, and five groundwater extraction wells, designated E2-1 through E2-5, were installed approximately 30 feet downgradient of Plot 2. The extraction wells were installed with 6-inch Schedule 40 PVC blank casing and 0.020-inch slotted PVC screen. The extraction wells were screened from approximately 5 feet above the Qal/UMCf contact to approximately 20 feet below the Qal/UMCf contact for a total screen interval of 25 feet. The detailed drawings of the extraction system are provided in Appendix F.

4.5.2 Groundwater Extraction System Components and Installation

The groundwater extraction system includes eight ½-horse power extraction well pumps, electrical panel, switches, control contactors, and motor starters. This installed system pumps groundwater from the extraction wells to the existing GWTP equalization tank through the existing piping for IWF extraction well I-AR, which is located nearby the AP Area Down and Up Flushing Treatability Study area. System controls shut down the extraction well pumps if the high-level alarm in the GWTP equalization tank is triggered. Extraction well pumps are protected against running dry by a motor pump protector, which turns off the well pumps when low water levels are detected and automatically restarts the pumps by means of individually adjustable timers. Extraction wells are also shut down if the high-level alarm at the GWTP influent equalization tank is triggered. If the high-level alarm is triggered, the system requires a manual restart via a reset button on the control box. The system above-ground piping, valves, and associated groundwater conveyance features were installed in secondary containment (i.e., double-walled piping for above-ground conveyance, a spill containment shed for manifold components, and concrete-lined well vaults for wellheads). In addition, the aboveground piping was protected against freezing with insulation and burial with sand.

Totalizing flow meters, globe valves, and sample ports are installed for each extraction well to monitor the extraction flow rate, total amount of water extracted, adjust extraction flow rates, and allow for sample collection. System operations during the treatability study were coordinated with the GWTP operator, Envirogen Technologies, Inc. Additional system details are provided in Appendix F.

4.5.3 Groundwater Extraction System Startup and Operation

System startup and testing of the extraction system began on October 25, 2016, with only the Plot 1 extraction wells operating. System startup activities for the Plot 2 extraction wells were conducted from June 30, 2017 to July 11, 2017 and included the following:

- Inspection and testing of extraction system piping;
- Testing, troubleshooting, and adjusting system controls, alarms, and telemetry system; and
- Monitoring and adjusting flow rates for the extraction wells.

After the initial startup period, routine system operation, maintenance, and monitoring (OM&M) was performed through January 31, 2018, the designated end date for the treatability study. Groundwater samples were collected from all injection, monitoring, and extraction wells associated with the AP Area Down and Up Flushing Treatability Study to establish baseline conditions prior to down flushing and up flushing. The following list summarizes the OM&M activities completed for the extraction system.

- Performed daily monitoring activities including the following:
    - Inspected and recorded the condition of the extraction system for leaks, alarm conditions, extraction pump operation, and volume of water extracted from each extraction well; and
    - Coordinated discharge pumping rate with Envirogen Technologies, Inc. (ETI).
- Performed weekly monitoring activities including the following:
    - Collected water samples from each of the eight extraction wells for perchlorate and hexavalent chromium analysis through their respective sampling ports; and
    - Measured groundwater levels in each of the 18 monitoring wells.
- Performed bimonthly monitoring activities including the following:
    - Measured groundwater levels and collected water samples from each of the 18 monitoring wells for perchlorate and hexavalent chromium analysis.
- Performed routine maintenance and troubleshooting activities including, but not limited to, the following:
    - Installed and operated a telemetry system and controls for extraction system, including performing routine inspections and repairs;
    - Cleaned and repaired extraction well pumps;
    - Inspected and repaired piping, fittings, and valves; and
    - Inspected secondary containment of manifold and piping.

4.5.4 Ongoing Extraction System Operation

After the conclusion of the AP Area Down and Up Flushing Treatability Study period on January 31, 2018, the extraction system continued to operate at the discretion of the Trust due to its effectiveness at removing perchlorate mass from the groundwater. On April 1, 2018, responsibility for operation of the AP Area extraction system was transferred to ETI, whose personnel will continue to operate the extraction system and conduct all appropriate OM&M activities.

4.6 MANAGEMENT OF INVESTIGATION-DERIVED WASTES

Investigation-derived waste generated during the field testing program was managed according to applicable state, federal, and local regulations and as described in *Field Guidance Document No. 001, Managing Investigation-Derived Waste* (ENVIRON, 2014d). The investigation-derived waste that was generated during the field testing program included soil cuttings, personal protective equipment, equipment decontamination water, and groundwater generated during groundwater sampling and well development. Investigation-derived soil waste was stored in plastic-lined roll-off bins. Solids were characterized by collecting representative samples, as necessary, to determine disposal options. Waste water generated during purging or decontamination activities was temporarily stored in 500-gallon totes and transferred into the GW-11 Pond. Soil bins were labeled with “pending analysis” labels, the date accumulation began, contents, source, and contact information, and stored in a designated area until being hauled offsite under proper manifest documentation to Apex Regional Landfill in Las Vegas, Nevada.

4.7 DATA VALIDATION

The laboratory analytical data were verified and validated in accordance with procedures described in the NDEP *Data Verification and Validation Requirements - Supplement April 2009* established for the BMI Plant Sites and Common Areas Projects, Henderson, Nevada (NDEP, 2009); and with correspondence from NDEP personnel. The analytical data were evaluated for quality assurance/quality control based on the following documents: *Quality Assurance Project Plan, Revision 1* (ENVIRON, 2014a); *Quality Assurance Project Plan, Revision 2* (Ramboll Environ, Inc., 2017b); NDEP *Revised Guidance on Qualifying Data due to Blank Contamination for the BMI Complex and Common Areas*, (NDEP, 2012); *National Functional Guidelines for Inorganic Superfund Data Review*, (USEPA, 2014a); *National Functional Guidelines for Superfund Organic Methods Data Review*, (USEPA, 2014b); *National Functional Guidelines for High Resolution Superfund Methods Data Review,* (USEPA, 2016); *National Functional Guidelines for Inorganic Superfund Methods Data Review*, (USEPA, 2017a); *National Functional Guidelines for Superfund Organic Methods Data Review*, (USEPA, 2017b); the USEPA *Test Methods for Evaluating Solid Waste*, *Third Edition (SW-846)*, including Updates I, II, IIA, IIB, III, and IV (USEPA, 1996); and laboratory methods. The samples were validated based on the quality assurance project plans (QAPPs) and other references in place at time of validation. All samples were validated to Stage 2A. For the final round of sampling, 90 percent of the soil and groundwater data were validated to Stage 2B and 10 percent to Stage 4. Field quality blanks were validated to Stage 2A only. The Data Validation Summary Report (DVSR) for the AP Area Down and Up Flushing Treatability Study is included in Appendix H.

Data from injection and monitoring wells as they pertained to the chemical testing associated with the In-Situ Chromium Treatability Study were submitted previously as an appendix to the *In-Situ Chromium Treatability Study Results Report* (Tetra Tech, Inc., 2018b) and are not included in Appendix H.

4.8 SYSTEM DECOMMISSIONING

On April 9, 2018 through April 11, 2018 the injection wells at the AP Area Down and Up Flushing Treatability Study work area were abandoned in conformance with the Notice of Intent to Drill Card Number 37995, waiver number MO-3196, and the approval letter from the Nevada Department of Conservation and Natural Resources and NDWR dated July 13, 2016. In conformance with state regulations, the injection wells were abandoned as follows:

- The well boxes and associated concrete were removed from the subsurface (broken out) and placed in a bin as construction debris.
- An attempt was made by the driller to pull the PVC casing out using the drill hoist and cable winch. Any casing pulled out was placed in the construction debris bin.
- Each casing/hole was filled with bentonite-cement grout to within approximately 1.5 feet of surface.
- 6 to 8 inches of bentonite chips were placed as a bridge.
- A concrete mushroom plug was placed over the filled hole.

The remaining system components, including the groundwater monitoring wells, were left intact and are being utilized by ETI as part of the ongoing extraction system operation.

Used PVC piping, hosing, and general construction debris associated with this treatability study were placed in a 15-cubic yard trash bin provided by Logistical Solutions, LLC (LSI) and transported by LSI offsite for disposal as construction debris. The soil stockpile generated during the removal of an approximate layer of 0.5 feet of chat from Plot 1 and Plot 2 prior to implementation of down flushing in the AP Area was re-graded on March 1 and March 2, 2018. The stockpiled soil was spread out by subcontractor LSI using a skip-loader, front-loader (to compact the soil), and a water truck (to suppress dust and provide moisture for soil compaction).

5.0 ANALYSIS OF RESULTS

This section provides an analysis of the results for the treatability study activities described in Section 4.0. A summary of key findings based on this analysis is provided in Section 6.1.

5.1 TREATABILITY STUDY GEOLOGY

The geology of the treatability study area is illustrated in cross-sections A-A’ (Figure 4a), B-B’ (Figure 4b), and C-C’ (Figure 4c). Stratigraphic units identified in the AP area include the Qal and UMCf. Within the study area, the Qal consists mainly of poorly-stratified silty sand and silty sand with gravel. The gravel content of the silty sand is variable both laterally and vertically. Isolated lenses of sand and gravel are interspersed within the silty sands. A poorly developed caliche layer ranging in thickness between about 1 and 4 feet was encountered at a depth of about 6 feet across most of the area. The UMCf consists predominantly of silt and silt with sand within the study area. To the depths investigated, the UMCf appears to be less heterogeneous than the Qal.

The geology observed from the paleochannel investigation that was performed to the south of the treatability study area is illustrated in cross-section D-D’ (Figure 4d). Boring logs indicate a well-graded gravelly sand or well-graded gravel present from approximately 30 to 39 feet bgs at monitoring wells DFW-04 and DFW-05, but not at DFW-03. Even though there is not a deep soil boring present east of DFW-05 to determine the width of the paleochannel, there is enough geologic evidence to confirm the presence of a northward trending paleochannel at this location. Further, monitoring well DFW-06, which is located south of BT Tanks, also has the same gravelly sand interval present at 32 to 39 feet bgs, which also confirms the paleochannel at this location. Based on the geologic information it appears that this paleochannel runs northward under the AP-5 Pond and not under Plots 1 or 2.

5.2 DOWN FLUSHING

5.2.1 Infiltration Testing

The infiltration rates reported by GES are the mean of all individual measurements taken during each test. Review of the test data for Plots 1 and 2 (Figures 6a and 6b, respectively) shows that in many of the double-ring tests, infiltration rates decreased from high early values to relatively constant steady-state values, which are indicated by the horizontal red lines in Figures 6a and 6b. The steady-state infiltration rates are considered more representative of long-term infiltration rates than the mean values summarized in Appendix I.

The infiltration test results (Figures 6a and 6b) had an overall range of 1.9 to 5.5 in/hr, with mean values of 3.0 in/hr for Plot 1 and 3.3 in/hr for Plot 2. For comparison, the water application rates and areas shown in ***Table 1*** correspond to infiltration rates of 0.12 to 1.07 in/hr. If the data for Plot 1, Zone 9 (Phase 1) are excluded because the water application rate was greater than the infiltration rate (i.e., runoff was observed during operation), the range of water application rates is 0.12 to 0.30 in/hr.

The relatively significant difference between the infiltration test data and infiltration rates observed during down flushing system operation suggests that the double ring infiltrometer testing may not have been representative of actual field conditions. This difference may be due to soil disturbance during installation of the double ring apparatus prior to testing. Shallow soils in the AP area contain varying amounts of gravel, and voids or preferential flow pathways can be created when the rings encounter gravel as they are driven into place. The relatively high infiltration rates observed in the double ring infiltrometer tests suggest that artifacts related to the gravelly soils may have caused the test results to be biased toward higher values.

5.2.2 Down Flushing System Performance

Drip irrigation tubing was found to be a practical means for applying water to large areas at rates close to the maximum observed infiltration rate for the soil. Perchlorate concentration data from the down flushing baseline (Figures 5a through 5c and Appendix B) and confirmation soil borings (Figures 7a through 7f and Appendix B) were used to develop three-dimensional models of the spatial distribution of perchlorate beneath Plots 1 and 2 before and after down flushing (Appendix K). The models were developed using Earth Volumetric Studio (EVS), an advanced data visualization and geostatistical analysis software package using a three-dimensional kriging algorithm (Earth Volumetric Studio [computer software], 2016). In addition to modeling perchlorate concentrations, EVS was used to model the geometry of the contact between the Qal and UMCf based on data from the soil boring logs (Appendices A and K), and the water table surface was modeled using groundwater elevation data from the shallow monitoring wells, injection wells, and extraction wells collected during the baseline groundwater monitoring round (Appendix D). EVS was used to estimate the mass of perchlorate in the unsaturated zone (i.e., between the ground surface and water table), in the saturated Qal aquifer (between the water table and the Qal/UMCf contact), and in the UMCf (below the Qal/UMCf contact) beneath Plots 1 and 2. EVS performs the mass calculations within a user-specified constant concentration shell and set of geologic layers. The soil volumes and chemical masses are integrated based on the concentrations at all nodes, and then summed to obtain the total analyte mass within the shell. For soil, the analyte masses are directly computed from the cell volumes, soil density, and concentration.

To maintain consistency with other efforts to estimate perchlorate mass at the NERT site, the mass estimates have been updated using the mean dry bulk density (i.e., 1.47 g/mL for the Qal and 1.27 g/mL for the UMCf) and mean porosity values (i.e., 0.44 for the Qal and 0.54 for the UMCf) proposed in the 2018 Mass Estimate for the Remedial Investigation Study Area (Ramboll Environ, Inc., 2018). It should be noted that the soil physical property values used in the calculations affect the absolute perchlorate mass calculation but does not affect the estimated percent change in mass, to the extent that the physical properties of the soils (other than moisture content) remain unchanged between the baseline and confirmation sampling events. The EVS 3-D models are shown in Appendix K. The perchlorate mass estimates are summarized in ***Table 2***.

Table 2 Down Flushing Perchlorate Mass Reduction

Hydrostratigraphic Unit[1]	**Baseline Mass (pounds)**	**Post-Treatment Mass (pounds)**	**Mass Reduction**	
			Pounds	**Percent**
Plot 1				
Unsaturated Qal	1,791	47	1,744	97%
Saturated Qal[2]	206	22	184	89%
Entire Qal	1,997	69	1,928	97%
UMCf	6,471	3,152	3,319	51%
Plot 2				
Unsaturated Qal	2,366	22	2,344	99%

Hydrostratigraphic Unit[1]	Baseline Mass (pounds)	Post-Treatment Mass (pounds)	Mass Reduction	
			Pounds	Percent
Saturated Qal[2]	192	79	113	59%
Entire Qal	2,558	101	2,457	96%
UMCf	1,808	1,013	795	44%

Notes:

[1] The depths of the defined hydrostratigraphic units varied based on the lithology and moisture content observed in the field and are generally defined based on the following elevations:

- Unsaturated Qal: Ground surface to 1727 - 1732 feet amsl
- Saturated Qal: 1727 - 1732 feet amsl to 1724 - 1733 feet amsl
- UMCf: 1724 – 1733 feet amsl to approximately 1712 feet amsl

[2] Calculation for Saturated Qal assumes water table elevation from baseline groundwater sampling event

Table 2 shows that perchlorate mass in the unsaturated Qal was reduced by approximately 97 percent (Plot 1) and 99 percent (Plot 2) in response to down flushing. Somewhat smaller mass reductions of 89 percent and 59 percent were observed in the saturated Qal beneath Plot 1 and Plot 2, respectively. The smaller mass reductions observed in the saturated Qal may be attributed to inflow of contaminated groundwater beneath the flushing plots following down flushing.

Perchlorate mass reductions of 51 percent (Plot 1) and 44 percent (Plot 2) were also observed in the UMCf to a depth of 42.5 feet, a positive result which was not expected. The reduction of perchlorate mass in the UMCf is attributed to water being drawn downward from the saturated Qal and laterally through the UMCf in response to the cone of depression created by the groundwater extraction wells.

The large mass reductions observed in Plot 1 and Plot 2 were achieved with the application of only about 2 pore volumes of water. In the prior Soil Flushing Treatability Study (Tetra Tech, Inc., 2017), 90 percent reductions in pore water perchlorate concentrations were observed after the application of approximately 6 to 14 pore volumes of water. The prior Soil Flushing Treatability Study was performed in an area that underwent extensive cut-and-fill during remediation and construction of the Central Retention Basin, whereas the AP Area underwent shallow excavation and was backfilled with a thin layer of uncompacted chat. The difference in down flushing performance between the two areas could be a result of heterogeneity introduced by backfill and compaction operations in the Central Retention Basin area.

5.2.3 Vadose Zone Modeling

Analysis of the timing of flows and leachate concentrations in response to down flushing required the simulation of fluid flow and solute transport in the vadose zone. The computer model VS2DT developed by the United States Geological Survey (Healy, 1990) was used to conduct the preliminary numerical simulations. Additional modeling was performed to evaluate down flushing performance using site-specific soil properties (from soil samples collected from borings required for the AP Area Down and Up Flushing Treatability Study) and to evaluate actual down flushing performance during implementation of this treatability study. Preliminary and post-flushing modeling results are described below. Details on the model construction and parameterization are provided in Appendix J.

5.2.3.1 Preliminary Modeling

Preliminary vadose zone and saturated zone modeling was conducted before any AP Area Up and Down Flushing Treatability Study data were collected within Plots 1 and 2 (i.e., physical and aquifer properties in the preliminary modeling were derived from two nearby historical soil borings (SA179 and SA70) and two nearby wells M-37 and I-AR. While the modeling scenarios conducted did not explicitly end up simulating actual site conditions, they did bracket the possible range of site conditions observed at Plots 1 and 2. The important conclusion drawn from this preliminary modeling effort was that extraction wells were needed closer to Plots 1 and 2 to reduce travel times for removal of flushed water and to allow evaluation of the effectiveness of capturing down flushing water during this treatability study. Extraction of the flushed water by the IWF wells, which are more than 250 feet and 430 feet away from the northern edges of Plot 1 and Plot 2, respectively, would have required more than 3 months of travel time and the effects of down flushing would have been reduced due to mixing with ambient groundwater and the dissipation of groundwater mounding.

5.2.3.2 Post-Flushing Modeling

Two post-flushing numerical models were developed using VS2DT: one representing Plot 1 and one representing Plot 2. In Plot 1, down flushing through Zones 1, 2, 4, 5, 7, and 8 was simulated from March 31, 2017 to July 31, 2017; in Plot 2, down flushing through Zones 10, 11, 13, 14, 16, and 17 was simulated from October 27, 2017 through January 22, 2018 (see ***Table 1*** and Figure 3). The post-flushing models were developed using site-specific data collected during the treatability study. In Plot 1, the simulated down flushing water first reaches monitoring well UFMW-01S approximately 19 days after down flushing commences (see Figure 8a). This time is defined as the inflection point on the hydrograph, when the hydraulic head in the monitoring well, which had been decreasing because of pumping at the extraction well, begins to increase. The area of highest concentration was in the vadose zone, just below and towards the northern edge of the down flushing zone; the infiltrating water was very effective at moving this high-concentration vadose zone water towards the extraction well (Figure 8b).

In Plot 2, the simulated down flushing water reaches monitoring well UFMW-04S approximately 14 days after the down flushing treatment was applied (see Figure 9a). Concentrations along this cross section were not as high in Plot 2 as in Plot 1, and the area of highest concentration was near the southern edge of Plot 2, so the infiltrating water was not quite as effective at moving this higher-concentration vadose zone water towards the extraction well (Figure 9b), but overall still effective at reducing perchlorate concentrations in the vadose zone.

5.3 UP FLUSHING PROGRAM

5.3.1 Distribution of Impacts

Perchlorate and hexavalent soil concentrations prior to soil flushing were determined using soil samples collected from the injection well borings and are depicted along with the injection well screen intervals in Figures 5a and 5b. Summary data tables with the analytical results for the soil samples and groundwater samples are summarized in Appendix B. In general, perchlorate concentrations in soil increased with depth to 60 feet bgs, the maximum depth investigated. The highest perchlorate concentration in soil was 4,900 mg/kg, from a soil sample collected at 60 feet bgs from boring E1-2. Hexavalent chromium concentrations in soil were consistently low throughout the treatability study area with the concentrations below detection limits in the majority of the samples collected. The maximum hexavalent chromium concentration in soil was 2.8 mg/kg from a soil sample collected at 60 feet bgs from boring E1-1. Perchlorate concentrations in groundwater ranged from 510 mg/L to 1,500 mg/L in the shallow screened interval, from 660 mg/L to 1,900 mg/L in the intermediate screened interval, and from 1,700 mg/L to 2,900 mg/L in the deep screened interval. Hexavalent chromium concentrations in groundwater ranged from less than 0.25 µg/L to 9.7 µg/L in the shallow screened interval, from 6.4 µg/L to 25 µg/L in the intermediate screened interval, and from 12 µg/L to 29 µg/L in the deep screened interval.

As noted previously, up flushing was not implemented, following consultation with NDEP, due to the presence of high perchlorate concentrations in the UMCf at 60 feet bgs, the depth of the deep injection wells. As a result, the up flushing program was limited to aquifer and injection testing. The following subsections describe the results of the aquifer and injection testing performed.

5.3.2 Aquifer Testing

As previously described in Section 4.4.5, aquifer testing consisting of slug testing and/or specific capacity testing was periodically performed in select wells during this treatability study. Following the completion of the slug tests and specific capacity tests, the test data were downloaded from the transducer or entered from field data sheets and analyzed using AQTESOLV software (HydroSOLVE, Inc., 2007). The Bouwer and Rice method for analyzing slug tests in an unconfined aquifer was used to estimate hydraulic conductivity (Bouwer & Rice, 1976). The specific capacity test data were analyzed using the Theis method (Theis, 1935), Hantush-Jacob leaky aquifer solution (Hantush & Jacob, 1955) or Cooper-Jacob unconfined solution (Cooper & Jacob, 1946). The number of aquifer tests conducted at each well tested was dependent upon the hydraulic conductivity and associated recharge rate of the well. If multiple tests were conducted, the corresponding hydraulic conductivity estimates were averaged. Results obtained from the slug and specific capacity testing, which includes the AQTESOLV interpretation plots, are provided in Appendix E.

The estimated hydraulic conductivity values (K values) obtained from the slug tests in the intermediate and deep wells are generally consistent with the lithologies observed within the screened interval of the wells, which primarily consisted of silty sand and sandy silt. Prior estimates of the hydraulic conductivity for the UMCf have ranged from less than 0.01 feet per day (ft/day) to more than 10 ft/day (Ramboll Environ, Inc., 2015b). The estimates from the slug tests ranged from 0.3 to 12.9 ft/day, which are consistent with the previous estimated range for the UMCf. Results of the specific capacity tests revealed that the estimates of the hydraulic conductivity for intermediate well UFIW-06I are similar to the corresponding slug test hydraulic conductivity estimates. The hydraulic conductivity estimates from specific capacity tests conducted on the shallow wells are not likely representative of the overall hydraulic conductivity of the Qal as they are likely to be heavily influenced by the limited saturated thickness of less than 2 feet.

Based on the slug test data, a decrease in hydraulic conductivity was observed in several injection wells: UFIW-01I, UFIW-04I, UFIW-05I, and UFIW-08I. Post-injection hydraulic conductivity values were calculated to be approximately an order of magnitude lower than pre-injection hydraulic conductivity values in wells UFIW-01I and UFIW-04I. Post-injection hydraulic conductivity values for wells UFIW-05I and UFIW-08I also showed small decreases (less than one order of magnitude) compared with the corresponding pre-injection hydraulic conductivity values. No significant changes were observed between the hydraulic conductivity estimates pre- and post-injection in the monitoring wells tested, indicating that decreases in hydraulic conductivity associated with injection testing were likely limited to the immediate vicinity of the injection wells. Scaling associated with the injection of CPS (specifically from the calcium in the CPS solution and/or the native calcium under reducing conditions) may be a potential cause of the decrease in hydraulic conductivity.

5.3.3 Injection Testing

Injections were not performed in the deep injection wells as there were high perchlorate concentrations present at and directly below the depth of the screened intervals and there was concern that injections may push contamination deeper into the UMCf. CPS was selected as an injection amendment to preliminarily evaluate the potential to inject the chemical as part of the In-Situ Chromium Treatability Study. Additionally, tracer dyes were used to evaluate the vertical and horizontal distribution of the injections, as well as the groundwater flow rate, within the treatability study area. The following summarizes the injection results for Plots 1 and 2. Summary tables of the injections are provided in Appendix G.

Even though the planned injections were not accomplished as part of the study, injection testing was performed on the shallow and intermediate injection wells within Plot 1 and Plot 2 using SLMW injected into the injection wells at various pressures using an injection trailer to assess the varying injection rates that could be achieved at each well. For the shallow injection wells in Plot 1, maximum sustained pressures were at or below 10 pounds per square inch gauge (psig) and average flow rates ranged from 4.0 to 6.0 gpm. For the intermediate injection wells in Plot 1, maximum sustained pressures were at or below 10 psig and average flow rates ranged from 1.0 to 9.0 gpm. For the shallow injection wells in Plot 2, maximum sustained pressures were at or below 11 psig and average flow rates ranged from 1.0 to 6.0 gpm. For the intermediate injection wells in Plot 2, maximum sustained pressures were at or below 22.5 psig and average flow rates ranged from 0.5 to 10.0 gpm. Additional injection testing using only SLMW was performed on the intermediate injection wells in Plot 2 on November 2, 2016, in order to further evaluate flow rates at different pressures and to preliminarily test the direct injection system designed and installed by Tetra Tech (further discussed in the paragraph below). The maximum sustained pressures for the intermediate injection wells during this additional testing were at or below 15 psig and average flow rates ranged from 1.17 to 3.10 gpm. Table 3 and Table 4 provides a summary of the injection activities performed at Plot 1 and Plot 2.

Table 3 Summary of Plot 1 Injections

Injection Zone	Tracer Dye[1] (mL)	CPS Solution (gallons)	SLMW (gallons)	SLMW Chase Water (gallons)	Average Injection Rates[2] (gpm)	Maximum Injection Pressure (psig)
Injection Event #1 – September 20 to 23, 2016						
Shallow	990	54	6,350	800	3.0 to 4.6	13
Intermediate	651	54	9,154	1,200	3.0 to 5.0	10
Injection Event #2 – August 7, 2017						
Shallow	0	15	135	975	4.6	13
Intermediate	0	15	135	975	5.6	7.0

Notes:

CPS: calcium polysulfide
SLMW: stabilized Lake Mead water

[1] Rhodamine WT tracer dye was injected into the shallow injection wells and fluorescein (aka uranine) tracer dye was injected into the intermediate injection wells.

[2] Average injection rates for the shallow and intermediate injections wells during Injection Event #2 did not have a range as the wells were manifolded together.

Table 4 Summary of Plot 2 Injections

Injection Zone	Tracer Dye[1] (mL)	CPS Solution (gallons)	SLMW (gallons)	SLMW Chase Water (gallons)	Average Injection Rates[2] (gpm)	Maximum Injection Pressure (psig)
Injection Event #1 – November 2 to 4, 2016						
Shallow	2,844	6.3	5,100	158	1.1 to 3.3	13
Intermediate	1,272	5.7	4,619	1,332	1.2 to 5.9	20
Injection Event #2 – August 8, 2017						
Shallow	0	15	135	975	4.5	21
Intermediate	0	15	135	975	4.1 to 4.5	15

Notes:

CPS: calcium polysulfide
SLMW: stabilized Lake Mead water

[1] Rhodamine WT tracer dye was injected into the shallow injection wells and fluorescein (aka uranine) tracer dye was injected into the intermediate injection wells.

[2] The average injection rate for the shallow injections wells during Injection Event #2 did not have a range as the wells were manifolded together.

The injection testing demonstrated that injections into both the Qal and UMCf are viable within the treatability study area. The injection methodologies of the injection trailer and the direct injection system were both demonstrated to be effective means for delivering injectate to the subsurface as evidenced by the ability to inject and injection rates achieved (Tables 3 and 4). An injection trailer or injection platform is advantageous for its modular design and the ease to mobilize it to different injection areas as needed. A direct injection system is advantageous for its simplicity and ability to operate continuously with little to no supervision. While both methodologies are viable for the implementation of up flushing, one methodology may be a more suitable choice depending on specific conditions or constraints related to up flushing implementation. Such conditions may involve design considerations such as available layout space, whether up flushing will be short-term or long-term, or the need to alter the injection amendment concentrations or constituents.

5.4 EXTRACTION SYSTEM OPERATION

The extraction system removed a total volume of approximately 4,608,000 gallons of groundwater over the entire duration of the treatability study operational period (October 2016 to January 2018). Based on the extraction well groundwater concentration and extraction rate data, an estimated total of 36,395 pounds of perchlorate was removed by the extraction system during the treatability study operational period (Figure 10).

The system flow rate was typically at or below 5.5 gpm until July 11, 2017, corresponding to when the Plot 2 extraction wells began operating after ETI's approval to increase the cumulative system flow rate from 5.5 gpm to 10 gpm and then 12.5 gpm. The addition of the Plot 2 extraction wells and the increased system flow rate resulted in an increased rate of perchlorate mass removal by the system for the second half of the treatability study operational period. This increase in perchlorate mass removal occurred even as perchlorate mass removal in the Plot 1 extraction wells began to exhibit a decreasing trend in the Plot 1 extraction wells.

5.5 GROUNDWATER MONITORING

Groundwater gauging was generally performed for each of the 18 groundwater monitoring wells on a weekly basis throughout the treatability study. In addition, the 18 groundwater monitoring wells were sampled approximately every 2 months throughout the treatability study. The following sections present the results of the groundwater gauging and sampling for the primary chemical of potential concern, perchlorate. Summary data tables of the groundwater monitoring results are presented in Appendix B. Groundwater monitoring field logs are provided in Appendix D.

5.5.1 Groundwater Gauging

Groundwater elevation measurements were taken from 18 shallow, intermediate, and deep wells of Plot 1 and Plot 2 on a weekly basis during the AP Area Down and Up Flushing Treatability Study. Baseline groundwater elevation contours and flow direction for the shallow, intermediate, and deep zones are presented in Figures 11a, 11b, and 11c. The horizontal and vertical groundwater gradients within the treatability study area were significantly influenced by nearby down flushing and groundwater extraction activities. The groundwater elevation data for the treatability study are presented in Figures 12a and 12b. The operational periods of the groundwater extraction system and the five phases of down flushing are also indicated on the figures for reference.

At Plot 1, groundwater elevations increased by up to 3 feet in the shallow groundwater monitoring wells, by up to 2.5 feet in the intermediate groundwater monitoring wells, and by up to 3 feet in the deep groundwater monitoring wells from October 2016 to January 2017. From January 2017 to May 2017, groundwater elevations in the shallow, intermediate, and deep groundwater monitoring wells fluctuated, but generally remained elevated from baseline conditions. From May 2017 to January 2018, groundwater elevations decreased with all three shallow groundwater monitoring wells going dry and groundwater elevations decreasing by up to 3 feet in the intermediate and deep monitoring wells.

At Plot 2, groundwater elevations increased by up to 2.5 feet in shallow, intermediate, and deep groundwater monitoring wells from October 2016 to January 2017. From January 2017 through January 2018, groundwater elevations decreased by up to 1.5 feet in the shallow groundwater monitoring wells, by up to 2 feet in the intermediate monitoring wells, and by up to 2 feet in the deep monitoring wells.

In general, groundwater elevations generally increased during down flushing at Plot 1 and then gradually decreased throughout the treatability study, likely because of groundwater extraction.

5.5.2 Perchlorate

Seven groundwater monitoring events were performed as part of the treatability study. These events were conducted in August 2016 (baseline), January 2017, April 2017, June 2017, August 2017, November 2017, and January 2018. Perchlorate was analyzed periodically throughout the treatability study to monitor changes in concentration from baseline values as down flushing and groundwater extraction operations progressed.

Shallow Monitoring Wells

Groundwater results for the shallow monitoring wells screened in the Qal are summarized in ***Table 5***.

Table 5 Perchlorate Groundwater Results in Shallow Monitoring Wells

Well ID	Perchlorate Concentration (mg/L)						
	August 2016	January 2017	April 2017	June 2017	August 2017	November 2017	January 2018
Plot 1							
UFMW-01S	950	2,000	Dry	260	92	Dry	Dry
UFMW-02S	1,200	15	270	41	Dry	Dry	Dry
UFMW-03S	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Plot 2							
UFMW-04S	220	240	210	150	130	21	35
UFMW-05S	610	550	440	460	290	230	180
UFMW-06S	730 c	560	770	740	490	360	27

Notes:

mg/L – milligrams per liter
Dry – Well was observed to be dry.
c – Matrix spike and/or matrix spike duplicate was outside of acceptable limits.

Perchlorate concentrations in samples from the shallow monitoring wells generally decreased during the treatability study; however, there were several instances where the wells were observed to be dry and no sample could be collected during the monitoring events. Compared to baseline, the perchlorate concentration in groundwater samples collected from UFMW-01S decreased by approximately 90 percent by August 2017, the last monitoring event when sufficient water was present in the well to collect a sample. Similarly, the perchlorate concentration in groundwater samples collected from UFMW-02S decreased by 97 percent by June 2017 when compared to baseline.

Perchlorate concentrations in groundwater samples collected from the Plot 2 shallow monitoring wells exhibited a decreasing trend throughout the treatability study. Compared to baseline concentrations, perchlorate concentrations in groundwater samples collected from UFMW-04S, UFMW-05S, and UFMW-06S at the time of the final montioring event had decreased by 84 percent, 70 percent, and 96 percent, respectively.

The overall reduction in perchlorate concentrations observed in samples collected from the shallow monitoring wells was likely due to mixing of the groundwater with the SLMW that was flushed through the vadose zone. As flushing progressed, the perchlorate concentration in the flushed water likely decreased and, near the end of the flushing period, operation of the groundwater extraction wells may have pulled this lower concentration water toward the monitoring wells.

Intermediate Monitoring Wells

Groundwater results for samples from the intermediate monitoring wells screened in the UMCf are summarized in ***Table 6***.

Table 6 Perchlorate Groundwater Results in Intermediate Monitoring Wells

Well ID	Perchlorate Concentration (mg/L)						
	August 2016	January 2017	April 2017	June 2017	August 2017	November 2017	January 2018
Plot 1							
UFMW-01I	920	NS	450	220	150	160	250
UFMW-02I	1,900	NS	500	550	430	370	470
UFMW-03I	1,400	NS	140	130	160	230	390
Plot 2							
UFMW-04I	400	NS	330	350	240	31	66
UFMW-05I	610	NS	410	470	350	230	110
UFMW-06I	700	NS	590	740	610	340	58

Notes:

mg/L – milligrams per liter
NS – not sampled

Perchlorate concentrations in samples from the intermediate Plot 1 monitoring wells generally decreased during the treatability study. Compared to the baseline concentration, the perchlorate concentrations in groundwater samples collected from UFMW-01I, UFMW-02I, and UFMW-03I at the time of the final monitoring event had decreased by 73 percent, 75 percent, and 72 percent, respectively. The overall reduction in perchlorate concentrations observed in samples collected from the intermediate monitoring wells was likely due to mixing of the groundwater with the SLMW that was flushed through the vadose zone. As noted above, the perchlorate concentration in the flushed water likely decreased near the end of the flushing period and operation of the groundwater extraction wells may have pulled this lower concentration water toward the monitoring wells

Perchlorate concentrations in groundwater samples collected from the Plot 2 intermediate monitoring wells also exhibited a decreasing trend. Compared to baseline concentrations, perchlorate concentrations in groundwater samples collected from UFMW-04I, UFMW-05I, and UFMW-06I at the time of the final montioring event had decreased by 84 percent, 82 percent, and 92 percent, respectively. Although the intermediate monitoring wells are screened beneath the groundwater table, the timing of the reduction of perchlorate in the Plot 2 monitoring well samples coincides with the application of Plot 2 down flushing beginning in July 2017.

The decreasing concentrations observed in samples from the intermediate wells likely indicate that down flushing was not causing perchlorate to migrate deeper into the aquifer, which would have been an undesirable result. Groundwater extracted from the nearby extraction wells likely mitigated any downward migration of perchlorate, by pulling the water laterally through the formation.

Deep Monitoring Wells

Groundwater results for samples from the intermediate monitoring wells screened in the UMCf are summarized in ***Table 7***.

Table 7 Perchlorate Groundwater Results in Deep Monitoring Wells

Well ID	**Perchlorate Concentration (mg/L)**						
	August 2016	**January 2017**	**April 2017**	**June 2017**	**August 2017**	**November 2017**	**January 2018**
Plot 1							
UFMW-01D	1,700	NS	NS	690	560	530	630
UFMW-02D	2,900	NS	NS	1,300	980	950	1,200
UFMW-03D	2,200	NS	NS	420	610	480	620
Plot 2							
UFMW-04D	870	NS	NS	840	670	220	150
UFMW-05D	1,400	NS	NS	1,900	1,400	630	660
UFMW-06D	1,700	NS	NS	1,300	1,300 F1	1,300	550

Notes:

mg/L – milligrams per liter
NS – not sampled
F1 – Matrix spike and/or matrix spike duplicate recovery was outside of acceptable limits.

Perchlorate concentrations in samples from the deep Plot 1 monitoring wells generally decreased during the treatability study. Compared to the baseline concentration, the perchlorate concentrations in groundwater samples collected from UFMW-01D, UFMW-02D, and UFMW-03D at the time of the final monitoring event had decreased by 63 percent, 59 percent, and 72 percent, respectively. The overall reduction in perchlorate concentrations observed in samples collected from the deep monitoring wells was likely due to the operation of the groundwater extraction wells that may have pulled less-impacted groundwater toward the monitoring wells.

Perchlorate concentrations in groundwater samples collected from the Plot 2 deep monitoring wells also exhibited a decreasing trend. Compared to baseline concentrations, perchlorate concentrations in groundwater samples collected from UFMW-04D, UFMW-05D, and UFMW-06D at the time of the final montioring event had decreased by 83 percent, 53 percent, and 68 percent, respectively. Although the deep monitoring wells are screened beneath the groundwater table, the timing of the reduction of perchlorate in the Plot 2 monitoring well samples coincide with the application of Plot 2 down flushing beginning in July 2017.

The decreasing concentrations observed in samples from the deep wells likely indicate that down flushing was not migrating perchlorate deeper into the aquifer, which would have been an undesirable result. Groundwater extraction from the nearby extraction wells likely mitigated any downward migration of perchlorate, by pulling the water laterally through the formation.

5.5.3 Tracer Dye

During the injection testing activities summarized in Section 4.4.6, tracer dyes were injected to evaluate the vertical and horizontal distribution of the injections, as well as the groundwater flow rate within the study area. Rhodamine WT was injected into the shallow injection wells and fluorescein was injected into the intermediate injection wells of both Plot 1 and Plot 2. The groundwater in monitoring wells associated with Plot 1 and Plot 2 was checked periodically, typically during groundwater monitoring events, for the presence of tracer dye. An AquaFluor® handheld fluorometer, calibrated to secondary standards for each Rhodamine WT and fluorescein, was used to measure tracer dye concentrations in samples collected from the monitoring wells. Additionally, the visual appearance of the groundwater was noted during these events to record if any changes in sample coloration could be attributed to the presence of tracer dye.

The tracer dyes have not been observed at the downgradient monitoring wells, approximately 420 days following the initial injections. The expected travel time from the injection wells to the downgradient monitoring wells was estimated to range from 41 to 67 days for the shallow injection interval, and from 52 to 784 days based on site-specific field parameters collected and slug test results (Appendix E). It is uncertain why the tracer dyes were not observed during the treatability study, but may be due to slower than anticipated groundwater velocity, absorption of the tracer dye onto the soil, significant dilution from down flushing activities, or the presence of preferential pathways that avoid the downgradient monitoring wells.

6.0 SUMMARY OF KEY FINDINGS

This section presents the overall findings of the treatability study and provides cost considerations for future implementation of this technology at the NERT site.

6.1 AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY

The main findings of the AP Area Down and Up Flushing Treatability Study are as follows:

- During the initial well installation and groundwater monitoring events, it was discovered that perchlorate concentrations in the AP Area increased with depth up to 60 feet bgs, the maximum depth investigated. The highest perchlorate concentration in soil was 4,900 mg/kg, from a soil sample collected at 60 feet bgs. The groundwater concentrations in the deep screened interval (maximum concentration of 2,900 mg/L), exceeded the perchlorate concentrations in the shallow screened interval (maximum concentration of 1,500 mg/L) and the intermediate screened interval (maximum concentration of 1,900 mg/L). As a result, the scope of the up flushing program was significantly reduced, after consultation with NDEP, to avoid pushing contamination deeper into the UMCf.
- Perchlorate mass reductions in soil of 97 percent and 99 percent were achieved by down flushing in the unsaturated zone beneath Plot 1 and Plot 2 with the application of as little as two pore volumes of water.
- Perchlorate mass reductions in soil of 51 percent and 44 percent were observed in the UMCf beneath Plot 1 and Plot 2 during the Treatability Study. The reductions in perchlorate concentrations are attributed to flushing from water drawn downward from the saturated Qal and laterally through the UMCf in response to cone of depression created from the groundwater extraction wells. The estimated perchlorate mass reduction in each hydrostratigraphic unit is presented in ***Table 8***:

Table 8 Down Flushing Perchlorate Mass Reduction

Hydrostratigraphic Unit[1]	Baseline Mass (pounds)	Post-Treatment Mass (pounds)	Mass Reduction	
			Pounds	Percent
Plot 1				
Unsaturated Qal	1,791	47	1,744	97%
Saturated Qal	206	22	184	89%
Entire Qal	1,997	69	1,928	97%
UMCf	6,471	3,152	3,319	51%
Plot 2				
Unsaturated Qal	2,366	22	2,344	99%
Saturated Qal	192	79	113	59%
Entire Qal	2,558	101	2,457	96%
UMCf	1,808	1,013	795	44%

Notes:

[1] The depths of the defined hydrostratigraphic units varied based on the lithology and moisture content observed in the field and are generally defined based on the following elevations:

- Unsaturated Qal: Ground surface to 1727 - 1732 feet above mean sea level (amsl)
- Saturated Qal: 1727 - 1732 feet amsl to 1724 - 1733 feet amsl
- UMCf: 1724 – 1733 feet amsl to approximately 1712 feet amsl

[2] Calculation for Saturated Qal assumes water table elevation from baseline groundwater sampling event.

- The extraction wells in the AP Area removed an estimated total of 36,395 pounds of perchlorate and a total volume of approximately 4,600,000 gallons of groundwater during the Treatability Study operational period (October 2016 to January 2018).
- Multiple rounds of injections were successfully performed using SLMW, tracer dyes, and CPS within the saturated Qal and the UMCf. For injection wells screened within the Qal, maximum injection rates varied from 1 to 6 gpm with a maximum injection pressure of 21 psi. For injection wells screened within the UMCf, maximum injection rates varied from 0.5 to 10 gpm with a maximum injection pressure of 22.5 psi.

The down flushing results indicate that application of down flushing at the Site would require fewer pore volumes of water, less time, and less cost to remove perchlorate impacts from the unsaturated zone than what was indicated by the previous Soil Flushing Treatability Study in the Central Retention Basin. In addition, perchlorate mass reductions were observed in the UMCf. These results suggest that down flushing coupled with longer term groundwater extraction in the UMCf could be an effective means for reducing contaminant concentrations in both the Qal and the UMCf. The results from the Soil Flushing Treatability Study conducted in the Central Retention Basin indicate that amending the flushing water with carbon donor to enhance in-situ bioremediation may offer the potential to further improve performance and cost effectiveness of down flushing. The operation of the groundwater extraction wells and the aquifer testing in the AP Area provided useful information for future studies and the Feasibility Study with respect to the ability to inject into and extract from the UMCf.

6.2 COST CONSIDERATIONS

The AP Area Down and Up Flushing Treatability Study provides valuable refinement of the cost considerations for potential full-scale implementation of down flushing at the Site. As requested by NDEP, these preliminary indications are presented in the following subsections, but are subject to revision during the FS. During the FS, NERT will evaluate the applicability of a variety of remedial technologies in order to achieve the RAOs established for the Site.

6.2.1 Treatability Study Cost Summary

Table 9 AP Area Down and Up Flushing Treatability Study Cost Summary provides a high-level cost summary for implementation of this AP Area Down and Up Flushing Treatability Study. It should be noted that costs for treatability studies can vary tremendously and are directly related to the type of study, extent of monitoring, and length of the study. Data obtained and costs incurred during the treatability study will be used to inform the development of alternative costs in the Feasibility Study; however, due to the nature of treatability studies, costs are inherently higher than likely larger scale operations, and cannot be easily extrapolated to represent larger-scale system design, installation, and operational costs. These costs for implementing the treatability study should not be used for developing full-scale implementation costs on a per-acre basis. For example, treatment footprints, durations, and associated operational costs will vary significantly depending on the specific risk-based remedial action goals established during the FS and other alternative implementation and operational variables that have not yet been defined.

Table 9 AP Area Down and Up Flushing Treatability Study Cost Summary

Task	Cost
Project Planning, Coordination, and Work Plan	$50,000
Conceptual Design and Layout for Up and Down Flushing Systems	$200,000
Site-specific Groundwater Model Development & Testing	$50,000

Task	Cost
Permitting	$50,000
Pre-Construction Demolition (asphalt, concrete, blast wall removal)	$100,000
Electrical and Piping Connections to IWF	$200,000
Final Design and Injection Testing for Up Flushing System	$200,000
Final Design and Testing for Down Flushing System	$200,000
Field Preparation and Utility Locates	$60,000
Down Flushing System Installation, Testing, Chat Removal, and Startup	$600,000
Plot 1 Up Flushing Well Installation and Testing	$610,000
Plot 2 Up Flushing and Extraction Well Installation and Testing	$700,000
Down Flushing and Extraction System Operation, Maintenance, and Monitoring	$1,050,000
Post-flushing Soil Borings, Confirmation Sampling, and System Decommissioning	$200,000
Data Analysis and Reporting	$200,000
Final Well Abandonment	$50,000
Total	**$4,520,000**

6.2.2 Preliminary Indications of Costs for Soil Flushing

While the prior Soil Flushing Treatability Study Report (for the study in the Central Retention Basin area) estimated that soil flushing might cost $100,000 to $400,000 per acre, the more recent study indicates that full scale implementation of soil flushing would cost approximately $65,000 to $250,000 per acre, which reflects the -50%/+100% accuracy range typical of conceptual-level estimates. This conceptual-level cost estimate range is based on the following assumptions:

- The soil flushing will be applied to an assumed 150 acres at the Site. This area corresponds to the on-site footprint of the higher concentration portion of the perchlorate plume. It is not definitive and is selected only for the purpose of providing a basis of estimate. The area of application would need to be further evaluated as part of the Feasibility Study after review of the Remedial Investigation results. To the extent that the actual area of application of soil flushing were less than 100 acres, the cost per acre might increase.
- The soil flushing water application rate is assumed to be 400 gpm. The rate of application will need to consider the future ability to capture and treat the infiltrated water. Infrastructure improvements in the IWF, supplemental groundwater extraction wells, GWTP and GWETS would be necessary and are not included in the scope of the soil flushing cost estimate.
- Approximately 2 pore volumes of water will be applied, which equates to 5,250 acre-ft, based on an estimated porosity of 50% for the Qal, 35 feet average depth of the Qal, and 150 acres.
- The source of the water will consist of one or more of: Stabilized Lake Mead water, reclaimed water from the City of Henderson, and effluent from the GWETS. A key consideration in water source is its TDS concentration. It is unlikely that GWETS effluent would be used as the sole source of water because it

has high TDS, which might ultimately impact bioremediation rates in the FBRs if TDS levels increase in groundwater, but it could be blended with SLWM and/or reclaimed water. City of Henderson reclaimed water distribution lines exist onsite.

- It is estimated that soil flushing for 150 acres would take approximately 8 years, based on 50% porosity for the Qal, 2 pore volumes, 35 feet average depth of the Qal, and 400 gpm. This duration would change to extent that the assumptions change. For example, the duration would be approximately 5 years if the application rate were 600 gpm.
- The soil flushing water will be applied through surface flooding, drip irrigation and/or spray irrigation, depending on location, terrain and surface features. Flatter areas would tend be graded into basins that would be flooded, while areas with greater slopes might tend to have water applied through drip irrigation. Areas with obstacles, such as utilities and railroad tracks, might be spray irrigated, probably during the winter when evaporation would be less. Areas where chat backfill has been applied will likely need the chat to be removed first, because the AP Area soil flushing found the chat to contain low permeability fines which restricted infiltration. The cost estimate includes the temporary removal of chat, stockpiling and replacement for approximately 20% of the soil flushing area.
- It is assumed that approximately one-third of the areas graded for infiltration basins will be in areas where the Site Management Plan will apply. The sampling protocols provided in the Site Management Plan will be following in those areas. It is assumed that the sampling results will not require any soil to be disposed off-site.
- It is assumed that compaction of regraded soil will not be required.
- The soil flushing application area at any one time will be approximately 4 acres, based on 400 gpm and the average application rates observed during the AP Area treatability study (approximately 0.2 inches per hour).
- A carbon substrate such as molasses will be added to the soil flushing water to enhance in-situ bioremediation of the COPCs in the flushed water and in the groundwater. Treatability studies have indicated that carbon substrate can induce in-situ bioremediation to reduce concentrations of perchlorate, chlorate, nitrate, chromium and chloroform. The carbon substrate will also help to reduce the COPC mass loading to the GWETS. The amount of carbon substrate to be applied is based on the stoichiometric demand observed in the UNLV treatability studies.
- It is assumed that no surface obstructions and/or utilities will have to be removed to access the surface soils to allow soil flushing to proceed.
- No pore water or groundwater sampling will be performed to monitor performance. Confirmation soil borings will be collected before and after the soil flushing within the excavated basin at an approximate sampling frequency of 4 soil borings per acre.

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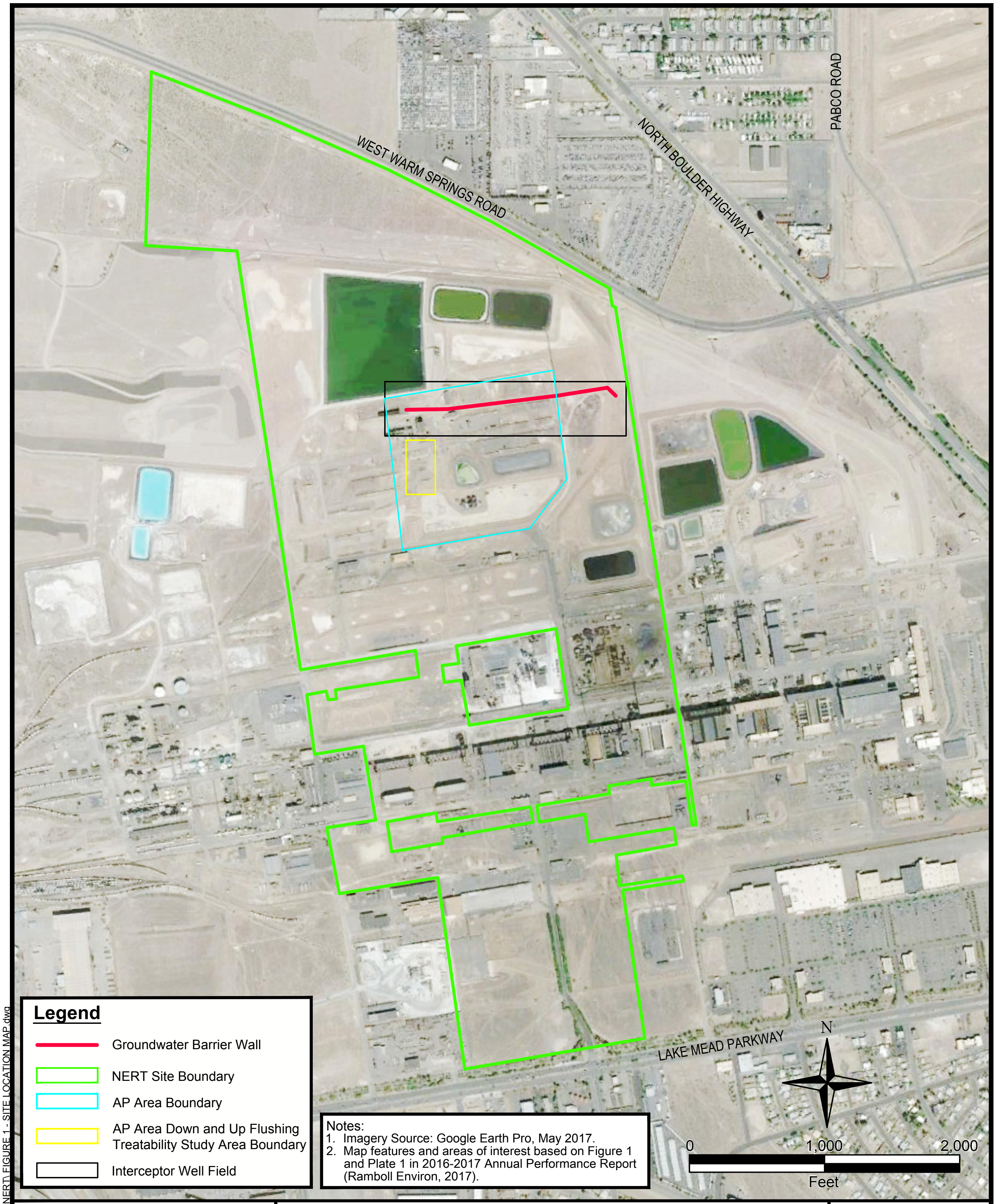
Figures



Legend

🟥 Groundwater Barrier Wall

🟩 NERT Site Boundary

🟦 AP Area Boundary

🟨 AP Area Down and Up Flushing Treatability Study Area Boundary

☐ Interceptor Well Field

Notes:
1. Imagery Source: Google Earth Pro, May 2017.
2. Map features and areas of interest based on Figure 1 and Plate 1 in 2016-2017 Annual Performance Report (Ramboll Environ, 2017).

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILTY STUDY RESULTS REPORT
HENDERSON, NEVADA

SITE LOCATION MAP

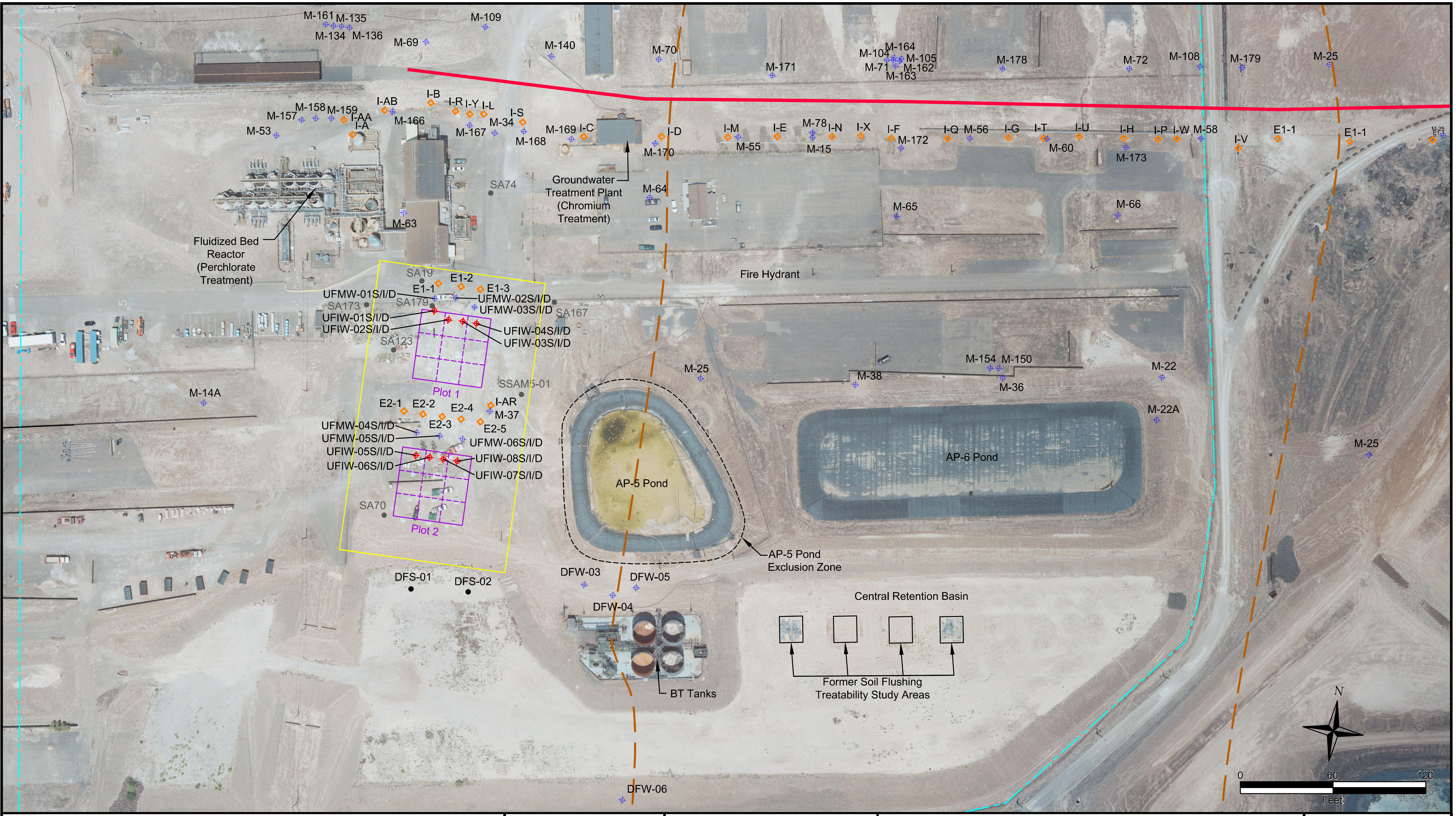
Project No: 117-7502018

Date: APRIL 26, 2018

Designed By: DVK

Figure No.
1

\\tts318fs1\.tt.local\ces\ 87600015-NERT\ FIGURE 1 - SITE LOCATION MAP.dwg



Legend

⌖ Monitoring Well
⌖ Injection Well Cluster
◇ Extraction Well
● Soil Boring
● Historical Soil Boring
— — Reported Approximate Location of Paleochannels
▬ Groundwater Barrier Wall
▭ AP Area Treatability Study Area
▭ AP Area Boundary
▦ Soil Down Flushing Plot

Notes:
1. Imagery Source: Aerotech Mapping, August 2016.
2. Reported approximate locations of paleochannels obtained from Plate 1 of 2017 Annual Performance Report (Ramboll Environ, 2017).

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AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
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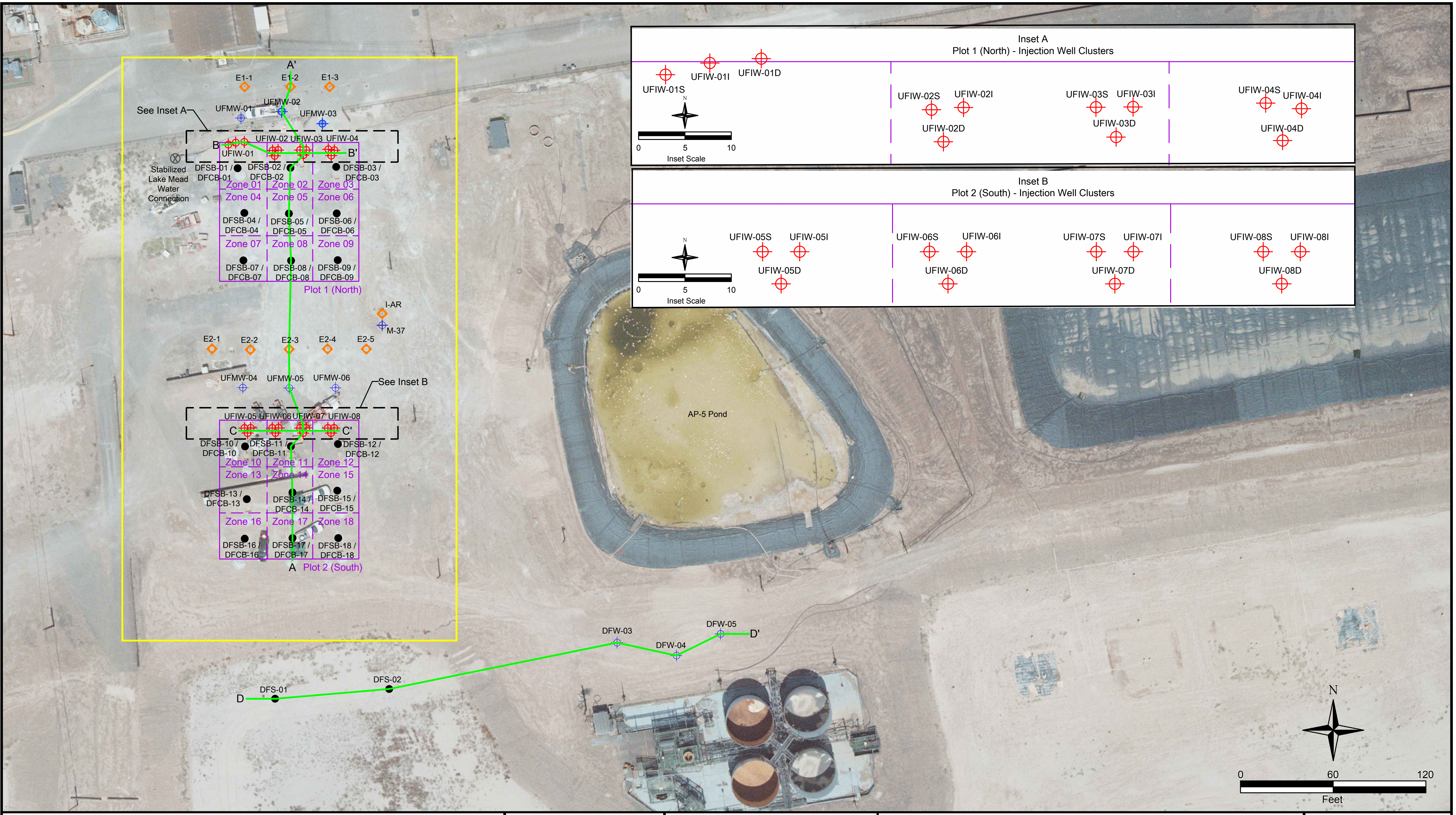
AP AREA SITE MAP

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.
2

\\tts318fs3\tt.local\ces\87600014-NERT-M12\ FIGURE 2 - AP AREA SITE MAP : L.dwg



Legend

- ⌖ Monitoring Well
- ⌖ Injection Well
- ◇ Extraction Well
- ● Soil Boring
- ▦ Soil Down Flushing Plot
- ▭ AP Area Down and Up Flushing Treatability Study Area Boundary
- A—A' Cross-Section Line

Note:
1. Imagery Source: Aerotech Mapping, August 2016.

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PLOT 1 AND PLOT 2 AREA SITE MAP

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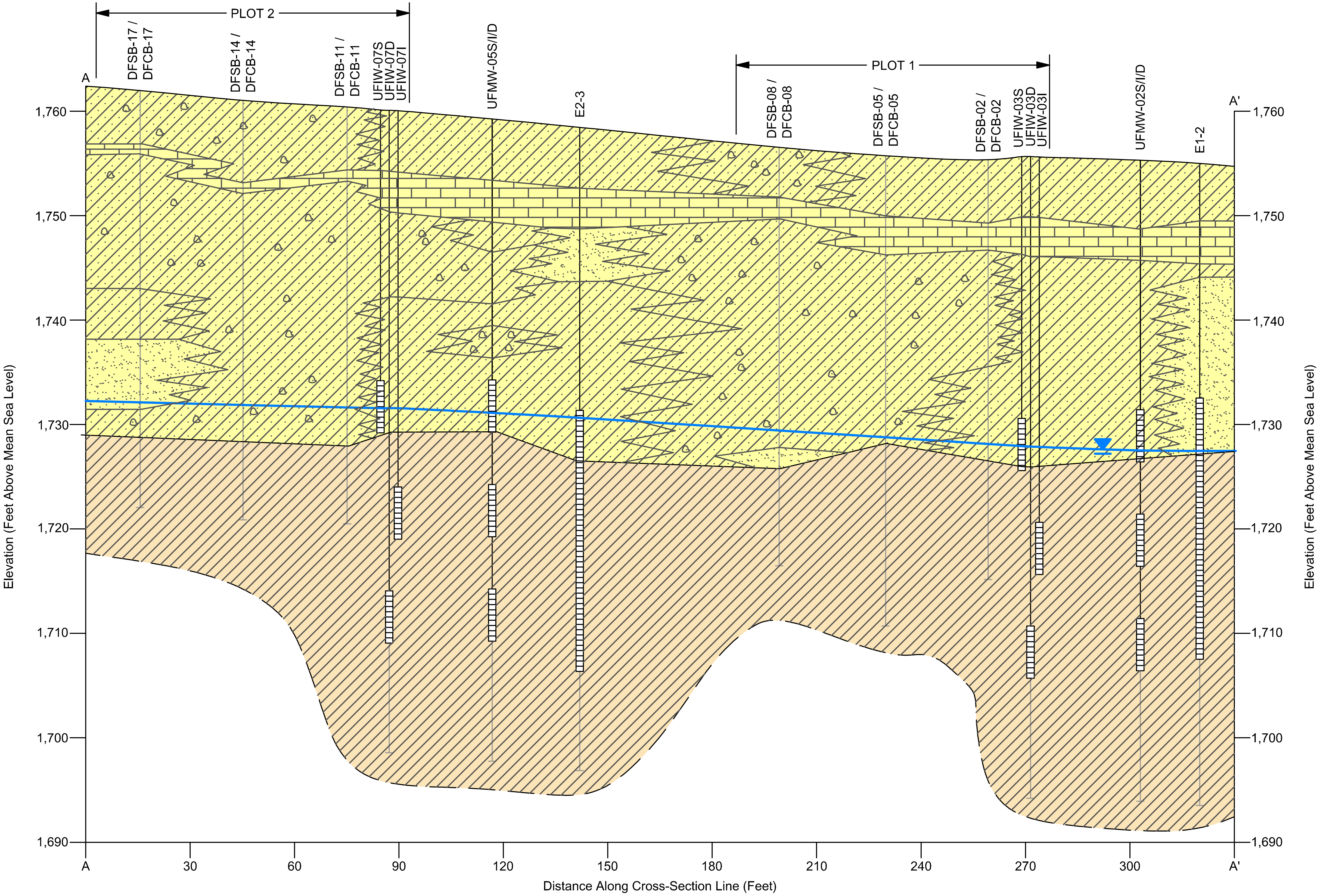
Figure No.

3

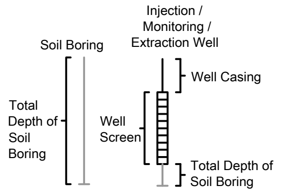
\\tts318fs3.tt.local\ces\Projects\87600M13-18\CAD\Final Report\FIGURE 3 - PLOT 1 AND PLOT 2 AREA SITE MAP_JL r.dwg



Legend

- 🟨 Quaternary Alluvium (Qal)
- 🟧 Upper Muddy Creek Formation (UMCf)
- ▤ Caliche
- ▨ Silty Sand with Gravel
- ▨ Silty Sand
- ▨ Silt
- ⁘ Sand

▼	Groundwater Elevation
S	Shallow Well (Screened in Qal)
I	Intermediate Well (Screened in UMCf)
D	Deep Well (Screened in UMCf)



Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.
2. AMSL = above mean sea level.
3. 3x Vertical Exageration.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
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GEOLOGICAL CROSS-SECTION A-A'

Project No:	117-7502018
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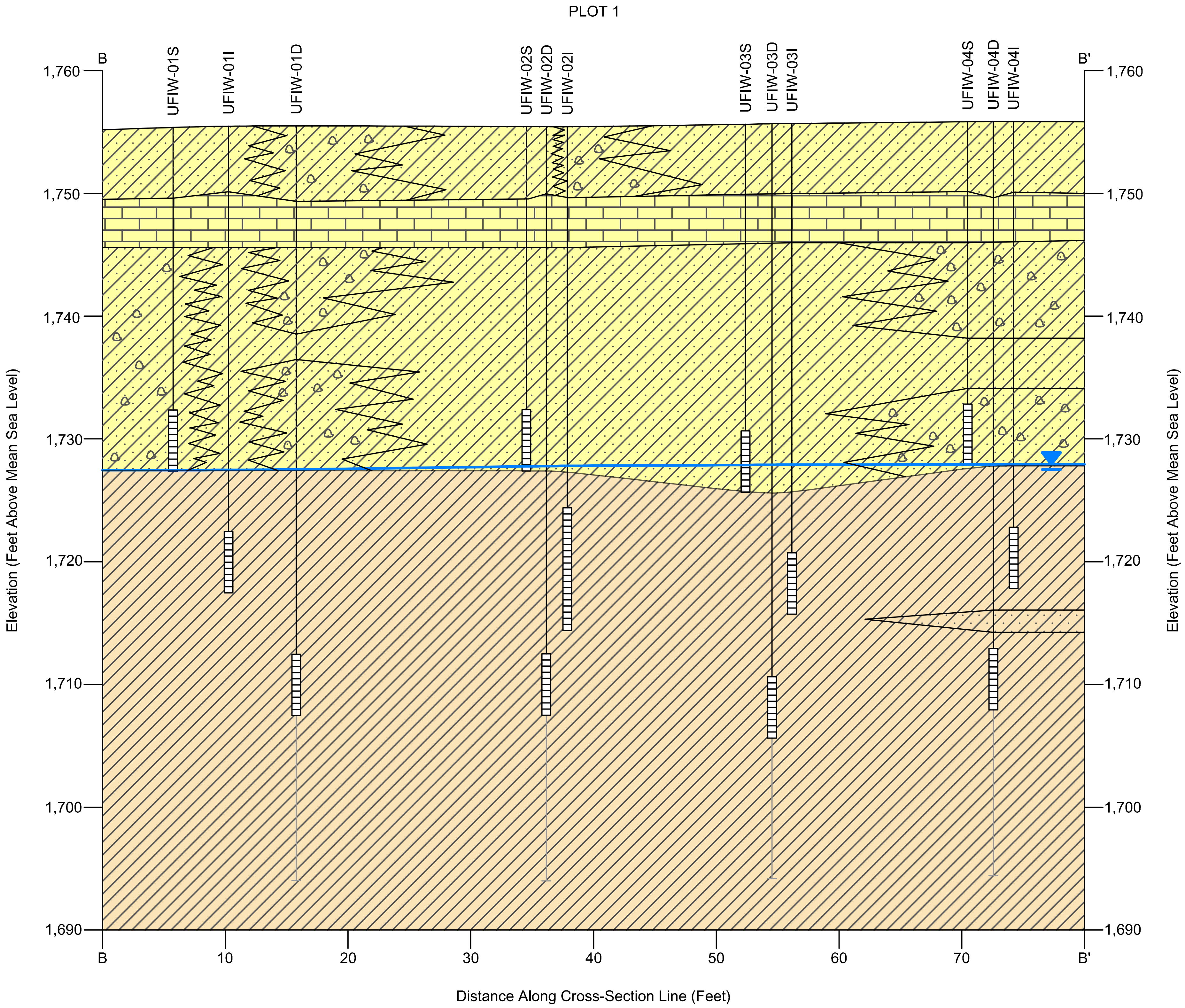
Figure No.	4a

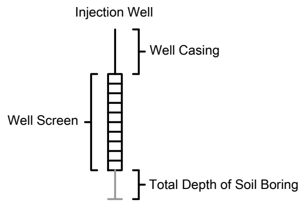
\\tts318fs1\.tt.local\ces\ 87600015-NERT\ FIGURE 4A - GEOLOGICAL CROSS-SECTION A-A□R.dwg



Legend

🟨 Quaternary Alluvium (Qal)
🟧 Upper Muddy Creek Formation (UMCf)
▦ Caliche
▨ Silty Sand with Gravel
▨ Silty Sand
▨ Silt

Groundwater Elevation
S Shallow Well (Screened in Qal)
I Intermediate Well (Screened in UMCf)
D Deep Well (Screened in UMCf)



Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.
2. AMSL = above mean sea level.
3. 3x Vertical Exageration.

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GEOLOGICAL CROSS-SECTION B-B'

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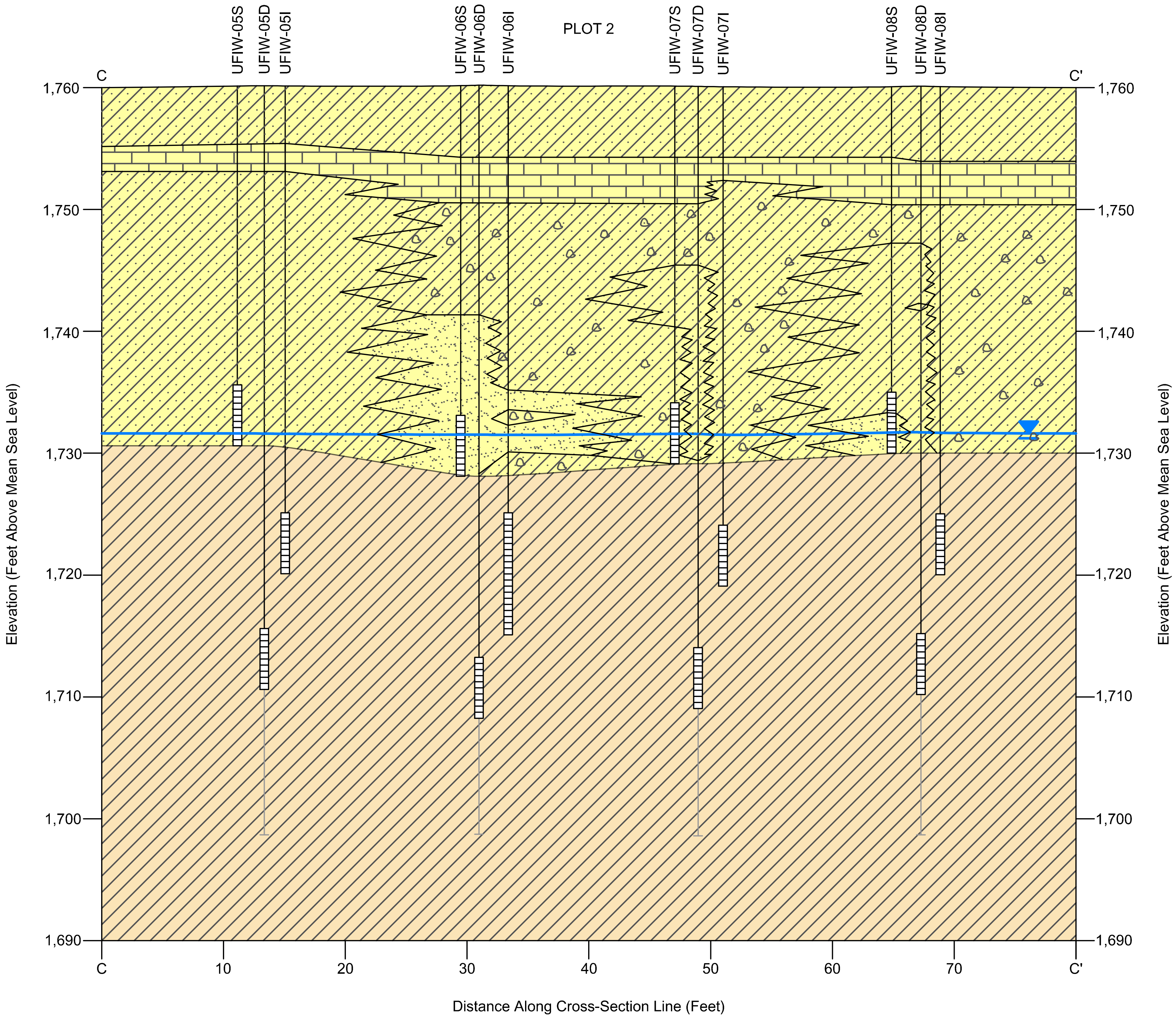
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.
4b

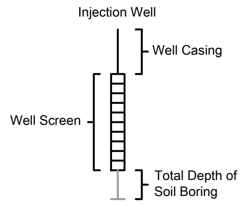
\\tts318fs1\.tt.local\ces\ 87600015-NERT\ FIGURE 4B - GEOLOGICAL CROSS-SECTION B-B'.dwg



\\tts318fs1\.tt.local\ces\ 87600015-NERT\ FIGURE 4C - GEOLOGICAL CROSS-SECTION C-C'.dwg

Legend

- 🟨 Quaternary Alluvium (Qal)
- 🟧 Upper Muddy Creek Formation (UMCf)
- ▤ Caliche
- ▨ Silty Sand with Gravel
- ▨ Silty Sand
- ▨ Silt
- ⁘ Sand
- ▢ Gravel
- ▼ Groundwater Elevation
- S Shallow Well (Screened in Qal)
- I Intermediate Well (Screened in UMCf)
- D Deep Well (Screened in UMCf)



Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.
2. AMSL = above mean sea level.
3. 3x Vertical Exageration.

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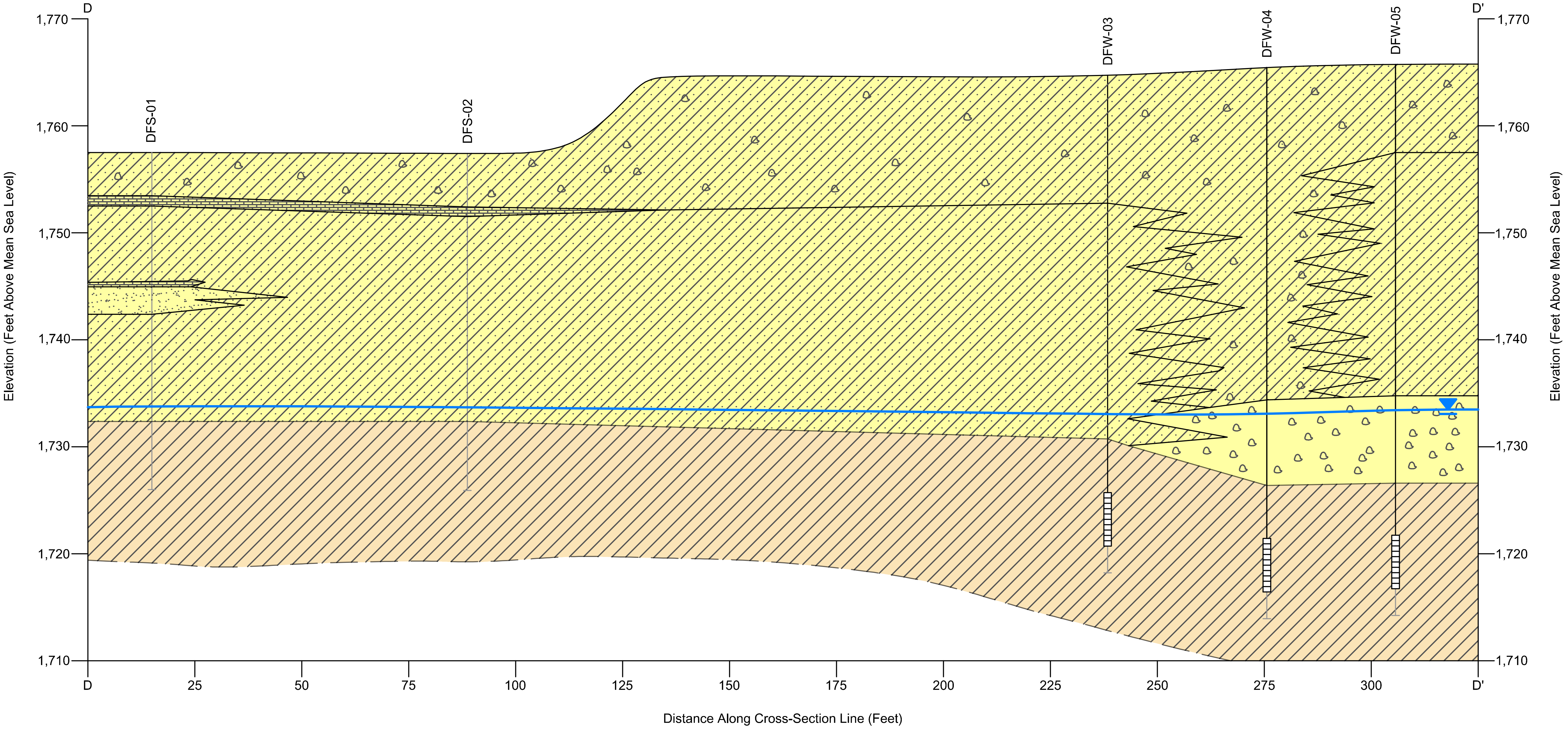
AP AREA DOWN AND UP FLUSHING TREATABILTY STUDY RESULTS REPORT
HENDERSON, NEVADA

GEOLOGICAL CROSS-SECTION C-C'

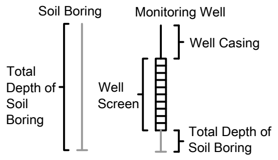
Project No: 117-7502018
Date: APRIL 26, 2018
Designed By: DVK

Figure No.
4c



Legend

- 🟨 Quaternary Alluvium (Qal)
- 🟧 Upper Muddy Creek Formation (UMCf)
- ▦ Caliche
- ▨ Silty Sand with Gravel
- ▨ Silty Sand
- ▨ Silt
- ⁘ Sand
- ⁂ Gravel
- ▼ Groundwater Elevation



Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.
2. AMSL = above mean sea level.
3. 3x Vertical Exageration.

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HENDERSON, NEVADA

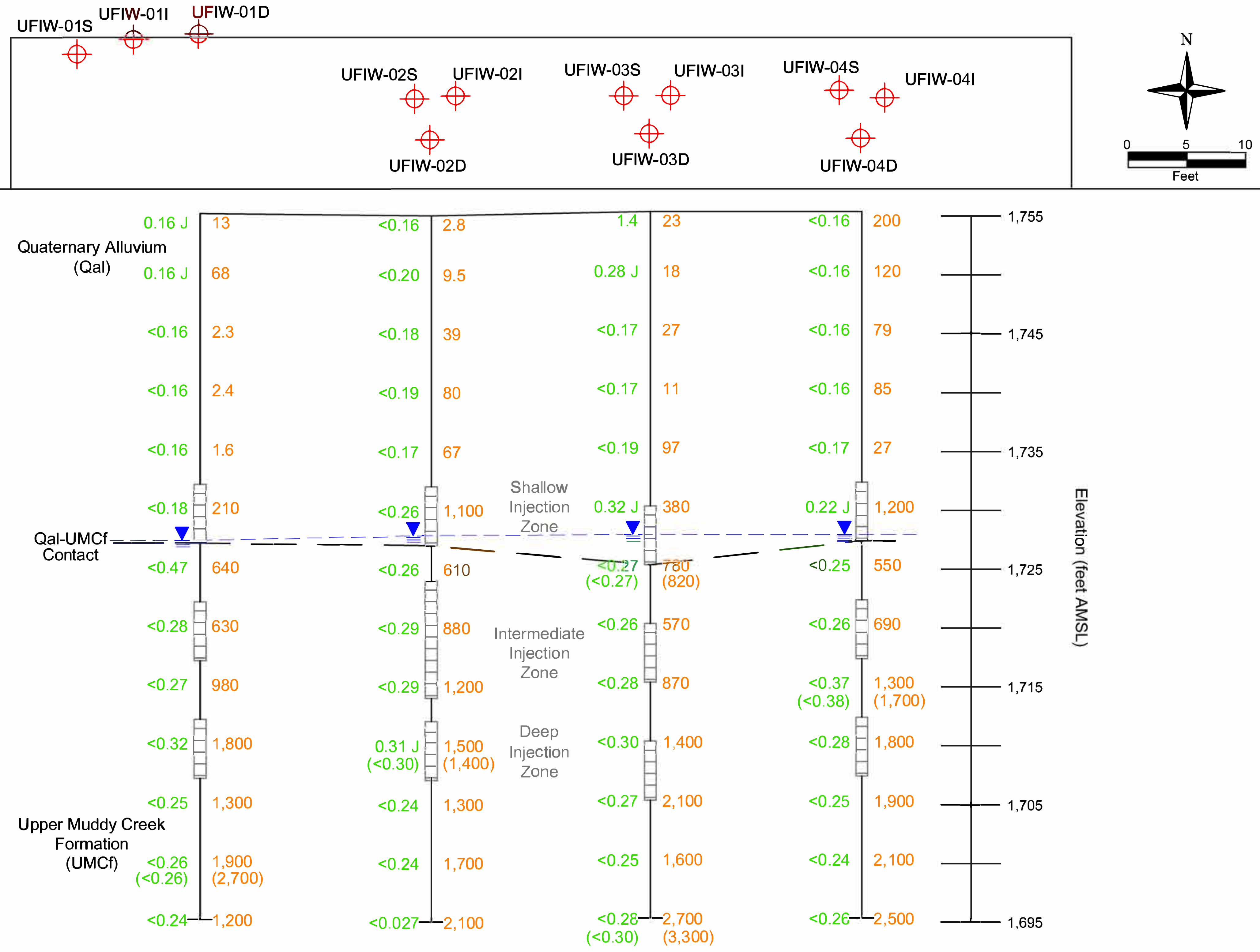
GEOLOGICAL CROSS-SECTION D-D'

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.

4d

\\tts318fs1\.tt.local\ces\ 87600015-NERT\ FIGURE 4D - GEOLOGICAL CROSS-SECTION D-D.dwg



Legend

▼	Groundwater Level
1.4	Pre-Injection Hexavalent Chromium Concentration (mg/kg)
550	Pre-Injection Perchlorate Concentration (mg/kg)
<0.29	Indicates Concentration Below Laboratory Reporting Limit
(<0.26)(2,700)	Indicates Duplicate Sample Concentration
0.31 J	Indicates Concentration is Less Than Lab Reporting Limit but Greater Than or Equal to the Method Detection Limit
AMSL	above mean sea level
mg/kg	milligrams per kilogram

Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.

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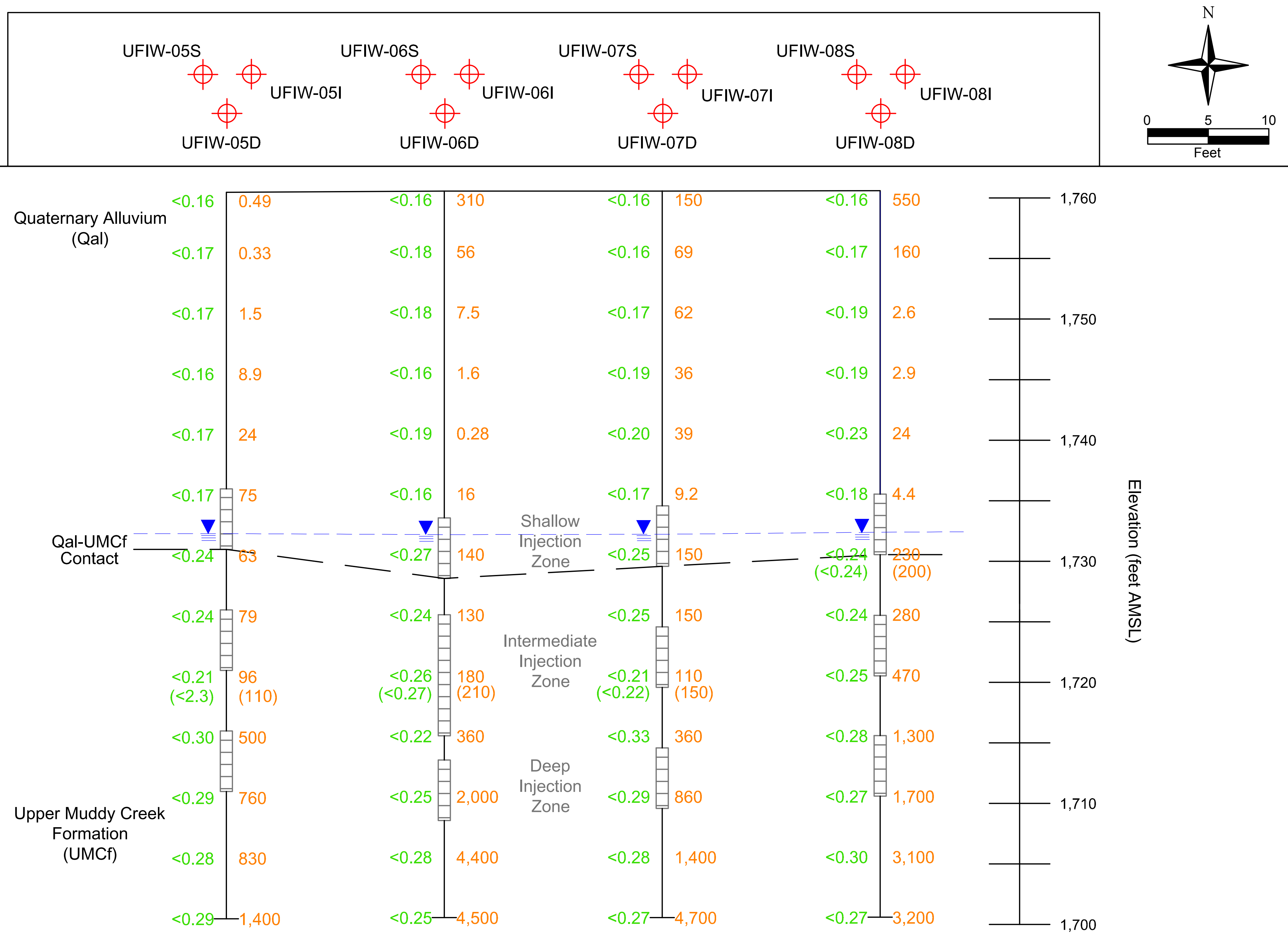
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 1 PRE-INJECTION SOIL CONCENTRATIONS AT DEPTH

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK
Figure No.	5a



Legend

▼	Groundwater Level
<0.16	Pre-Injection Hexavalent Chromium Concentration (mg/kg)
550	Pre-Injection Perchlorate Concentration (mg/kg)
<0.18	Indicates Concentration Below Laboratory Reporting Limit
(110) (<2.3)	Indicates Duplicate Sample Concentration

AMSL	above mean sea level
mg/kg	milligrams per kilogram

Note:

1. Groundwater elevations shown were measured in August 2016 as part of the baseline groundwater monitoring event; recent groundwater elevations not depicted because ongoing groundwater extraction and soil down flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.

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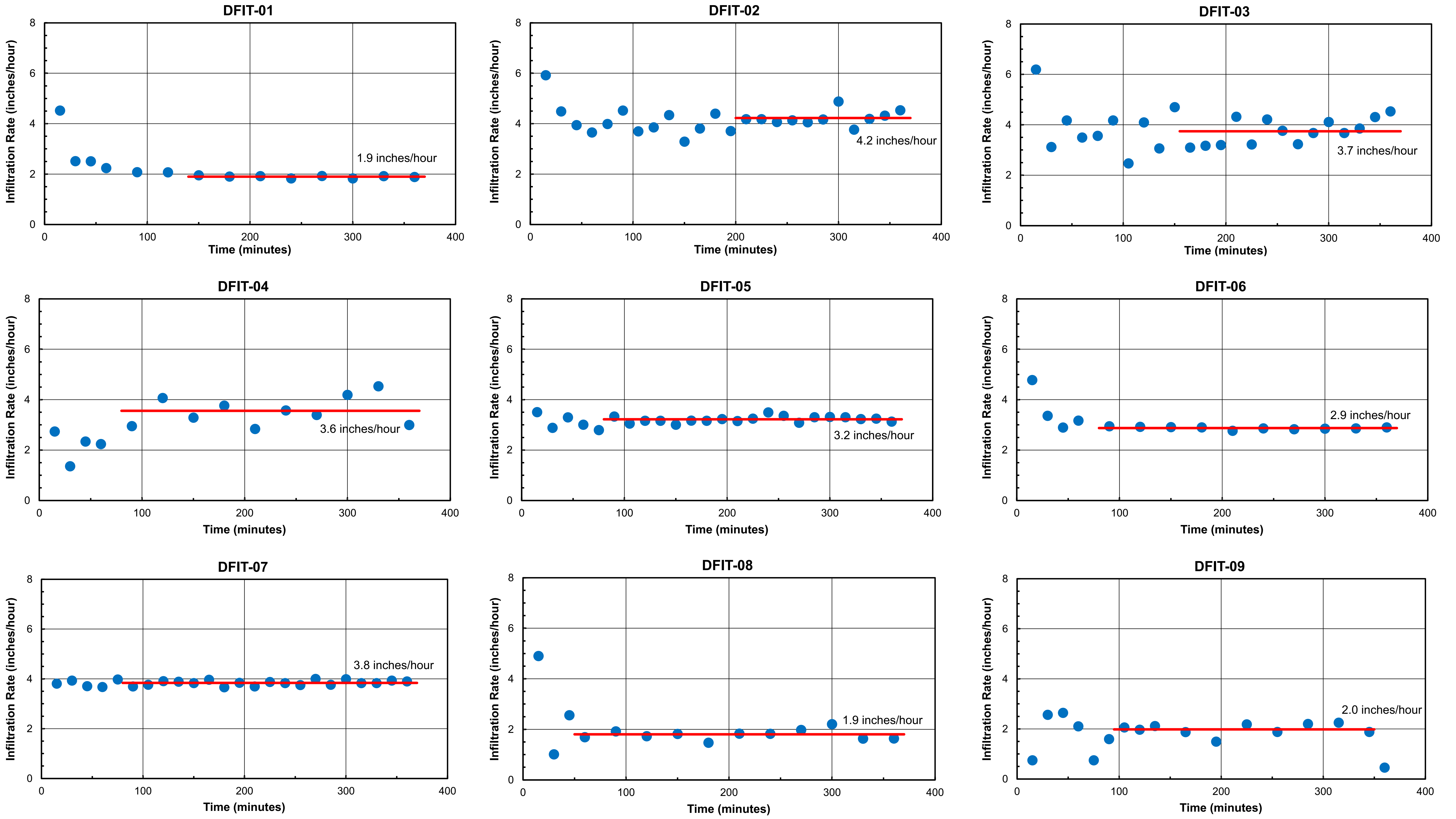
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 2 PRE-INJECTION SOIL CONCENTRATIONS AT DEPTH

Project No: 117-7502018
Date: APRIL 26, 2018
Designed By: DVK

Figure No.
5b



Note:
1. Infiltration test locations correspond to similarly numbered down flushing soil boring and confirmation boring locations shown on Figure 3. For example, DFIT-01 corresponds to the location of DFSB-01/DFCB-01

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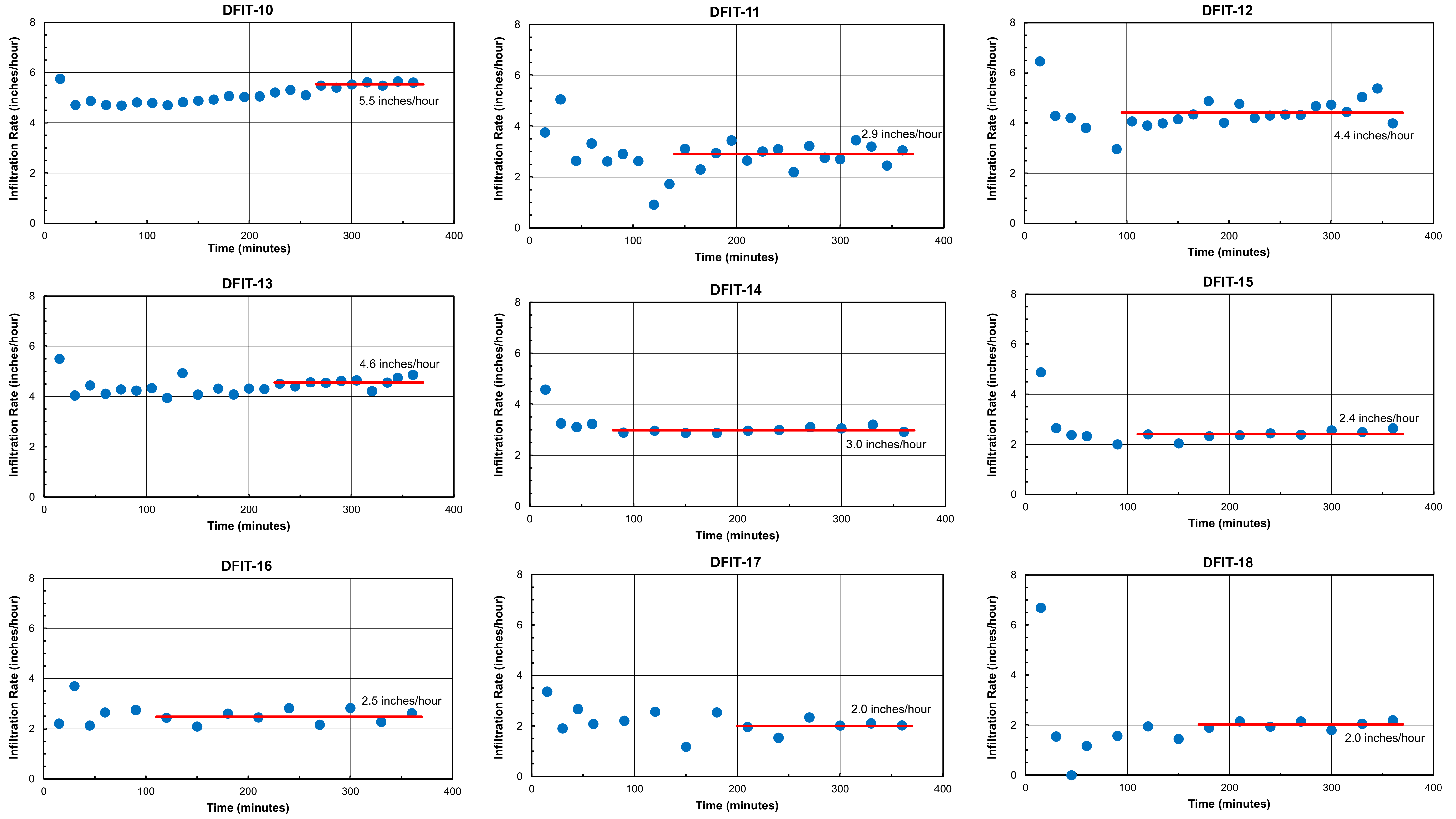
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

INFILTRATION TEST RESULTS
PLOT 1

Project No.:	117-7502018
Date:	APRIL 18, 2018
Designed By:	DVK

Figure No.
6a

P:\GIS\35000_NERT\EVS\Corel\INFILTARTION RESULTS 1.cdr



Note:
1. Infiltration test locations correspond to similarly numbered down flushing soil boring and confirmation boring locations shown on Figure 3. For example, DFIT-10 corresponds to the location of DFSB-10/DFCB-010.

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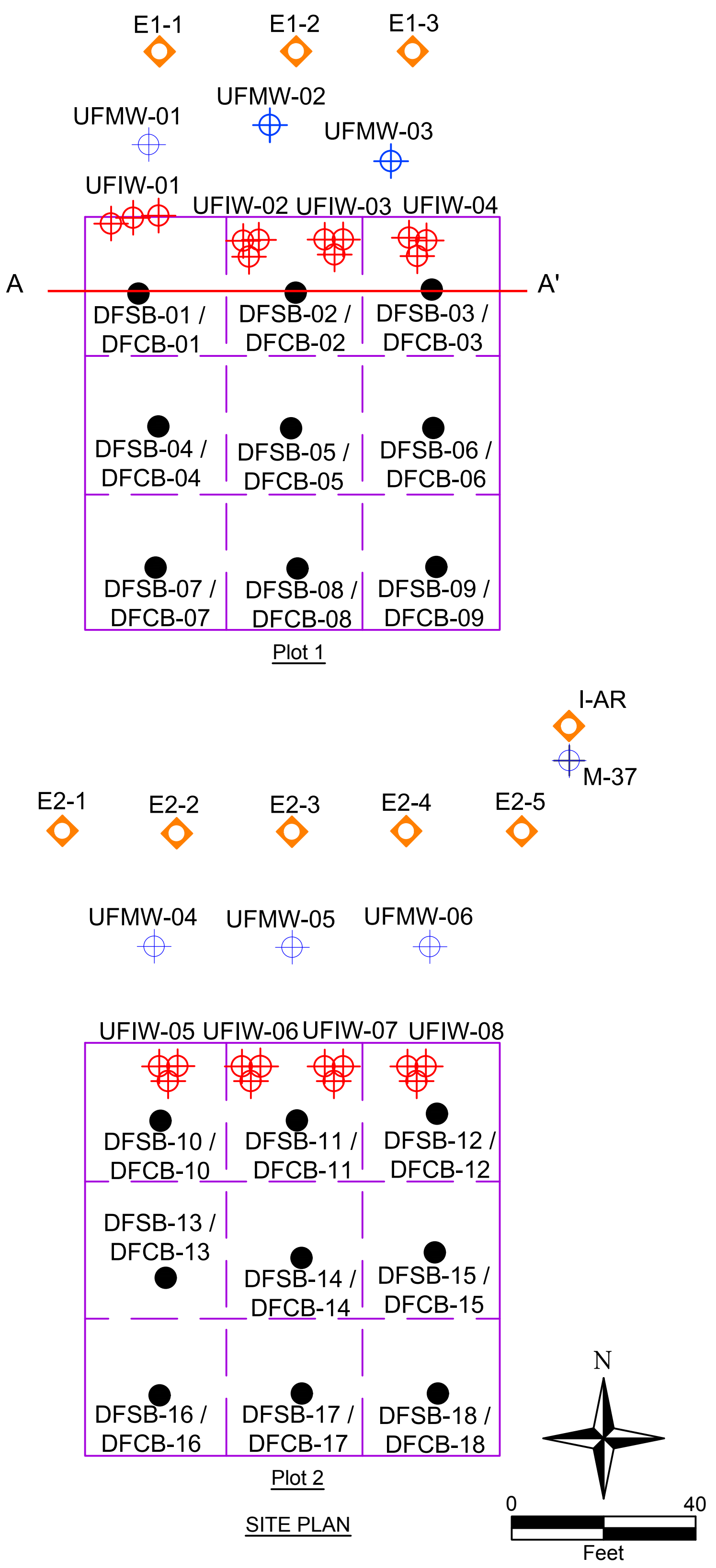
HENDERSON, NEVADA

INFILTRATION TEST RESULTS
PLOT 2

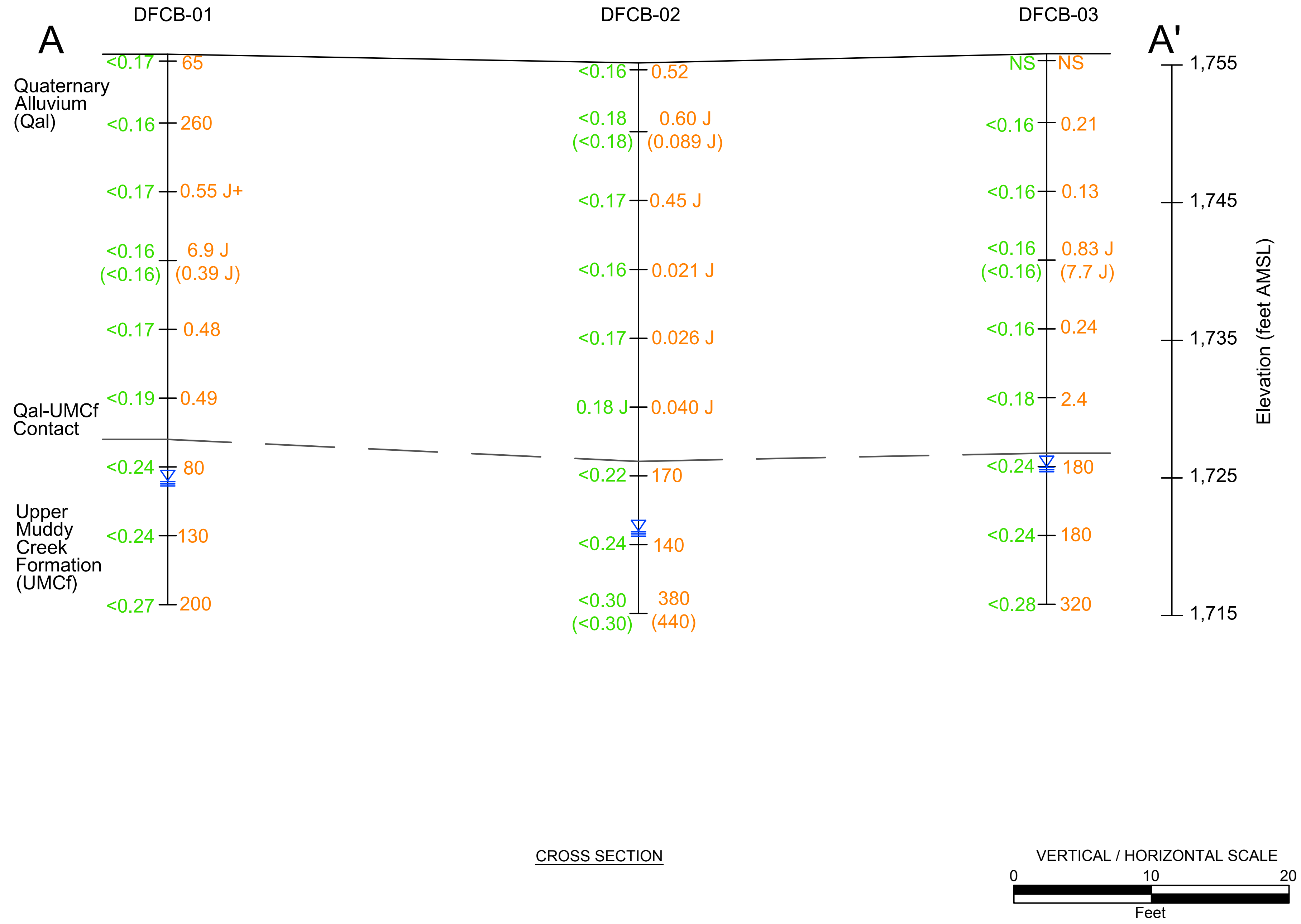
Project No.:	117-7502018
Date:	APRIL 18, 2018
Designed By:	DVK

Figure No.
6b

P:\GIS\35000_NERT\EVS\Corel\INFILTARTION RESULTS 2.cdr



SITE PLAN



CROSS SECTION

Legend

🟦	First Encountered Groundwater	AMSL	above mean sea level	A—A'	Confirmation Sample Cross-Section Line
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram		
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected		
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring		
J	Indicates Estimated Concentration	◇	Extraction Well		
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well		
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well		
		<0.24	Indicates Concentration Is Less Than The Detection Limit		

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

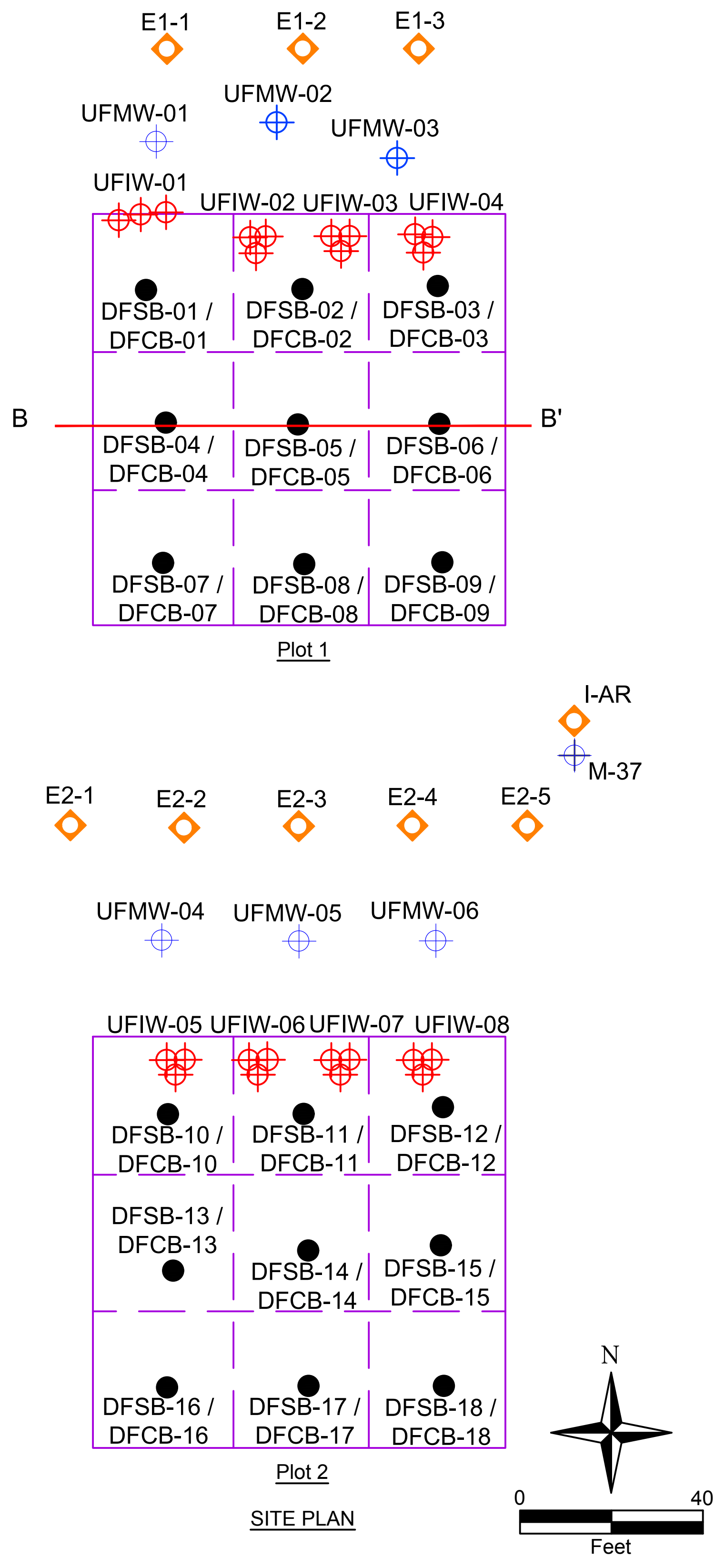
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 1 CONFIRMATION PERCHLORATE AND HEXAVALENT CHROMIUM SOIL CONCENTRATIONS (SECTION 1 OF 3)

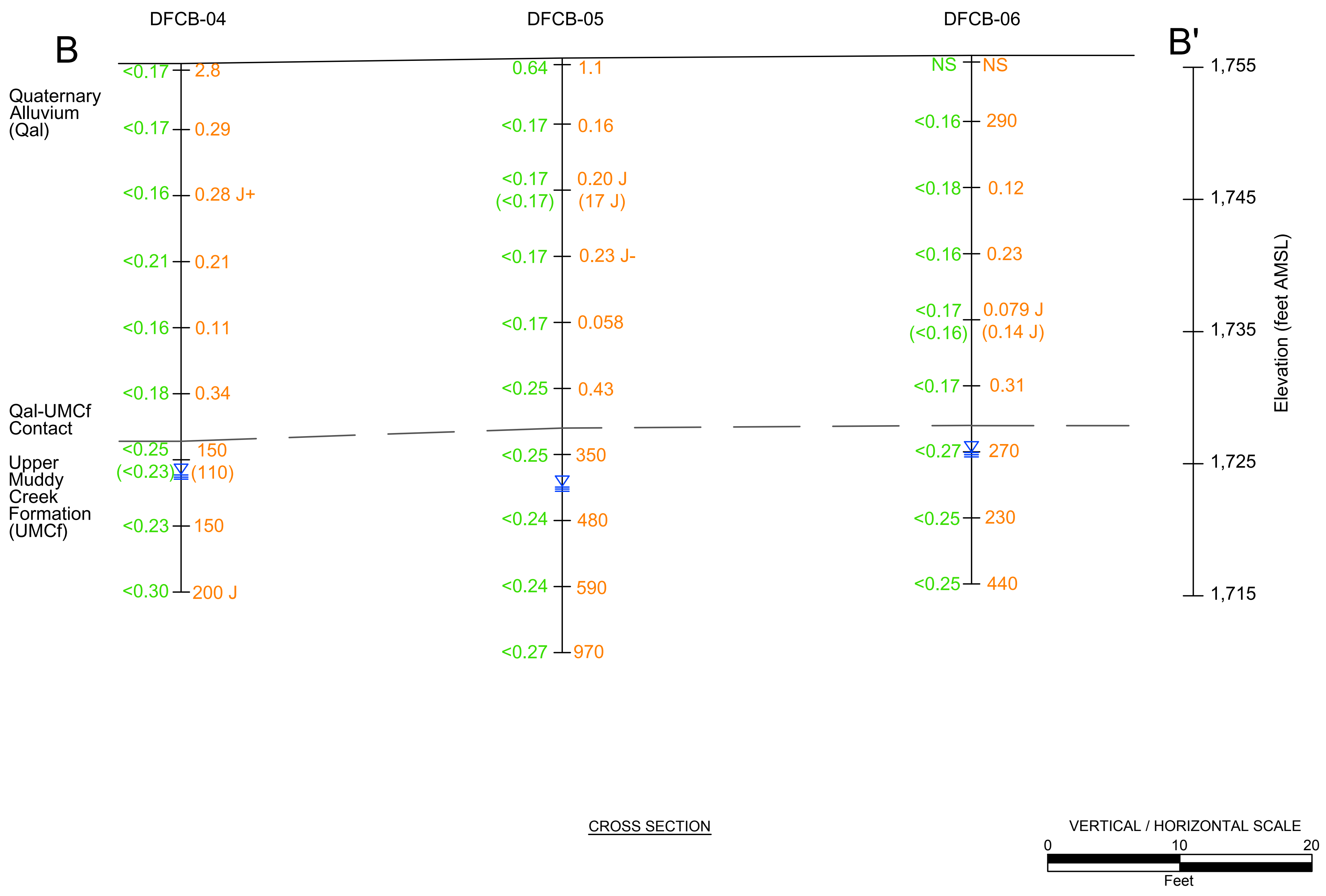
Project No: 117-7502018
Date: OCTOBER 23, 2018
Designed By: CL

Figure No.
7a

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



SITE PLAN



CROSS SECTION

Legend

▽	First Encountered Groundwater	AMSL	above mean sea level
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring
J	Indicates Estimated Concentration	◇	Extraction Well
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well
		<0.24	Indicates Concentration Is Less Than The Detection Limit

B___B' Confirmation Sample Cross-Section Line

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

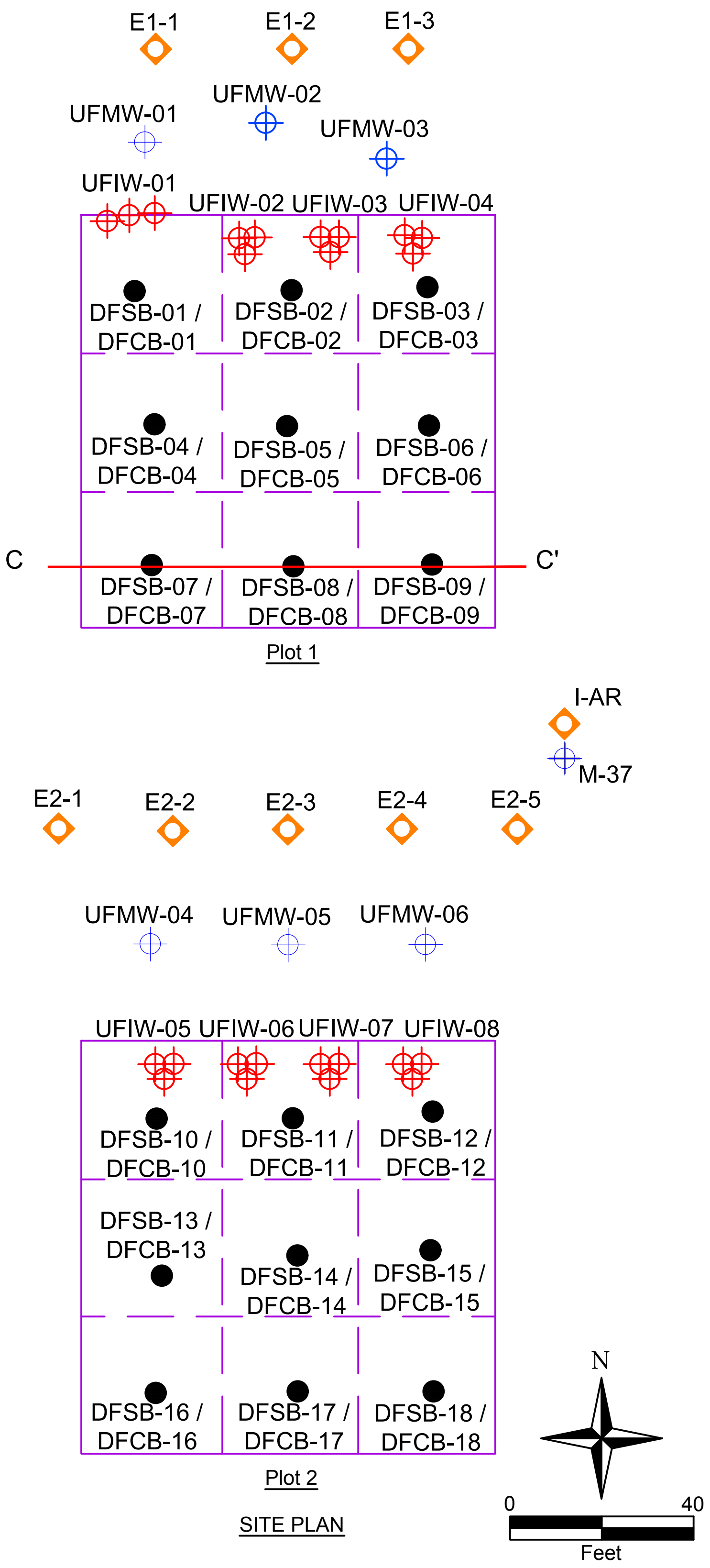
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 1 CONFIRMATION PERCHLORATE AND HEXAVALENT
CHROMIUM SOIL CONCENTRATIONS (SECTION 2 OF 3)

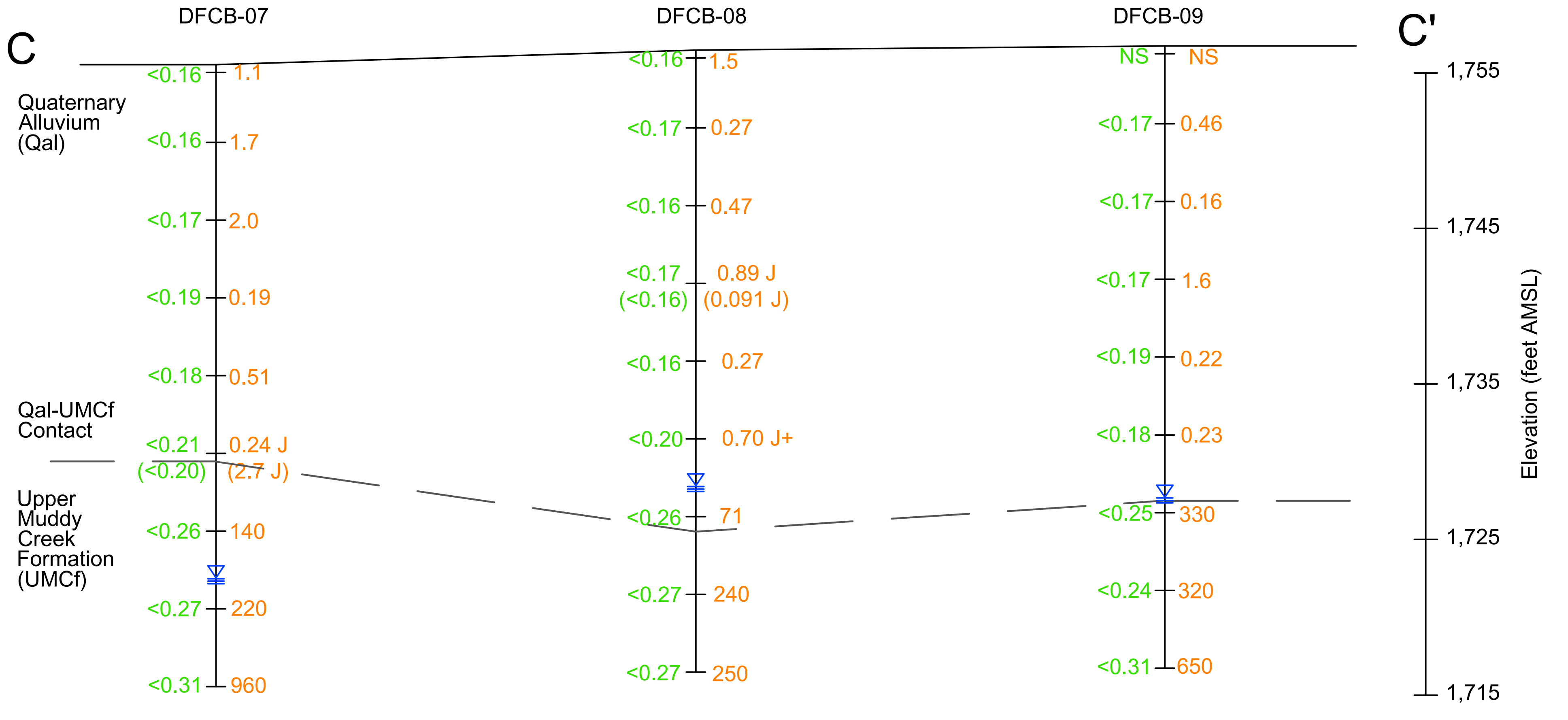
Project No:	117-7502018
Date:	OCTOBER 23, 2018
Designed By:	CL

Figure No.
7b

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



SITE PLAN



CROSS SECTION

VERTICAL / HORIZONTAL SCALE

0 10 20

Feet

Legend

⊻	First Encountered Groundwater	AMSL	above mean sea level
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring
J	Indicates Estimated Concentration	◇	Extraction Well
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well
		<0.24	Indicates Concentration Is Less Than The Detection Limit

C___C' Confirmation Sample Cross-Section Line

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HENDERSON, NEVADA

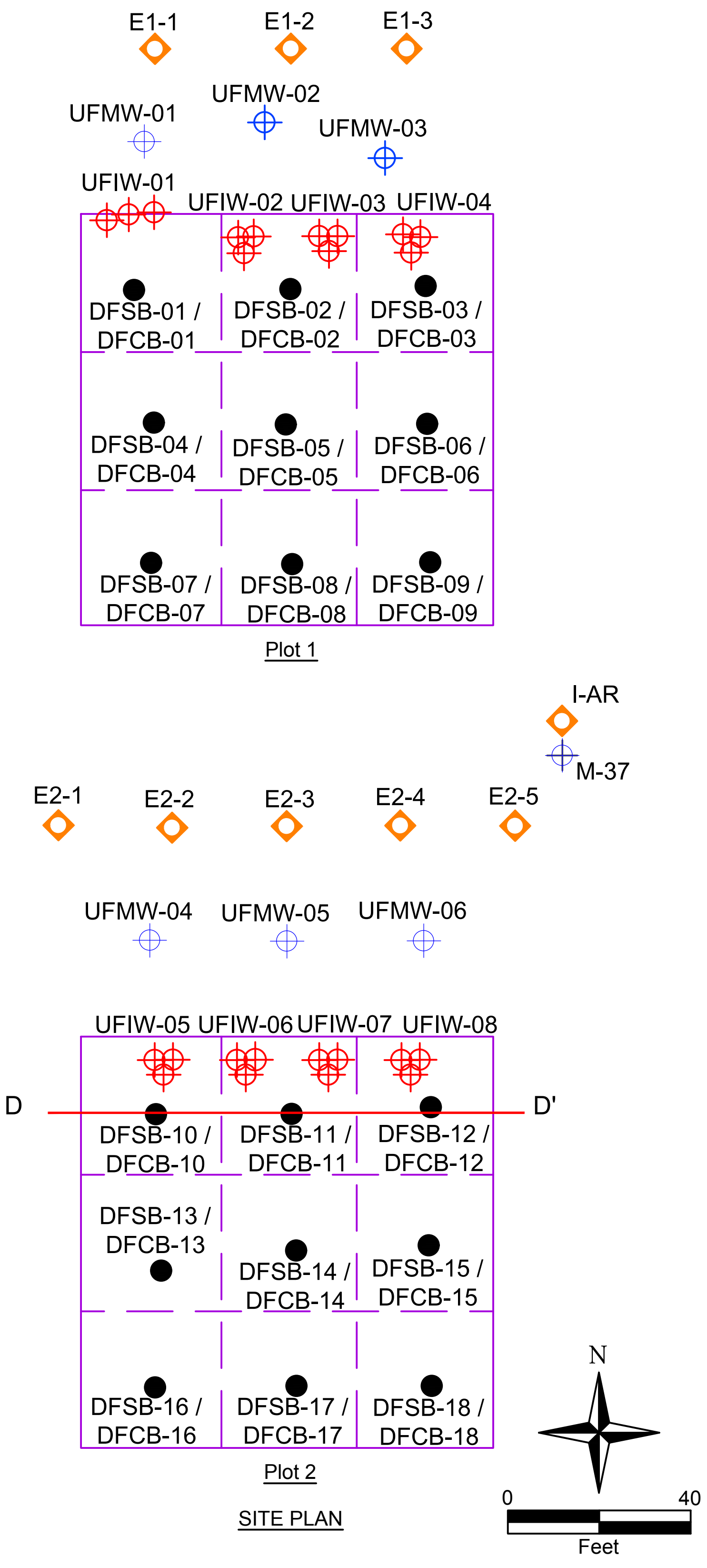
PLOT 1 CONFIRMATION PERCHLORATE AND HEXAVALENT
CHROMIUM SOIL CONCENTRATIONS (SECTION 3 OF 3)

Project No:	117-7502018
Date:	OCTOBER 23, 2018
Designed By:	CL

Figure No.

7c

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



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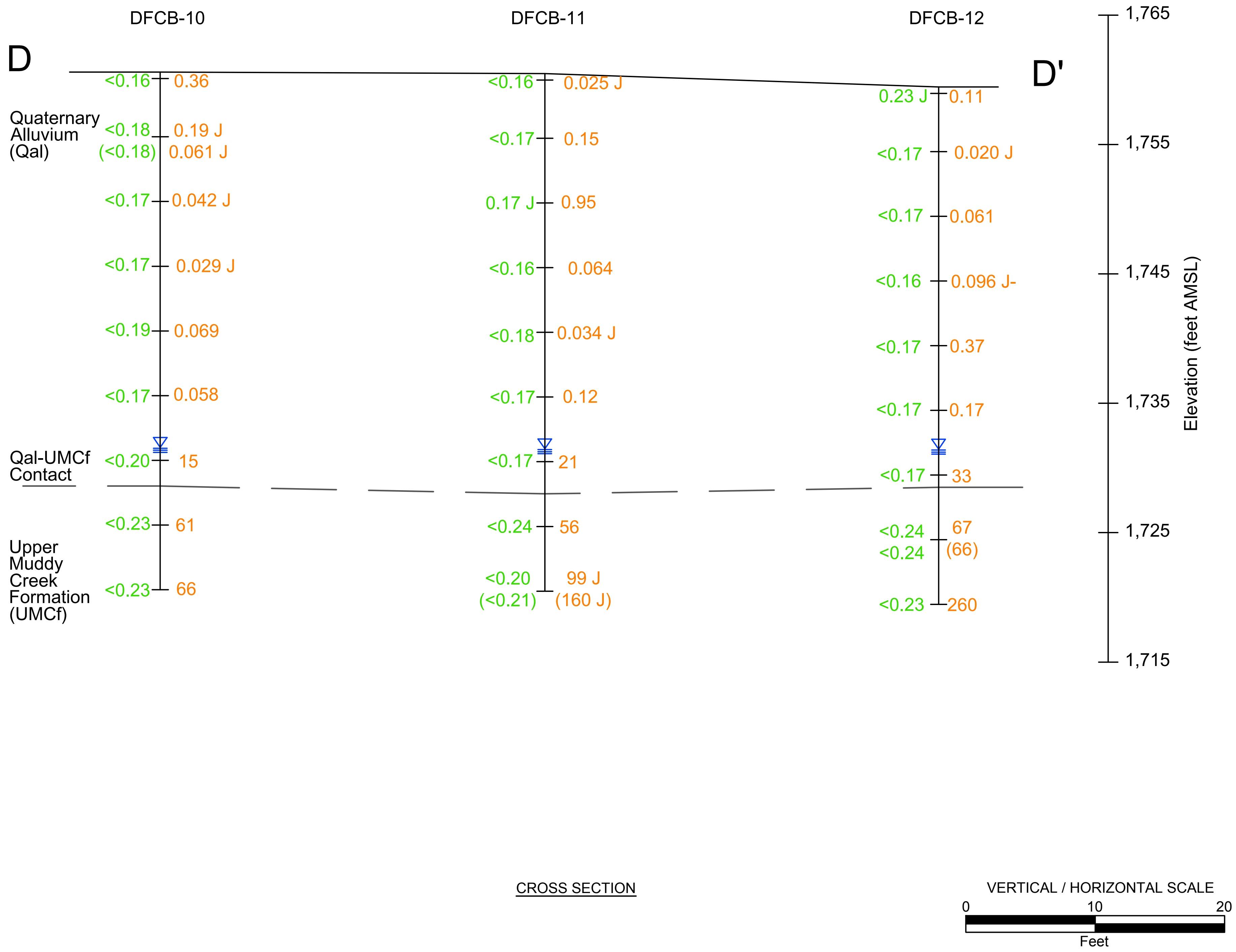

CROSS SECTION

Legend

⊻	First Encountered Groundwater	AMSL	above mean sea level	D___D'	Confirmation Sample Cross-Section Line
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram		
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected		
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring		
J	Indicates Estimated Concentration	◇	Extraction Well		
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well		
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well		
		<0.24	Indicates Concentration Is Less Than The Detection Limit		

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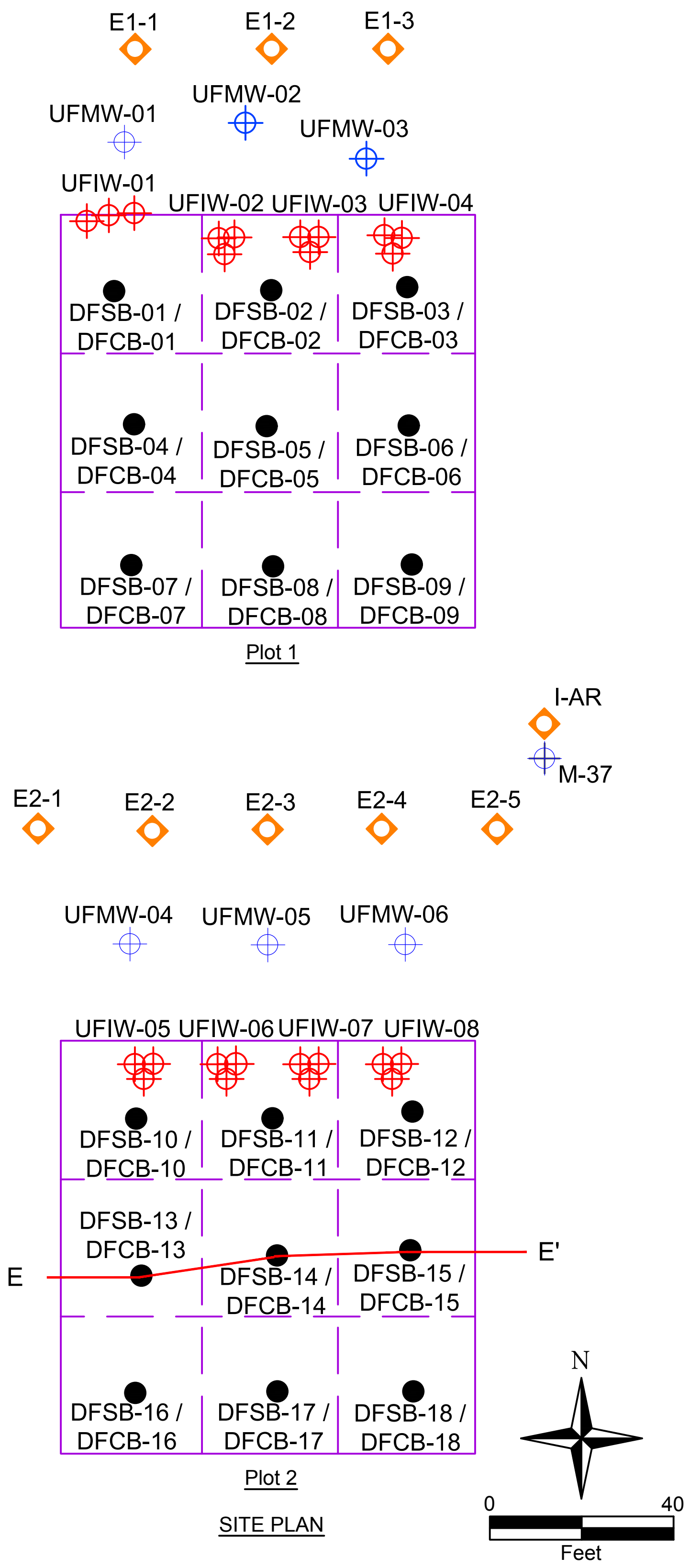
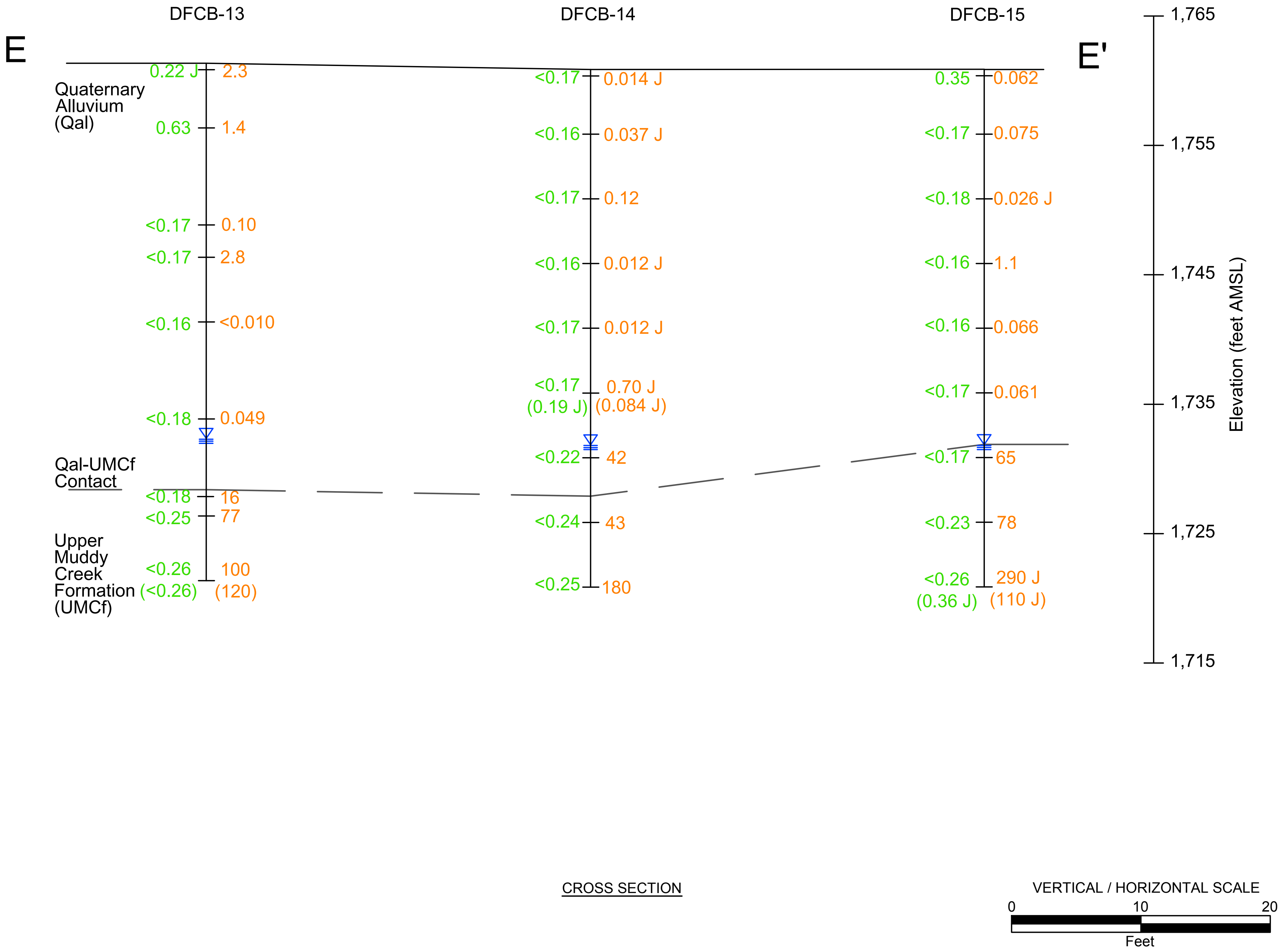
PLOT 2 CONFIRMATION PERCHLORATE AND HEXAVALENT
CHROMIUM SOIL CONCENTRATIONS (SECTION 1 OF 3)

Project No:	117-7502018
Date:	OCTOBER 23, 2018
Designed By:	CL
Figure No.	7d

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



SITE PLAN



CROSS SECTION

Legend

⊻	First Encountered Groundwater	AMSL	above mean sea level
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring
J	Indicates Estimated Concentration	◇	Extraction Well
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well
		<0.24	Indicates Concentration Is Less Than The Detection Limit

E ___ E' Confirmation Sample Cross-Section Line

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

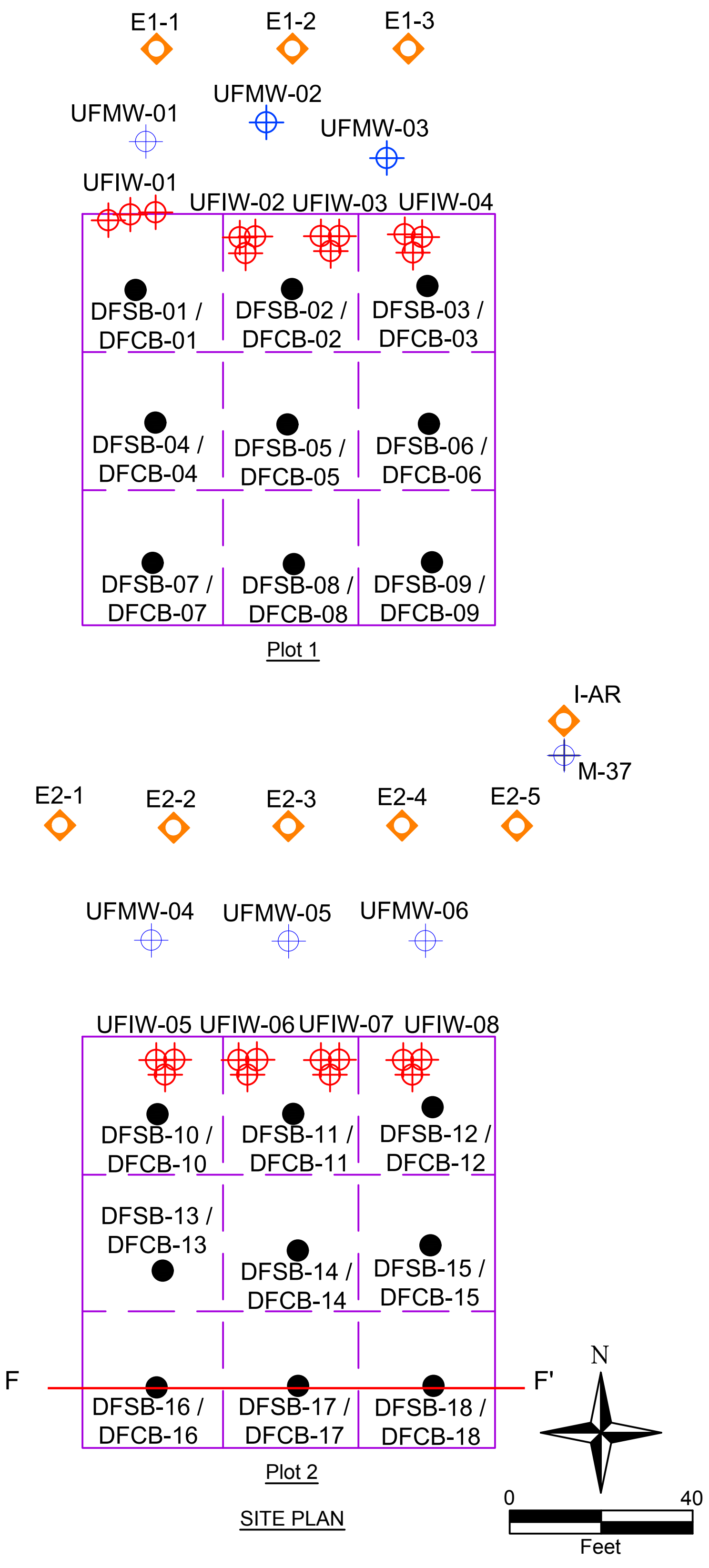
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 2 CONFIRMATION PERCHLORATE AND HEXAVALENT
CHROMIUM SOIL CONCENTRATIONS (SECTION 2 OF 3)

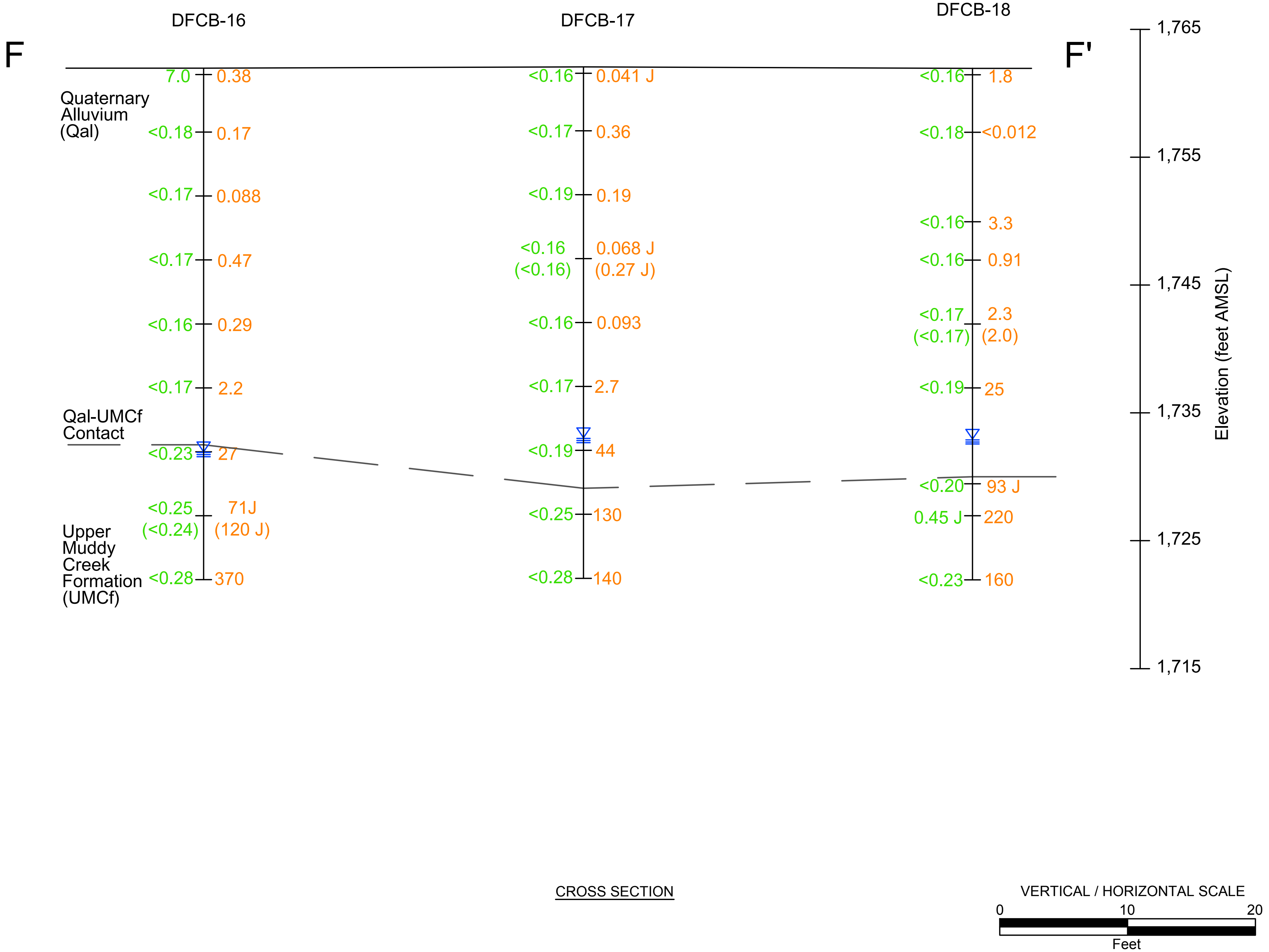
Project No: 117-7502018
Date: OCTOBER 23, 2018
Designed By: CL

Figure No.
7e

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



SITE PLAN



CROSS SECTION

Legend

∇	First Encountered Groundwater	AMSL	above mean sea level	F___F'	Confirmation Sample Cross-Section Line
65	Confirmation Perchlorate Concentration (mg/kg)	mg/kg	milligrams per kilogram		
210	Confirmation Hexavalent Chromium Concentration (mg/kg)	NS	No sample collected		
(440)	Indicates Duplicate Sample Concentration	●	Soil Boring		
J	Indicates Estimated Concentration	◇	Extraction Well		
J+	Indicates Estimated Concentration, May Be Biased High	⊕	Monitoring Well		
J-	Indicates Estimated Concentration, May Be Biased Low	⊕	Injection Well		
		<0.24	Indicates Concentration Is Less Than The Detection Limit		

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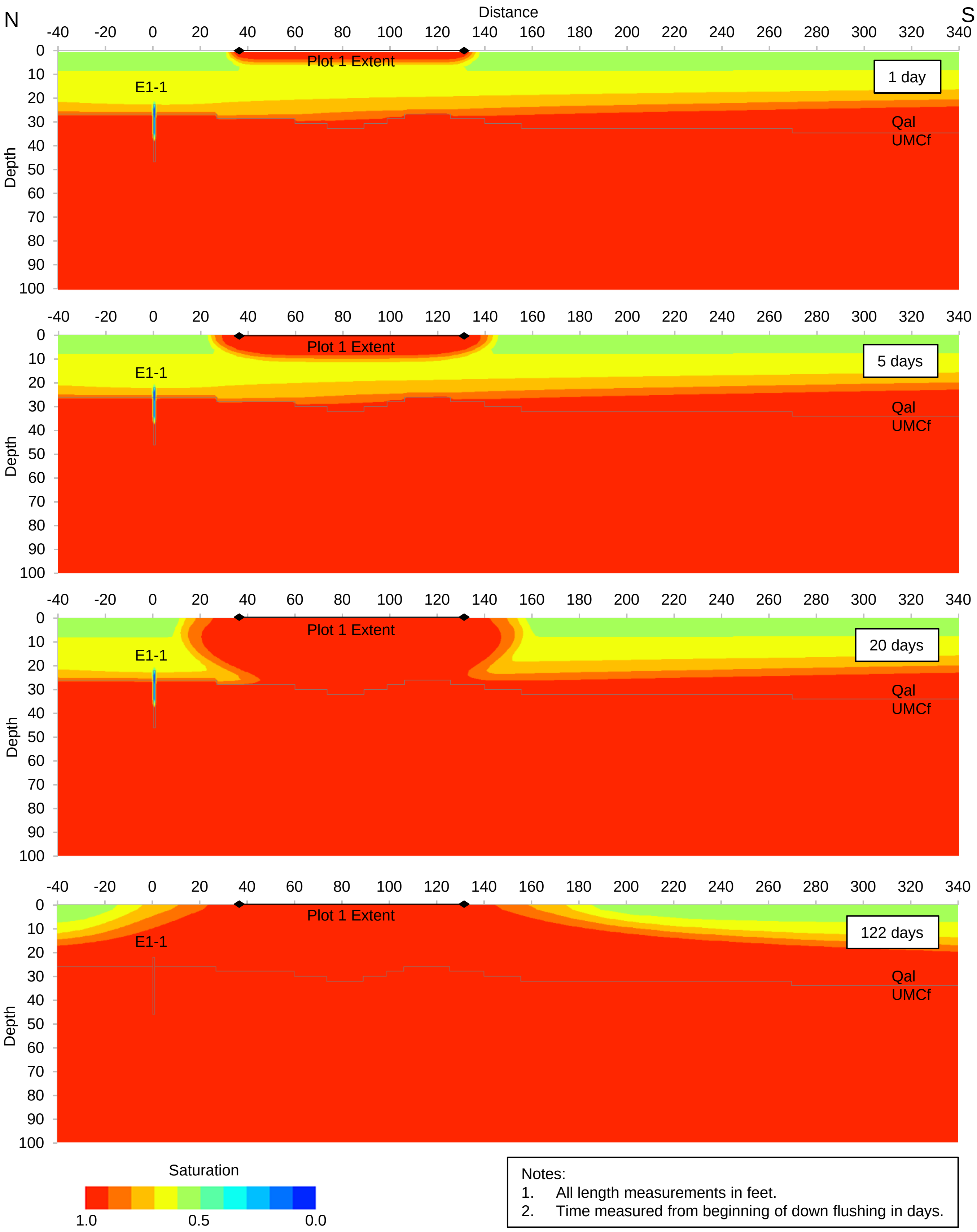
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 2 CONFIRMATION PERCHLORATE AND HEXAVALENT CHROMIUM SOIL CONCENTRATIONS (SECTION 3 OF 3)

Project No: 117-7502018
Date: OCTOBER 23, 2018
Designed By: CL
Figure No. 7f

\\tts318fs3.tt.local\CES\Projects\87600M13-18\CAD\Final Report\ FIGURE 7 - CONFIRMATION PERCHLORATE CHROMIUM CROSS SECTIONS.dwg



Notes:

1. All length measurements in feet.
2. Time measured from beginning of down flushing in days.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

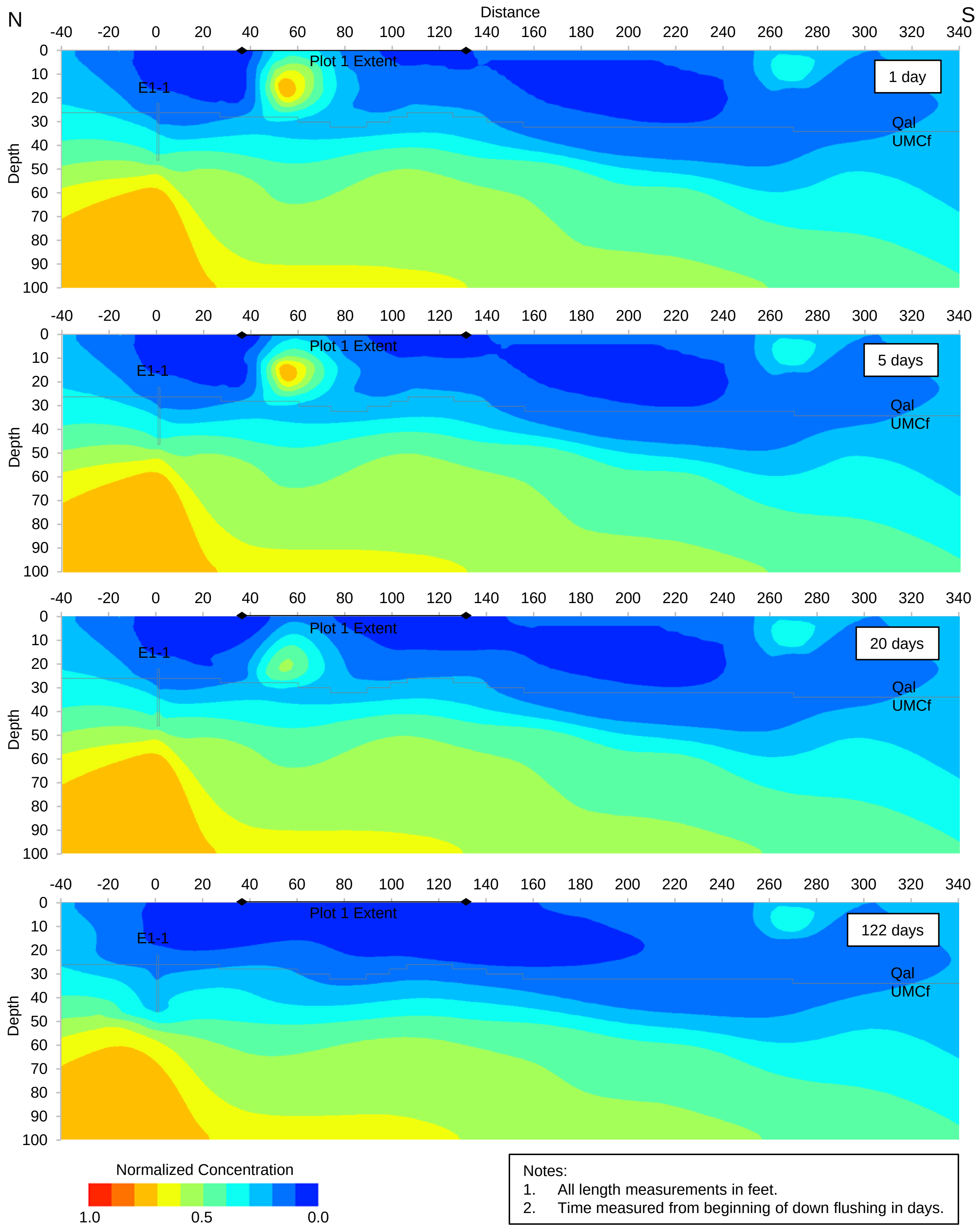
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

SIMULATED SATURATION: PLOT 1

Project No.: 117-7502018
Date: MAY 4, 2018
Designed By: ACC

Figure No.
8a

\\tts134fs1\SUP-Projects\BLD01\520225_NERT\AP-Area Up Down Flush TS\Treatability Results Report\ Fig8_Plot1_revD.pptx



Notes:
1. All length measurements in feet.
2. Time measured from beginning of down flushing in days.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

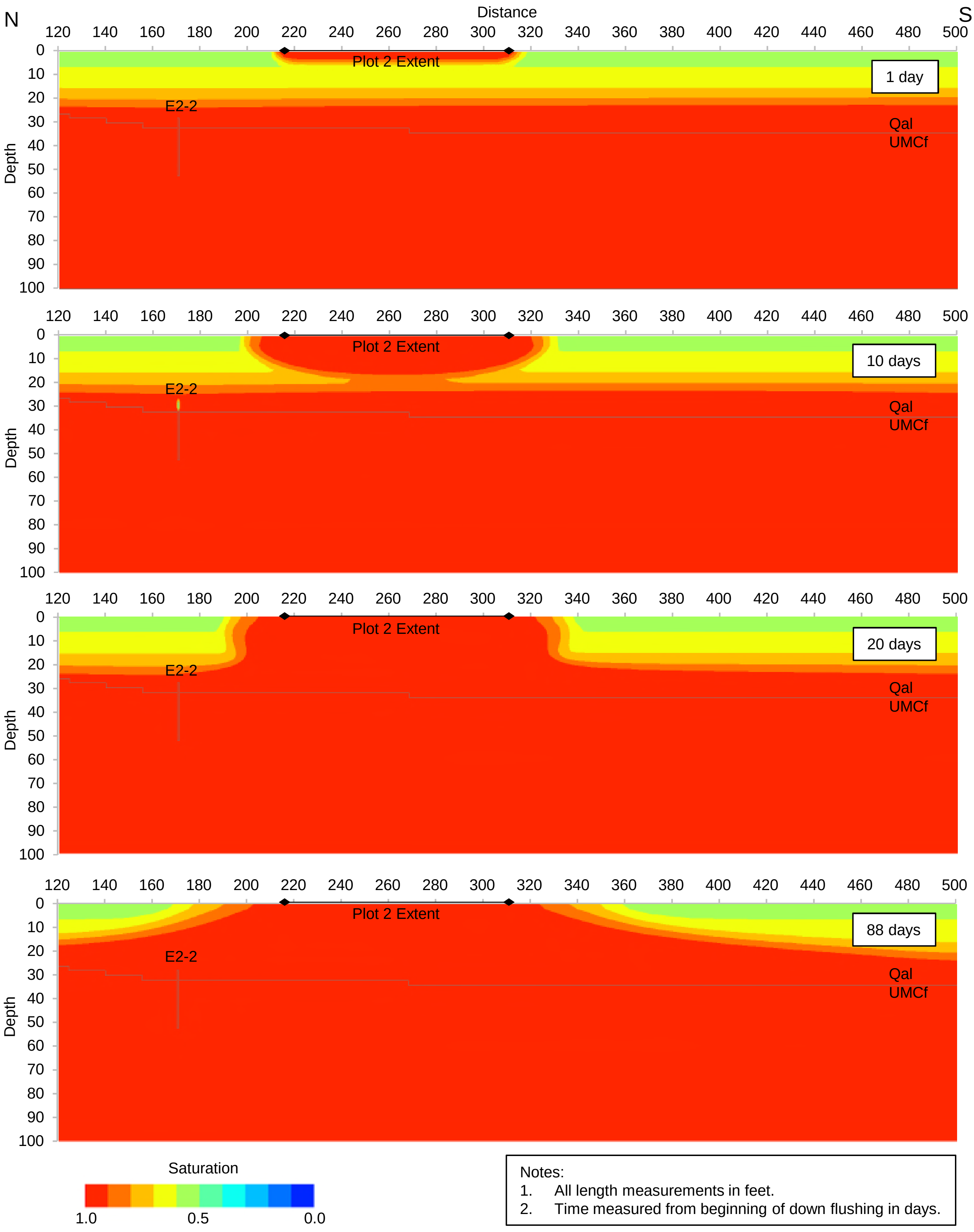
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

SIMULATED CONCENTRATION: PLOT 1

Project No.:	117-7502018
Date:	MAY 4, 2018
Designed By:	ACC

Figure No.
8b

\\tts134fs1\SUP-Projects\BLD01\520225_NERT\AP-Area Up Down Flush TS\Treatability Results Report\ Fig8_Plot1_revD.pptx



Notes:
1. All length measurements in feet.
2. Time measured from beginning of down flushing in days.

\\tts134fs1\SUP-Projects\BLD01\520225_NERTAP-Area Up Down Flush TS\Treatability Results Report\ Fig9_Plot2_revD.pptx

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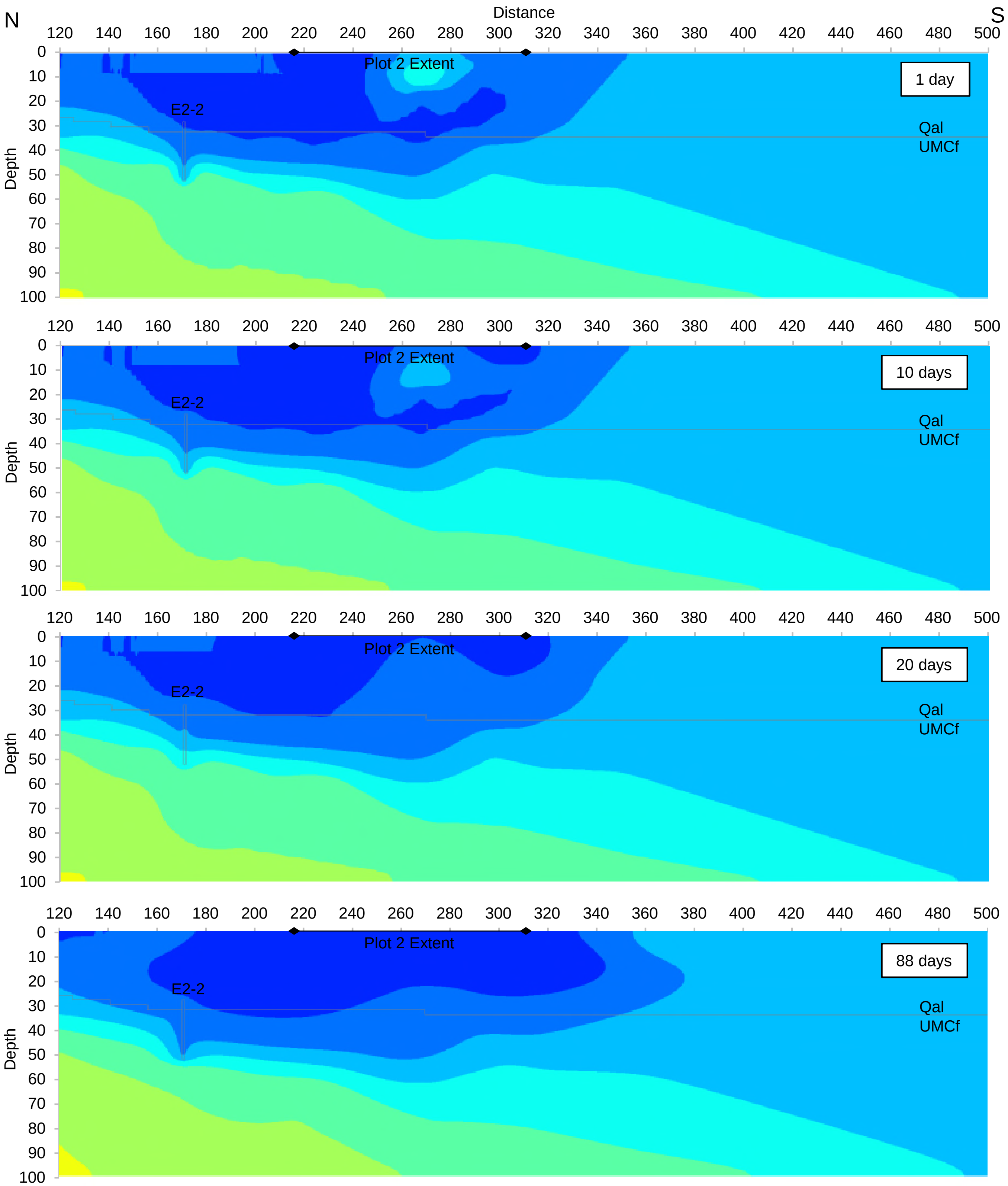
HENDERSON, NEVADA

SIMULATED SATURATION: PLOT 2

Project No.:	117-7502018
Date:	MAY 4, 2018
Designed By:	ACC

Figure No.

9a



Normalized Concentration

🟥🟧🟧🟨🟩🟩🟦🟦🟦🟦

1.0 0.5 0.0

Notes:
1. All length measurements in feet.
2. Time measured from beginning of down flushing in days.

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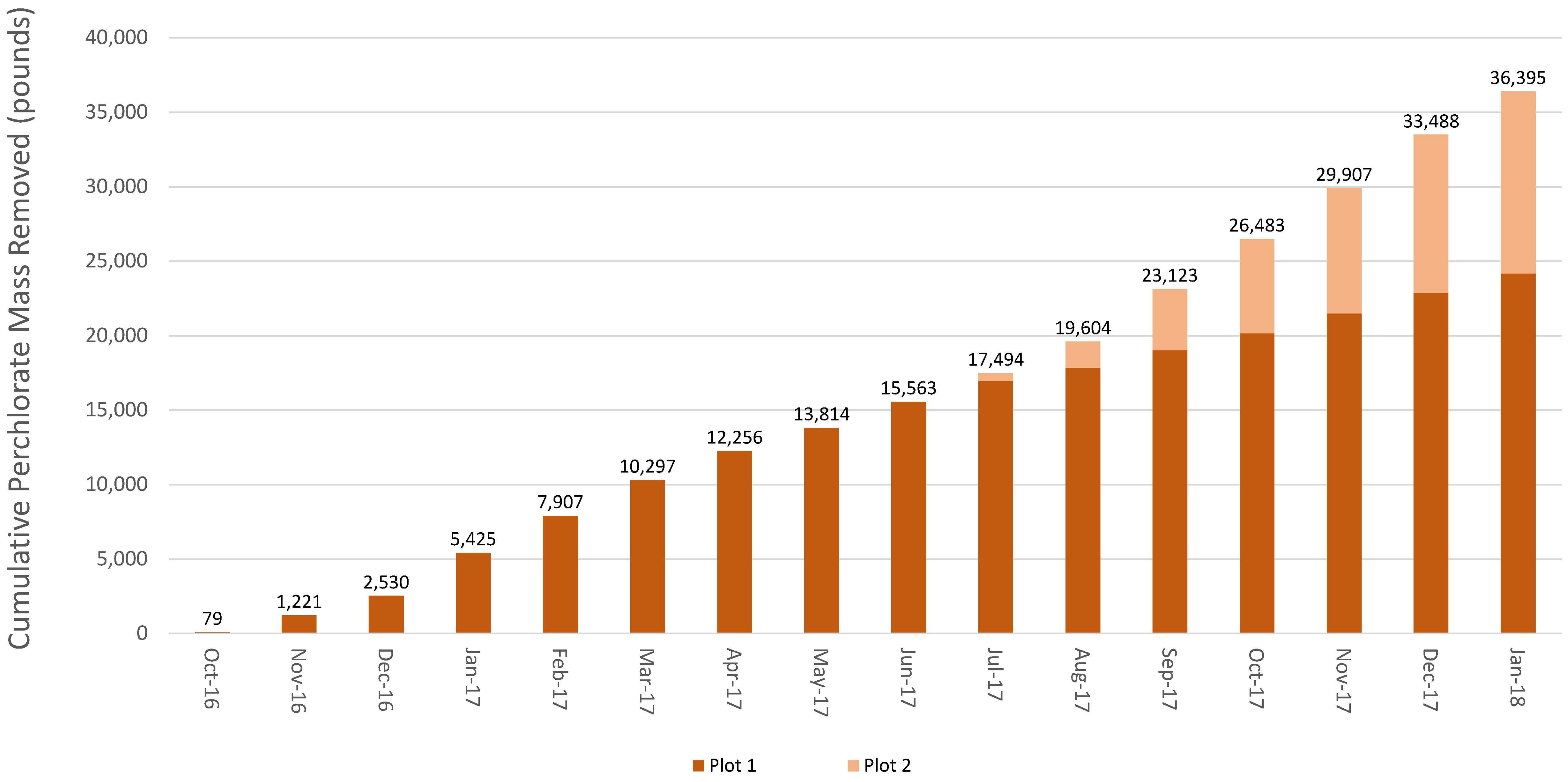
HENDERSON, NEVADA

SIMULATED CONCENTRATION: PLOT 2

Project No.:	117-7502018
Date:	MAY 4, 2018
Designed By:	ACC

Figure No.
9b

\\tts134fs1\SUP-Projects\BLD01\520225_NERT\AP-Area Up Down Flush TS\Treatability Results Report\ Fig9_Plot2_revD.pptx



Note:

1. Only Plot 1 extraction system operated from October 2016 to July 2017; Concurrent operation of Plot 2 extraction system began in July 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

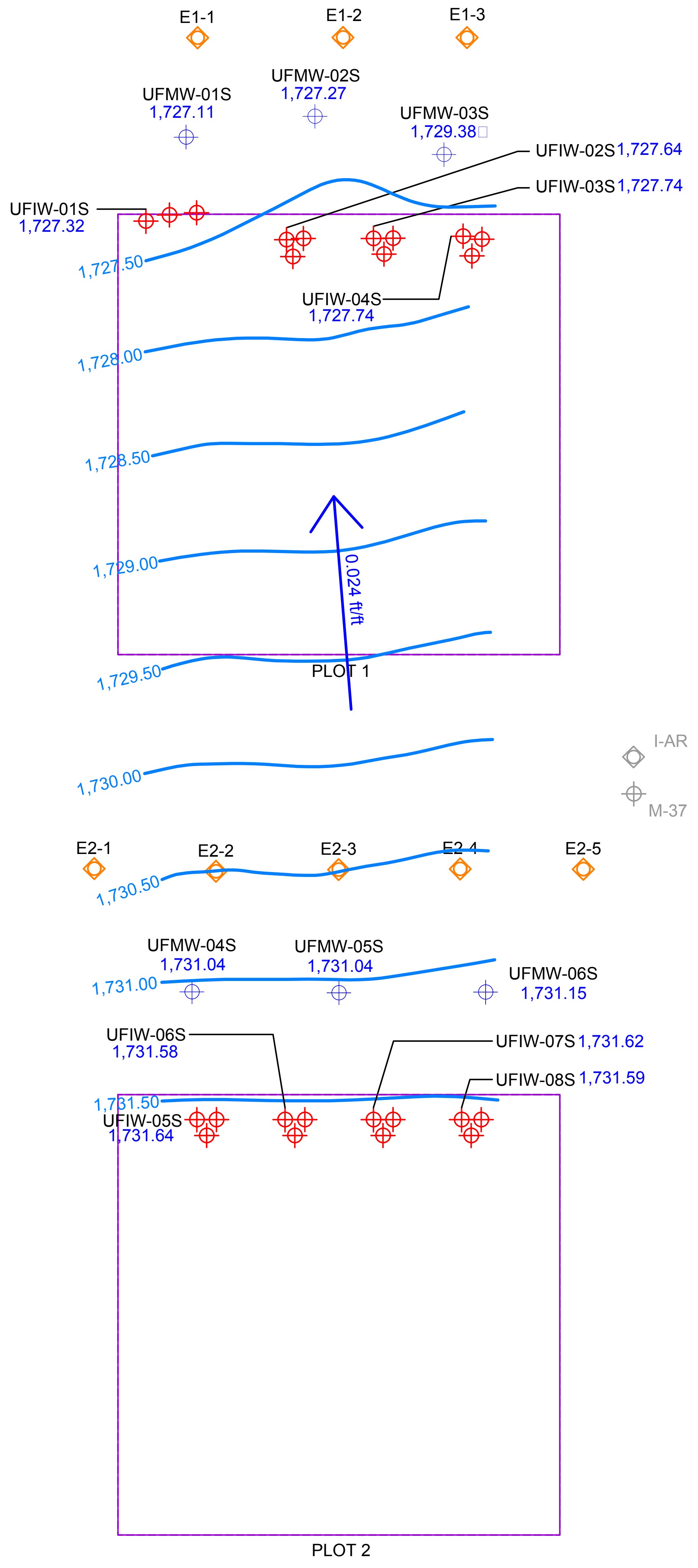
EXTRACTION SYSTEM
CUMULATIVE PERCHLORATE MASS REMOVED

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.

10

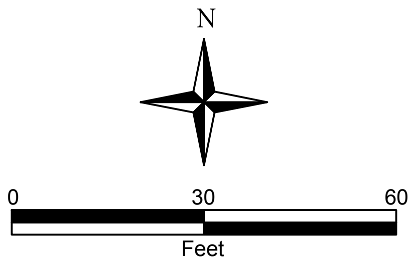
\\tts318fs3\.tt.local\ces\87600014-NERT-M12\ FIGURE 10 - EXTRACTION SYSTEM - CUMULATIVE PERCHLORATE MASS REMOVED.dwg



Legend

UFMW-01S ⌖	Monitoring Well (Triple Completion)
UFIW-01S ⌖	Injection Well (Single Completion)
E1-2 ◇	Extraction Well
M-37 ⌖	Monitoring Well (Not Associated with Treatability Study)
I-AR ◇	IWF Extraction Well (Not Associated with Treatability Study)
1,731.64	Groundwater Elevation (feet AMSL)
1,731.50 ∼	Groundwater Elevation Contour (feet AMSL)
0.024 ft/ft →	Flow Direction and Hydraulic Gradient (ft/ft)
S	Shallow Well (Screened in □al)
□al	□uaternary Alluvium
AMSL	Above Mean Sea Level
ft/ft	Feet per Foot
□	Groundwater elevation not used in developing contours

Notes:
1. Only shallow wells were used to develop shallow groundwater contours.
2. Groundwater elevations shown were measured in August 2016; recent groundwater elevations not depicted because ongoing groundwater extraction and soil flushing activities as part of the treatability study have created conditions that are not as representative of natural groundwater elevations.



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

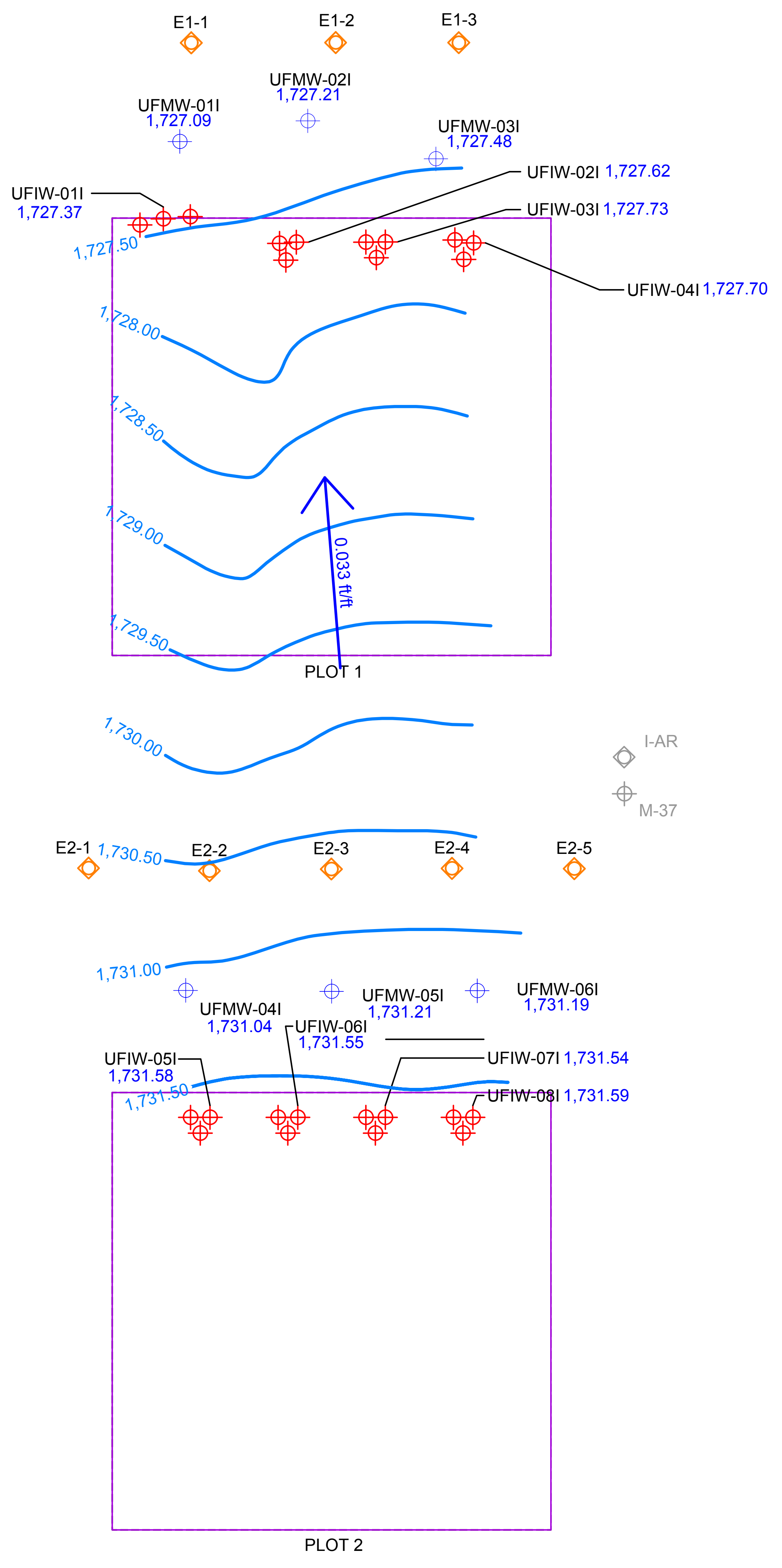
AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

GROUNDWATER CONTOURS AND FLOW DIRECTION - SHALLOW WELLS
AUGUST 2016

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.
11a

\\tts318fs3\tt.local\ces\87600014-NERT-M12\ FIGURE 11A - GW CONTOURS AND FLOW DIRECTION - SHALLOW WELLS r.dwg

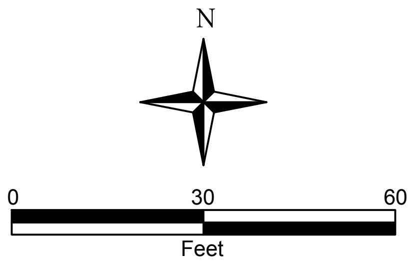


Legend

UFMW-01I ⌖	Monitoring Well (Triple Completion)
UFIW-01I ⌖	Injection Well (Single Completion)
E1-2 ◇	Extraction Well
M-37 ⌖	Monitoring Well (Not Associated with Treatability Study)
I-AR ◇	IWF Extraction Well (Not Associated with Treatability Study)
1,731.58	Groundwater Elevation (feet AMSL)
1,731.50 ～	Groundwater Elevation Contour (feet AMSL)
0.033 ft/ft →	Flow Direction and Hydraulic Gradient (ft/ft)
I	Intermediate Well (Screened in UMCf)
UMCf	Upper Muddy Creek Formation
AMSL	Above Mean Sea Level
ft/ft	Feet per Foot

Notes:

1. Only intermediate wells were used to develop intermediate groundwater contours.
2. Groundwater elevations shown were measured in August 2016; recent groundwater elevations not depicted because ongoing groundwater extraction and soil flushing activities as part of the treatability study have created conditions that are not as representative of natural groundwater elevations.



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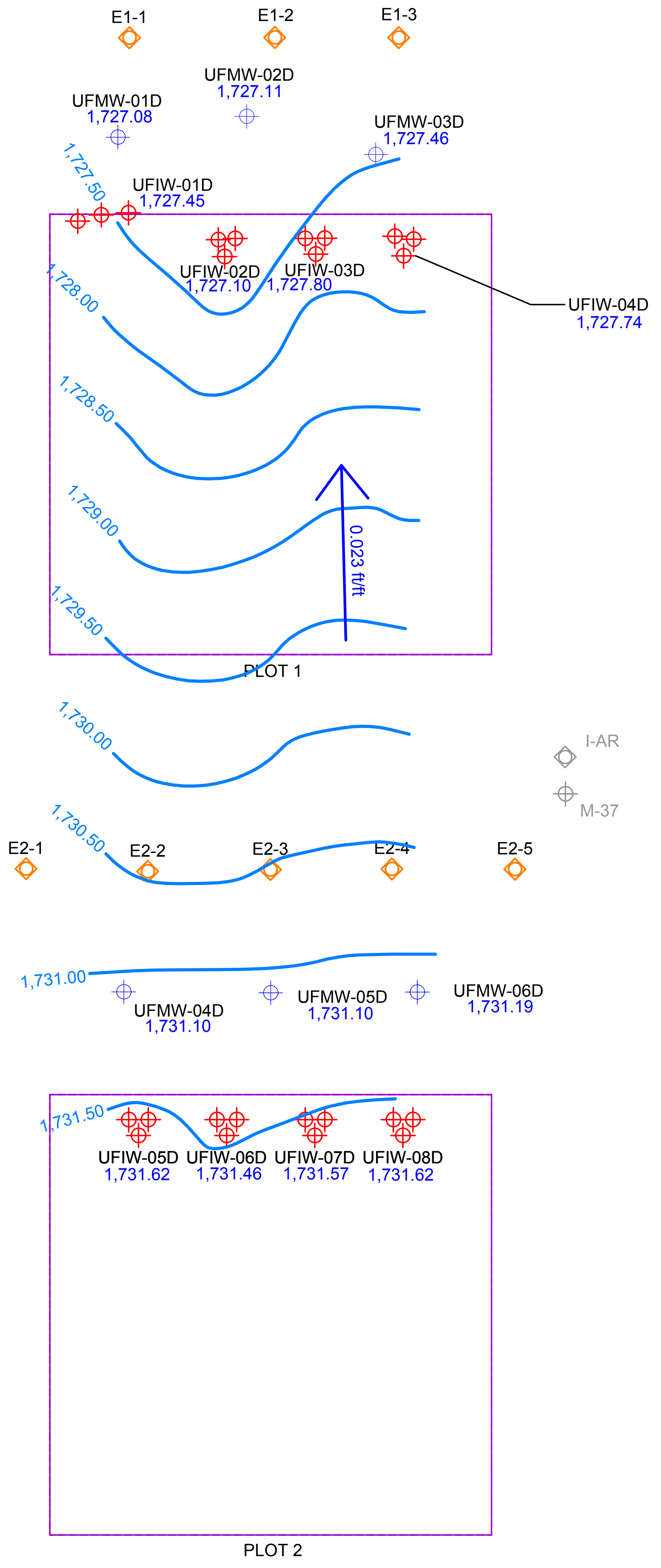
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

GROUNDWATER CONTOURS AND FLOW DIRECTION - INTERMEDIATE WELLS
AUGUST 2016

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK
Figure No.	11b

\\tts318fs3\tt.local\ces\87600014-NERT-M12\ FIGURE 11B - GW CONTOURS AND FLOW DIRECTION - INTERMEDIATE WELLS r.dwg

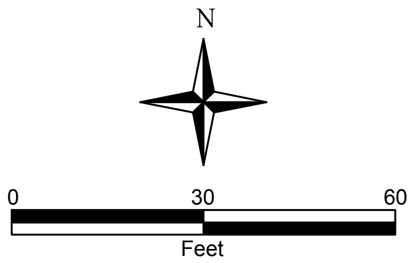


Legend

UFMW-01D ⊕	Monitoring Well (Triple Completion)
UFIW-01D ⊕	Injection Well (Single Completion)
E1-2 ◇	Extraction Well
M-37 ⊕	Monitoring Well (Not Associated with Treatability Study)
I-AR ◇	IWF Extraction Well (Not Associated with Treatability Study)
1,731.62	Groundwater Elevation (feet AMSL)
1,731.50 ～	Groundwater Elevation Contour (feet AMSL)
0.023 ft/ft →	Flow Direction and Hydraulic Gradient (ft/ft)
D	Deep Well (Screened in UMCf)
UMCf	Upper Muddy Creek Formation
AMSL	Above Mean Sea Level
ft/ft	Feet per Foot

Notes:

1. Only deep wells were used to develop deep groundwater contours.
2. Groundwater elevations shown were measured in August 2016; recent groundwater elevations not depicted because ongoing groundwater extraction and soil flushing activities as part of the treatability study have created conditions that are not representative of natural groundwater elevations.



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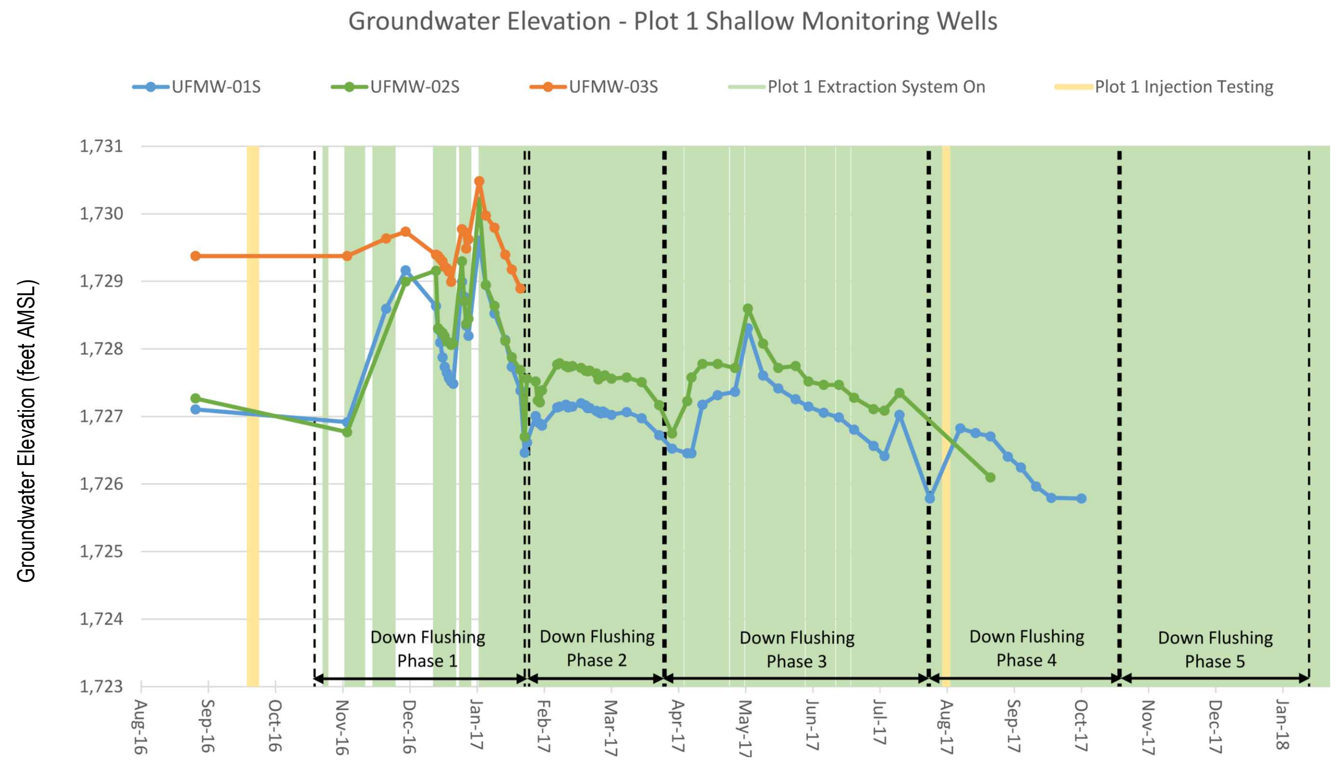
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

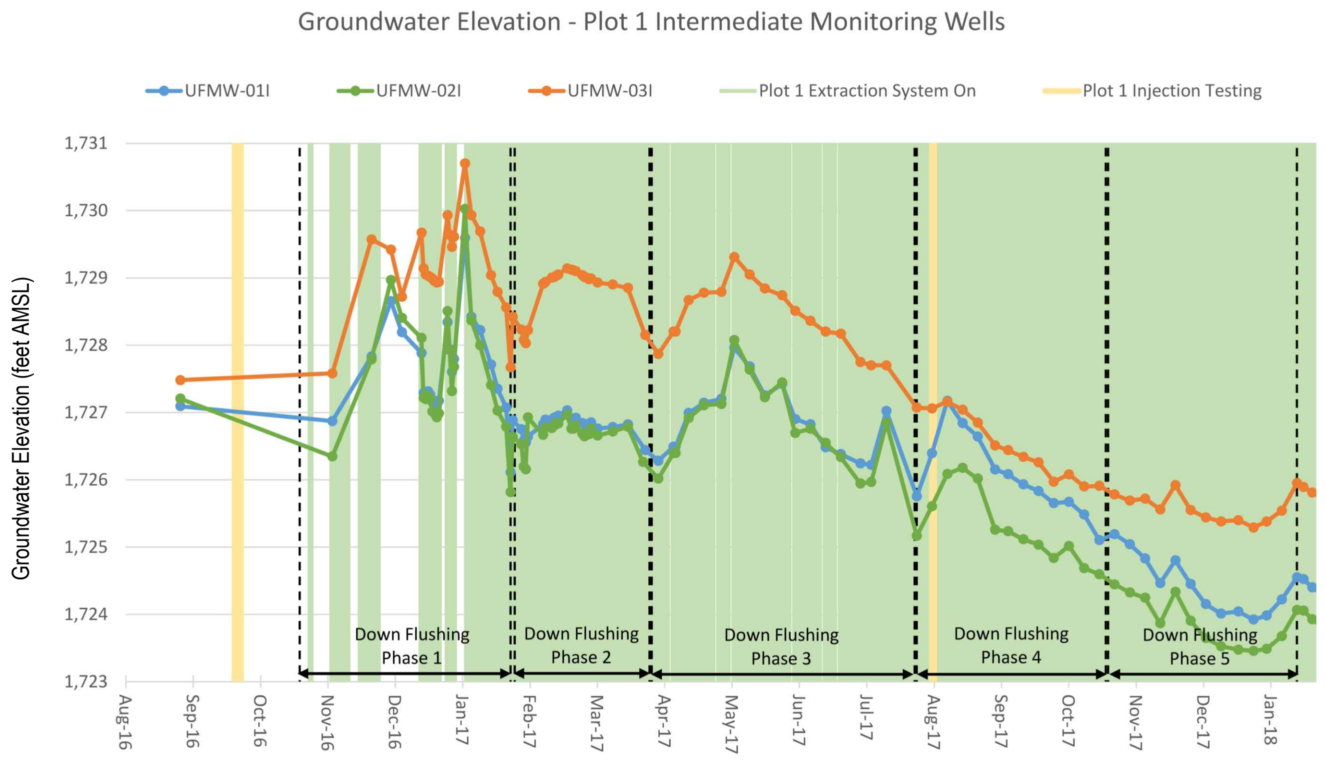
GROUNDWATER CONTOURS AND FLOW DIRECTION - DEEP WELLS
AUGUST 2016

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK
Figure No.	**11c**

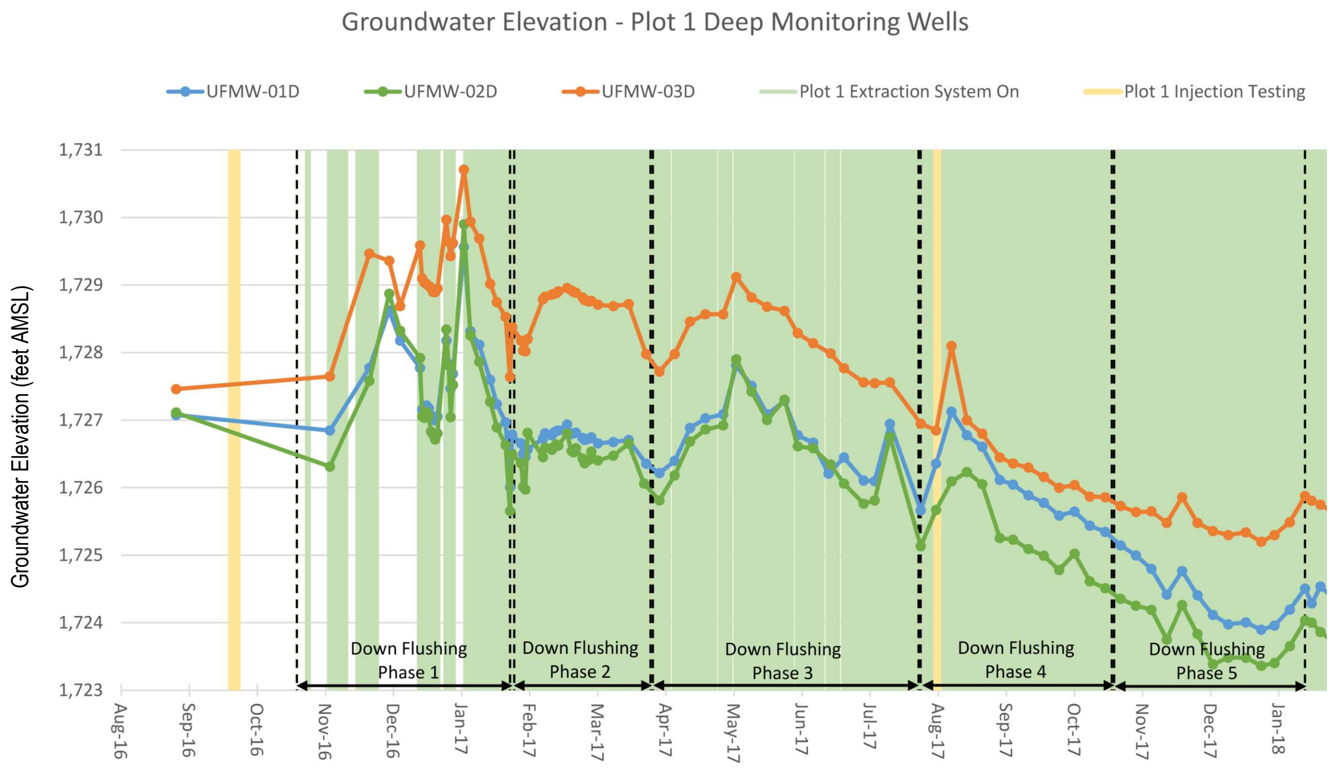
\\tts318fs3\tt.local\ces\87600014-NERT-M12\ FIGURE 11C - GW CONTOURS AND FLOW DIRECTION - DEEP WELLS r.dwg



Groundwater Elevation - Plot 1 Shallow Monitoring Wells



Groundwater Elevation - Plot 1 Intermediate Monitoring Wells



Groundwater Elevation - Plot 1 Deep Monitoring Wells

Note:

1. AMSL = above mean sea level.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

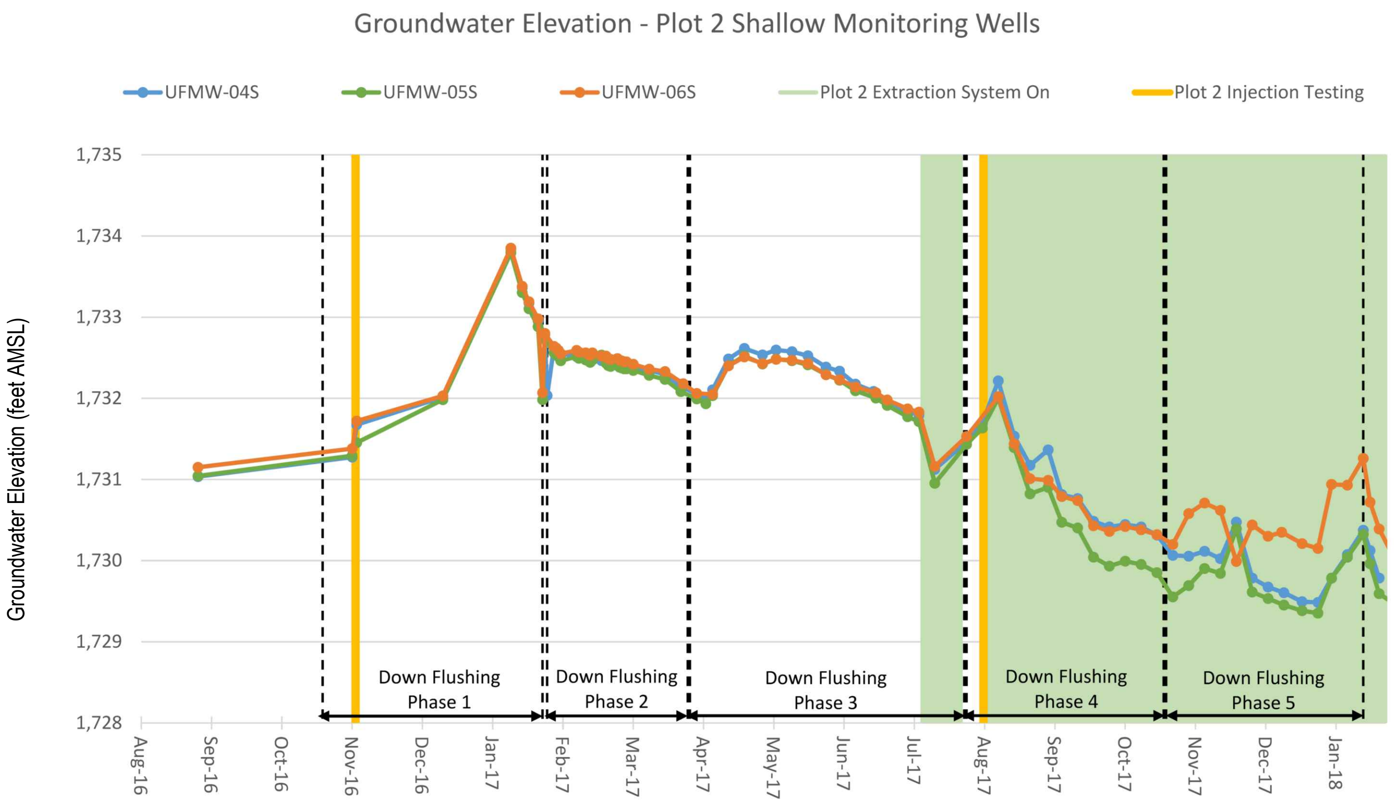
PLOT 1 MONITORING WELL GROUNDWATER ELEVATIONS VERSUS TIME

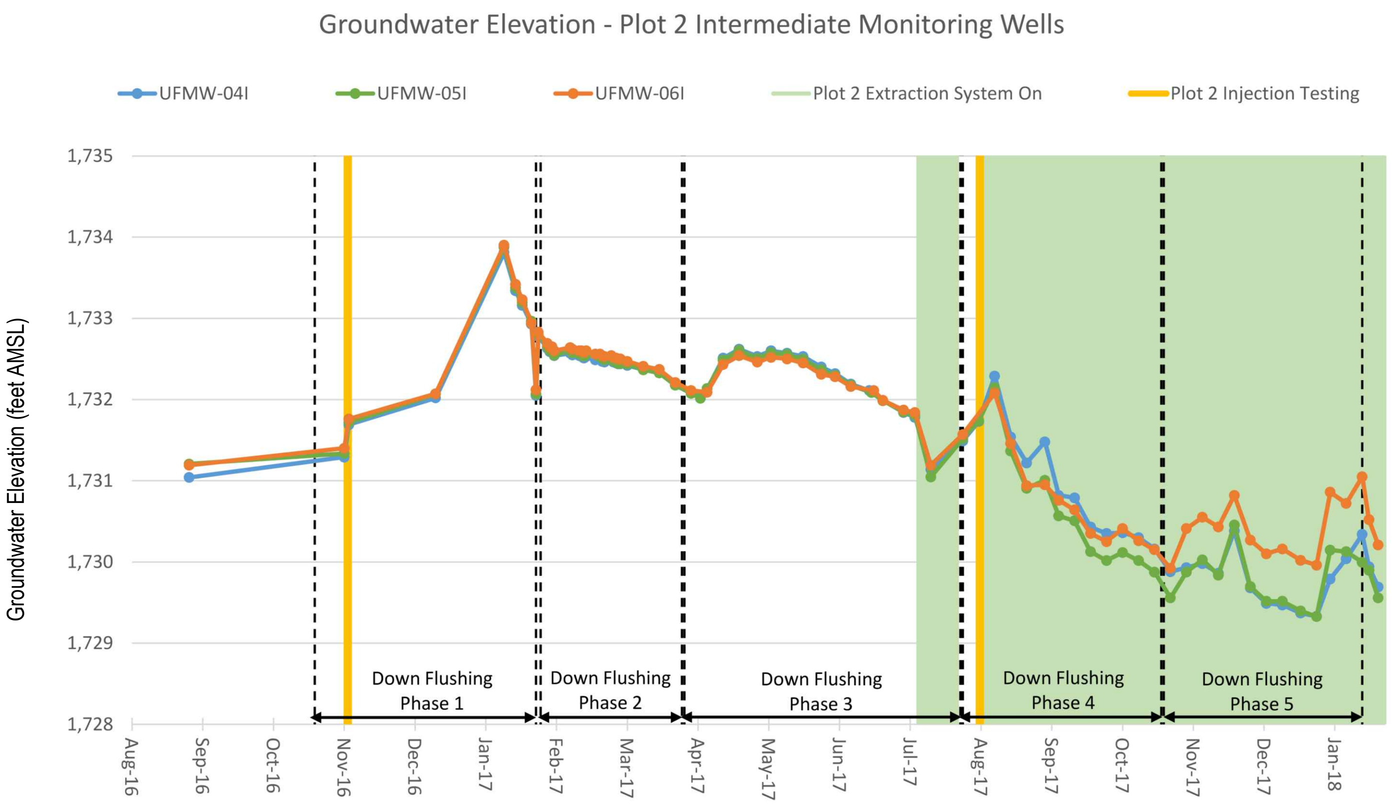
Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

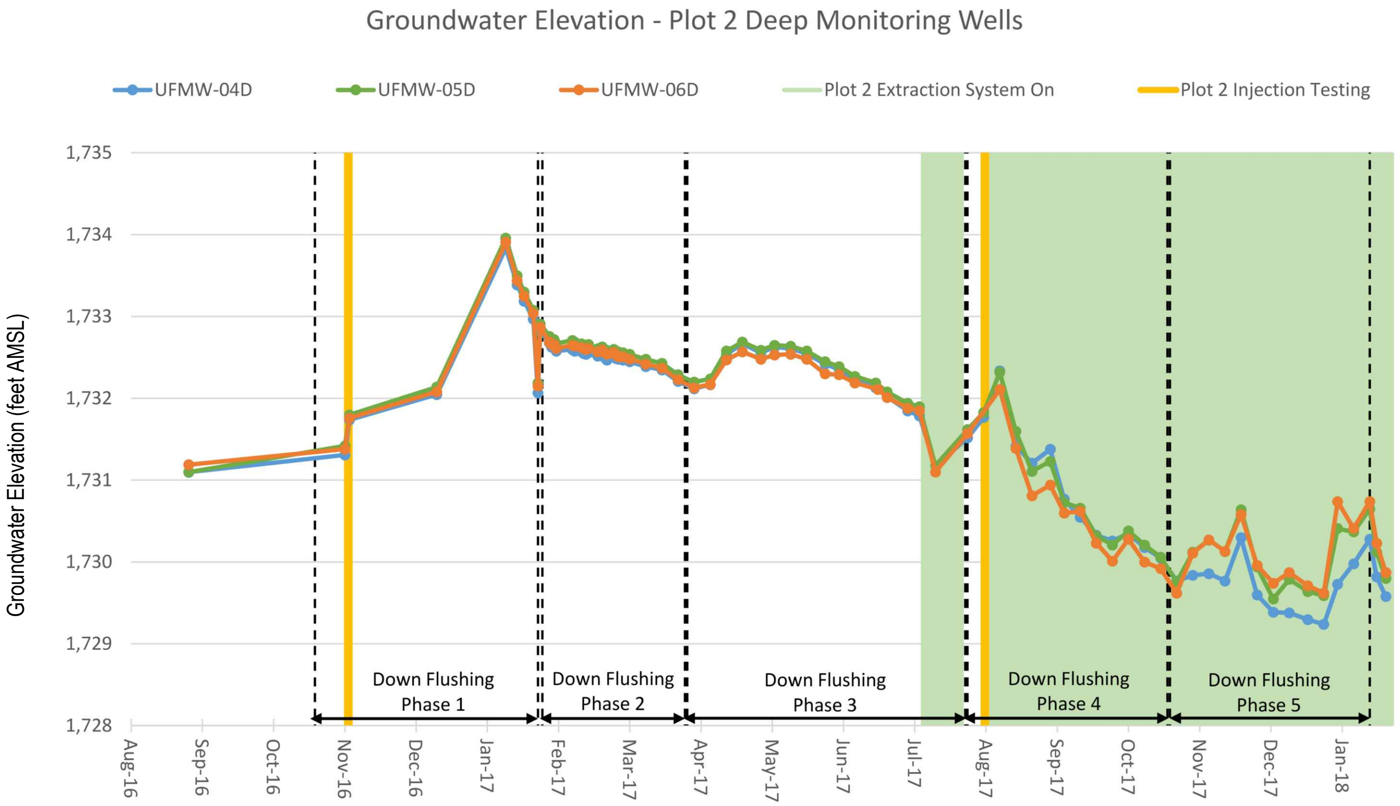
Figure No.

12a

\\tts318fs3\.tt.local\ces\87600014-NERT-M12\ Rev-FIGURE 12A - PLOT 1 MONITORING WELL GROUNDWATER ELEVATIONS VERSUS TIME.dwg







Note:
1. AMSL = above mean sea level.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

AP AREA DOWN AND UP FLUSHING TREATABILITY STUDY RESULTS REPORT
HENDERSON, NEVADA

PLOT 2 MONITORING WELL GROUNDWATER ELEVATIONS VERSUS TIME

Project No:	117-7502018
Date:	APRIL 26, 2018
Designed By:	DVK

Figure No.
12b

\\tts318fs3\.tt.local\ces\87600014-NERT-M12\ FIGURE 12B - PLOT 2 MONITORING WELL GROUNDWATER ELEVATIONS VERSUS TIME.dwg