Vacuum Enhanced Recovery Treatability Study Work Plan
Nevada Environmental Response Trust Site Henderson, Nevada

PREPARED FOR

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
AP	Ammonium Perchlorate
bgs	below ground surface
BMI	Basic Management Incorporated
cm/s	centimeters per second
DO	Dissolved Oxygen
EDD	electronic data deliverable
FBR	Fluidized Bed Reactor
ft/ft	feet per foot
gpm	gallons per minute
GWETS	Groundwater Extraction and Treatment System
GWTP	Groundwater Treatment Plant
in Hg	inches of mercury
IWF	Interceptor Well Field
mg/L	milligrams per liter
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NERT or Trust	Nevada Environmental Response Trust
ORP	oxidation-reduction potential
PDF	portable document format
PID	photoionization detector
PVC	polyvinyl chloride
Qal	Quaternary alluvial
Site	Nevada Environmental Response Trust Site
Tetra Tech	Tetra Tech, Inc.
UMCf	Upper Muddy Creek formation
US EPA	United States Environmental Protection Agency
VER	Vacuum Enhanced Recovery
VOC	volatile organic compound
WBZ	water-bearing zone
Work Plan	Vacuum Enhanced Recovery Treatability Study Work Plan

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.

Description of Services Provided: Vacuum Enhanced Recovery Treatability Study Work Plan, Nevada Environmental Response Trust Site, Henderson, Nevada

8/23/17

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Date

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

1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this Vacuum Enhanced Recovery (VER) Treatability Study Work Plan (Work Plan) for the NERT site (Site), located in Clark County, Nevada (Figure 1). This Work Plan is being submitted to the Nevada Division of Environmental Protection (NDEP) as part of the Remedial Investigation consistent with the Interim Consent Agreement effective February 14, 2011. The Work Plan presents the technical approach and scope of work for the design and implementation of a VER treatability study in the vicinity of the Interceptor Well Field (IWF) within the former ammonium perchlorate (AP) production area of the Site (Figure 2).

1.1 PROJECT OBJECTIVES

NERT owns and operates a groundwater extraction and treatment system (GWETS) which consists of three groundwater extraction systems (the IWF, Athens Road Wells Field, and Seep Well Field), three lift stations, influent and effluent pipelines, an equalization pond (GW-11) and equalization tanks, the Groundwater Treatment Plant (GWTP), and a Biological Treatment Plant. The IWF and downgradient barrier wall comprise the groundwater extraction system constructed on the Site to recover groundwater with elevated perchlorate and hexavalent chromium concentrations near the former AP production area. The IWF currently consists of 30 wells that were installed between 1986 and 2010 that are generally constructed to a depth such that the well screens straddle the contact between the Quaternary alluvial (Qal) deposits and underlying Upper Muddy Creek formation (UMCf) (Tetra Tech, Inc., 2015). The barrier wall was constructed in 2001 approximately 50 feet downgradient of the IWF to function as a physical barrier across the higher concentration portion of the perchlorate and hexavalent chromium plume. The barrier wall is approximately 1,600 feet in length and 60 feet deep with approximately 30 feet of the wall installed within the UMCf (Ramboll Environ, 2016a). Based on groundwater concentration data from annual sampling events, elevated concentrations of perchlorate were detected in monitoring wells located downgradient of the barrier wall at depths deeper than the total depth of the barrier wall (Ramboll Environ, 2016a). In this context, Tetra Tech has developed the following objectives for the study:

- Evaluate the extent to which vacuum-enhancement will improve groundwater recovery in the UMCf compared to conventional pumping;
- Evaluate the extent to which operating deeper groundwater extraction wells (completed within the UMCf) in the vicinity of the IWF, may affect the operation of the IWF;
- Collect critical design data to support the feasibility study.

The results of the treatability study will be critical in determining how VER technology could be used at a larger scale at the NERT Site, if successful.

1.2 WORK PLAN ORGANIZATION

The Work Plan is organized as follows:

- **Introduction (Section 1.0):** Provides the primary objectives of the VER treatability study along with relevant background information, including regional geology and hydrogeology.
- **Technology Description (Section 2.0):** Provides an overview of VER technologies along with their relative advantages and disadvantages for application at the Site.
- **Drilling and Well Installations (Section 3.0):** Provides a description of the field activities to be completed along with associated permits required prior to conducting the VER treatability study.
- **Treatability Study Conceptual Design (Section 4.0):** Summarizes the conceptual design of the VER treatability study including system configuration, testing program, monitoring parameters and frequency, and data evaluation.

- **Permitting Requirements and Health and Safety (Section 5.0):** Provides a description of how chemical and physical hazards associated with the field activities will be addressed.
- **Reporting and Data Validation (Section 6.0):** Summarizes reporting related to the design and execution of preliminary field activities, VER treatability study, and evaluation of the VER treatability study data and technology.
- **Schedule (Section 7.0):** Provides a proposed schedule for conducting the drilling and well installations, VER treatability study, and associated reporting.
- **References (Section 8.0):** Lists the documents referenced in this Work Plan.

1.3 BACKGROUND

1.3.1 General

The Site has been used for industrial purposes since 1942, when it was initially developed by the United States government as a magnesium plant to support World War II military operations. Since that time, the Site and the surrounding properties have been used for chemical manufacturing, including the production of various chlorate and perchlorate compounds. Entities that operated at the Site include Western Electrochemical Company, American Potash and Chemical Company, Kerr-McGee Chemical Corporation, and Tronox, LLC. On February 14, 2011, NERT took title to the Site as part of the settlement of the Tronox Chapter 11 bankruptcy proceedings. As part of a long-term lease, Tronox operates a manufacturing facility on 114 acres of the Site producing manganese and boron products. Historical industrial production and related waste management activities conducted at the Site have resulted in the contamination of various environmental media, including soil, groundwater, and surface water. The most notable site-related contaminants of potential concern are perchlorate and hexavalent chromium (Ramboll Environ, 2016a).

1.3.2 Groundwater Extraction and Treatment System (GWETS)

Groundwater extraction has been implemented at the Site to address impacts to groundwater resulting from historical releases of perchlorate, chlorate, and hexavalent chromium. Collectively, the entire system of extraction wells, water conveyances, and treatment plants is referred to as the GWETS.

The GWETS treats water from three groundwater extraction well fields: the IWF; Athens Road Well Field; and the Seep Well Field (Figure 1). Pipelines and lift stations convey groundwater from the well fields to the Site to be treated by the on-site treatment plant. This treatment plant is comprised of the following components: the GWTP to reduce hexavalent chromium to trivalent chromium and then precipitates trivalent chromium from groundwater extracted from the IWF; the Biological Treatment Plant that utilizes Fluidized Bed Reactors (FBRs) to treat perchlorate in groundwater from all of the well fields; the GW-11 Pond, which is used for water storage and equalization; the Equalization Area, which includes equalization tanks and a granular activated carbon pretreatment system; and the effluent pump station and pipeline, which convey treated effluent from the FBR treatment plant to an outfall at the Las Vegas Wash (Tetra Tech, Inc., 2015).

The IWF was installed in the shallow water bearing zone starting in 1986. The IWF extracts contaminated groundwater on-site, downgradient from the on-site source areas. The IWF consists of 30 wells, 28 of which are currently active (as of August 2017). Well depths range from 35 feet to 51 feet below ground surface (bgs). The IWF has been operating at approximately 66.8 gallon per minute (gpm) over the reporting periods from 2011 to 2016 with average discharge for individual IWF wells for July 2015 to June 2016 ranging from 0.2 gpm (I-G) to 7.3 gpm (I-J) (Ramboll Environ, 2016a).

To further enhance groundwater capture, a barrier wall was constructed in 2001 approximately 50 feet downgradient of the IWF across the higher concentration portion of the perchlorate and hexavalent chromium plume (Figure 2). The barrier wall is approximately 1,600 feet in length, 60 feet deep, and constructed to tie into approximately 30 feet of the UMCf (Ramboll Environ, 2016a).

The GWTP, located adjacent to the IWF and barrier wall (Figure 2), has been treating groundwater extracted from the IWF since its construction in 1986 to 1987. Envirogen Technologies, Inc. has operated and maintained the GWTP and the rest of the GWETS since July 25, 2013.

Historical data demonstrate that the GWTP has sufficient capacity to treat chromium at the concentrations present in IWF groundwater at flow rates up to 75 gpm with an acceptable chromium removal efficiency. The design treatment capacity of the GWTP is not known, but is constrained by the sizing and performance of the existing equipment. (Tetra Tech, Inc., 2015)

1.4 REGIONAL GEOLOGY AND HYDROGEOLOGY

1.4.1 Regional Geology

The Site is located at the southeast end of the Las Vegas Valley, a 55-mile long northwest-southeast trending structural basin that is bounded on the west by the Spring Mountains, on the north by the southern ends of the Sheep and Las Vegas Ranges, on the east by Frenchman and Sunrise Mountains, and on the south by the River Mountains and McCullough Range. The Las Vegas Valley is underlain by a structural basin comprised of Precambrian crystalline rocks; Precambrian and Paleozoic carbonate rocks; Permian, Triassic, and Jurassic clastic rocks; and Miocene igneous rocks (Plume, 1989).

The clastic sedimentary valley-fill deposits of Las Vegas Valley are more than 4,000 feet thick beneath Henderson (Plume, 1989). The lithology of the top 250 feet consists of Qal deposits, transitional Muddy Creek Formation, and Pleistocene UMCf (ENVIRON, 2014a).

1.4.2 Alluvium

The Site is immediately underlain by Qal deposits that slope to the north toward the Las Vegas Wash. The alluvium generally consists of a reddish-brown heterogeneous mixture of well-graded sand and gravel with lesser amounts of silt, clay and caliche. Beds or units observed in the area are typically discontinuous due to the mode of deposition. Cobbles and boulders are common, and clasts within the alluvium are primarily composed of volcanic material. The thickness of these alluvial deposits ranges from less than one foot to more than 50 feet.

Several known major paleochannels transect the region, from as far south as the Site, towards the Las Vegas Wash. These paleochannels were eroded into the surface of the UMCf during infrequent flood runoff periods with stream-deposited sands and gravels. The generally uniform sand and gravel deposits are narrow, vary in thickness, and exhibit higher permeability than the adjacent well-graded deposits (ENVIRON, 2014a).

1.4.3 Upper Muddy Creek Formation

The UMCf represents deposition in an alluvial apron environment from the Spring Mountains to the west, grading into fluvial, paludal (swamp), playa, and lacustrine environments further out into the valley center (ENVIRON, 2014a). The UMCf underlies the transitional Muddy Creek Formation or alluvium, and consists of interbedded fine-grained sediments (clay and silt representing the first and second fine-grained facies) and coarse-grained (sand, silt, and gravel representing the first and second coarse-grained facies) that become progressively finer-grained to the north towards the central portion of the Las Vegas Valley.

1.4.4 Hydrogeology

According to previous work performed around the region, the depth to groundwater ranges from approximately 27 to 80 feet bgs, and is generally deepest in the southern portion of the Site and becomes shallower to the north toward the Las Vegas Wash. The ground surface across the Site generally slopes downward to the north at a gradient of approximately 0.02 feet per foot (ft/ft) (Ramboll Environ, 2016a). Off-site to the north, the topographic surface continues at the same gradient to approximately Sunset Road, at which point it flattens to a gradient of

0.01 ft/ft to the Las Vegas Wash (Ramboll Environ, 2016a). The shallow groundwater gradient generally mimics the surface topography (Ramboll Environ, 2016a). The direction of groundwater flow on the Site is generally north to north-northwest and then changes slightly to the northeast towards the Las Vegas Wash.

The NDEP has defined the following three water-bearing zones (WBZs) that occur within the Site:

- Shallow WBZ – The first occurrence of groundwater in the area occurs within either the alluvium or the Upper Muddy Creek Formation. Groundwater in the Shallow WBZ occurs under unconfined to partially confined conditions and is considered the "water table aquifer." At the Site, the Shallow WBZ is comprised of the saturated portions of the alluvium and the uppermost portion of the UMCf to depths of approximately 90 feet bgs (Ramboll Environ, 2016a).
- Middle WBZ – Groundwater in the Middle WBZ generally occurs between 90 and 300 feet bgs. Water-bearing units in the Middle WBZ are confined (ENVIRON, 2014a). Groundwater in the Middle WBZ exhibits an upward vertical gradient (Ramboll Environ, 2016a).
- Deep WBZ – Groundwater in the Deep WBZ generally occurs between 300 and 400 feet bgs. Water-bearing units in Deep WBZ are confined. Groundwater in the Deep WBZ exhibits an upward vertical gradient (Ramboll Environ, 2016a).

1.5 TREATABILITY STUDY AREA GEOLOGY AND HYDROGEOLOGY

The location of the proposed VER treatability study area is shown on Figure 2. The VER treatability study will be conducted within the UMCf, which is encountered below approximately 35 feet bgs (Ramboll Environ, 2016a). Depth to groundwater ranges from approximately 26 to 44 feet bgs (Ramboll Environ, 2016a). Groundwater elevations for wells directly downgradient (north) of the barrier wall (wells M-69 through M-74) were generally four to 12 feet lower than water levels in corresponding wells upgradient (south) of the IWF (wells I-Y/M-167, M-55, M-56, M-58, M-67, and M-68). The difference in groundwater elevations is attributed to the barrier wall functioning as an effective barrier to groundwater flow (Ramboll Environ, 2016a). Tetra Tech estimates the hydraulic conductivity within the UMCf ranges from approximately 1.0 to 2.5 ft/day using slug test data obtained as part of the AP Area Soil Flushing Treatability Study. The hydraulic gradient within the proposed study area ranges from approximately 0.015-0.025 ft/ft (Figure 3). The groundwater flow direction within the proposed study area is to the north with localized flow patterns toward the IWF (Figure 3).

1.6 EXTENT OF PERCHLORATE AND HEXAVALENT CHROMIUM IMPACTS

1.6.1 Perchlorate

A more thorough discussion of the nature and extent of perchlorate impacts at the Site is provided in the October 31, 2016 Annual Remedial Performance Report for Chromium and Perchlorate, Nevada Environmental Response Trust Site, Henderson, Nevada prepared by Ramboll Environ (Ramboll Environ, 2016a). For the purposes of this work plan, an abbreviated discussion of perchlorate impacts and mass recovery trends within and in proximity to the VER treatability study area is presented herein.

The components of the groundwater extraction system located in proximity to the proposed VER treatability study area are the IWF and barrier wall (Figure 2). The IWF was designed to target the highest concentrations of perchlorate at the Site. During the period from July 2015 to June 2016, approximately 205,700 pounds of perchlorate was captured by the IWF. A general decrease in perchlorate concentrations has been detected in the IWF wells since perchlorate sampling started in 2002, but precipitation events, modification of site drainage patterns in 2010 and 2011, and infiltration have contributed to variability in perchlorate concentrations at the Site since 2012.

During the May 2016 sampling event, elevated perchlorate concentrations were detected in deeper monitoring wells downgradient of the barrier wall; groundwater collected from monitoring well M-162 contained a concentration of 98 mg/L and groundwater collected from monitoring well M-164 contained a concentration of 770 mg/L. Both wells M-162 and M-164 have screened intervals at depths deeper than the completion depth of the barrier wall of approximately 60 feet bgs. M-162 is screened between 100 and 110 feet bgs and M-164 is screened between 60 and 70 feet bgs. As part of the Phase 2 Remedial Investigation being implemented by Ramboll Environ, installation of deeper on-site UMCf wells in the vicinity of the IWF has occurred which will help evaluate the lateral and vertical extent of perchlorate impacts at depths below that of the the barrier wall (Figure 2) (Ramboll Environ, 2016b). Implementation of the Phase 2 Remedial Investigation is underway, but not complete, as of the date of this work plan. Preliminary results are available for sampling of monitoring wells M-65D, M-66D, M-72D, M-140D, M-221, and M-222. Monitoring wells M-65D, M-221, and M-222 are located upgradient of monitoring wells M-162 and M-164 (Figure 2). Results from recent sampling indicate that perchlorate concentrations are approximately 570 mg/L in groundwater collected from M-65D at 60-70 feet bgs. However, the perchlorate concentrations in groundwater collected from MW-221, screened from 75 to 85 feet bgs, are three orders of magnitude less at approximately at 0.5 mg/L, and four orders of magnitude less in a recent groundwater sample collected from MW-222, screened from 100 to 110 feet bgs, at 0.01 mg/L. The results from groundwater collected from MW-221 and MW-222 were somewhat unanticipated because they are much less than the 98 mg/L of perchlorate in groundwater adjacent to M-162, which is located approximately 500 feet downgradient. Groundwater samples collected from the other monitoring wells, M-66D, M-72D, and M-140D, had perchlorate concentrations ranging from 250 to 490 mg/L at 60-70 feet bgs; however, there was no further vertical delineation of the perchlorate impacts at these locations. A perchlorate plume map depicting the extent of impacts in the shallow groundwater in the vicinity of the VER treatability study area is provided as Figure 4. A geologic cross section, which includes monitoring wells and perchlorate concentrations from the May 2016 groundwater sampling event, is provided as Figure 5.

1.6.2 Hexavalent Chromium

While perchlorate is the primary contaminant of concern for the VER treatability study, other contaminants of concern will be evaluated as well; in particular hexavalent chromium. Hexavalent chromium concentrations are expected to be present up to 25 mg/L. Therefore, the VER treatability study will also be used to evaluate the hexavalent chromium removal rate. Hexavalent chromium concentrations in groundwater samples collected from wells immediately downgradient of the barrier wall were generally an order of magnitude less than perchlorate concentrations during the July 2015 to June 2016 reporting period. The highest total chromium concentration detected in a groundwater sample collected from a well immediately downgradient of the barrier wall during the July 2015 to June 2016 reporting period was 12 mg/L in M-72. The concentration of perchlorate detected in groundwater collected from M-72 during the corresponding July 2015 to June 2016 reporting period was 1,100 mg/L (Ramboll Environ, 2016a). A chromium plume map depicting the extent of impacts in the shallow groundwater in the vicinity of the VER treatability study area is provided as Figure 6.

2.0 TECHNOLOGY DESCRIPTION

VER is a technique of applying high vacuum or negative pressure on a recovery well and the surrounding formation to enhance the liquid recovery of that well by increasing the net effective drawdown. VER also increases the mass removal of the volatile and semi-volatile contaminants, by maximizing dewatering and facilitating volatilization from previously saturated sediments via the increased air movement (Ayyaswami, 1996). Tetra Tech considers VER to be a cost-effective technology that can be successfully applied to:

- Enhancing the overall recovery of contaminants, especially under low permeability conditions as in the UMCf; and,
- Removing dissolved-phase contamination present in groundwater.

Implementation of a VER system is most applicable in fine-grained formations with a hydraulic conductivity between 10^{-3} to 10^{-5} centimeters per second (cm/s). The implementation of a VER system in a low permeability zone generally results in the development of rapid or significant drawdown with a narrow cone of depression and an associated steep hydraulic gradient (Blake & Gates, 1986). The geologic and hydrogeologic conditions within the VER treatability study area, specifically the UMCf, are similar to the recommended conditions for implementing VER. NERT's implementation of VER may provide multiple advantages over conventional recovery systems including increasing the size of the capture zone around an extraction well, reducing the number of recovery wells required, and accelerating the rate of mass removal. An additional advantage of utilizing VER at the Site is the ability to increase the radius of influence at the targeted depth interval without having to operate deeper extraction wells that could pull perchlorate down to deeper, less impacted zones.

VER has the potential to effectively recover the primary contaminants of concern in the VER treatability study area based on the physical properties of the contaminants. For example, perchlorate is soluble, persistent, and very mobile in groundwater, which enables the compound to be recovered using groundwater extraction (Roote, 2001). Hexavalent chromium is also soluble, persistent under aerobic conditions, and mobile in groundwater, which enables the compound to be recovered using groundwater extraction (Palmer & Puls, 1994).

3.0 DRILLING AND WELL INSTALLATIONS

This section describes the treatability study area details, conceptual well layout, utility clearance, soil and groundwater sampling, and well installation. The completion of these tasks will be used to progress and finalize design details for the VER treatability study.

3.1 TREATABILITY STUDY LOCATION

The VER treatability study area was selected because elevated perchlorate concentrations within the UMCf and existing extraction and monitoring wells are present. The VER treatability study area is located on the upgradient side of the barrier wall where downgradient elevated concentrations of perchlorate are present in groundwater at wells M-71, M-162, and M-164. The location of the proposed VER extraction wells, VER-01I and VER-01D, were selected to evaluate the effect of operating a VER extraction well in proximity to an IWF well, I-F. The placement of the VER extraction wells also facilitates the use of three monitoring wells installed as part of the Phase 2 Remedial Investigation (M-65D, M-221, and M-222) in the VER treatability study performance monitoring plan. The proposed locations of nested performance monitoring wells VMW-01I/D and VMW-02I/D were selected to reduce data gaps in the existing monitoring well network and help evaluate the VER extraction well radius of influence . As discussed in Section 1.6.1, groundwater quality data from wells M-65D, M-221, and M-222 indicate that perchlorate concentrations decline by orders of magnitude at depths below 70 feet bgs, which are approximately 200 feet upgradient of the IWF. Elevated concentrations of perchlorate are present at 110 feet bgs at M-162, located approximately 200 feet down gradient of the IWF, but much lower concentrations of perchlorate were found at 110 feet bgs at M-222. Tetra Tech will use the sample results from the proposed deep VER well, VER-01D, and deep monitoring wells VMW-01D and VMW-02D to further evaluate whether deeper perchlorate impacts are present at depths below the IWF in the VER treatability study area.

It is anticipated that substantial new site investigation information will be produced by the Phase 2 Remedial Investigation between the date of this workplan and the commencement of the VER treatability study. It is possible that the new information will lead to adjustments to this workplan in order to better achieve its objectives. Any significant adjustments will be conferred with the Trust and NDEP and properly documented prior to their implementation.

3.2 FIELD ACTIVITIES

All field work described herein will be conducted in accordance with the existing Site Management Plan, Revision 3 (Ramboll Environ, 2017) and Field Sampling Plan (ENVIRON, 2014b). Tetra Tech, on behalf of NERT, will prepare applications and obtain required permits prior to the installation of the wells. The wells will be drilled in accordance with the Nevada Division of Water Resources requirements, following submittal of a Notice of Intent to Drill, as described in Section 5.0.

3.2.1 Utility Clearance

Tetra Tech will review available utility maps and retain the services of a geophysical locator to check for underground utility lines prior to advancing borings. Each borehole will be cleared for utilities to at least 5 feet bgs using a Hydrovac unit that will inject pressurized water through a handheld wand and extract the resulting slurry by a powerful vacuum. Boring locations may be adjusted in the field to avoid existing utilities, structures, or other site features.

3.2.2 Soil Borings and Grab Groundwater Samples

Six soil borings will be drilled in the VER treatability study area to obtain lithologic information, physical parameters, and contaminant concentrations. These borings will be completed as four monitoring wells (VMW-

01I, VMW-01D, VMW-02I, VMW-02D), one intermediate VER extraction well (VER-01I), and one deep VER extraction well (VER-01D) as shown on Figure 7. Tetra Tech will retain a licensed drilling contractor to advance the soil boring using hollow-stem auger or rotary vibratory drilling technology, if deemed necessary, to permit the collection of continuous soil cores for accurate lithologic logging and sampling. Before the drill rig mobilizes to each soil boring location, down-hole drilling equipment will be cleaned with a high-pressure, high-temperature water spray to avoid potential cross-contamination.

The soil borings will be advanced through the alluvium and UMCf up to a total depth of 110 feet bgs to evaluate soil conditions within the alluvium and UMCf. Continuous soil samples will be collected utilizing a continuous sample tube system and/or split-spoon sampler (or similar sampling system), from ground surface to the total depth and logged using the Unified Soil Classification System by the on-site geologist. Soil samples will be collected at 5-foot intervals in the unsaturated zone to evaluate vadose zone impacts, at 10-foot intervals in the saturated zone, and at lithologic or color changes, and then submitted for laboratory analysis. In addition, a soil sample will be collected from boring locations VER-01I and VER-01D at the interval corresponding to the proposed screen interval of the monitoring wells and the VER extraction wells for sieve analysis to determine the grain size for the screen interval. The grain size data will be used to support the design and selection of a well screen slot size and filter pack material. Only one sample for grain size analysis is proposed from each extraction well for collection based on the assumption that the localized lithology corresponding to the proposed screen intervals is fairly homogenous. The drilling contractor will decontaminate soil collection equipment between samples. Soil samples for laboratory analysis will be collected in laboratory-supplied containers, labeled, placed in plastic bags, and stored in a cooler on ice for transport to the project analytical laboratory. Upon reaching groundwater, a minimum of one undisturbed soil sample will be collected from each borehole within the proposed screen interval using a Shelby tube, or similar, for physical parameter analysis. A summary of the baseline soil and groundwater sampling protocol is provided in Section 3.3 as Table 2.

A depth-discrete groundwater sample will be collected within the alluvium, if sufficient water is present, and at the top of the UMCf at each boring location to evaluate the contaminant impacts at this lithologic interface. Groundwater samples will be collected using a depth-discrete groundwater sampling tool (e.g., Hydropunch™ or Simulprobe™) or from temporary 2-inch wells. If temporary wells are installed, a minimum of three casing volumes of water will be purged prior to sampling, if the formation allows. Groundwater samples, collected with a small diameter disposable bailer, will be tested for general water quality parameters (temperature, pH, conductivity, and turbidity) using a portable water quality meter and then transferred into clean laboratory-supplied containers for laboratory analysis.

3.2.3 Well Installation

Once collection of the soil and groundwater samples is complete, the six soil borings will be completed as two clustered monitoring wells, VMW-01I/D and VMW-02I/D, one intermediate VER extraction well, VER-01I, and one deep VER extraction well, VER-01D (Figure 7). The monitoring wells will be used to obtain representative groundwater elevation data, vacuum data, and groundwater samples during the VER treatability study. The extraction wells and performance monitoring wells will be installed with screened intervals within the UMCf. The extraction wells, VER-01I and VER-01D, will be constructed with four-inch diameter, Schedule 80 polyvinyl chloride (PVC) and a wire-wrapped stainless steel well screen. The nested monitoring wells will be constructed with two-inch diameter, Schedule 80 PVC and a Schedule 80 PVC well screen. A washed sand filter pack will be installed in the annular space around the well screen and extended up to two feet above the top of screen interval. The screen slot size and filter pack sand will be selected based on the results of the grain size analysis described in Section 3.2.2. A minimum five-foot hydrated bentonite seal will be placed above the filter pack. The remainder of the annular space will be backfilled with cement containing approximately 5 percent bentonite. Well construction diagrams based on the anticipated well construction details are provided as Figure 8. A well construction table is provided as Table 1.

Table 1 Extraction Well and Monitoring Well Construction

Well ID	Riser Construction and Interval	Screen Construction and Interval [3]
VER-01I [1]	4-Inch Schedule 80 PVC (0 – 55 feet bgs)	4-Inch wire-wrapped 0.010-inch slot size stainless steel well screen (55 – 70 feet bgs)
VER-01D [2]	4-Inch Schedule 80 PVC (0 – 90 feet bgs)	4-Inch wire-wrapped 0.010-inch slot size stainless steel well screen (90 – 110 feet bgs)
VMW-01I	2-Inch Schedule 80 PVC (0 – 55 feet bgs)	2-Inch Schedule 80 PVC 0.010-inch slot size well screen (55 – 70 feet bgs)
VMW-01D	2-Inch Schedule 80 PVC (0 – 90 feet bgs)	2-Inch Schedule 80 PVC 0.010-inch slot size well screen (90 – 110 feet bgs)
VMW-02I	2-Inch Schedule 80 PVC (0 – 55 feet bgs)	2-Inch Schedule 80 PVC 0.010-inch slot size well screen (55 – 70 feet bgs)
VMW-02D	2-Inch Schedule 80 PVC (0 – 90 feet bgs)	2-Inch Schedule 80 PVC 0.010-inch slot size well screen (90 – 110 feet bgs)

Notes:

1. VER-01I will be installed with a 5-foot sump from 70 to 75 feet bgs.
2. VER-01D will be installed with a 5-foot sump from 110 to 115 feet bgs.
3. Screen slot size may be adjusted based on the results of the sieve analysis.

The surface completions for the wells may vary based on whether they are located in vehicle traffic areas. In traffic areas, flush-mounted, tamper-resistant, traffic-rated well boxes will be installed, at an elevation approximately one-half inch above grade. In areas where there is no vehicle traffic, above-grade monuments may be installed approximately three feet above surrounding grade. If needed, three bollards surrounding the monuments will be installed.

3.2.4 Well Development

Following the completion of well construction, but no sooner than 24 hours after well construction is complete, Tetra Tech will develop the newly installed wells. Well development will consist of using a surge block and bailer to swab and surge the filter pack and remove sediment from the wells. This process will be followed by pumping with a submersible pump to purge the well of fine-grained sediment. Well development will be considered complete for the performance monitoring wells when three to ten casing volumes of water have been removed from the well, and index parameters consisting of pH, specific conductivity, turbidity, and temperature are stable (pH within 0.1 and other parameters within 10 percent) over three consecutive measurements. Well development for the extraction wells will be conducted over an approximate 6 to 8 hour period for each extraction well, during which index parameters will be collected. All index parameter readings will be recorded by Tetra Tech on well development logs. Groundwater sampling will not be conducted until at least one week following the completion of the well development.

3.2.5 Well Survey

Following installation of the two clustered groundwater monitoring wells, VMW-01I/D and VMW-02I/D, intermediate VER extraction well, VER-01I, and deep VER extraction well, VER-01D, a land surveyor will survey the horizontal coordinates of each well relative to North American Datum 83 with an accuracy of 0.1 foot, and the elevation of the ground surface and top of well casing measuring point relative to North American Vertical Datum 88 with accuracies of 0.1 foot and 0.01 foot, respectively.

3.3 LABORATORY ANALYSIS

Soil samples will be collected at 5-foot intervals in the unsaturated zone, at 10-foot intervals in the saturated zone, and at lithologic or color changes, and then submitted for laboratory analysis per the analytical methods provided below in Table 2. Selected saturated soil samples will also be analyzed for physical parameters and grain size. As vertical delineation of impacts is currently being performed by others, groundwater samples will be collected within the alluvium, if sufficient water is present, and at the top of the UMCf only at each boring location to supplement the existing vertical profiling. The groundwater samples will be submitted for laboratory analysis per the analytical methods provided below in Table 2.

Table 2 Baseline Soil and Groundwater Sampling Protocol

Parameter(s)	Method	Purpose
Soil Analyses		
Perchlorate	E314	Assess vertical extent of perchlorate in unsaturated and saturated soil
Chlorate	E300.1	Assess vertical extent of chlorate in unsaturated and saturated soil
Chlorite	E300.1	Assess vertical extent of chlorite in unsaturated and saturated soil
Hexavalent Chromium	SW7199	Assess vertical extent of hexavalent chromium in unsaturated and saturated soil
Total Chromium	SW-6010B	Assess vertical extent of chromium in unsaturated and saturated soil
Physical Parameters [1]	Various	Assess geophysical properties of soil
Groundwater Analyses		
Perchlorate	E314	Assess vertical extent of perchlorate impacts
Chlorate	E300.1	Assess vertical extent of chlorate impacts
Chlorite	E300.1	Assess vertical extent of chlorite impacts
Hexavalent Chromium	SW7199	Assess vertical extent of hexavalent chromium impacts
Total Chromium	200.7	Assess vertical extent of chromium impacts
VOCs	SW-846 5035A	Assess vertical extent of VOC impacts, including chloroform

Notes:

1. Physical parameters include native-state permeability to water (hydraulic conductivity), grain density, grain size, dry bulk density, total porosity, air-filled porosity, moisture content and total pore fluid saturation (reported as water only).

3.4 WASTE MANAGEMENT

Waste generated during the well installation and development activities will be managed according to applicable state, federal, and local regulations and as described in Field Guidance Document No. 001, Managing Investigation-Derived Waste (ENVIRON, 2014b). The anticipated waste generated includes soil cuttings, personal protective equipment, equipment decontamination water, and groundwater generated during depth-discrete groundwater sampling and well development. Soil cuttings will be stored in plastic-lined roll-off bins. Solids will be characterized by collecting representative samples, as necessary, to determine disposal options. Depending upon the size of the container and volume of material, one sample may be sufficient for characterization, or several samples may be composited in the field. Generally, a minimum of one composite sample will be collected for up to five roll-off bins, unless observations of the collected soil suggest non-uniformity or other factors which might warrant collection of additional samples for material characterization. Waste sample analysis will be determined in conjunction with the receiving waste facility's analysis requirements. Waste water generated during purging or decontamination activities will be temporarily stored in 55-gallon drums or poly-totes and transferred into the GW-11 Pond. Containers used to store waste will be labeled with "pending analysis" labels, the date accumulation began, contents, source, and contact information, and stored in a designated area.

4.0 TREATABILITY STUDY CONCEPTUAL DESIGN

4.1 TREATBILITY STUDY OVERVIEW

The conceptual design for the treatability study, including system configuration, equipment, components of a performance monitoring plan, and management of extracted soil vapor and groundwater is described in the following sections. Baseline static groundwater elevations will be monitored over a period of one week prior to initiating the VER treatability study to evaluate typical daily fluctuations in groundwater elevations.

The VER treatability study consists of the following phases divided into two sequential, independent tests (intermediate and deep) to evaluate groundwater extraction performance with and without VER:

<u>Intermediate VER Treatability Study (Test 1; VER-01I):</u>

- Phase A - step-drawdown test;
- Phase B - constant-rate pumping test; and
- Phase C - VER test and post-VER test groundwater elevation monitoring period.

<u>Deep VER Treatability Study (Test 2; VER-01D):</u>

- Phase A - step-drawdown test;
- Phase B - constant-rate pumping test; and
- Phase C - VER test and post-VER test groundwater elevation monitoring period.

As discussed in Section 3.1, Tetra Tech proposes to use the sample results from the VER wells, VER-01I and VER-01D, and the deep monitoring wells, VMW-01D and VMW-02D, to further evaluate whether deeper perchlorate impacts are present within the proposed VER treatability study area. Following completion of Test 1, Tetra Tech will evaluate the results and initiate Test 2 if Test 1 is successful and significant concentrations of perchlorate are present in the deeper screened interval. Water extracted during these tests will be managed as discussed in Section 4.6.

4.1.1 Step-Drawdown Test (Phase A)

The step-drawdown test will be performed by pumping at three rates for approximately two hours each, similar to the procedure that was performed for the GWETS 2013 Optimization Project (ENVIRON, 2015). The rates will be confirmed during well development but may be 1 gpm, 3 gpm and 5 gpm. Flow rates will be monitored throughout the test with a direct reading rotameter-type flow meter and a totalizing flow meter. All flow rate changes and interruptions will be recorded, and the causes for such changes will be noted, if known. Flow rates will be adjusted to maintain the target rates through the duration of each step.

Electronic pressure transducer/data logger units will be used to record groundwater level changes over time in the extraction and observation wells. The pressure transducers will be set at least one day before aquifer performance testing begins to record barometric and diurnal effects on static water levels. Atmospheric pressure will be recorded throughout the test period to correct the pressure transducer data for barometric pressure fluctuations. Water levels will also be manually monitored and recorded on a periodic basis as a backup.

Water level recovery data will be collected from the time pumping is terminated until the end of the test, defined as when water levels have recovered to within 90 percent of initial static levels. The results of the step-drawdown tests will be evaluated to determine the pump size, well efficiency, and target extraction rate for the constant-rate pump tests described below.

4.1.2 Constant-Rate Pumping Test (Phase B)

After water levels in the extraction and monitoring wells have recovered following the step-drawdown test, constant-rate pumping tests will be conducted. The flow rate for this test will be determined using the data obtained during the step-drawdown test. Flow rates, drawdown, and water level recovery data will be monitored as described above for the step-drawdown test. In addition, at least one monitoring well outside the likely area of influence of the pumping test will be monitored. In order to obtain the radius of influence of each well at steady state conditions, pumping will continue until water levels as measured at the newly installed monitoring wells, VMW-01 and VMW-02, change less than 0.01 ft over the period of 30 minutes. Water management procedures for extracted groundwater are discussed in Section 4.6.

4.1.3 VER Test (Phase C)

The VER test will be conducted following the constant-rate test after confirming the aquifer has recovered to baseline conditions and making the necessary wellhead modifications and system connections. During the VER test, a submersible pump placed in VER-01I or VER-01D will be used to depress groundwater while an approximate vacuum of 18 to 23 inches of mercury (in Hg) is applied to VER-01I or VER-01D using a liquid-ring pump or a high vacuum blower. The data to be obtained during the VER test are:

- Groundwater radius of influence;
- Extraction rate;
- Extracted groundwater concentrations;
- Required vacuum pressure;
- Vapor extraction radius of influence;
- Air flow rate; and
- Extracted vapor concentrations.

The VER test will continue until near equilibrium conditions are achieved. For this test, near equilibrium conditions will be considered achieved when water levels, as measured at the newly installed monitoring wells VMW-01 and VMW-02, change less than 0.01 ft over the period of 30 minutes. The equilibrium conditions are based on water levels as the vapor phase will typically reach equilibrium much sooner than the water phase. Once the equilibrium conditions have been met, the groundwater pump and blower will be turned off and the post-VER test groundwater elevation monitoring period will begin. The post-VER test groundwater elevation monitoring period will continue until baseline conditions are reached and the data obtained will be used to evaluate changes in groundwater elevation and groundwater recharge rates after VER implementation. The performance monitoring network, field measurements, and samples collected during the VER treatability study are described in Section 4.3. Water management procedures for extracted groundwater at discussed in Section 4.6.

4.2 SYSTEM CONFIGURATION

This section focuses on the individual components that comprise the VER system. Based on considerations regarding cost and operational flexibility, Tetra Tech may utilize a mobile, trailer-mounted VER system provided by a subcontractor or design an on-site VER system to conduct the VER treatability study (Figure 9). Tetra Tech will conduct this analysis and confer with the Trust on which system will be used.

The groundwater extraction portion of the VER system at VER-01I and VER-01D will utilize the following key components:

- Groundwater extraction pump that discharges groundwater to an aboveground storage tank;
- Well manifold; and
- Flowmeter, pressure gauges, valves, and connections.

The vacuum-enhancement portion of the VER system at VER-01I and VER-01D will utilize the following key components:

- Drop tube and well manifold;
- Suction separator (air-liquid separator, also referred to as a knock-out tank);
- Liquid-ring pump or high vacuum blower that applies vacuum to the extraction well and transfers soil vapor from the suction separator to a vapor-phase carbon vessel;
- Centrifugal pump that transfers effluent (liquid phase) from the suction separator to an aboveground storage tank;
- Flowmeters for soil vapor and effluent (located after the suction separator);
- Pressure and vacuum gauges, valves, connections, and discharge piping; and
- Vapor-phase carbon vessel.

4.3 EQUIPMENT NEEDS

The field instruments needed to complete the VER treatability study consist of:

- Photoionizaton detector (PID) equipped with a 11.7 eV lamp;
- Water level meters;
- Water quality meter; and
- Submersible pressure transducers with data logging capabilities.

The equipment needed to complete the VER treatability study consists of:

- Pitot tube with gauges (soil vapor emissions flow rate monitoring);
- Magnehelic® differential pressure gauges;
- Orfice meter/flow sensor;
- Tedlar bags or Summa canisters, air sampling pump, and sample tubing;
- Groundwater sample tubing;
- Groundwater sampling bottleware and coolers;
- Personal protective equipment (Level D [personal protective equipment] in conjunction with nitrile, leather, and/or Kevlar gloves);
- Traffic control equipment including cones, cone bars, traffic control barriers, and high-visibility flags; and
- Portable generator (or an equivalent short-term power source).

4.4 MONITORING PLAN

This section describes the conceptual monitoring program to determine the effectiveness of VER during the treatability study. The monitoring program will consist of groundwater elevation and vacuum readings from the monitoring and extraction wells, groundwater and soil vapor sampling from the extraction well, and field measurements.

The effective radius of influence of the VER extraction well will be measured by installing pressure transducers equipped with a data logger and a well manifold with a vacuum gauge in four performance monitoring wells. The performance monitoring wells listed in Table 3 were selected to provide monitoring points that align with the four cardinal directions (quadrants) surrounding VER-01I and VER-01D. Depth-to-water measurements will be collected during the step-drawdown test, constant-rate pumping test, and VER pilot test on a hourly basis from each of the performance monitoring wells. Vacuum measurements will be collected on a hourly basis from each of the performance monitoring wells and the VER extraction well during the VER pilot test. The depth to water measurements will be collected using an electronic water level meter and vacuum readings will be collected using magnehelic gauges. The four monitoring wells included in the performance monitoring program and supplemental monitoring wells (where depth to water measurements may be collected on a periodic basis) are identifed in Table 3.

Table 3 Monitoring Wells in the Performance Monitoring Program

Monitoring Well	Location and Distance from VER Extraction Well	Purpose
VMW-01I/D	45 Feet Northwest of VER-01I and 20 Feet Northeast of VER-01D	Nested Performance Monitoring Well #1; Assess extent of vacuum influence and drawdown
VMW-02I/D	30 Feet Southwest of VER-01I and 50 Feet South of VER-01D	Nested Performance Monitoring Well #2: Assess extent of vacuum influence and drawdown
M-172 (Screened 26.1 to 36.9 ft bgs)	26 Feet Northwest of VER-01I and 15 Feet East of VER-01D	Performance Monitoring Well #3: Assess extent of vacuum influence and drawdown
M-78 (Screened 21.5-41.5 ft bgs)	130 Feet Northwest of VER-01I and 100 Feet West of VER-01D	Performance Monitoring Well #4: Assess extent of vacuum influence and drawdown
M-56 (Screened 15.1-40 ft bgs)	85 Feet Northeast of VER-01I and 100 Feet East of VER-01D	Performance Monitoring Well #5: Assess extent of vacuum influence and drawdown
I-F (Screened 11.8-41.8 ft bgs)	40 Feet Northwest of VER-01I and 10 Feet Northeast of VER-01D	IWF Well: Assess extent of drawdown and potential effects of VER extraction well operation
M-65 (Screened 14.4-39 ft bgs)	65 Feet Southwest of VER-01I and 90 Feet South of VER-01D	Supplemental Well: Assess extent of drawdown
M-65D [1] (Screened 60-70 ft bgs)	70 Feet South-southeast of VER-01I and 100 Feet Southeast of VER-01D	Supplemental Well: Assess extent of drawdown
M-162 (Screened 100-110 ft bgs)	130 Feet North of VER-01I and 110 feet North of VER-01D	Supplemental Well: Assess extent of drawdown
M-163 (Screened 80-90 ft bgs)	130 Feet North of VER-01I and 100 Feet North of VER-01D	Supplemental Well: Assess extent of drawdown
M-164 (Screened 60-70 ft bgs)	140 Feet North of VER-01I and 115 Feet North of VER-01D	Supplemental Well: Assess extent of drawdown
M-221 [1] (Screened 75-85 ft bgs)	70 Feet South-southeast of VER-01I and 100 Feet Southeast of VER-01D	Supplemental Well: Assess extent of drawdown
M-222 [1] (Screened 100-110 ft bgs)	80 Feet Southwest of VER-01I and 90 Feet Southwest of VER-01D	Supplemental Well: Assess extent of drawdown
VER-01I (Screened 55-70 ft bgs)	35 Feet Southeast of VER-01D	Supplemental Well: Assess extent of drawdown (during the deep VER pilot test)

Notes:

1. Monitoring wells M-65D, M-221, and M-222 are proposed to be installed as part of the Phase 2 Remedial Investigation.

4.4.1 Constant-Rate Pumping Test Monitoring (Phase B)

During the constant-rate pumping tests (i.e. Phase B) for each the intermediate VER and deep VER tests, groundwater samples will be collected before the start of the test and every 12 hours after the start of the test until the the performance monitoring criteria are achieved. Table 4 presents the sampling protocol for a 24-hour test for use as an example.

Groundwater samples will be collected using a groundwater sample port installed on the extraction well manifold (Figure 9). The extracted groundwater will be sampled during the constant-rate pumping test for general water quality parameters, primary contaminants, as well as volatile organic compounds (VOCs), as presented in Table 4. The samples will be analyzed for VOCs since chloroform is known to be present in the shallow WBZ in the vicinity of the VER treatability study area (Ramboll Environ, 2016a) and will need to be evaluated.

Table 4 Groundwater Sampling Protocol for the Constant-Rate Pumping Test (Phase B)

Analytical Requirements		**Sampling Frequency (Hours After Start of Constant-Rate Pumping Test)**		
Parameter	**Analytical Method**	**BL**	**12**	**24**
EC	Field Meter	X	X	X
pH	Field Meter	X	X	X
DO	Field Meter	X	X	X
ORP	Field Meter	X	X	X
Temperature	Field Meter	X	X	X
Turbidity	Field Meter	X	X	X
Laboratory Analyses				
Perchlorate	E314	X	X	X
Chlorate/Chlorite	E300.1	X	X	X
Hexavalent Chromium	SW7199	X	X	X
Total Chromium	SW-6010B or 6020	X	X	X
VOCs	SW-846 5035A	X	X	X

Acronyms:

BL: Baseline
DO: Dissolved oxygen
EC: Electrical conductivity
ORP: Oxidation-reduction potential
VOCs: Volatile organic compounds

4.4.2 VER Test Monitoring (Phase C)

During Phase C of the intermediate VER and deep VER tests, baseline groundwater samples will be collected before the start of the test and every 12 hours following the start of the test up. Groundwater samples will be collected using a groundwater sample port installed on the extraction well manifold (Figure 9). The groundwater sampling protocol for the VER pilot test is presented in Table 5. This table presents the sampling protocol for a 60-hour test for use as an example. The groundwater sample collected at the end of the VER pilot test will be analyzed for additional parameters consisting of alkalinity, calcium, hardness, iron, magnesium, manganese, nitrate, sulfate, sulfite, total dissolved metals, total nitrogen, total phosphorus, total dissolved solids, and total suspended solids. The concentrations of these parameters will have an effect on the design of a potential water treatment unit and may affect the recovery well construction for potential full-scale application.

Table 5 Groundwater Sampling Protocol for the VER Test (Phase C)

Analytical Requirements		Sampling Frequency (Hours After Start of VER Test)					
Parameter	**Analytical Method**	**BL**	**12**	**24**	**36**	**48**	**60***
EC	Field Meter	X	X	X	X	X	X
pH	Field Meter	X	X	X	X	X	X
DO	Field Meter	X	X	X	X	X	X
ORP	Field Meter	X	X	X	X	X	X
Temperature	Field Meter	X	X	X	X	X	X
Turbidity	Field Meter	X	X	X	X	X	X
Perchlorate	E314	X	X	X	X	X	X
Chlorate/Chlorite	E300.1	X	X	X	X	X	X
VOCs	SW-846 8260B	X	X	X	X	X	X
Hexavalent Chromium	SW7199	X	X	X	X	X	X
Total Chromium	200.7	X	X	X	X	X	X
Alkalinity	SM 2320B						X
Calcium	200.7						X
Dissolved Metals	SW6010/6020						X
Ferrous and Ferric Iron	HACH Method 8008 & 8147						X
Hardness	SM 2340C						X
Magnesium	200.7						X
Manganese	SW6010B						X
Nitrate	E300/SW9056						X
Sulfate	E300/SW9056						X
Sulfite	HACH Method 8131						X
Total Nitrogen	E351.1						X
Total Phosphorus	E365.1						X
TDS	SM 2540C						X
TOC	SM 5310B						X
TSS	160.2						X

Acronyms and Notes:

BL: Baseline
DO: Dissolved oxygen
EC: Electrical conductivity
ORP: Oxidation-reduction potential
TDS: Total dissolved solids
TOC: Total organic carbon
TSS: Total suspended solids
VOCs: Volatile organic compounds
Dissolved metals includes the following: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, uranium, vanadium, and zinc

* The final sampling event will correspond with the end of the VER Test.

Soil vapor samples will be collected from the influent and effluent vapor treatment soil vapor sample ports, SP-302 and SP-303, as depicted on Figure 9. The soil vapor sampling protocol for the VER pilot test during Phase C of the intermediate VER and deep VER tests is presented as Table 6. This table presents the sampling protocol for a 60-hour test for use as an example.

Table 6 Soil Vapor (Air) Sampling Protocol for the VER Test (Phase C)

Analytical Requirements		Sampling Frequency (Hours After Start of VER Test)							
Parameter	**Analytical Method**	**BL**	**4**	**8**	**12**	**24**	**36**	**48**	**60***
Field Parameters									
PID Measurements	Field Meter	X	X	X	X	X	X	X	X
Laboratory Analyses									
VOCs	TO-15	X	X	X	X	X	X	X	X

Acronyms and Notes:

BL: Baseline
PID: Photoionization detector
*The final sampling event will correspond with the end of the VER test.

The field measurements to be collected during Phase C of the intermediate VER and deep VER tests are summarized in Table 7.

Table 7 VER Treatability Study Field Measurements (Phase C)

Field Measurement	Equipment	Purpose
Groundwater Pumping Rate	Flowmeter	Determining the groundwater extraction rate during the VER treatability study
Groundwater Elevation	Pressure Transducers or Water Level Meter	Determining radius of influence for VER-01I and VER-01D and drawdown in performance monitoring wells during the VER treatability study, and groundwater recharge/recovery rates after the VER pilot test
Groundwater Quality Parameters (pH, DO, EC, ORP, Temperature, Turbidity)	YSI or Horiba Water Quality Meter	Evaluating groundwater quality and aquifer characteristics during the VER treatability study
Vapor-Phase VOCs	PID	Measuring the organic vapor concentration of the air extracted from VER-01I and VER-01D
Air Flow Rate (Soil Vapor Emissions Rate)	Orifice Meter/Flow Sensor	Determining the soil vapor extraction rate during the VER pilot test
Vacuum Influence (At Monitoring Wells)	Magnehelic® Differential Pressure Gauges	Determining radius of influence for VER-01I and VER-01D, measured at performance monitoring well wellhead
VER System Vacuum	Differential Pressure Gauge	Maintaining constant pressure during the VER treatability study at the liquid-ring pump

Acronyms and Abbreviations:

DO: Dissolved oxygen
EC: Electrical conductivity
ORP: Oxidation-reduction potential
PID: Photoionization detector
VER: Vacuum Enhanced Recovery
VOCs: Volatile organic compounds

4.5 MASS REMOVAL ESTIMATION

Estimates of mass removal rates for groundwater and soil vapor extraction will be calculated separately using analytical data and volumetric flow rates of groundwater and soil vapor emissions collected during the treatability study. Mass removal rates for groundwater will be estimated for both Phases B and C in the intermediate VER and deep VER tests, but mass removal rates for soil vapor extraction will only be estimated for Phase C in the intermediate VER and deep VER tests. A comparative analysis of mass removal rates will be conducted as part of the evaluation and interpretation of the VER treatability study data.

4.6 MANAGEMENT OF EXTRACTED GROUNDWATER AND SOIL VAPOR

Extracted groundwater, personal protective equipment, and equipment decontamination water generated during the VER treatability study will be managed according to applicable state, federal, and local regulations and as described in Field Guidance Document No. 001, Managing Investigation-Derived Waste (ENVIRON, 2014b).

Extracted groundwater will be temporarily stored in an aboveground storage tank staged within a secondary containment berm pending the receipt of analytical results of waste characterization sampling prior to transfer via discharge piping or a tanker truck to the on-site GWTP. Equipment decontamination water will be temporarily stored in 55-gallon drums and transferred into the GW-11 Pond. Waste storage containers will be labeled with "pending analysis" labels, the date accumulation began, contents, source, and contact information, and stored in a designated area.

As discussed in Section 5.0, due to the relatively low chloroform and other VOC concentrations present in the vicinity of the treatability study area, an air permit from Clark County Department of Air Quality and vapor treatment will not be required for implementation of VER. However, a vapor-phase carbon treatment system will be used during the VER phase of both the intermediate test and deep test as a precautionary measure.

4.7 EVALUATION AND INTERPRETATION OF STUDY DATA

Groundwater flow modeling will be used to simulate the aquifer tests at the VER test wells, VER-01I and VER-01D. The objectives for the groundwater flow modeling are to simulate the extraction of groundwater with and without vacuum in the UMCf from the VER test wells and to estimate the expected drawdown, pumping rates and the capture zone at the VER test wells. The simulated drawdown and capture zone will be used to predict if the IWF wells will be influenced by the VER wells in the UMCf. Developing a calibrated model will be critical in determining how VER technology could be used at a larger scale at the NERT Site, if successful.

The groundwater flow model for this treatability study (VER Model) will be based on Ramboll Environ's Phase 5 groundwater flow model (Ramboll Environ, 2016c) and will be calibrated to the constant rate-aquifer tests (Phase B of the intermediate and deep VER tests). The model parameters that will likely be modified during calibration include horizontal and vertical hydraulic conductivity and storage coefficients to match water level changes from this aquifer testing. To obtain a more accurate calibration, the VER Model grid will be further discretized both horizontally and vertically to simulate the correct location of the well screens in the pumping and monitoring wells. The model grid will also be reduced in spatial extent to focus on the VER study area to reduce computational time. Boundary conditions will be set far enough away to not influence water-level changes at the IWF or VER wells, The VER Model will be converted to MODFLOW-SURFACT to utilize their PCG5 (preconditioned conjugate gradient) solver and ATO (adaptive time-stepping and output control) package, which is more robust, faster, and able to achieve convergence for complex groundwater conditions, such as this study. The VER Model will also use the MNW (multi-node well) or FWL (fracture-well) package, which allows the user to specify well pump levels so extraction wells will not dry up, but will be drawdown-limited based on the water-level and pump elevations.

Once the VER Model is calibrated, then it will be used to simulate the VER test at the VER test wells. Conventional groundwater flow models, such as MODFLOW, cannot directly simulate VER. Therefore, a correction factor will be applied to the extraction rate at the VER test wells (under vacuum) to simulate the effects of VER in low permeability sediments, such as the UMCf. The correction factor is an exponential term that relates the radius of influence to the distance to the downgradient stagnation point. Multiplying the VER well extraction rates by this correction factor will create more drawdown and a larger capture zone (i.e, with vacuum) then would be simulated without the correction factor (i.e., no vacuum).

5.0 PERMITTING REQUIREMENTS AND HEALTH AND SAFETY

5.1 PERMITTING REQUIREMENTS

The VER treatability study will require a NAC 534.441 Waiver to Drill a Monitoring Well and a NAC 534.320 Notice of Intent to Drill to install monitoring wells. As required, the 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.

Proposed extraction wells VER-01I and VER-01D are outside of the quarter-quarter section permitted for current extraction wells associated with the AP Area Soil Flushing Treatability Study under Permit #86355E. The new extraction wells will require a new Permit to Appropriate Water for Environmental Purposes issued by the Nevada Division of Water Resources.

Dust Control Permit #47835 was issued by the Clark County Department of Air Quality on June 15, 2017 for proposed treatability study activities within the AP Area, including the VER treatability study area.

Clark County Rule 12.1.1(a) exempts sources from obtaining a minor source air permit if they fall below the potential to emit thresholds for criterial pollutants listed in Rule 12.1.1(c). The threshold for VOCs is 5 tons per year (TPY). Using available groundwater concentrations and maximum estimated vapor flow rates, Tetra Tech has determined the potential VOC emissions from the proposed VER treatability study will not approach this threshold. A minor source air permit, therefore, is not anticipated to be required.

5.2 HEALTH AND SAFETY

Field work will be conducted in accordance with an Activity Hazard Analysis and other elements of the site-wide Health and Safety Plan, which will address potential chemical and physical hazards associated with the VER treatability study and associated tasks. It is anticipated that modified Level D personal protective equipment will be required for all field activities.

6.0 REPORTING AND DATA VALIDATION

6.1 REPORTING

Throughout the duration of the VER Treatability Study, monthly progress reporting will be prepared consistent with those being produced for other studies currently in progress.

Following completion, a VER Treatability Study Report will be prepared. The report will include the following:

- Summary of soil and groundwater analytical results;
- Summary of effectiveness monitoring program data and VER treatability study results;
- Summary of mass recovery data; and
- Results of groundwater modeling to evaluate the effect operating deeper extraction wells will have on groundwater flow and the operation of the existing IWF wells.

6.2 DATA VALIDATION

Field sampling will be conducted in accordance with the existing Site Management Plan Revision 3 (Ramboll Environ, 2017) and Field Sampling Plan (ENVIRON, 2014b). Sampling and analytical methods are selected to meet the project data quality objectives (DQOs) and quality control criteria. Analytical data collected during the completion of the VER Treatability Study will be verified and validated in accordance with US EPA Region 9 Superfund Data Evaluation/Validation Guidance, NDEP Remediation of the Basic Management Incorporated (BMI) Complex and Common Areas data validation guidance documents (collectively referred to herein as the validation protocols). Data verification and validation will be performed by a competent, qualified person with prior environmental data validation experience, knowledge of the task-specific objectives, and knowledge of analytical methodology.

Soil, groundwater, and soil vapor samples will be sent to a qualified laboratory for analysis. Soil samples for geophysical properties, including porosity, hydraulic conductivity, and grain size, will be sent to a qualified geotechnical laboratory for analysis. Laboratories will provide data in portable document format (PDF) and in electronic data deliverables (EDD) that contain sufficient and appropriate data to allow verification and validation at the required levels. Validation will be based on quality control requirements found in the US EPA functional guidelines, analytical methods, the site-wide quality assurance project plan, NDEP documents, and laboratory standard operating procedures. The soil, groundwater, and soil vapor samples require a Stage 2A verification and validation. For 90 percent of the soil, groundwater, and soil vapor samples, a Level III data package will be requested from the laboratory. For 10 percent of the soil, groundwater, and soil vapor samples, a Level IV data package will be requested from the laboratory. The waste characterization samples, consisting of soil cuttings generated during the monitoring well installation activities, and soil samples for geophysical properties require a Stage 1 verification and validation.

Data quality flags as assigned by the analytical laboratory will be independently reviewed against the validation protocols. Individual values may be flagged as non-detect, detected and qualified (e.g., biased high, biased low, estimated), or rejected. An analysis result flagged as rejected cannot be used. At the completion of data validation, validation findings will be uploaded to the NERT database, and a Data Validation Summary Report will be prepared and presented with the VER Treatability Study Report.

7.0 SCHEDULE

The following table provides the general schedule for the primary deliverables and activities associated with implementing the VER treatability study. This schedule is contingent upon Trust and NDEP and EPA approval of this Work Plan, regulatory agency approval of applicable permits, Trust approval of funding and notice to proceed.

Table 8 Preliminary Project Schedule

Task/Milestone	Estimated Start Date	Estimated Completion Date
Monitoring and VER Well Installation	September 2017	September 2017
VER Treatability Study	October 2017	December 2017
VER Treatability Study Report	December 2017	March 2018

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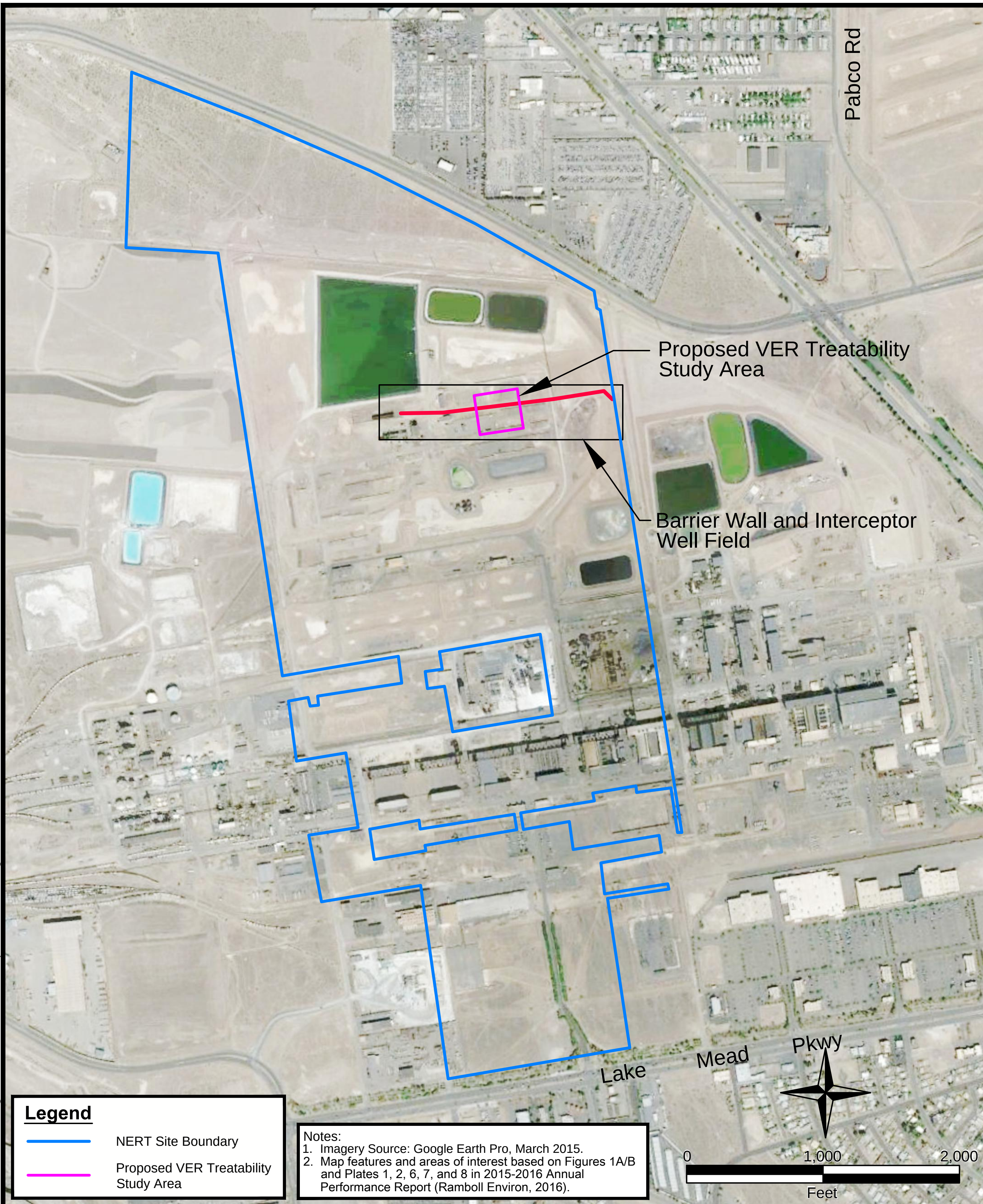
Figures



Legend

NERT Site Boundary

Proposed VER Treatability Study Area

Notes:
1. Imagery Source: Google Earth Pro, March 2015.
2. Map features and areas of interest based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

\\tts318fs1\tt.local\ces\ 87600015-NERT\ Figure 1 - Site Location Map 87600015.dwg

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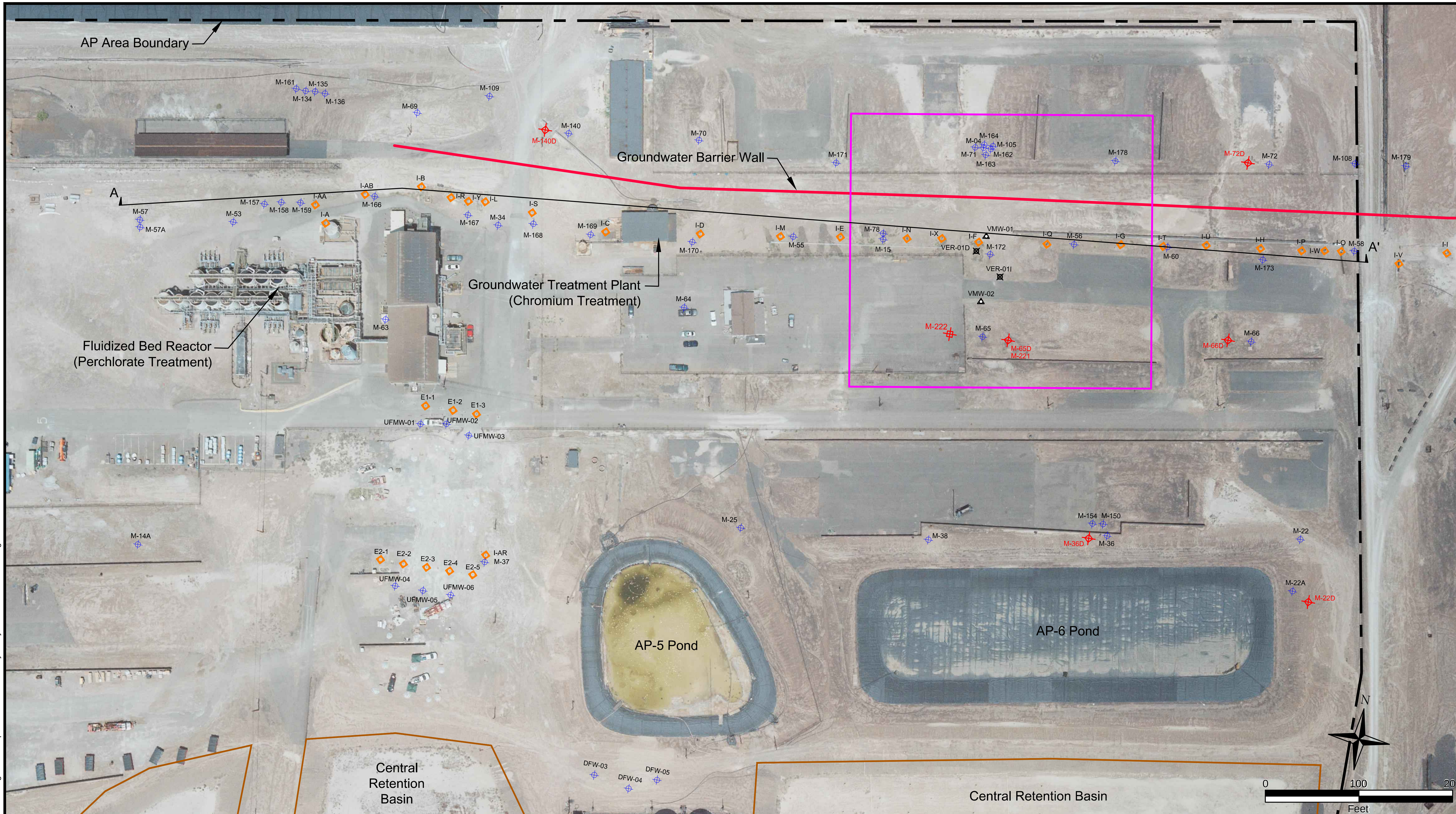
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

SITE LOCATION MAP

Project No:	87600015
Date:	AUGUST 23, 2017
Designed By:	CL
Figure No.	1



Legend

M-55	Monitoring Well	VER-01I	Proposed Intermediate VER Well Location (Tt)
I-M	Extraction Well	VER-01D	Proposed Deep VER Well Location (Tt)
MW-22D	Planned Deeper Shallow WBZ Well (Ramboll)	VMW-01	Proposed Middle WBZ Well (Tt)
MW-222	Planned Middle WBZ Well (Ramboll)	A A'	Cross Section Line
	Proposed VER Treatability Study Area		

Notes:

1. Imagery Source: Aerotech Mapping, August 2016.
2. Monitoring well, extraction well, and groundwater barrier wall locations based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

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VACUUM ENHANCED RECOVERY TREATABILTY STUDY

PROPOSED VER TREATABILITY STUDY LOCATION

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Date:	AUGUST 23, 2017
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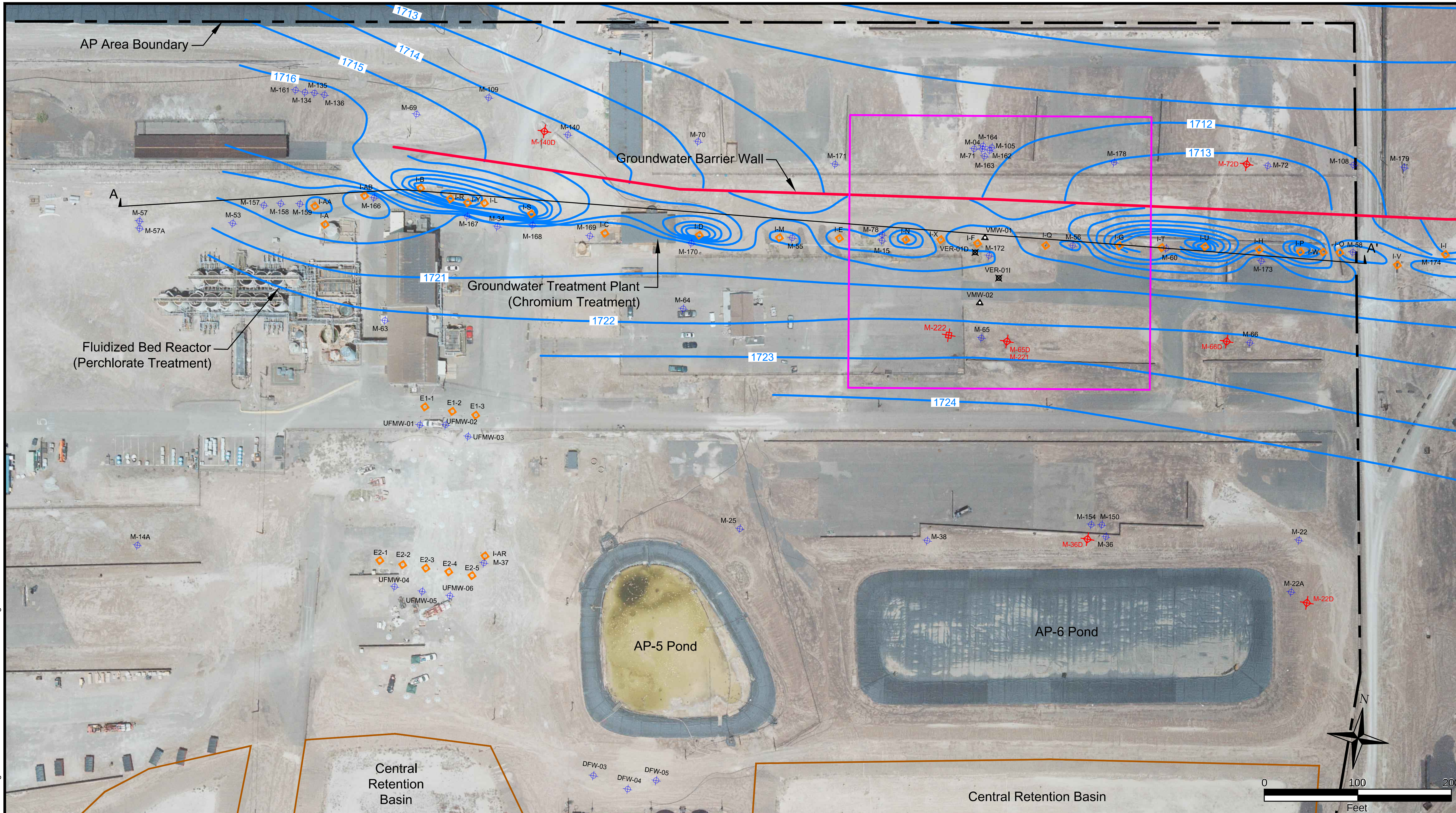
Figure No.	2

\\tts318fs1\tt.local\ces\ 87600015-NERT\ Figure 2 - Proposed VER Treatability Study Location 87600015.dwg



Legend

M-55	Monitoring Well	VER-01I	Proposed Intermediate VER Well Location (Tt)
I-M	Extraction Well	VER-01D	Proposed Deep VER Well Location (Tt)
MW-22D	Planned Deeper Shallow WBZ Well (Ramboll)	VMW-01	Proposed Middle WBZ Well (Tt)
MW-222	Planned Middle WBZ Well (Ramboll)	A A'	Cross Section Line
	Proposed VER Treatability Study Area	1713	Approximate Potentiometric Surface Contour (Feet Above Mean Sea Level)

Notes:

1. Imagery Source: Aerotech Mapping, August 2016.
2. Monitoring well, extraction well, and groundwater barrier wall locations based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

GROUNDWATER ELEVATIONS

Project No:	87600015
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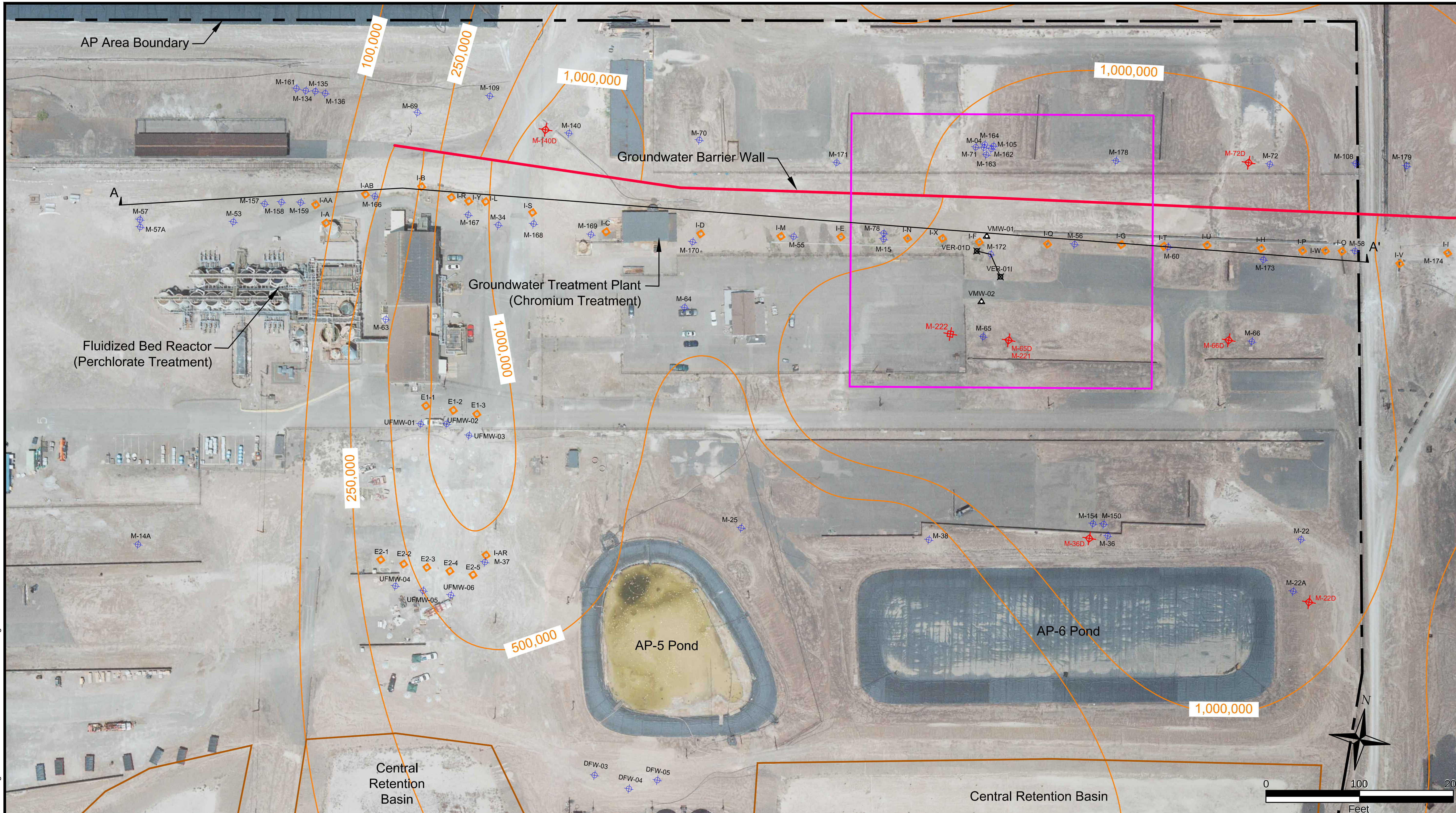
Figure No.	3

\\tts318fs1\tt.local\ces\ 87600015-NERT\ Figure 3 - Groundwater Elevations 87600015.dwg



Legend

M-55	Monitoring Well	VER-01I	Proposed Intermediate VER Well Location (Tt)
I-M	Extraction Well	VER-01D	Proposed Deep VER Well Location (Tt)
MW-22D	Planned Deeper Shallow WBZ Well (Ramboll)	VMW-01	Proposed Middle WBZ Well (Tt)
MW-222	Planned Middle WBZ Well (Ramboll)	A A'	Cross Section Line
	Proposed VER Treatability Study Area	1,000,000	Approximate Perchlorate Contour (µg/L; Micrograms Per Liter)

Notes:

1. Imagery Source: Aerotech Mapping, August 2016.
2. Monitoring well, extraction well, and groundwater barrier wall locations based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

PERCHLORATE PLUME

Project No:	87600015
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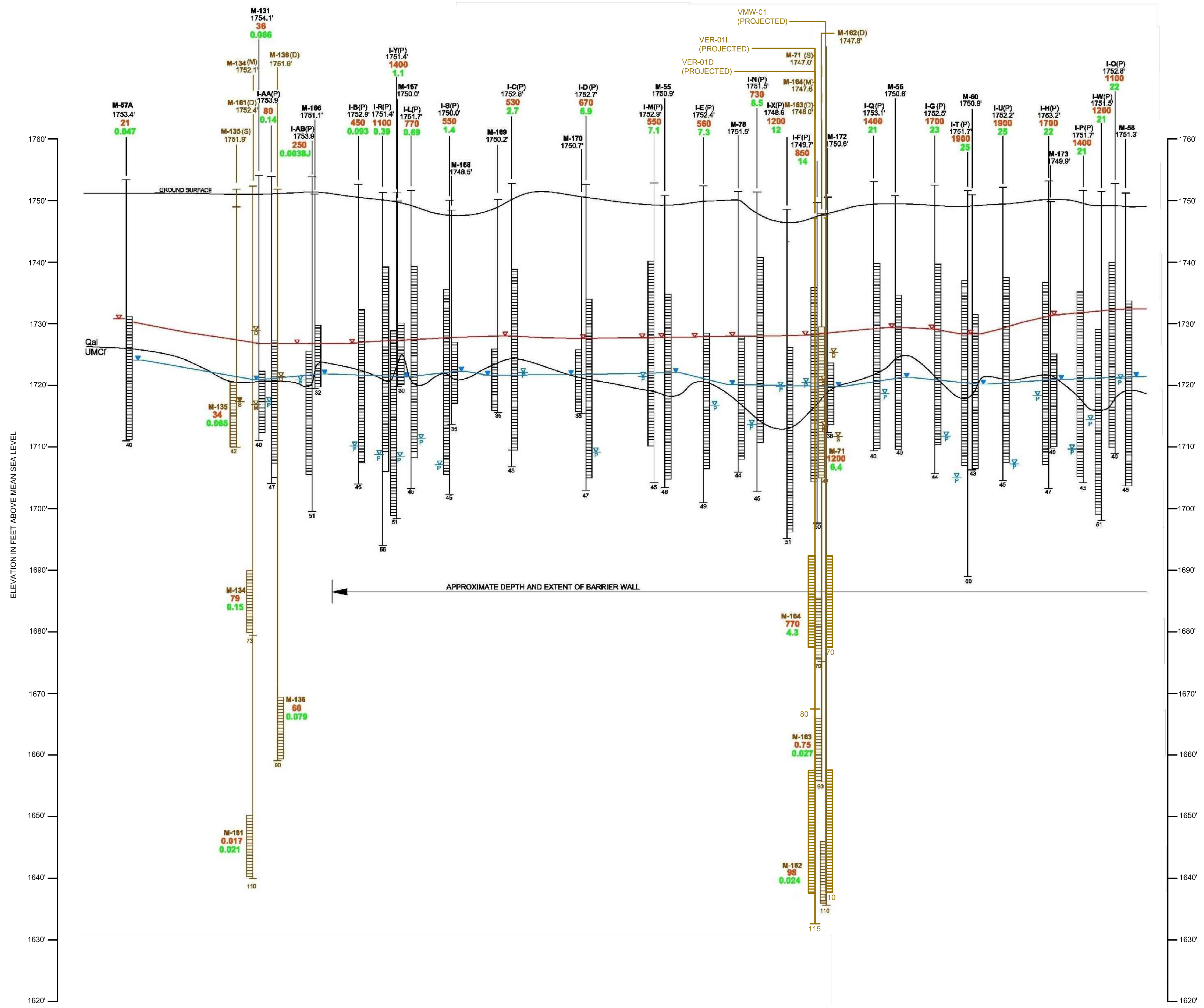
Figure No.	4

\\tts318fs1.tt.local\ces\ 87600015-NERT\ Figure 4 - Perchlorate Plume 87600015.dwg



Projected 1750.0'
1750.0' Top of Casing Elevation
Screened Interval
(S) Shallow
(M) Middle
(D) Deep
(R) Right
(L) Left
Blank Casing
QAL-UMCf Contact
57 57 Borehole Depth (FT BGS)

Legend

UMCf	Upper Muddy Creek Formation
Qal	Alluvium
(P)	Pumping
J	Estimated Concentration
940	Perchlorate Concentration, May 2016 (mg/L)
3.1	Total Chromium Concentration, May 2016 (mg/L)

Wells Upgradient Of Barrier Wall:

- Static Water Level Prior to Initial Pumping, September 1987
- Groundwater Levels Measured, May 2016
- Water Level from Pumping Well, May 2016

Wells Downgradient Of Barrier Wall:

- Water Level from Deep Well, May 2016
- Water Level from Middle Well, May 2016
- Water Level from Shallow Well, May 2016

Vertical Scale in Feet: 0 5 10
Horizontal Scale in Feet: 0' 40' 80'

Notes:

1. Hydrogeologic Cross Section Source: Ramboll Environ, Annual Remedial Performance Report for Chromium and Perchlorate, October 31, 2016.
2. The shallow, middle, and deep screened interval designations are used to distinguish well screens in this cross section and do not refer to NDEP's definition of the water bearing zones (WBZs).

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

CROSS SECTION A-A'

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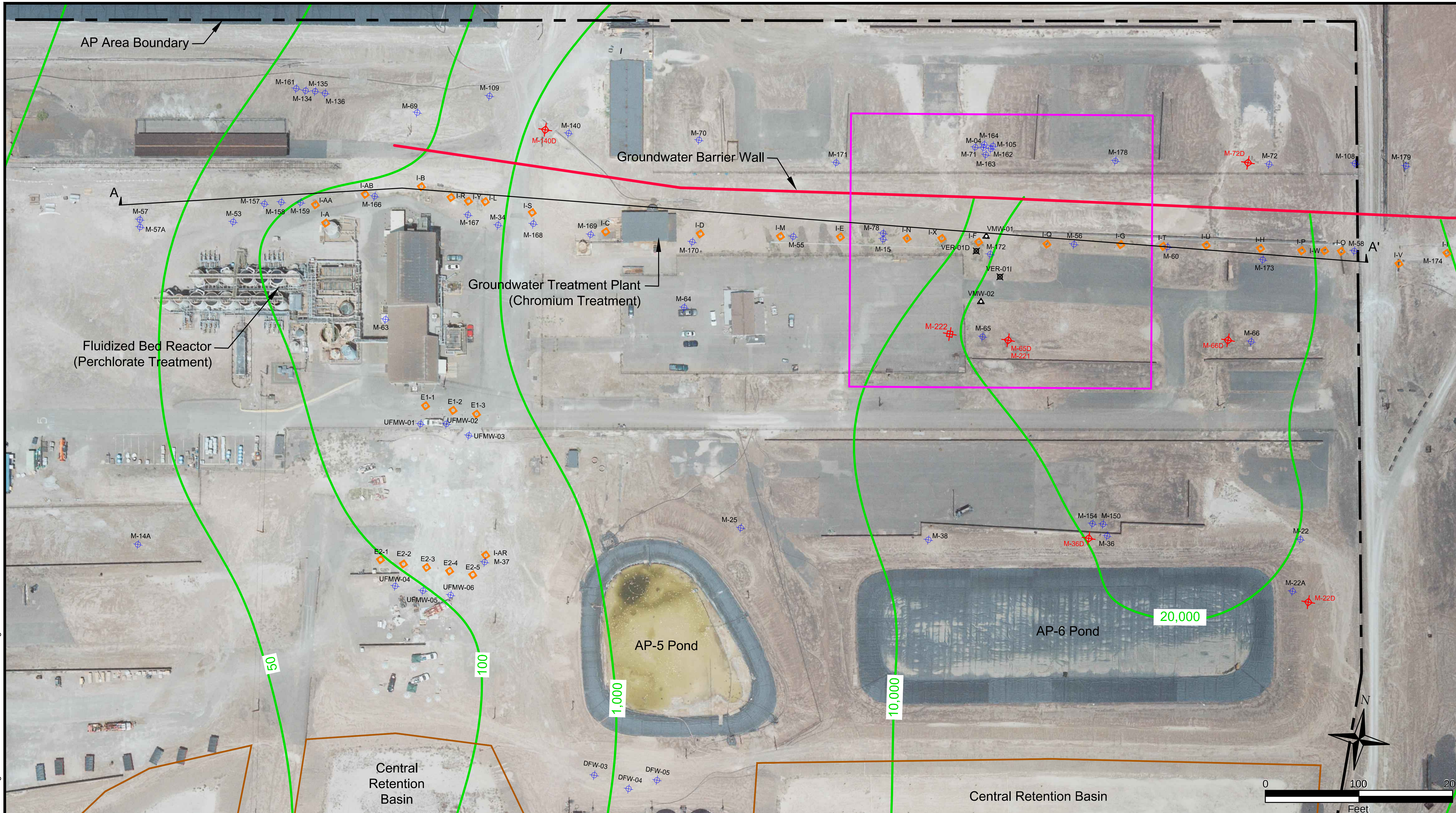
Figure No.	5

\\tts318fs1\tt.local\ces\ 87600015-NERT\ Figure 5 - Cross Section A-A' 87600015.dwg



\\tts318fs1.tt.local\ces\ 87600015-NERT\ Figure 6 - Chromium Plume 87600015.dwg

Legend

M-55	Monitoring Well	VER-01I	Proposed Intermediate VER Well Location (Tt)
I-M	Extraction Well	VER-01D	Proposed Deep VER Well Location (Tt)
MW-22D	Planned Deeper Shallow WBZ Well (Ramboll)	VMW-01	Proposed Middle WBZ Well (Tt)
MW-222	Planned Middle WBZ Well (Ramboll)	A A'	Cross Section Line
	Proposed VER Treatability Study Area	1,000	Approximate Chromium Contour (µg/L; Micrograms Per Liter)

Notes:

1. Imagery Source: Aerotech Mapping, August 2016.
2. Monitoring well, extraction well, and groundwater barrier wall locations based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

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VACUUM ENHANCED RECOVERY TREATABILTY STUDY

CHROMIUM PLUME

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Figure No.	6

Legend

M-65	Monitoring Well	VER-01I	Proposed Intermediate VER Well Location (Tt)
I-F	Extraction Well	VER-01D	Proposed Deep VER Well Location (Tt)
MW-66D	Planned Deeper Shallow WBZ Well (Ramboll)	VMW-01	Proposed Middle WBZ Well (Tt)
MW-222	Planned Middle WBZ Well (Ramboll)		Staging Area for VER Treatability Study Equipment
	Proposed VER Treatability Study Area		

Notes:
1. Imagery Source: Aerotech Mapping, August 2016.
2. Monitoring well, extraction well, and groundwater barrier wall locations based on Figures 1A/B and Plates 1, 2, 6, 7, and 8 in 2015-2016 Annual Performance Report (Ramboll Environ, 2016).

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

PROPOSED VER TREATABILITY STUDY LAYOUT

Project No: 87600015
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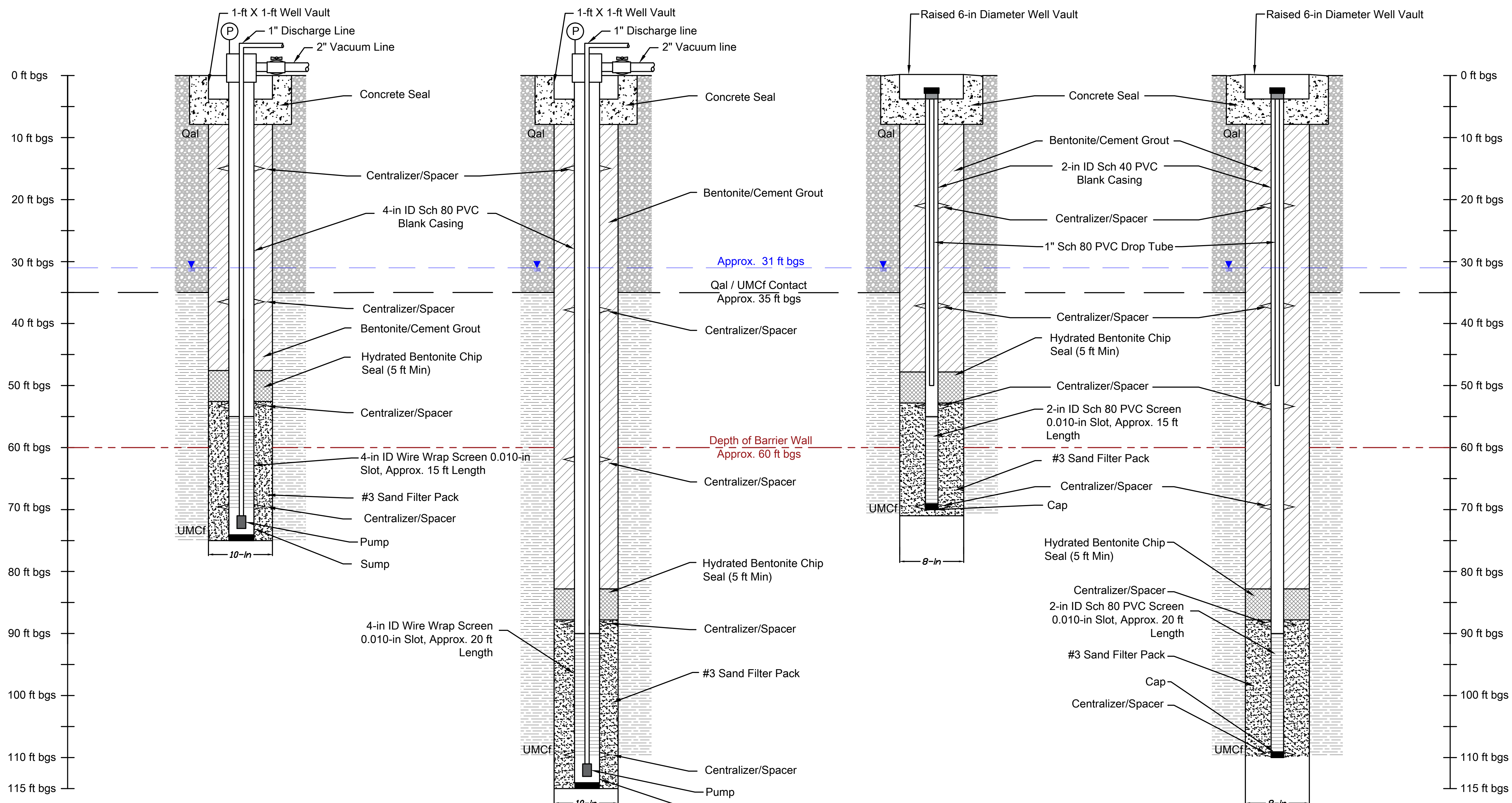
Figure No.
7

\\tts318fs1\tt.local\ces\ 87600015-NERT\ Figure 7 - Proposed Treatability Study Layout 87600015.dwg



Detail
Typical Intermediate Extraction Well
VER-01I

Detail
Typical Deep Extraction Well
VER-01D

Detail
Typical Shallow Monitoring Well
VMW-01S and VMW-02S

Detail
Typical Deep Monitoring Well
VMW-01D and VMW-02D

\\tts318fs1.tt.local\ces\ 87600015-NERT\ Figure 8 - Well Construction Diagrams 86700015.dwg

Legend

▼	Groundwater Level
Qal	Quaternary Alluvium
UMCf	Upper Muddy Creek Formation
FT BGS	Feet Below Ground Surface
Ⓟ	Pressure Gauge
	Valve

Notes:
1. Actual borehole size, well casing / screen depth, slot size interval, etc. to be determined based on field data and conditions and results of grain size analysis.
2. Scaled to approximate depth.

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VACUUM ENHANCED RECOVERY TREATABILTY STUDY

WELL CONSTRUCTION DIAGRAMS

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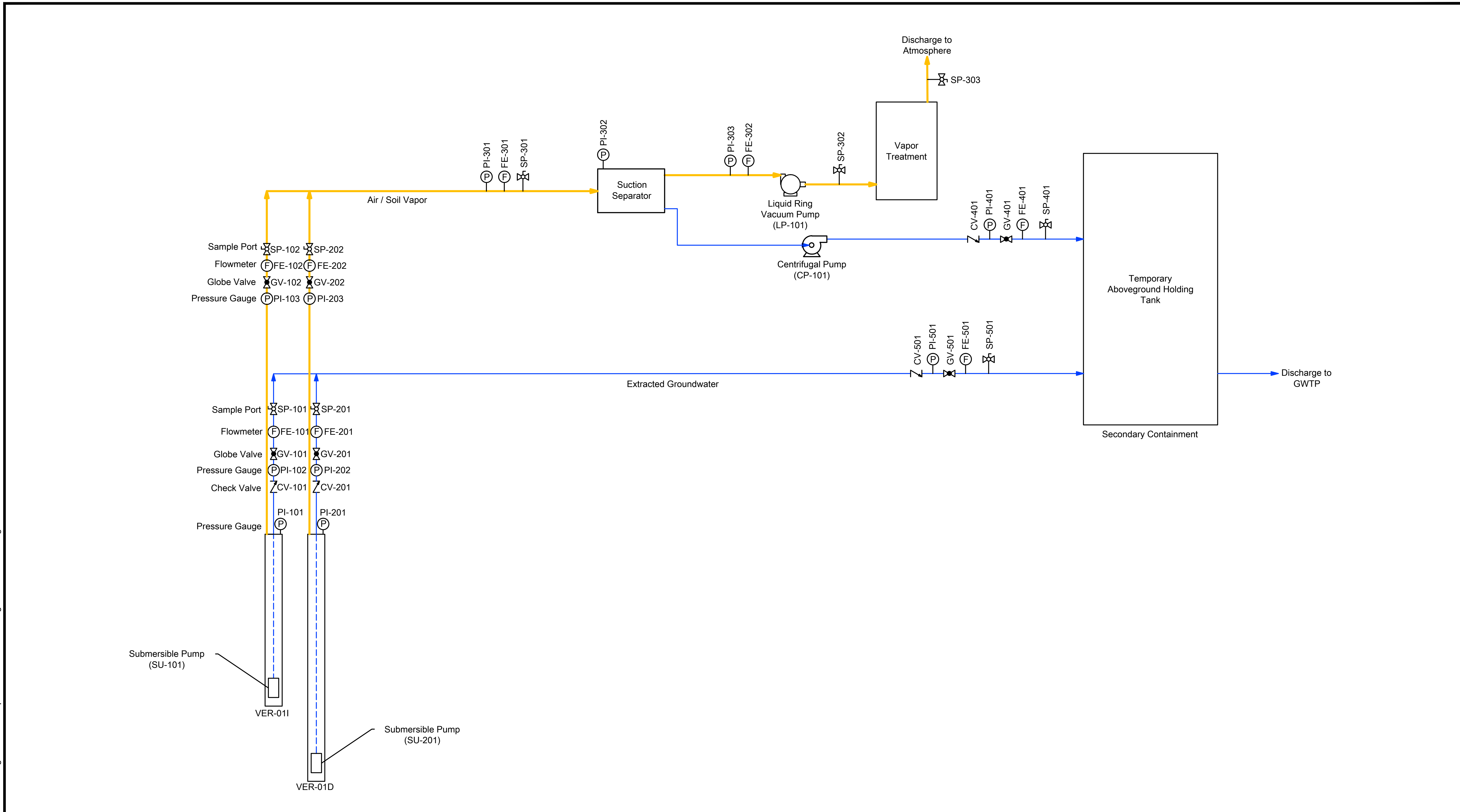
Figure No.	**8**



Legend

- Check Valve
- Pressure Gauge
- Globe Valve
- Flowmeter
- Sample Port

Extracted Groundwater Conveyance (Double Containment)

Air/Soil Vapor Conveyance

Notes:
1. Downhole pump extraction VER schematic depicted.
2. Vapor phase treatment may be conducted using on-site or mobile treatment such as skid-mounted granulated activated carbon vessels or similar.
3. Extracted groundwater will be temporarily containerized on site in an aboveground storage tank prior to transfer to the on-site GWTPs.
4. System controls not shown.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

VACUUM ENHANCED RECOVERY TREATABILTY STUDY

CONCEPTUAL PROCESS FLOW DIAGRAM

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Figure No.	9