# Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum
## Nevada Environmental Response Trust Site
## Henderson, Nevada

**PREPARED FOR**

**Nevada Environmental Response Trust**
35 E. Wacker Drive, Suite 690
Chicago, IL 60601

**PRESENTED BY**

**Tetra Tech, Inc.**
150 S. 4th Street, Unit A
Henderson, NV 89015

**November 11, 2019**

# TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## ATTACHMENTS



## APPENDICES

# LIST OF ACRONYMS/ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|---|---|
| ASTM | ASTM International |
| AWF | Athens Road Well Field |
| bgs | below ground surface |
| BL | baseline |
| BOR | Bureau of Reclamation |
| COH | City of Henderson |
| DO | dissolved oxygen |
| EC | electrical conductivity |
| EVO | emulsified vegetable oil |
| FS | Feasibility Study |
| ft/day | feet per day |
| ft/ft | feet per foot |
| IDW | investigation-derived waste |
| ISB | in-situ bioremediation |
| lbs/day | pounds per day |
| lbs/ft$^3$ | pounds per cubic foot |
| µg/L | micrograms per liter |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| NAC | Nevada Administrative Code |
| NDEP | Nevada Division of Environmental Protection |
| NDWR | Nevada Division of Water Resources |
| NERT or Trust | Nevada Environmental Response Trust |
| NMR | nuclear magnetic resonance |
| Nsat | normal saturated |
| ORP | oxidation-reduction potential |
| PLFA | phospholipid fatty acids |
| PVC | polyvinyl chloride |
| QA/QC | quality assurance/quality control |
| RAO | remedial action objective |
| RCRA | Resource Conservation and Recovery Act |
| RI | Remedial Investigation |
| Site | Nevada Environmental Response Trust site |

| Acronyms/Abbreviations | Definition |
|---|---|
| SLMW | stabilized Lake Mead water |
| SRB | sulfate-reducing bacteria |
| SWF | Seep Well Field |
| TDS | total dissolved solids |
| TKN | total kjeldahl nitrogen |
| Tetra Tech | Tetra Tech, Inc. |
| TOC | total organic compound |
| UAS | unmanned aerial system |
| UIC | Underground Injection Control |
| UMCf | Upper Muddy Creek formation |
| UMCf-cg | Upper Muddy Creek formation-coarse grained facies |
| UNLV | University of Nevada at Las Vegas |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VFAs | volatile fatty acids |
| Wash | Las Vegas Wash |
| Work Plan | *Las Vegas Wash Bioremediation Pilot Study Work Plan* |
| Work Plan Addendum | *Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum* |

# CERTIFICATION

**Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum**

**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 of the Trustee

**Signature:** Jay A Steinberg ______, 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:** 11/11/19

# 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:*** Prepared Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum, Nevada Environmental Response Trust Site, Henderson, Nevada

Kyle S. Hansen

November 11, 2019

**Kyle Hansen, CEM**
Field Operations Manager/Geologist
Tetra Tech, Inc.

Date

Nevada CEM Certificate Number: 2167
Nevada CEM Expiration Date: September 18, 2020

# 1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this *Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum* (referred to as the Work Plan Addendum) for implementation of an in-situ bioremediation (ISB) pilot study adjacent to the Las Vegas Wash (Wash), which is downgradient of the NERT site (Site), located in Clark County, Nevada (Figure 1). This Work Plan Addendum is being submitted to the Nevada Division of Environmental Protection (NDEP) under the Interim Consent Agreement effective February 14, 2011. The Work Plan Addendum presents the results of the pre-design field and laboratory activities described in the approved *Las Vegas Wash Bioremediation Pilot Study Work Plan* (Tetra Tech, 2017) (referred to as the Work Plan) and the subsequent *Treatability/Pilot Study Modification No. 2 – Las Vegas Wash Bioremediation Pilot Study* (Tetra Tech, 2018) (referred to as Modification No. 2). This Work Plan Addendum provides information on the final design for implementation of the ISB pilot study based on the result of the Phase 1 pre-design activities and additional experience gained through the ongoing implementation of other NERT studies.

## 1.1 PROJECT OBJECTIVES

The activities described in this Work Plan Addendum are being conducted to support remedy selection as part of a Remedial Investigation and Feasibility Study (RI/FS) process. Currently, the RI is being conducted in four investigation sub-areas: the On-Site NERT RI Study Area; the Off-Site NERT RI Study Area; the NDEP Downgradient Study Area; and the Eastside Study Area. These investigation sub-areas are now collectively referred to as the NERT RI Study Area (Figure 1).

A primary remedial action objective (RAO) established for Operable Unit 3 (OU-3), located north of Galleria Drive and extending to the Wash, is to mitigate the discharge of chemicals of potential concern (COPCs) in groundwater to the Wash by reducing COPC concentration in the alluvial aquifer and Upper Muddy Creek formation (UMCf) to meet applicable or relevant and appropriate requirements (ARARs) (Ramboll Environ, 2017a). Based on data collected from September 2018 through December 2018, an estimated 35.8 pounds per day (lbs/day) of perchlorate mass flux to the Wash was measured between the Pabco Rd and Homestead weirs (Ramboll, 2018a). As a result, additional technical evaluation of location-specific remedial options is necessary to support remedy selection in areas adjacent to the Wash.

As established in the Work Plan, the overall objective of the pilot study is to demonstrate and evaluate the effectiveness and implementability of ISB in a geologically complex area where perchlorate-contaminated groundwater is thought to be migrating into the Wash as evidenced from previous investigations in the Downgradient Study Area (AECOM, 2018).  This pilot study will build on the results of the previous ISB treatability study performed downgradient of the Athens Road Well Field (AWF) near the City of Henderson (COH) Bird Viewing Ponds (Tetra Tech, 2016) and the ongoing Seep Well Field (SWF) Area Bioremediation Treatability Study. An overview of the ISB treatability and pilot studies performed as part of NERT's overall RI/FS implementation strategy are provided in Section 4.2. Although the previous COH and ongoing SWF area bioremediation treatability studies focused only on the alluvium and more transmissive paleochannel deposits, both the forthcoming Galleria Drive Bioremediation Treatability Study and this Las Vegas Wash Bioremediation Pilot Study will also evaluate implementation of ISB in the UMCf, in which ISB field testing for remediation of perchlorate has not been evaluated to date. It is important to evaluate the effectiveness and implementability of ISB in the UMCf due to the presence of high concentrations of perchlorate that have been observed in the UMCf, some of which are likely contributing concentrations of perchlorate above applicable standards to the overlying alluvium and surface water due to contaminant upflux (to be further discussed in the forthcoming OU-1/OU-2 RI Report). As a result, and if effective, full-scale remediation may be required in select areas within the UMCf in order to achieve RAOs. Although both the Galleria Drive Bioremediation Treatability Study and Las Vegas Wash Bioremediation Pilot Study will evaluate ISB in the UMCf, separate studies for the UMCf are necessary to examine ISB in varying lithological characteristics, saturated thicknesses, and chemical/geochemical compositions of the groundwater that will likely be encountered during full-scale remediation.

Upon completion of the various current and future OU-3 area treatability and pilot studies and the OU-3 RI and risk assessments, it will be the objective of the OU-3 FS to incorporate all available study data, nature and extent of COPCs (as identified in the OU-3 RI Report), and potential risks to human health and the environment (as identified in the various risk assessments relevant to OU-3) to complete technology and alternative screening in accordance with the criteria established in 40 CFR 300.430.e.7 (implementability, effectiveness, and cost) to produce an array of remedies for OU-3. The Las Vegas Wash Bioremediation Pilot Study is intended to provide key information needed for the FS to evaluate design, optimization/scale-up, and cost of this technology and its effectiveness on the RAO of mitigation of the perchlorate mass flux to the Wash to the extent that ISB is selected as part of the final remedy.

A summary of the Trust's prior implementations of ISB, site background information prior to the pre-design field activities and ISB technology description can be found in the Work Plan. Specifically, site background is described in Section 1.3 of the Work Plan and the description of the planned ISB technology and previous and ongoing treatability studies appears in Section 2.0 of the Work Plan.

## 1.2 WORK PLAN ADDENDUM ORGANIZATION

This Work Plan Addendum is organized as follows:

- **Introduction (Section 1.0):** Provides the primary objectives of this Work Plan Addendum and field pilot study.
- **Phase 1 Pre-Design Field and Laboratory Activities (Section 2.0):** Provides a description of the field and laboratory activities that have been completed to date.
- **Phase 1 Pre-Design Field and Laboratory Results (Section 3.0):** Provides a description of the geology, hydrogeology, and soil and groundwater results from the data collected during the field and laboratory activities that have been completed to date.
- **Phase 2 Pilot Study Considerations and Modifications (Section 4.0):** Provides a summary of the relevant discoveries since the Work Plan, a brief overview of other ISB treatability studies that have been completed or are in progress at the NERT site, and a summary of the modifications to the original pilot study conceptual design based on this new information.
- **Phase 2 Revised Pilot Study Design (Section 5.0):** Describes the revised pilot study design including objectives, study location, injection and monitoring well layout, and injection design.
- **Phase 2 Effectiveness Monitoring Program (Section 6.0)**: Presents the effectiveness monitoring program for the pilot study, including the field, analytical, and microbial groundwater monitoring and data validation requirements, as well as mass flux evaluations.
- **Phase 2 Access and Permitting Requirements (Section 7.0):** Summarizes access agreement and permitting requirements for pilot study implementation.
- **Phase 2 Reporting (Section 8.0):** Summarizes reporting related to design, execution, and evaluation of the pilot study.
- **Phase 2 Schedule (Section 9.0):** Summarizes the schedule for conducting the pilot study and associated reporting.
- **References (Section 10.0):** Lists the documents referenced in this Work Plan Addendum.

# 2.0 PHASE 1 PRE-DESIGN FIELD AND LABORATORY ACTIVITIES

This section describes the various pre-design field and laboratory activities that have been completed to date. The objectives of the Phase 1 pre-design activities were to accomplish the following:

- Characterize the lithology in sufficient detail to refine the conceptual ISB injection well spacing.
- Identify preferential flow pathways (such as paleochannels and transmissive zones) in order to better target injections.
- Assess localized vertical and horizontal distribution of perchlorate to appropriately target the pilot study.
- Accurately identify groundwater flow directions and rates to design the injection wells and perform injections to best address perchlorate migration into the Wash.
- Estimate acclimation time, perchlorate biodegradation rates, adsorption capacity; and evaluate hydraulic, physical, and chemical relationships between the alluvium and UMCf through bench-scale testing.

To gather the appropriate data to meet these objectives, initial pre-design field and laboratory activities were performed from March 2018 to July 2018 in accordance with the approved Work Plan. Based on the results of these initial pre-design activities, additional pre-design work was recommended in Modification No. 2 (Tetra Tech, 2018a), which NDEP approved in August 2018. NDEP recommended additional drilling work in their approval letter. The pre-design field work described in Modification No. 2 and in the subsequent NDEP approval letter was performed from August 2018 to January 2019. The pre-design activities that have been conducted to date to provide information to meet the Phase 1 pre-design objectives include: soil boring and monitoring well installation, soil and groundwater sampling, aquifer testing (including slug tests, single-borehole dilution tests, and nuclear magnetic resonance [NMR] logging), transducer data collection, surface water sampling, and laboratory bench-scale studies.

A summary of these activities and their purpose are presented in this section with results of these activities discussed in detail in Section 3. All field work was conducted in general accordance with the existing *Field Sampling Plan, Revision 1* (ENVIRON, 2014), Work Plan, and Modification No. 2 (Tetra Tech, 2018a). A data validation summary report will be provided for all data presented in this report at the conclusion of the pilot study in the final Las Vegas Wash Bioremediation Pilot Study Results Report.

## 2.1 PILOT STUDY LOCATIONS

Per the conceptual design presented in the Work Plan, the pre-design work was performed at two separate locations, identified as the Transect 1a and Transect 1b study areas shown in Figures 2 and 3, respectively. These locations are upgradient of the Wash and were selected as potential study areas to perform the Las Vegas Wash Bioremediation Pilot Study. A summary of each location is provided below.

- ***Transect 1a –*** This study area is located directly east of Pabco Road on property owned by the COH. Using data known at the time of the Work Plan, this location was selected to intercept perchlorate contamination generally greater than 5,000 micrograms per liter ($\mu$g/L), which represents one of two higher perchlorate concentration locations within the Downgradient Study Area that is contributing to the total mass flux migrating into the Wash.
- ***Transect 1b –*** This study area is located immediately upgradient of the Wash on Clark County-owned property and was selected to treat contamination potentially migrating into the Wash from a second area that generally has perchlorate concentrations in groundwater greater than 5,000 $\mu$g/L. Additionally, this area also aligned with the evaluation of surface water data, which indicates that there is an increase in the perchlorate mass flux entering the Wash between Bostick, Calico Ridge, and Homestead Weirs, all of which are located downgradient of the Transect 1b study area.

It should be noted that following completion of the Phase 1 pre-design activities described herein, the results from both the Transect 1a and 1b study areas were presented to the Trust and discussed with regards to the data collected and overall pilot study objectives. Based on these discussions, the Transect 1a study area was eliminated from the upcoming Phase 2 pilot study program. The results from the Phase 1 activities associated with Transect 1a study area are summarized in Sections 2 and 3, with additional details on the basis for elimination of the Transect 1a study area from the pilot study program provided in Section 4.3.1.

## 2.2 ACCESS AGREEMENT

The Trust obtained access agreements for all field pilot study activities (including forthcoming injections and monitoring) from the applicable agencies and property owners. Pre-design and pilot study activities performed for the Transect 1a study area are located on COH property. Pre-design and pilot study activities performed for the Transect 1b study area are located on land under jurisdiction of the United States Bureau of Reclamation (BOR), COH, and Clark County. As a result, three separate access agreements were required to complete the pre-design work. The BOR agreement, which was approved for installation and use of monitoring wells on October 11, 2018, will remain active for the period authorized by the March 2018 *Finding of No Significant Impact LC-17-19 for Final Environmental Assessment, Right of Use – Downgradient Study Area Activities* (BOR, 2018). Although the timeframe is not specifically stated in the March 2018 document, the agreement is stated to be in place for the duration of the NDEP Phase I and II investigations of the Downgradient Study Area. The COH agreement was approved on March 6, 2018 and will remain active through December 31, 2024. The Clark County agreement was approved on May 15, 2018 and will terminate on September 1, 2023.

## 2.3 INSTALLATION OF SOIL BORINGS AND MONITORING WELLS

Soil borings and monitoring wells were installed to provide information on the lithology, hydrogeology, and contaminant distribution within both transects. In accordance with the Work Plan, initial pre-design drilling activities associated with both the Transect 1a and 1b study areas began on March 26, 2018 and were completed on June 27, 2018. Based on the recommendations associated with Modification No. 2, additional drilling activities within the vicinity of Transect 1b began on August 27, 2018 and were completed on November 9, 2018. Locations of soil borings/monitoring wells are shown for the Transect 1a and 1b study areas in Figures 2 and 3, respectively. This section presents details of the installation activities performed to date during the multiple mobilizations.

### 2.3.1 Pre-Drilling Activities

Pre-drilling activities consisted of preparation and submittal of well permit applications and completion of biological surveys and utility clearances. Tetra Tech, on behalf of NERT, prepared and submitted all required applications and obtained required permits prior to the installation of soil borings and monitoring wells. A Monitoring Well Drilling Waiver (Nevada Administrative Code [NAC] 534.441) and a Notice of Intent to Drill Card (NAC 534.320) were submitted to the Nevada Division of Water Resources (NDWR) for each drilling effort. The Monitoring Well Drilling Waiver also included a completed, signed, and notarized Affidavit of Intent to Plug a Monitoring Well as a required attachment. The access agreements require that all pre-design monitoring wells be abandoned prior to the expiration date of the applicable access agreements, unless amended. As required, well abandonment will be performed in accordance with the NDWR requirements.

Prior to drilling activities, Tetra Tech contacted USA North Utility Locating Services, reviewed available utility maps, and retained the services of a geophysical locator to check for underground utility lines. Each drilling location was also cleared to a depth of 5 feet below ground surface (bgs) using hand augering to ensure the area was clear of utilities. As an additional precaution, each drilling location within the COH landfill (located upgradient of the Transect 1b study area) was cleared to a depth of 10 feet bgs by air knife operations.

Although much of the habitat within the pilot study areas has been heavily disturbed, it is possible for the Mojave Desert tortoise (*Gopherus agassizii*) to be present based on review of historical documentation. Because the field work could affect the desert tortoise, biological surveys were performed to document the presence/absence of the tortoise prior to performing any field work. Although no federally listed avian species are anticipated to nest in these areas, the biological survey also included an avian survey to determine the presence/absence of migratory bird nests. The surveys were completed by an authorized desert tortoise biologist on March 22-23, 2018, for the Transect 1a study area and May 16-17, 2018 for the Transect 1b study area. The biologist completed a 100 percent coverage desert tortoise survey of the project area, which included consideration of the dirt access roads within the land parcels. No desert tortoise individuals or signs of desert tortoise presence (burrows, scat, carcasses) were observed during the survey. Although several avian species were observed during the surveys, no migratory bird nests were observed within the survey areas. Technical memorandums documenting the biological surveys are provided in Appendix A. In addition to biological surveys and in accordance with the environmental commitments outlined in the March 2018 *Finding of No Significant Impact LC-17-19 for Final Environmental Assessment, Right of Use – Downgradient Study Area Activities* (BOR, 2018), a biological monitor was present onsite during installation of soil borings and monitoring wells on BOR land.

## 2.3.2 Soil Boring Installation

Soil borings were installed within each of the Transect 1a and Transect 1b study areas to provide area-specific lithological information and contaminant concentration data to incorporate into the development of the final pilot study design. Drilling and monitoring well installation activities were conducted by Cascade Drilling, LP using rotosonic drilling methods. During the initial Phase 1 activities, 28 soil borings (12 in the Transect 1a study area and 16 in the Transect 1b study area) were advanced to approximately 120 feet bgs, which was the selected depth based on prior investigations that suggested the alluvial extended to a greater depth near the Wash. During the activities associated with Modification No. 2, 15 soil borings were advanced to depths up to 250 feet bgs in the Transect 1b study area to ensure that it was possible to reach semi-consolidated UMCf or bedrock within that depth. As part of this modification, if bedrock was encountered prior to reaching 250 feet bgs, then the boring was advanced up to 15 feet into bedrock to evaluate its characteristics. If semi-consolidated UMCf wass encountered prior to reaching 250 feet bgs, the boring was advanced to the shallower of a total depth of 250 feet or up to 50 feet into the semi-consolidated UMCf and then terminated. The exception to this guidance was installation of soil boring LVWPS-MW219C, at which relatively thin, alternating layers of unconsolidated and semi-consolidated UMCf and reworked bedrock material were encountered at approximately 53 feet bgs until the material was observed to become continuously more consolidated from 135 to 145 feet bgs, at which point the borehole was terminated. Continuous soil cores were logged by a Tetra Tech geologist from ground surface to total depth using the Unified Soil Classification System. Photographs of soil cores were also collected during drilling activities. Copies of the soil boring logs and core photographs are provided in Appendix B.

### 2.3.2.1 Soil Sampling

During drilling activities in the Transect 1a study area, soil samples were collected from the top of the water table to the base of the boring. Depending on location and lithology encountered, either six, seven, or ten soil samples were collected from each boring to better characterize vertical distribution of perchlorate in soil. During drilling activities in the Transect 1b study area, soil samples were collected at approximate 10-foot intervals from the top of the water table to the base of the boring during field activities associated with both the initial Phase 1 pre-design and subsequent Modification No. 2. All soil samples were analyzed for perchlorate. To provide additional characterization of the subsurface, 18 soil samples were also analyzed for a suite of analytes in accordance with Table 1 of the Work Plan. Finally, 15 soil samples were collected from depths ranging from 10 to 150 feet bgs and analyzed for phospholipid fatty acids (PLFA) and the perchlorate-reductase gene to characterize the viable biomass population and relative proportions of different bacterial structural groups and their likely potential to adapt to the addition of an external source of organic carbon and changes in the environment. All soil samples for laboratory analysis were collected in laboratory-supplied containers, labeled, placed in plastic bags, and stored in a cooler on ice for transport under chain-of-custody documentation to the appropriate laboratory, either TestAmerica Laboratories, Inc. or Microbial Insights, Inc.

The Work Plan specified that undisturbed soil samples would be collected from representative lithological units from select boreholes upon reaching groundwater using a Shelby tube and analyzed for physical parameters including moisture content, porosity, soil density, and specific gravity. Data obtained from these analyses were used for the design and setup of the laboratory column studies performed at University of Nevada at Las Vegas (UNLV). In the Transect 1a study area, nine Shelby tubes were collected from both the saturated alluvium and UMCf at three locations (namely, LVWPS-MW102B, LVWPS-MW109, and LVWPS-MW110). In the Transect 1b study area, five Shelby tubes were collected from the saturated alluvium and UMCf at three locations (LVWPS-MW202, LVWPS-206C, and LVWPS-MW209).

Finally, during soil boring installation, representative soil was collected and transported to UNLV for use in the laboratory bench tests (described in Section 2.7). During drilling activities in the Transect 1a study area, soil was collected from both the saturated alluvium and UMCf from boring LVWPS-MW105. During drilling activities in the Transect 1b study area, soil was collected from the saturated alluvium, unconsolidated UMCf, and semi-consolidated UMCf from soil borings LVWPS-MW201B and LVWPS-MW210B.

#### 2.3.2.2 Discrete Groundwater Sampling

Depth-discrete groundwater samples were also collected from select boreholes within the alluvium and unconsolidated UMCf to assist in the vertical profiling of perchlorate distribution in groundwater. Depth-discrete groundwater samples were collected during advancement of the soil borings using a sealed push-ahead groundwater sampling tool. The tool was threaded to the base of the sonic drill rod and driven ahead of the casing into undisturbed soil at the target depth. The push-ahead tool was then partially unthreaded to expose slots allowing formation water to enter the previously sealed tool. The groundwater samples were then collected from the push-ahead tool using a disposable bailer. Depths selected for collection of depth-discrete groundwater samples were targeted based on two factors: (1) targeted zone had to be capable of producing enough water to efficiently collect a groundwater sample within a reasonable timeframe (less than two hours), and (2) targeted zone would not be screened and therefore sampled in subsequent groundwater sampling events. All 16 depth-discrete groundwater samples were analyzed for perchlorate, and eight samples were also analyzed for nitrate and chlorate. Depth-discrete groundwater samples were analyzed for a limited suite of parameters (perchlorate, chlorate, and nitrate) to minimize required sample volumes and therefore, time required to collect samples, particularly in the finer sediments of the UMCf.

### 2.3.3 Monitoring Well Installation

As part of the pre-design phase (mobilizations associated with both the initial Phase 1 and subsequent Modification No. 2), a total of 85 monitoring wells were installed at 38 locations within the Transect 1a and Transect 1b study areas. Specifically, 21 monitoring wells were installed within the Transect 1a study area (well identification noted as the 100 series wells) and 64 monitoring wells installed within the Transect 1b study area (well identification noted as the 200 series wells). Monitoring wells were screened across multiple lithological units, including saturated alluvium, UMCf (both unconsolidated and semi-consolidated), and fractured/weathered bedrock. At all 38 locations, initial soil borings were converted to permanent monitoring wells. At 27 of the locations, multiple monitoring wells were installed as a paired or clustered set of monitoring wells to evaluate the vertical distribution of perchlorate and vertical gradients. Depths and screened intervals for the paired/clustered monitoring wells were selected based on lithology encountered during installation of the initial boring at each location. Where borehole logs indicated multiple permeable productive zones, up to five monitoring wells were installed and screened at various intervals to evaluate the perchlorate concentration and hydraulic gradient changes with depth.

In general, total well depth, slot size, filter pack, and length of the well screens were determined in the field based on lithology encountered. During Modification No. 2 drilling activities, soil analytical results were used when available to guide the total number of monitoring wells (and associated screened intervals) installed at each location. The majority of monitoring wells were constructed using either 2-inch Schedule 40 or Schedule 80 polyvinyl chloride (PVC) casing (depending on depth) and screened with 2-inch diameter slotted PVC well screen. During the initial mobilization for Phase 1 activities, six monitoring wells were installed with 4-inch diameter Schedule 40 PVC and screened with 4-inch diameter slotted PVC well screen. These monitoring wells were used for single-borehole dilution testing (Section 2.6.2). During the mobilization for Modification No. 2, the deepest monitoring well at each location was installed with 4-inch diameter Schedule 80 PVC casing and screened with 4-inch diameter slotted PVC well screen to allow for the use of the higher-resolution NMR logging tool in characterizing the deeper sediments. Well construction details for all monitoring wells installed are summarized in Appendix B, Tables B.1 and B.2.

All monitoring wells were completed with flush-mounted, traffic-rated well boxes, at an elevation approximately 0.5 inch above grade. Following well construction, but no sooner than 48 hours after well construction was complete, the newly installed monitoring wells were developed 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 a minimum of three casing volumes of water had been removed from the well and index parameters (consisting of pH, specific conductivity, turbidity and temperature) were stable over three consecutive measurements. Slow recovery prevented a full three casing volumes from being removed from four monitoring wells screened within the semi-consolidated UMCf (namely, LVWPS-MW103B, LVWPS-MW203C, LVWPS-MW204C, and LVWPS-MW226B). Field adjustments were made to continue developing the wells until the silt had been removed from the bottoms of the monitoring wells and the turbidity had begun to decrease in the water removed.

Once all monitoring well installation activities were complete, a Nevada-licensed land surveyor surveyed the horizontal coordinates of each monitoring 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 points relative to North American Vertical Datum 88 were surveyed with accuracies of 0.1 foot and 0.01 foot, respectively.

### 2.3.4 Management of Investigation-Derived Waste

Investigation-derived waste (IDW) generated was managed in accordance with applicable state, federal, and local regulations and as described in *Field Sampling Plan, Revision 1* (ENVIRON, 2014). During drilling mobilizations, IDW included soil cuttings, personal protective equipment, equipment decontamination water, and groundwater generated during depth-discrete groundwater sampling and monitoring well development. Investigation-derived soil waste was containerized onsite in plastic-lined, 10-cubic-yard roll-off bins. The roll-offs were labeled to indicate contents, source, and date when accumulation began. Initial soil cuttings generated from March 26 to April 26, 2018 were contained in three roll-off bins, with one composite soil sample collected from each for profiling purposes. The samples were analyzed for the following: perchlorate by USEPA Method 314.0; volatile organic compounds by United States Environmental Protection Agency (USEPA) Method 8260B; Resource Conservation and Recovery Act (RCRA) 8 Metals by USEPA Method 6010B and 7471A; flashpoint ignitability by USEPA Method SW846 7.1.2; pH by USEPA Method 9045C; perchlorate by USEPA Method 314.0; and total and toxicity characteristic leaching procedure – Metals by USEPA Method 1311 extraction/USEPA Method 6010B. Results indicated that the soil cuttings were non-hazardous waste. Soil cuttings generated during subsequent mobilizations for the Transect 1b, which included a total of 16 bins, were disposed of under the same waste profile. All IDW was disposed at Apex Landfill, Las Vegas, Nevada.

Waste water generated during purging or decontamination activities was temporarily stored in 55-gallon drums and/or 500-gallon totes and transferred into the GW-11 Pond for onsite treatment in the groundwater extraction and treatment system.

## 2.4 GROUNDWATER SAMPLING

Following completion of monitoring well development activities, all newly installed monitoring and existing nearby monitoring wells were sampled within each study area. In May 2018, groundwater samples were collected from all 21 newly installed monitoring wells within the Transect 1a study area (event baseline [BL] 01 for the 100 series wells). In June 2018, groundwater samples were collected from all 27 newly installed monitoring wells and one existing monitoring well (WMW4.9S) within the Transect 1b study area (event BL01 for the 200 series wells). Additionally, as part of the BL01 event for the 200 series wells, six existing monitoring wells located upgradient of the Transect 1b study area (namely, LNDMW1, MW-02, MW-04, MW-13, MW-20, and MW-25) were sampled as part of AECOM's July 2018 Phase 1 groundwater sampling event associated the NERT RI Downgradient Study Area. Upon completion of drilling and well development activities associated with Modification No. 2, a comprehensive groundwater sampling event was performed in November 2018 (event BL02) that included all 64 monitoring wells installed during both phases of drilling for the Transect 1b study area, as well as 10 existing monitoring wells (MW-02, MW-04, MW-13, MW-20, MW-25, NERT4.51S1, NERT4.71S1, NERT4.93S1, NERT5.11S1, and WMW4.9S).

Groundwater sampling activities followed the guidance of the *Field Sampling Plan, Revision 1* (ENVIRON, 2014). Prior to groundwater sample collection, groundwater levels were gauged in all monitoring wells for use in potentiometric contouring. In general, groundwater samples were collected using low-flow purging and sampling techniques. During low-flow purging of the monitoring wells, a pump capable of purging between approximately 0.1 to 0.13 gallons per minute was used to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water was passed through a flow-through cell field water analyzer for continuous monitoring of field parameters (temperature, pH, turbidity, electrical conductivity, dissolved oxygen [DO], and oxidation reduction potential [ORP]). Field parameters were monitored and recorded on field sampling forms during purging. The monitoring wells were sampled when purging was complete, which was when the field parameter readings and water levels stabilized. Because a limited volume of groundwater was available for initial groundwater sample collection from monitoring wells screened in the semi-consolidated UMCf that continued to recover from well development (namely, LVWPS-MW203C, LVWPS-MW204C, and LVWPS-MW226B), a disposable bailer was used for sample collection instead of low-flow pumping as described above. Monitoring well LVWPS-MW203C was sampled using a low-flow pump during the BL02 event in November 2018 after approximately 4 months of recovery following well development. Per NDEP letter dated June 27, 2016, field-filtering of water samples for perchlorate analysis was not required. Filtering for dissolved metals was conducted in the field using a 0.45-micron filter. Following completion of sampling, purge water generated during groundwater sampling activities was temporarily stored in 55-gallon drums and transferred into the GW-11 Pond for onsite treatment in the groundwater extraction and treatment system.

Groundwater samples were analyzed for a variety of field and laboratory parameters in accordance with Table 2 of the Work Plan to establish baseline conditions for the final pilot study design. Exceptions to this included the six additional upgradient monitoring wells (LNDMW-1, MW-02, MW-04, MW-13, MW-20, and MW-25) that were added to the sampling program as part of AECOM's Downgradient RI July 2018 sampling event. These six monitoring wells were only analyzed for perchlorate, chlorate, nitrate, sulfate, and total dissolved solids (TDS). Additionally, the November 2018 comprehensive sampling event for the Transect 1b study area included the full suite of analytes (listed in Table 2 of the Work Plan) in groundwater samples collected from newly installed monitoring wells associated with Modification No. 2, but only perchlorate and chlorate were analyzed in groundwater samples collected from pre-existing monitoring wells.

In addition to the collection of groundwater samples, Bio-traps®, which are patented devices available through a specialized microbiology consulting firm, Microbial Insights, were installed in three monitoring wells within the Transect 1a study area (LVWPS-MW103 and LVWPS-MW107A/B) and nine monitoring wells within the Transect 1b study area (LVWPS-MW203B, LVWPS-MW204B, LVWPS-MW206C, LVWPS-MW210A/B/C, LVWPS-

MW212D, LVWPS-MW222C, and LVWPS-MW223A). The Bio-traps® were retrieved after approximately 30 days and sent to Microbial Insights, Inc. for analysis of the perchlorate reductase enzyme and PLFA.

In addition, groundwater was collected from monitoring wells LVWPS-MW110, LVWPS-MW201B, and LVWPS-MW210C and transported to UNLV for use in the bench-scale studies described in Section 2.7.

## 2.5 SURFACE WATER SAMPLING

Groundwater from the Transect 1a and 1b areas ultimately discharges into the Wash. The local groundwater flow patterns within the Transect 1b study area are complex because the study area is immediately adjacent to the Wash and multiple engineered erosion mitigation weirs. By design, the weirs impact the surface water elevation profile in the Wash. The Work Plan anticipated that the weirs tend to cause the Wash surface water to recharge the localized groundwater upstream of the weirs and cause groundwater to discharge to the Wash downstream of the weirs. To determine exactly where the areas transition from recharge to discharge (and vice versa) would require a level of groundwater investigation that is beyond the scope of this pilot study. However, a simplified approach proposed in the Work Plan was to identify the general groundwater flow direction in the vicinity of the Wash so that the injection well transect(s) and monitoring wells could be properly located. Surface water discharge patterns were also evaluated during the timeframe of the Phase 1 pre-design activities through a thermal infrared and distributed temperature study performed by AECOM that involved monitoring and evaluation of surface water temperatures to identify potential groundwater discharge locations into the Las Vegas Wash. Results of this study will be discussed in detail in the forthcoming OU-3 RI.

As part of this evaluation, the surface water elevations from United States Geological Survey (USGS) stream gages collected at the same time groundwater elevations were measured in nearby monitoring wells in the Transect 1b study area were used to help assess the groundwater flow directions. Specifically, surface water elevation data recorded at three nearby gages (namely, USGS stream gages at Pabco, Bostick, and Homestead Weirs) were used. Two additional USGS gages at Middle Way and Lower Narrows Weir were originally planned for gaging in the Work Plan; however, they could not be located during field observations. Therefore, these gauges were not measured as part of the pre-design activities.

Pursuant to the *RI Phase 2 Investigation Modification No. 3* (Ramboll Environ, 2017b), *RI Phase 2 Investigation Modification No. 10* (Ramboll, 2018c), and *RI Phase 2 Investigation Modification No. 14* (Ramboll, 2018d), surface water samples are currently being collected monthly to evaluate the mass flux of perchlorate migrating into the Wash. Surface water samples are analyzed for perchlorate, chlorate, and TDS. The results from these sampling events are presented as part of the Semi-Annual and Annual Performance Monitoring Reports and detailed evaluation of the surface water and mass loading to the Wash will be performed as part of the forthcoming OU-3 RI. For purposes of the Phase 1 pre-design activities associated with this pilot study, three additional surface water sampling locations were added to the July 2018 monthly surface water sampling event to further evaluate groundwater discharge and perchlorate mass flux into the Wash downgradient of the Transect 1b study area. In addition to the routine monthly analysis of perchlorate, chlorate, and TDS, nine individual surface water locations and four multi-sample surface water transect locations were also analyzed for chloride, dissolved metals, sulfate, and total organic carbon. All surface water sampling locations are presented on Figure 4.

## 2.6 AQUIFER TESTING

The objective of the aquifer testing program was to obtain information regarding aquifer hydraulic conductivity, groundwater flow velocity, and total and mobile porosity in the Transect 1a and Transect 1b study areas. Initial aquifer testing activities, including slug testing, borehole dilution, and NMR logging, were performed in May/June 2018 for the Transect 1a study area, followed by performance of the same work for the initial set of monitoring wells in the Transect 1b study area in July 2018. Aquifer testing activities associated with the monitoring wells installed as part of Modification No. 2 were performed from November 2018 through January 2019. This section summarizes the general procedures of the aquifer testing activities. The results for each of the Transect 1a and Transect 1b study areas are presented in Sections 3.1.4 and 3.2.4. The supporting technical memorandums that present the detailed results for slug testing (including AQTESOLV [HydroSOLVE, 2007] plots), borehole dilution testing, NMR logging, and transducer data collection are provided in Appendices C, D, E, and F, respectively.

### 2.6.1 Slug Tests

Slug tests were performed in both newly installed and selected existing monitoring wells to estimate location-specific aquifer hydraulic conductivity in the screened interval of wells within the bioremediation pilot study areas. Slug tests were performed in 81 of the 85 newly installed monitoring wells and 3 existing monitoring wells (NERT4.93S1, WMW4.9S, and MW-13). Specifically, 20 of the 21 monitoring wells within the Transect 1a study area and 61 of the 64 monitoring wells within the Transect 1B study area were slug tested. One monitoring well within the Transect 1a study area (LVWPS-MW103B) and three monitoring wells within the Transect 1b study area (LVWPS-MW203C, LVWPS-MW204C, and LVWPS-226B) were not slug tested due to ongoing slow recovery following well development because these monitoring wells are screened in the semi-consolidated UMCf.

The slug tests were performed in general accordance with ASTM International Standard D 4044-96 (ASTM International, 2008). Prior to conducting each slug test, the water level in the monitoring well was measured manually with an electronic water level probe to determine the static groundwater level. An electronic pressure transducer/data logger was suspended in the monitoring 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 monitoring 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. Barometric pressure changes during testing were monitored and recorded using a pressure transducer placed above the water table.

At the end of each test, the pressure transducer was removed from the monitoring well and the water level displacement data were downloaded to a laptop computer and corrected for barometric pressure effects, if necessary. The corrected data were interpreted using AQTESOLV for Windows (Duffield, 2014). Where possible, both the falling-head and rising-head data were analyzed to cross-check the interpretation results.

### 2.6.2 Single-Borehole Dilution Testing

Single-borehole dilution tests were performed in select monitoring wells to evaluate volumetric flow in both the alluvium and UMCf. These tests consist of mixing a tracer compound into the groundwater in a monitoring well and observing the decline in tracer concentration in the monitoring well as a function of time using downhole instruments (Pitrak et al. 2007). The decline in tracer concentration in the well is due to dilution by volumetric groundwater flow, with results used to estimate groundwater velocity in the immediate vicinity of the monitoring well.

Tracers used in single-borehole dilution tests are typically chloride or bromide salts, or fluorescent dyes. Based on the proximity of the pilot study area to the Wash, fluorescent dye tracers were not used. Water quality results from pre-design groundwater sampling indicate that groundwater in monitoring wells proposed for single-borehole dilution testing has a specific conductance of 2,000 to 9,000 microsiemens per centimeter. As a result, the fairly high specific conductance supported the use of distilled water or stabilized Lake Mead water (SLMW) as a tracer. Distilled and SLMW water have successfully been used as the tracer during pre-design testing activities associated with other treatability studies at NERT. Based on data collected during groundwater sampling as part of the pre-design activities, the specific conductance was high enough that either distilled water or SLMW would serve as an effective tracer.

Single-borehole dilution tests were performed in the two newly installed 4-inch diameter monitoring wells (LVWPS-MW107A/B) to evaluate volumetric flow in the alluvium and UMCf within the Transect 1a study area. Single-borehole dilution tests were performed in 19 monitoring wells (both 2-inch and 4-inch monitoring wells) within the vicinity of Transect 1b study area over the course of the aquifer testing events conducted following each of the two drilling efforts. The 19 monitoring wells tested within the Transect 1b study area were LVWPS-MW201A, LVWPS-MW203B, LVWPS-MW206B, LVWPS-MW208A, LVWPS-MW210A/B/C/D/E, LVWPS-MW214, LVWPS-MW217A/B/C, LVWPS-MW220A/B, LVWPS-MW222A, and LVWPS-MW223A/B/C.

### 2.6.3 Nuclear Magnetic Resonance Logging

NMR logging was performed in the deepest monitoring well within each paired/clustered monitoring well configuration to further delineate any localized preferential flow pathways within the pilot study areas. This technology can be used in open or PVC-cased wells to provide high-resolution downhole estimates of hydraulic conductivity, total water content, total water-filled porosity, mobile porosity (approximately equivalent to effective porosity), and relative pore-size distributions below the water table (Walsh et al. 2013). Above the water table, NMR provides volumetric water content measurements. The specific tool used depended on the diameter of the well, because larger diameter wells require a larger tool that has a larger radius of investigation. All tools provided a measurement approximately every 1.5 to 2 feet of depth. The high-resolution estimates of hydraulic conductivity were compared to the lithologic logs and aquifer testing results for each monitoring well to assess the possibility of preferential flow.

Because the translation of NMR data to hydraulic conductivity requires the use of an empirical relationship, the correct model for the degree of consolidation of the formation must be selected to yield accurate estimates of hydraulic conductivity. The boreholes examined using NMR transitioned from unconsolidated to semi-consolidated UMCf, so the unconsolidated model was used for the upper portion of each borehole, and the semi-consolidated model was used for the lower portion. The point at which sediments transitioned from unconsolidated to semi-consolidated was identified by the field geologist based on field observations at the time of drilling.

NMR logging was performed in the deepest monitoring well within each paired/clustered monitoring well configuration following each of the drilling efforts. In June 2018, NMR logging was performed in 12 monitoring wells in the Transect 1a study area. In July 2018, NMR logging of 16 monitoring wells was completed following initial monitoring well installation in the Transect 1b study area. Following monitoring well installation associated with Modification No. 2, 15 newly installed monitoring wells in the Transect 1b study area were logged in November/December 2018. It should be noted that the five locations to which additional deep borings were added during Modification No.2 were relogged to obtain data at the greater depths within the new deepest well within that monitoring well cluster. Furthermore, the deep monitoring wells logged as part of the Modification No. 2 work were all installed as 4-inch diameter monitoring wells as the larger diameter monitoring well allowed for the use of a larger NMR tool to penetrate farther into the formation. Finally, one monitoring well (LVWPS-MW218C) could not be logged below 23 feet bgs because of a bend in the well casing.

### 2.6.4 Transducer Installation and Data Collection

Transducers were installed in selected newly installed pre-design monitoring wells to assess vertical and horizontal gradients in the alluvium and UMCf within the Transect 1a and Transect 1b study areas and to evaluate localized groundwater/surface water interactions over time within the Transect 1b study area. Downhole pressure transducers were In-Situ Rugged TROLL units, and the barometric transducers were In-Situ Rugged BaroTROLL units.

Within the Transect 1a study area, transducers were installed in May 2018 in monitoring wells LVWPS-MW101A/B, LVWPS-MW107C, LVWPS-MW111A/B, and LVWPS-MW112A/B. A barometric pressure transducer was installed in LVWPS-MW112B to facilitate the compensation of water-level monitoring data for changes in barometric pressure. Data were downloaded in July and December 2018. Within the Transect 1b study area, transducers were installed in July 2018 in monitoring wells LVWPS-MW201A/B, LVWPS-MW206A/B/C, and LVWPS-MW210A/B/C. In December 2018, transducers were also installed in monitoring wells LVWPS-MW206D/E, LVWPS-MW210D/E, and LVWPS-MW222A/B/C. A barometric pressure transducer was installed in LVWPS-MW206B. Data are recorded on 15-minute intervals. Data were downloaded in December 2018 from the transducers installed in July 2018. Data from transducers installed in December 2018 will be downloaded within six months following installation (July 2019).

In addition to transducers installed as part of the pre-design activities, data were also obtained from transducers installed by AECOM in nearby existing monitoring wells NERT4.51S1, NERT4.71S1, NERT4.93S1, and NERT5.11S1 as part of the on-going Downgradient Study Area RI field work. The groundwater elevation data were compared to available data from USGS stream gaging stations and AECOM to assist in assessing localized groundwater/surface water interactions over time.

Results of the transducer data collection and evaluation are presented in Section 3.1.4.4 and 3.2.4.4 for Transect 1a and Transect 1b study areas, respectively.

## 2.7 LABORATORY STUDIES

Bench-scale laboratory studies performed in connection with previous and on-going treatability studies have provided significant data on the biodegradation potential of perchlorate and other electron acceptors using emulsified vegetable oil (EVO) as the carbon substrate, as well as further information on the potential longevity of the carbon substrate. The original proposal presented in the Work Plan included batch microcosm testing, column studies, and EVO sorption/desorption tests. The Work Plan also indicated that a single study would be performed for the Las Vegas Wash Bioremediation Pilot Study and Galleria Drive Bioremediation Treatability Study, presuming that soil lithological and geochemical characteristics were similar. Preliminary chemical and lithological analyses have indicated that the soils from the two areas are geochemically and mineralogically quite different. Therefore, these two areas were not combined for purposes of bench-scale testing. However, the geochemical and lithological makeup for the alluvium and portions of the UMCf are similar to the subsurface environment present in the Seep Well Field Area Bioremediation Treatability Study. As a result, batch microcosm and EVO sorption/desorption laboratory testing, as well as on-going field application, for the SWF Area Bioremediation Treatability Study have provided preliminary information on acclimation time, biodegradation rates, and adsorption capacities. Therefore, additional batch microcosm testing was not performed for the Las Vegas Wash Bioremediation Pilot Study. However, both batch sorption and column sorption/desorption tests were included in the bench-scale testing for both the alluvium and UMCf within the pilot study area. The sorption tests are performed to understand the interactions of site-specific soil with the EVO, including substrate movement and how it desorbs over time, to support biodegradation.

Per the Work Plan, column diffusion studies have been designed to simulate the upward migration of perchlorate from the UMCf into the alluvium and help establish the hydraulic, physical, and chemical relationship between these two lithological zones. These tests have been designed to understand the potential for upflux or transport of perchlorate from the UMCf into the alluvium in order to factor in this "upflux effect" during remedial implementation and make modifications to the carbon substrate injection protocol (if required). It may be hypothesized that once the perchlorate in the alluvium groundwater is remediated, perchlorate in the UMCf may move via molecular diffusion into the alluvial portions of the formation. Understanding such transport behavior could be advantageous to addressing the perchlorate that could be residing in the upper portions of the UMCf. Modifying remedial operations and injection protocol within these two zones will optimize perchlorate remediation during the pilot study and allow for transport behavior evaluation. It should be noted that the upflux effect will be discussed in greater detail in the forthcoming OU-1/OU-2 and OU-3 RI Reports and the understanding of this behavior will be critical to selection of the final remedy.

To perform the bench-scale tests, soil and groundwater were collected from the saturated alluvium and UMCf in both the Transect 1a and Transect 1b study areas, as explained in Section 2.3.2.1 and 2.4. Specifically, soil was collected from boring LVWPS-MW105, located within the Transect 1a study area, and borings LVWPS-MW201B and LVWPS-MW210B, located within the Transect 1b study area. Following well installation/development, groundwater was collected from monitoring wells LVWPS-MW201B and LVWPS-MW210C. All collected soil and groundwater were placed in 3-gallon buckets, individually labeled based on depth and boring, and transported to UNLV for testing.

At the time of this Work Plan Addendum, batch sorption tests have been completed, column sorption/desorption tests are on-going, and column diffusion tests are constructed and expected to be completed in August 2019. Completion of the column testing is not currently required to finalize the design presented in this Work Plan Addendum. As described in Section 4, the ISB pilot study will focus on both alluvium and UMCf with a refined set of objectives that further evaluate the upflux component within the study area, which will compliment other investigations of the upflux effect being conducted by the Trust. Although the bench-scale studies will provide information on the potential for upflux into the alluvium from the UMCf, these results will not change the pilot study design itself with respect to initial injection well spacings and carbon substrate quantities. During pilot study implementation, field data will be obtained that will provide additional information with regards to: 1) lithological details and mass flux estimates for both alluvium and UMCf within the injection well transects; 2) microbial response and perchlorate degradation response and the differences between the two units; and 3) field observations during injections (both injectability and tracing of the injected dye [described in Section 4.2.4]). This information in combination with the results of the laboratory column study will provide necessary data to determine the timing and carbon substrate dosages (and any modifications thereof) for the subsequent injection events into both the alluvium and UMCf. Results and conclusions on the laboratory bench-scale testing (batch microcosm and EVO sorption/desorption) performed on similar material as part of the SWF Bioremediation Treatability Study are presented in Section 3.3.

# 3.0 PHASE 1 PRE-DESIGN FIELD AND LABORATORY RESULTS

As explained in Section 2.0, several pre-design activities were completed to collect the data required to optimize the final pilot study locations and design. These data have been used to characterize the lithology, evaluate vertical and horizontal distribution of perchlorate, identify preferential flow pathways, and determine groundwater flow directions and rates. This section presents the results of these pre-design activities with respect to Transects 1a and Transect 1b study areas. A discussion of how these results differed from our previous understanding of the study areas at the time of the Work Plan can be found in Section 4.1.1.

## 3.1 TRANSECT 1A STUDY AREA RESULTS

Data collected during the soil boring and monitoring well installation, groundwater sampling, and aquifer testing were compiled to provide an overview of the geology, hydrogeology, nature and extent of contamination, and hydraulic properties of the Transect 1a study area. Monitoring well locations discussed within this section are shown on Figure 2. As previously noted in Section 2.1, the Transect 1a study area has been eliminated from the upcoming Phase 2 pilot study program. However, the results from the Phase 1 activities associated with Transect 1a study area are summarized herein, with additional details on the basis for eliminating the Transect 1a study area from the pilot study program provided in Section 4.3.1.

### 3.1.1 Geology

Data from the soil boring and monitoring well installation activities were compiled to provide a description of the geology of the Transect 1a study area. Geologic cross-sections of the Transect 1a study area are presented in Figures 5a and 5b. A review of the lithology observed during soil boring installation indicates that the uppermost 17.5 to 55 feet of material within the Transect 1a study area consists of alluvium ranging from silty sands to sandy gravel with minor lenses of sandy silt. The UMCf underlying the alluvium in the Transect 1a study area predominantly consists of clay to sandy silt. The contact between alluvium and UMCf is shallowest towards the southeastern portion of the study area near locations LVWPS-MW106, LVWPS-MW110, and LVWPS-MW103A/B, where saturated alluvium is minimal or absent. The depth to the alluvium-UMCf contact increases with proximity to the Wash in the northeastern portion of the study area.

In general, the uppermost UMCf is unconsolidated silt, and stratified to laminated light greenish gray clay layers are common. Organic matter occurs on bedding surfaces (including possible paleo seed pods) and in more massive organic-rich layers, as shown on Figures 5a and 5b. The deeper UMCf below approximately 70-80 feet bgs is semi-consolidated, and gypsum occurs as disseminated very fine to coarse grained crystals up to 2 inches in length and in beds composed almost entirely of gypsum. In the southeastern portion of the study area (LVWPS-MW103A/B, LVWPS-MW106, LVWPS-MW110), gypsum occurs in the UMCf from approximately 40-55 feet bgs to the base of the soil borings.

### 3.1.2 Hydrogeology

Based on data collected during the installation of soil borings and monitoring wells, groundwater was first encountered at approximately 15 feet bgs in the Transect 1a study area. Within the southeastern portion of the study area near locations LVWPS-MW106, LVWPS-MW110, and LVWPS-MW103A/B, water was first encountered near the bottom of the alluvium or just below the top of the unconsolidated UMCf. Toward the northern portion of the study area, there was significant saturated alluvium.

Following monitoring well installation, synoptic groundwater levels were collected in all monitoring wells during the May 2018 sampling event and then again in July 2018 in conjunction with the adjacent SWF Area Bioremediation Treatability Study monitoring wells to provide a larger, more comprehensive dataset. Depth to water measurements during each of these events are provided in Table G.1 in Appendix G. During both the May and

July 2018 gauging events, groundwater flow in the southern portion of the study area was towards the northeast. Groundwater flow in the northern portion of the study area was primarily towards the east, likely influenced by the Wash and potentially by the presence of a north-south oriented paleochannel immediately east of the study area (Figure 6).

Figure 6 presents a groundwater potentiometric surface map of the uppermost saturated zone in the Transect 1a study area. In the uppermost saturated zone, the calculated average eastward hydraulic gradient in the study area was 0.006 feet per foot (ft/ft), and the calculated average northeastward hydraulic gradient was 0.01 ft/ft.

The vertical gradient within the UMCf is upward throughout the study area and ranges from 0.04 to 0.19 ft/ft. The vertical gradient between the alluvium and the UMCf is upward throughout the study area and ranges from 0.08 to 0.32 ft/ft. The exception is location LVWPS-MW112, where there is a downward vertical gradient of 0.02 ft/ft. In general, the magnitude of the upward vertical gradient is largest in the western portion of the study area. The magnitude of the vertical hydraulic gradient is smaller toward the east, closer to the paleochannel adjacent to the Transect 1a study area near location LVWPS-MW112. The strong vertical gradient implies that there are significant barriers to vertical flow in the study area, which is typical in a laminated, partially cemented, fine-grained formation such as the UMCf. By contrast, the vertical hydraulic gradient in the northeastern portion of the study area progressively decreases, indicating an improved vertical connection between the alluvium and the top of the UMCf.

## 3.1.3 Analytical Results

As described in Sections 2.3.2 and 2.4, soil and groundwater samples were collected during and/or following monitoring well installation to evaluate the vertical and horizontal distribution of perchlorate in soil and groundwater. Soil and groundwater samples were collected for analysis of a variety of chemical, geochemical, and microbial parameters to determine the geochemical and microbial characteristics of the aquifer within the study area. This section presents the results of the soil and groundwater sampling associated with the Transect 1a study area.

### 3.1.3.1 Soil Analytical Results

As described in Section 2.3.2.1, six soil samples were collected at eight of the 12 locations distributed from the top of the water table to the base of the boring at 120 feet bgs. At four of the 12 locations, 10 soil samples were collected from the top of the water table to the base of the boring. Samples were collected to characterize distribution of perchlorate in soil with depth. Soil analytical results are presented in Table H.1 in Appendix H and summarized in ***Table 1***. Perchlorate concentrations in soil within the Transect 1a study area have also been plotted on the geologic cross-sections presented as Figures 7a and 7b.

***Table 1*** Perchlorate Concentration Ranges in Soil - Transect 1a Study Area

| Lithology | Sample Depth (ft bgs) | Perchlorate (mg/kg) |
|---|---|---|
| Alluvium | 21.5 – 47 | <0.012 – 3.2 |
| UMCf | 27.5 – 76.5 | <0.012 – 5.3 |
| Semi-consolidated UMCf | 62 – 120 | <0.012 – <0.24 |

**Notes:**
ft bgs – feet below ground surface
mg/kg – milligrams per kilogram
UMCf – Upper Muddy Creek formation

Perchlorate concentrations ranged from less than 0.012 to 5.3 milligrams per kilogram (mg/kg) in soil samples collected from both the saturated alluvium and unconsolidated UMCf. Perchlorate was not detected in soil samples collected from the deeper, semi-consolidated UMCf below approximately 77 feet bgs within the Transect 1a study area. The highest perchlorate concentration of 5.3 mg/kg was detected in the soil sample collected from the unconsolidated UMCf at LVWPS-MW103 at 27.5 feet bgs.

As described in Section 2.3.2.1, six soil samples (four samples from the unconsolidated UMCf and two samples from the semi-consolidated UMCf) were collected from LVWPS-MW102B and LVWPS-MW110 and analyzed for a suite of analytes to provide additional characterization of the subsurface. These additional analyses included anions and cations (alkalinity, bicarbonate, carbonate, calcium, chloride, magnesium, nitrate, potassium, and sulfate), chlorate, dissolved metals, hexavalent chromium, phosphorus, soil pH, TDS, total kjeldahl nitrogen (TKN), and total organic carbon (TOC). A summary of these results is presented below.

- Anions and cations were analyzed to assess the salt loading in the soil. Predominant among the anions were chloride (maximum of 140 mg/L) and sulfate (maximum of 2,300 mg/L at one location while the others were below 130 mg/L). These results indicate that there is unlikely to be any toxic impact on native microorganisms for perchlorate biodegradation.
- Chlorate results ranged from 0.19 J to 8.0 J mg/kg. Data qualifier J indicates that a laboratory result is an estimated quantity and that the associated numerical value is the approximate concentration of the analyte in the sample.
- Dissolved metals were analyzed to assess potential secondary impacts of bioremediation. Results indicate that one solitary location had an arsenic concentration of 820 $\mu$g/L, while all the other samples ranged from less than 2.5 $\mu$g/L to 11 $\mu$g/L. Therefore, it does not appear that arsenic mobilization would be an issue at this site. However, groundwater sampling of arsenic will be performed as part of the monitoring program. Although iron was detected as high as 970 $\mu$g/L at one location, it was less than 330 $\mu$g/L in all remaining samples, indicating that precipitation of iron is unlikely to be an issue with regards to being a contributary factor for aquifer permeability reduction. Manganese was detected at very low concentrations as well, ranging from 3.6 J $\mu$g/L to 33 $\mu$g/L, indicating the unlikelihood of its precipitation at problematic levels during ISB. Finally, dissolved chromium was detected at very low concentrations (maximum of 36 $\mu$g/L) in two of the six samples and is unlikely to be a problematic contaminant of concern at this site.
- Hexavalent chromium was not detected above the sample detection limit in any soil samples collected within the Transect 1a study area.
- Phosphorus concentrations ranged from 300 to 1,200 mg/kg, which indicates that there appears to be significant phosphorus bound to the soil. However, bound phosphorus is not always available as a micronutrient to native microorganisms and therefore as measured in groundwater in the area (phosphorus was not detected above the sample detection limit in any groundwater sample), dilute phosphorus may need to be included in the ISB injection solutions.
- Soil pH was measured at 7.1 to 7.7 standard units.
- TDS was analyzed on the water extract, with results indicating that concentrations increase with depth as the highest concentrations were observed in the semi-consolidated UMCf at concentrations up to 3,900 mg/L. This is expected given the observed presence of gypsum at depth. At these levels, no toxicity of native microorganisms is expected based on the results from previous and on-going ISB treatability studies.
- Total kjeldahl nitrogen (TKN) was detected at concentrations of up to 630 J mg/kg, which indicates that there is sufficient nitrogen to serve as a micronutrient for native microorganisms during bioremediation.
- TOC concentrations ranged from less than 600 mg/kg to 69,000 mg/kg. TOC is likely high because of ancient deposits of plant material that is still undergoing decay. It is very unlikely that this plant material is providing an available and usable source of organic carbon for microorganisms based on the presence of

aerobic groundwater conditions. Plant material is often hard to degrade as it contains long chain organics such as lignin.

Four soil samples were sent to Microbial Insights for analysis of PLFA and the perchlorate-reductase enzyme. Due to microbial samples collected in the alluvium in the nearby SWF Area Bioremediation Treatability Study, the focus of these samples was the UMCf. Samples were collected from LVWPS-MW102B (depths of 22.5 – 23 and 58 – 58.5 feet bgs) and LVWPS-MW110 (depths of 29-29.8 and 46-46.5 feet bgs); these depths represented the depth the uppermost saturated zone and then a sample collected from the same boring at a deeper depth within the UMCf. Soil microbial results are presented in Table H.2 in Appendix H. The key findings of the microbial analysis indicate that two of the four samples have notable microbially active populations in the range of $10^5$ cells/gram. Total microbial populations for the other two samples are less than the detection limit for those samples at the $10^5$ cells/gram level. Biomass populations below this level do not indicate that the soil is devoid of microorganisms, as sometimes subsurface soils contain metals, humics, and other inhibitors, which could lower microbial populations that may not be reflected in associated groundwater. The proportion of the Normal saturated fats (Nsats) in PLFA are significant in both samples that had detections. Higher proportions of Nsats are generally reflective of a native soil microbial population that is not as diverse in terms of community structure. Again, as in the case of biomass populations, lower diversity in soil, potentially due to the presence of inhibitory substances, do not reflect lower diversity in associated groundwater as described in the groundwater analytical section results (Section 3.1.3.4). of the general bacteria (normal saturated [Nsats], which are found in all organisms) are significant in both samples that had detections, indicating a microbial population that is not particularly diverse in this area. However, results also indicate that proteobacteria are present, which is important for biodegradation of perchlorate and other electron acceptors (such as nitrate) once the carbon substrate has been injected.

Ratios for slowed growth and decreased permeability of the cell membrane provide information on the “health” of the gram-negative microbial community and how this population is responding to the conditions present in the environment. Higher ratios (greater than 1.0) could be reflective of a community that is stressed and an environment that may not be as supportive of the existing microbial community, often due to the lack of available carbon substrate. The ratios of slowed growth and decreased permeability in the soil samples collected from the Transect 1a study area indicate an environment that is generally not toxic to microorganisms and would likely be supportive of perchlorate bioremediation upon the addition of a carbon substrate. Finally, the perchlorate reductase enzyme was not detected above the laboratory detection limit of $2.5 \times 10^4$ cells/gram, which is not unexpected considering this enzyme is specific to perchlorate reduction processes and the fact that ISB via the addition of an organic carbon substrate has not yet been implemented within this pilot study area.

### 3.1.3.2 Soil Geotechnical Results

As explained in Section 2.3.2.1, nine Shelby tubes were collected from both the saturated alluvium and unconsolidated UMCf at three locations (namely, LVWPS-MW102B, LVWPS-MW109, and LVWPS-MW110) within the Transect 1a study area. The Shelby tube samples were analyzed for the following physical parameters: specific gravity by ASTM D854, moisture content by ASTM D2216, total porosity by APR RP40, bulk dry density by ASTM D2937, and sieve analysis by ASTM D6913. Soil geotechnical results are presented in Table H.3 in Appendix H.

Aquifer porosity and specific gravity of the aquifer solids were determined for both the saturated alluvium and unconsolidated UMCf. Total porosity was 28 percent in the sample collected from the alluvium and ranged from 50.6 to 65.2 percent in the samples collected from unconsolidated UMCf. It should be noted that total porosity often overestimates the effective porosity in an aquifer. Whereas total porosity measures the volume occupied by water in a fixed volume of aquifer material, effective porosity measures the portion of the pore space that is connected and can transmit water. Specific gravity was 2.607 in the sample collected from the alluvium and ranged from 2.583 to 2.722 in the samples collected from the unconsolidated UMCf. Bulk dry density was 117 pounds per cubic foot (lbs/ft$^3$) in the sample collected from the alluvium and ranged from 56.0 to 83.3 lbs/ft$^3$ in the samples collected from the unconsolidated UMCf. The sieve analysis confirms the field observations, which indicated that the UMCf in the Transect 1a study area was generally composed of silt and clay with varying percentages of fine sand.

### 3.1.3.3 Depth-Discrete Groundwater Analytical Results

The purpose of the depth-discrete groundwater sampling was to evaluate potential variation in groundwater concentrations with depth. As described in Section 2.3.2.2, six depth-discrete groundwater samples were collected at five locations from varying depths in the alluvium and unconsolidated UMCf that were not screened during monitoring well installation. All depth-discrete groundwater samples were analyzed for perchlorate and two samples (one each from the alluvium and unconsolidated UMCf) were also analyzed for nitrate and chlorate. Perchlorate concentrations in depth-discrete groundwater samples in the alluvium and UMCf ranged from 4,900 to 5,700 µg/L and 8.5 to 4,300 µg/L, respectively. Chlorate and nitrate concentrations were greater in groundwater samples collected from the alluvium than the unconsolidated UMCf. Chlorate concentrations measured in groundwater from the alluvium and unconsolidated UMCf were 15,000 and 940 µg/L, respectively. Nitrate concentrations measured in groundwater from the alluvium and UMCf were 10 and 1.7 mg/L, respectively. Depth-discrete groundwater results are presented in Appendix H, Table H.4.

### 3.1.3.4 Groundwater Analytical Results

As described in Section 2.4, a groundwater sampling event was conducted during the pre-design phase for the Transect 1a study area in May 2018. Groundwater samples were collected from all 21 newly installed monitoring wells and analyzed for the full suite of parameters presented in the Work Plan. Groundwater sampling field logs are provided in Appendix G, and complete analytical results are provided in Appendix H, Table H.5.

#### 3.1.3.4.1 Groundwater Chemical and Geochemical Results

***Table 2*** presents a summary of the groundwater concentration ranges of perchlorate and chlorate, as well as other noteworthy parameters with respect to the bioremediation process, for the Transect 1a study area. Perchlorate concentrations in groundwater within this area have also been plotted on the geologic cross-sections presented as Figures 8a and 8b. Groundwater sampling field logs are provided in Appendix D.

***Table 2*** Concentration Ranges in Groundwater - Transect 1a Study Area

| Analyte | Concentrations in the Alluvium (16 – 52 ft bgs) | Concentrations in the Unconsolidated UMCf (30 – 77 ft bgs) | Concentrations in the Semi-consolidated UMCf (77 – 120 ft bgs) |
|---|---|---|---|
| Perchlorate (µg/L) | 2,500 – 7,700 | < 2.5 – 9,400 | < 50 |
| Chlorate (µg/L) | 8,400 – 31,000 | < 50 – 71,000 | < 250 – 580 J |
| Nitrate as N (mg/L) | 5.7 – 14 | < 1.1 – 17 | < 5.5 |
| Sulfate (mg/L) | 1,500 – 3,000 | 2,500 – 22,000 | 26,000 – 80,000 |
| TDS (mg/L) | 4,600 – 6,200 | 6,100 – 39,000 | 56,000 – 130,000 |

**Notes:**
ft bgs – feet below ground surface
J – Result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.
µg/L – micrograms per liter
mg/L – milligrams per liter
TDS – total dissolved solids
UMCf – Upper Muddy Creek formation

Perchlorate was detected above the sample detection limit in groundwater samples collected from most monitoring wells screened in the alluvium and unconsolidated UMCf within the Transect 1a study area, with the exception of two monitoring wells screened in the unconsolidated UMCf in the center of the study area (LVWPS-MW107B and LVWPS-MW110). In general, the range of perchlorate concentrations measured in the alluvium is similar to the range in the unconsolidated UMCf. Perchlorate was detected below the sample detection limit in groundwater samples collected from the four monitoring wells screened in the semi-consolidated UMCf within the 77 to 120 feet bgs interval (LVWPS-MW102B, LVWPS-MW103B, LVWPS-MW107C, and LVWPS-MW108C), which is consistent with soil analytical results discussed in Section 3.1.3.1. It should be noted, however, that the four groundwater samples collected from the monitoring wells screened within the semi-consolidated UMCf that did not have detections of perchlorate had an elevated sample detection limit of 50 μg/L. The analytical laboratory reported that sample dilutions were necessary due to interferences caused by chloride, sulfate, and TDS. Specifically, high anion and TDS concentrations like those encountered in groundwater from the 77-120 feet bgs interval in the Transect 1a study area may interfere with the instrumentation used in perchlorate analysis. As a result, the analytical laboratory must run an initial dilution on the groundwater sample, which elevates the laboratory detection and reporting limits.

Chlorate concentrations followed a similar pattern with respect to vertical distribution in the alluvium and unconsolidated UMCf and also had elevated sample detection limits in groundwater samples collected from the semi-consolidated UMCf. However, chlorate concentrations in groundwater were generally one order of magnitude greater than perchlorate concentrations. Chlorate was detected below the elevated sample detection limit of 250 μg/L in groundwater samples collected from three of the four semi-consolidated UMCf monitoring wells. The groundwater sample collected from monitoring well LVWPS-MW103B, which is screened in the semi-consolidated UMCf, had a chlorate detection of 580 J μg/L.

Nitrate, which is often the preferred electron acceptor compared to perchlorate during anaerobic bioremediation in the presence of a carbon substrate (denitrification generally occurs prior to perchlorate biodegradation), was detected at concentrations up to 17 mg/L in groundwater samples collected from monitoring wells screened in the alluvium and unconsolidated UMCf. Nitrate was not detected above the laboratory detection limit of 5.5 mg/L (which is also an elevated detection limit due to initial dilutions required as described above) in groundwater samples collected from the deeper monitoring wells screened in the semi-consolidated UMCf from 77-120 feet bgs.

Sulfate and TDS were detected in groundwater samples in monitoring wells screened in the alluvium at concentrations of up to 3,000 and 6,200 mg/L, respectively. In groundwater samples collected from the unconsolidated UMCf (30-77 feet bgs), however, sulfate and TDS were detected at higher concentrations of up to 22,000 and 39,000 mg/L, respectively. Sulfate and TDS were detected at concentrations up to 80,000 and 130,000 mg/L, respectively, in groundwater samples collected from the semi-consolidated UMCf (77-120 feet bgs). The high TDS concentrations are attributed to the sulfate concentrations and associated cations, rather than the chlorate and perchlorate concentrations.

In addition to the key parameters of perchlorate, chlorate, nitrate, sulfate, and TDS, groundwater samples were also analyzed for the full suite of parameters presented in the Work Plan. A summary of these results is provided below:

- Chloride concentrations in groundwater ranged from 700 to 1,200 mg/L in the alluvium, 820 to 3,400 mg/L in the UMCf, and 10,000 to 15,000 mg/L in the semi-consolidated UMCf. Chloride is an important component that makes up the TDS in groundwater and is key to the salt content that in very saline conditions poses toxicity issues for native microorganisms. At the concentrations observed in the alluvium and unconsolidated UMCf, chloride should not pose a problem for biodegradation of perchlorate. However, it is possible that the high concentrations present in groundwater within the semi-unconsolidated UMCf may be toxic or slow down the metabolic rate of microorganisms.

- Dissolved metals and total manganese were analyzed to assess potential secondary impacts of bioremediation. Key metals of chromium, iron and manganese were generally not detected in groundwater or present at very low concentrations, which indicate that very little iron or manganese is likely to precipitate during ISB operations and that chromium is not a potential contaminant of concern in this groundwater setting. The highest detection of dissolved arsenic was 76 μg/L.
- The maximum concentration of hexavalent chromium in groundwater was 25 μg/L in the alluvium and 46 μg/L in the unconsolidated UMCf. Hexavalent chromium was not detected above the sample detection limit in groundwater in the semi-consolidated UMCf.
- Total nitrogen was measured at concentrations up to 14 mg/L in the alluvium, 17 mg/L in the unconsolidated UMCf, and 19 mg/L in the semi-consolidated UMCf. TKN was also analyzed and either not detected or detected at similar concentrations as total nitrogen. Total nitrogen concentrations signify that it is unlikely that nitrogen will be required to be supplemented as a nutrient source for microorganisms.
- Total phosphorus was detected at concentrations ranging from less than the sample detection limit to 0.42 mg/L. Concentrations at these low levels indicate the likely need to add this macronutrient for the growth and development of microorganisms for perchlorate biodegradation.
- Field parameters including DO and ORP indicate that the groundwater is generally aerobic. Groundwater pH generally ranged between 6 and 8 standard units, which indicates that there should be no hindrances to the growth and development of microorganisms. Ferrous iron and sulfide were only detected at five locations at concentrations of up to 0.25 and 1.9 mg/L, respectively, which is expected since ferrous iron and sulfide are normally produced during strongly reducing conditions that result in iron mobilization and sulfate reduction.
- TDS was generally detected at concentrations less than 10,000 mg/L in groundwater samples collected from the alluvium and unconsolidated UMCf. Elevated TDS concentrations were detected as high as 130,000 mg/L in groundwater samples collected from the semi-consolidated UMCf. The extremely high TDS concentrations observed in groundwater from the semi-consolidated zone indicates a severe limitation for biodegradation and likely toxicity to the microorganisms due to salt intolerance.
- Alkalinity (as calcium carbonate) ranged from 79 to 260 mg/L, which represents a similar range measured during baseline sampling activities at previous ISB study areas. These ranges were expected as alkalinity will generally increase once the microbial activity increases during bioremediation following the addition of a carbon substrate.
- Methane concentrations generally ranged from less than the sample detection limit to 0.87 mg/L, which was expected since methanogenic conditions require highly reducing conditions and the aquifer present within the Transect 1a study area is generally aerobic.
- TOC concentrations were generally below 4 mg/L in groundwater samples collected from the alluvium and unconsolidated UMCf, with the highest TOC concentration of 7.2 mg/L detected in a groundwater sample collected from the semi-consolidated UMCf. At these low concentrations, groundwater must be supplemented with a carbon substrate for perchlorate biodegradation to occur.
- No volatile fatty acids (VFAs) were detected in groundwater samples collected from the Transect 1a study area. This result was expected since carbon substrate injections have not occurred.

#### 3.1.3.4.2 Groundwater Microbial Results

As explained in Section 2.4, Bio-Traps® were placed in three monitoring wells within the Transect 1a study area (LVWPS-MW103B and LVWPS-MW107A/B), retrieved after approximately one month, and shipped to Microbial Insights for analyses. Groundwater microbial results are presented in Appendix H, Table H.6. Microbial biomass results ranged from $2.58 \times 10^4$ to $1.05 \times 10^5$ cells/gram. These numbers indicate adequate microbial populations in groundwater that could possess the ability to biodegrade perchlorate and other inorganic electron acceptors such as chlorate and nitrate, upon the addition of an external source of organic carbon. A sizable proportion of the bacterial population (greater than 70 percent) were comprised of the Proteobacteria group, which was observed in

Bio-traps® from all three monitoring wells. These high proportions of Proteobacteria are reflective of a bacterial group that is highly adaptive and is likely to opportunistically consume carbon substrates that are added to the groundwater for perchlorate biodegradation. On the other hand, the low proportions (less than 5 percent) of observed metal-reducing bacteria and sulfate-reducing bacteria (SRB)/actinomycetes) reveal redox conditions that are not overly reducing. Eukaryotes were not detected in two of the three samples and were found at 1.29 percent of the overall bacterial proportion in the third sample, which indicates that these scavengers of valuable contaminant-reducing bacteria do not pose a significant threat in this groundwater environment.

As explained in Section 3.1.3.1, ratios for slowed growth and for decreased permeability of the cell membrane provide information on the "health" of the gram-negative microbial community and how this population is responding to the conditions present in the environment. The ratios of slowed growth and decreased permeability from all three Bio-traps® are less than 0.56, which indicate that there is unlikely to be environmental toxicity to native microorganisms in the subsurface within the Transect 1a study area. Finally, the perchlorate reductase enzyme was not detected above the sample detection limit of 2.5 x $10^2$ cells/gram in any of the three Bio-traps®, as expected, which is typical of observations in groundwater at other areas of the site such as the successful on-going SWF study where this enzyme was not detected during pre-injection sampling events.

In summary, the groundwater in Transect 1a appears to possess a microbial community that should respond favorably to the addition of a carbon substrate, even though the soil results presented in Section 3.1.3.1 indicate lower microbial populations and some environmental stress in two of the four soil samples collected from the Transect 1a study area.

### 3.1.4 Aquifer Testing Results

As explained in Section 2.6, an aquifer testing program was implemented to obtain information regarding aquifer hydraulic conductivity, groundwater flow velocity, and total and mobile porosity in the Transect 1a study area. This section summarizes the results from these aquifer testing activities (slug testing, borehole dilution, NMR logging, and initial long-term transducer data collection). The supporting summary memos for slug testing, borehole dilution testing, NMR logging, and transducer data collection are presented in Appendices C, D, E, and F, respectively. The appendices include AQTESOLV (HydroSOLVE, 2007) interpretation plots of slug tests, borehole dilution test plots, NMR logs, and preliminary hydrographs.

#### 3.1.4.1 Slug Tests

Using the procedures presented in Section 2.6.1 and Appendix C, slug tests were performed in 20 of the 21 newly installed monitoring wells to estimate location-specific aquifer hydraulic conductivity in the screened interval of monitoring wells within the Transect 1a study area. Slug test results support the field observation that hydraulic conductivity generally decreases with depth. The average hydraulic conductivity in the alluvium was approximately 28 feet per day (ft/day), while the average hydraulic conductivity in the unconsolidated UMCf was significantly lower at approximately 1.5 ft/day. Hydraulic conductivity estimates for the semi-consolidated, gypsum-rich deeper portion of the UMCf (LVWPS-MW102B, LVWPS-MW107C, and LVWPS-MW108C) averaged 0.8 ft/day. It should be noted that monitoring wells were intentionally screened in more productive zones of the semi-consolidated UMCf, where possible. Although not slug tested, monitoring well LVWPS-MW103B, which exhibited slow recovery rates following well development, is likely to have a more typical hydraulic conductivity for the semi-consolidated UMCf of less than 0.01 ft/day. The decrease in hydraulic conductivity with depth and increased cementation is expected, but it is also associated with slower flow rates.

#### 3.1.4.2 Single-Borehole Dilution Testing

Using the procedures presented in Section 2.6.2 and Appendix D, single-borehole dilution tests were performed in two monitoring wells (LVWPS-MW107A/B) to evaluate groundwater flow velocities in the alluvium and unconsolidated UMCf within the Transect 1a study area. Results indicate that the average flow velocity in monitoring well LVWPS-MW107A (screened in the alluvium) is approximately 4 ft/day, and the average flow velocity in monitoring well LVWPS-MW107B (screened in the unconsolidated UMCf) is approximately 0.04 ft/day, depending on hydraulic conditions. It should be noted that monitoring well LVWPS-MW107B had a low hydraulic conductivity compared to most other unconsolidated UMCf monitoring wells installed within the Transect 1a study area. As a result, typical groundwater flow rates in the UMCf within the Transect 1a study area may be higher.

#### 3.1.4.3 Nuclear Magnetic Resonance Logging

As explained in Section 2.6.3 and Appendix E, NMR logging was performed in the deepest monitoring well at each of the 12 locations to further delineate any localized preferential flow pathways within the Transect 1a study area. NMR estimates of hydraulic conductivity generally agreed with estimates derived using slug testing within an order of magnitude.

The NMR water content logs show an increase in water content at the contact between the alluvium and UMCf, which is expected given that the higher clay content of the UMCf is generally associated with higher porosity. NMR also provides an estimate of mobile porosity, which is approximately equivalent to effective porosity and provides a distinction between “more bound” water and “more mobile” water. In the uppermost, least consolidated portion of the UMCf, the logged mobile porosity was fairly high, often reaching 15 percent. These values are greater than what would be expected for a typical mixture of silt and clay, but match well with the hydraulic conductivity of the unconsolidated UMCf obtained from slug tests, which was also higher than expected for a typical mixture of silt and clay. By contrast, the mobile porosity of the semi-consolidated, deeper part of the UMCf was typically logged to be less than 5 percent.

#### 3.1.4.4 Transducer Data Collection

As explained in Section 2.6.4 and Appendix F, data from transducers installed in the Transect 1a study area monitoring wells were downloaded in July and December 2018. The data were corrected for barometric pressure and compared to the surface water elevation data from the nearby Pabco Road gauging station (USGS 09419700 Las Vegas Wash at Pabco Rd Nr Henderson, NV). The comparison indicated that the Transect 1a study area monitoring wells were not visibly influenced by short-term temporal variations in the water levels in the Wash. The preliminary data also indicate that the vertical gradients between the alluvium and UMCf do not appear to vary significantly or change direction over time.

## 3.2 TRANSECT 1B STUDY AREA RESULTS

Data collected during soil boring and monitoring well installation, groundwater sampling, surface water sampling, and aquifer testing were compiled to provide an overview of the geology, hydrogeology, nature and extent of contamination, and hydraulic properties of the Transect 1b study area. Monitoring well and surface water sampling locations discussed within this section are shown on Figure 3.

### 3.2.1 Geology

Data from the soil boring and monitoring well installation activities were compiled to provide a description of the geology of the Transect 1b study area. Geologic cross-sections of the Transect 1b study area are presented in Figures 9a, 9b, and 9c.

As shown in the geologic cross-sections, a fault zone and significant heterogeneity were encountered in both the alluvium and UMCf, which are further described in this section. The following summary identifies the geologic complexities encountered that are unique to this study area:

- A fault zone immediately adjacent to the bedrock outcrop.
- Evidence of additional faulting just west of the fault zone.
- Down-dropped blocks of bedrock present beneath varying thicknesses of UMCf and alluvium.

- Complex interlayering of bedrock and UMCf associated with the fault zone.
- An apparent coarse-grained facies of the UMCf consisting of alluvial fan material that infilled a portion of the down-dropped block adjacent to the fault zone.
- A deep north-south paleochannel that formed on top of the down-dropped block, just west of the alluvial fan material.
- Thick sequences of alluvium deposited in the paleochannel and adjacent to it as the down-dropped area filled with sediment to its current elevation.
- Deeper-than-expected sequences of unconsolidated fine-grained UMCf atop semi-consolidated UMCf.
- A deep east-west paleochannel likely associated with the Wash.

Within the Transect 1b study area, the ground surface slopes downward to the northeast toward the Wash. Bedrock outcrops in the eastern portion of the study area, as shown on Figure 3, and influences both groundwater flow and local geology. The bedrock outcropping in the area is mapped as Horse Springs Formation, which locally consists of carbonate rocks interbedded with sandstone, siltstone, and shale (Plume, 1989; Bell and Smith, 1980). Lithology encountered during drilling suggests that the bedrock outcrop on the eastern side of the Transect 1b study area is part of a fault-bounded block and that unconsolidated valley-fill sediments of the alluvium and UMCf were deposited on the western, down-dropped side of the fault zone.

Saturated alluvium, ranging from silty sand to sandy gravel with minor lenses of sandy silt, is present throughout the study area, overlying the UMCf. The thickness of the alluvium is greatest in the vicinity of LVWPS-MW205 and LVWPS-MW209, where sand and gravel extend to approximately 120 feet bgs, as shown in Figure 9a. Often, main basin drainages such as the Wash have existed for a long time and have underlying paleochannels near their current location. The existence of numerous paleochannels converging on the current Wash location implies that a significant paleochannel exists at or near the current Wash location. Based on the depths to the erosional contact between the alluvium and UMCf observed in the Transect 1b study area, the deep alluvium adjacent to the Wash at LVWPS-MW205 and LVWPS-MW209 likely reflects an east-west paleochannel of the Wash. A generally north-south oriented paleochannel likely trends from LVWPS-MW224 towards the Calico Ridge Weir, as shown on Figure 10. An additional potential paleochannel in the western portion of the Transect 1b study area has been identified in previous reports (Ramboll, 2018b). However, this paleochannel was not encountered during pre-design drilling.

The UMCf in the Transect 1b study area, which is primarily composed of silt to silty fine sand, is coarser than the UMCf observed in the Transect 1a study area. Like the Transect 1a study area, the deeper portions of the UMCf are semi-consolidated with abundant gypsum. Near the bedrock outcrop in the eastern portion of the Transect 1b study area, the UMCf coarsens further and is interbedded with a wedge of alluvial fan material, which likely represents a coarse-grained facies of the UMCf (UMCf-cg). The UMCf-cg consists of silty sand with up to 10 percent angular to subangular gravel. These gravels are commonly angular carbonate clasts, suggesting the sediments originated locally from the Horse Springs Formation.

In the eastern portion of the study area, bedrock was encountered below the UMCf-cg during drilling. Bedrock encountered at depth was primarily sandstone and siltstone, which is consistent with mapped lithologies of the Horse Springs Formation (Plume, 1989). The depth to bedrock, which ranges from 105 feet bgs at LVWPS-MW221 to 235 feet bgs at LVWPS-MW222, is likely fault controlled as shown on Figures 9a and 9b. Faulting adjacent to the bedrock outcrop resulted in deep, unconsolidated UMCf-cg up to 235 feet bgs on the western, down-dropped side of the fault zone. By contrast, the eastern portion of the fault zone contains more consolidated materials, specifically relatively thin, alternating layers of UMCf and reworked Horse Springs Formation as encountered at LVWPS-MW214 and LVWPS-MW219C.

### 3.2.2 Hydrogeology

Conceptually, the groundwater flow in the Transect 1b study area is governed by two primary hydrogeologic influences: (1) the Wash and its underlying paleochannel, and (2) the fault zone and its associated paleochannel.

Because the materials filling the fault zone and the paleochannels are generally more transmissive than the surrounding materials, groundwater flow appears to be converging toward the fault zone and paleochannels. Hence, the unconsolidated UMCf is very likely discharging into the Wash paleochannel and into the fault zone.

Based on data collected during the installation of soil borings and monitoring wells, groundwater was first encountered at approximately 25 feet bgs in the alluvium. Once saturation was encountered, all underlying materials were also saturated. Groundwater levels were gauged during both the June and November 2018 groundwater sampling events. Depth to water measurements are provided in Table G.1 in Appendix G.1. During both the June and November 2018 gauging events, groundwater flow in the northern portion of the Transect 1b study area was towards the east/northeast, approximately paralleling the Wash. Groundwater flow in the center and southern portions of the Transect 1b study area was primarily towards the north, paralleling the paleochannel and fault zone described in Section 3.2.1.

Figure 10 presents a groundwater potentiometric surface map of the uppermost saturated zone in the Transect 1b study area. Within the uppermost saturated zone, the calculated average east-northeastward hydraulic gradient approximately paralleling the Wash in the Transect 1b study area was 0.008 ft/ft. The calculated average northward hydraulic gradient paralleling the paleochannel and fault zone is 0.004 ft/ft.

Adjacent to the Wash, vertical gradients appear to be governed by the direction of flow between groundwater and the Wash. Conceptually, and as previously discussed, upstream of each weir, water should discharge from the Wash, recharging groundwater. Downstream of the weirs, groundwater should discharge into the Wash. Therefore, the groundwater vertical gradients would be expected to be downward upstream of each weir, due to recharge from the Wash. Downstream of each weir, an upward vertical gradient is expected, as groundwater should be discharging into the Wash. The data that support this conceptual model can be observed in Figure 11, which presents an overview of the vertical gradient direction for the clustered monitoring wells within the Transect 1b study area. For example, at LVWPS-MW203, which is upstream of the Bostick Weir, the vertical gradient is downward. At LVWPS-MW210, which is downstream of the Calico Ridge Weir, the vertical gradient is generally upward, and therefore, groundwater should be discharging into the Wash. Groundwater perchlorate concentrations, which are discussed in Section 3.2.3.4, further support this conceptual model. For example, at LVWPS-MW203 upstream of the Bostick Weir, perchlorate concentrations in groundwater are lower, where water from the Wash likely recharges the groundwater, diluting the perchlorate concentration.

The magnitude of the vertical gradients is generally small, ranging from about 0.05 ft/ft upward to 0.05 ft/ft downward. These relatively low gradients are reflective of reasonably good connections between the various lithological units.

## 3.2.3 Analytical Results

As described in Sections 2.3.2.1, 2.4, and 2.5, soil, groundwater, and surface water samples were collected during the pre-design phase. Soil, depth-discrete groundwater, and groundwater samples were collected both during and/or following monitoring well installation to evaluate the vertical and horizontal distribution of perchlorate in soil and groundwater. Soil and groundwater samples were also collected for analysis of a variety of chemical, geochemical, and microbial parameters to determine the geochemical and microbial make-up of the aquifer within the study area. Surface water samples were collected to monitor the mass flux of perchlorate migrating into the Wash. This section presents the results of the soil, depth-discrete groundwater, groundwater, and surface water sampling associated with Transect 1b study area.

### 3.2.3.1 Soil Analytical Results

As described in Section 2.3.2.1, soil samples were collected at approximately 10-foot intervals from the top of the water table to the base of the boring in the Transect 1b study area at each of the 64 locations to characterize the distribution of perchlorate in soil with depth. Soil analytical results for this study area are presented in Table H.7 in

Appendix H and summarized in ***Table 3***. Perchlorate concentrations in soil within the Transect 1b study area have also been plotted on the geologic cross-sections presented as Figures 12a, 12b and 12c.

***Table 3*** Perchlorate Concentration Ranges in Soil – Transect 1b Study Area

| Lithology | Sample Depth (ft bgs) | Perchlorate (mg/kg) |
|---|---|---|
| Alluvium | 10 – 120 | <0.011 – 3.3 |
| Unconsolidated UMCf/UMCf-cg | 23 – 230 | <0.011 – 17 |
| Semi-consolidated UMCf (1) | 53 – 220 | <0.0011 – 5.6(2) |

**Notes:**
ft bgs – feet below ground surface
mg/kg – milligrams per kilogram
UMCf – Upper Muddy Creek formation
UMCf-cg – Upper Muddy Creek formation coarse-grained facies
(1) Soil samples collected below 53 feet bgs from LVWPS-MW214 and LVWPS-MW219, which consisted of alternating layers of unconsolidated UMCf, semi-consolidated UMCf, and reworked Horse Springs Formation, were grouped with semi-consolidated UMCf.
(2) Perchlorate concentrations in soil samples collected from the semi-consolidated UMCf were generally less than 0.89 mg/kg, with the exception of one soil sample collected from the uppermost portion of the semi-consolidated UMCf at LVWPS-MW226B (depth of 60 feet bgs) that had a perchlorate detection of 5.6 mg/kg.

Perchlorate concentrations in soil samples ranged from less than 0.0011 to 17 mg/kg. In general, perchlorate was primarily detected in soil samples collected from the saturated alluvium and unconsolidated UMCf/UMCf-cg at depths up to 170 feet bgs. However, soil samples collected from 170-230 feet bgs at location LVWPS-MW222 had perchlorate detections ranging from 0.13 to 0.32 mg/kg. The highest perchlorate concentrations were observed in soil samples collected from the unconsolidated UMCf at LVWPS-MW204 and LVWPS-MW217, where concentrations were 10 mg/kg at 120 feet bgs and 17 mg/kg at 170 feet bgs, respectively. As noted in ***Table 3***, perchlorate concentrations in soil samples collected from the semi-consolidated UMCf were generally less than 0.89 mg/kg, with the exception of one soil sample collected from the uppermost portion of the semi-consolidated UMCf at LVWPS-MW226B (depth of 60 feet bgs) that had a perchlorate detection of 5.6 mg/kg.

In general, perchlorate was not detected above the sample detection limit in soil samples collected from the bottom of each of the deep soil borings installed as part of the Modification No. 2 field activities. The exception was the soil sample collected from the bottom of the boring at LVWPS-MW218C at 164 feet bgs, which had a perchlorate detection of 1.3 mg/kg. This result was unexpected, given the semi-consolidated nature of the material sampled. Therefore, this depth interval at LVWPS-MW218 was resampled during subsequent installation of monitoring well LVWPS-MW218B approximately 7 feet south of LVWPS-MW218C. Perchlorate was detected less than the sample detection limit of 0.011 mg/kg in the soil sample collected at 164 feet bgs at LVWPS-MW218B, which indicates that the original sample detection may have been caused from drag-down of soil cuttings during drilling activities.

As described in Section 2.3.2.1, 12 soil samples (8 samples from the alluvium, 3 samples from the unconsolidated UMCf/UMCf-cg, and one sample from the semi-consolidated UMCf) collected during the initial drilling mobilization were also analyzed for a suite of analytes listed in Table 1 of the Work Plan to provide additional characterization of the subsurface. These additional analyses included anions and cations (alkalinity, bicarbonate, carbonate, calcium, chloride, magnesium, nitrate, potassium, and sulfate), chlorate, dissolved metals, hexavalent chromium, phosphorus, soil pH, TDS, TKN, and TOC. A summary of these results is presented below.

- Anions and cations were analyzed to assess the salt loading in the soil. Predominant among the anions were chloride (maximum of 160 mg/L) and sulfate (maximum of 1,200 mg/L at one location while the others were below 140 mg/L). These results indicate that there is unlikely to be any toxic impact on native microorganisms for perchlorate biodegradation.

- Chlorate results ranged from less than 0.066 mg/kg in the semi-consolidated UMCf to 7.2 mg/kg in the unconsolidated UMCf.
- Dissolved metals were analyzed to assess potential secondary impacts of bioremediation. Results indicate that arsenic detections were generally below 9.3 μg/L, and therefore, it does not appear that arsenic mobilization would be an issue within the Transect 1b study area. Iron was detected as high as 2,300 μg/L and 6,400 μg/L in two soil samples collected from the alluvium, with remaining soil detections ranging from 41 to 810 μg/L at one location. Concentrations at these ranges indicate that precipitation of iron is unlikely to be an issue as far as being a contributary factor for aquifer permeability reduction. Manganese was detected at very low concentrations as well, with a high concentration of 79 μg/L, indicating the unlikelihood of its precipitation at problematic levels during ISB. Finally, dissolved chromium was detected at very low concentrations (maximum of 9.6 μg/L) and is unlikely to be a problematic contaminant of concern within the Transect 1b study area.
- Hexavalent chromium was only detected above the sample detection limit at one location, with a soil concentration of 0.18 J mg/kg.
- Phosphorus concentrations in soil samples collected from the alluvium and unconsolidated UMCf ranged from 470 to 1,300 mg/kg, which indicates that there appears to be significant phosphorus bound to the soil. However, bound phosphorus is not always available as a micronutrient to native microorganisms and therefore, dilute phosphorus may need to be included in the ISB injection solutions.
- Soil pH ranged from 7.8 to 8.6 standard units.
- TDS was analyzed on the water extract, with results indicating the highest concentration was observed in the semi-consolidated UMCf at a concentration of 2,000 mg/L. This is expected given the observed presence of gypsum at depth. At these levels, no toxicity of native microorganisms is expected, as the completed and on-going studies have indicated.
- TKN was detected at concentrations of up to 120 mg/kg in samples collected from the alluvium and unconsolidated UMCf. These concentrations indicate that there is sufficient nitrogen to serve as a macronutrient for native microorganisms during bioremediation.
- TOC was detected at concentrations ranging from 2,300 to 39,000 mg/kg. As previously explained, TOC is likely high because of ancient deposits of plant material that is still undergoing decay and is very unlikely to be providing an available and usable source of organic carbon for microorganisms.

Eleven soil samples were collected at varying depths from six different locations and sent to Microbial Insights for analysis of PLFA and the perchlorate-reductase enzyme. Six of these samples were collected from the alluvium, four samples were collected from the unconsolidated UMCf-cg/UMCf, and one sample was collected from the semi-consolidated UMCf. Soil microbial results are presented in Table H.8 in Appendix H. The key findings of the microbial analysis indicate that seven of the eleven samples were below the sample detection limit for soil biomass population counts. There appeared to be no correlation between depth/lithological unit and biomass counts. The remaining four samples had biomass counts ranging from $1.4 \times 10^5$ to $2.08 \times 10^7$ cells/gram. Among these four samples, Proteobacteria were present although the general bacteria (Nsats) appeared to be the predominant bacterial group. Proteobacteria, which are a key adaptive bacterial group for perchlorate biodegradation, are much more predominant compared to soil proportions for this group in the Transect 1b vicinity. Proteobacteria generally represent a wide variety of aerobes and anaerobes and their presence in high proportions is generally a strong indication that perchlorate, as well as other electron acceptors, should biodegrade upon the addition of a carbon substrate. The ratios of slowed growth are generally much greater than 1.0, which indicates an environment that could be lacking in a carbon substrate food source for the native microorganisms. However, three of the four samples did not have a decreased permeability and the fourth had a decreased permeability ratio of 0.23, which indicates that there does not appear to be any environmental toxicity in the subsurface that should prevent the proliferation of microorganisms once an adequate carbon substrate food source is made available. Finally, the perchlorate reductase enzyme was not detected above the laboratory detection limit of 2.00 x $10^4$ cells/gram in any samples, as expected.

### 3.2.3.2 Soil Geotechnical Results

As explained in Section 2.3.2.1, five Shelby tubes were collected from the saturated alluvium and unconsolidated UMCf at three locations (LVWPS-MW202, LVWPS-206C, and LVWPS-MW209) within the Transect 1b study area. Soil geotechnical results are presented in Table H.9 in Appendix H. The Shelby tube samples were analyzed for the following physical parameters: specific gravity by ASTM D854, moisture content by ASTM D2216, total porosity by APR RP40, bulk dry density by ASTM D2937, and sieve analysis by ASTM D6913.

Aquifer porosity and specific gravity of the aquifer solids were determined for both the saturated alluvium and unconsolidated UMCf. Total porosity ranged from 29.6 to 53.6 percent in samples collected from the alluvium and ranged from 57.4 to 61.9 percent in samples collected from the unconsolidated UMCf. As previously explained, total porosity often overestimates the effective porosity in an aquifer. Whereas total porosity measures the volume occupied by water in a fixed volume of aquifer material, effective porosity measures the portion of the pore space that can transmit water. Specific gravity ranged from 2.598 to 2.661 in the samples collected from the alluvium and ranged from 2.609 to 2.633 in samples collected from the unconsolidated UMCf. Bulk dry density was 75 to 116.8 lbs/$ft^3$ in the samples collected from the alluvium and ranged from 62.6 to 69.2 lbs/$ft^3$ in samples collected from the unconsolidated UMCf.

As discussed in Section 3.2.1, the field lithologic logs indicate that the UMCf in the Transect 1b study area, particularly in the eastern portion of the study area, was generally coarser grained than that in the Transect 1a study area. This observation is supported by the sieve analyses, which show that in the Transect 1b study area, the UMCf samples would generally be classified as silty sand while the UMCf samples from Transect 1a study area would be classified as fine-grained (primarily silt and clay).

### 3.2.3.3 Depth-Discrete Groundwater Analytical Results

As described in Section 2.3.2.2, depth-discrete groundwater samples were collected using a sealed push-ahead groundwater sampling tool during the first drilling mobilization to evaluate the potential variation in groundwater concentrations with depth. As part of the initial pre-design drilling activities associated with the Transect 1b study area, ten depth-discrete groundwater samples were collected at eight locations within the alluvium. Depth-discrete groundwater samples were not collected during Modification No. 2 activities because a cluster of up to three monitoring wells were planned at all locations. Depth-discrete groundwater results are presented in Appendix H, Table H.10, and have been included in the groundwater perchlorate concentration profiles plotted on the geologic cross-sections in Figures 13a, 13b, and 13c. All depth-discrete groundwater samples were analyzed for perchlorate, while a subset of five groundwater samples was also analyzed for nitrate and chlorate. Perchlorate concentrations ranged from 720 to 4,600 μg/L. Chlorate concentrations ranged from 1,800 to 20,000 μg/L. Nitrate concentrations ranged from 8.6 to 20 mg/L.

### 3.2.3.4 Groundwater Analytical Results

As described in Section 2.4, groundwater sampling was conducted during two separate pre-design monitoring events for the Transect 1b study area (events BL01 and BL02). During the first groundwater sampling event in June 2018 (event BL01), all newly installed monitoring wells and existing monitoring well WMW4.9S were sampled for a full suite of parameters in accordance with Table 2 of the Work Plan. Six additional monitoring wells (LNDMW-1, MW-02, MW-04, MW-13, MW-20, and MW-25) were sampled in July 2018 for perchlorate, chlorate, nitrate, sulfate, and TDS as part of AECOM's Downgradient RI sampling event. During the second groundwater sampling event in November 2018 (event BL02), all newly installed monitoring wells as part of Modification No. 2 were sampled for the full suite of parameters in accordance with Table 2 of the Work Plan. In addition to the newly installed monitoring wells, the November 2018 groundwater sampling event also included collecting of groundwater samples from the previously installed pre-design monitoring wells and 10 existing monitoring wells (MW-02, MW-04, MW-13, MW-20, MW-25, NERT4.51S1, NERT4.71S1, NERT4.93S1, NERT5.11S1, and WMW4.9S). These additional groundwater samples were only sampled for perchlorate and chlorate. Groundwater sampling field logs are provided in Appendix G.

#### 3.2.3.4.1 Groundwater Chemical and Geochemical Results

A summary of the groundwater concentration ranges of perchlorate and chlorate, as well as other noteworthy parameters with respect to the bioremediation process, from all sampling events for the Transect 1b study area is presented in ***Table 4***. Complete analytical results are provided in Appendix H, Table H.11. Perchlorate concentrations in groundwater within the Transect 1b study area have also been plotted on the geologic cross-sections presented as Figures 13a, 13b, and 13c. Groundwater sampling field logs are provided in Appendix G.

***Table 4*** Concentration Ranges in Groundwater – Transect 1b Study Area

| Analyte | Concentrations in the Alluvium (10 – 120 ft bgs) | Concentrations in the Unconsolidated UMCf/UMCf-cg (60 – 234 ft bgs) | Concentrations in the Semi-consolidated UMCf(1) (75 – 205 ft bgs) |
|---|---|---|---|
| Perchlorate (µg/L) | 110 – 8,600 | <0.50 – 16,000 | <0.50 – 1,400 |
| Chlorate (µg/L) | <10 – 24,000 | <10 – 22,000 | <20 – 3,500 |
| Nitrate as N (mg/L) | 2.6 – 23 | <0.11 – 17 | <0.28 – <5.5 |
| Sulfate (mg/L) | 640 – 2,400 | 1,400 – 3,100 | 2,000 – 14,000 |
| TDS (mg/L) | 1,900 – 5,900 | 3,200 – 8,500 | 4,200 – 36,000 |

**Notes:**
ft bgs – feet below ground surface
µg/L – micrograms per liter
mg/L – milligrams per liter
TDS – total dissolved solids
UMCf – Upper Muddy Creek formation
UMCf-cg – Upper Muddy Creek formation – coarse grained facies
(1) Monitoring wells LVWPS-MW219B and LVWPS-MW219C, which are screened in alternating layers of unconsolidated UMCf, semi-consolidated UMCf, and reworked Horse Springs Formation, were grouped with semi-consolidated UMCf.
(2) Screened lithology for some existing monitoring wells is unknown, and therefore, analytical results for monitoring wells LNDMW-1, MW-02, MW-20, and MW-25 are not included in this summary table.

Perchlorate was detected at concentrations above the sample detection limit in groundwater samples collected from 69 of the 74 monitoring wells screened in the alluvium, unconsolidated UMCf/UMCf-cg, and semi-consolidated UMCf within the Transect 1b study area. As presented in ***Table 4***, the highest perchlorate concentrations were observed in groundwater samples collected from monitoring wells screened in the UMCf/UMCf-cg, with concentrations as high as 16,000 µg/L in the groundwater sample collected from LVWPS-MW204B (screened from 101.5 to 121.2 feet bgs) and 13,000 µg/L in the groundwater sample collected from LVWPS-MW210C (screened from 100.3 to 120 feet bgs). These elevated groundwater concentrations are generally consistent with soil results discussed in Section 3.2.3.1. The highest perchlorate concentration in groundwater samples collected from the alluvium was 8,600 µg/L at MW-04, which is located upgradient of the Transect 1b study area.

Perchlorate was detected below the sample detection limit in groundwater samples collected from three of the five monitoring wells installed in the semi-consolidated UMCf. Groundwater samples collected from the remaining two monitoring wells screened in the semi-consolidated UMCf, namely, LVWPS-MW204C and LVWPS-MW226B, had perchlorate concentrations of 1,400 and 290 μg/L, respectively. Sometimes, drag-down of soil cuttings during drilling can cause the initial samples from a monitoring well to be non-representative of concentrations in the formation, particularly when the screened formation has sufficiently low hydraulic conductivity that only minimal purging is possible during well development and sampling. Both semi-consolidated UMCf monitoring wells in question met these conditions. Furthermore, groundwater samples collected from monitoring well LVWPS-MW203C, which is screened in the semi-consolidated UMCf, exhibited a similar trend, with perchlorate initially detected at 120 μg/L during the first sampling event (BL01 in June 2018), followed by a perchlorate concentration less than the sample detection limit of 25 μg/L in the subsequent groundwater sampling event performed in November 2018 (event BL02). As a result, it is likely that these concentrations will decrease over time. Finally, perchlorate concentrations in groundwater samples collected from monitoring wells LVWPS-MW219B/C, which are screened in alternative layers of unconsolidated UMCf, semi-consolidated UMCf, and reworked Horse Springs Formation, were less than 0.50 and 35 μg/L, respectively.

Chlorate concentrations followed a similar pattern with respect to vertical distribution in the alluvium and unconsolidated UMCf and also had elevated sample detection limits in groundwater samples collected from the semi-consolidated UMCf. However, chlorate concentrations in groundwater were generally one order of magnitude greater than perchlorate concentrations. Chlorate detections in groundwater in the semi-consolidated UMCf followed a similar pattern as perchlorate. Chlorate was detected below the elevated sample detection limit (due to initial sample dilutions required as described in Section 3.1.3.4) of 100 μg/L in groundwater samples collected from three of the five semi-consolidated UMCf monitoring wells. The groundwater samples collected from monitoring wells LVWPS-MW204C and LVWPS-MW226B, which are screened in the semi-consolidated UMCf, had chlorate detections of 3,500 and 1,100 J μg/L, respectively.

Nitrate, which is the most likely competing electron acceptor and carbon substrate consumer during bioremediation, was detected at concentrations up to 23 mg/L in groundwater samples collected from monitoring wells screened in the alluvium and up to 17 mg/L in monitoring wells screened in the unconsolidated UMCf-cg. Nitrate was not detected above the laboratory detection limit of 5.5 mg/L (which is also an elevated detection limit due to initial dilutions required as described above) in groundwater samples collected from the deeper monitoring wells screened in the semi-consolidated UMCf.

Sulfate and TDS were detected in groundwater samples in monitoring wells screened in the alluvium and unconsolidated UMCf/UMCf-cg at concentrations of up to 3,100 and 8,500 mg/L, respectively. Sulfate and TDS were detected at concentrations up to 14,000 and 36,000 mg/L, respectively, in groundwater samples collected from the semi-consolidated UMCf. The high TDS concentrations are attributed to the sulfate concentrations and associated cations due to the observation of gypsum in the semi-consolidated UMCf during drilling, rather than the chlorate and perchlorate concentrations.

In addition to the key parameters of perchlorate, chlorate, nitrate, sulfate, and TDS, groundwater samples were also analyzed for the full suite of parameters presented in the Work Plan. A summary of these results is provided below:

- Chloride concentrations in groundwater generally ranged from 190 to 1,600 mg/L. Chloride concentrations in groundwater samples collected from the semi-consolidated UMCf were significantly higher, ranging from 2,700 to 8,400 mg/L. This is consistent with the high TDS concentrations in the semi-consolidated UMCf. As previously explained, chloride concentrations at the high levels present in the semi-consolidated UMCf may be toxic or slow down the metabolic rate of microorganisms.
- Dissolved metals and total manganese were analyzed to assess potential secondary impacts of bioremediation. Results indicate that arsenic concentrations were generally low, with a maximum concentration of 85 µg/L (similar to concentrations observed at the on-going SWF Area Bioremediation Treatability Study). Although iron and manganese were detected in groundwater samples collected from the alluvium, unconsolidated UMCf/UMCf-cg, and/or semi-consolidated UMCf, concentrations of these

constituents were very low, which indicates very little iron or manganese is likely to precipitate during ISB operations.

- Hexavalent chromium concentrations in groundwater were generally less than 34 µg/L, with isolated detections up to 71 µg/L. The highest hexavalent chromium concentrations were detected at LVWPS-MW204, which is notably the same location where the highest groundwater perchlorate concentration of 16,000 µg/L was detected. Similarly, detections of dissolved chromium were low, with a maximum concentration of 84 µg/L. These low chromium concentrations suggest that chromium is not unlikely to be a problematic contaminant of concern within the Transect 1b study area.
- In addition to nitrate, groundwater samples were analyzed for total nitrogen, including TKN and nitrite. In general, nitrate was the primary species of nitrogen in groundwater, and nitrite and TKN were not detected above the sample detection limit at most monitoring wells within the Transect 1b study area. Isolated detections of up to 6.2 mg/L TKN and up to 5.1 mg/L nitrite were measured. Concentrations of total nitrogen up to 23 mg/L suggest that there is sufficient nitrogen to serve as a macronutrient for native microorganisms during bioremediation.
- Phosphorous concentrations were generally less than the sample detection limit or detected at very low concentrations, generally less than 0.5 mg/L, with isolated detections up to 2.4 mg/L. This indicates that this macronutrient will likely be required to be added to the injectate solution for perchlorate bioremediation, which is similar to previous and on-going ISB treatability studies performed at NERT. Field parameters including DO and ORP indicate that the groundwater is generally aerobic. Groundwater pH generally ranged between 6 and 8 standard units, which indicates that there should be no hindrances to the growth and development of microorganisms. Ferrous iron was only detected at three locations at concentrations of up to 0.5 mg/L, while sulfide was only detected at one location at a concentration of 0.04 mg/L. This was expected since ferrous iron and sulfide are normally produced during strongly reducing conditions that result in iron mobilization and sulfate reduction.
- TDS was detected at concentrations less than 8,500 mg/L in groundwater samples collected from the alluvium and unconsolidated UMCf/UMCf-cg. Elevated TDS concentrations were detected as high as 36,000 mg/L in groundwater samples collected from the semi-consolidated UMCf, which could result in toxicity to microorganisms due to salt intolerance.
- Alkalinity as calcium carbonate ranged from 28 to 300 mg/L. As previously explained, these ranges were expected as alkalinity will generally increase once the microbial activity increases during bioremediation following the addition of a carbon substrate.
- Methane concentrations in groundwater were typically less than the sample detection limit of 0.00025 mg/L, with isolated detections up to 0.0037 mg/L, which was expected due to the lack of strongly reducing conditions present within the Transect 1b study area.
- TOC concentrations in groundwater were generally less than 4.7 mg/L, with two isolated detections of 19 and 34 mg/L. At these low concentrations, the addition of a carbon substrate will be required for perchlorate bioremediation.
- No volatile fatty acids (VFAs) were detected in groundwater samples collected from the Transect 1b study area. This result was expected since carbon substrate injections have not occurred.

#### 3.2.3.4.2 Groundwater Microbial Results

As explained in Section 2.4, Bio-traps® were placed in nine monitoring wells within the Transect 1b study area (LVWPS-MW203B, LVWPS-MW204B, LVWPS-MW206C, LVWPS-MW210A/B/C, LVWPS-MW212D, LVWPS-MW222C, and LVWPS-MW223A) and retrieved after approximately one month and shipped to Microbial Insights for analyses. Groundwater microbial results are presented in Appendix H, Table H.12. Microbial biomass results ranged from $3.09 \times 10^4$ to $2.63 \times 10^5$ cells/gram. These numbers are indicative of adequate microbial populations in groundwater that could possess the ability to biodegrade perchlorate and other inorganic electron acceptors such as chlorate and nitrate, upon the addition of an external source of organic carbon. A sizable proportion of proteobacteria (greater than 50 percent in all Bio-traps®) was observed, which indicates a proliferation of the appropriate bacterial community that is gram negative, has the ability to use a variety of carbon sources, has adapted easily to the groundwater environment, and is representative of both aerobic and anaerobic bacteria. The low proportions (less than 10 percent) of metal reducing bacteria and sulfate reducing bacteria (SRB)/actinomycetes) reveal redox conditions that are not overly reducing. Eukaryotes percentages are also less than 10 percent, which indicates that these scavengers of valuable contaminant-reducing bacteria do not pose a significant threat in this groundwater.

As explained in Section 3.1.3.1, ratios for slowed growth and decreased permeability of the cell membrane provide information on the "health" of the gram-negative microbial community and how this population is responding to the conditions present in the environment. The ratios of slowed growth are greater than 1.0 indicating the likely absence of a carbon substrate food source in groundwater. However, the ratios of decreased permeability in all nine Bio-traps® are less than 0.22, indicating that there is unlikely to be any environmental toxicity to native microorganisms in this subsurface area once a carbon substrate food source is made available. Finally, the perchlorate reductase enzyme was detected at $2.89 \times 10^2$ cells/bead in one Bio-trap®, which was retrieved from monitoring well LVWPS-MW210C. The perchlorate reductase enzyme was less than the laboratory detection limit of $2.5 \times 10^2$ cells/gram in the remaining Bio-traps®, which is typical of observations in groundwater from other areas of the Site such as the on-going SWF Area Bioremediation Treatability Study where this enzyme was not detected in locations where active perchlorate degradation was not occurring.

In summary, the groundwater in Transect 1b appears to possess a microbial community that should respond favorably to the addition of a carbon substrate, even though the soil in some vicinities show lower microbial populations and some indication of environmental stress.

### 3.2.3.5 Surface Water Analytical Results

As described in Section 2.5, monthly surface water samples are currently collected to evaluate the mass flux of perchlorate migrating into the Wash. In addition to the routine monthly analysis of perchlorate, chlorate, and TDS, an expanded group of sampling locations and parameters were analyzed as part of the July 2018 surface water sampling event to further evaluate groundwater discharge and perchlorate mass flux into the Wash downgradient of the Transect 1b study area. All locations where surface water samples were collected in July 2018, plus additional locations that are periodically sampled, are presented on Figure 4. Analytical results from the July 2018 monthly surface water sampling event are presented in Table H.13. in Appendix H.

Surface water sampling results were used in recent perchlorate mass loading estimates, which suggest approximately 30.6 lbs/day discharge into the Wash between Historic Lateral and Homestead Weirs (Ramboll, 2018a and Attachment 1 to this Work Plan Addendum). Perchlorate concentrations in surface water samples collected as part of the Phase 1 pre-design activities in July 2018 between Historic Lateral and Homestead Weirs (LVW5.3, LVWPS5.1, LVWPS4.9, LVW4.75, #7 Lower Narrow, LVWPS4.4, and LVW4.2) ranged from 1.6 J to 72 μg/L. The highest perchlorate concentration of 72 μg/L was detected in surface water collected from sampling location LVWPS4.4, which is located downstream of the Lower Narrows Weir. Where surface water samples were collected in a transect configuration, perchlorate concentrations were often greater near the southern bank than near the northern bank of the Wash, which indicates perchlorate-contaminated groundwater may be discharging into the Wash along its southern bank downgradient of the Transect 1b study area.

Theoretically, groundwater should discharge from within the footprint of the Transect 1b study area to the Wash downstream of weirs and be recharged by the Wash upstream of weirs (four weir structures are located downgradient of the Transect 1b study area). In July 2018, perchlorate concentrations between Calico Ridge and Homestead Weirs ranged from 35 to 72 μg/L along the southern bank of the Wash. These perchlorate concentrations were significantly higher than those measured upstream of the Calico Ridge Weir in the Transect 1b study area, where perchlorate concentrations ranged from 7.5 to 13 μg/L along the southern bank. The higher concentrations may indicate that groundwater is likely discharging downstream of the Calico Ridge Weir. This is further supported by the upward vertical gradients observed at the monitoring well cluster LVWPS-

MW210A/B/C/DE, which is located on immediately south of the Wash, downstream of the Calico Ridge Weir. Additionally, recent thermal imaging conducted by AECOM as part of the Downgradient RI indicated potential groundwater discharge immediately downstream of Calico Ridge Weir near the LVWPS-MW210 cluster; transect samples collected near the south bank had concentrations that were similar in magnitude to those collected from LVWPS-MW210A/B, while samples on the north bank had much lower concentrations (Figure 7, AECOM, 2018).

In general, chlorate concentrations in surface water follow a similar pattern to perchlorate concentrations. Chlorate in surface water samples collected between the Historic Lateral and Homestead Weirs in July 2018 ranged from 79 to 370 μg/L. Like perchlorate, chlorate concentrations were commonly highest near the southern bank of the Wash downgradient of the Transect 1b study area.

Additional analyses were added to a subset of surface water samples to further evaluate conditions in the Wash. Sulfate and chloride were analyzed to evaluate their use as tracers to identify locations of groundwater discharge into surface water, specifically from the UMCf to the Wash. In the UMCf near the Transect 1b study area, sulfate concentrations were measured between 1,400 to 14,000 mg/L, and chloride concentrations were measured from 260 to 8,400 mg/L, so in theory, discharge of UMCf water into surface water could increase concentrations of these constituents. However, near the Transect 1b study area, sulfate concentrations in surface water ranged from 400 to 470 mg/L, and chloride concentrations in surface water ranged from 210 to 240 mg/L. These ranges were so narrow that neither sulfate or chloride could be effectively used as tracers of groundwater discharge to surface water in the Transect 1b study area. Additionally, total organic carbon concentrations ranged from 4.5 to 6.3 mg/L, which were relatively consistent within sampling transects and throughout the Wash, regardless of river mile. Finally, dissolved arsenic concentrations ranged from less than 5.0 to 6.8 μg/L in surface water collected between Historic Lateral and Homestead Weirs. The highest arsenic detection of 6.8 μg/L was measured in surface water collected from LVW4.75-1, which is downstream of the Calico Ridge Weir. Dissolved iron was not detected above the sample detection limit of 50 μg/L in any surface water sample collected. Dissolved manganese concentrations ranged from less than 15 to 49 μg/L, with no clear pattern.

## 3.2.4 Aquifer Testing Results

As previously explained in Section 2.6, an aquifer testing program was implemented to obtain information regarding aquifer hydraulic conductivity, groundwater flow velocity, and total and mobile porosity in the areas where the pilot study is planned. This section summarizes the results from the aquifer testing activities (slug testing, borehole dilution, NMR logging, and initial long-term transducer data downloads) performed in the Transect 1b study area. The supporting summary memos for slug testing, borehole dilution testing, NMR logging, and transducer data collection are presented in Appendices C, D, E, and F, respectively. The appendices include AQTESOLV (HydroSOLVE, 2007) interpretation plots of slug tests, borehole dilution test plots, NMR logs, and preliminary hydrographs.

### 3.2.4.1 Slug Tests

Using the procedures presented in Section 2.6.1 and Appendix C, slug tests were performed in 61 newly installed and three existing monitoring wells (NERT4.93S1, WMW4.9S and MW-13) to estimate location-specific aquifer hydraulic conductivity in the screened interval of wells within the Transect 1b study area. Alluvium in the Transect 1b study area is coarse grained, high conductivity sand and gravel, with an average hydraulic conductivity of approximately 92 ft/day. In the western portion of the Transect 1b study area, the unconsolidated UMCf had an average hydraulic conductivity of approximately 1 ft/day. Below the alluvium near the fault zone adjacent to the bedrock outcrop, the UMCf-cg had an average hydraulic conductivity of 6 ft/day. In the western portion of the study, the semi-consolidated UMCf encountered below the unconsolidated UMCf had a hydraulic conductivity that was so low that the slug tests could not be performed on three monitoring wells (LVWPS-MW203C, LVWPS-MW204C, and LVWPS-MW226B) due to ongoing recovery from well development and groundwater sampling. Where slightly higher hydraulic conductivities permitted slug testing, the estimated hydraulic conductivity values for the semi-consolidated UMCf were approximately 0.2 ft/day.

### 3.2.4.2 Single-Borehole Dilution Testing

Using the procedures presented in Section 2.6.2 and Appendix D, single-borehole dilution tests were performed in 19 monitoring wells (LVWPS-MW201A, LVWPS-MW203B, LVWPS-MW206B, LVWPS-MW208A, LVWPS-MW210A/B/C/D/E, LVWPS-MW214, LVWPS-MW217A/B/C, LVWPS-MW220A/B, LVWPS-MW222A, and LVWPS-MW223A/B/C) to evaluate groundwater flow velocities in the alluvium and unconsolidated UMCf-cg and UMCf within the Transect 1b study area.

Results indicate that the groundwater flow velocities in the alluvium ranges from about 2 to 250 ft/day. The highest groundwater flow velocities (91, 100, and 251 ft/day) were in shallow monitoring wells very close to the Wash (LVWPS-MW201A, LVWPS-MW210A, and LVWPS-MW214). A fourth monitoring well (LVWPS-MW217A) had such a high groundwater flow velocity that the tracer water was removed as fast as it could be emplaced. Therefore, no estimates of groundwater flow velocity could be made. The elevated groundwater flow velocities are likely due to the proximity to the Wash and its paleochannel, combined with the increased flow rate associated with converging flow paths exiting the basin near the Lower Narrows Weir area. If these particular cases are set aside, the areas away from the immediate vicinity of the Wash indicate that the groundwater flow velocities ranges from about 2 to 30 ft/day, which is similar to the flow velocities encountered in the alluvium in the previous In-Situ Bioremediation Treatability Study near the COH ponds (Tetra Tech, 2016) but higher than the on-going Seep Well Field In-Situ Bioremediation Treatability Study.

The unconsolidated UMCf and UMCf-cg have significantly lower groundwater flow velocities, averaging 0.3 ft/day and ranging from 0.01 to 1.2 ft/day. A comparison of the unconsolidated UMCf and UMCf-cg groundwater flow velocity estimates shows that the average and range for each unit is nearly identical.

### 3.2.4.3 Nuclear Magnetic Resonance Logging

As explained in Section 2.6.3, NMR logging was performed in the deepest monitoring well at each of the 26 locations to further delineate any localized preferential flow pathways within the Transect 1b study area. NMR estimates of hydraulic conductivity generally agreed with estimates derived using slug testing within an order of magnitude. NMR logging profiles are provided in Appendix E.

The NMR water content logs were very useful for delineating the contact between the alluvium and UMCf/UMCf-cg in the Transect 1b study area. The contact between the alluvium and UMCf underneath the western portion of Transect 1b is clearly visible because the water content of the UMCf is typically between 50 and 60 percent. However, the contact between the alluvium and the UMCf-cg under the eastern portion of the study area is also often visible as an increase in water content, though not as large. Both the UMCf and the UMCf-cg tend to have higher water content than the alluvium due to their overall finer grain size.

NMR also provides an estimate of mobile porosity, which is approximately equivalent to effective porosity and provides a distinction between “more bound” water and “more mobile” water. In the uppermost, least consolidated portion of the UMCf, the logged mobile porosity was fairly high, often reaching 15 percent. In the case of the UMCf, these values are higher than what would be expected for a typical mixture of silt and clay, but they match well with the hydraulic conductivity of the unconsolidated UMCf. In the case of the UMCf-cg, which has a higher percentage of sand, the relatively high mobile porosity values are consistent with the logged lithology. By contrast, the mobile porosity of the semi-consolidated, deeper part of the UMCf was typically logged to be less than 5 percent. This contrast is visible in many of the deeper NMR logs. For example, the logs for LVWPS-MW204C and LVWPS-MW224C clearly show the decrease in mobile porosity after semi-consolidated UMCf was encountered.

### 3.2.4.4 Transducer Data Collection

As explained in Section 2.6.4 and Appendix F, data from the initial set of transducers installed in monitoring wells within the Transect 1b study area were downloaded in December 2018. However, data from the deeper monitoring wells installed as part of Modification No. 2 have not yet been downloaded. The data were corrected for barometric pressure and compared to the surface water elevation data from the nearby Bostick Weir gauging station (USGS 09419747 LV Wash Abv Bostick Weir Nr Henderson, NV). The comparison indicated that many of the Transect 1b monitoring wells were visibly influenced by water levels in the Wash. For example, monitoring wells LVWPS-MW201A, LVWPS-MW206A/B/C, and LVWPS-MW210A/B/C all show daily groundwater elevation changes that correspond closely to the Wash surface water elevation changes. Monitoring well LVWPS-MW201B, does not show daily changes that match the Wash. However, when the Wash surface water elevation increases significantly, there is a corresponding increase in groundwater elevation at LVWPS-MW201B approximately one day later.

Also, the preliminary data indicate that the vertical gradients between the alluvium and UMCf may change direction over time in some locations. For example, the gradient changes from slightly downward to slightly upward between LVWPS-MW206B and LVWPS-MW206C at least once. The gradient also changes from slightly upward to slightly downward between LVWPS-MW210B and LVWPS-MW210C. This phenomenon and its possible causes will be investigated further over the course of monitoring and when data from the remaining two monitoring wells in each cluster are available.

## 3.3 PRELIMINARY LABORATORY BENCH-SCALE RESULTS

Bench-scale laboratory studies have been performed as part of previous and on-going treatability studies and have provided significant data on the biodegradation potential of perchlorate and other electron acceptors, as well as information on the potential longevity of the carbon substrate. As explained in Section 2.7, although batch microcosm testing wasn't performed for soil and groundwater from the Wash pilot study areas, microcosm testing has been performed on similar alluvium and UMCf soil and groundwater as part of the SWF Area Bioremediation Treatability Study (Tetra Tech, 2019). Results from these batch microcosm studies have shown that most of the nitrate in groundwater is degraded completely within 4 days when using EVO as the carbon substrate. Batch microcosms also indicated that perchlorate degraded completely within 10 days for trials in the UMCf using EVO and within 20 days in the alluvium with the same carbon substrate.

EVO batch sorption/desorption tests on soil and groundwater from the UMCf were performed to understand the interactions of site-specific soil with EVO and compare these results to previous ranges determined as part of bench-scale testing for the SWF Area Bioremediation Treatability Study. As part of this testing, different quantities of wet soil from the 58-65 feet bgs zone were placed in centrifuge tubes with known quantities of EVO. Standard adsorption test procedures of centrifuging, supernatant extraction, and soil incineration were used to determine the adsorption capacity of soil. Results indicated that the oil adsorption in wet soil ranged from 0.015 to 0.093 grams of oil/gram of soil for the alluvium and 0.054 to 0.1 grams of oil/gram of soil for the UMCf, which is approximately 2 to 2.5 times less than the adsorption results for the UMCf determined during the bench-scale study associated with the on-going SWF Area Bioremediation Treatability Study. This indicates that the quantities of EVO required for the Las Vegas Wash Bioremediation Pilot Study are likely to be much lower than the quantities required for the SWF Area Bioremediation Treatability Study (further discussed in Section 5.4 and Appendix I).

Four columns are currently operating as part of the sorption/desorption bench-scale testing. Two columns are packed with soil from the alluvium and the other two columns are packed with soil from the UMCf. These are being run at the low and medium soil sorption capacity that were determined from the batch sorption tests. Tests are being run at the approximate field groundwater flow rates that were determined, while applying pressure to simulate field conditions.

Per Section 2.7, column diffusion studies are being currently performed to simulate the upward migration of perchlorate from the UMCf into the alluvium and help establish the hydraulic, physical, and chemical relationship between these two lithological zones. It is anticipated that these column studies will be completed in September 2019. Completion of the testing is not currently required to finalize the design presented in this Work Plan Addendum as described in Section 2.7. However, the results from the column studies will be combined with the on-going pilot study effectiveness monitoring results to determine any changes that may be required for subsequent carbon substrate injection events during the pilot study.

Results of these on-going bench-scale tests will be provided in the monthly reports as they become available and completely summarized in the UNLV Bench-Scale Study Results Report, which will be included as an appendix to the final Las Vegas Wash Bioremediation Pilot Study Results Report to be submitted following completion of the pilot study.

# 4.0 PHASE 2 PILOT STUDY CONSIDERATIONS AND MODIFICATIONS

As explained in Section 1.1, the overall objective of the pilot study is to demonstrate and evaluate the effectiveness and implementability of ISB in a geologically complex area where perchlorate-contaminated groundwater is migrating into the Wash. The Phase 2 study design and objectives presented herein have been expanded upon and modified from the conceptual design and objectives that were presented in the Work Plan based on the results described in Sections 2.0 and 3.0 of this Work Plan Addendum and in consideration of the Trust's overall RI/FS implementation strategy and associated data obtained through other facets of its investigation.

The Phase 1 pre-design of the Work Plan was conceived and implemented because there was relatively sparse information about the lithology, hydrogeology and contaminant distribution in the pilot study areas. The bifurcation of the study into two distinct phases afforded the Trust the opportunity to evaluate newly available data to determine the optimal strategy for the Phase 2 efforts. The Phase 1 pre-design activities have produced valuable information that has significantly expanded the understanding of the pilot study areas and informed the conceptual site model near the Wash, which will benefit the Trust's overall RI/FS implementation strategy. Additionally, since the conceptual design in the Work Plan was submitted, other bioremediation treatability studies (both completed and on-going) have provided valuable data with respect to the preparation of this Work Plan Addendum.

This section presents a summary of the relevant discoveries since submittal of the Work Plan (data collected during Phase 1 pre-design and other investigations), a brief overview of the other ISB treatability studies that have been completed or are in progress, and a summary of the modifications to the original pilot study conceptual design, based on this new information.

## 4.1 RELEVANT DISCOVERIES

Information gained from the Phase 1 pre-design phase and from other Trust investigations performed since the Work Plan was submitted has informed the revision of the pilot study design. The relevant discoveries are described below.

- The groundwater flow near the Wash is more easterly, and the change from northerly flow to more easterly flow occurs approximately 1,000 feet south of the Wash, which is farther away from the Wash than was previously expected. This understanding is important not only with respect to this pilot study but also for evaluation of potential future remedies as part of the overall FS. Specifically, for this pilot study, the localized groundwater flow direction is important for implementation of ISB via injection well transects, which should be oriented generally perpendicular to groundwater flow.
- The groundwater flow direction and velocities near the Wash appear to be influenced by a paleochannel underlying the Wash and weirs within the Wash. This paleochannel tends to be parallel or subparallel to the current-day Wash, and appears to be located immediately adjacent to and under the present-day Wash. The paleochannel underlying the Wash is very significant because flow velocities in that paleochannel appear to be much higher than in the surrounding alluvium, which is an important factor for evaluating potential future remedial options as well as refining the pilot study design and location.
- Three weirs (Bostick, Calico Ridge, and Lower Narrows) are located in portions of the Wash that are in the general vicinity of the pilot study area. The weirs have significant effects on the nearby perchlorate concentrations in groundwater because the lower concentration surface water tends to enter the groundwater system just upgradient of the weirs and groundwater tends to seep back into the Wash downgradient of the weirs. The effects of the complex flow pattern and associated

perchlorate concentration changes need to be incorporated into the planning and execution of an effectiveness monitoring program to determine remedial effectiveness.

- The groundwater flow velocities within approximately 500 feet of the Wash in the Transect 1b study area appear to be up to 250 feet per day. This is significantly faster (approximately an order of magnitude greater) than observed in the tributary paleochannels in the vicinity of the on-going SWF Area Bioremediation Treatability Study area and the In-Situ Bioremediation Treatability Study performed near the COH Bird Viewing Ponds (Tetra Tech, 2016). This discovery is important because the high groundwater flow velocities near the Wash will complicate implementation of potential future remedies. Therefore, placement of a remedial system near the Wash requires careful consideration and should account for these higher groundwater velocities.
- The depth at which perchlorate was encountered in soil (primarily detected at depths of up to 170 feet bgs, with detections at one location as deep as 230 feet bgs) was much deeper in the Transect 1b study area than expected.
- The concentrations of perchlorate in soil (up to 17 mg/kg) and groundwater (up to 16,000 μg/L) in the Transect 1b study area were greater than previously known.
- The depth of the alluvium is much deeper (up to 120 feet bgs) in the Transect 1b study area than was previously known.
- The average daily mass flux of perchlorate in the Wash has been better defined. In the 2016 Annual Performance Report, sampling in the Wash indicated a perchlorate flux of 20.9 lbs/day at Pabco Road and 59.4 lbs/day at Northshore Road (Ramboll Environ, 2016). The 2019 Semi-Annual Remedial Performance Memorandum showed similar results of 19.4 lbs/day at Pabco Road and 66.8 lbs/day at Northshore Road (Ramboll, 2018a and Attachment 1 to this Work Plan Addendum). However, additional surface water sampling points were added between these locations to provide a slightly more detailed estimate of flux into the Wash. Based on these additional data, it is now estimated that the average daily perchlorate flux is 24.6 lbs/day at the Historic Lateral Weir, 55.2 lbs/day at the Homestead Weir, and 68.8 lbs/day at the Rainbow Gardens Weir. This indicates, as shown on Figure 6 of the 2019 Semi-Annual Performance Memorandum (Ramboll, 2018a and Attachment 1 to this Work Plan Addendum), that the Wash gains an average daily perchlorate mass flux of 5.2 lbs/day between Pabco Road and Historic Lateral Weirs, 30.6 lbs/day between the Historic Lateral Weir and Homestead Weir, and 13.6 lbs/day between the Homestead Weir and Rainbow Gardens Weir. The average daily perchlorate flux into the Wash then declines by 2.6 lbs/day between the Rainbow Gardens Weir and Northshore Road. This concentration decline is not well understood at this time and is in an area outside of the Las Vegas Wash Bioremediation Pilot Study footprint; however, it is expected to be addressed as part of the forthcoming RI Report for OU- 3.
- Pilot study activities performed in the Transect 1b study area will evaluate remediation effectiveness and implementability of ISB in an upgradient location where the largest increase in perchlorate mass flux into the Wash occurs, namely between the Historic Lateral Weir and Homestead Weir, which has an estimated mass flux of 30.6 lbs/day. The data now show the Transect 1a study area is not only less geologically complex and similar to the SWF Area Bioremediation Treatability Study area but also in the general location that appears to correlate to the smallest increase in perchlorate mass flux measured between the Pabco Road and Historic Lateral Weirs of 5.2 lbs/day.

## 4.2 IN-SITU BIOREMEDIATION TREATABILITY/PILOT STUDIES AT NERT

To date, five ISB studies have either been completed or are on-going at the NERT site. These studies range from small, short duration proof of concept studies to larger-scale pilot studies. ***Table 5*** presents a high-level overview of each of the ISB studies and their key differentiators.

***Table 5*** In-Situ Bioremediation Treatability and Pilot Study Overview

| Study Features | GW ISB TS | SWF Area ISB TS | Galleria Drive ISB TS | Las Vegas Wash ISB Pilot Study | | | Unit 4 Source Area ISB TS |
|---|---|---|---|---|---|---|---|
| Status | Completed | On-going; extended for long-term evaluation | Phase 1 complete; Phase 2 to begin in 3Q 2019[1] | Phase 1 complete; Phase 2 to begin in 3Q 2019 | | | Phase 1 in-progress; Phase 2 to begin in 2020 |
| Differentiators | Proof of Concept | Different geology; lower flow rate | First Study in UMCf; unique geochemistry | First pilot study, geologically complex area, three lithological units to be treated | | | High concentration source area |
| Targeted Treatment Lithology | Alluvium | Alluvium | UMCf | Alluvium | UMCf | UMCf-cg | UMCf |
| Targeted Treatment Interval (ft bgs) | 20 to 35 | 15 to 45 | 65 to 85 | 25 to 95 | 80 to 175 | 60 to 180 | 83 to 118 |
| General Lithology | Sandy silt with gravel (paleochannel) | Sand, gravel, silt lenses | Silt/clay layers; gypsum throughout | Sand, gravel, some silt lenses (paleochannel) | Silt to silty fine sand; little to no gypsum | Coarse-grain, silty sand with up to 10% gravel | Mostly clay, some silt |
| Groundwater Flow Velocity (ft/day) | 32 | 10 | 3 | 2 to 30 | 0.01 to 0.6 | 0.01 to 1.2 | 0.5 to 1 |
| **Maximum Groundwater Concentrations** | | | | | | | |
| Perchlorate (μg/L) | 34,000 | 25,000 | 14,000 | 8,600 | 16,000 | 13,000 | 5,300,000 |
| Chlorate (μg/L) | 130,000 | 67,000 | 19,000 | 24,000 | 22,000 | 18,000 | 33,000,000 |
| Nitrate (mg/L) | 17 | 18 | 38 | 23 | 17 | 17 | 87 |
| Sulfate (mg/L) | 2,200 | 4,700 | 19,000 | 2,400 | 3,100 | 2,700 | 1,400 |
| TDS (mg/L) | 7,600 | 6,700 | 43,000 | 5,900 | 8,500 | 6,200 | 58,000 |

**Notes:**

TS – Treatability Study
ft bgs – feet below ground surface
ft/day – feet per day
μg/L – micrograms per liter
mg/L – milligrams per liter
(1) As of the date of this Work Plan Addendum, the final location of the Galleria Drive Bioremediation Treatability Study is being reevaluated.

As observed in ***Table 5***, each study has a unique set of characteristics, which consist of differences in targeted lithology, targeted treatment interval (i.e., variation from relatively small to large saturated thicknesses), groundwater flow velocities, groundwater concentrations (perchlorate concentrations ranging from 8,600 to 5,300,000 μg/L), and geochemical characteristics (such as high sulfate and TDS concentrations). Because of these variations in treatability and pilot studies, important data related to effectiveness, implementability, and cost of an ISB remedy in a variety of lithological settings observed across the site is necessary and will be available for evaluation in the forthcoming FS.

At the time of this Work Plan Addendum, one ISB treatability study has been completed (GW ISB Treatability Study) and one treatability study has been on-going since 2017 (SWF Area ISB Treatability Study). Key findings and lessons learned to-date indicate that ISB could be a viable technology at the NERT site. Overall, groundwater chemical, geochemical, and microbial data collected during the previous and on-going studies indicate that slow-release carbon substrate (EVO) has the ability to create, sustain, and carry out biodegradation of perchlorate in groundwater under a range of groundwater flow velocity conditions (average of 10 to 32 ft/day) in a small portion of a fast-flowing alluvial paleochannel as well as in general alluvial material consisting of sand, gravel, and silt lenses.

Building on the lessons learned from the previous studies and accounting for evaluations in other on-going studies, the Las Vegas Wash Bioremediation Pilot Study has several unique characteristics when compared to other studies. Some of the key differentiators include:

- Location immediately upgradient of the Las Vegas Wash;
- Three lithological units of the alluvium, UMCf, and UMCf-cg;
- Large saturated thicknesses in all three lithological units;
- Range of groundwater flow rates;
- Large, deep paleochannel near the Wash that is likely representative of areas that are expected be targeted by a final remedy;
- Fault-zone channel; and
- Different chemical and geochemical composition from other studies that are evaluating the UMCf (Galleria Drive and Unit 4 Source Area ISB Treatability Studies).

The objectives and design of the Las Vegas Wash Bioremediation Pilot Study to properly evaluate ISB with respect to these key differentiators are further described in Section 5.0.

## 4.3 MODIFICATIONS TO CONCEPTUAL DESIGN

Several modifications to the conceptual pilot study design have been made based on the summary of the relevant discoveries presented in Section 4.1. This section presents an overview of these modifications and the reasons why these changes are appropriate for the Las Vegas Wash Bioremediation Pilot Study.

### 4.3.1 Elimination of Transect 1a Study Area

Based on the information presented in Section 4.1 and 4.2, Phase 2 activities associated with the Las Vegas Wash Bioremediation Pilot Study will eliminate the Transect 1a study area and focus on the Transect 1b study area for the following reasons:

- The lithology, aquifer properties, and groundwater contamination characterized within the Transect 1a study area (as described in Section 3.1) are similar to the alluvium that is being evaluated as part of the on-going SWF Area Bioremediation Treatability Study and to the UMCf that is present within the Transect 1b study area that will be targeted during this pilot study.
- The Transect 1b study area is situated on a main paleochannel, is more complex than originally anticipated (as described in Section 3.2.1), has contamination in alluvium, UMCf and UMCf-cg, and includes a combination of both high and low groundwater flow rates (as described in Section 3.2.4 and presented in ***Table 5***).
- The Transect 1b study area is also situated in a key location of subsurface discharge to the Wash, as detailed in Section 3.2.3.5, where remediation will likely be required as part of a full-scale remedy.

In summary, evaluation of in-situ bioremediation within the Transect 1b study area will meet all the objectives of the pilot study program by itself; and therefore, a study within the Transect 1a study area is not warranted at this time since there is not a unique characteristic to justify evaluating ISB implementability at that location. Furthermore, the data generated through the implementation of ISB at Transect 1a would not materially benefit evaluation of the technology during the FS.

## 4.3.2 Revised Transect 1b Study Area Focus and General Layout

The purpose of a pilot study is to collect data needed to evaluate the key FS criteria (effectiveness, implementability, and cost) and to gather additional data in this complex geologic setting to inform the evaluation of ISB as a component to the final remedy. Based on the data collected during the Phase 1 pre-design activities and discussed in Section 3.2, the Transect 1b study area was discovered to be geologically complex and includes significant heterogeneity, large and deep paleochannels, fault-zone channels, large saturated thicknesses of alluvium, UMCf, and UMCf-cg, and perchlorate and chlorate contamination at concentrations and depths greater than previously expected. Additionally, based on the data collected during the Phase 1 activities and other investigations (AECOM, 2018), groundwater within the Transect 1b study area flows into the Wash and contributes to the perchlorate mass flux observed between the Historic Lateral and Rainbow Gardens Weir (largest flux zones into the Wash, totaling 44.2 lbs/day based on 2018 data [Ramboll, 2018a]). The discovery of these complexities presents the opportunity to refine the previous general objective of the study to more detailed objectives that are specific to effectiveness, implementability, and cost of ISB in different lithologies in an area upgradient of the Wash that will very likely require remediation as part of the full-scale remedy implemented for OU-3.

Due to the refinement of objectives and varying lithology and site complexities discovered within the Transect 1b study area, it was appropriate to revise the original conceptual design of a single injection transect that spanned the entire Transect 1b study area. The revised design includes three separate, smaller injection transects (referred to herein as Zones 1, 2, and 3). As part of this revised design, each of the three zones will now target separate areas that have different lithological settings and characteristics. These remediation zones include: Zone 1 – UMCf Only, Zone 2 – Combination of Alluvium and UMCf, and Zone 3 – UMCf-cg Only (shown in Figure 14). Advantages to this approach include the following:

- Smaller, isolated zones allow for an evaluation of more detailed objectives, and therefore, maximizes the data collected during this study with respect to effectiveness, implementability and costs as they relate to a particular lithological setting.
- Each of the three zones can evaluate ISB application targeting unique characteristics of varied lithological settings that are likely to be observed throughout OU-3 and may require treatment as part of the full-scale remedy (i.e., deep alluvial paleochannels, UMCf, and UMCf-cg).
- The design of injection transects into separate zones allows for isolation and evaluation of ISB in three very different subsurface environments (deep alluvial paleochannel and large saturated thicknesses of both UMCf and UMCf-cg) to evaluate ISB performance independent of the interactions with other areas. A single, larger injection well transect would make it more difficult to discern how ISB performed in any individual setting (i.e., alluvium, UMCf, or UMCf-cg), which would limit the formation-specific data obtained during the pilot study to inform the potential full-scale design and associated cost components during evaluation of an ISB remedy in the FS.
- Evaluation of UMCf and UMCf-cg only in Zones 1 and 3 allows for assessment of ISB effectiveness associated with contaminant upflux (i.e., does remediation of the UMCf/UMCf-cg in an area with a known upward gradient have any effect on contaminant concentrations in the overlying alluvium groundwater).
- Separate, smaller transects minimize the footprint and disturbed area associated with the pilot study.
- Hydraulic monitoring during injections and extraction of groundwater to be used for injection can be monitored in these distinct environments to collect data for updating the existing groundwater model to allow more accurate evaluation of possible extraction or injection-based components to the final remedy (i.e., pump and treat) during the FS. The revised pilot study design, including details of each zone, objectives, design, and layout are provided in Section 5.0.

# 5.0 PHASE 2 REVISED PILOT STUDY DESIGN

This section presents the revised design of the Las Vegas Wash Bioremediation Pilot Study, including the objectives, location and orientation of the injection well transect(s), number and spacing of injection wells, targeted injection intervals, and injection protocols for each of the three remediation zones.

## 5.1 DESIGN OF REMEDIATION ZONES

As explained in Section 4.3.2, the pilot study design will now focus on three separate remediation zones with each zone having a set of specific objectives. These remediation zones include: Zone 1 – UMCf Only, Zone 2 – Combination of Alluvium and UMCf, and Zone 3 – UMCf-cg Only (presented on Figure 14). The pilot study design has taken into account the objectives and focus of previous and on-going studies to mitigate redundancy. This section provides details of the location, objectives, and injection and monitoring well layout for each of the three remediation zones. Because well construction and injection processes will be similar for the three remediation zones, details of these components are summarized in Sections 5.2 through 5.4, respectively.

### 5.1.1 Zone 1 – UMCf Only

The UMCf within the pilot study area consists of silt to silty fine sand, and the deeper portions of the UMCf are semi-consolidated in nature with abundant gypsum, as explained in Section 3.2.1. During the Phase 1 pre-design groundwater sampling, the highest detection of perchlorate in groundwater of 16,000 μg/L was observed in the groundwater sample collected from monitoring well LVWPS-MW204B, which is screened within the unconsolidated UMCf from approximately 100 to 120 feet bgs.

Zone 1 will focus on the implementation of ISB within the vicinity of monitoring wells LVWPS-MW204 and LVWPS-MW217 (Figure 14) and will target contamination present only within the unconsolidated UMCf only for two primary reasons. First, concentrations of perchlorate decrease dramatically as the UMCf transitions from unconsolidated to semi-consolidated. Although groundwater samples collected from monitoring well LVWPS-MW204C (screened in the deeper semi-consolidated UMCf) had small detections of perchlorate and chlorate, it is likely that these concentrations are a result of drag-down of soil cuttings during drilling. Drag-down can cause initial groundwater samples from a monitoring well to be non-representative of concentrations in the formation, particularly when the screened formation has sufficiently low hydraulic conductivity that only minimal purging is possible during well development and sampling. Second, step-rate injection testing performed as part of the Galleria Drive Bioremediation Treatability Study indicated that ISB would be difficult to implement in the semi-consolidated UMCf due to the extremely low injection rates achieved in this formation even at high injection pressures. Based on these findings and conclusions, implementation of ISB in the Zone 1 will focus only on the unconsolidated UMCf.

#### 5.1.1.1 Zone 1 Objectives

Evaluation of ISB within a zone that only focuses on the UMCf allows for assessment of the following specific objectives.

- Determine if ISB can effectively create a biologically active zone for remediation of perchlorate- and chlorate-contaminated groundwater within the UMCf and compare the effectiveness with respect to variations in lithology between the UMCf within Zone 1 and UMCf-cg within Zone 3 (discussed in Section 5.1.3.1).
- Evaluate ISB implementation and operational components within the UMCf, including injection protocols, achievable injection rates, subsurface distribution of injectate, injection well spacing, and construction methods.

- Determine whether remediation in the UMCf in an area with elevated perchlorate and chlorate concentrations in groundwater and a known upward gradient has any effect on contaminant concentrations in the overlying alluvium groundwater, and if so, whether the effect differs depending on UMCf lithology (comparison of results from Zones 1 and 3). This data can be used to evaluate the potential effectiveness of remediation of small areas of elevated concentration in the UMCf with respect to achieving long-term remedial goals for OU-3.
- Determine the approximate length of time that ISB could be expected to affect concentrations in the UMCf and the resulting injection frequency required to maintain these concentration reductions.
- Evaluate if dual-nested injection wells are effective in delivering substrate to large saturated thicknesses of the UMCf since nested injection wells can be a cost-effective option as opposed to multiple separate injection wells.

### 5.1.1.2 Zone 1 – Pilot Study Layout and Well Design

Both injection wells and a supplemental monitoring well network will be installed in Zone 1 to collect data for evaluation of the objectives presented in Section 5.1.1.1. The final injection and monitoring well construction and layout design are based on the pre-design results described in Section 3.0 and lessons learned from previous and on-going treatability studies, which continue to be evaluated. The injection and monitoring well layout are presented in Figure 15.

### 5.1.1.2.1 Injection Well Transect Location and Length

The injection wells will be installed in a single injection well transect row located upgradient of monitoring well clusters LVWPS-MW204 and LVWPS-MW217 as shown in Figure 15. The location was selected based on the Phase 1 pre-design data that indicated the highest detections of perchlorate were observed in groundwater samples collected from the UMCf at these two locations. Consideration was also given to site accessibility when selecting the transect location. The injection well transect is oriented generally perpendicular to groundwater flow to intersect contaminated groundwater flowing through the Zone 1 study area.

The high level of site heterogeneity (as described in Section 3.2.1) informs the selection of the injection well transect length. Past investigations have indicated that the chemical and hydrogeological properties of the aquifer can vary significantly over relatively short distances. Such differences can influence both the implementability and effectiveness of remediation. For example, pilot study results from ISB implementation in an injection well transect that is installed within a high hydraulic conductivity zone would likely differ from results of the same ISB approach implemented within a low hydraulic conductivity zone. A full-scale remedy would be expected to encounter significant heterogeneity, and therefore, the Zone 1 transect length must be sufficient to include representative heterogeneity in the aquifer in order to maximize the usefulness of the data collected for evaluation of ISB as a full-scale remedy in the FS.

Based on the data collected during the Phase 1 pre-design activities (and depicted in Figure 9b), the variation of lithology between monitoring well LVWPS-MW204 and LVWPS-MW217 (located approximately 150 feet apart) is pronounced, with a 15-foot difference observed in the alluvium/UMCf contact and 40-foot difference observed in the unconsolidated/semi-consolidated UMCf contact. Furthermore, NMR data indicates that the LWVPS-MW217 area has an overall higher hydraulic conductivity in the UMCf than the LVWPS-MW204 area, and the slug test results support that observation. Such data provide evidence that significant heterogeneity exists over relatively short distances within the UMCf in this area; as a result, the injection transect should be long enough to incorporate this relevant heterogeneity. Therefore, based on the Phase 1 pre-design data, the pilot study design will focus on an approximately 200-foot long transect within the Zone 1 study area, with the exact location selected to incorporate as much of the observed heterogeneity as possible.

To determine the optimal placement for the 200-foot long injection well transect within Zone 1, initial pilot borings will be installed in an approximate 300-foot staggered row situated perpendicular to groundwater flow and generally in-line with existing monitoring well cluster LVWPS-MW204. As part of this effort, five pilot borings will be installed on approximately 50-foot centers, with each location drilled to a depth of approximately 160 to 175 feet bgs, or terminated at the top of the semi-consolidated UMCf. Monitoring wells will be constructed at each location using 4-inch Schedule 80 PVC casing and screened with 4-inch diameter slotted PVC well screen in the deepest portion of the unconsolidated UMCf. Four-inch diameter wells are proposed to allow for the use of the larger-diameter NMR logging tool (which can more reliably penetrate past the disturbed zone around the well) in characterizing the deeper sediments. Total well depth, slot size of well screen, filter pack, and length of the well screens for each location will be determined in the field based on lithology encountered during installation, but will likely be similar to UMCf wells installed to-date. Following well construction, but no sooner than 48 hours after well construction is complete, the newly installed monitoring wells will be developed using a surge block and bailer to swab and surge the filter pack and remove sediment from the wells. Upon completion of installation activities, groundwater sampling, slug testing, and NMR logging using the methods described in Section 2.4, 2.6.1, and 2.6.3, respectively, will be performed at each of the five newly installed monitoring wells. Groundwater samples will be analyzed for perchlorate and chlorate to determine contaminant distribution along the pilot boring transect within the Zone 1 study area. Both slug testing and NMR logging will be performed as part of the aquifer testing program to further delineate localized preferential flow pathways within the Zone 1 pilot study area.

The data collected from the pilot boring installation and testing activities will be evaluated to determine optimal placement of the 200-foot long injection well transect. The 200-foot long transect will be situated based on perchlorate and chlorate concentrations within the UMCf in conjunction with the most heterogeneous portion of the investigated area. Monitoring wells installed as part of the pilot boring phase will become part of the effectiveness monitoring for the pilot study.

##### 5.1.1.2.2 Injection Well Spacing

As part of the pilot study design, a range of injection well spacings and associated injection quantities were evaluated using site-specific information from the Zone 1 study area with the goal of maximizing subsurface distribution of the injectate while using a reasonable number of injection wells and injectate quantities. The injection well spacing is determined based on site geology and hydrogeology, heterogeneity observed, computational modeling, lessons learned from previous treatability studies, and practitioner’s technical experience; however, the carbon substrate quantities are directly related to the injection well spacing and therefore, these two components should be considered in tandem during the design process. For the selected carbon substrate of EVO (further discussed in Section 5.4.1), a key design consideration is the injection of adequate quantities of water to distribute the injected EVO to create a biologically active zone for the reduction of perchlorate- and chlorate-contaminated groundwater. Ultimately, although the site lithology and hydraulic properties may support a range of injection well spacings, a greater injection well spacing will require a greater quantity of distribution water and rate of injection to achieve adequate subsurface distribution within the biologically active zone. Therefore, although a greater injection well spacing results in a smaller number of injection wells (and therefore, lower drilling costs), it also results in a greater quantity of water required to be injected, which increases the duration and costs of each injection event. The drilling costs represent an initial capital expenditure, while the injection costs represent an ongoing expense. Counter to this, a closer injection well spacing will increase the capital investment associated with injection well installation, but less injectate would be required, decreasing the duration and costs of each injection event. However, less injectate could also result in the need for increased frequency of carbon substrate reinjection events and creation of a thinner biologically active zone.

To support the design for the Zone 1 study area, an evaluation was performed for a range of injection well spacings, injectate quantities and injection rates. A number of estimates using site-specific data and technical design experience were completed; in addition, numerical simulations were performed using screening-level MODFLOW groundwater flow models. The estimations and simulations evaluated a range of injection well spacings, rates, and injection regimes to arrive at the final recommended design. A technical memorandum summarizing these design components, calculations, and modeling scenarios is provided in Appendix I.

Based on the calculations and simulations presented in Appendix I, the remedial design for the Zone 1 study area includes a total of eight dual-nested injection wells to be installed and screened within the unconsolidated UMCf and spaced approximately 25-feet apart within the 200-foot long injection well transect (conceptually presented in Figure 15). The guidance, estimations, screening model, and design summary presented in Appendix I indicate an injection well spacing of 25 feet in the unconsolidated UMCf within the Zone 1 study area is ideal (based on information available at the time of this Work Plan Addendum) to achieve relatively even subsurface distribution and to account for variability and non-uniform groundwater flow and lithology.

Injection wells will be screened within the unconsolidated UMCf to target the highest perchlorate concentrations observed in groundwater samples collected from the unconsolidated UMCf (namely, 16,000 μg/L at LVWPS-MW204B and 9,200 μg/L at LVWPS-MW217B). Due to the large saturated thickness of the unconsolidated UMCf that has elevated perchlorate and chlorate concentrations in groundwater, injection wells will likely be installed in a dual-nested well configuration with varying injection well depths and screened intervals based on the depth of the alluvium/UMCf contact and subsequent transition to the semi-consolidated UMCf. Nested injection well configurations within the Zone 1 injection well transect will consist of two separately screened injection wells installed within the same borehole to optimize carbon substrate distribution throughout the large targeted saturated thickness of UMCf. Based on the lithology observed at nearby monitoring well clusters LVWPS-MW204 and LVWPS-MW217, it is anticipated that the injection well depths will range from 135 to 175 feet bgs, with the well screens targeting the impacted portion of the unconsolidated UMCf which varies in thickness from 50 to 80 feet. Final depths and screened intervals for each injection well location will be selected based on lithology encountered during installation. The conceptual injection well screen intervals are displayed on Figure 16.

### 5.1.1.2.3 Effectiveness Monitoring Well Layout

To provide a sufficiently effective monitoring well network to meet the more detailed objectives, the final pilot study design for the Zone 1 area includes both newly proposed and existing monitoring wells installed as part of pre-design activities. These monitoring wells will be installed throughout the Zone 1 study area and periodically sampled to determine remediation effectiveness following ISB injections. The final monitoring well network cannot be finalized at this time because the pilot borings (previously described in Section 5.5.5.2.1) have not yet been installed. However, a conceptual depiction of the effectiveness monitoring well network has been provided in Figure 15, which presents the approximate layout of the injection and monitoring wells, including the spacing and distances from the injection well transect. As shown in Figure 15, the conceptual monitoring well layout consists monitoring well clusters at 10 locations (two upgradient and eight downgradient) within the Zone 1 study area to determine remedial effectiveness. The two existing monitoring well clusters in the Zone 1 study area (namely, LVWPS-MW204 and LVWPS-MW217) and the monitoring wells installed as part of the pilot boring and monitoring well installation will be incorporated into the effectiveness monitoring program and the final pilot study design to the extent possible to increase program efficiency by reducing the overall scale of Phase 2 monitoring well installation. Additional details of the layout are noted as follows:

- Two monitoring well clusters (consisting of one monitoring well screened in the alluvium and two monitoring wells screened at similar intervals to the injection wells within the unconsolidated UMCf) will be installed approximately 50 feet upgradient of the injection well transect, which allows for sufficient distances so as to not be impacted by injections. These upgradient monitoring wells will be used to determine the contaminant concentrations in groundwater migrating through the injection well transect and to refine the mass flux entering the Zone 1 study area.
- A combination of existing, pilot boring, and additional newly installed monitoring wells at eight locations at varying distances downgradient of the injection well transect (generally located 25, 50, 100, and 150 feet downgradient) will be used to monitor ISB effectiveness and estimate the zone of influence of the carbon substrate following injections. This monitoring well layout was selected based on the rate and direction of

the groundwater flow within the Zone 1 study area so that the downgradient extent of remediation can be quantified, and results could be observed within the 18-month pilot study duration. Monitoring wells will not only be spaced along the length of the study area but also spatially varied throughout the study area both directly in-line and off-set of the individual injection wells to evaluate remediation with respect to the heterogeneity and preferential flow paths that exist throughout the study area.

- Due to the large saturated thickness targeted and specific Zone 1 study objectives, five of the eight downgradient monitoring well locations will consist of a three-well cluster with one monitoring well screened in the alluvium and two monitoring wells screened in different intervals within the unconsolidated UMCf. The remaining three of the eight locations will consist of a monitoring well pair with two monitoring wells screened at different intervals within the unconsolidated UMCf (similar depth intervals as the injection wells). Monitoring wells installed as part of the pilot boring and monitoring well installation will be utilized in the Zone 1 effectiveness monitoring network. These downgradient monitoring wells will be installed to evaluate ISB effectiveness within the various targeted injection intervals in the unconsolidated UMCf as well as to monitor for potential reductions in the alluvium as a result of remediation of the perchlorate and chlorate contamination present in the UMCf.

#### 5.1.1.3 Estimation of Perchlorate Mass Flux

A preliminary estimate of the mass flux of perchlorate through the Zone 1 study area was generated using available pre-design and existing data and the commercially available Earth Volumetric Software (EVS) to create site-specific three-dimensional distributions of hydraulic conductivity, perchlorate, and groundwater elevation. Calculations of mass flux past the transect line were then performed by calculating the mass flux of water passing through a vertical plane and multiplying that by the concentration of perchlorate in the water. The “kriging” geostatistical method is used for interpolation during this process. The calculation process is as follows:

1. A 3D block representing the hydraulic conductivity of the subsurface is generated by interpolation of the slug-test data collected during the Phase 1 pre-design (data provided in Appendix C).
2. A 3D block representing the hydraulic gradient is generated by interpolating the hydraulic head pressures measured in the groundwater wells in the area, and processing it using the gradient module in EVS.
3. A 3D block of the perchlorate concentrations is developed based on interpolation of the concentrations of perchlorate observed in groundwater samples collected from each of the monitoring wells during the Phase 1 pre-design (data provided in Appendix H).
4. The resulting values for each node in each block are then multiplied together to create a 3D block representing the product of hydraulic conductivity, hydraulic gradient and perchlorate concentration at each node.
5. The resultant 3D block is then sliced using a cross-sectional plane placed at the approximate location and length of the proposed injection well transect. The height of the plane is the thickness of the target geologic unit.
6. The volumetrics module of EVS is then used to integrate the cross-sectional area associated with each of the nodes on the plane and the mass-flux product block to calculate the total mass flux at every node to get a single mass flux value for the cross-sectional plane. As part of its process, the volumetrics module accounts for the conversion from the perchlorate concentration units of micrograms per liter to pounds.

Using this mass flux calculation method and the site-specific data collected during the Phase 1 pre-design, the perchlorate mass flux estimate through the UMCf within the Zone 1 study area is approximately 0.6 lbs/day. It should be noted that upgradient perchlorate data are relatively sparse, and therefore, this number is an estimate and subject to refinement based on additional data collected during the Phase 2 pilot study. Although this preliminary estimation of mass flux is relatively small, performing the study at this location will still allow for evaluation of all necessary objectives described in Section 5.1.1.1.

## 5.1.2 Zone 2 –Alluvium and UMCf

Zone 2 is located within a projected main paleochannel (Figure 14) that consists of a large saturated thickness of alluvium overlaying a smaller saturated thickness of UMCf. As described in Section 3.2.1, saturated alluvium, ranging from silty sand to sandy gravel with minor lenses of sandy silt, is present throughout the area, overlying the UMCf. Based on the depths to the erosional contact between the alluvium and UMCf observed within the Transect 1b study area, the deep alluvium observed at well cluster LVWPS-MW209 is likely connected to a generally north-south oriented wide paleochannel trending from location LVWPS-MW224 towards the Calico Ridge Weir, as shown on Figure 10. As a result, Zone 2 will evaluate ISB effectiveness and implementability within a main north-south oriented paleochannel, which is likely representative of other paleochannels upgradient of the Wash. Additionally, the unconsolidated UMCf that underlies the alluvial paleochannel will be included in the remedial design for Zone 2 to evaluate the combination of the alluvium and UMCf.

### 5.1.2.1 Zone 2 Objectives

Evaluation of ISB within Zone 2 encompasses both the alluvium and UMCf and allows for assessment of the following specific objectives.

- Determine if ISB can effectively create a biologically active zone for remediation of perchlorate- and chlorate-contaminated groundwater within a main, deep paleochannel located upgradient of the Wash, which will be important data to evaluate in the FS since targeting such paleochannels will most likely be a key component of the final remedy.
- Verify ISB effectiveness and injectate distribution in large saturated thicknesses of alluvium, which are up to three times greater within the Zone 2 area than has been evaluated in previous treatability studies.
- Determine if synergistic effects occur when both alluvium and UMCf are injected with carbon substrate; combined remediation of these two units has not been evaluated to-date.
- Evaluate injectate distribution in a dual-nested injection well configuration within the alluvium (previously only tested in single/paired injection wells) since nested injection wells can be a cost-effective option for large saturated thicknesses as opposed to multiple separate injection wells; Single injection wells will be installed in the UMCf, which will also be a contrast to the Zone 1 and Zone 3 implementation in the UMCf and UMCf-cg, which will evaluate both dual-nested and triple-nested injection wells.
- Evaluate implementation of single injection wells in the UMCf as compared to the nested injection wells targeting the UMCf within Zone 1.
- Verify that ISB implementation and operational components within the alluvium are in line with previous studies or if variations are required based on the large saturated alluvium targeted, with particular focus on carbon substrate distribution, evaluation of optimal chase water quantities, and injection frequencies required to maintain a biologically active zone for perchlorate and chlorate biodegradation.

### 5.1.2.2 Zone 2 – Pilot Study Layout and Well Design

Both injection wells and a supplemental monitoring well network will be installed in the Zone 2 area to collect data for evaluation of the objectives presented in Section 5.1.2.1. The final injection and monitoring well construction and layout design are based on the pre-design results described in Section 3.0 and lessons learned from previous and on-going treatability studies, which continue to be evaluated. The injection and monitoring well layout are presented in Figure 17.

#### 5.1.2.2.1 Injection Well Transect Location and Length

As previously explained, based on the depths to the erosional contact between the alluvium and UMCf observed within the Transect 1b study area, the deep alluvium observed at well cluster LVWPS-MW209 is likely connected to a generally north-south oriented, wide paleochannel trending from location LVWPS-MW224 towards the Calico Ridge Weir. The Zone 2 study area will focus on this main paleochannel. Phase 1 aquifer testing results indicated groundwater flow velocities in the alluvium of up to 250 ft/day in select monitoring wells located within 500 feet of the Wash. Such high flow velocities would be expected to decrease the residence time of the EVO substrate to the point that a biologically active zone would not develop; furthermore, there would be a high potential for the injectate to discharge to the Wash. For these reasons, the alluvial injection well transect will be located approximately 1,000 feet hydraulically upgradient of the Wash in an area where groundwater flow velocities range from 2 to 30 ft/day. Locating the injection well transect in this area will minimize the potential for injectate to be discharged to the Wash and increase residence time for remediation to occur.

The injection wells within Zone 2 will be installed in a single injection well transect row that is situated across this main paleochannel and approximately 300 feet in length, which is slightly longer than the 200-foot injection transect length proposed for Zones 1 and 3. Based on the most recent available UMCf elevation data, the main paleochannels have been measured to be 300 to 700 feet wide within OU-2 and OU-3. Because the paleochannel environment varies across the entire width of the channel (i.e., historical cut banks, meanders across the channel width through time, point bars, and high and low energy environments), it is critical for the transect to span those different environments so that the variability associated with them will affect the results of the study. As described in the Zone 2 objectives, the intent of the injection well transect within Zone 2 is to assess whether ISB can be effective in creating a biologically active zone that spans across a main paleochannel. Therefore, the minimum width of a main paleochannel of 300 feet is considered appropriate for the injection well transect length and no pilot borings will be required.

#### 5.1.2.2.2 Injection Well Spacing

Similar to the process described in Section 5.1.1.2.2, an evaluation was performed for a range of injection well spacings, injectate quantities and injection rates for both the alluvium and UMCf within the Zone 2 study area. A number of evaluations using site-specific data and technical design experience as well as numerical simulations were performed using screening-level MODFLOW groundwater flow models. These estimations and simulations evaluated a range of injection well spacings, rates, and injection regimes to arrive at the final recommended design. A technical memorandum summarizing these design components, estimations, and modeling scenarios is provided in Appendix I.

Based on the estimations and simulations presented in Appendix I, the remedial design for the Zone 2 study area includes nine dual-nested injection wells spaced approximately 35 feet apart in the alluvium and 12 single injection wells spaced approximately 25 feet apart in the UMCf. The injection well spacing in the alluvium is different than the spacing in the UMCf due to the varying geologic and hydraulic properties between the two lithological units. The guidance, estimations, screening model and design summary presented in Appendix I indicate that an injection well spacing of 35 feet in the alluvium and 25 feet in the unconsolidated UMCf within the Zone 2 study area should be adequate to achieve relatively even subsurface distribution and to account for variability and non-uniform groundwater flow and lithology.

Due to the large saturated thickness of the alluvium within the deep paleochannel, injection wells will be installed in a dual-nested well configuration with varying injection well depths and screened intervals based on the depth of water and subsequent depth of the alluvium/UMCf contact. The injection wells targeting the unconsolidated UMCf will be installed as single injection wells due to a relatively small saturated thickness in the UMCf within the Zone 2 area. Separate boreholes will be used for the nested injection wells installed in the alluvium and single injection wells installed in the unconsolidated UMCf due to the different injection well spacings and to maintain better control of the carbon substrate injections. Based on the lithology observed at nearby monitoring well clusters LVWPS-MW208, LVWPS-MW221, LVWPS-MW223, and LVWPS-MW224, it is anticipated that the injection wells installed within the alluvium will have depths ranging from 75 to 100 feet bgs (conceptually presented in Figure 16), with screens targeting the saturated alluvium that varies in thickness from 45 to 65 feet. A review of the same lithology indicates that the injection wells installed within the UMCf will likely have depths ranging from 105 to 145 feet bgs (conceptually presented in Figure 16), with screens targeting the saturated UMCf that varies from approximately 18 to 30 feet. Final depths and screened lengths for each injection well location will be selected based on lithology encountered during installation.

#### 5.1.2.2.3 Effectiveness Monitoring Well Layout

The effectiveness monitoring well network within the Zone 2 area includes both newly proposed and existing monitoring wells installed as part of pre-design activities. These monitoring wells will be installed throughout the Zone 2 study area and periodically sampled to determine remediation effectiveness following ISB injections. Because pilot borings are not required for the Zone 2 study area, the monitoring well layout presented in Figure 17 is not conceptual, but the actual proposed layout based on all information collected to date. As observed in Figure 17, the effectiveness monitoring well network will consist of three existing monitoring well clusters (namely, LVWPS-MW208A/B, LVWPSMW221A/B, and LVWPS-MW223A/B/C) and 44 new monitoring wells to be installed at 16 locations within the Zone 2 study area to determine remediation effectiveness. Details of the monitoring well network are as follows:

- Three monitoring well clusters (expected to consist of two monitoring wells screened in the different intervals in the alluvium [similar to injection well intervals] and one monitoring well screened in the unconsolidated UMCf; total of nine monitoring wells) will be installed approximately 50 feet upgradient of the injection well transect, which allows for sufficient distance so as to not be impacted by injections. These upgradient monitoring wells will be used to determine the general contaminant concentrations in groundwater that is migrating into the injection well transect and refine the mass flux entering the Zone 2 area within both the alluvium and UMCf.
- Two monitoring well clusters (each with three monitoring wells similar to the upgradient wells; total of six monitoring wells) will be installed cross-gradient of the injection well transect to provide information regarding lateral distribution of contaminants just outside the targeted area as well as information regarding the radius of influence of injection wells in the injection well line. Cross-gradient monitoring wells screened within the alluvium will be installed approximately 17 feet from the injection well transect, while cross-gradient monitoring wells screened in the UMCf will be installed approximately 12 feet from the injection well transect line. These distances represent the approximate targeted radius of influence (i.e., half the distance between the injection wells).
- Downgradient monitoring wells screened in the alluvium will be installed at nine locations at varying distances from the injection well transect (generally located 50, 100, 200, and 350 feet downgradient; total of 22 monitoring wells) while downgradient monitoring wells screened in the UMCf will be installed at seven locations at varying distances from the injection well transect (generally located 25, 50, and 100 feet downgradient; total of seven monitoring wells). These downgradient monitoring wells will be installed to monitor ISB effectiveness and help estimate the radius of influence of the carbon substrate following injections. This monitoring well layout was selected based on the rate and direction of the groundwater flow within the alluvium and UMCf within the Zone 2 study area so that the downgradient extent of remediation can be quantified, and results could be observed within the 18-month pilot study duration. Due to the higher groundwater flow rates observed in the alluvium when compared to the groundwater flow rates observed in the UMCf, monitoring wells screened in the alluvium are spaced at farther distances downgradient of the injection well transect than the monitoring wells screened in the UMCf. As with Zone 1, the monitoring wells are not only spaced along the length of the study area but also spatially varied throughout the study area both directly in-line and off-set from the individual injection wells to evaluate remediation with respect to the heterogeneity and preferential flow paths that exist throughout the study area.
- Existing monitoring well clusters LVWPS-MW208, LVWPS-MW221, and LVWPS-MW223, which are located approximately 200 feet downgradient and/or side gradient of the proposed injection well transect, will be incorporated as effectiveness monitoring wells within the Zone 2 study area. Select existing monitoring wells located farther downgradient and outside of the Zone 2 study area (namely LVWPS-

MW207, LVWPS-MW209/A, LVWPS-MW210A/B, LVWPS-MW211, LVWPS-MW212A/B, LVWPS-MW218A, LVWPS-MW220A, and LVWPS-MW224A) will also be sampled on a quarterly basis to monitor for potential remedial effects farther downgradient within the paleochannel (further discussed in Section 5.1.1). These 11 existing monitoring wells will also be sampled monthly for the first six months for the presence of dye only (as discussed in Section 5.4.3).

- Due to the combination of injections in both the alluvium and UMCf as well as the specific Zone 2 study objectives, the new monitoring well locations will consist of a cluster of monitoring wells screened in different intervals of the alluvium (similar to the injection well intervals) and/or the unconsolidated UMCf (as shown in Figure 17). If the saturated thickness of the alluvium encountered during drilling is larger than expected due to the alluvial paleochannel, an additional monitoring well may be installed and screened in the alluvium at up to four locations. These additional wells will allow for the entire saturated thickness to be represented in the effectiveness monitoring network, without increased screen length for monitoring wells beyond a maximum of 25 feet.

#### 5.1.2.3 Estimation of Perchlorate Mass Flux

Using the mass flux calculation method described in Section 5.1.1.3 and the site-specific data collected during the Phase 1 pre-design activities, the estimate of perchlorate mass flux through the Zone 2 study area for the combined alluvium and UMCf is approximately 2 lbs/day. It should be noted that the mass-flux calculations for the Zone 2 study area were performed for a cross-sectional plane located approximately 200 feet north of the proposed injection well transect presented in Figure 17 in order to better utilize the available site data. It was assumed that the conditions 200 feet north were comparable to those at the proposed injection transect location. As previously noted, the mass flux through the study area is an estimate and subject to refinement based on additional data collected during the Phase 2 pilot study. Although this preliminary estimation of mass flux is relatively small, performing the study at this location will still allow for evaluation of all necessary objectives described in Section 5.1.2.1.

### 5.1.3 Zone 3 – UMCf-cg Only

Zone 3 is located immediately west of the bedrock outcrop (Figure 14), where the UMCf coarsens and is interbedded with UMCf-cg that consists of silty sand and up to 10 percent subangular gravel (as described in Section 3.2.1). This coarser facies of the UMCf has not been encountered in other portions of this pilot study area or previous treatability study areas but has been previously identified elsewhere during investigations within the larger plume area. The UMCf-cg locally extends up to 235 feet bgs due to faulting adjacent to the bedrock outcrop; however, the contact with the underlying bedrock likely steeply rises to approximately 105 feet bgs towards the west, as shown on Figure 9b. Perchlorate concentrations in groundwater samples collected from monitoring wells screened within the UMCf-cg range from 160 to 13,000 μg/L depending on location. As a result, Zone 3 will evaluate ISB effectiveness and implementability within the UMCf-cg, which is a lithological unit in which ISB has not yet been evaluated in either previous or on-going treatability studies.

#### 5.1.3.1 Zone 3 Objectives

Evaluation of ISB within a zone that only focuses on the UMCf-cg allows for assessment of the following specific objectives.

- Determine if ISB can effectively create a biologically active zone for remediation of perchlorate- and chlorate-contaminated groundwater within the UMCf-cg and compare the effectiveness with respect to variations in lithology between the UMCf within Zone 1 (discussed in Section 5.1.1.1) and UMCf-cg within Zone 3.
- Evaluate ISB implementation and operational components within the UMCf-cg, including injection protocols, achievable injection rates, subsurface distribution of injectate, injection well spacing, and construction methods.

- Determine whether remediation in the UMCf-cg in an area with elevated contaminant concentrations in groundwater and a known upward gradient has any effect on contaminant concentrations in the overlying alluvium groundwater, and if so, whether the effect differs depending on UMCf lithology (comparison of results from Zones 1 and 3).
- Determine the approximate length of time that ISB could be expected to affect concentrations in the UMCf-cg and the resulting injection frequency required to maintain these concentration reductions.
- Evaluate if nested injection wells are effective in delivering substrate to large saturated thicknesses of the UMCf-cg since nested injection wells can be a cost-effective option as opposed to multiple separate injection wells.

### 5.1.3.2 Zone 3 – Pilot Study Layout and Well Design

Both injection wells and a supplemental monitoring well network will be installed in the Zone 3 area to collect data for evaluation of the objectives presented in Section 5.1.3.1. The final injection and monitoring well construction and layout design are based on the pre-design results described in Section 3.0 and lessons learned from previous and on-going treatability studies, which continue to be evaluated. The injection and monitoring well layout are presented in Figure 18.

### 5.1.3.2.1 Injection Well Transect Location and Length

The injection wells within the Zone 3 study area will be installed in a single injection well transect row that is approximately 200 linear feet in total length located immediately west of the bedrock outcrop and approximately 200 feet to the east of the Zone 2 study area. This location was selected based on the following: Phase 1 pre-design data indicating the presence of perchlorate contamination within UMCf-cg in a fault zone adjacent to the bedrock outcrop, site accessibility, and groundwater flow directions, while ensuring sufficient distance from the Zone 2 study area. The injection well transect will be generally oriented perpendicular to groundwater flow in order to intersect contaminated groundwater flowing through Zone 3 study area.

As previously explained for Zone 1 in Section 5.1.1.2.1, past investigations and data collected during the Phase 1 pre-design activities have indicated that the chemical and hydrogeological properties of the aquifer can vary significantly over relatively short distances. Therefore, the length of the injection well transect should be carefully selected to account for site heterogeneities (such as variation in lithology and hydraulic properties) to maximize the usefulness of the data collected during the pilot study. Based on the data collected during the Phase 1 pre-design (and observed in Figure 9b), there is significant variability in the fault zone within the Zone 3 study area including a 40-foot elevation difference observed in the alluvium/UMCf-cg contact and a 130-foot difference observed in the UMCf/bedrock contact over a short distance of less than 300 feet. Additionally, the perchlorate concentration profiles in both soil and groundwater vary across this same 300-foot distance as observed in Figures 12b and 13b, respectively, with majority of the perchlorate contamination generally located in an approximate 200-foot section residing in the western portion of the fault zone. Based on this Phase 1 pre-design data, the injection well transect within the Zone 3 study area is proposed to be approximately 200-feet long to account for the heterogeneity of the subsurface (with respect to both lithology and contaminant concentrations) while minimizing the footprint of the Zone 3 pilot study.

To determine the optimal placement of the injection well transect within the Zone 3 study area, initial pilot borings will be installed similar to the approach described in Section 5.1.1.2.1 for Zone 1 injection transect placement. Six pilot borings will be installed along an approximate 300-foot long staggered row situated perpendicular to groundwater flow and near existing monitoring well cluster LVWPS-MW222 (Figure 18). Pilot borings will be installed on approximately 50-foot centers, with each location drilled to a depth of up to 175 feet bgs. Monitoring wells will be constructed at each location as described in Section 5.1.1.2.1. Upon completion of installation activities, groundwater sampling, slug testing, and NMR logging using the methods described in Section 2.4, 2.6.1, and 2.6.3, respectively, will be performed at each of the five newly installed monitoring wells. Groundwater samples will be analyzed for perchlorate and chlorate to determine contaminant distribution along the pilot boring transect within the Zone 3 study area. Both slug testing and NMR logging will be performed as part of the aquifer testing program to further delineate any localized preferential flow pathways within the Zone 3 pilot study area.

The data collected from the pilot boring installation and testing activities will be evaluated to determine optimal placement of the 200-foot long injection well transect. The 200-foot long transect will be situated to capture the highest perchlorate and chlorate concentration areas in the UMCf-cg as well as significant variation in hydrogeologic properties within the Zone 3 study area.

#### 5.1.3.2.2 Injection Well Spacing

Similar to the process described in Section 5.1.1.2.2, an evaluation was performed for a range of injection well spacings, injectate quantities and injection rates for the UMCf-cg within the Zone 3 study area. A number of estimations using site-specific data and technical design experience as well as numerical simulations were performed using screening-level MODFLOW groundwater flow models. These estimations and simulations evaluated a range of injection well spacings, rates, and injection regimes to arrive at the final recommended design. A technical memorandum summarizing these design components, calculations, and modeling scenarios is provided in Appendix I.

Based on the estimations and simulations presented in Appendix I, the remedial design for the Zone 3 study area includes eight dual-nested or triple-nested injection wells spaced approximately 25 feet apart and screened within the UMCf-cg. The guidance, estimations, screening model and design summary presented in Appendix I indicate that an injection well spacing of 25 feet in the unconsolidated UMCf-cg within the Zone 3 study area should be adequate to achieve relatively even subsurface distribution and to account for variability and non-uniform groundwater flow and lithology. Additionally, using the same injection well spacing for implementation of ISB in the UMCf and UMCf-cg (Zones 1 and 3) will allow for a more direct comparison of the variations in ISB effectiveness and implementability between the two lithological units.

Due to the large saturated thickness of the UMCf-cg, injection wells will be installed at each of the eight locations in either a dual-nested or triple-nested well configuration with varying injection well depths and screened intervals based on the depth of the alluvium/UMCf-cg contact and depth at which bedrock is encountered below the UMCf-cg. Nested injection wells were selected to optimize carbon substrate distribution throughout the large targeted saturated thickness of UMCf-cg. Although UMCf-cg was encountered up to 235 feet bgs at LVWPS-MW222, ISB application at depths of lower perchlorate concentrations in the deepest UMCf-cg sediments is not necessary to meet project objectives outlined in Section 5.1.3.1. Therefore, a maximum targeted depth of 175 feet bgs was selected for Zone 3 of the pilot study, which is consistent with the anticipated maximum targeted depth of Zone 1 of the pilot study. Based on the lithology and perchlorate concentrations observed at nearby monitoring well clusters LVWPS-MW212, LVWPS-MW221 and LVWPS-MW222 and the maximum targeted depth of 175 feet bgs selected for Zone 3, it is anticipated that the injection well depths will range from 105 to 175 feet bgs, with varying screen lengths targeting approximately 30 to 120 feet of UMCf-cg. Based on available data, it is anticipated that six dual-nested and two triple-nested injection wells will be installed within the Zone 3 injection well transect. Final depths and screened intervals for each injection well location will be selected based on lithology encountered during installation.

#### 5.1.3.2.3 Effectiveness Monitoring Well Layout

The effectiveness monitoring well network within the Zone 3 study area includes both newly proposed and existing monitoring wells installed as part of pre-design activities. These monitoring wells will be installed throughout the Zone 3 study area and periodically sampled to determine remediation effectiveness following ISB injections. Because the pilot borings (previously described) have not yet been installed, the final effectiveness monitoring well network cannot be finalized at this time. However, a conceptual depiction of the effectiveness monitoring well network has been provided in Figure 18, which presents the approximate layout of the injection and monitoring wells, including the spacing and distances from the injection well transect. As shown in Figure 18, the conceptual monitoring well layout within the Zone 3 study consist of monitoring well clusters at 10 locations (two upgradient and eight downgradient) to determine remedial effectiveness. Monitoring wells installed as part of the pilot boring and monitoring well installation will be incorporated into the effectiveness monitoring program and the final pilot study design where possible. Additional details of the layout are noted as follows:

- Two monitoring well clusters (consisting of one monitoring well screened in the alluvium and at least two monitoring wells screened in different intervals of the UMCf-cg [similar to injection well intervals]) will be installed approximately 50 feet upgradient of the injection well transect, which allows for sufficient distance so as to not be impacted by injections. These upgradient monitoring wells will be used to determine the contaminant concentrations in groundwater migrating through the injection well transect and refine the mass flux entering the Zone 3 study area.
- A combination of existing, pilot boring, and additional newly installed monitoring wells at eight locations at varying distances downgradient of the injection well transect (generally located 25, 50, 100, and 150 feet downgradient) will be used to monitor ISB effectiveness and help estimate the zone of influence of the carbon substrate following injections. In order to increase program efficiency by reducing the overall scale of Phase 2 well installation, existing Phase 1 monitoring well cluster LVWPS-MW221, which is located approximately 100 feet downgradient will be used to monitor treatment effectiveness farther downgradient in Zone 3, rather than installing an additional monitoring well cluster 100 feet downgradient. This monitoring well layout was selected based on the rate and direction of the groundwater flow within the Zone 3 study area so that the downgradient extent of remediation can be quantified, and results could be observed within the 18-month pilot study duration. Monitoring wells will not only be spaced along the length of the study area but also spatially varied throughout the study area both directly in-line and off-set of the individual injection wells to evaluate remediation with respect to the heterogeneity and preferential flow paths that exist throughout the study area. In addition, monitoring wells LVWPS-MW212C/D, which are located approximately 250 feet downgradient, may be incorporated into the Zone 3 effectiveness monitoring network later in the pilot study based on effectiveness monitoring results observed at closer downgradient monitoring wells.
- Due to the large targeted saturated thickness of UMCf-cg and specific Zone 3 study objectives, each of the eight downgradient monitoring well locations will consist of at least two monitoring wells that are screened in different intervals of the UMCf-cg (similar to injection well intervals). Depending on the final targeted saturated thickness of the UMCf-cg, three monitoring wells may be installed and screened in the UMCf-cg at up to four these eight locations. These additional wells will allow for the entire saturated thickness to be represented in the effectiveness monitoring network, without increasing the screen length for monitoring wells beyond a maximum of 25 feet. Additionally, five of the eight downgradient monitoring well locations will also include one monitoring well screened in the alluvium to monitor for potential reductions in the alluvium as a result of remediation of the perchlorate and chlorate contamination present in the UMCf-cg.

#### 5.1.3.3 Estimation of Perchlorate Mass Flux

Using the mass flux calculation method described in Section 5.1.1.3 and the site-specific data collected during the Phase 1 pre-design activities, the estimate of perchlorate mass flux within the UMCf-cg through the Zone 3 study area is approximately 0.1 lbs/day. It should be noted that the mass-flux calculations for the Zone 3 study area were performed for a cross-sectional plane located approximately 200 feet north of the proposed injection well transect presented in Figure 18 in order to better utilize the available site data. It was assumed that the conditions 200 feet north were similar enough to those at the proposed injection transect location that the differences were negligible. As previously noted, the mass flux through the study area is an estimate and subject to refinement based on additional data collected during the Phase 2 pilot study. Although this preliminary estimation of mass flux is relatively small, performing the study at this location will still allow for evaluation of all necessary objectives described in Section 5.1.3.1.

## 5.2 INJECTION WELL CONSTRUCTION

Based on the design presented for each zone in Section 5.1, a total of 64 injection wells will be installed at 37 injection well locations distributed throughout the three pilot study zones. Due to the large saturated thickness of the alluvium and unconsolidated UMCf/UMCf-cg within the targeted remediation zones, injection wells will be installed in either a single or nested well configuration depending on the targeted injection interval along the injection well transect. The final depths and targeted screened interval will vary depending on zone and location within the zone and will be based on the depth to water, depth of the alluvium/UMCf/UMCf-cg contact and subsequent contact of the semi-consolidated UMCf or bedrock. As explained in Section 5.1, nested injection well configurations will consist of either two or three separately screened injection wells installed within the same borehole to optimize carbon substrate distribution. Separate boreholes will be used for nested injection wells installed in the alluvium and nested injection wells installed in the unconsolidated UMCf/UMCf-cg due to the different injection well spacings and to maintain better control of the carbon substrate injections. An example of the conceptual injection well layout for each of the three remediation zones is provided in Figure 16.

Due to the remote location with lower potential for buried utilities, the one-call utility locates will be relied on for identification of potential subsurface utilities in the pilot study area and therefore, hand augering or air knifing will not be performed for each location prior to drilling. Injection wells will be installed using rotosonic drilling methods. All injection wells will be constructed with 2-inch diameter, Schedule 40 or 80 PVC (depending on depth; generally alluvial wells will be Schedule 40, while UMCf and UMCf-cg wells will be Schedule 80) with an appropriately sized slotted PVC well screen and associated sand pack. Injection well screen size and sand pack at each injection well location will be determined based on the lithology observed during drilling. The sand filter pack will be installed in the annular space around the well screen and extend a minimum of 2 feet above the top of the screened interval. The remainder of the annular space will be backfilled with 2 feet of hydrated bentonite, followed by neat cement grout to ground surface. To ensure adequate space for the sand pack and bentonite seal, a minimum 2-inch annulus will be provided for each injection well. Because of the large saturated thickness that is being targeted for bioremediation (up to 175 feet depending on location within the injection well transect), a pragmatic approach for determining injection well screen lengths is being adopted for purposes of pilot study implementation. Specifically, depending on the injection well location, associated lithology, and preferential flow zones within each remediation zone, each injection well will be constructed with varying injection well screen lengths of up to a maximum of 35 feet. Exact screen intervals will be determined based on the lithology observed during drilling. A minimum 5-foot spacing (2-foot sand pack above screen, 1-foot transition seal sand, and 2-foot hydrated bentonite seal) will be placed in between screened intervals to prevent communication between injection intervals. The majority of injection wells will be completed with flush-mounted, traffic-rated well boxes, at an elevation of approximately 0.5-inch above grade. Injection wells within the Zone 3 area will include a combination of both flush-mount and above-ground completions with bollards because select monitoring wells are anticipated to be located immediately downgradient of the COH landfill stormwater drainage and aboveground wells would reduce the potential for surface water runoff from inadvertently entering the well. Following injection well construction, but no sooner than 48 hours after construction is complete, each of the newly installed injection wells will be developed. Following installation, all injection wells will be surveyed by a Nevada-licensed land surveyor.

## 5.3 EFFECTIVENESS MONITORING WELL CONSTRUCTION

To provide a sufficiently effective monitoring well network for each of the three remediation zones, the final pilot study design includes both newly proposed and existing monitoring wells installed as part of pre-design activities and other site investigations as described in Section 5.1. New monitoring wells are proposed at a total of 36 locations at varying distances upgradient, cross gradient, and downgradient of the injection well transects within the three remediation zones. As explained within Section 5.1, each remediation zone will include new monitoring locations that may consist of either a single monitoring well or a cluster of monitoring wells to evaluate remediation within the various targeted injection intervals within the alluvium and/or unconsolidated UMCf/UMCf-cg. Because the pilot borings (previously described in Section 5.1) have not yet been installed in Zones 1 and 3, the final effectiveness monitoring well network layout cannot be finalized at this time. However, a conceptual depiction of the effectiveness monitoring well network has been provided for Zones 1 and 3 in Figures 15 and 18. Figure 17 provides the locations of both new and existing monitoring wells proposed for incorporation into the effectiveness monitoring program for the Zone 2 study area during the pilot study; the new locations shown are the actual proposed locations since the design is not being refined by the installation of pilot borings.

Monitoring wells will be constructed of 2-inch Schedule 40 or 80 PVC casing and screened with 2-inch diameter, slotted PVC well screen at varying intervals within the alluvium and unconsolidated UMCf/UMCf-cg. Monitoring wells will be installed by the same methods and procedures as the pre-design monitoring wells discussed in Sections 2.3.3. Final depths and screened intervals for the paired/clustered monitoring wells will be selected based on lithology encountered during installation of the initial boring at each location. The majority of monitoring wells will be completed with flush-mounted, traffic-rated well boxes at an elevation approximately 0.5 inch above grade. Monitoring wells within the Zone 3 area will include a combination of both flush-mount and above-ground completions with bollards because select monitoring wells are anticipated to be located immediately downgradient of the COH landfill stormwater drainage. Following monitoring well construction, but no sooner than 48 hours after construction is complete, each of the newly installed monitoring wells will be developed. Following installation, all monitoring wells will be surveyed by a Nevada-licensed land surveyor.

## 5.4 INJECTION DESIGN

This section presents the design for injections of carbon substrate and subsequent distribution water for the pilot study. Results from the previous bioremediation treatability study on COH property (Tetra Tech, 2016) and the on-going SWF Area Bioremediation Treatability Study have provided preliminary findings on the longevity of each carbon substrate injection event, lateral and downgradient coverage or influence of the injections, and impact of the distribution water. Because the Las Vegas Wash Bioremediation Pilot Study will be performed in the alluvium and unconsolidated UMCf/UMCf-cg, the results of the previous and on-going studies performed in the alluvium have only been used as general guidance for the design needs of this study with respect to carbon substrate injections and follow-up distribution water.

### 5.4.1 Carbon Substrate Injections

Injections of carbon substrate and/or other amendments have been performed during numerous injection events associated with previous and on-going treatability studies performed for NERT. As a result, the experience and lessons learned from previous injection events will be incorporated into the Las Vegas Wash Bioremediation Pilot Study to optimize field injection operations. The injections will be performed in general accordance with the Field Guidance Document for injections (Appendix J). As part of the injection process, the carbon substrate will be pressure-injected into injection wells within each remediation zone using a mobile injection system, consisting of a tanker or trailer unit with a manifold piping system and hoses supplied with valves and regulators for controlling and monitoring the rates of injection. Prior to each injection, the injection solution will be prepared in a truck-mounted batch tank using water for dilution of the carbon substrate. The injection solution will be prepared by thoroughly mixing the carbon substrate, additional amendments, and water in the mixing tank. The injection solution will then be pressure-injected into the injection wells through a manifold with hoses equipped with quick disconnect fittings. Pressure gauges and a flow totalizer will be used to monitor the pressure and flow rates during injection at each injection well. The injection pressures and flow rates per injection well will be maximized to the extent possible based on injection operation capabilities and the ability of the formation to accept the injectate under pressures within the limits of the Underground Injection Control (UIC) Permit. Step-rate injection tests will also be performed prior to the injections to determine injection rates so that the injection design can be modified if required.

Based on the previous treatability studies, bench-scale study results, and pre-design results, EVO was selected as the primary carbon substrate. In addition to EVO, a soluble substrate and select additional nutrients and amendments will be blended into the carbon substrate solution, similar to previous ISB treatability studies. The soluble substrate, namely glycerin, will be added to the injectate solution to serve as an immediate source of carbon to drive the groundwater anaerobic rapidly and reduce acclimation time at the start of the study. Phosphate will also be added to serve as a nutrient for the microorganisms. Finally, sodium sulfite will be added to the injectate solution for alluvium injections in Zone 2 to serve as an oxygen scavenger. Based on previous and on-going treatability studies (including laboratory results for the various bench-scale studies performed by UNLV) and the Bio-Trap® results, bioaugmentation does not appear to be necessary for perchlorate biodegradation within the pilot study areas and, as a result, has not been included in the field pilot study.

Preliminary carbon substrate quantities have been estimated based on the designed injection well spacing selected for each of the three remediation zones. A summary of the key factors to consider when determining injectate quantities, the calculation process that was used for preliminary estimates, and the results of those estimations are summarized in Appendix I. Preliminary quantities are presented in ***Table 6***.

***Table 6*** Preliminary Carbon Substrate Quantities and Injection Volumes

| Study Area | Approximate Substrate Quantities (gallons) | Approximate Injection Volumes Substrate and Water (gallons) |
|---|---|---|
| Zone 1 – UMCf Only | 6,100 | 144,000 |
| Zone 2 – Alluvium | 13,000 | 249,500 |
| Zone 2 – UMCf | 3,300 | 33,000 |
| Zone 3 – UMCf-cg Only | 7,000 | 164,500 |

Final quantities of the carbon substrate and associated amendments will be based on the following:

- Results and findings of the pilot boring installation activities;
- Final construction details of the injection wells and the associated lithological and soil characteristics of the alluvium and unconsolidated UMCf/UMCf-cg that are observed during well installation;
- Chemistry and geochemistry of the groundwater collected during the baseline groundwater sampling event occurring immediately prior to injections from the newly installed pilot study injection and monitoring wells (described in Section 6.0);
- Stoichiometric requirements for the carbon substrate based on the mass of perchlorate and other electron acceptors that will migrate through the pilot study area;
- Results and findings of the previous and on-going UNLV laboratory studies, field treatability studies, and literature case studies.

It should be noted that final injection quantities will be based on data collected during installation of the injection and monitoring wells and baseline groundwater sampling and aquifer testing activities. At the request of NDEP, Tetra Tech, on behalf of the Trust, will provide final injectate quantity details and justification to NDEP prior to the purchase of the carbon substrate.

Prior to performing the injections, the carbon substrate solution (EVO, glycerin, phosphate, and sodium sulfite) will be diluted with water. This dilution is generally performed at a ratio of 1:4 parts of carbon substrate (including amendments) to water. However, this dilution may be increased up to 1:20 for injections into the UMCf/UMCf-cg due to the lower hydraulic conductivity within this zone compared to the alluvium. Water used for dilution activities will be obtained from either extracted groundwater from nearby monitoring wells or from a nearby City of Henderson hydrant (further discussed in Section 5.4.2). Preliminary estimates for water volumes required for injections are presented in ***Table 6***, with calculation details provided in Appendix I. An evaluation of water sources is provided in Section 5.4.2

Based on the anticipated 18-month pilot study timeframe following completion of injection well installation, it is anticipated that two injection events spaced 6 to 8 months apart will occur in the UMCf within Zones 1, 2, and 3. Injections into the targeted alluvium within Zone 2 are anticipated to be performed approximately once every four to five months, for a total of up to three injection events. This is a slightly increased injection frequency compared to the UMCf injections due to the presence of the large paleochannel and elevated groundwater flow rates in the alluvium within Zone 2. These approximated injection frequencies are estimated based on results from previous laboratory bench-scale and field treatability studies with ISB application in the alluvium as well as the geologic and hydrogeologic properties of the targeted lithological unit (such as hydraulic conductivities and groundwater flow rates in the alluvium, UMCf, and/or UMCf-cg) within each remediation zone based on the pre-design data discussed in Section 3.2. It should be noted that this frequency is approximated for budgeting and timing purposes and the actual injection frequency will be determined based on the effectiveness monitoring results following the injection events. Specifically, results will be evaluated for a wide range of parameters to determine the appropriate injection frequency and will include assessment of nitrate, chlorate, and perchlorate concentration trends as well as the overall aquifer response to the injections with respect to changes in geochemistry (such as dissolved oxygen and redox measurements), sulfate, and total organic carbon.

### 5.4.2 Distribution Water

A designated quantity of water will be injected into each injection well with or following each injection event of carbon substrate in all remediation zones. Distribution water is an important component of bioremediation design because it will improve the subsurface distribution of the carbon substrate within the injection well transect to create a more complete biologically active zone. The final quantity of water that will be added as distribution water will be determined following injection well installation based on factors such as final injection well screen intervals, soil type/lithology of the saturated soil in the vicinity of the injection well transect, and saturated thickness of the targeted injection zone.

As presented in the conceptual design in the Work Plan and previously described in Section 5.4.1, there are two choices for available water sources used for the injectate distribution and subsequent distribution water during the injections, namely COH water obtained from a nearby hydrant or extracted groundwater from nearby monitoring wells. It should be noted that for the previous treatability study near the COH water treatment facility, hydrant water was used as the source for distribution water (Tetra Tech, 2016), while the SWF Area Bioremediation Treatability Study, which has similar perchlorate and chlorate concentrations as the Las Vegas Wash Bioremediation Pilot Study area, continues to use extracted groundwater from monitoring wells located upgradient of the treatability study area during periodic injection events.

Careful consideration should be given when selecting between City of Henderson hydrant water and extracted groundwater. There are multiple advantages of using extracted groundwater including the following:

- Dilution of natural conditions with clean City of Henderson hydrant water could potentially decrease existing chemical concentrations in the immediate vicinity of the study area, which would in turn modify calculated and predicted kinetics and remedial study evaluation of degradation. The approach of using site groundwater from within the same area as injections will remove any such effects when determining remediation effectiveness.
- This process would assist in overall water conservation by using extracted groundwater as distribution water. Using groundwater from within the pilot study location avoids the need to procure and/or purchase

water from an outside source, which renders the remediation more green and economical, and reduces truck traffic and dust generation.

- Lastly, the application of distribution water is twofold: distribution of donor to the surrounding formation and second, flushing and clearing the injection well of any residual donor to reduce biomass buildup within the injection well. Therefore, utilizing extracted groundwater will have the same net effect of clearing the well and annular space of donor, similar to the option of using COH water, thus limiting any biomass buildup within the well. Furthermore, the Las Vegas Wash Bioremediation Pilot Study will include periodic, short-term duration injection events and not implemented via a continual feed injection system unlike other ISB applications at adjacent sites. Therefore, the quantity of water used during injections is a very small fraction compared to the quantity of groundwater flowing through the area during the treatment period, resulting in minimum potential for biomass buildup.

Based on the above and past experience at SWF Area Bioremediation Treatability Study, it is recommended that extracted groundwater be utilized for injections into both the alluvium and UMCf/UMCf-cg associated with the Las Vegas Wash Bioremediation Pilot Study. It should be noted that the SWF Area Bioremediation Treatability Study was extended in 2019 to examine long-term operation and maintenance considerations and associated injection well longevity. At this time, results indicate that extracted groundwater has been sufficient for use in the injectate solution and subsequent distribution water. Because the study continues to be performed, both the application of City of Henderson hydrant water and extracted groundwater from nearby monitoring wells will continue to be evaluated so that on-going lessons learned can be used in the final evaluation of the water source for the Las Vegas wash Bioremediation Pilot Study. To implement extracted groundwater as the water source for injections, groundwater will be extracted from new and/or existing monitoring wells in the immediate vicinity of the pilot study injection well transect. This process would be accomplished by extracting water from the nearby monitoring wells (screened in the alluvium) and transferring the water to onsite frac tanks for use during the injection process. Using the extracted alluvium groundwater as the water source for injections into the alluvium, UMCf, and UMCf-cg does not add contamination or relocate the contaminated groundwater outside of the general pilot study area or introduce new contamination into different lithological units. This component to the Phase 2 design was discussed with Bureau of Water Pollution Control UIC program staff during meetings held in March 2019. The UIC program staff indicated that this would likely be an acceptable approach provided that the water quality conditions are fairly consistent between the various lithological units. However, if this approach is not approved, extracted alluvium water will be used for injections into the alluvium and COH hydrant water will be used as the water source for injections into the UMCf and UMCf-cg.

Based on initial hydraulic testing (borehole dilution and slug tests), it is anticipated that up to 5 extraction wells will be required based on water needs for the injection activities. Extraction wells will be installed in upgradient/cross-gradient locations outside of the remediation zones and installed as six-inch wells. Additionally, monitoring well LVWPS-MW206B, which is a 4-inch monitoring well installed as part of Phase 1 pre-design activities, will also be used as an extraction well as needed due to its ideal location between remediation zones and slug testing and NMR results indicating a hydraulic conductivity of up to 191 ft/day. Hydraulic data will be collected during extraction activities and provided to the Trust for use in updating the existing groundwater model, which will allow more accurate evaluation of possible extraction or injection-based components to the final remedy (i.e., pump and treat) during the FS.

### 5.4.3 Tracer Injection

As part of the injection design, a tracer will also be injected and periodically monitored to provide additional data to aid in the evaluation of study objectives. Specific objectives of the tracer study are as follows:

- Assess radius of influence of the injection wells;
- Evaluate travel times of the injectate/dye;

- Determine whether water from the UMCf discharges into the alluvium and vice versa (i.e. the evaluation of the upflux component); and
- Estimate effective porosity of the formation near each injection well transect;

To collect data to evaluate the objectives described above, two separate fluorescent dye tracers will be used during the study. One dye will be introduced during the first UMCf injection event in each of the three zones, while a different dye will be introduced during the first alluvial injection event in Zone 2. The dyes and specific injection concentrations will be selected after pre-injection dye concentrations are determined during the baseline sampling event. The selected dyes are expected to be fluorescein and rhodamine WT so that commercially available field probes (previously purchased as part of the Downgradient RI) can be used to perform field assessment of tracer dye concentrations during injection. The concentration of injected dye will be such that it is visible during injections and very near the injections, but would be expected to dilute to minimally visible or non-visible levels prior to reaching the Wash. Dye will only be included as part of the injectate during the first injection event in each zone.

In order to more accurately determine the effective porosity of the formation in the vicinity of each injection well transect, two dose response well clusters will be installed at a strategic location within each of the three zones for a total of 18 additional monitoring wells (six well clusters, consisting of three monitoring wells per cluster). Exact location of the dose response monitoring wells will be determined following installation of injection wells. The dose response monitoring wells will be screened across the same intervals as the nearby injection wells. During the injection process, groundwater from the dose response monitoring wells will be monitored using visual observation and commercially available field probes (previously purchased as part of the Downgradient RI) to determine when breakthrough occurs and log the concentrations of dye at specific cumulative injection volumes. Groundwater samples will also be collected for laboratory analysis on a daily basis during active dye injections to confirm the field-measured dye concentrations. Lastly, samples of the injectate solution will be periodically collected and analyzed for dye to confirm the targeted injection dye concentration.

During injection activities, field personnel will visually monitor nearby monitoring wells for tracer dye to better assess the ROI of the injection wells, in particular within the Zone 2 study area where cross-gradient monitoring wells are installed in direct line with the injection well transect (as shown in Figure 17). If visual breakthrough of dye occurs at nearby (non-dose response) monitoring wells during the course of injection, periodic field measurements of dye concentration will also be performed. Additionally, charcoal samplers will be installed prior to the injections in nearby monitoring wells (upgradient, downgradient, and cross-gradient monitoring wells in the immediate vicinity of the injection well transects within each remediation zone) and collected following completion of the injection event. Charcoal samplers continue to collect dye over a period of time, thereby concentrating the dye within the sampler, which improves the chances of detecting low concentrations of dye. Upon retrieval of the charcoal sampler, a groundwater sample will also be collected from each location and analyzed for concentration if the dye is detected in the charcoal sampler. This two-step analysis process allows presence/absence analysis at all locations, but also permits quantitative analysis where the dye is found to be present.

Groundwater and surface water samples will also be periodically collected during the pilot study following the first injection event (further discussed in Section 6.1). Groundwater samples will be analyzed for the dye to collect data to evaluate the remaining primary objective of assessing potential upflux. In addition, surface water samples will also be periodically collected following the first injection event. If surface water results indicate the presence of the injected dye, these results may inform approximately where the injected, tracer-tagged water from the study area is entering the Wash. Although surface water will be periodically monitored, evidence of dye in the Wash may not be detected during the pilot study due to the location and size of the injection well transects as well as frequency and location of surface water sample collection. The use of charcoal samplers, which as described above collects dye over a period of time and concentrates the dye within the sampler, will improve the likelihood of detection of the dye in the Wash given the recognized challenges.

If available, the results of the RI tracer testing will be reviewed prior to injection of dyes within the pilot study area to evaluate potential outcomes/lessons learned and to maximize the collection of useful data from the tracer injections.

### 5.4.4 Hydraulic Response

Transducers will be installed in select nearby monitoring wells within each remediation zone to evaluate hydraulic response during injection and extraction operations. Data will also be collected to document the injection and extraction rates as well as changes in water levels associated with injection and extraction activities. Such data is expected to be useful in updating the existing Phase 5 transient groundwater flow model for the NERT site. Therefore, the data collected will be provided to the existing groundwater modeling team, with the understanding that the groundwater flow model can then be updated and used to more accurately evaluate options for remedies involving groundwater extraction and injection as part of the FS.

## 5.5 STAGING AREA CONSTRUCTION AND ROAD IMPROVEMENTS

The existing access roads within the general pilot study area are unimproved dirt roads that, in select locations, are too soft and/or rutted to allow vehicles to safely access the injection well sites and other work areas. As a result, in order to implement the work described in Sections 5.1 through 5.4, gravel may be placed in select locations to slightly raise the road elevation, provide a more robust driving surface, and/or reduce the potential for erosion and release of fugitive dust during drilling, injection, and/or monitoring activities. A staging area will also be established for temporary storage of materials and equipment during drilling and injection activities, to park or turn-around vehicles, and to perform other work activities. This staging area will be located within close proximity to the general pilot study area at a location within the fenced COH landfill or immediately within the pilot study area on land under jurisdiction of Clark County, depending on the outcome of access approvals.

# 6.0 PHASE 2 EFFECTIVENESS MONITORING PROGRAM

This section describes the monitoring program that will be implemented during the pilot study, which will consist of periodic groundwater monitoring and aquifer testing. The data collected will be used to assess the effectiveness of ISB in reducing contaminant concentrations during the pilot study, determine the frequency and timing of subsequent injection events, and monitor for changes in the hydrogeologic environment during the study.

## 6.1 GROUNDWATER MONITORING

A groundwater monitoring program will be implemented to evaluate the effectiveness of ISB at reducing contaminant concentrations in groundwater in each of the remediation zones within the pilot study area. This section presents the details of the monitoring program, which include monitoring wells to be sampled, anticipated sampling frequency and analysis, and groundwater sampling procedures. The anticipated monitoring program with respect to these components is described herein. The actual selected monitoring wells, frequency of sampling, and specific parameters to be analyzed during each individual event may be adjusted based on the results from the pilot study effectiveness monitoring events.

### 6.1.1 Monitoring Well Network

The monitoring well network will consist of monitoring wells located upgradient, cross gradient, and downgradient of the injection well transects within each remediation zone as described in Section 5.1 and shown in Figures 15, 17, and 18. The monitoring well network associated with each of the three remediation zones includes a total of 113 monitoring wells, which consists of 14 pre-design monitoring wells installed as part of Phase 1 (described in Section 2.3), 11 newly installed pilot boring monitoring wells proposed as part of the Phase 2 pilot study (described in Section 5.1), and 88 newly installed monitoring wells at up to 36 locations proposed as part of the Phase 2 pilot study (described in Section 5.1). An additional 16 monitoring wells (11 pre-design monitoring wells installed as part of Phase 1 and 5 newly installed extraction wells) will also be sampled on a lesser frequency during the pilot study timeframe to evaluate potential remedial impacts in areas located farther downgradient of the Zone 2 study area due to the paleochannel influence and determine contaminant concentrations in monitoring wells used for extraction operations during injections. Because injections are not targeting semi-consolidated material, monitoring wells within the pilot study area screened within semi-consolidated material were not included in the effectiveness monitoring program. The monitoring wells to be sampled during the pilot study may be adjusted based on the results from the pilot study effectiveness monitoring events. A summary of the monitoring wells to be sampled and their sampling frequency is further discussed in Section 6.1.2 and presented in ***Table 7***.

As requested by NDEP, all 64 monitoring wells installed as part of the Phase 1 pre-design will be sampled during baseline, regardless of their position within or near a remediation zone.

### 6.1.2 Sampling Frequency

A comprehensive baseline groundwater sampling event will be performed to establish baseline concentrations prior to performing the first injection event. Groundwater samples will be collected from all injection and monitoring wells within the entire pilot study area, which includes newly installed injection and monitoring wells, monitoring wells installed as part of the pilot boring installation in Zones 1 and 3, and all monitoring wells installed during Phase 1 pre-design investigations. Note that after this initial baseline groundwater sampling event to characterize the entire pilot study vicinity prior to implementation, only select Phase 1 pre-design monitoring wells located within the three remediation zones will be sampled as part of the effectiveness monitoring network, as described in Section 6.1.1.

After injections have occurred, groundwater samples will be periodically collected from the upgradient, cross-gradient, and downgradient monitoring wells within each remediation zone to determine the effectiveness of ISB in reducing contaminant concentrations in groundwater. The planned frequency for the groundwater monitoring events varies depending on remediation zone and is summarized in ***Table 7***. In general, groundwater monitoring occurs on a monthly basis. However, due to the slower groundwater flow rates present in the UMCf, the frequency of UMCf groundwater sampling reduces to bimonthly approximately four months following each injection event. It should be noted that the actual frequency of groundwater sampling may be adjusted based on the results of the pilot study effectiveness monitoring events.

***Table 7*** Proposed Sampling Frequency

| Study Area | Month of Pilot Study | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| Zone 1 | X | X | X | X | X | | X | | X | X | X | X | X | | X | | X | | X |
| Zone 2 | | | | | | | | | | | | | | | | | | | |
| Alluvium | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| UMCf | X | X | X | X | X | | X | | X | X | X | X | X | | X | | X | | X |
| Zone 3 | X | X | X | X | X | | X | | X | X | X | X | X | | X | | X | | X |

**Notes:**

(1) Sampling at Month 0 represents the baseline groundwater sampling event.
(2) Biweekly groundwater sampling will be performed during the first two months following the first injection event into the alluvium within the Zone 2 study area to capture initial reductions that are likely to be observed sooner than other areas due to higher groundwater flow rates.
(3) It is estimated that the second injection event into the UMCf and UMCf-cg in Zones 1, 2, and 3 may be performed approximately 8 months into the study. Therefore, sampling during months 9 – 12 represent the four monthly sampling events immediately following the second injection event.

In addition to the monitoring wells located within each remediation zone, 16 existing monitoring wells located outside of the remediation zones (11 pre-design monitoring wells installed as part of Phase 1 and 5 newly installed extraction wells) will be sampled on quarterly basis during the pilot study timeframe to evaluate potential remedial effects in areas located farther downgradient of the Zone 2 study area due to the paleochannel influence and to determine contaminant concentrations in monitoring wells used for extraction operations during injections.

### 6.1.3 Effectiveness Monitoring Parameters

During the pilot study, groundwater samples will be periodically collected and analyzed for a variety of field, laboratory, and microbial parameters listed in, which presents the analyses, associated methods, and purpose. As part of the baseline groundwater sampling event, groundwater samples collected from all injection and monitoring wells will be analyzed for perchlorate, chlorate, and nitrate. Groundwater samples collected from all monitoring wells within each remediation zone will also be analyzed for sulfate and TOC. Additionally, groundwater samples will be collected from up to 27 monitoring wells (three locations within each of the three remediation zones, each location consisting of three monitoring wells at varying depths) and analyzed for the larger suite of field and laboratory analytes listed in ***Table 8*** to further establish the baseline geochemical environment of the subsurface. Bio-Traps® will also be deployed in clustered monitoring wells at one upgradient and one downgradient location within each remediation zone (total of six locations) during the baseline sampling event and will remain in the monitoring wells for approximately 30 days. The purpose of the Bio-traps® is to evaluate the microbial response to carbon substrate addition. Once retrieved, the Bio-traps® will be sent to Microbial Insights for analysis of PLFA and the presence and quantification of the perchlorate reductase enzyme.

For the tracer study, baseline samples will also be collected from the 122 monitoring wells and 18 dose response monitoring wells located within each of the three remediation zones and analyzed for tracer dye to ensure that no tracer dye is already present in the system from tests performed elsewhere, industrial processes, or any other sources. As described in Section 5.4.3, groundwater samples will be collected from dose response monitoring wells and analyzed for dye using a fluorometer during the injection process, with periodic groundwater samples collected for lab analysis for confirmation of field fluorometer readings. At the conclusion of the first injection event, samples will also be collected from up to 99 monitoring wells located within each of three remediation zones, which includes dose response monitoring wells, monitoring wells located either immediately upgradient or within 50 feet downgradient or cross-gradient of the injection well transects, and all monitoring wells screened within the alluvium that are part of the Zone 2 remediation area.

During post-injection monitoring events, groundwater samples will be collected from the effectiveness monitoring wells and associated frequencies described in Sections 6.1.1 and 6.1.2 and analyzed for perchlorate, chlorate, nitrate, sulfate, and TOC. These monitoring wells (plus the 11 pre-design monitoring wells in areas located farther downgradient of the Zone 2 study area due to the paleochannel influence) will also be analyzed for tracer dye (including all dyes selected for injections) during biweekly and monthly sampling events for the first six months following the first injection event. Additionally, groundwater samples collected from up to 27 monitoring wells (three locations within each of three remediation zones, each location consisting of three monitoring wells at varying depths) will also be analyzed for the parameters listed in ***Table 8***. Specific parameters to be sampled during each individual event may be adjusted based on the results from previous pilot study effectiveness monitoring events. During two separate effectiveness monitoring events at some point in time following injections, Bio-traps® will again be deployed in clustered monitoring wells in the same six locations to evaluate PLFA and the presence of the perchlorate reductase enzyme following the injections.

***Table 8*** Groundwater Effectiveness Monitoring Protocol

| Parameter | Analytical Method | Purpose |
|---|---|---|
| **Field Parameters** | | |
| EC | Field Meter | Assess geochemical conditions |
| pH | Field Meter | |
| DO | Field Meter | |
| ORP | Field Meter | |
| Temperature | Field Meter | |
| Turbidity | Field Meter | |
| Ferrous Iron | HACH Field Kit | Assess effect of reducing conditions on iron |
| Sulfide | HACH Method 8131 | Examine secondary geochemical impacts |
| **Laboratory Parameters** | | |
| Perchlorate | E314.0 | Assess remediation effectiveness |
| Chlorate | E300.1B | Assess remediation effectiveness |
| TOC | SM5310B | Assess carbon substrate distribution in the aquifer |
| TDS | SM2540C | Assess any impact of salts on delayed or slower perchlorate biodegradation in the flow-through mode |
| Alkalinity | SM2320B | Assess geochemical conditions |
| Nitrate | E300.0 | Assessment of nitrate as the most likely competing electron acceptor and carbon substrate consumer |
| Sulfate | E300.0 | Assessment of sulfate as an electron acceptor and potential carbon substrate consumer |

| Parameter | Analytical Method | Purpose |
|---|---|---|
| Total Nitrogen | E351.2/E300.0 | Examine the need for micronutrients |
| Total Phosphorus | E365.3 | Examine the need for micronutrients |
| Methane | RSK175 | Examine secondary geochemical impacts |
| Dissolved Metals(1) | SW6010B/6020 | Assess secondary impacts of remediation |
| Hexavalent Chromium | E218.6 | Examine impact of reductive biological treatment on hexavalent chromium in groundwater |
| VFAs | VFA-IC | Surrogate carbon substrate assessment |
| Tracer Dye | Fluorescence | Assess hydraulic properties |
| PLFA | Microbial Insights PLFA | Examine microbial response to carbon substrate addition |
| Perchlorate Reductase Enzyme | Microbial Insights Census-DNA | Examine microbial response to carbon substrate addition |

**Notes:**
BL: Baseline
EC: Electrical conductivity
DO: Dissolved Oxygen
ORP: Oxidation-reduction potential
PLFA: Phospholipid Fatty Acids
TOC: Total organic carbon
TDS: Total dissolved solids
VFAs: Volatile Fatty Acids
(1) Metals include arsenic, calcium, chromium, iron, and manganese.

All pilot study field samples and field quality assurance/quality control (QA/QC) samples will be evaluated for quality and usability. Field QA/QC samples will include equipment blanks, field blanks, field duplicates, and matrix spike/matrix spike duplicates. The QA/QC samples will provide information on the effects of sampling procedures and assess sampling contamination, laboratory performance, and matrix effects.

The laboratory analytical data will be verified and validated in accordance with procedures described in the *Quality Assurance Project Plan, Revision 2* (Ramboll Environ, 2017c), *NDEP Data Verification and Validation Requirements* (NDEP, 2018), and email communication on NDEP data validation guidance (Clough, 2018).

### 6.1.4 Groundwater Sampling Procedures

General groundwater sampling activities will follow the guidance of the *Field Sampling Plan, Revision 1* (ENVIRON, 2014). Prior to groundwater sample collection, groundwater levels will be gauged in all monitoring wells for use in potentiometric contouring. Groundwater samples will be collected using low-flow purging and sampling techniques. During this purging, a pump capable of purging between approximately 0.1 to 0.13 gallons per minute will be used to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water will pass through a flow-through cell analyzer for continuous monitoring of field parameters (temperature, pH, turbidity, EC, DO, and ORP). Field parameters will be monitored and recorded on field sampling forms during purging. After the field parameter readings and water levels have stabilized, the monitoring wells will be sampled. Filtering for dissolved metals analyses will be conducted in the field using a 0.45-micron filter. Following completion of sampling, purge water generated during groundwater sampling activities will be temporarily stored in 55-gallon drums or totes and transferred into the GW-11 Pond for onsite treatment in the groundwater extraction and treatment system.

Samples for dye analysis will be collected using laboratory-provided, flow-through charcoal samplers, which concentrate the dye so that lower levels in groundwater can be effectively analyzed. In addition, a laboratory-provided bottle of water will be collected according to laboratory protocol from each sample location to be analyzed only if tracer is detected in the charcoal sampler. This two-step analysis process allows presence/absence analysis at all locations, but also permits quantitative analysis where the dye is found to be present. Groundwater samples collected for dye analysis from dose response monitoring wells during the first injection event will be collected via disposable bailers.

To evaluate the effects of the daily Wash cycles on water quality, conductivity probes will be installed in two monitoring wells located close to the Wash. The conductivity probes will be downloaded periodically and compared to the flow records for the Wash. If cyclical changes are noted, samples may be collected from these monitoring wells at times corresponding to peaks and lows to determine whether these cycles correlate to perchlorate concentrations. If corresponding perchlorate changes are noted, the observed cycle may be used to guide sampling times to ensure that representative samples are collected from the wells near the Wash that are monitored as part of Zone 1 and the downgradient portion of Zone 2.

## 6.2 SURFACE WATER MONITORING

As explained in Section 2.5, surface water samples are currently collected on a monthly basis to monitor the mass flux of perchlorate migrating into the Wash. As part of the on-going monthly surface water sampling, surface water samples are collected from three transect locations within the Wash that are located downgradient of the Transect 1b study area between Historical Lateral and Homestead Weirs, namely LVW5.3, LVW4.75, and LVW4.2 (shown on Figure 4). Monthly surface water samples are currently analyzed for perchlorate, chlorate, and TDS. For monthly surface water sampling events that occur during the pilot study timeframe, surface water samples that are collected from these three transect locations will also be analyzed for TOC. Baseline and monthly surface water samples collected during the first six months following the first injection event will also include analysis for tracer dye. Surface water samples will be collected for dye analysis from seven locations, including three transect locations (LVW5.3, LVW4.75, and LVW4.2; shown on Figure 4), three locations along the southern bank of the Wash previously sampled during Phase pre-design activities (namely, LVWPS4.4, LVWPS4.9, and LVWPS5.1; shown on Figure 4) and one new location immediately downgradient of Calico Ridge Weir. During transect sampling, samples for dye analysis will be collected from a location near the southern bank of the Wash, rather than from the transect locations; the seven sampled locations will be field-located using GPS. The frequency of surface water sampling, selected locations, and specific parameters to be sampled during each individual event may be adjusted based on the results from prior surface water sampling events.

Surface water samples will be collected using similar techniques to those used during collection of surface water samples required under *Surface Water Sampling and Analysis Plan, Revision 3* (Tetra Tech, 2018b). Samples for dye analysis will be collected by attaching the charcoal sampler to a weight and placing it in the water near the bank of the Wash, with collection of the sample approximately one week later. Multiple samplers may be emplaced to ensure that one can be retrieved later for analysis. Field parameters (temperature, pH, turbidity, EC, DO, and ORP) will be monitored and recorded on field sampling forms prior to sample collection. All samples will be validated as described in Section 6.1.3.

## 6.3 AQUIFER TESTING

Prior to carbon substrate injections, baseline aquifer testing (consisting of slug tests, borehole dilution tests, and NMR logging) will be performed using the same methods described in Section 2.6 in select newly installed monitoring wells in each of the remediation zones. Specifically, slug tests will be performed on all newly installed monitoring wells described in Section 5.1 to determine pre-injection hydraulic conditions. Borehole dilution tests will be performed in newly installed monitoring wells at up to 12 new locations, with the focus being on characterizing the groundwater flow rates in areas downgradient of the injection wells.

Following carbon substrate injections, slug tests will be performed periodically throughout the pilot study to examine subsurface conductivity changes following carbon substrate injections. In addition to slug testing, transducers will be installed in select upgradient, cross-gradient, and downgradient monitoring wells within each of the three remediation zones and in monitoring wells near the extraction wells. Data will be downloaded from newly installed transducers and previously installed transducers (described in Section 2.6.4) on a quarterly basis to continue to evaluate hydraulic response during injection and extraction operations, determine vertical and horizontal gradients in the alluvium and UMCf, and assess localized groundwater/surface water interactions over time within the pilot study area.

## 6.4 INJECTION WELL MONITORING

Because injection wells are subject to periodic injection of EVO, nutrients, and distribution water, it is important that the injection wells maintain the long-term ability to accept the carbon substrate so that perchlorate biodegradation is sustained. As injections occur, injection well screens and surrounding filter packs could accumulate biomass, inorganic precipitates, and intermediate by-products of EVO hydrolysis. This phenomenon can result in changes to the injectability (i.e., increases in injection pressures required for subsurface distribution) and may require corrective measures to promote injection well longevity and ensure successful long-term operation of ISB. Due to the importance of continued injectability, the SWF Area Bioremediation Treatability Study was extended in December 2018 to evaluate the long-term effects of injections and develop a more in-depth understanding of the long-term operation and maintenance requirements associated with ISB systems at the NERT site (Tetra Tech, 2018c).

For the Las Vegas Wash Bioremediation Pilot Study, data will be collected during the injection events, including injection pressures and injection rates at each injection well. This data and the lessons learned as part of the on-going SWF Area Bioremediation Treatability Study extension will be evaluated and compared with each injection event to project if and when injection well maintenance (such as well redevelopment) may be required.

# 7.0 PHASE 2 ACCESS AND PERMITTING REQUIREMENTS

Access agreements and multiple permits will be required to be in place prior to start-up of pilot study activities. This section presents a summary of the access and permit requirements that will likely be required for the implementation of the activities described in this Work Plan Addendum.

## 7.1 ACCESS AGREEMENTS

Access agreements were initially secured with BOR, COH, and Clark County (as described in Section 2.2) for all pre-design and conceptual field pilot study work described in the Work Plan. Updates to the access agreement with Clark County will be required to install the planned injection and monitoring well network and complete the associated road improvements described in Section 5.5. Additional authorization will be required from BOR for use of an existing access road that crosses BOR land from East Galleria Drive. Use of this access road is expected to be authorized under the existing *Finding of No Significant Impact LC-17-19 for Final Environmental Assessment, Right of Use – Downgradient Study Area Activities* (BOR, 2018). Finally, authorization will be required from the COH to use the upgradient COH landfill as a staging area during drilling and injection activities and a Licensed Location Authorization for Access Agreement application will be prepared to obtain permission to install additional upgradient monitoring wells within the COH landfill.

## 7.2 PERMITTING

This section presents a summary of the permits that will be required for the activities that are being proposed for phase 2 of the pilot study. In addition to the permits described here, a review of other potential permitting requirements was conducted. Based on the project design, a discharge permit will not be required since there will be no sustained wastewater discharges from injection and monitoring well operations. Water from short term well development and sampling will be collected and treated in the groundwater extraction and treatment system at the NERT site.

### 7.2.1 County Permitting

Per the Clark County Department of Air Quality, a dust control permit is required for activities that result in soil disturbance greater than 0.25 acres. A review of installation activities associated with the pilot study indicates that the soil disturbance will be greater than 0.25 acres during drilling activities. As a result, Tetra Tech, on behalf of NERT, will prepare and submit the required dust control permitting application. No air permitting other than dust control is anticipated because there will be no air emissions associated with the injection/monitoring wells or equipment needed for their installation and operation that would trigger minor source permitting. Following completion of drilling activities, the dust control permit will be closed as injection activities do not constitute construction disturbance.

### 7.2.2 Nevada Construction Stormwater General Permit

Authorization under the Construction Stormwater General Permit (NVR00000), administered by NDEP, will not be required if the staging area described in Section 5.5 is located within the existing COH landfill. However, if access discussions result in the staging area being placed on land under Clark County jurisdiction, a Construction Stormwater General Permit is anticipated because cumulative disturbances associated with drilling and road improvements are expected to exceed 1 acre. If required, a Notice of Intent will be filed with NDEP to request authorization under the general permit. The general permit requires preparation of a stormwater pollution prevention plan to describe the work to be done and the best management practices that will be put in place to prevent stormwater discharges. Following final stabilization of the site, as required by the general permit, a Notice of Termination will be filed with NDEP.

### 7.2.3 Well Installation Permitting

Pilot study activities will require a NAC 534.441 Monitoring Well Drilling Waiver and NAC 534.320 Notice of Intent Card prior to installation of injection and monitoring wells. The Monitoring Well Drilling Waiver also requires a completed, signed, and notarized Affidavit of Intent to Abandon a Monitoring Well as an attachment. As required, all injection and monitoring wells will be drilled by a licensed well driller pursuant to Nevada Revised Statutes 534.160 and will be constructed pursuant to NAC Chapter 534 – Underground Water and Wells. To the extent that any injection and monitoring wells associated with this pilot study are to be abandoned, abandonment will be done in accordance with the provisions contained in NAC 534.4365 and all other applicable rules and regulations for plugging wells in the State of Nevada.

### 7.2.4 NDEP – Underground Injection Control Program

This pilot study will require UIC permit authorization, which is anticipated to be issued under the NDEP UIC General Permit for Long-Term Remediation for injection of carbon substrate, amendments, dye, and water into the saturated subsurface. Permit authorization is expected to be a modification to the existing general permit authorization, GU07RL-51057, issued for the bioremediation treatability/pilot studies to date. Alternatively, NDEP may require application for issuance of an individual UIC permit. The UIC permit will require injection reports to be submitted on a semi-annual basis.

### 7.2.5 Water Appropriation Permit

Pursuant to Nevada Revised Statutes 533.335 and 533.437, an application for a Permit to Appropriate the Public Waters of the State of Nevada for Environmental Purposes (Water Appropriation Permit) will be required to support the extraction of groundwater from nearby monitoring wells to be used as distribution water during injection operations. The Water Appropriation Permit will require extraction reports to be submitted on an annual basis to present total water extracted during the calendar year.

# 8.0 PHASE 2 REPORTING

Monthly status updates will be provided to the Trust and NDEP summarizing the progress and results of the pilot study. Detailed performance criteria (both qualitative and quantitative), performance metrics, and associated performance confirmation methods have been developed to assist in evaluating the pilot study results and are presented in Appendix K. Following completion of the pilot study, a final Las Vegas Wash Bioremediation Pilot Study Results Report will be prepared and submitted for NDEP and USEPA review. This report will summarize the pilot study activities and results. This report will include the following:

- Summary and application of bench-scale testing results, including final UNLV bench-scale summary report;
- Field pilot study implementation details based on the design presented herein, including presentation of the final injection and monitoring well layout, targeted injection depths and intervals, and a summary of injection and monitoring activities within each remediation zone;
- Summary of groundwater analytical data collected as part of the effectiveness monitoring program;
- Evaluation of the specific study objectives within each remediation zone and performance criteria presented in Appendix K;
- Determination of the technology's effectiveness, implementability, and a range of costs for full-scale application and other relevant components required for proper evaluation in the FS, including:
    - Potential layout and plan for full-scale implementation and/or expansion of existing pilot study infrastructure;
    - Preliminary estimates of capital and operating costs for full-scale implementation; and
    - Management of possible temporary reductions in aquifer transmissivity and any release of secondary constituents (e.g., arsenic).

# 9.0 PHASE 2 SCHEDULE

It is the intent of the Trust to prepare an update to its master Gantt schedule upon NDEP and USEPA approval of this Work Plan Addendum. Generally speaking, and assuming timely receipt of agency approvals and issuance of all necessary permits, mobilization should begin in December 2019 with the first injection event following approximately five months later upon completion of pilot boring installation, injection and monitoring well installation, and baseline groundwater characterization.

# 10.0 REFERENCES

AECOM, 2018. Data Gap Investigation Plan – Phase II Groundwater Quality Assessment, NERT Remedial Investigation – Downgradient Study Area. December.

AFCEE, Environmental Science Division, Technology Transfer Outreach Office. (2007). *Protocol for In Situ Bioremediation of Chlorinated Solvents Using Edible Oil, Final.* Prepared by Solutions IES, Inc., Terra Systems, Inc., and Parsons Infrastructure & Technology Group, Inc. October.

ASTM International. (2008). D 4044-96. "Standard Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers."

Bell and Smith. (1980). Geologic Map of the Henderson Quadrangle, Nevada. Nevada Bureau of Mines and Geology, Map 67.

Clough, Steve to Weiquan Dong. (2018). "2018 11 26 Facility ID H-000539 NERT." Email. November 26.

Duffield, G. M. (2014). *AQTESOLV for Windows Version 4.5 Users Guide.*

ENVIRON. (2014). *Field Sampling Plan, Revision 1, Nevada Environmental Response Trust Site, Henderson, Nevada.* July 18.

ESTCP. (2006). *Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil.* Prepared by: Solutions-IES. May

HydroSOLVE, Inc. (2007). *AQTESOLV* (version 4.50) – Professional. Developed by Glenn M. Duffield.

Nevada Division of Environmental Protection (NDEP). (2009). *Data Verification and Validation Requirements – Supplement April 2009*.

NDEP. (2018). "Data Validation Guidance, BMI Plant Sites and Common Areas Projects, Henderson, Nevada." July 13.

Pitrak, M., Mares, S., and Kobr, M. (2007). "A Simple Borehole Dilution Technique in Measuring Horizontal Ground Water Flow." *Ground Water*, volume 45, issue 1.

Plume, R. (1989). *Ground-Water Conditions in Las Vegas Valley, Clark County, Nevada. Part 1: Hydrologic Framework*.

Ramboll Environ. (2016). *Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust, Henderson, Nevada*. October 31.

Ramboll Environ. (2017a). *RI/FS Work Plan Addendum: Phase 3 Investigation, Revision 1, Nevada Environmental Response Trust, Henderson, Nevada*. October 27.

Ramboll Environ. (2017b). *Remedial Investigation Phase 2, Investigation Modification No. 3, Nevada Environmental Response Trust, Henderson, Nevada*. May 31.

Ramboll Environ. (2017c). *Quality Assurance Project Plan, Revision 2, Nevada Environmental Response Trust Site, Henderson, Nevada.*

Ramboll. (2018a). *Semi-Annual Remedial Performance Memorandum for Chromium and Perchlorate, Nevada Environmental Response Trust, Henderson, Nevada*. May 1.

Ramboll. (2018b). *Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust, Henderson, Nevada*. November 9.

Ramboll. (2018c). *Remedial Investigation Phase 2, Investigation Modification No. 10, Nevada Environmental Response Trust, Henderson, Nevada*. March 1.

Ramboll. (2018d). *Remedial Investigation Phase 2, Investigation Modification No. 14, Nevada Environmental Response Trust, Henderson, Nevada*. September 11.

Solutions-IES, Inc. (2006). *Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil.* Environmental Security Technology Certification Program. May.

Tetra Tech. (2015). *Health and Safety Plan for Site-Wide Investigations and Remedial Activities, Nevada Environmental Response Trust, Henderson, Nevada*.

Tetra Tech. (2016). *Groundwater Bioremediation Treatability Study Results Report, Nevada Environmental Response Trust, Henderson, Nevada.* November 23.

Tetra Tech. (2017). *Las Vegas Wash Bioremediation Pilot Study Work Plan, Nevada Environmental Response Trust, Henderson, Nevada.* September 22.

Tetra Tech. (2018a). "Treatability/Pilot Study Modification No. 2 – Las Vegas Wash Bioremediation Pilot Study Nevada Environmental Response Trust Site, Henderson, Nevada," Technical Memorandum. August 17.

Tetra Tech. (2018b). *Surface Water Sampling and Analysis Plan, Revision 3, Las Vegas Wash, Nevada Environmental Response Trust, Henderson, Nevada*. October.

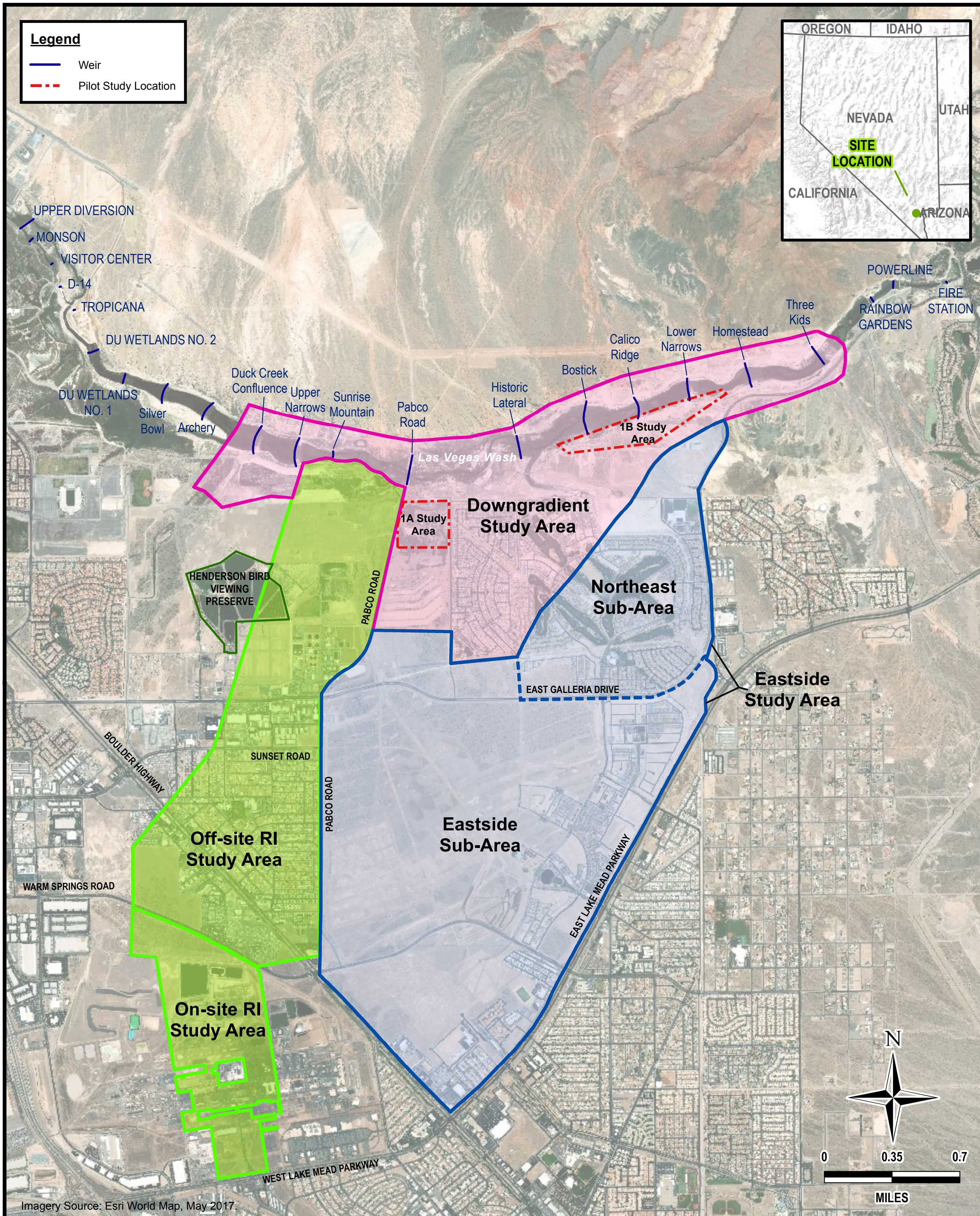
Tetra Tech. (2018c). *Treatability/Pilot Study Modification No. 6 – Seep Well Field Area Bioremediation Treatability Study, Nevada Environmental Response Trust, Henderson, Nevada.* December.

Tetra Tech. (2019). *Draft Seep Well Field Area Bioremediation Treatability Study Results Report, Nevada Environmental Response Trust, Henderson, Nevada.* May.

United States Bureau of Reclamation (BOR). (2018). *Finding of No Significant Impact and Final Environmental Assessment, Right of Use – Downgradient Study Area Activities*. March.

Walsh, D., Turner, P., Grunewald, E., Zhang, H., Butler Jr., J., Reboulet, E., Knobbe, S., Christy, T., Lane Jr., J., Johnson, C., Munday, T., Fitzpatrick, A. (2013). "A Small-Diameter NMR Logging Tool for Ground-water Investigations," *Ground Water*, volume 51, issue 6, November.

# Figures




M:\GIS\NERT\M19\Work Plan Addendum\Figure1.mxd

TETRA TECH

www.tetratech.com

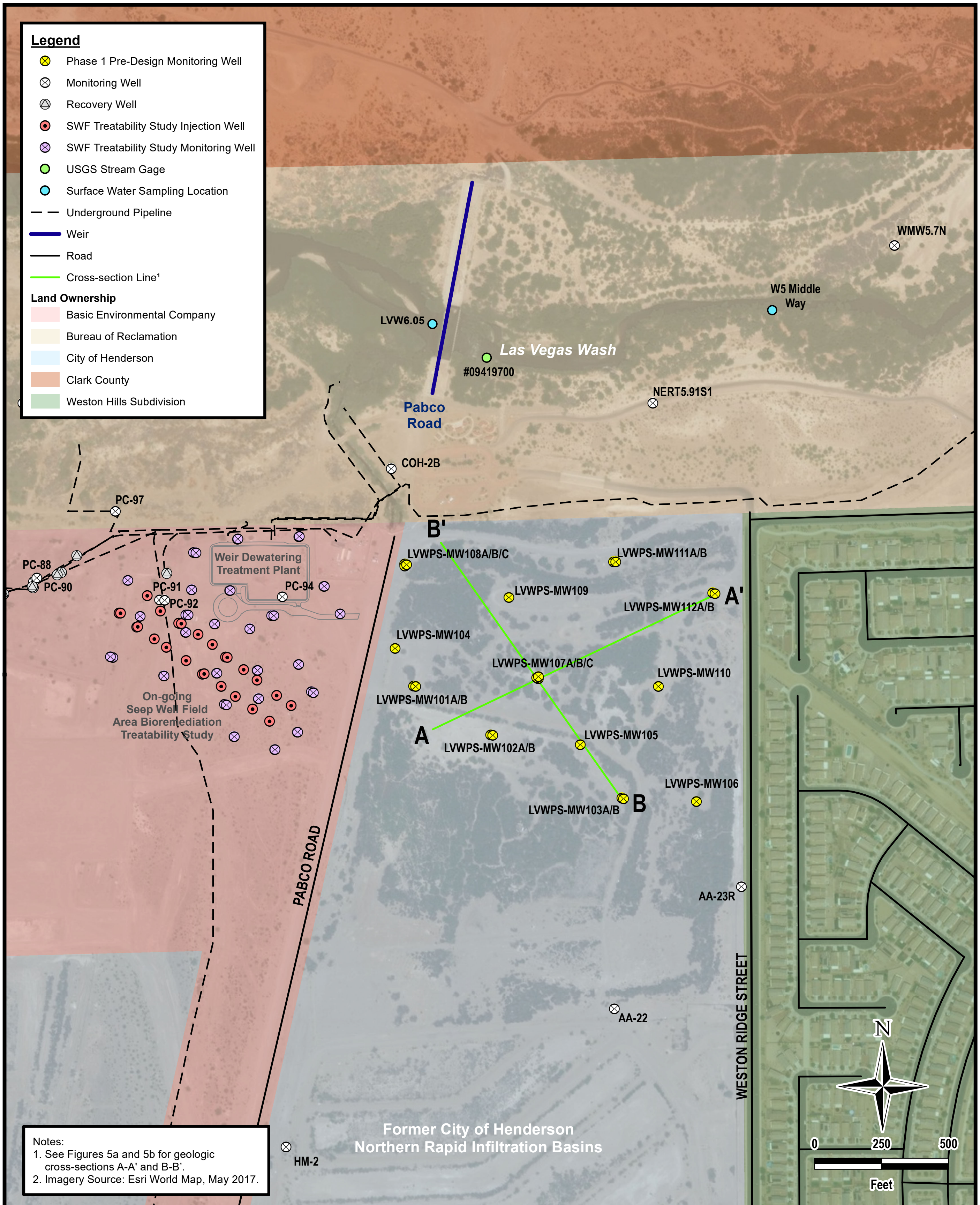

150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


**NEVADA ENVIRONMENTAL RESPONSE TRUST**

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PILOT STUDY LOCATIONS**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | FEBRUARY 7, 2019 |
| DESIGNED BY: | WG |
| Figure No. | 1 |




Notes:
1. See Figures 5a and 5b for geologic cross-sections A-A' and B-B'.
2. Imagery Source: Esri World Map, May 2017.

M:\GIS\NERT\M19\Work Plan Addendum\Figure 2\Figure2_0612.mxd

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

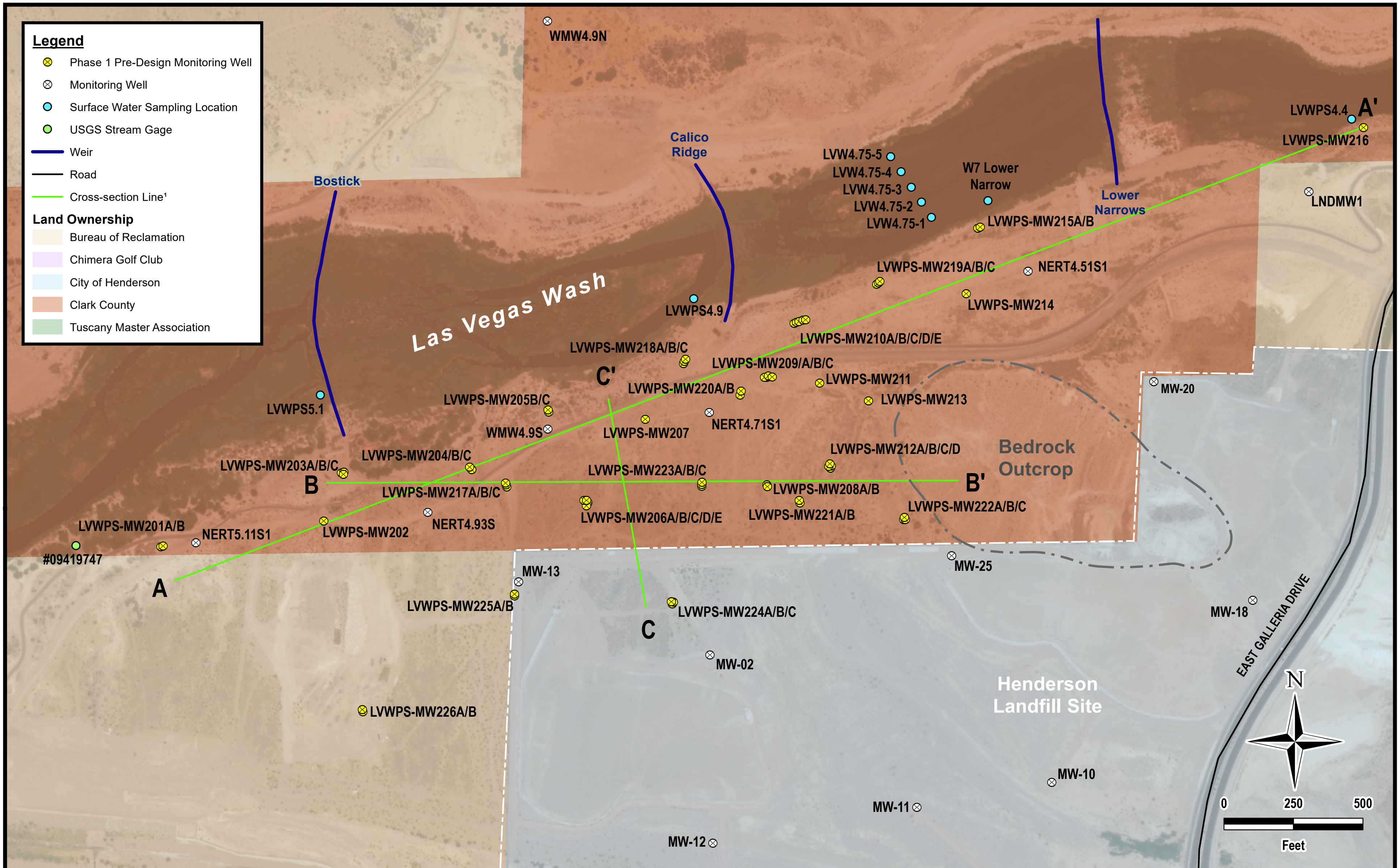
NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PRE-DESIGN ACTIVITIES**
**TRANSECT 1A STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | JUNE 12, 2019 |
| DESIGNED BY: | WG |

Figure No.
2




Notes:
1. See Figures 9a, 9b, and 9c for geologic cross-sections A-A', B-B', and C-C'.
2. Imagery Source: Esri World Map, May 2017.

M:\GIS\NERT\M19\Work Plan Addendum\Figure 3\Figure3_0612.mxd

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

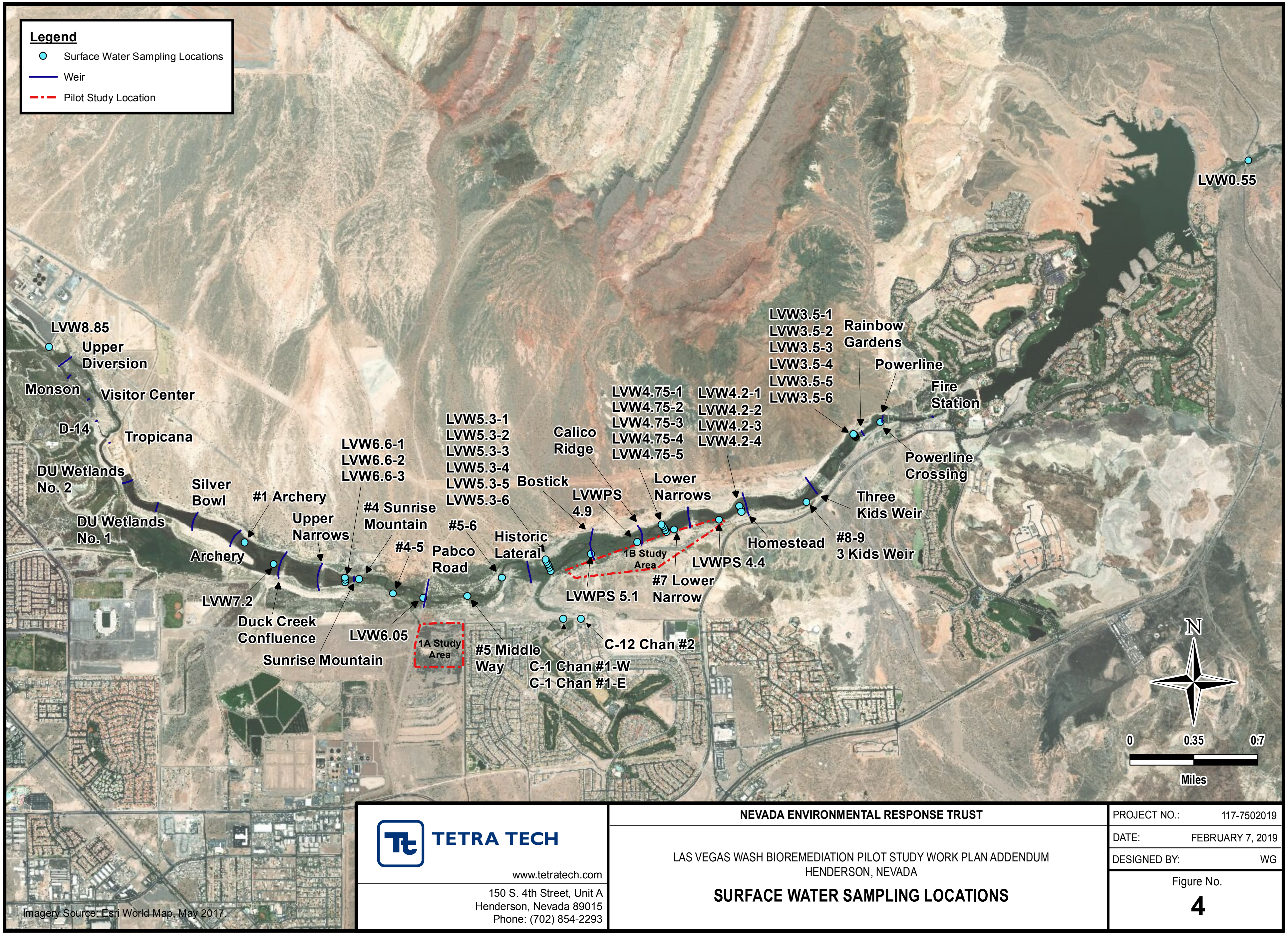
**NEVADA ENVIRONMENTAL RESPONSE TRUST**

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PRE-DESIGN ACTIVITIES**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | JUNE 12, 2019 |
| DESIGNED BY: | WG |

Figure No.
**3**




M:\GIS\NERT\M19\Work Plan Addendum\Figure4.mxd

TETRA TECH
www.tetratech.com

150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

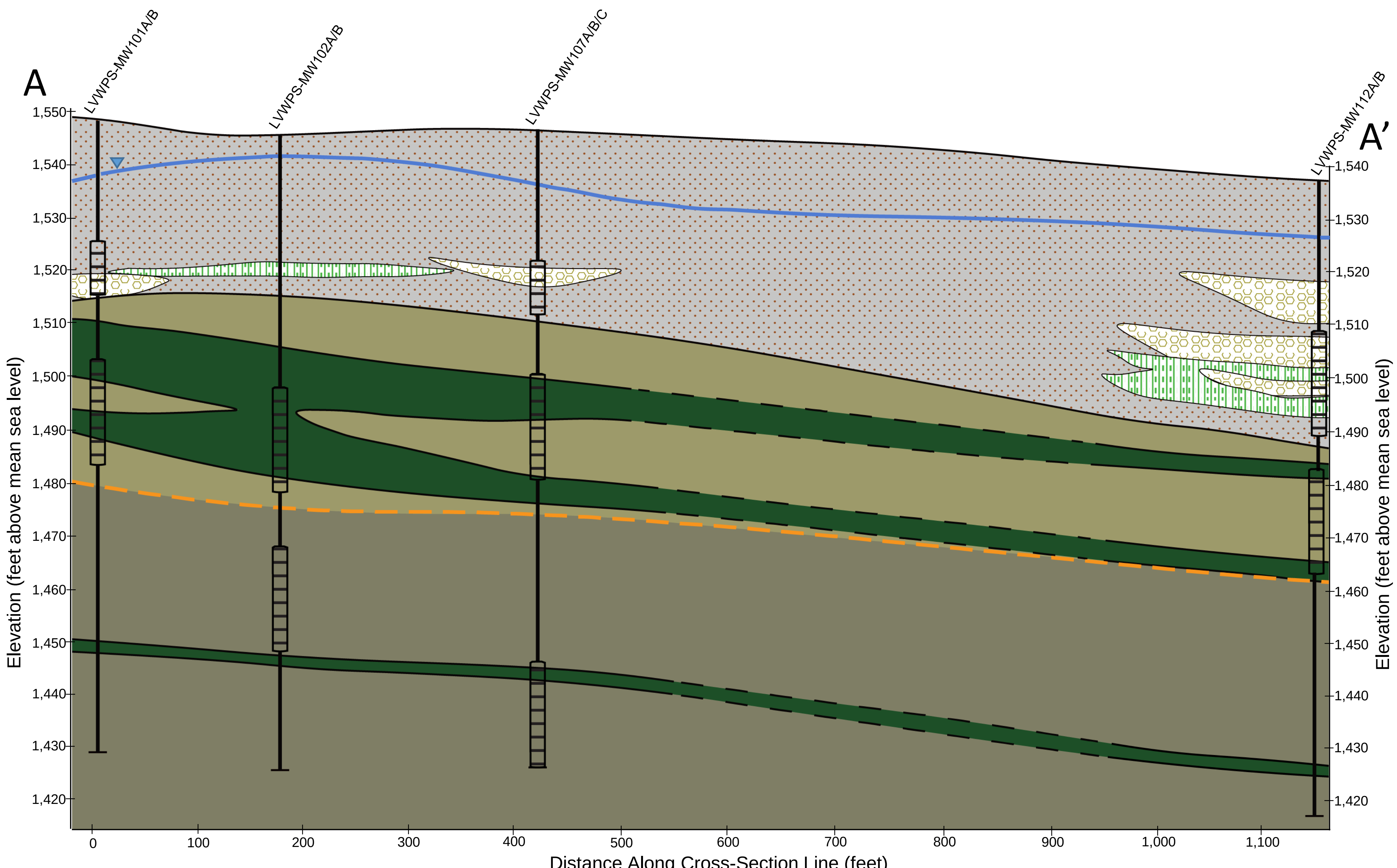
NEVADA ENVIRONMENTAL RESPONSE TRUST

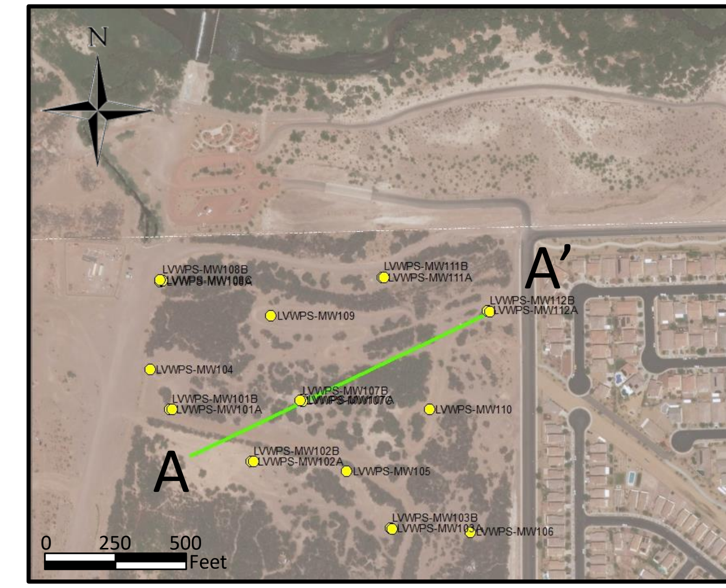
LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

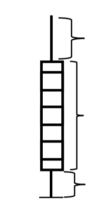
**SURFACE WATER SAMPLING LOCATIONS**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | FEBRUARY 7, 2019 |
| DESIGNED BY: | WG |

Figure No.
**4**




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section A-A' from a maximum distance of 170 feet.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

\\ttes134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx

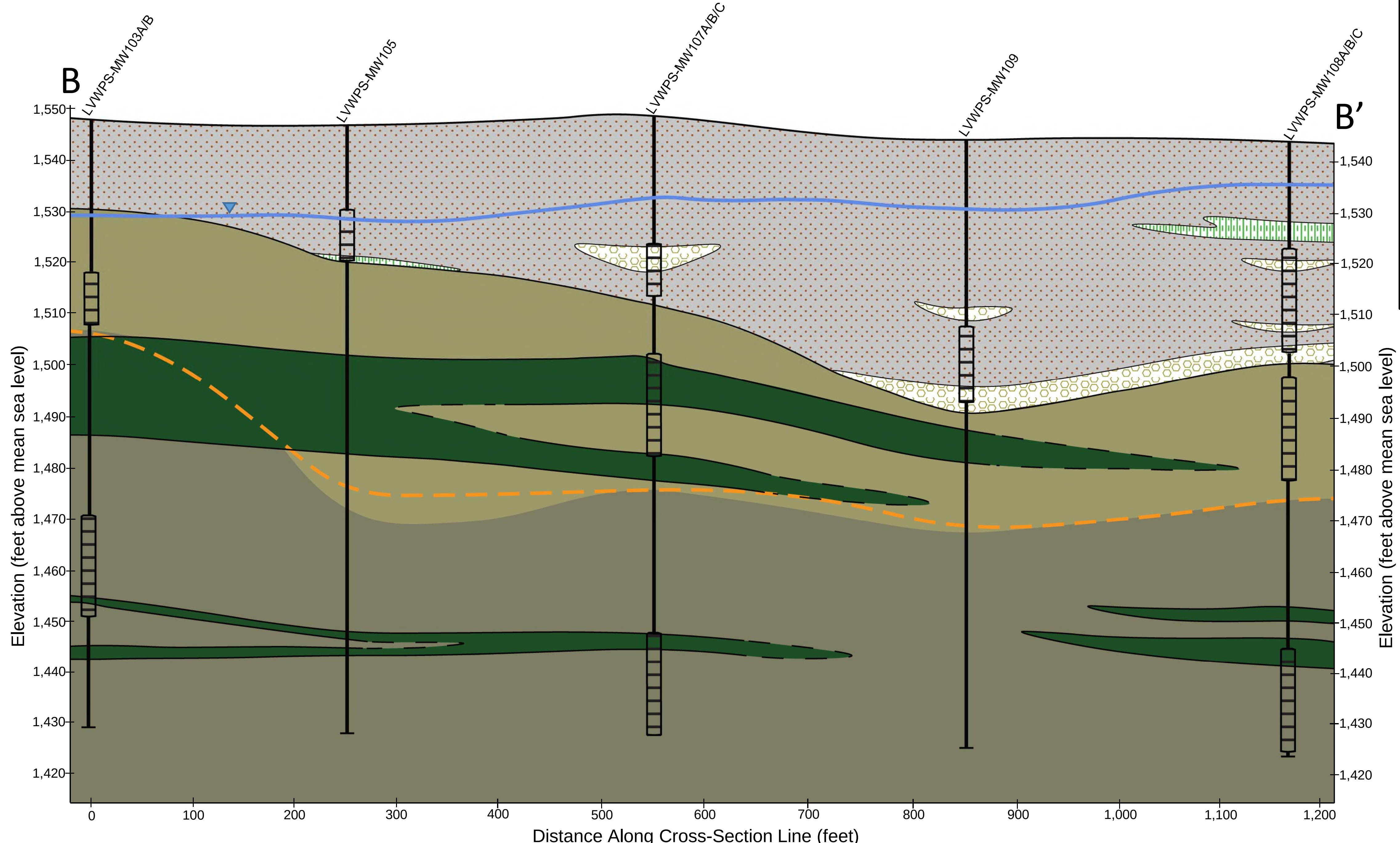

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

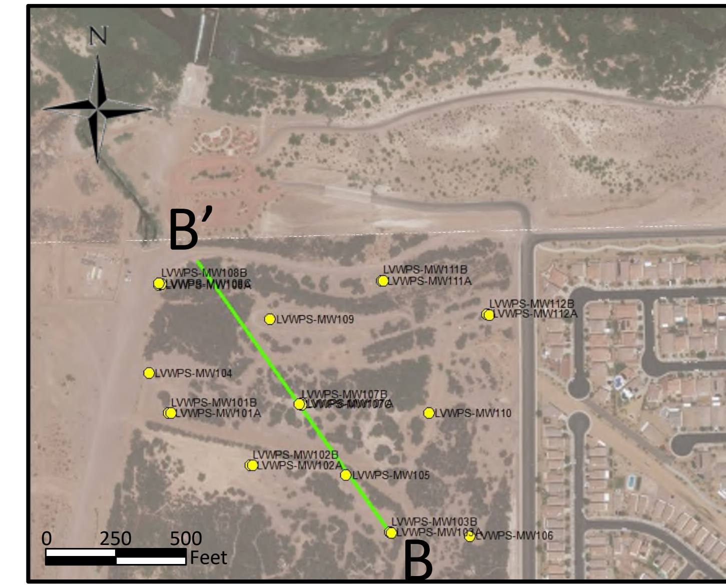

NEVADA ENVIRONMENTAL RESPONSE TRUST

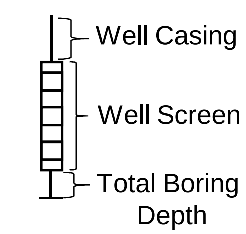
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**CROSS-SECTION A-A'**
**TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 5a |




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section B-B' from a maximum distance of 155 feet.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

\\tts134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx

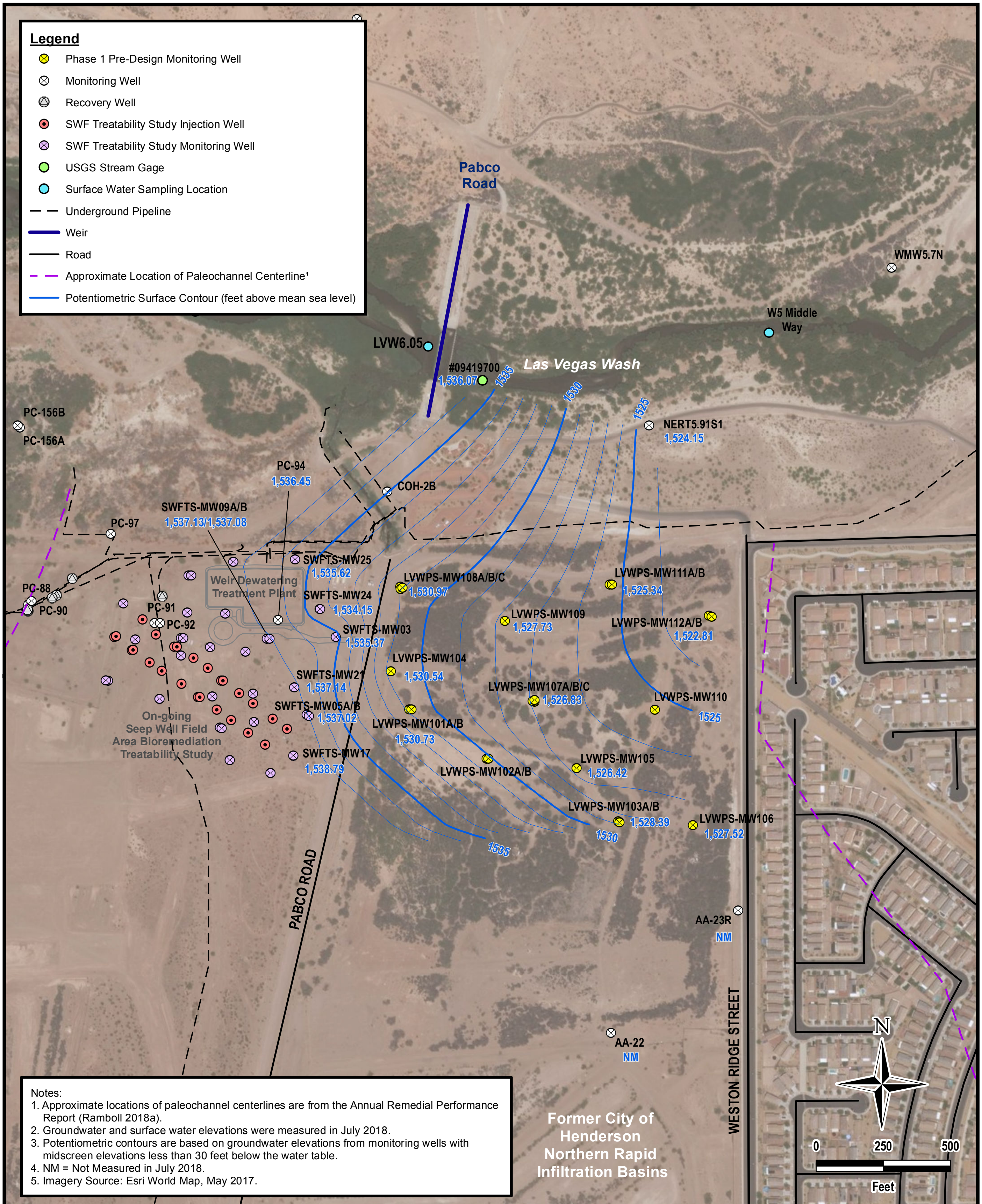
TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**CROSS-SECTION B-B'**
**TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | AUGUST 8, 2019 |
| Designed By: | MRB |
| Figure No. | 5b |




Notes:
1. Approximate locations of paleochannel centerlines are from the Annual Remedial Performance Report (Ramboll 2018a).
2. Groundwater and surface water elevations were measured in July 2018.
3. Potentiometric contours are based on groundwater elevations from monitoring wells with midscreen elevations less than 30 feet below the water table.
4. NM = Not Measured in July 2018.
5. Imagery Source: Esri World Map, May 2017.

M:\GIS\NERT\M19\Work Plan Addendum\Figure6.mxd

TETRA TECH

www.tetratech.com

150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

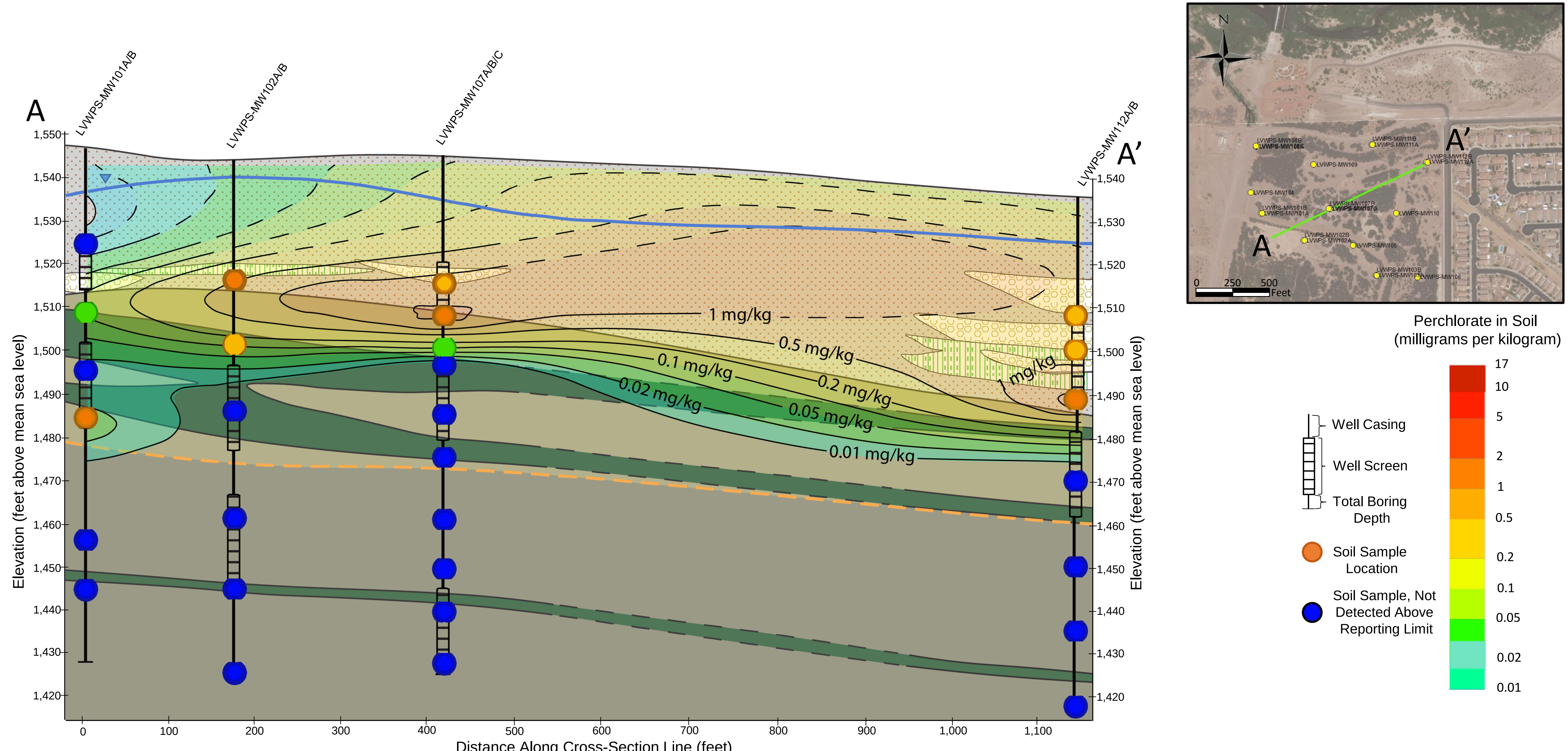
NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**GROUNDWATER POTENTIOMETRIC SURFACE MAP**
**TRANSECT 1A STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | FEBRUARY 11, 2019 |
| DESIGNED BY: | WG |

Figure No.
**6**




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section A-A' from a maximum distance of 170 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

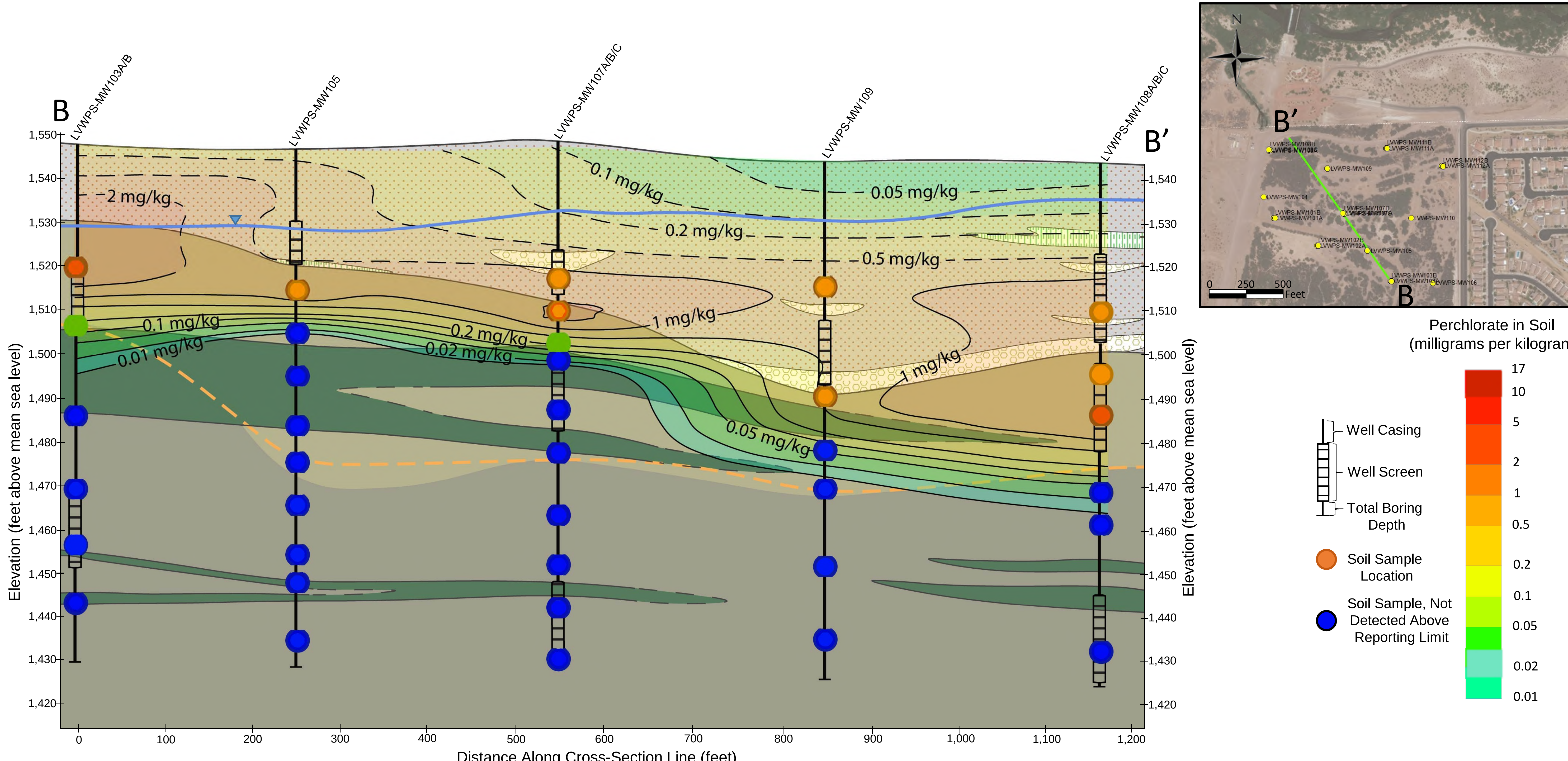
TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN SOIL ALONG CROSS-SECTION A-A' – TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 7a |




## Legend

| | | |
|---|---|---|
| Alluvium – Sand | Alluvium – Sandy Silt and Silty Sand (>30% Silt) | Upper Muddy Creek Formation – Silt and Sandy Silt with Clay |
| Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel) | Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay | Upper Muddy Creek Formation – Organic – Rich Silt and Clay |

----- Inferred Contact

Water Table

Depth to First Gypsum Encounter

Notes:
1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section B-B’ from a maximum distance of 155 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

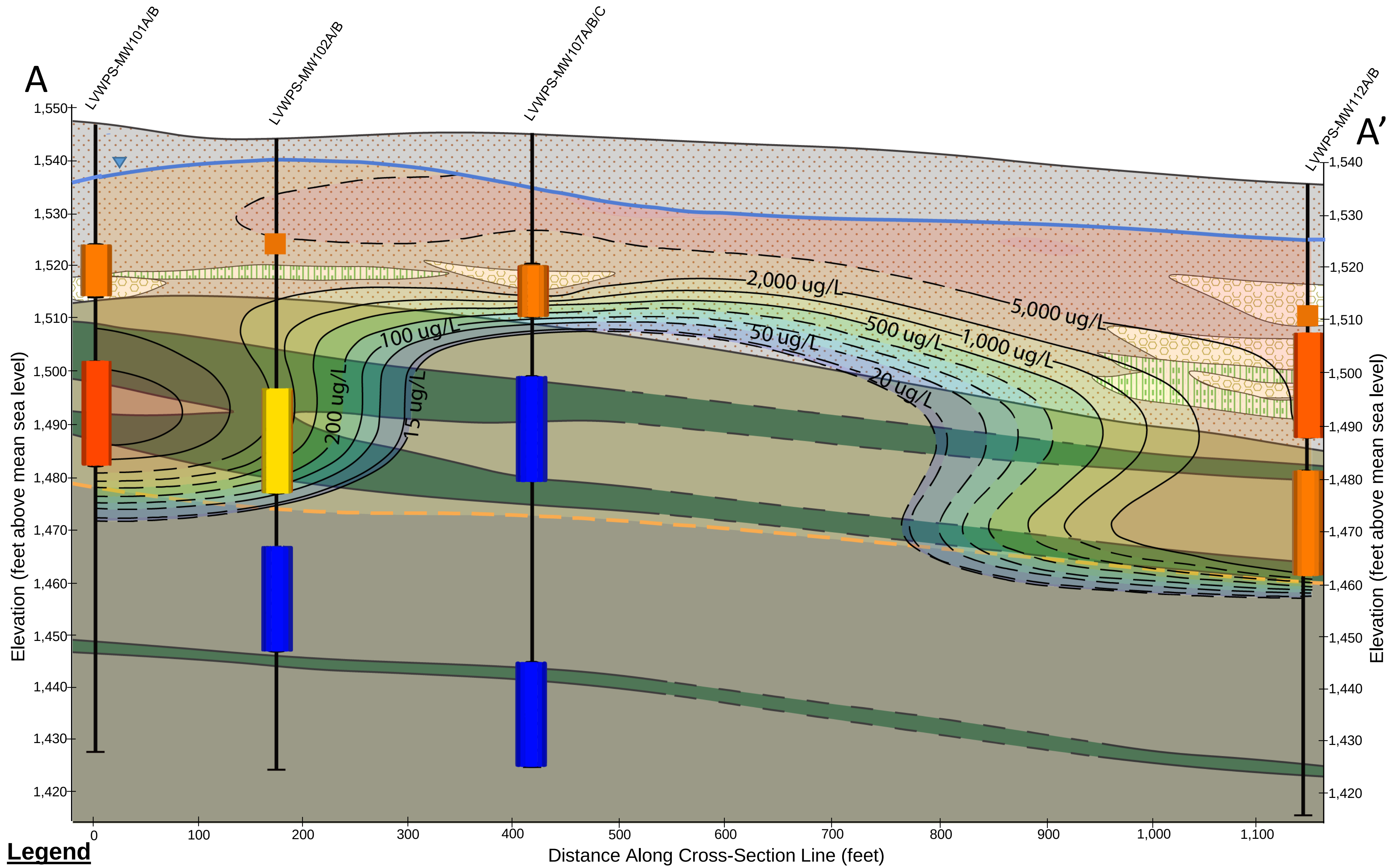

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

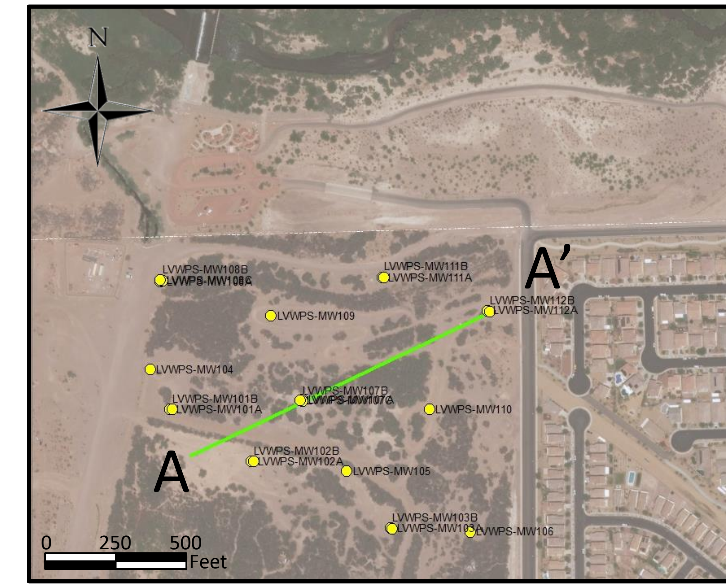

NEVADA ENVIRONMENTAL RESPONSE TRUST

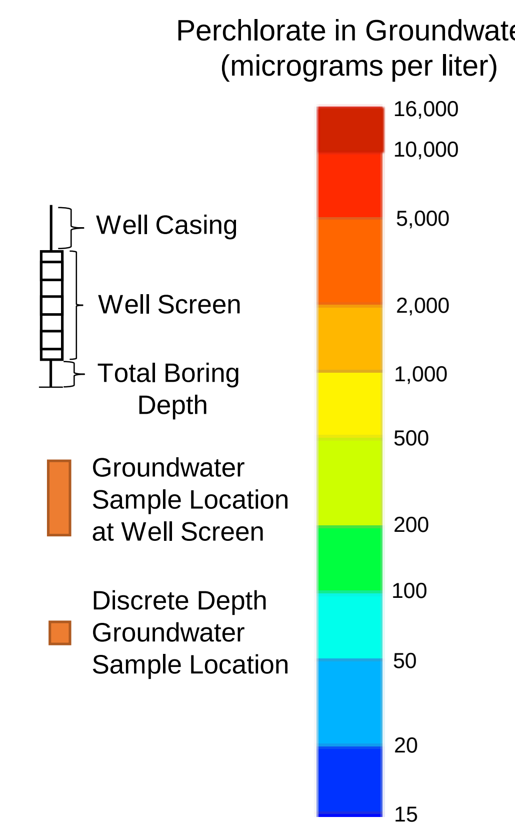
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN SOIL ALONG CROSS-SECTION B-B’ – TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | AUGUST 8, 2019 |
| Designed By: | MRB |
| Figure No. | **7b** |




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- ----- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:

1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section A-A' from a maximum distance of 170 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. For visual clarity, groundwater samples with perchlorate concentrations less than the sample detection limit are represented with dark blue screens even when the detection limit was elevated because of an initial sample dilution.
6. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

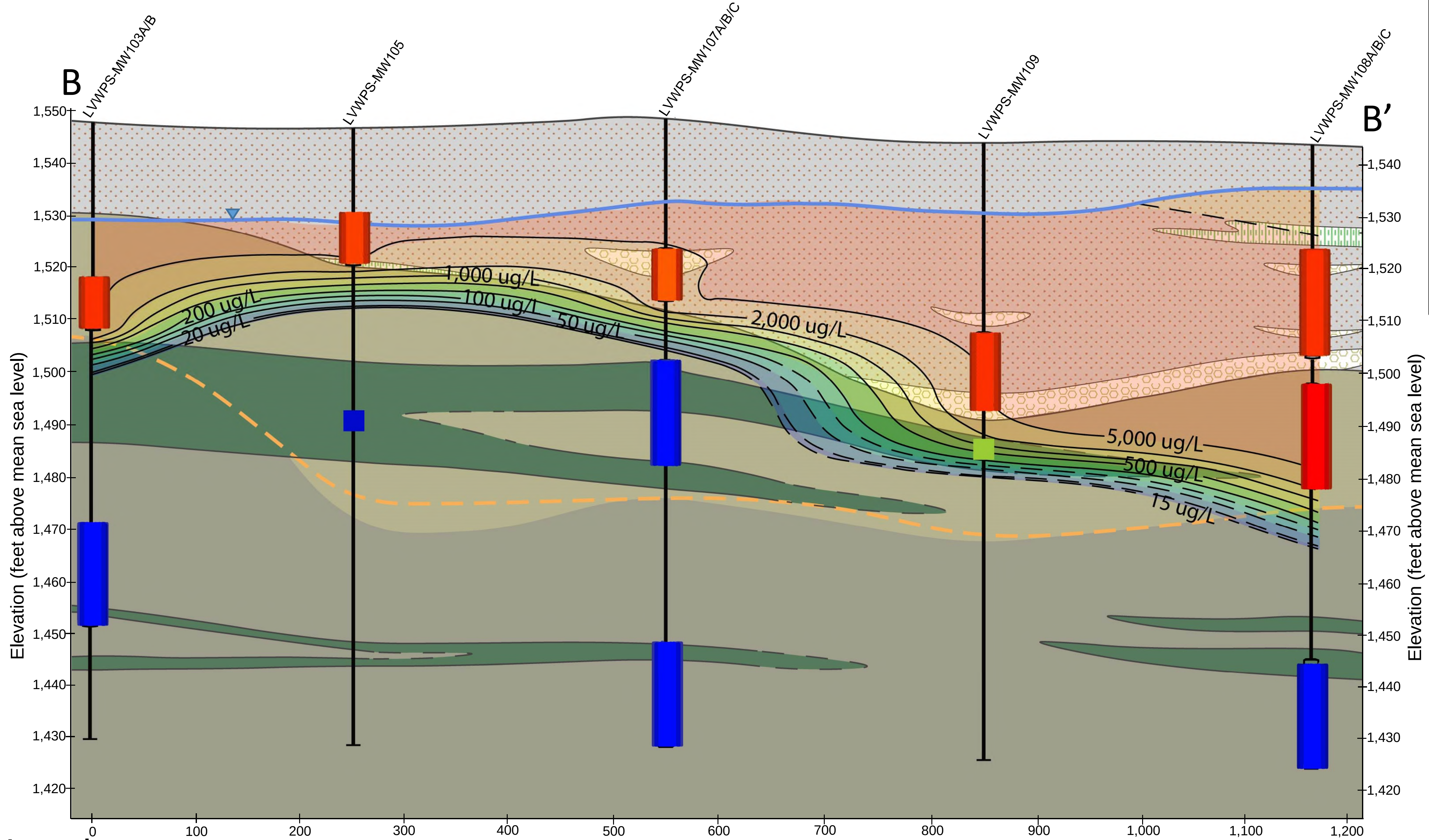
NEVADA ENVIRONMENTAL RESPONSE TRUST

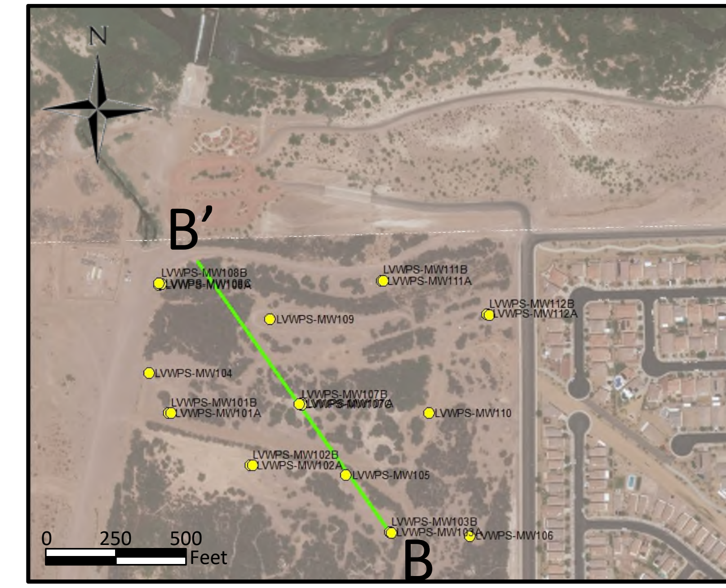
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

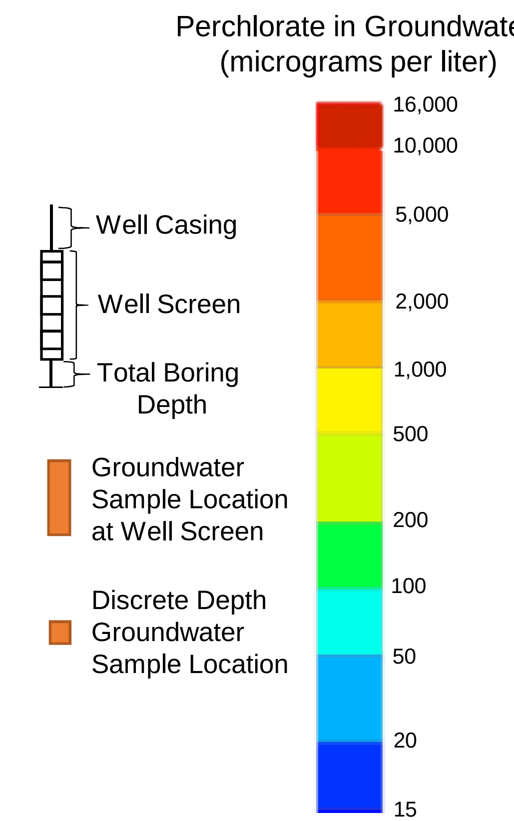
**PERCHLORATE CONCENTRATIONS IN GROUNDWATER ALONG CROSS-SECTION A-A' – TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 8a |

\\tts134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on July 9, 2018.
2. Wells are projected onto section B-B’ from a maximum distance of 155 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. For visual clarity, groundwater samples with perchlorate concentrations less than the sample detection limit are represented with dark blue screens even when the detection limit was elevated because of an initial sample dilution.
6. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

\\tts134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx

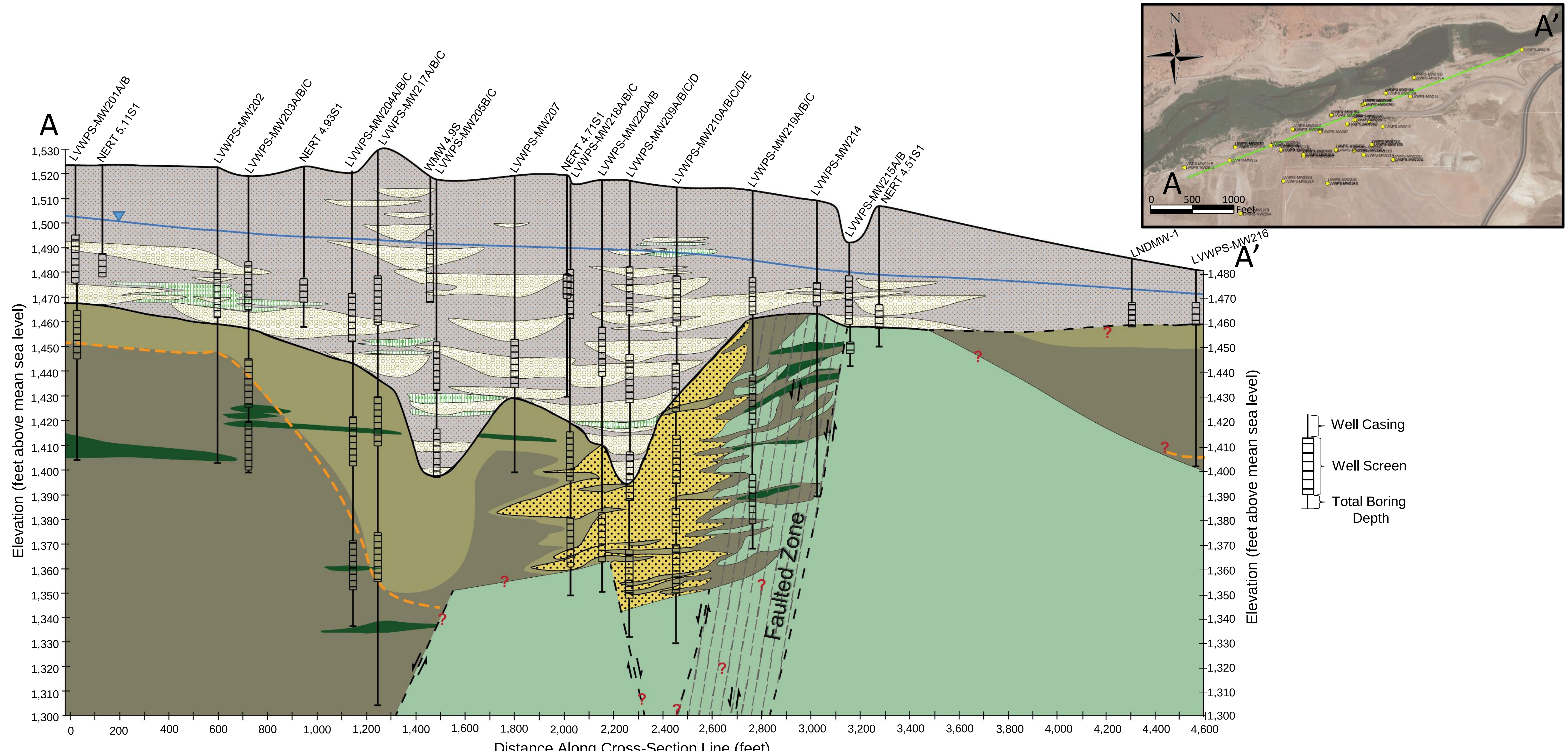

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN GROUNDWATER ALONG CROSS-SECTION B-B’ – TRANSECT 1A STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | AUGUST 8, 2019 |
| Designed By: | MRB |
| Figure No. | 8b |




## Legend

| | |
|---|---|
| Alluvium – Sand | Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel) |
| Alluvium – Sandy Silt and Silty Sand (>30% Silt) | Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation |
| Upper Muddy Creek Formation – Silt and Sandy Silt with Clay | Upper Muddy Creek Formation – Organic – Rich Silt and Clay |
| Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay | Bedrock – Horse Springs Formation |
| Fault | --?-- Inferred Contact |
| Depth to First Gypsum Encounter | Water Table |

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section A-A’ from a maximum distance of 160 feet.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

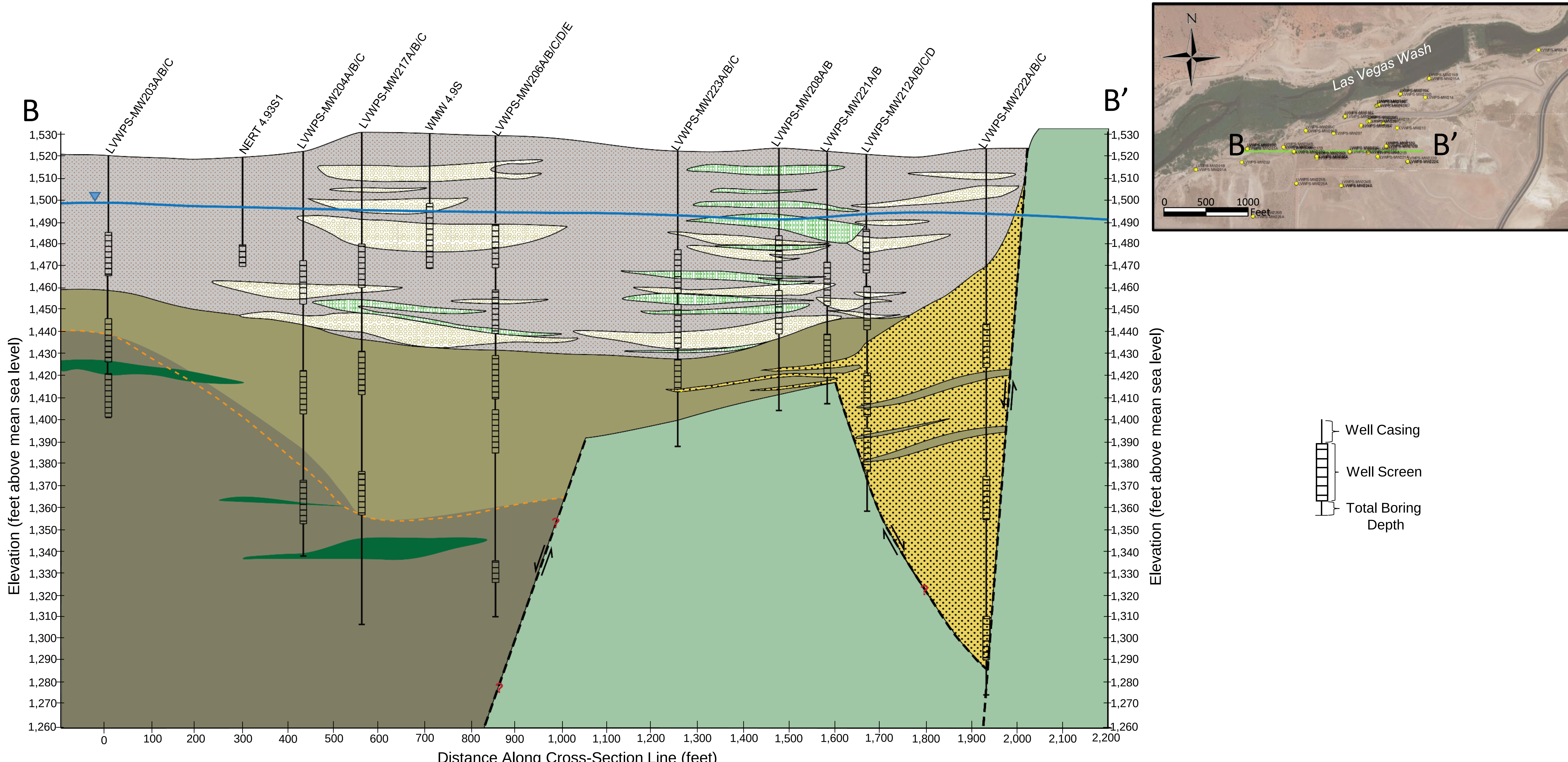

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**CROSS-SECTION A-A’**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 9a |




## Legend

| | | | |
|---|---|---|---|
| Alluvium – Sand | Alluvium – Sandy Silt and Silty Sand (>30% Silt) | Upper Muddy Creek Formation – Silt and Sandy Silt with Clay | Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay |
| Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel) | Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation | Upper Muddy Creek Formation – Organic – Rich Silt and Clay | Bedrock – Horse Springs Formation |

Fault

Depth to First Gypsum Encounter

--?-- Inferred Contact

Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section B-B’ from a maximum distance of 190 feet.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

\\tts134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

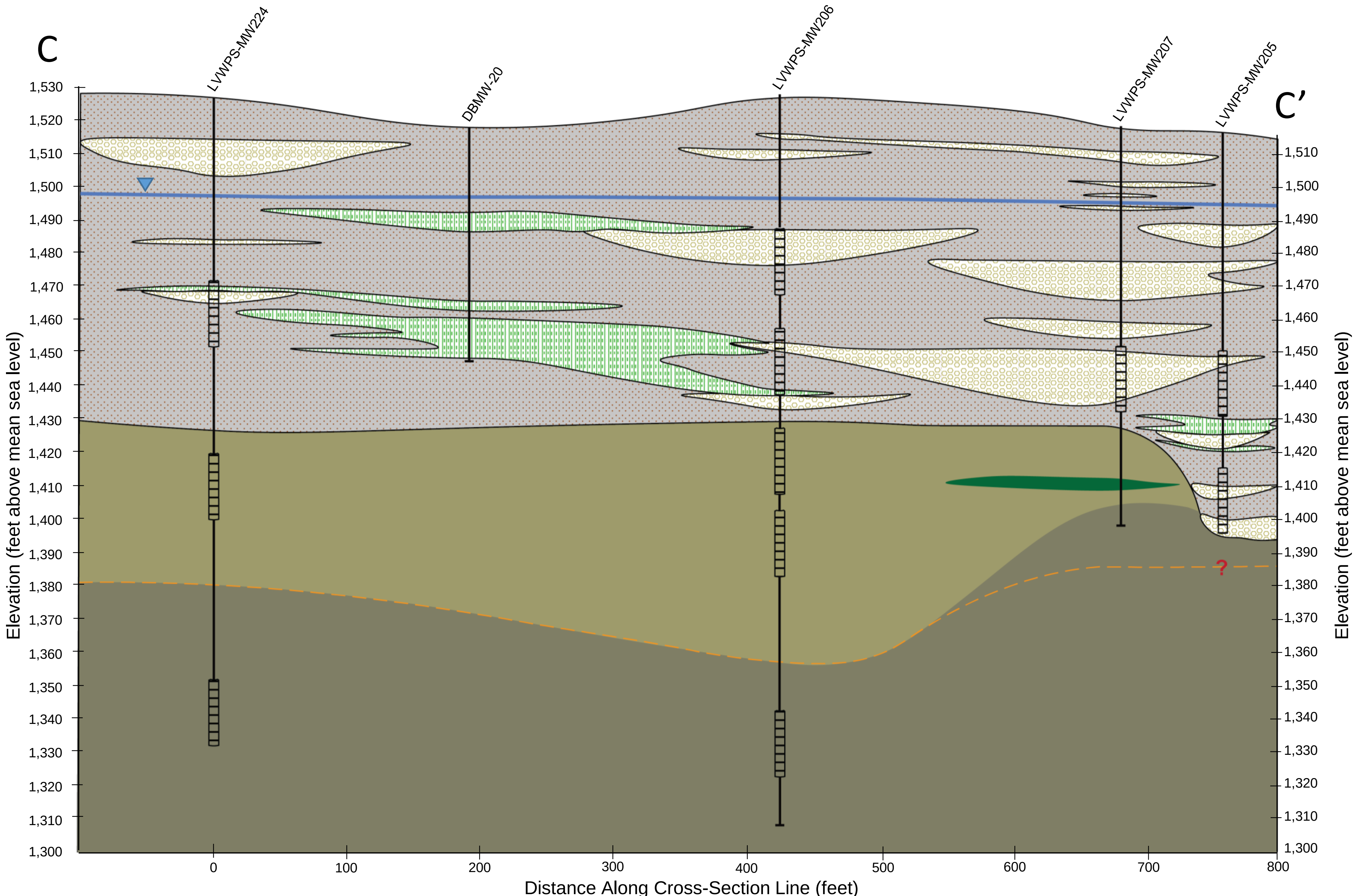
NEVADA ENVIRONMENTAL RESPONSE TRUST

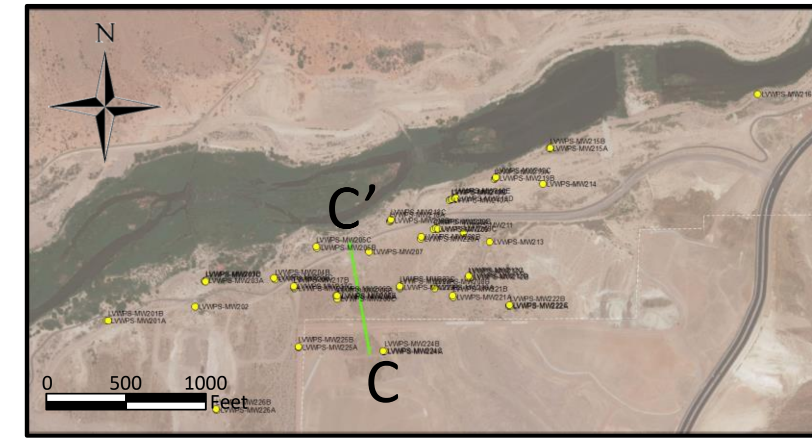
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

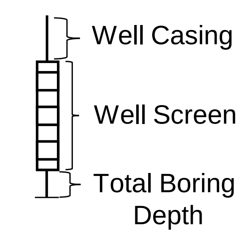
**CROSS-SECTION B-B’**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |

Figure No.
**9b**




## Legend

- Alluvium – Sand
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Fault
- Depth to First Gypsum Encounter
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Bedrock – Horse Springs Formation
- --?-- Inferred Contact
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section C-C' from a maximum distance of 220 feet.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.


TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

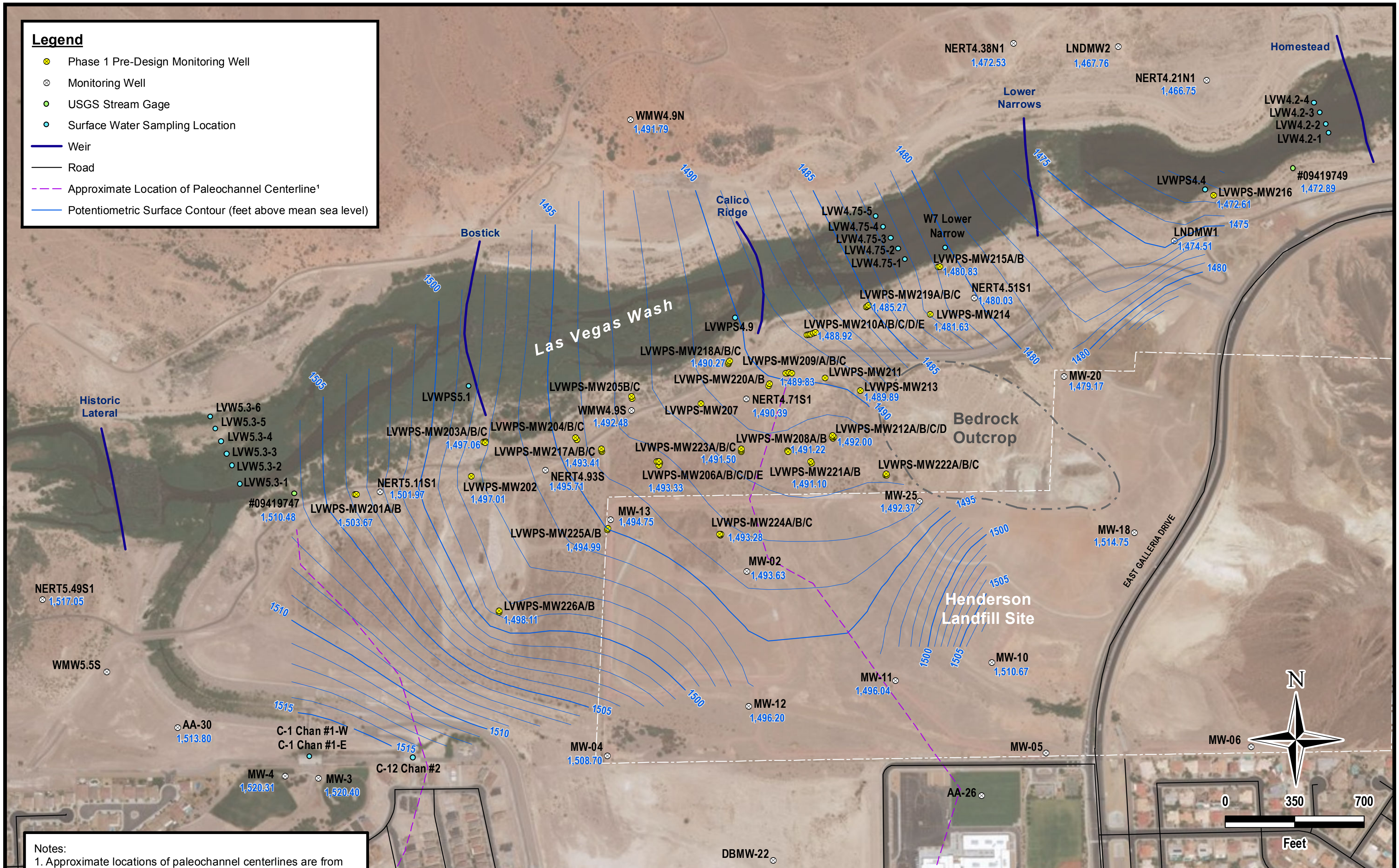

NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**CROSS-SECTION C-C'**
**TRANSECT 1B STUDY A REA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 9c |

\\tts134fs1\GEOSUPVOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx




Notes:
1. Approximate locations of paleochannel centerlines are from the Annual Remedial Performance Report (Ramboll 2018a). The easternmost paleochannel shown was revised based on lithology encountered during pre-design drilling.
2. Groundwater and surface water elevations were measured in November 2018.
3. Potentiometric contours are based on groundwater elevations from monitoring wells with midscreen elevations less than 30 feet below the water table.
4. Imagery Source: Esri World Map, May 2017.

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

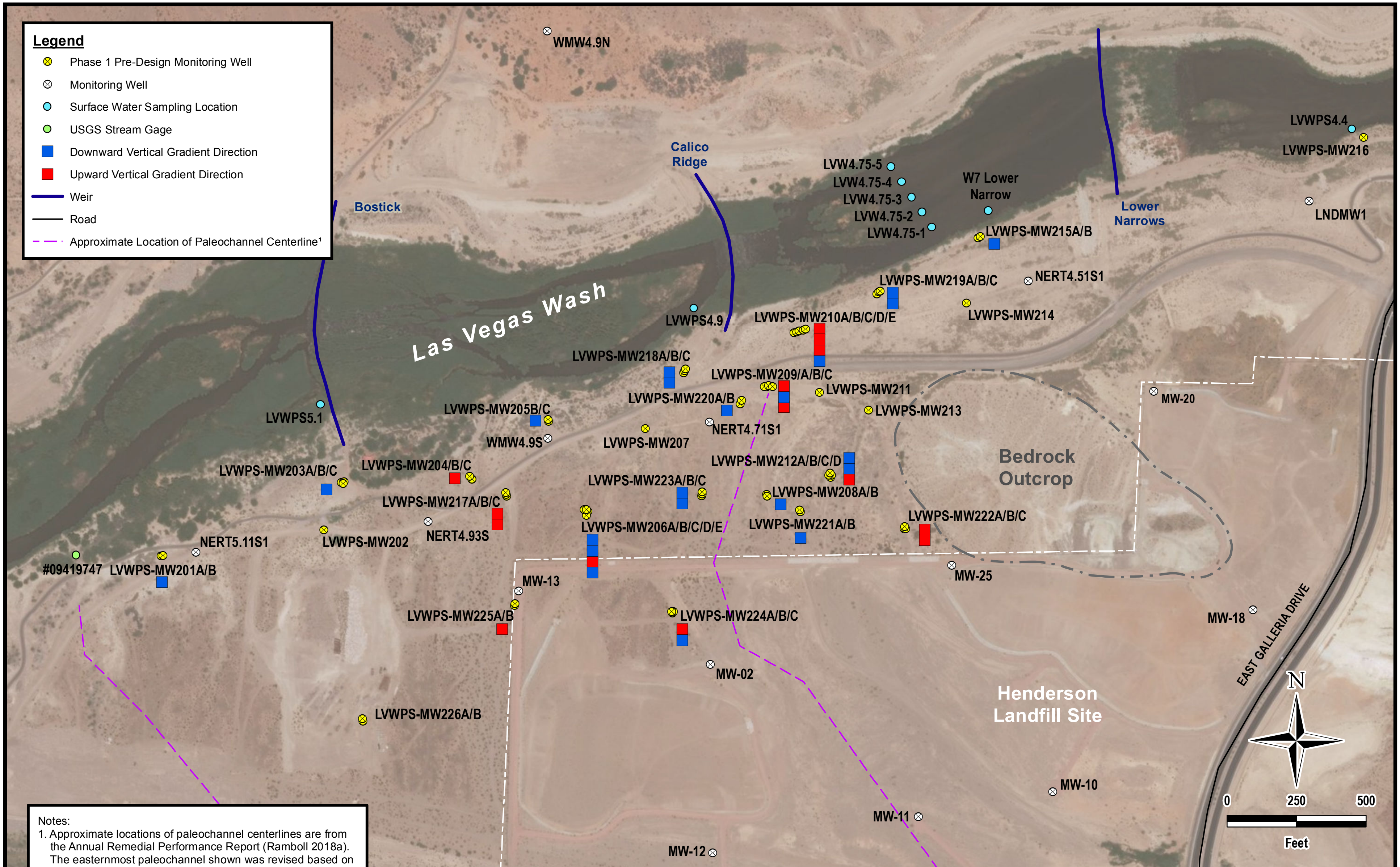
NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**GROUNDWATER POTENTIOMETRIC SURFACE MAP**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | FEBRUARY 13, 2019 |
| DESIGNED BY: | WG |
| Figure No. | 10 |

M:\GIS\NERT\M19\Work Plan Addendum\Figure10.mxd




Notes:
1. Approximate locations of paleochannel centerlines are from the Annual Remedial Performance Report (Ramboll 2018a). The easternmost paleochannel shown was revised based on lithology encountered during pre-design drilling.
2. Vertical gradients calculated using groundwater elevations measured in November 2018.
3. Vertical gradient symbols for clustered wells are stacked to represent the changes in vertical gradient with depth.
4. Vertical gradient for well pair LVWPS-MW226A/B not calculated due to slow ongoing recovery of LVWPS-MW226B following well development.
5. Imagery Source: Esri World Map, May 2017.

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

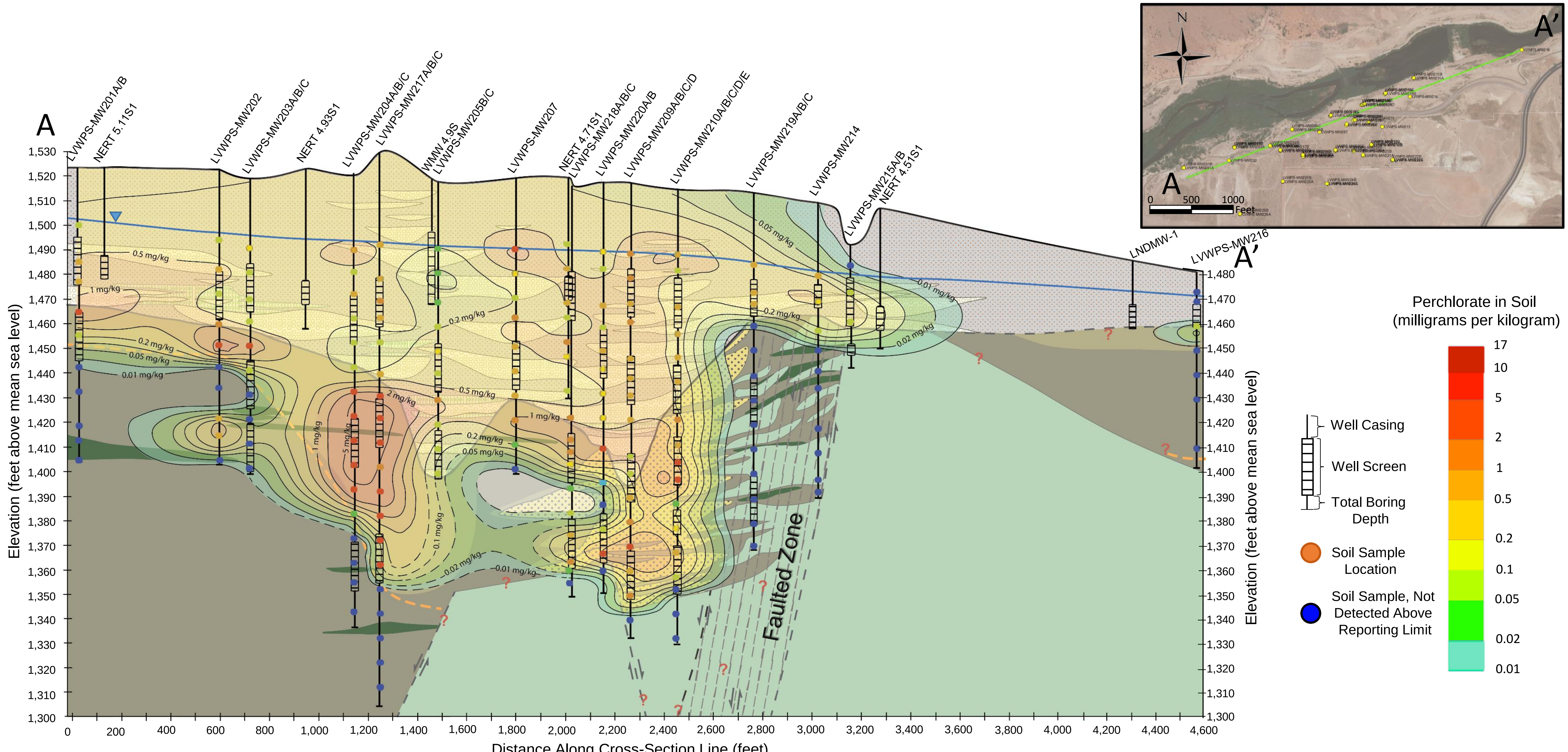
NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**VERTICAL HYDRAULIC GRADIENTS**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | FEBRUARY 11, 2019 |
| DESIGNED BY: | WG |

Figure No.
**11**




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Bedrock – Horse Springs Formation
- Fault
- --?-- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section A-A’ from a maximum distance of 160 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.


TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

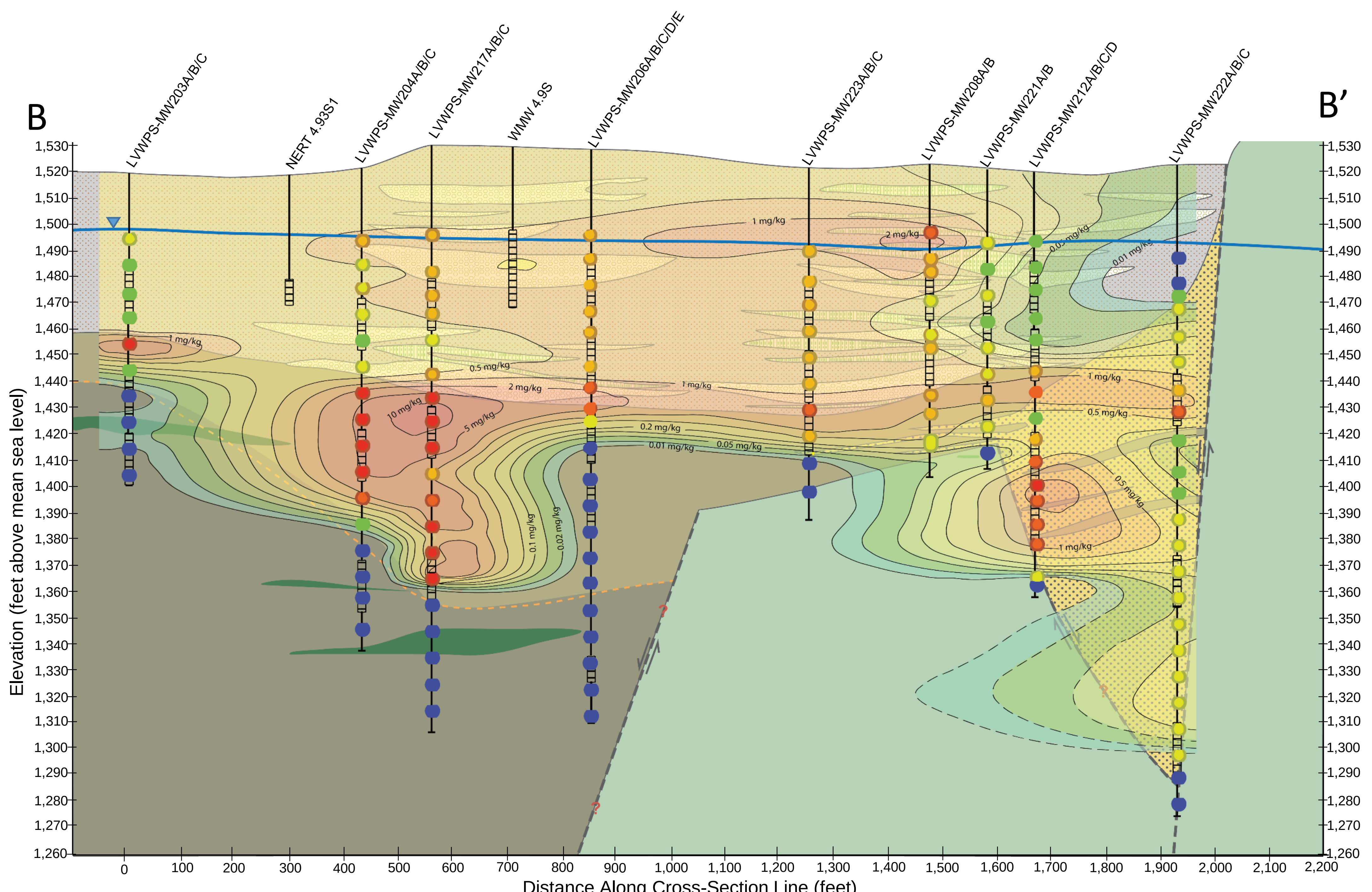

NEVADA ENVIRONMENTAL RESPONSE TRUST

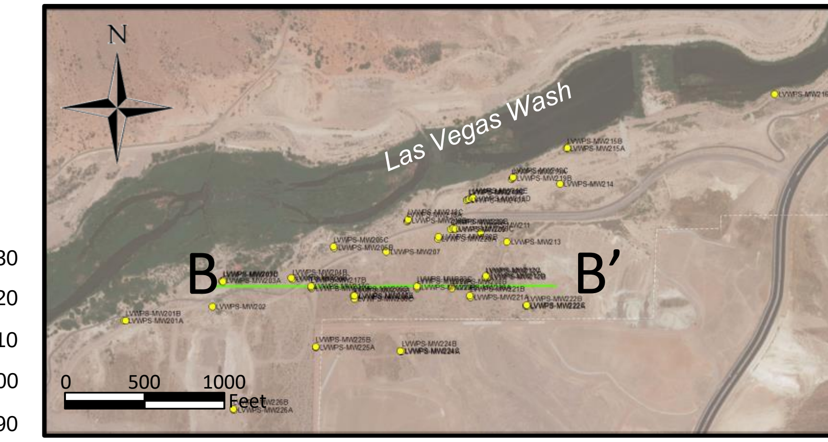
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

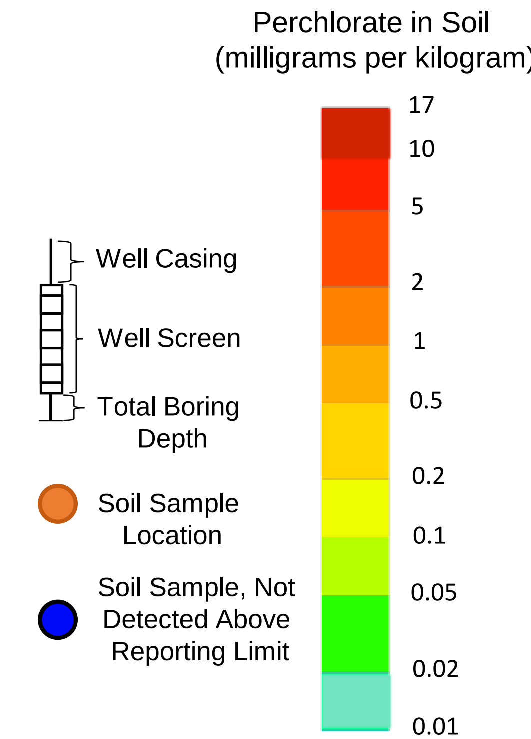
**PERCHLORATE CONCENTRATIONS IN SOIL ALONG CROSS-SECTION A-A’ – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | **12a** |

\\tts134fs1\GEOSUP\VOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Bedrock – Horse Springs Formation
- Fault
- --?-- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section B-B' from a maximum distance of 190 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

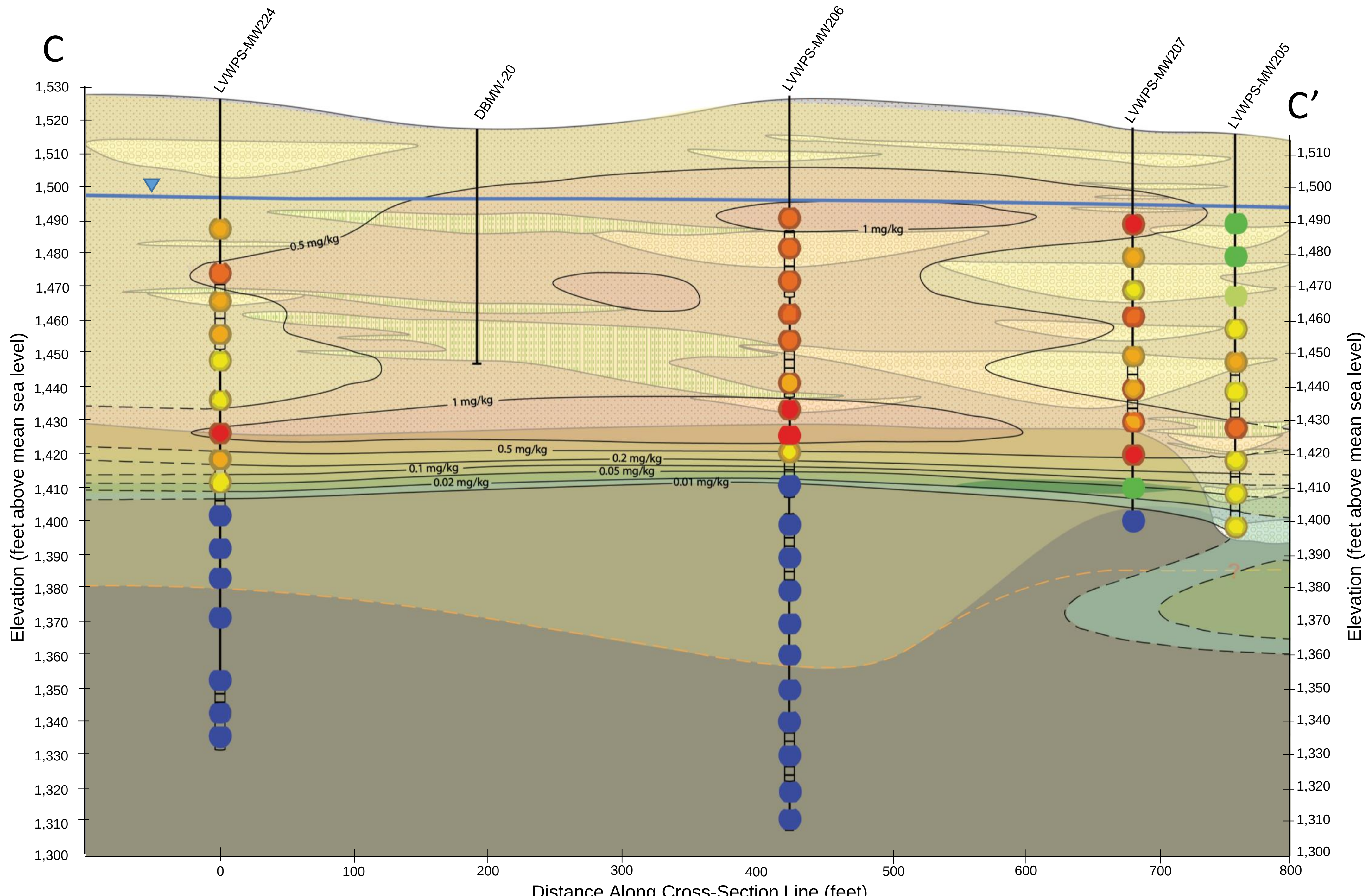

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

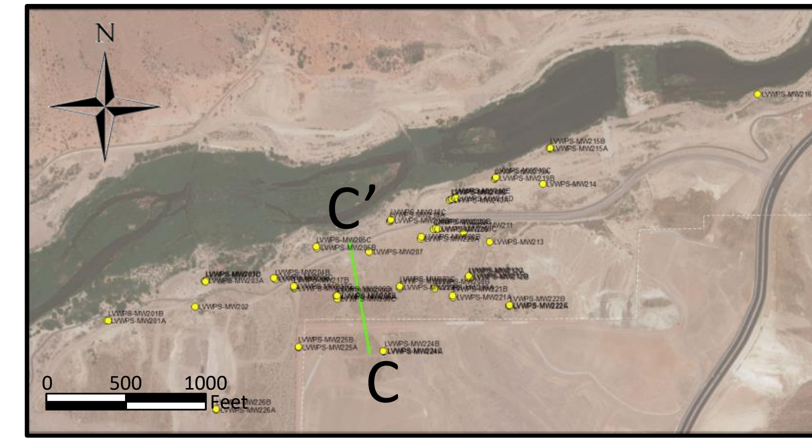

NEVADA ENVIRONMENTAL RESPONSE TRUST

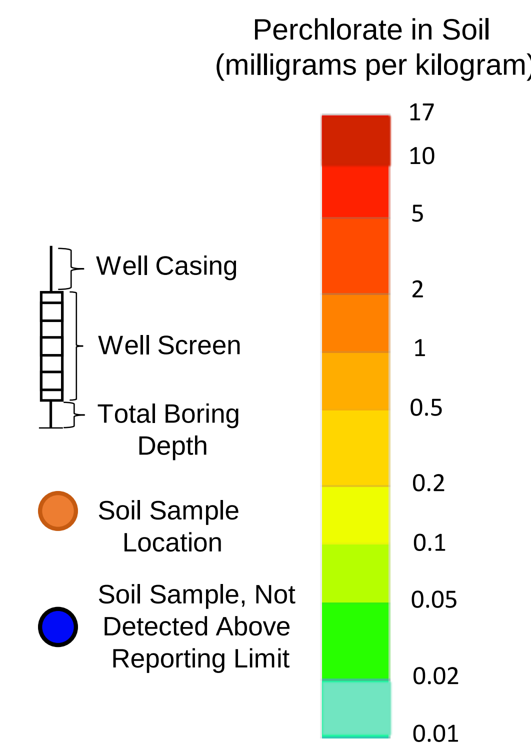
LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN SOIL ALONG CROSS-SECTION B-B' – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | **12b** |




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Bedrock – Horse Springs Formation
- Fault
- --?-- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section C-C’ from a maximum distance of 220 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.


TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

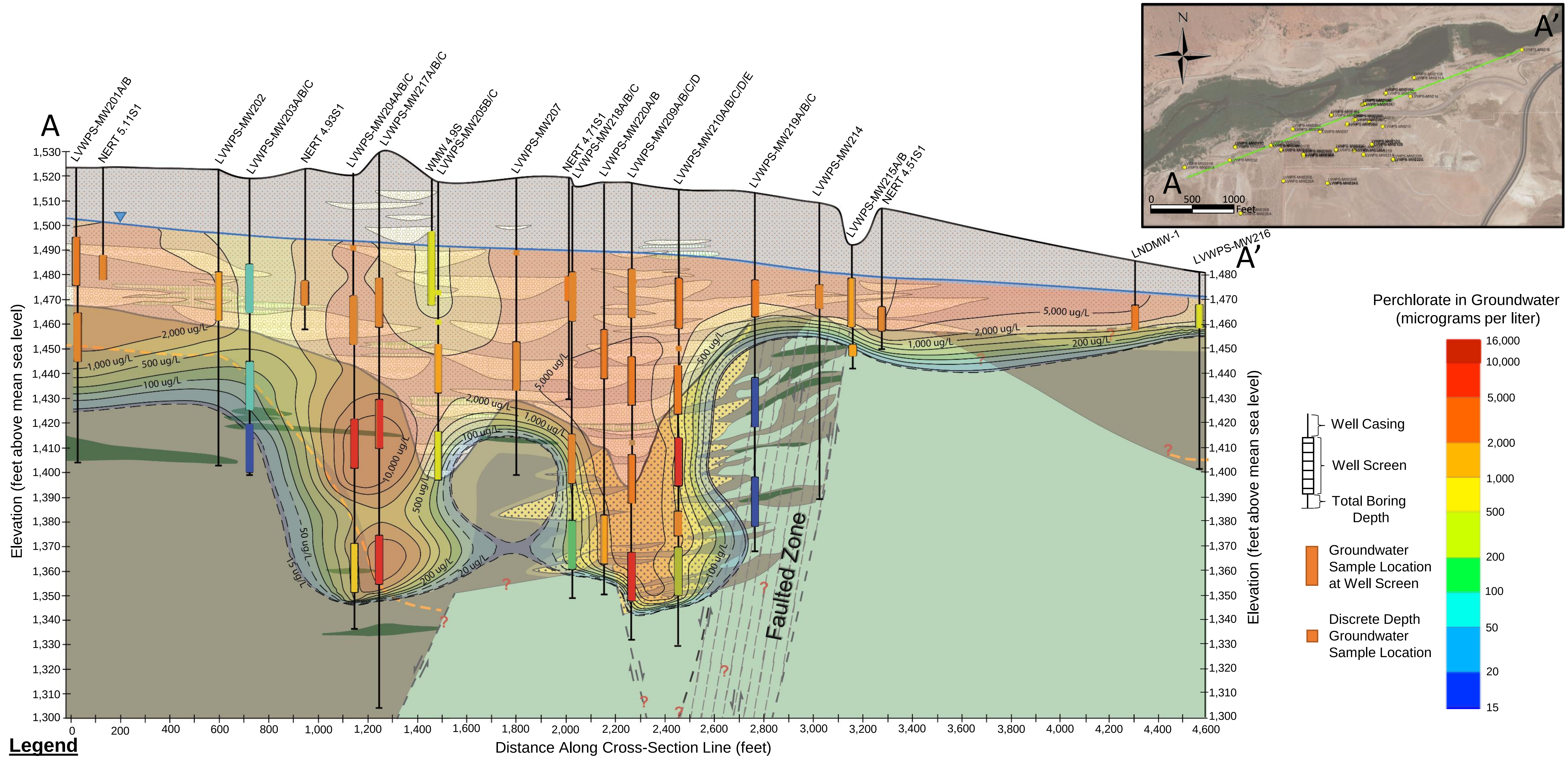

NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN SOIL ALONG CROSS-SECTION C-C’ – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 12c |

\\tts134fs1\GEOSUP\VOL1\Projects\Data\NERT\M19\Cross Section\Cross_Sect_Geo_Mod2.pptx




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Bedrock – Horse Springs Formation
- Fault
- --?-- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section A-A' from a maximum distance of 160 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. For visual clarity, groundwater samples with perchlorate concentrations less than the sample detection limit are represented with dark blue screens even when the detection limit was elevated because of an initial sample dilution.
6. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

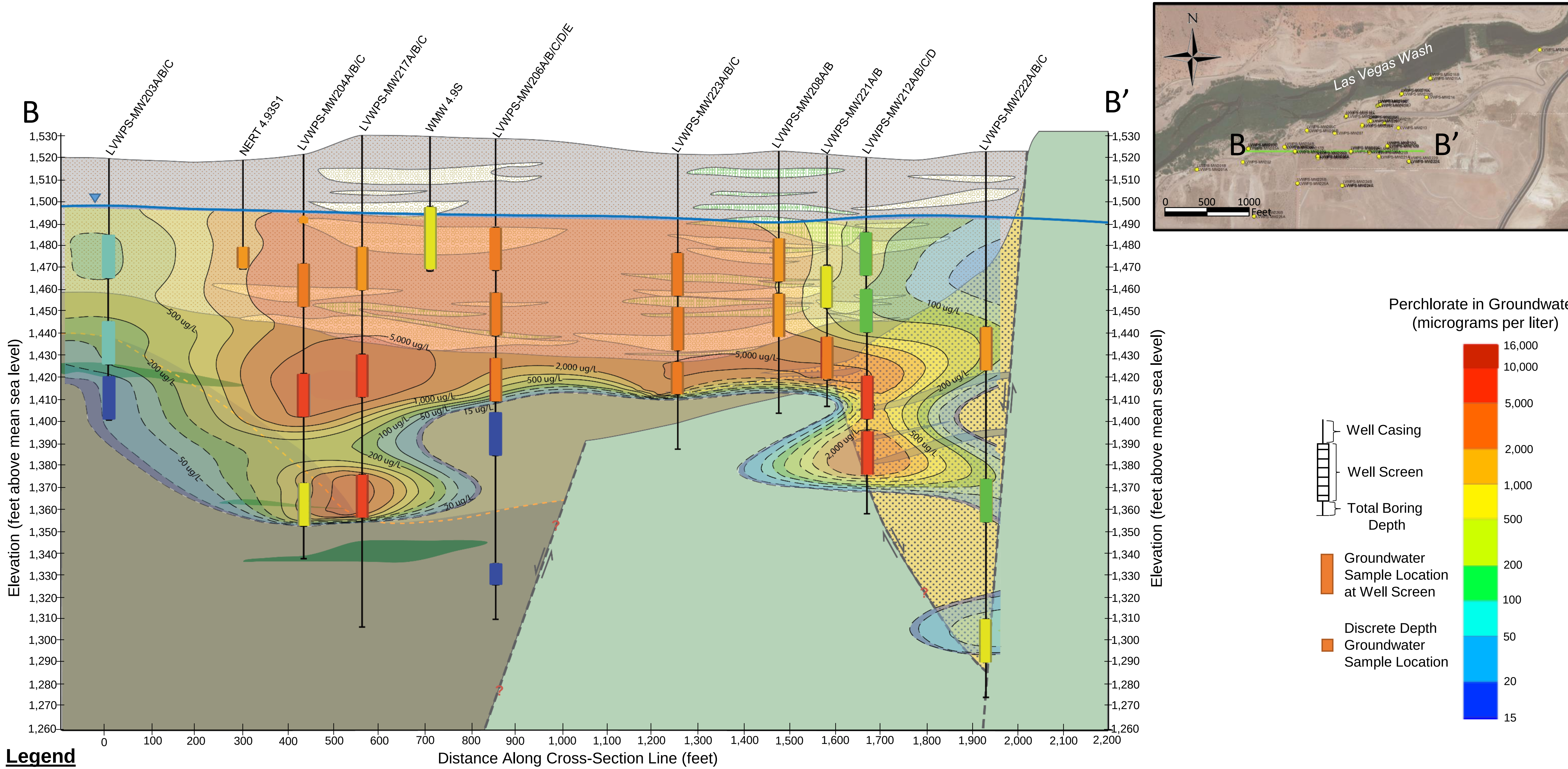

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN GROUNDWATER ALONG CROSS-SECTION A-A' – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 13a |




## Legend

- Alluvium – Sand
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Fault
- Depth to First Gypsum Encounter
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Bedrock – Horse Springs Formation
- --?-- Inferred Contact
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section B-B’ from a maximum distance of 190 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. For visual clarity, groundwater samples with perchlorate concentrations less than the sample detection limit are represented with dark blue screens even when the detection limit was elevated because of an initial sample dilution.
6. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

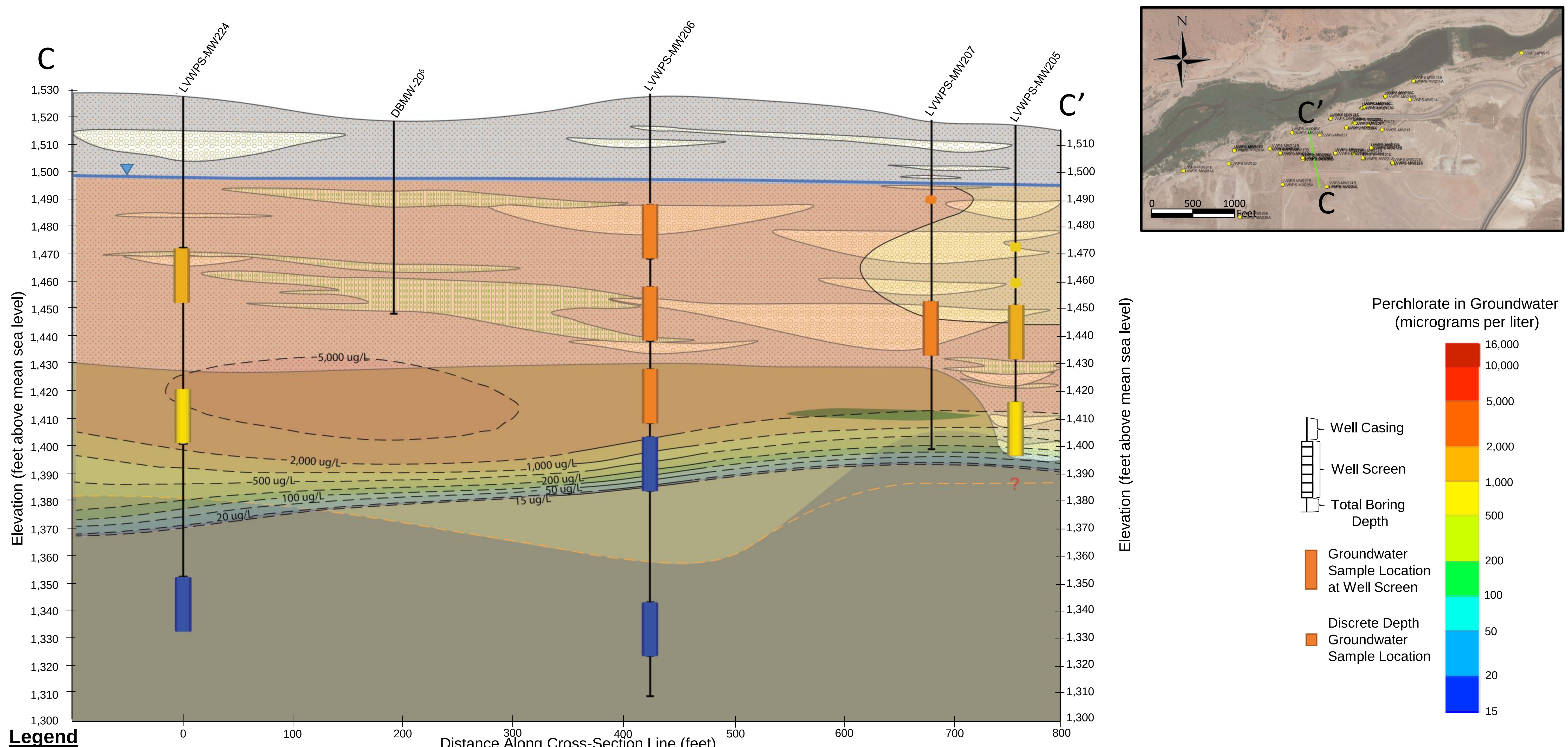

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN GROUNDWATER ALONG CROSS-SECTION B-B’ – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 13b |




## Legend

- Alluvium – Sand
- Alluvium – Gravel and Sand with Gravel Channel Fill (>30% Gravel)
- Alluvium – Sandy Silt and Silty Sand (>30% Silt)
- Silty Sand with Minor Gravel – Possible Coarse – Grained Facies of Upper Muddy Creek Formation
- Upper Muddy Creek Formation – Silt and Sandy Silt with Clay
- Upper Muddy Creek Formation – Organic – Rich Silt and Clay
- Semi – Consolidated Upper Muddy Creek Formation – Silt and Clay
- Bedrock – Horse Springs Formation
- Fault
- --?-- Inferred Contact
- Depth to First Gypsum Encounter
- Water Table

Notes:
1. Water table elevation is based on water level measurements collected on November 12, 2018.
2. Wells are projected onto section C-C’ from a maximum distance of 220 feet. Therefore, posted perchlorate data may differ from the contoured concentration at the section in some locations.
3. Each well was completed in a separate borehole; for simplicity, the clustered wells are shown as a single location with multiple screens on the cross-section.
4. Concentrations shown are interpolated by EVS using the closest available data set. Where concentrations are inferred, data is projected using dashed lines.
5. For visual clarity, groundwater samples with perchlorate concentrations less than the sample detection limit are represented with dark blue screens even when the detection limit was elevated because of an initial sample dilution.
6. Groundwater sample not collected from existing monitoring well DBMW-20.
7. Semi-consolidated Upper Muddy Creek formation contact represents the depth of the first occurrence of more cemented and consolidated material. Degree of cementation and consolidation varies with depth.

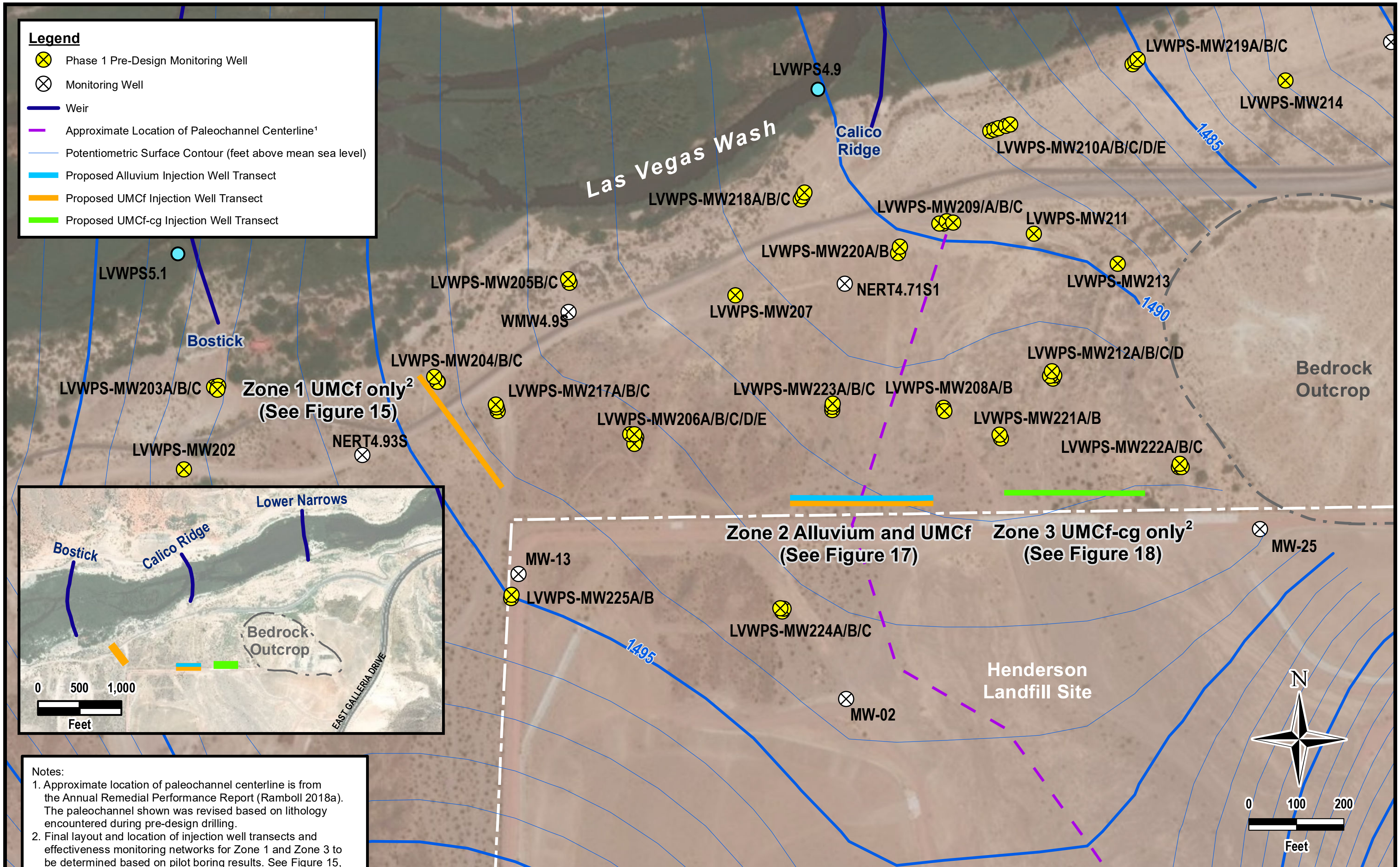

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293


NEVADA ENVIRONMENTAL RESPONSE TRUST

LAS VEGAS WASH PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PERCHLORATE CONCENTRATIONS IN GROUNDWATER ALONG CROSS-SECTION C-C’ – TRANSECT 1B STUDY AREA**

| | |
|---|---|
| Project No.: | 117-7502019 |
| Date: | JULY 8, 2019 |
| Designed By: | MRB |
| Figure No. | 13c |




Notes:

1. Approximate location of paleochannel centerline is from the Annual Remedial Performance Report (Ramboll 2018a). The paleochannel shown was revised based on lithology encountered during pre-design drilling.
2. Final layout and location of injection well transects and effectiveness monitoring networks for Zone 1 and Zone 3 to be determined based on pilot boring results. See Figure 15, Figure 17, and Figure 18 for additional details on injection and monitoring well configurations for each of the three remediation zones.
3. Groundwater and surface water elevations were measured in November 2018.
4. Potentiometric contours are based on groundwater elevations from monitoring wells with midscreen elevations less than 30 feet below the water table.
5. Imagery Source: Esri World Map, May 2017.

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

NEVADA ENVIRONMENTAL RESPONSE TRUST

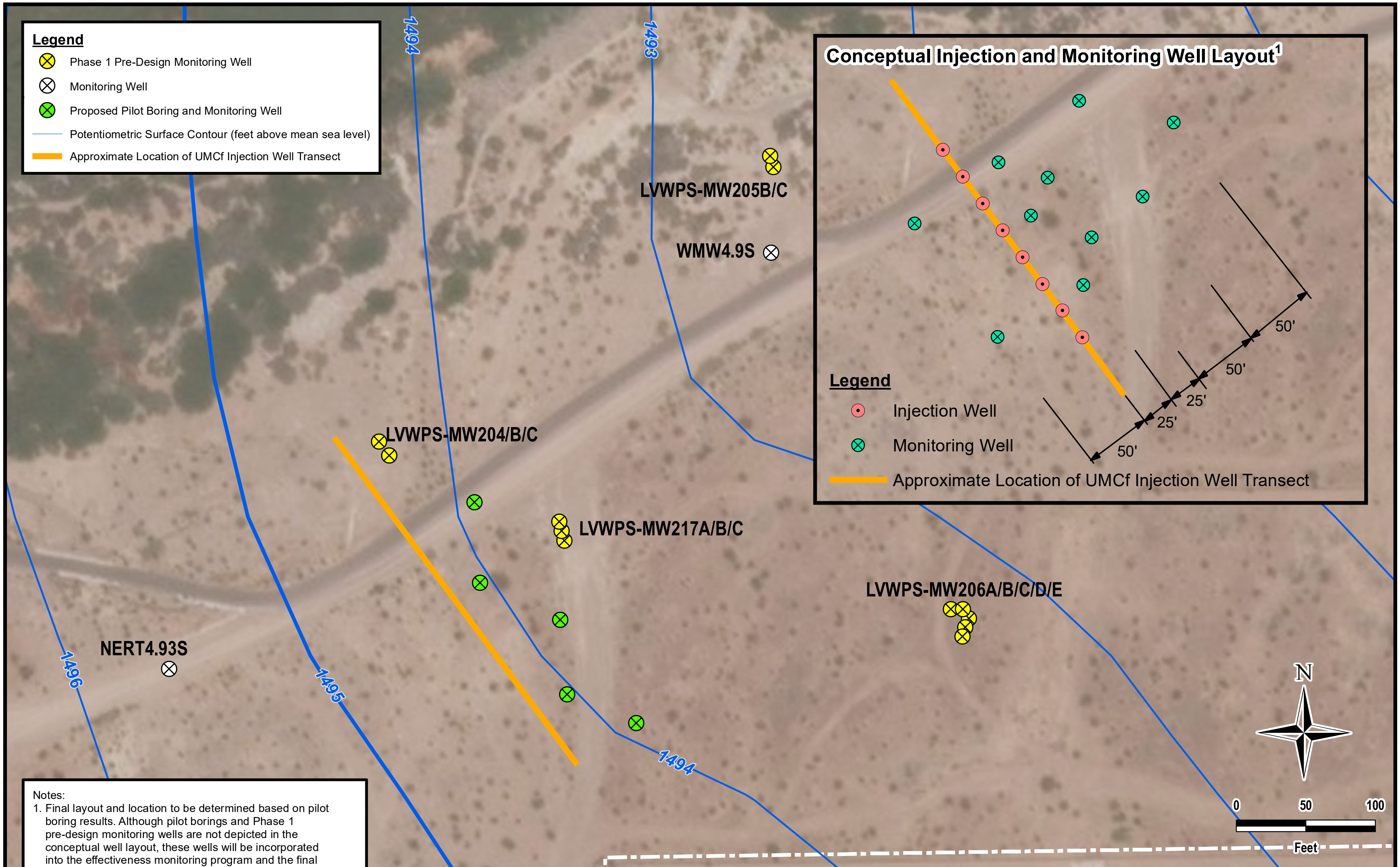
LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**PILOT STUDY DESIGN**
**TRANSECT 1B STUDY AREA**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | AUGUST 8, 2019 |
| DESIGNED BY: | ACC |

Figure No.
**14**

GEOIRVVOL1\PROJECTS\DATA\CAD\GIS\NERT\M19\Work Plan Addendum\Figure 14\Figure14_0808.mxd




Notes:
1. Final layout and location to be determined based on pilot boring results. Although pilot borings and Phase 1 pre-design monitoring wells are not depicted in the conceptual well layout, these wells will be incorporated into the effectiveness monitoring program and the final pilot study design to the extent possible to increase program efficiency by reducing the overall scale of Phase 2 monitoring well installation.
2. Groundwater and surface water elevations were measured in November 2018.
3. Potentiometric contours are based on groundwater elevations from monitoring wells with midscreen elevations less than 30 feet below the water table.
4. Imagery Source: Esri World Map, May 2017.

TETRA TECH

www.tetratech.com

150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

NEVADA ENVIRONMENTAL RESPONSE TRUST

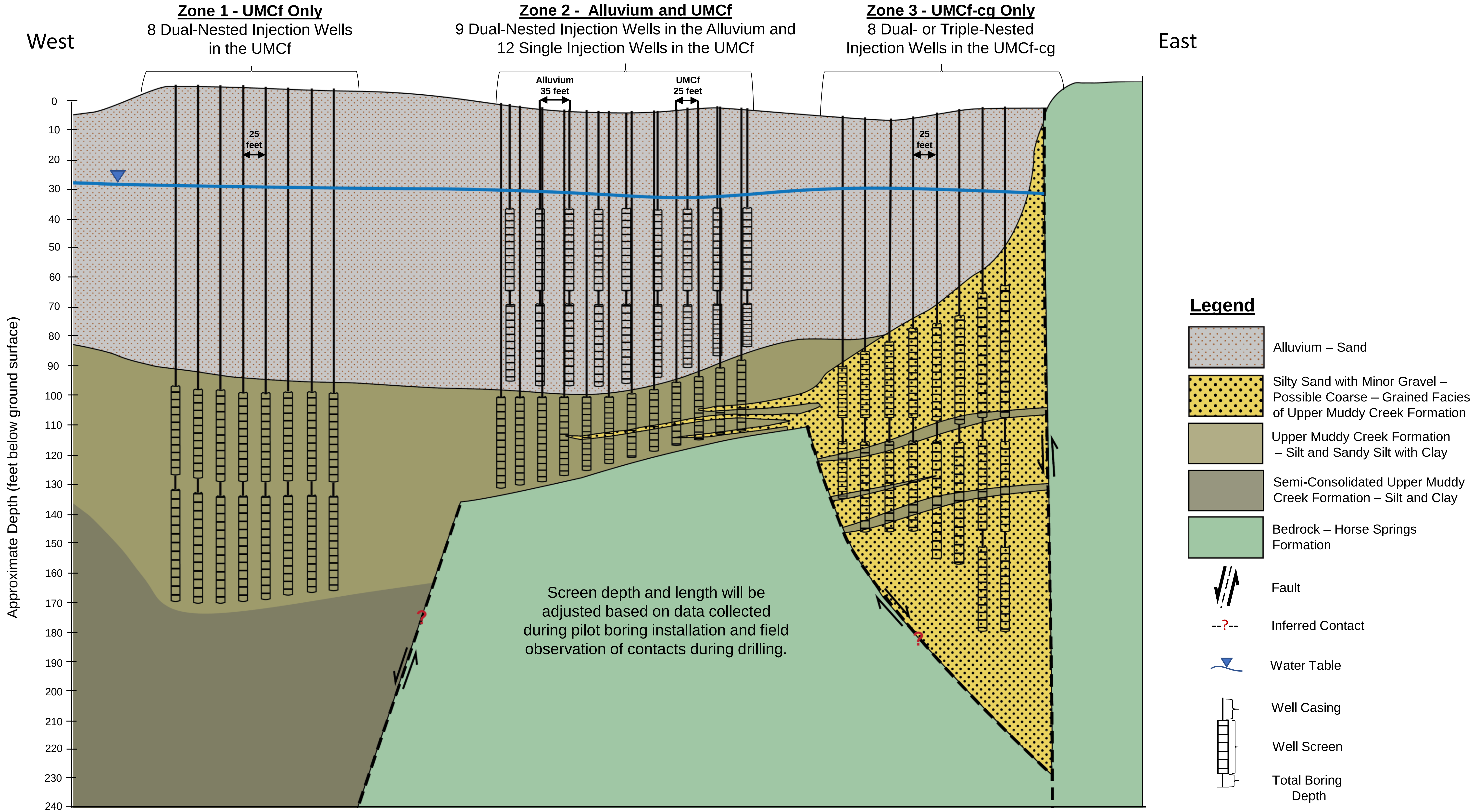
LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**ZONE 1 PILOT STUDY DESIGN**
**(UMCF ONLY)**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | AUGUST 8, 2019 |
| DESIGNED BY: | ACC |

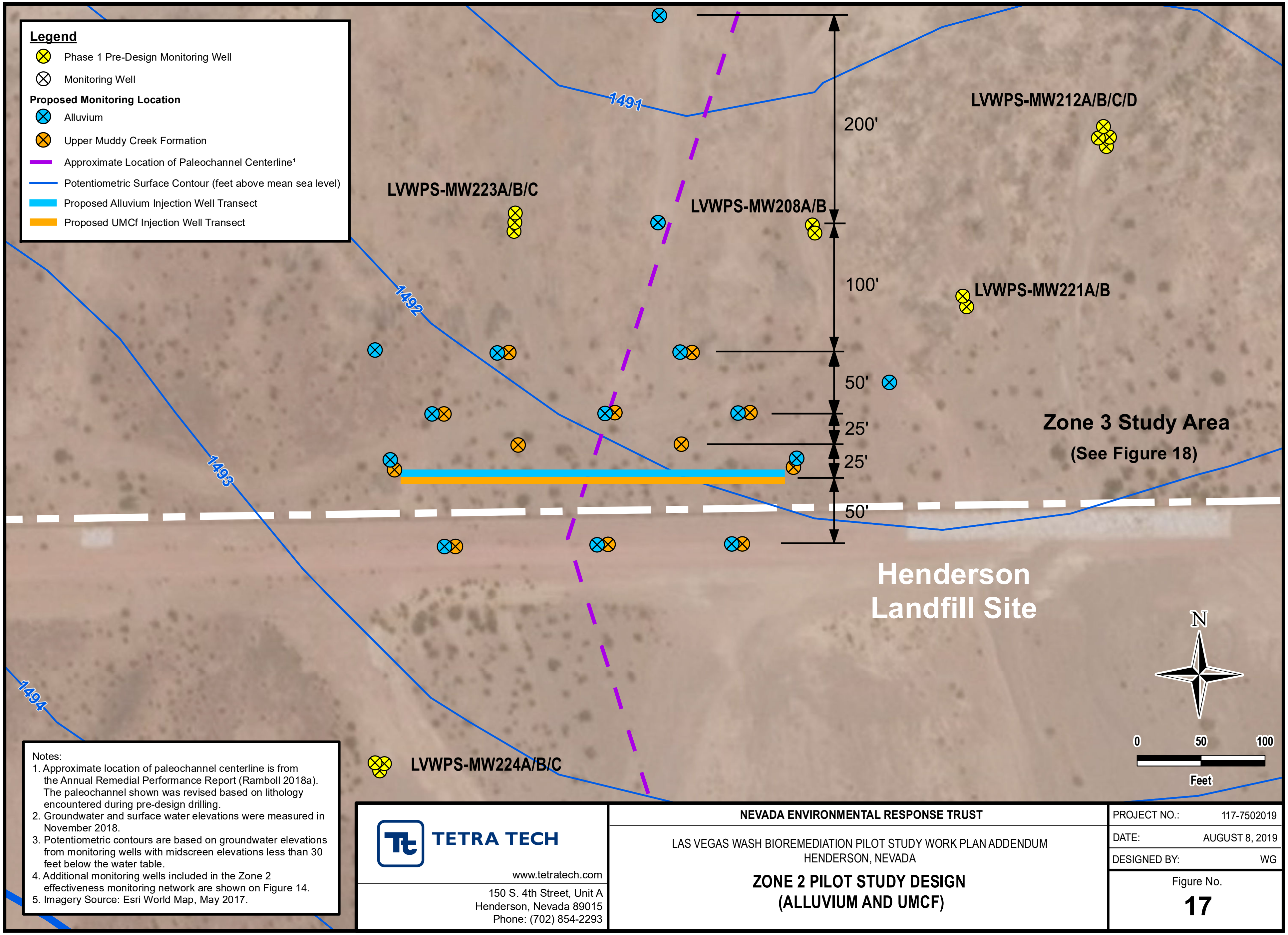
Figure No.
**15**

GEO\RVVOL1\PROJECTS\DATA\ACAD\GIS\NERT\M19\Work Plan Addendum\Figure 15\Figure15_080619.mxd

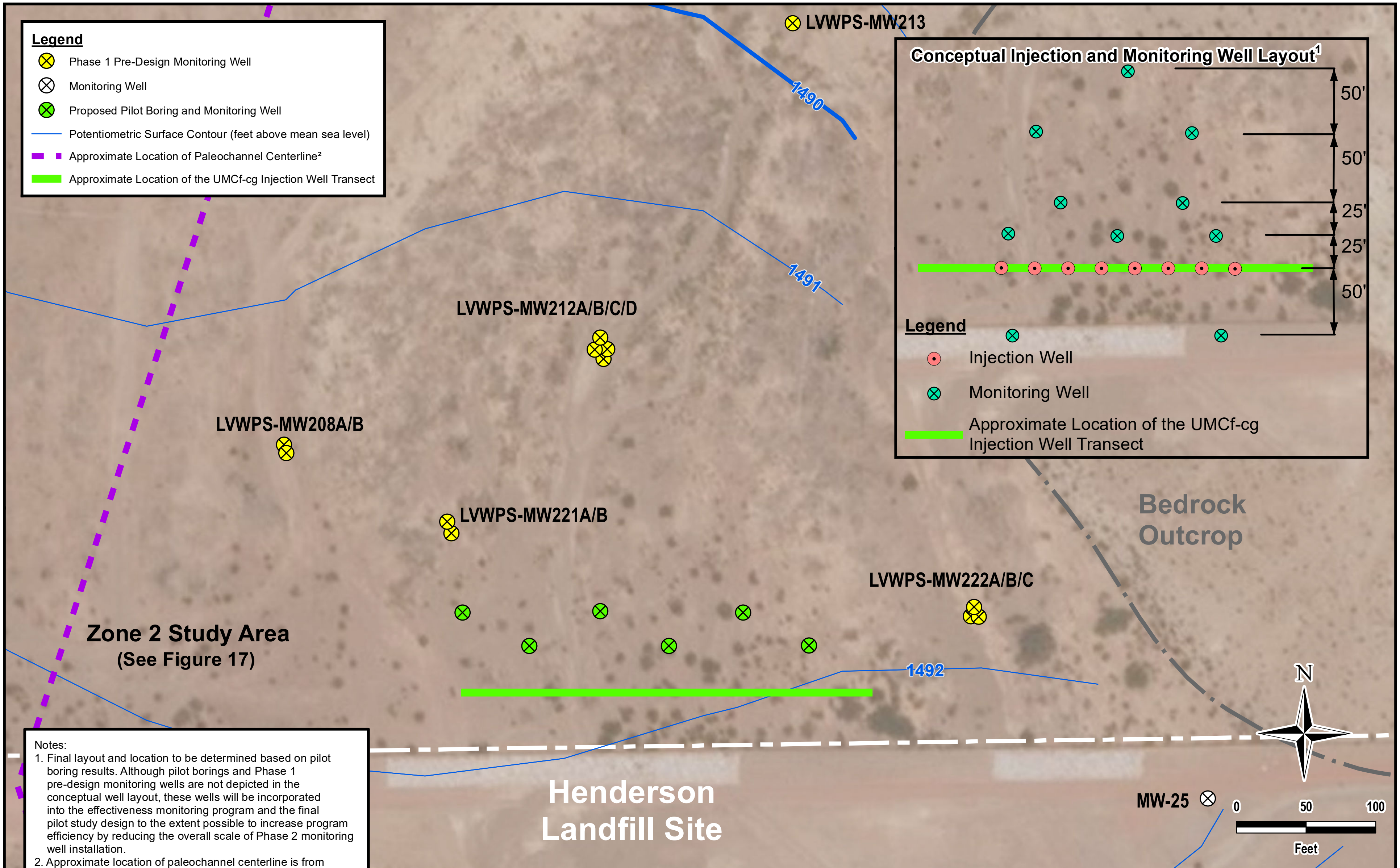



Note:
1. Geologic contacts displayed in this diagram are approximate and based on the closest available geologic data. Injection well construction will vary based on lithologic contacts observed during installation.

| | | |
|---|---|---|
| TETRA TECH<br>www.tetratech.com<br>150 S. 4th Street, Unit A<br>Henderson, Nevada 89015<br>Phone: (702) 854-2293 | NEVADA ENVIRONMENTAL RESPONSE TRUST<br>LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM<br>HENDERSON, NEVADA<br>CONCEPTUAL INJECTION WELL DESIGN | Project No.: 117-7502019<br>Date: JULY 11, 2019<br>Designed By: BCS<br>Figure No.<br>16 |




GEOIRVVOL1\PROJECTS\DATA\CAD\GIS\NERT\M19\Work Plan Addendum\Figure16\Figure16_Zone2_v2.mxd




Notes:
1. Final layout and location to be determined based on pilot boring results. Although pilot borings and Phase 1 pre-design monitoring wells are not depicted in the conceptual well layout, these wells will be incorporated into the effectiveness monitoring program and the final pilot study design to the extent possible to increase program efficiency by reducing the overall scale of Phase 2 monitoring well installation.
2. Approximate location of paleochannel centerline is from the Annual Remedial Performance Report (Ramboll 2018a). Thepaleochannel shown was revised based on lithology encountered during pre-design drilling.
3. Groundwater and surface water elevations were measured in November 2018.
4. Potentiometric contours are based on groundwater elevations from monitoring wells with midscreen elevations less than 30 feet below the water table.
5. Imagery Source: Esri World Map, May 2017.

TETRA TECH
www.tetratech.com
150 S. 4th Street, Unit A
Henderson, Nevada 89015
Phone: (702) 854-2293

NEVADA ENVIRONMENTAL RESPONSE TRUST

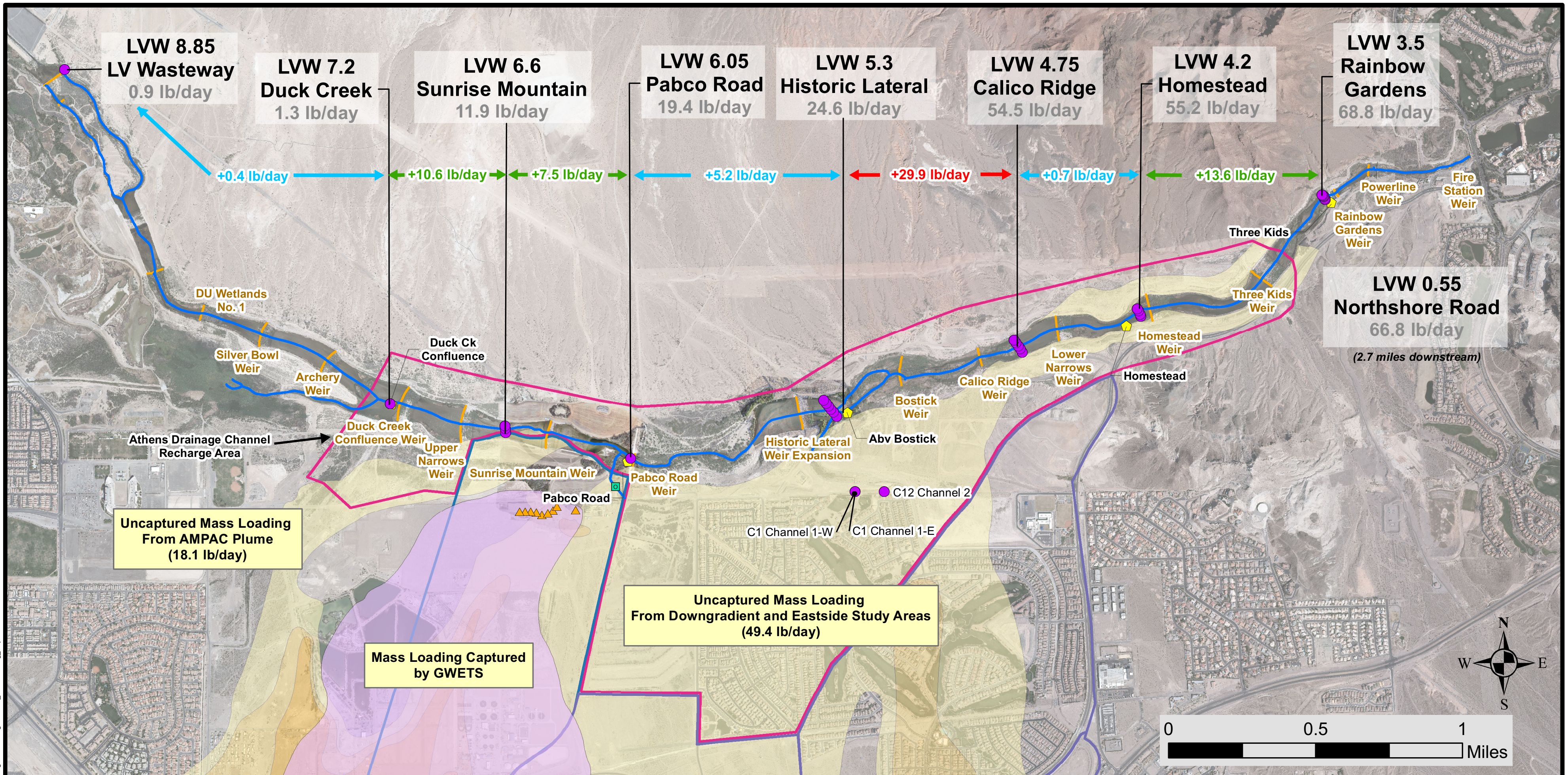
LAS VEGAS WASH BIOREMEDIATION PILOT STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

**ZONE 3 PILOT STUDY DESIGN (UMCF-CG ONLY)**

| | |
|---|---|
| PROJECT NO.: | 117-7502019 |
| DATE: | AUGUST 8, 2019 |
| DESIGNED BY: | ACC |
| Figure No. | 18 |

GEOIRVVOL1\PROJECTS\DATA\ACAD\GIS\NERT\M19\Work Plan Addendum\Figure 17\Figure17_080819.mxd

# Attachment 1
## Select Figures from Referenced Documents




## Legend

- NERT Surface Water Sample
- USGS Continuous Streamflow Location
- NERT/AMPAC/TIMET/COH Outfall Location
- Extraction Wells
- Las Vegas Wash
- Weirs
- Downgradient Study Area
- Eastside Study Area
- NERT Off-Site Study Area
- NERT Site

**Perchlorate Isoconcentration**

- <1 mg/L
- 1-10
- 10-25
- 25-100
- 100-250
- 250-500
- 500-1,000
- >1,000 mg/L

RAMBOLL

**Las Vegas Wash Loading**
**September - December 2018**

Nevada Environmental Response Trust Site
Henderson, Nevada

| Date: 4/8/2019 | Contract Number: 1690011198-031 | | Figure |
|---|---|---|---|
| Drafter: ME | Approved: | Revised: | 6 |

H:\LePetomane\NERT\GWM\Annual Performance Reports\2018 semi-Annual\Figures\GIS\Fig 6 - LVW_MassLoading_September-December2018.mxd