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LAS VEGAS WASH ZVI-ENHANCED BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM

NEVADA ENVIRONMENTAL RESPONSE TRUST SITE HENDERSON, NEVADA

RAMBOLL

Las Vegas Wash ZVI-Enhanced Bioremediation Treatability 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 system(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, Inc., 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: [signature]

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: 9/29/21

**Las Vegas Wash ZVI-Enhanced Bioremediation Treatability Study
Work Plan Addendum**

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

Responsible Certified Environmental Manager (CEM) for this project

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 provided 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.

September 29, 2021

John M. Pekala, PG
Principal

Date

Certified Environmental Manager
Ramboll US Consulting, Inc.
CEM Certificate Number: 2347
CEM Expiration Date: September 20, 2022

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APPENDICES

ACRONYMS AND ABBREVIATIONS

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
BEC	Basic Environmental Company
bgs	below ground surface
Borax	sodium tetraborate
CEM	Certified Environmental Manager
COPC	Chemical of Potential Concern
CSU	Colorado State University
DAP	diammonium phosphate
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DOC	dissolved organic carbon
EBCT	empty bed contact time
ENVIRON	ENVIRON International Corporation
ESTCP	Environmental Security Technology Certification Program
EVO	emulsified vegetable oil
FBR	fluidized bed reactor
ft/day	feet per day
ft/ft	feet per foot
g	grams
g/L	grams per liter
H_2	hydrogen
HSA	hollow-stem auger
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliters
mL/min	milliliters per minute
mV	millivolts
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NERT Site	Nevada Environmental Response Trust Site
NERT	Nevada Environmental Response Trust
nm	nanomolar
NO_3	Nitrate
O&M	operation and maintenance
ORP	oxidation reduction potential
OU	Operable Unit

OU-2	Operable Unit 2
pcrA	perchlorate reductase subunit A
pcrB	perchlorate reductase subunit B
PLFA	phospholipid fatty acid analysis
PPE	personal protective equipment
Prima	Prima Environmental, Inc.
PVC	polyvinyl chloride
qPCR	quantitative polymerase chain reaction
Ramboll Environ	Ramboll Environ US Corporation
Ramboll	Ramboll US Corporation or Ramboll US Consulting, Inc.
RAO	Remedial Action Objective
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
SRB	sulfate-reducing bacteria
SVOC	semivolatile organic compound
SWF	Seep Well Field
TDS	total dissolved solids
Tetra Tech	Tetra Tech, Inc.
TKN	total Kjeldahl nitrogen
TMR	Telescopic Mesh Refinement
TOC	total organic carbon
TPH	total petroleum hydrocarbons
Transect 1A	Transect 1A Study Area
Trust	Nevada Environmental Response Trust
UIC	Underground Injection Control
UMCf	Upper Muddy Creek Formation
UNLV	University of Nevada, Las Vegas
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound
ZVI	Zero-Valent Iron

1. INTRODUCTION

At the request of the Nevada Environmental Response Trust (NERT or "the Trust"), Ramboll US Consulting, Inc. (Ramboll) has prepared this Las Vegas Wash Zero-Valent Iron (ZVI)-Enhanced Bioremediation Treatability Study Work Plan Addendum (Work Plan Addendum). This Work Plan Addendum is being submitted to the Nevada Division of Environmental Protection (NDEP) in accordance with the Interim Consent Agreement effective February 14, 2011. This document describes the scope of work to implement and assess a field test of ZVI-enhanced bioremediation in an area downgradient of the Nevada Environmental Response Trust Site (NERT Site) and upgradient of the Las Vegas Wash (Figure 1-1).

The scope of work described in this Work Plan Addendum both advances some and supersedes other portions of the Galleria Drive ZVI-Enhanced Bioremediation Treatability Study Work Plan (2017 Work Plan; Ramboll Environ 2017c). As described in the 2017 Work Plan, the overall aim of this treatability study program is to design, construct, and monitor a field test that uses granular ZVI to stimulate in-situ removal of perchlorate, chlorate, and nitrate in a passive groundwater treatment system. The field test was to be implemented on a parcel of land owned by Basic Environmental Company (BEC) and identified on Figure 1-1 (hereafter referred to as the "Galleria Parcel"). However, during the latter part of 2019 and after substantial laboratory testing and field investigation in this area was performed, the Trust learned of potential property access limitations due to commercial and residential development along Galleria Drive. Field methods and results associated with the pre-design investigations performed at the Galleria Parcel were submitted to NDEP in preliminary form in monthly progress reports. This information has been compiled in the Galleria Parcel Pre-Design Investigation Summary provided as Appendix A.

Subsequent to an analysis of alternative locations within the NERT Remedial Investigation (RI) Study Area to perform a field test, Ramboll was directed by the Trust to shift the ZVI-enhanced bioremediation treatability study to an area referred to as Transect 1A Study Area (Transect 1A), which is also identified on Figure 1-1. This area had previously been identified as a candidate for the Las Vegas Wash Bioremediation Pilot Study[1] and thus underwent Phase 1 pre-design investigation activities by Tetra Tech, Inc. (Tetra Tech), on behalf of the Trust, between March and July 2018. Transect 1A became available for the ZVI treatability testing when the Las Vegas Wash Bioremediation Pilot Study was relocated further to the east along Las Vegas Wash (Tetra Tech 2019).

Resulting from the relocation of the proposed field testing, additional, but limited, pre-design data was necessary to supplement the previously collected data in Transect 1A for the purpose of designing a field test of ZVI-enhanced bioremediation. The scope of

1 The Las Vegas Wash Bioremediation Pilot Study is a treatability study being conducted by the Trust to evaluate an alternative technical approach (in-situ bioremediation [ISB] using an organic carbon substrate) to stimulate perchlorate reduction in groundwater. The Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019) presented Phase 1 pre-design field investigation results for Transect 1A for the purposes of evaluating the location for that technical approach. Results from Tetra Tech's investigation of Transect 1A have been used for the development of this Work Plan Addendum.

work describing the limited additional data collection is described in Treatability Study Modification No. 9 (Ramboll 2019a), which was approved by NDEP on October 14, 2019. This Work Plan Addendum provides the proposed field test design for evaluation of ZVI-enhanced bioremediation at Transect 1A. This Work Plan Addendum also presents the results of the pre-design field investigations and bench-scale testing activities described in the 2017 Work Plan (Ramboll Environ 2017c), as well as subsequent field and bench-scale testing work performed at Transect 1A in accordance with Treatability Study Modification No. 9 (Ramboll 2019a).

The work described in this Work Plan Addendum is being conducted to support final remedy selection as part of the Remedial Investigation and Feasibility Study (RI/FS). Currently, the RI is being conducted in three Operable Units (OUs), as shown in Figure 1-1. OU-1 is comprised of the NERT Site and former parcels once owned by NERT, extending north as far as West Warm Springs Road. OU-2 is generally divided into two areas: 1) the NERT Off-Site Study Area component of OU-2 located west of Pabco Road; and 2) the Eastside Sub-Area component of OU-2 located east of Pabco Road. OU-3 is divided into three areas. The southwestern portion of OU-3 (west of Pabco Road and south of the Las Vegas Wash) is also referred to as the northern portion of the Off-Site Study Area, while the southeastern portion (north and west of Galleria Road) is referred to as the Northeast Sub-Area. The central and northern portions of OU-3 are collectively referred to as the Downgradient Study Area. These three OUs are collectively referred to as the NERT RI Study Area.

1.1 Technology Overview and Rationale

ZVI-enhanced bioremediation, and ZVI generally, were identified by the Trust in 2017 as potential remedial technologies for treating groundwater at NERT due to several key positive attributes, including:

- The reaction of ZVI in water promotes geochemical reduction of the aqueous environment and production of dissolved hydrogen (H_2) – two conditions demonstrated to stimulate biological reduction of perchlorate. Unlike other applications of ZVI, the stimulation of biological perchlorate reduction does not require the ZVI to have direct contact with perchlorate.
- The conditions stimulated by ZVI have the potential to preferentially promote perchlorate-reducing bacteria that are autotrophic (i.e., organisms that can use inorganic carbon for cell growth) as opposed to heterotrophic (i.e., organisms requiring an external organic carbon source for cell growth). Autotrophic processes result in less biomass development which would reduce the potential for biofouling, provided that sufficient inorganic carbon is available in the aquifer to sustain cell growth.
- Coarse-grain or granular ZVI (the type used for ZVI-enhanced bioremediation) corrodes very slowly in groundwater and will last for decades under typical conditions. This longevity allows for implementation of a very long-lasting passive groundwater treatment alternative with potentially lower operation and maintenance (O&M) costs when compared to more active alternatives such as technologies requiring regular injection of carbon-based electron donors and/or other amendments.

- ZVI can reduce other chemicals in groundwater in the NERT RI Study Area, including hexavalent chromium, chlorate, and nitrate reducing the electron donor demand for biological perchlorate reduction.

- ZVI is widely employed as an in-situ boundary treatment technology, which aligns well with established Remedial Action Objectives (RAOs) for all OUs, including the RAO for OU-3 to mitigate discharge to Las Vegas Wash.

- Through the use of different emplacement methods, ZVI has applicability to both the alluvium and the Upper Muddy Creek formation (UMCf) within the NERT RI Study Area, and therefore, could have applicability in all OUs.

- ZVI is readily available through commercial vendors and is a safe and widely used material that can be placed in the subsurface using a variety of techniques, including conventional trenching, placement within boreholes, in-situ soil mixing, and by injection or other specialized methods.

A detailed discussion on the technology background of ZVI and ZVI-enhanced bioremediation can be found in Section 2.1, but the overall conceptual approach for ZVI-enhanced bioremediation being proposed for field testing herein is summarized below:

1. ZVI-enhanced bioremediation begins with emplacement of a granular ZVI backfill (i.e., a mixture of ZVI, sand and/or gravel) in the subsurface to intercept contaminated groundwater in a passive manner.

2. Groundwater flows through the ZVI backfill following the natural hydraulic gradient and at the natural groundwater velocity. Because natural conditions drive the flow, ZVI-enhanced bioremediation is a passive process.

3. Groundwater in contact with granular ZVI causes the slow and predictable corrosion of ZVI and generation of dissolved hydrogen. Chlorate and nitrate concentrations decrease within the granular ZVI and sand mixture.

4. The groundwater exiting the ZVI backfill is enriched with dissolved hydrogen, has decreased concentrations of chlorate and nitrate, and will be in a geochemically reduced state, which is necessary to support biological perchlorate reduction. These conditions are highly favorable for biological perchlorate reduction, hence the term "ZVI-enhanced bioremediation."

5. The conditions favorable for biological perchlorate reduction occur within and some distance downgradient of the ZVI backfill zone and will cause changes to the microbial community over time, ultimately resulting in a robust and sustainable perchlorate-reducing microbial community.

ZVI-enhanced bioremediation could provide significant benefit over other remedial technologies being evaluated by the Trust in terms of long-term cost-effectiveness. As indicated above, ZVI-enhanced bioremediation is a passive technology and is therefore expected to have significantly lower O&M costs compared to other remedial technologies. Moreover, because ZVI corrodes slowly, the treatment may be longer-lasting than other in-situ approaches. This is significant because a key component of the NERT conceptual site model (CSM), as presented in the RI Report for OU-1 and OU-2 (Ramboll 2021b), is the effect of matrix diffusion, where chemicals of potential concern (COPCs) present in the UMCf slowly migrate upward into the more permeable alluvium. As a result, groundwater concentrations of perchlorate in the alluvium have not been declining significantly even though the Groundwater Extraction and Treatment System (GWETS), which primarily targets the alluvium, has been in operation for over 20 years. The effect of matrix diffusion from the lower permeability UMCf will cause concentrations in the higher permeability alluvium to remain above regulatory levels for a long period of time. As shown by the mass estimates for perchlorate and chromium (Ramboll 2021b), most of the remaining COPC mass is contained in the lower permeability UMCf. Therefore, a remedy will need to be in place for decades to address the effects of this matrix diffusion.

Another important consideration coming into focus through the execution of the RI is that the subsurface conditions and land use vary significantly throughout the NERT RI Study Area. This makes it likely that to achieve RAOs, a final remedy will need to be comprised of multiple remedial technologies working in parallel. Just like other remedial technologies being considered, understanding the benefits and limitations of ZVI-enhanced bioremediation is crucial to assess the locations and conditions where the technology can be implemented as part of final remedy and how it would work in concert with other technologies.

Options beyond groundwater extraction and treatment, in-situ bioremediation (ISB) using organic substrates, and no action must be explored such that cost-effective remedial action alternatives can be evaluated in the FS. While ISB using organic substrates has been tested throughout the NERT RI Study Area, ZVI-enhanced bioremediation has not. Moreover, while ZVI has been demonstrated elsewhere to treat perchlorate, chlorate, and nitrate, it has not yet been demonstrated in the field in the NERT RI Study Area. Field testing of ZVI-enhanced bioremediation is necessary to appropriately evaluate it and prepare reliable remediation cost estimates.

The Phase 1 bench-scale testing (presented in Section 5) has confirmed that granular ZVI can reduce perchlorate, chlorate, and nitrate in NERT groundwater. ZVI rapidly removes nitrate and chlorate, reducing electron donor demand. For removal of perchlorate, development of a robust, functional microbial community is the key factor. The bench-scale testing results support proceeding with a field test of ZVI-enhanced bioremediation in the NERT RI Study Area. There are three important aspects of performance that need further investigation during a field test:

- Precipitation reactions can reduce the longevity of ZVI by reducing permeability of the ZVI backfill. This aging is addressed in the design through geochemical modeling and performance monitoring. Data from a field test is necessary to inform the geochemical model and make it useful as a predictive design tool.

- ZVI may be passivated (rendered inert) by nitrate and other chemicals under certain geochemical conditions. While passivation was not observed in bench-scale testing, the durations of those tests were likely too brief to adequately assess passivation. Passivation will be assessed during field testing.

- The ability to stimulate and sustain a robust perchlorate-reducing microbial community needs to be confirmed in a field test. While this was achieved in bench-scale testing, the field presents a more challenging environment.

The proposed Phase 2 field test presented in this Work Plan Addendum is designed to build on the information gained through Phase 1 pre-design field investigation (presented in Sections 3 and 4) and the Phase 1 bench-scale testing (presented in Section 5) and specifically investigate these three important aspects of performance.

1.2 Treatability Study Objectives and Approach

The 2017 Work Plan stated the overall objectives of the treatability study and presented the plan for Phase 1 pre-design field investigation of the Galleria Parcel and the associated bench-scale testing. The 2017 Work Plan presented the overall objectives as follows:

"The overall objectives of the treatability study are to 1) determine whether ZVI alone can promote the biological reduction of perchlorate, chlorate, and other co-contaminants (e.g., nitrate and hexavalent chromium) contained in the groundwater in the Eastside Sub-Area; 2) evaluate whether other amendments would be necessary to either enhance ZVI performance or reduce the potential deleterious effects of site-specific groundwater conditions (e.g., the presence of nitrate) on ZVI treatment performance; and 3) provide important information for the design of a full-scale remedial system intended to mitigate migration of contaminants at the mid-plume boundary."

Implementation of the 2017 Work Plan occurred from 2018-2019 and much has already been accomplished in terms of understanding the performance of ZVI-Enhanced bioremediation at NERT based on the bench-scale testing presented in Section 5. Moreover, as a result of the transition from the Galleria Parcel to Transect 1A described in Treatability Study Modification No. 9 (Ramboll 2019a), the objectives of the treatability study were updated accordingly. Besides the move from a mid-plume boundary test in OU-2 to a distal-plume boundary treatment in OU-3, the objectives were refined to focus on two ZVI emplacement methods suitable for the Transect 1A Study Area.

The refined objectives for the field treatability study of ZVI-enhanced bioremediation are as follows:

1. Confirm the results of the laboratory testing demonstrating that nitrate, chlorate, and perchlorate can be degraded in the field using ZVI, where ZVI acts as both a reactive media and source of hydrogen to support biological degradation.

2. Evaluate the performance of two methods of emplacing ZVI as well as the impact of the ZVI dosage under field conditions.

3. Assess the distribution of hydrogen and the associated biologically active zone generated by the ZVI inside and downgradient of the reactive zones under actual groundwater flow conditions.

4. Evaluate methods of increasing and sustaining biological perchlorate reduction via inoculation and nutrient addition.

5. Monitor the geochemical changes that take place inside and downgradient of the ZVI treatment zones under actual groundwater flow conditions and model hydrogen production, ZVI mass loss, passivation, and precipitation of inorganic species to assess the potential longevity of granular ZVI in the NERT RI Study Area.

6. Provide data to allow evaluation of ZVI-enhanced bioremediation treatment under field conditions and provide key design, performance, monitoring, and cost criteria for use during the FS for comparison of remedial alternatives.

The proposed Phase 2 field test is not intended to achieve final water quality objectives as may be defined in the final remedy, but rather to provide data to allow evaluation of ZVI-enhanced bioremediation under field conditions and provide key design and performance criteria to inform the FS and future remedial design. Therefore, performance objectives are defined based on the technical design requirements, and not solely on water quality criteria consistent with potential clean up goals for target constituents.

This treatability study is being performed in a phased approach, as originally established by the 2017 Work Plan, that utilizes 1) existing data, 2) the results of pre-design field investigations, 3) data from batch microcosm and column tests, 4) quantitative analysis including geochemical and numerical modeling, and 5) field testing to assess the potential effectiveness of ZVI-enhanced bioremediation while collecting information necessary to support evaluation of remedial alternatives incorporating ZVI in the FS for inclusion in a final remedy, as appropriate.

1.3 Work Plan Addendum Organization

This Work Plan Addendum is organized as follows:

- **Section 1** presents the objectives and organization of the work plan addendum.
- **Section 2** provides relevant background information on the technology.
- **Section 3** provides a summary of Phase 1 pre-design field activities performed at Transect 1A.
- **Section 4** provides results of Phase 1 pre-design field activities performed at Transect 1A.
- **Section 5** describes Phase 1 bench-scale testing activities performed in support of this treatability study.
- **Section 6** describes geochemical and reactive transport modeling work performed in support of the Phase 2 field test design.

- **Section 7** provides the proposed Phase 2 field test design.
- **Section 8** describes the proposed Phase 2 performance monitoring program.
- **Section 9** describes Phase 2 property access and permitting requirements.
- **Section 10** describes the Phase 2 reporting to be performed.
- **Section 11** discusses the schedule for the Phase 2 field test.
- **Section 12** lists citations for key documents referenced in this Work Plan Addendum.

2. TECHNOLOGY BACKGROUND

The following sections provide a summary of background information related to ZVI and ZVI-enhanced bioremediation to provide some useful context for the discussions in the remainder of this Work Plan Addendum. Additional technical background information is presented in the 2017 Work Plan.

2.1 Biological Perchlorate Reduction

The remediation of perchlorate-impacted groundwater using microbiological processes is a proven approach that is well documented in the technical literature (Chaudhuri et al. 2002). Naturally-occurring bacteria accomplish perchlorate removal through mediation of a series of oxidation-reduction (redox) reactions where electrons are shuttled from one compound (an "electron donor") to another compound (an "electron acceptor") and through this process the bacteria gain energy. In the case of microbial perchlorate reduction, perchlorate accepts electrons from an electron donor and is thereby transformed to a reduced form. The bacteria capable of this activity are therefore referred to perchlorate-reducing bacteria. Perchlorate-reducing bacteria use specific enzymes to perform the electron shuttling and through this process they gain energy. This process is the same regardless of what electron donor is used, however, perchlorate-reducing bacteria have preferences for specific electron donors.

In general, perchlorate-reducing bacteria sequentially reduce perchlorate to chlorate, then chlorite, then finally to chloride and oxygen. The reduction of perchlorate is the rate limiting step in this process, so that chlorate and chlorite do not accumulate when sufficient electron donor is present (Ucar et al. 2016). Thus, bioremediation has the advantage that perchlorate is completely reduced to non-toxic end products as shown in Equation 1 (Rikken et al. 1996).

$$ClO_{4^-} + 4H_{2(aq)} \rightarrow Cl^- + 4H_2O \qquad \text{(Equation 1)}$$

Naturally occurring perchlorate-reducing bacteria are ubiquitous in the environment (Coates et al. 1999). Different species of perchlorate-reducing bacteria have been identified that utilize a variety of electron donors such as hydrogen, simple organic acids (e.g., formate and acetate) and alcohols, aromatic hydrocarbons, reduced humic substances, ferrous iron, and hydrogen sulfide (Coates and Achenbach 2004; Batista, 2017). Examples of these electron donors currently being utilized at NERT include the addition of ethanol to support the reduction of perchlorate in the Fluidized Bed Reactors (FBRs) and the addition of emulsified vegetable oil (EVO) to support the reduction of perchlorate in ISB treatability studies being conducted by Tetra Tech (Tetra Tech 2016, 2019, 2020).

The enzyme involved in reducing perchlorate to chlorate and subsequently chlorite is perchlorate reductase, while chlorite is further reduced to chloride by the enzyme chlorite dismutase (De Long et al. 2012). However, chlorate and chlorite are rarely observed to accumulate during biological perchlorate reduction (Ucar et al. 2016). All identified perchlorate reducers have been shown to reduce chlorate as well, while some chlorate reducers are unable to respire on perchlorate (Coates and Achenbach 2004).

Furthermore, some perchlorate-reducing bacteria can also use nitrate as an electron acceptor (Coates et al. 1999).

Hydrogen-utilizing bacteria can either be heterotrophic (i.e., organisms that require an external carbon source for cell growth) or autotrophic (i.e., organisms that can use inorganic carbon for cell growth). Autotrophic perchlorate-degrading bacteria that grow solely on inorganic energy and carbon sources have now been isolated and cultured (Zhang et al. 2002). Utilization of hydrogen by autotrophic bacteria has several practical advantages over heterotrophic bacteria. These include the generation of smaller amounts of biomass, which minimizes blockage of pore spaces, and the elimination of the need to provide external carbon sources, which can greatly reduce the operation and maintenance cost of bioremediation systems in the field (Miller and Logan 2000).

2.2 ZVI as an Electron Donor

There are multiple examples of the removal of perchlorate by autotrophic bacteria in hydrogen gas fed bioreactors in the literature (Giblin et al. 2000; Miller and Logan 2000; Nerenberg et al. 2002). However, the low solubility of hydrogen in water and its hazardous nature related to storage and handling has limited application of hydrogen gas bioreactors. In contrast, ZVI can provide for a safe, long-term supply of dissolved hydrogen via the corrosion process shown in Equation 2.

$$Fe^0 + 2H_2O \rightarrow Fe^{2+} + 2OH^- + H_{2(g)} \qquad \text{(Equation 2)}$$

The resulting reaction provides steady, predictable levels of dissolved hydrogen and increases the pH locally. The presence of a steady supply of hydrogen can support the activity of autotrophic perchlorate-reducing bacteria, which will use carbon dioxide as a carbon source (typically present as alkalinity in groundwater).

ZVI is a strong reducing agent that has been used for nearly 30 years as an in-situ treatment material for remediating groundwater contaminated with a variety of anthropogenic chemicals, including both organic and inorganic compounds, and is considered one of the original “sustainable” remedies for treating contaminated groundwater. ZVI is relatively inexpensive, safe to handle, and ZVI has the additional benefit that many compounds are reduced abiotically on the ZVI surface. These include nitrate and chlorate, although abiotic perchlorate reduction is exceedingly slow due to the large activation energy barrier with perchlorate (Gurol and Kim 2000).

Research on the use of granular ZVI for perchlorate remediation has been ongoing since the mid-2000s and has been shown to be highly effective in promoting bioremediation of perchlorate in groundwater (e.g., Moore et al. 2003; Sanchez 2003; Yu et al. 2006; Warner et al. 2008; London et al. 2013). The use of ZVI as a source of hydrogen to stimulate perchlorate reduction by autotrophic bacteria has been demonstrated in numerous laboratory studies including microcosm experiments (Yu et al. 2006; Son et al. 2006) and column studies (Son et al. 2006; Yu et al. 2007; Huang and Sorial 2007; Arthur 2011).

The microcosm studies have shown that degradation of perchlorate concentrations ranging from 500 to 65,000 micrograms per liter (µg/L) followed Monod kinetics in the presence of ZVI and perchlorate-reducing bacteria and that the overall rate of perchlorate reduction was largely controlled by biomass density (Yu et al. 2006). Perchlorate biodegradation rates with ZVI were comparable to those observed using acetate and hydrogen as electron donors (Son et al. 2006). Repetitive spiking of the bottles with perchlorate indicated that perchlorate reduction was sustained and even enhanced over time, probably due to the growth of perchlorate-reducing bacteria. Biodegradation performance was optimal in a pH range of 7 to 9 and stoichiometric amounts of chloride were produced, confirming complete degradation of the perchlorate to terminal end products (Yu et al. 2006). The reduction rate was reduced but not completely inhibited by the presence of nitrate, perhaps due to competition for hydrogen with nitrate-reducing bacteria (Miller and Logan 2000).

While the previously microcosm studies cited did not address nutrient limitation, nutrient limitation has been assessed in other studies utilizing heterotrophic perchlorate-reducing bacteria (Kucharzyk et al. 2012). In this study, optimal growth and performance of the perchlorate reducing bacteria required both a source of nutrients containing ammonia, phosphorus, and potassium, as well as trace minerals. In particular, the presence of molybdenum has been shown to be very important because it is a component of the enzymes that mediate chlorate and perchlorate reduction (Chaudhuri et al. 2002).

Studies where gas columns were packed with ZVI materials demonstrated that near complete removal of perchlorate at concentrations up to 16,000 µg/L could be accomplished over extended time periods (e.g., up to two years) using flow-through systems (Son et al. 2006; Yu et al. 2007; Arthur 2011). The residence times in these systems varied from minutes to days and up to 5,000 pore volumes of water were passed through some of the columns without significant plugging issues. Complete perchlorate removal was observed in the columns over a wide range of operational conditions, although breakthrough of perchlorate in the column effluent was observed at long residence times if the effluent pH reached 9 to 10 (Yu et al. 2007). The reduction of perchlorate biodegradation at elevated pH has been reported by other researchers (Shrout et al. 2005). Since the rise in pH is a byproduct of the ZVI corrosion reaction, efforts should be made to limit the residence times in full-scale ZVI systems so that the pH downgradient of emplaced ZVI does not exceed the operational range for the bacteria.

Analysis of the biomass in the column after the studies were complete indicated that the majority of the biomass related to perchlorate reduction was attached to ZVI surfaces and not in the liquid phase (Yu et al. 2007). This suggests the perchlorate-reducing bacteria have adapted to live close to the source of hydrogen produced by ZVI corrosion, which lessens competition with other types of hydrogen-utilizing bacteria. The study also indicates the corrosion rate (and hydrogen generation) for the ZVI in these studies was higher than normally observed, suggesting the presence of bacteria at the ZVI surface may increase the rate of corrosion, perhaps due to the production of degradation end products such oxygen and chloride, which are known to accelerate corrosion rates. Thus, there may be a synergistic relationship between ZVI and autotrophic bacteria in facilitating the reduction of perchlorate.

Thus far, there are few examples in the published literature of field application of ZVI specifically for perchlorate remediation. One such example is an Environmental Security Technology Certification Program (ESTCP) study performed by the same research groups who conducted the laboratory microcosm and column studies (Yu et al. 2006, 2007). In this case, a 300-gallon reactor was packed with 4,400 pounds (lbs) of Peerless cast iron aggregate to create a system capable of treating groundwater contaminated with 40 µg/L of perchlorate and 4.5 milligrams per liter (mg/L) of nitrate (as NO_3-N) obtained from an extraction well in Rialto, California (ESCTP 2010).

The ESTCP system operated effectively for three months, removing 95% of the perchlorate and virtually all of the nitrate, at a flowrate of 4 gallons per minute (gpm). However, at that point, progressive loss of hydraulic conductivity (and short-circuiting) occurred in the reactor and perchlorate and nitrate removal deteriorated. The cause of the reactor plugging was not definitively determined, but it was likely the result of a failure to adequately account for precipitation reactions due to the interaction of high levels of dissolved oxygen (DO) and carbonates and the ZVI. High concentrations of carbonate and phosphate in groundwater can result in the formation and precipitation of siderite ($FeCO_3$) and vivianite ($Fe_3(PO_4)_2$) minerals in ZVI systems (Shrout et al. 2005). The issue with the carbonates may have been a combination of naturally occurring carbonate in the groundwater and carbonate added during the field test to provide a source of carbon for the autotrophic bacteria. In addition to reducing the hydraulic conductivity in the reaction, the precipitates also have the potential to passivate the ZVI surfaces (Sanchez et al. 2004).

The potential negative impact of these precipitation processes is well known with ZVI applications and can be anticipated with geochemical modeling or managed in the vast majority of ZVI installations. ZVI walls typically age geochemically in groundwater applications, but the observed rate of the corrosion and precipitation reactions are generally sufficiently slow such that ZVI functionally can last for decades when installed as an in-situ groundwater treatment remedy. For example, the oldest full-scale commercial ZVI in-situ groundwater treatment system was installed in November 1994 in Sunnyvale, California (Warner et al. 1998), and it remains functional today (Warner 2021).

To emphasize the last point, Ramboll has extensive experience on a project in Sacramento, California where a passive groundwater treatment system was installed in 2006 using ZVI for perchlorate and trichloroethylene (TCE) treatment (Dowman et al. 2006). Since then, sustained perchlorate removal has been observed for over 12 years (unpublished field demonstration data). In this study, perchlorate concentrations upgradient of the ZVI range from 10 to 20 mg/L, while downgradient concentrations have been consistently below detection limits. Autotrophic perchlorate reducing bacteria, capable of using carbon dioxide as a carbon source for growth, are the most plausible explanation for this sustained performance without the addition of organic substrates or other amendments. No loss of permeability or diminished perchlorate reduction capability have been observed during this study.

As indicated above, there is strong literature related to use of autotrophic perchlorate-degrading bacteria and ZVI to treat perchlorate in ground water. The use of ZVI is also well established as a field technology. A key feature of ZVI is its longevity in groundwater making it one of the most sustainable and resilient groundwater treatment materials widely applied. Moreover, corrosion is a slow, predictable process, which allows ZVI systems to be designed and operated passively with low O&M costs and no significant aboveground infrastructure. Therefore, if demonstrated effective in this application, ZVI-enhanced bioremediation could provide a highly cost-effective long-term and sustainable treatment for perchlorate and chlorate (and potentially other COPCs such as hexavalent chromium) in groundwater in the various OUs with relatively little impact to future development.

3. PHASE 1 PRE-DESIGN FIELD INVESTIGATION ACTIVITIES

As discussed in Section 1, the location of the treatability study was transitioned in late 2019 from the Galleria Parcel to Transect 1A originally identified through the Las Vegas Wash Pilot Study Work Plan (Tetra Tech 2017). The initial Phase 1 pre-design field investigation activities associated with the Galleria Parcel were previously presented to NDEP in monthly progress reports and are further summarized in Appendix A. This section summarizes the implementation of Phase 1 pre-design field investigation activities associated with Transect 1A. The purpose of this investigation was to supplement the results of previous investigations performed by Tetra Tech and collect soil and groundwater for the Phase 1 bench-scale testing described in Section 5. The results of Tetra Tech's investigations of Transect 1A are reported in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019). The Phase 1 pre-design field investigation conducted by Ramboll at Transect 1A was proposed in Treatability Study Modification No. 9 (Ramboll 2019a), which was approved by NDEP on October 14, 2019 and included the following activities:

- Gaining the proper clearances to access the property and permits to perform the investigation activities described herein;
- Clearing the drilling locations for subsurface and overhead utilities;
- Advancing soil borings and collecting soil samples;
- Installing and developing groundwater monitoring wells;
- Sampling existing and newly-installed groundwater monitoring wells;
- Performing hydraulic testing, including single borehole dilution testing and slug testing; and
- Managing investigation-derived waste.

All field work described herein was conducted in general accordance with the existing Field Sampling Plan, Revision 1 (ENVIRON 2014a) and the Quality Assurance Project Plan (QAPP), Revision 6 (Ramboll 2021a).

While this section is limited to describing the field investigation activities conducted at Transect 1A, Treatability Study Modification No. 9 (Ramboll 2019a) also specified limited bench-scale testing to confirm the suitability of the soil and groundwater conditions at Transect 1A for a field test. The bench-scale testing methods and results are presented in Section 5.

3.1 Objectives

The primary goal of the Phase 1 pre-design field investigation at Transect 1A was to characterize the geology and hydrogeology in sufficient detail to design a Phase 2 field test. Specific objectives included the following:

- Build on Tetra Tech's initial Phase 1 pre-design investigation of Transect 1A from the Las Vegas Wash Bioremediation Pilot Study to collect additional data deemed necessary to confirm the suitability of Transect 1A for a Phase 2 field test of ZVI-enhanced bioremediation;

- Assess localized vertical and horizontal distribution of perchlorate, chlorate, nitrate, and other chemicals;
- Characterize the baseline geochemical and biological conditions in the field test area; and
- Collect representative soil and groundwater from the proposed field test area for use in bench-scale testing (bench-scale testing is described in Section 5).

3.2 Field Methods

The following sections describe the field activities and methods associated with the Phase 1 pre-design investigations at Transect 1A.

3.2.1 Access Agreement and Permitting

The Transect 1A parcel is owned by the City of Henderson (COH). All field investigation work described herein was performed under an existing access agreement between the Trust and the COH.

Following access agreement coordination, Ramboll, on behalf of NERT, prepared and submitted required applications and obtained required permits prior to field activities, including Nevada Administrative Code (NAC) 534.441 Monitor Well Drilling Waivers, NAC 534.320 Notice of Intent Cards, and a NDEP U240 Chemical Use Request Form. The Monitoring Well Drilling Waivers also required a completed, signed, and notarized Affidavit of Intent to Abandon a Well as an attachment. The NDEP U240 Chemical Use Request Form was required to conduct borehole dilution testing using deionized water.

3.2.2 Utility Clearance

Prior to drilling activities, Ramboll contacted USA North Utility Locating Services, reviewed available utility maps for Transect 1A, and retained the services of a geophysical locator, Ground Penetrating Radar Systems of Las Vegas, Nevada, to survey for underground utility lines. In addition, location ZTS-MW113 was cleared to five feet below ground surface (bgs) using a hand auger and locations ZTS-MW114 and ZTS-MW115 were cleared to 10 feet bgs using an air knife prior to drilling.

3.2.3 Installation of Soil Borings and Monitoring Wells

As specified in Treatability Study Modification No. 9 (Ramboll 2019a), Ramboll conducted additional sampling activities at Transect 1A between November 18 and 23, 2019.

Details of these sampling activities are provided below, and locations are depicted in Figure 3-1. Soil boring and monitoring well construction logs are provided in Appendix B. Analytical results are presented in Sections 4.3 (soil) and 4.4 (groundwater).

3.2.3.1 Soil Borings

Three soil borings, designated ZTS-MW113, ZTS-MW114, and ZTS-MW115 (shown on Figure 3-1), were advanced using rotary sonic drilling equipment operated by Cascade Drilling to obtain area-specific lithological information and chemical concentrations.

Borings were advanced to terminal depths of 40 feet bgs (ZTS-MW113 and ZTS-MW115) and 80 feet bgs (ZTS-MW114). Soil boring and monitoring well construction logs are provided in Appendix B. Each boring was located next to an existing well (or well cluster) installed by Tetra Tech during the Phase 1 pre-design investigations at Transect 1A to supplement the existing data by targeting intervals not previously characterized. Soil samples with 0.5 ft sample lengths were collected at predetermined depths (see Table 3-1 below).

Table 3-1: **Soil Sample Depths**

Location	Soil Sample Depths (Top of the Interval)
ZTS-MW113	10, 15, 20, and 25 feet bgs
ZTS-MW114	45 feet bgs
ZTS-MW115	35 and 40 feet bgs

Soil samples for laboratory analysis were collected in laboratory-supplied containers, labeled, sealed in plastic bags, stored in coolers on ice, and transported to Eurofins Calscience Laboratories, Inc. of Irvine, California (Eurofins Calscience) for the analyses listed in Table 3-2 below.[2]

Table 3-2: **Laboratory Analysis of Soil Samples**

Analyte	Method
Perchlorate	EPA Method 314.0
Chlorate	EPA Method 300.1
Nitrate	EPA Method 300.0
Total Chromium	EPA Method 6010B
Total Organic Carbon	SM 5310B
Percent Moisture	--

In addition to the analyses listed above, representative samples of alluvium and UMCf soils were sent to Colorado State University (CSU; Fort Collins, Colorado) for quantitative polymerase chain reaction (qPCR) deoxyribonucleic acid (DNA) testing to assess the presence of perchlorate reductase and chlorite dismutase genes, which can be used to assess the level of activity of biological perchlorate-reducing bacteria. Alluvium soil was collected from approximately 17 to 17.5 feet bgs at boring location ZTS-MW113 and 19 to 19.5 feet bgs at boring location ZTS-MW115; and UMCf soil was collected from 36.5 to 37 feet bgs at boring location ZTS-MW113, 42 to 42.5 feet bgs at boring location ZTS-MW114, and 38.5 to 39 feet bgs at boring location ZTS-MW115.

[2] Prior to January 1, 2020, Eurofins Calscience Laboratory, Inc. was referred to as Eurofins TestAmerica Laboratories, Inc.

Finally, representative soil cores collected from the alluvium and UMCf at ZTS-MW115 were sent to Prima Environmental, Inc. (El Dorado Hills, California) (Prima) for batch microcosm testing (refer to Section 5). Alluvium samples for bench testing were collected from approximately 17 to 19 feet bgs, and UMCf samples were collected from approximately 30 to 33 feet bgs.

3.2.3.2 Groundwater Monitoring Wells

All groundwater monitoring wells were drilled in accordance with Nevada Division of Water Resources requirements, following submittal of a Notice of Intent to Drill. As required, all wells were drilled by a licensed well driller pursuant to Nevada Revised Statutes 534.160 and were constructed pursuant to NAC Chapter 534 – Underground Water and Wells.

Monitoring wells ZTS-MW113, ZTS-MW114, and ZTS-MW115 were installed in the soil borings described above as depicted in Figure 3-1. The wells were constructed using 4-inch diameter schedule 40 polyvinyl chloride (PVC) casing and screened with 4-inch diameter 0.010-inch slotted PVC well screen at ZTS-MW114 and 4-inch diameter 0.020-inch slotted PVC well screen at ZTS-MW113 and ZTS-MW115. Wells ZTS-MW113 and ZTS-MW115 were constructed with 10-foot screens (20 to 30 feet bgs) within the saturated alluvium, and well ZTS-MW114 was constructed with a 20-foot screen (50 to 70 feet bgs) in the UMCf.

A washed #2/12 sand filter pack was installed with the 0.010-inch slotted PVC well screen, and No. 3 sand filter pack was installed with the 0.020-inch slotted PVC well screen. Sand filter pack was installed in the annular space around each well screen and extended up to two feet above the top of the screen interval. For monitoring wells installed with a total depth of 30 feet bgs, the remainder of the annular space was backfilled to just below surface level with hydrated bentonite chips. For monitoring wells installed with a total depth greater than 30 feet bgs, the remainder of the annular space was backfilled with five feet of hydrated bentonite followed by neat cement grout. Wells were completed with surface level well boxes. Construction details for all existing and newly installed Transect 1A groundwater monitoring wells are provided in Table 3-3. Soil boring and monitoring well construction logs are provided in Appendix B.

The newly installed wells were developed by Cascade on November 25 and 26, 2019, at least 24 hours after well construction was complete. Monitoring well development at Transect 1A followed the same methods used at the Galleria Parcel, as described in Appendix A. All parameter readings were recorded on well development logs, which are included in Appendix C.

Following groundwater monitoring well installation, Atkins (Henderson, Nevada) surveyed 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 relative to North American Vertical Datum 88 (with an accuracy of 0.01 foot). Well surveying was performed on December 10, 2019.

3.2.4 Groundwater Sampling

Following well development, Ramboll contracted with OGI Environmental, LLC (Las Vegas, Nevada) to conduct a round of groundwater sampling at eight existing monitoring wells installed by Tetra Tech during initial pre-design investigations associated with the Las Vegas Wash Bioremediation Treatability Pilot Study[3] (LVWPS-MW101B, LVWPS-MW103A, LVWPS-MW106, LVWPS-MW107A, LVWPS-MW108A, LVWPS-MW108B, and LVWPS-MW109) and three newly installed wells (ZTS-MW113, ZTS-MW114, and ZTS-MW115). These wells are shown on Figure 3-1. Groundwater sampling was conducted between December 3 and 9, 2019. After measuring and recording the depth to groundwater, each well was purged by the contractor and sampled by Ramboll personnel using the standard low-flow groundwater sampling method described in the Field Sampling Plan, Revision 1 (ENVIRON 2014a). Groundwater sampling field logs are provided in Appendix C.

Groundwater samples were placed into laboratory-supplied containers, which were then sealed in plastic bags and stored on ice pending transport to the laboratory. Groundwater samples were delivered to Eurofins Calscience for the analyses listed in Table 3-4 below.

Table 3-4: **Laboratory Analysis of Groundwater Samples**

Analytes	Analytical Method
Perchlorate	EPA Method 314.0
Chlorate	EPA Method 300.1
Chloride	EPA Method 300.0
Sulfate	
Nitrate	
Metals (Ca, Mg, K, Na, Fe, Cr [total])	EPA Method 200.7
Bicarbonate	SM 2320B
Total Dissolved Solids (TDS)	SM 2540C
Total Organic Carbon (TOC)	SM 5310B
Dissolved Organic Carbon (DOC)	
Ferrous and Ferric Iron	SM 3500-Fe D

3 Monitoring wells with the LVWPS prefix were installed by Tetra Tech between March and July 2018 as part of the pre-design investigations associated with the Las Vegas Wash Bioremediation Pilot Study (Tetra Tech 2019).

In addition to the analysis listed above, samples collected from were sent to Pace Analytical (Pittsburgh, Pennsylvania) for dissolved hydrogen analysis using bubble strip method AM20GAX.

3.2.5 Hydraulic Testing

Hydraulic testing was performed to supplement existing data and further characterize hydraulic conditions at Transect 1A. Single-borehole dilution tests were conducted to estimate groundwater velocity, and slug tests were conducted to estimate hydraulic conductivity. Groundwater velocity and hydraulic conductivity are key parameters needed to design the ZVI field test. The hydraulic tests were conducted at all monitoring wells in the central portion of Transect 1A in order to fully characterize the range of values for these key parameters.

The following sections summarize the Transect 1A slug testing and single-borehole dilution testing performed by Ramboll. Detailed descriptions of hydraulic testing results are included in Appendix D.

3.2.5.1 Slug Tests

Slug tests at 20 out of 21 existing monitoring wells were performed previously by Tetra Tech.[4] Ramboll performed slug tests at new monitoring wells ZTS-MW113, ZTS-MW114, and ZTS-MW115 to supplement existing data from monitoring wells installed by Tetra Tech. The purpose of the slug testing was to estimate the hydraulic conductivity of the proposed field test area.

Slug tests were conducted by quickly lowering (falling head test) or raising (rising head test) a weighted slug with an approximate displacement of one gallon into the well, resulting in an instantaneous change in water level. The water level changes were monitored with a pressure transducer and then analyzed to estimate hydraulic conductivity. Detailed slug testing procedures and data analysis methods are included in Appendix D.

3.2.5.2 Single-Borehole Dilution Tests

Single-borehole dilution tests were performed in each of the three new 4-inch monitoring wells (ZTS-MW113, ZTS-MW114, and ZTS-MW115) and in 10 existing monitoring wells (LVWPS-MW102A, LVWPS-MW104, LVWPS-MW105, LVWPS-MW108A, LVWPS-MW108B, LVWPS-MW109, LVWPS-MW110, LVWPS-MW111A, LVWPS-MW111B, and LVWPS-MW112A). Previously, Tetra Tech performed borehole dilution tests at two wells (LVWPS-107A and LVWPS-107B). The purpose of these tests was to evaluate groundwater velocities within the proposed field test area. The additional tests conducted by Ramboll were needed to characterize the range of groundwater velocities present within Transect 1A for the field test design.

The testing method involved removing groundwater (which has a high electrical conductivity) from each well casing while simultaneously adding deionized water at approximately the same flow rate. Electrical conductivity was then monitored within the

4 Monitoring well LVWPS-MW103B was not slug tested due to slow recovery following well development because the well is screened in the semi-consolidated UMCf (Tetra Tech 2019).

well casing in real time to generate data used to estimate the groundwater velocity within the formation intercepted by the screened interval of each well. Detailed single-borehole dilution testing procedures and data analysis methods are included in Appendix D.

3.2.6 Management of Investigation-Derived Waste

Investigation-derived waste generated during the environmental investigations included soil cuttings, used personal protective equipment (PPE), equipment decontamination water, and groundwater generated during well development and sampling. Investigation-derived solid waste (i.e., soil cuttings) was accumulated in one plastic-lined roll-off bin. To characterize this bin, one composite sample, consisting of four sample aliquots collected from each corner of the roll-off container, was collected and analyzed for volatile organic compounds (VOCs) by United States Environmental Protection Agency (USEPA) Method 8260B, semi-volatile organic compounds (SVOCs) by USEPA Method 8270C, metals except mercury by USEPA Methods 6010B and 6020, mercury by USEPA Method 7471A, pH by USEPA Method 9045D, ignitability by USEPA Method 7.1.2, total petroleum hydrocarbons (TPH) by USEPA Method 8015B, and perchlorate by USEPA Methods 314.0 and 300.1B. Based on the results of these analyses, the solid waste was classified as non-hazardous and transported to Apex Regional Landfill in Las Vegas, Nevada for disposal.

Liquid waste (i.e., extracted groundwater and decontamination water) generated during field activities was temporarily stored in above-ground holding tanks then transferred into the GW-11 Pond for eventual treatment in the on-Site GWETS.

Bins and tanks were labeled with “pending analysis” labels, the date accumulation began, contents source, and contact information, and stored in a designated area. Management of IDW was performed in accordance with the requirements of the access agreement and according to applicable state, federal, and local regulations, as described in Field Guidance Document No. 001, Managing Investigation-Derived Waste (ENVIRON 2014a).

4. PHASE 1 PRE-DESIGN FIELD INVESTIGATION FINDINGS

Initial Transect 1A Phase 1 pre-design investigation efforts were performed in support of the Las Vegas Wash Bioremediation Pilot Study, and results were presented in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019). As discussed in Section 3, Ramboll conducted additional limited investigation to supplement the results of the previous investigation performed by Tetra Tech and to collect soil and groundwater for the Phase 1 bench-scale testing described in Section 5. This additional limited Phase 1 pre-design field investigation conducted at Transect 1A was proposed in Treatability Study Modification No. 9 (Ramboll 2019a), which was approved by NDEP on October 14, 2019.

The following sections present the consolidated results of Transect 1A Phase 1 pre-design investigations performed by Tetra Tech (mid-2018) and Ramboll (late 2019).

4.1 Geology

The NERT RI Study Area, including Transect 1A, is located within Las Vegas Valley. The valley fill deposits consist of a relatively thin series of Quaternary alluvium deposits over a thick unit of older Muddy Creek Formation sediments of Tertiary age. The conceptual geologic model for the Muddy Creek Formation shown on Figure 4-1 provides a useful framework for understanding the different depositional environments within the Las Vegas Valley. The UMCf sediments were deposited within a closed-basin environment, characterized by coarser-grained sediments near the surrounding mountains becoming finer-gained toward the basin interior, where saline mudflat, saline lakebed, and evaporite salt pan deposits formed. The saline mudflat and lakebed sediments are characterized by gypsum crystal deposition, whereas the fine-grained sand flat and dry mudflat sediments typically have caliche and calcium carbonate cementation. Transect 1A is situated near the basin interior where there is a transition from the dry mudflat to the gypsum-rich saline mudflat and lakebed deposits.

Geologic cross-sections illustrating subsurface conditions along the four alignments shown on Figure 4-2 are presented on Figures 4-3, 4-4, 4-5, and 4-6. Observations during drilling and review of existing boring logs indicate that approximately the uppermost 17.5 to 55 feet of material within Transect 1A consists of alluvium, ranging from silty sands to sandy gravel. Minor lenses of sandy silt are also present within the alluvium in some areas. The UMCf directly underlying the alluvium predominantly consists of fine-grained silt throughout. Perchlorate concentrations above 1 milligram per kilogram (mg/kg) are present in the UMCf (mudflat sediments) above the deeper gypsum-rich UMCf (saline lake sediments). The gypsum-rich subunit was encountered between 15 and 40 feet below the top of the UMCf, and within the subunit perchlorate was not detected or concentrations were below the perchlorate screening level of 0.015 mg/L. As noted above, the presence of gypsum is characteristic of fine-grained saline lakebed sediments. These sediments were deposited in a low energy environment, which is associated with low to very low hydraulic conductivity. As such, this unit appears to have retarded the downward migration of perchlorate within Transect 1A.

4.2 Hydrogeology

Groundwater was first encountered at depths ranging from approximately 9 to 22 feet bgs during installation of new monitoring wells ZTS-MW113, ZTS-MW114, and ZTS-MW115. These depths to groundwater generally correspond with Tetra Tech's observations during the initial round of groundwater monitoring well installation at Transect 1A. In the southern portion of Transect 1A, the groundwater table was generally observed at or slightly below the alluvium-UMCf contact. Because the depth to the alluvium-UMCf contact generally increases toward the north, more significant intervals of saturated alluvium are present in the northern portion of Transect 1A closer to Las Vegas Wash.

Following installation and development of the new monitoring wells, groundwater levels were measured at all Transect 1A wells as part of a comprehensive Transect 1A groundwater sampling event performed in December 2019. Depth to water measurements recorded during the December 2019 field effort are presented in Table 4-1. For wells screened in the alluvium, groundwater depths ranged from 12.7 to 21.7 feet bgs (1522.95 to 1531.19 feet above mean sea level [amsl]). For wells screened in the UMCf, groundwater depths ranged from 5.4 to 20.8 feet bgs (1522.53 to 1541.81 feet amsl).

Groundwater flow directions interpreted from December 2019 measurements are generally consistent with those presented in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019). A groundwater potentiometric surface map for the wells screened in the alluvium in Transect 1A is presented on Figure 4-7. Figure 4-8 presents the potentiometric surface measured at wells screened in the UMCf. As shown on Figure 4-7, Groundwater within Transect 1A for the uppermost saturated zone generally flows to the east, with a slight northerly component toward the southern end of the Transect 1A Study Area. As shown on Figure 4-8, groundwater within the UMCf within Transect 1A generally flows to the northeast. The calculated average hydraulic gradient for the uppermost saturated zone was 0.010 feet per foot (ft/ft) to the east, while the hydraulic gradient for the UMCf was 0.015 ft/ft to the northeast. The ranges of hydraulic gradient for the alluvium and the UMCf in Transect 1A were 0.006 to 0.013 ft/ft and 0.013 to 0.015 ft/ft respectively.

Vertical gradients indicate the direction and magnitude of vertical groundwater flow where monitoring well clusters are present. The vertical groundwater gradient observed at representative well clusters screened in the alluvium and UMCf was generally upward in the range of 0.08 to 0.34 ft/ft; however, a slight downward gradient of 0.02 ft/ft was observed at the LVWPS-MW112A/B well cluster in the northeastern part of Transect 1A. A larger upward vertical gradient was observed near the western border of Transect 1A at LVWPS-MW101A/B cluster and LVWPS-MW104/ZTS-MW114 cluster. Upward vertical gradients indicate that groundwater flow is moving from deep (i.e., the UMCf) to shallow (i.e., the alluvium). This is important for understanding how vertical groundwater flow may influence COPC transport. Vertical gradients calculated based on December 2019 measurements are summarized in Table 4-2 below and presented in Figure 4-9.

Table 4-2: Transect 1A Vertical Gradients

Well Pair	Vertical Gradient Direction	Vertical Gradient (ft/ft)
LVWPS-MW101A LVWPS-MW101B	Upward	0.34
ZTS-MW113 LVWPS-MW102A	Upward	0.25
LVWPS-MW104 ZTS-MW114	Upward	0.30
LVWPS-MW107A LVWPS-MW107B	Upward	0.15
LVWPS-MW108A LVWPS-MW108B	Upward	0.28
LVWPS-MW110 ZTS-MW115	Upward	0.08
LVWPS-MW111A LVWPS-MW111B	Upward	0.09
LVWPS-MW112A LVWPS-MW112B	Downward	0.02

4.3 Soil Analytical Results

The following sections summarize the results of soil sampling conducted by Tetra Tech in 2018 and Ramboll in 2019.

4.3.1 Chemical Analysis

4.3.1.1 Tetra Tech 2018 Soil Sample Analytical Results

Between March 27 and April 25, 2018, Tetra Tech collected soil samples from 12 soil borings associated with the LVWPS-MW101 through LVWPS-MW112 well clusters. Approximately six to 10 soil samples were collected from each soil boring ranging from the top of the water table to the bottom of each boring. Sample depths ranged from approximately 20 to 120 feet bgs.

All of Tetra Tech's 2018 soil samples were analyzed for perchlorate. Concentrations ranged from <0.012 to 3.2 mg/kg in the saturated alluvium (21.5 to 47 feet bgs), and <0.012 to 5.3 mg/kg in the UMCf (27.5 to 76.5 feet bgs), as shown in Figures 4-10a through 4-10f. The Leaching-based Soil Screening Level (SSL) for perchlorate is 0.015 mg/kg. Perchlorate concentrations were less than the SSL at depths below 77 ft bgs. Perchlorate was not detected above laboratory reporting limits in samples collected from the deeper, gypsum-rich subunit of the UMCf at depths ranging from 62 to 120 feet bgs.

A subset of soil samples collected from the UMCf in soil borings associated with the LVWPS-MW102A/B and LVWPS-MW110 wells were also analyzed for anions and cations (alkalinity, bicarbonate, carbonate, calcium, chloride, magnesium, nitrate, potassium, and sulfate), chlorate, dissolved metals, hexavalent chromium, phosphorus, soil pH, total dissolved solids (TDS), total Kjeldahl nitrogen (TKN), and total organic carbon (TOC). A summary of the results (adapted from Tetra Tech 2019) significant to ZVI-enhanced bioremediation is presented below.

- Anions and cations were analyzed in water extracts from 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 toxic effects on perchlorate-reducing bacteria.

- 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 from water extracts from the soil. One location had an arsenic concentration of 820 µg/L, while all the other samples ranged from less than 2.5 µg/L to 11 µg/L. Iron was detected as high as 970 µg/L at one location, it was less than 330 ug/L in all remaining samples. Manganese was detected at very low concentrations as well, ranging from 3.6 J µg/L to 33 µg/L. Dissolved chromium was detected at very low concentrations (maximum of 36 µg/L) in two of the six samples. Hexavalent chromium was not detected above the sample detection limit in any soil samples. At these concentrations, mobilization of metals is not expected to be a significant issue for a field test of ZVI-enhanced bioremediation, but dissolved metals will be monitored in groundwater during performance monitoring to assess mobilization of metals.

- Phosphorus concentrations ranged from 300 to 1,200 mg/kg, which indicates that there appears to be significant phosphorus bound to the soil, which could be used by perchlorate-reducing bacteria as a nutrient. However, bound phosphorus is not always bioavailable to microorganisms.

- 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 consistent with the observed presence of gypsum at depth. These results indicate that there is unlikely to be toxic effects on perchlorate-reducing bacteria.

- TKN was measured at concentrations of up to 630 mg/kg, which indicates that there is sufficient nitrogen to serve as a nutrient for perchlorate-reducing bacteria.

- TOC concentrations ranged from less than 600 mg/kg to 69,000 mg/kg. TOC is likely high in the UMCf because of ancient deposits of plant material that is still undergoing decay.

Comprehensive results of Tetra Tech's 2018 Transect 1A soil sampling effort are included in Section 3.1 of the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum and Table H.1 of Appendix H of same (Tetra Tech 2019).

4.3.1.2 Ramboll 2019 Soil Sample Analytical Results

Ramboll collected four soil samples from boring ZTS-MW113, one soil sample from boring ZTS-MW114, and two soil samples from boring ZTS-MW115 in November 2019, as described in Section 3.2.3.1. A summary of concentration ranges detected in these samples is presented in Figures 4-10g and 4-10h. Analytical results from the soil samples are presented in Table 4-3. Results were generally consistent with soil sampling conducted previously by Tetra tech (discussed in Section 4.3.1.1).

Perchlorate concentrations in soil collected in the alluvium at ZTS-MW113 and ZTS-MW115 ranged from <0.010 to 2.7 mg/kg (10 to 40.5 feet bgs). Perchlorate, chlorate, and nitrate concentrations increased with an increasing depth for both ZTS-MW113 and ZTS-MW115. The perchlorate concentration for the lone soil sample collected at ZTS-MW114 in the UMCf (45 to 45.5 feet bgs) was less than the laboratory reporting limit of 0.015 mg/kg. Concentrations of perchlorate, chlorate, and nitrate were higher in the alluvium than in the UMCf; however, the sampling included only one UMCf sample (ZTS-MW114 at 45 to 45.5 feet bgs). TOC concentrations in the alluvium soil ranged from 766 to 3,120 mg/kg while the TOC concentration in the UMCf at ZTS-MW114 was 36,500 mg/kg. The elevated concentration of TOC in the UMCf at ZTS-MW114 in the soil sample from 45 to 45.5 feet bgs likely coincided with an organic layer of the type previously identified by Tetra Tech (see Section 4.3.1.1).

4.3.2 Geotechnical Testing

Tetra Tech collected a total of nine Shelby tube samples for geotechnical testing as part of their initial pre-design investigation at Transect 1A. One sample was collected from the saturated alluvium at boring location LVWPS-MW109, and the remaining eight samples were collected from the UMCf at boring locations LVWPS-MW102B, LVWPS-MW109, and LVWPS-MW110. The results of Tetra Tech's geotechnical testing are summarized in the table below and presented in detail in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019). Additional geotechnical data collection was not included in Treatability Study Modification No. 9 (Ramboll 2019a) as the geotechnical testing performed by Tetra Tech was considered adequate. A summary of geotechnical testing results is shown below in Table 4-4.

Table 4-4: Summary of Geotechnical Analysis Results in Transect 1A

Geotechnical Parameter	Saturated Alluvium	UMCf
Total Porosity (volume percent)	28.0	50.6 – 65.2
Percent Moisture (percent)	22.6	38.1 – 66.5
Dry Density (pounds per cubic foot)	117.0	56.0 – 83.3
Specific Gravity (unitless)	2.607	2.583 – 2.722
Wet Density (pounds per cubic foot)	143.332	92.574 – 115.000
Note: The results summarized above were exported directly from the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019).		

4.3.3 Microbial Analysis

The following sections present the results of microbial analysis performed on soil samples collected by Tetra Tech in 2018 and Ramboll in 2019.

4.3.3.1 Tetra Tech 2018 Microbial Analysis

Tetra Tech collected a total of four soil samples for microbial analysis from Transect 1A during their April 2018 pre-design investigations. The focus of the microbial sampling was the UMCf. The samples were collected during installation of wells LVWPS-MW102B (22.5-23 and 58-58.5 feet bgs) and LVWPS-MW110 (29-29.8 and 46-46.5 feet bgs). The upper samples from each location represented the uppermost saturated zone, and the lower samples were collected from deeper zones within the UMCf. Samples were sent to Microbial Insights, Inc (Knoxville, Tennessee) for analyses. A microbial census of each sample was performed to assess the presence of perchlorate reductase gene (pcrA), and a microbial phospholipid fatty acid analysis (PLFA) was performed to assess the status and diversity of the overall microbial community.

The samples collected from LVWPS-MW102B were found to contain total biomass in the range of 7.23×10^5 to 8.45×10^5 cells per gram (cells/gram), meaning there were relatively low microbially active populations. However, the total biomass reported for both samples from LVWPS-MW110 was less than the detection limit of 9.63×10^5 cells/gram, indicating some variability in the distribution of bacteria exists across the site. PLFA analysis performed on samples from LVWPS-MW102B indicated a low diversity of bacteria in terms of community structure, potentially due to the presence of inhibitory conditions such as the presence of high TDS in the groundwater. The perchlorate reductase enzyme was not detected above the laboratory detection limit of 2.5×10^4 cells/gram. The non-detection was not unexpected considering that ISB had not yet been implemented (Tetra Tech 2019).

Bio-Traps® were placed in three monitoring wells in Transect 1A (LVWPS-MW103B and LVWPS-MW107A/B), retrieved after approximately one month, and shipped to Microbial Insights for analyses. Microbial biomass results ranged from 2.58×10^4 to 1.05×10^5 cells/gram. A sizable proportion of the bacterial population (greater than 70 percent) was 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. 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®.

These results describe conditions of generally low biological activity and diversity with an absence of biological perchlorate reduction, which is generally consistent with the native microbial community in other areas of the NERT RI Study Area. As has been observed during prior treatability studies, native microbial communities can be stimulated to support robust biological perchlorate reduction with these initial conditions (Tetra Tech 2016, Tetra Tech 2019, Tetra Tech 2020). While the above summarizes the analysis performed by Tetra Tech at Transect 1A that is applicable to this study, additional information regarding microbial analysis of samples collected by Tetra Tech is presented in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019).

4.3.3.2 Ramboll 2019 Microbial Analysis

To gain a better understanding of microbial community profile and dynamics, five soil samples were sent to CSU for qPCR analysis to assess the presence of perchlorate reductase and chlorite dismutase genes. The samples were collected from boring locations ZTS-MW113 (17.0-17.5 and 36.5-37.0 feet bgs), ZTS-MW114 (42.0-42.5 feet bgs), and ZTS-MW115 (19.0-19.5 and 38.5-39.0 feet bgs), as described in Section 3.2.3.1. Consistent with the Tetra Tech results, the qPCR results were below the detection limit of 2.5 x 10^3 copies in all samples. However, the CSU laboratory technicians suspected qPCR inhibition was occurring during analysis of all samples with the exception of the sample collected from 17.0 to 17.5 feet bgs at ZTS-MW113. Since it is difficult to extract DNA from soils containing clay, qPCR inhibition was suspected in the samples that had a high clay content.

4.4 Groundwater Analytical Results

As described in Section 3.2.4, a comprehensive groundwater monitoring event was conducted in December 2019, with samples collected from all existing and newly installed Transect 1A wells. Groundwater sampling field logs are provided in Appendix C. Analytical results for key parameters are summarized in Table 4-5 below. Analytical results and measured field parameters for each groundwater well sampled are provided in Tables 4-6 and Table 4-7, respectively.

Table 4-5: Summary of Groundwater Analytical Results in Transect 1A

Analyte/Field Parameter	Range		Average		Median	
	Alluvium	UMCf	Alluvium	UMCf	Alluvium	UMCf
Perchlorate (µg/L)	3,300 – 8,700	<4.8 – 9,400	4,940	3,120 [a]	4,100	1,620 [a]
Chlorate (µg/L)	11,000 – 54,000	<10 – 97,000	22,700	15,400 [a]	19,500	3,450 [a]

Table 4-5: Summary of Groundwater Analytical Results in Transect 1A

Analyte/Field Parameter	Range		Average		Median	
	Alluvium	**UMCf**	**Alluvium**	**UMCf**	**Alluvium**	**UMCf**
Chromium (total) (µg/L)	5.1 – 99	<2.5 – 370	37.9 [b]	82.7 [a]	32.5 [b]	65 [a]
Nitrate as NO_3 (mg/L)	32 – 64	<5 – 84	44.5	25.0 [a,b]	41.5	12.5 [a,b]
Sulfate (mg/L)	1,300 – 2,700	2,400 – 88,000	2,100	16,930	2,150	3,200
Dissolved Solids (total) (mg/L)	4,000 – 6,200	6,200 – 71,000	5,075	22,750	4,950	7,400
Dissolved Hydrogen (nM)	1.6 – 4.9	1.7 – 4.2	3.08	3.0	3.0	3.2
Carbon, Dissolved Organic (mg/L)	1.1 – 1.7	<0.65 – 6.8	1.32	2.20 [a,b]	1.30	0.82 [a,b]
Carbon, Total Organic (mg/L)	0.94 J – 2.2	<0.65 – 7.0	1.33 [b]	2.22 [a,b]	1.25 [b]	1.01 [a,b]
Total Alkalinity as $CaCO_3$ (mg/L)	86 – 270	80 – 170	155.1	103.7	140	95.5
Dissolved Oxygen (mg/L)	0.52 – 8.36	0.66 – 5.31	2.09	1.19	1.62	0.74
pH	7.34 – 7.82	7.48 – 8	7.52	7.78	7.49	7.77

Notes:
µg/L = micrograms per liter
mg/L = milligrams per liter
nM = nanomolar
UMCf = Upper Muddy Creek Formation
J = Concentration is estimated
< = Concentration is less than indicated laboratory method reporting limit

[a] Concentrations that are less than indicated laboratory method reporting limits are regarded as half the reporting limit for average or median calculations.
[b] Estimated concentrations are included in average or median calculations.

Perchlorate was detected above the method detection limit in all Transect 1A wells screened in the saturated alluvium, with concentrations ranging from 3,300 to 8,700 µg/L (Figure 4-11). Perchlorate concentrations measured in the groundwater samples representing the alluvium collected from Transect 1A generally appear to be evenly distributed with no obvious hot spots. Perchlorate concentrations in the UMCf ranged from <4.8 to 9,400 µg/L, and higher concentrations of perchlorate were generally detected in the western and southern portions of Transect 1A (Figure 4-12). On average, perchlorate concentrations in samples collected from wells screened in the upper portion of the UMCf were generally similar to those measured in the alluvium. Perchlorate was generally not detected above the method detection limit in samples from deeper UMCf wells; however, the detection limits were elevated in some cases due to high concentrations of other constituents that required the samples to be diluted prior to analysis. Generally, perchlorate concentrations exceed the groundwater screening level of 15 µg/L to a depth of approximately 78 ft bgs.

The distribution of chlorate in Transect 1A is similar to that of perchlorate. Chlorate concentrations in the alluvium ranged from 11,000 to 54,000 µg/L and appeared evenly distributed, while chlorate concentration in the UMCf ranged from <10 to 97,000 µg/L and higher concentrations in the UMCf were detected in the western and southern portions of the Transect 1A Study Area (Figure 4-13 and 4-14). Generally, chlorate concentrations exceed the groundwater screening level of 1,000 µg/L to a depth of approximately 97 ft bgs.

As shown in Table 4-5 above:

- Nitrate concentrations were generally found to be higher in the samples of saturated alluvium than the UMCf (Figure 4-15 and 4-16). Nitrate levels ranged from 32 to 64 mg/L in the alluvium and from <5 to 84 mg/L in the UMCf. The maximum depth where nitrate concentrations exceed the groundwater screening level of 44 mg/L was approximately 70 ft bgs.

- Sulfate concentrations in samples from deeper UMCf wells were generally about an order of magnitude higher than those in the saturated alluvium and the upper portion of the UMCf due to the increased presence of gypsum with depth.

- Average TOC and dissolved organic carbon (DOC) concentrations were higher in the UMCf than in the saturated alluvium. TOC concentrations in the alluvium ranged from 0.94 to 2.4 mg/L, while concentrations in the UMCf ranged from <0.65 to 7 mg/L. DOC concentrations were similar, ranging from 1.1 to 1.7 mg/L in the alluvium and <0.65 to 6.8 mg/L in the UMCf.

As presented in Table 4-6, groundwater samples from 10 wells were analyzed for dissolved hydrogen. Dissolved hydrogen concentrations ranged from 1.6 to 4.9 nanomolar (nM). The highest concentrations were detected in samples from LVWPS-MW107A (4.9 nM) and ZTS-MW114 (4.2 nM). These concentrations are typical of baseline groundwater conditions prior to application of ZVI (Sorel et al. 2002).

Additional analytical results presented in Table 4-6 are summarized below:

- Concentrations of bicarbonate as HCO_3 ranged from 97 to 330 mg/L. On average, bicarbonate concentrations were slightly higher in the saturated alluvium than the UMCf.
- Calcium concentrations ranged from 140 to 720 mg/L with no discernable trends.
- Chloride concentrations ranged from 700 to 16,000 mg/L, with considerably higher concentrations detected in the UMCf than in the alluvium.
- Total chromium concentrations ranged from <0.0025 to 0.37 mg/L with no discernable trends.

- TDS concentrations ranged from 4,000 to 71,000 mg/L, with considerably higher concentrations detected in the UMCf than in the alluvium.
- Total iron concentrations ranged from <0.050 to 41 mg/L. Ferric and ferrous iron analytical results show that the vast majority of iron is present in the form of ferric iron.
- Magnesium was detected at concentrations ranging from 140 to 14,000 mg/L. Concentrations were considerably higher in the UMCf than in the alluvium.
- Potassium concentrations ranged from 41 to 11,000 mg/L. Concentrations were considerably higher in the UMCf than in the alluvium.
- Sodium concentrations ranged from 590 to 14,000 mg/L. Concentrations were considerably higher in the UMCf than the alluvium.
- Total alkalinity as CaCO3 ranged from 80 to 270 mg/L. On average, total alkalinity was slightly higher in the saturated alluvium than the UMCf.

Groundwater field parameters (e.g., DO, oxidation reduction potential [ORP], temperature, pH, and conductivity) collected as part of groundwater sampling are provided in Table 4-7. DO concentrations averaged 2.1 mg/L in the alluvium and 1.2 mg/L in the UMCf. ORP values averaged 82.3 millivolts (mV) in the alluvium and -95.4 mV in the UMCf. The alluvium and UMCf had average pH values of 7.5 and 7.8, respectively.

4.5 Hydraulic Testing Results

As described in Section 3.2.5, hydraulic testing was performed to better characterize the hydraulic conductivity and groundwater velocity in the ZVI field test area. Hydraulic conductivity was measured using slug tests. Groundwater velocity was estimated using two different methods: the first method was based on the hydraulic conductivity results using Darcy's Law and the second method was based on borehole dilution test results.

Slug testing was attempted at all of the wells in the ZVI field test area. Tetra Tech performed slug tests at 20 of the 21 wells installed as part of their 2018 Phase 1 pre-design investigation at Transect 1A (LVWPS-MW103B was not tested due to insufficient recharge following well development). Detailed results of slug testing performed by Tetra Tech are presented in Appendix C of the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019). Ramboll performed slug tests at new monitoring wells ZTS-MW113, ZTS-MW114, and ZTS-MW115 in December 2019, with detailed results presented in Appendix D. The collective slug testing results indicate average hydraulic conductivities at Transect 1A are 24.2 ft/day, 2.0 ft/day and 0.8 ft/day for wells screened in the alluvium, UMCf (mudflat sediments), and UMCf (saline lake sediments), respectively. All of the slug test results are shown in Table 4-8, with summary statistics provided below in Table 4-9.

Groundwater velocity was first estimated from the slug test results using Darcy's Law. The hydraulic gradient at each well was estimated from the potentiometric surface contour maps shown in Figures 4-6 (alluvium) and 4-7 (UMCf). The effective porosity of the alluvium and UMCf was assumed to be 0.1 and 0.08, respectively, which are the averages measured in laboratory testing of soil samples collected in OU-2 as part of the

RI for OU-1 and OU-2 (Ramboll 2021b). The average groundwater velocities based on Darcy's Law are estimated to be 1.8, 0.3, and 0.2 ft/day for the alluvium, UMCf (mudflat sediments), and UMCf (saline lake sediments), respectively. The groundwater velocities estimated from Darcy's Law are shown in Table 4-8, with summary statistics provided below in Table 4-9. The velocities are also shown on Figures 4-7 and 4-8.

The second method for estimating groundwater velocity was based on borehole dilution testing. Tetra Tech performed borehole dilution tests on wells LVWPS-MW107A and LVWPS-MW107B during their investigation, which were re-analyzed by Ramboll. Ramboll performed borehole dilution tests on the three newly installed monitoring wells and 12 existing wells in January 2020. Additional information on testing procedures is presented in Appendix D. The average groundwater velocities based on borehole dilution testing are 2.9 ft/day and 1.2 ft/day for wells screened in the alluvium and the UMCf (mudflat sediments), respectively. Groundwater velocities from borehole dilution testing are shown in Table 4-8, with summary statistics shown below in Table 4-9. The velocities are also shown on Figures 4-7 and 4-8.

The groundwater velocities estimated from borehole dilution testing are generally higher than those estimated from Darcy's Law at the same wells. The borehole dilution test analysis is based on the assumption that there is no vertical flow within the well being tested. However, there is generally an upward vertical gradient throughout the Transect 1A Study Area, as shown in Table 4-2. As a result, there may be an upward bias in the groundwater velocities from the borehole dilution tests. Thus, the field test design is based on the average velocities from Darcy's Law of 1.8 ft/d and 0.3 ft/d in the alluvium and UMCf (mudflat sediments), respectively.

Table 4-9: Summary of Hydraulic Testing in Transect 1A

Hydraulic Property	Lithology	Min	Max	Ave	Med	Std Dev	Sample Size
Effective Porosity [a]	Alluvium	0.06	0.14	0.10	0.11	0.04	5
	UMCf	0.01	0.26	0.08	0.06	0.05	177
Hydraulic Conductivity from Slug Testing (ft/d)	Alluvium	2.5	85	24.25	14.61	29.75	10
	UMCf (mudflat sediments)	0.001	6.41	1.98	1.45	2.17	10
	UMCf (saline lake sediments)	0.05	1.40	0.82	1.00	0.70	3
Groundwater Velocity based on Darcy's Law (ft/d)	Alluvium	0.15	5.10	1.77	1.37	1.78	10
	UMCf (mudflat sediments)	0.0002	1.04	0.33	0.25	0.35	10
	UMCf (saline lake sediments)	0.01	0.26	0.15	0.18	0.13	3

Hydraulic Property	Lithology	Min	Max	Ave	Med	Std Dev	Sample Size
Groundwater Velocity from Borehole Dilution Testing (ft/d)	Alluvium	0.28	6.29	2.85	2.88	1.68	9
	UMCf (mudflat sediments)	0.24	2.36	1.22	1.20	0.79	6

Notes:
ft/d = feet/day
UMCf = Upper Muddy Creek Formation

[a] Effective porosities are from measurements in OU-2 area in Ramboll's Remedial Investigation Report for OU-1 and OU-2 (Ramboll 2021b). Effective porosities larger than 0.2 are considered disturbed and are excluded from the summary statistics for average, median, standard deviation, and sample size.

4.6 Pre-Design Field Investigation Conclusions

As discussed in Section 3.1, the primary objective of the Phase 1 pre-design field investigation was to characterize the geology, hydrogeology, chemistry, and biology in sufficient detail to confirm Transect 1A is suitable for a Phase 2 field test and to collect data necessary to refine the design for a Phase 2 field test.

Based on a review of hydrogeological and analytical data, Ramboll concludes the Transect 1A Study Area is well suited for a Phase 2 field test of ZVI-enhanced bioremediation to support the Phase 2 field test objectives discussed in Section 1. Additional conclusions of the Phase 1 pre-design field investigation follow.

- The geology provides sufficient depth of saturated alluvium to adequately test the ZVI-enhanced bioremediation in permeable media while also allowing field testing in the upper portion of the UMCf at a reasonable depth below ground surface.
- The average groundwater velocity in the alluvium of 1.8 feet/day is high but not high enough to make design of a field test of ZVI-enhanced bioremediation impractical and will be a good test for multiple test configurations.
- The average groundwater velocity in the UMCf is 0.3 feet/day, which will be a good test for ZVI-enhanced bioremediation under lower velocity flow conditions.
- The chemical composition of the groundwater is broadly representative of conditions in OU-3 and does not contain constituents that may represent extreme conditions (such as ultra-high TDS) that inhibit microbial processes. However, due to the presence of constituents that may promote passivation of the ZVI surface (e.g., nitrate) and/or precipitation of mineral species, the field test must include these considerations during the design. These processes will be assessed using geochemical modeling (as described in Section 6) and by the performance monitoring (as described in Section 8).
- Microbial analysis of soil and groundwater indicate that perchlorate-reducing bacteria are present in low numbers. However, the Phase 1 bench-scale testing

discussed in Section 5 and in other treatability studies (Tetra Tech 2016, 2019, 2020) demonstrate that these numbers can be stimulated. Therefore, the effectiveness of the stimulation of perchlorate-reducing bacteria through the addition of a laboratory produced biological inoculum (as further discussed in Section 5.2.3) will be assessed during the Phase 2 field test.

In combination, the factors listed above should provide an appropriate environment in which to assess the effectiveness, longevity, and cost of a ZVI-enhanced bioremediation and provide valuable insights into how the technology may be applied more broadly across the NERT RI Study Area.

5. PHASE 1 BENCH-SCALE TESTING

The following sections describe the Phase 1 bench-scale testing program that has been completed, which coupled with the Phase 1 pre-design field investigation data presented in Section 4, provides information necessary to design and implement the Phase 2 field test described in Section 7. Bench-scale testing was performed using soil and groundwater obtained during the initial Phase 1 pre-design field investigation activities at the Galleria Parcel in 2018 and 2019 (See Appendix A), and subsequent testing was performed using soil and groundwater obtained from Transect 1A consistent with Treatability Study Modification No. 9 (Ramboll 2019a). Bench-scale reports are included in Appendix E (Galleria Parcel) and Appendix F (Transect 1A).

5.1 Galleria Parcel Bench-Scale Testing

Batch microcosm and column tests were conducted at the University of Nevada, Las Vegas (UNLV) under the direction of Jacimaria R. Batista, Ph.D., P.E. using soil and groundwater collected during the pre-design field investigation. Dr. Batista has performed previous bench-scale treatability studies on behalf the Trust generally focused on other carbon donors for the application of ISB within the NERT RI Study Area.

Bench-scale testing was conducted in a phased approach, such that knowledge gained was used to inform subsequent tests; however, in some cases tests were performed in parallel to minimize the overall duration of the program. The Galleria Parcel bench-scale testing program consisted of the following steps:

- **Batch microcosm testing** was performed using soil and groundwater from the alluvium and UMCf to demonstrate removal and destruction of nitrate, chlorate, and perchlorate by ZVI and perchlorate-reducing bacteria under site specific conditions. Variables tested included varying ZVI dose and grain size, as well as other parameters important for designing subsequent column and field tests.

- **Flow-through column testing** was performed using conditions established during batch microcosm testing to assess performance under dynamic flow conditions and evaluate potential for plugging or other impacts due to precipitation or biofouling in order to determine design parameters for the field test.

5.1.1 Objectives

Bench-scale testing was the initial step in assessing the applicability of ZVI to promote biological reduction of nitrate, chlorate, and perchlorate under site conditions. The overall objectives of bench-scale testing included the following:

- Evaluate the performance of ZVI in well-mixed microcosm bottles in reducing nitrate, chlorate, and perchlorate under approximate site geochemical conditions.

- Select the ZVI material in terms of particle size distribution and loading to promote effective degradation of nitrate, chlorate, and perchlorate.

- Use batch microcosm testing results to design the subsequent column tests.

5.1.2 Batch Microcosm Testing

Batch microcosm testing methods, materials, and results are summarized in the following sections. The final detailed report prepared by UNLV is included in Appendix E.

5.1.2.1 Methods and Materials

Soil and groundwater samples used in the initial bench tests were collected during the Phase 1 pre-design investigation at the Galleria Parcel before the location of the treatability study was changed (See Appendix A). Soil samples were collected from pilot boring ES-10 soil cores at a depth of 15 to 70 feet bgs. To obtain soil samples representative of the formation, approximately equal volumes of borehole cuttings were collected from the alluvium and UMCf at roughly 2.5-foot depth intervals and mixed in sterilized plastic pans using sterilized hand shovels. Groundwater samples were collected from monitoring wells installed during the pre-design field investigation (ES-10 and ES-34) in accordance with the Field Sampling and Analysis Plan (ENVIRON 2014a). Both soil and groundwater samples were transported to UNLV on ice and stored in a refrigerator at 4 degrees Celsius.

The batch microcosm tests were conducted using ZVI products available from Connelly-GPM, Inc. of Chicago, Illinois (Connelly-GPM), a well-known supplier of ZVI for remedial applications. These products are listed in Table 5-1, along with their respective particle size distributions. Product specification sheets for each of the ZVI blends listed below are provided in the UNLV Report (Appendix E).

Table 5-1: Particle Size Distribution of ZVI Products

Designation	Sieve Analysis	
	90% Passing	10% Retained
CC-1107	2.38 mm	0.841 mm
ETI CC-1004	2.38 mm	0.297 mm
CC-1190	1.19 mm	--
CC-1101	0.595 mm	0.210 mm
CC-1200	0.595 mm	0.595 mm

The products listed in Table 5-1 are all made by Connelly-GPM from the same stock material. However, the ZVI will oxidize shortly after the manufacturing process is complete and since finer particle sizes have a higher surface area, these materials will contain a higher fraction of iron oxide compared to coarser materials. The ETI CC-1004 ZVI is the standard product and the most common grade sold by Connelly-GPM for groundwater remediation applications. The CC-1107 ZVI is coarser (e.g., has a larger particle size) than ETI CC-1004. The CC-1190 ZVI has an intermediate average particle size with a wider distribution at the low end. The CC-1101 ZVI has the second smallest particle size distribution, while the CC-1200 ZVI is the smallest particle size material and is a fine powder.

The ZVI products listed above were added to sacrificial microcosms at doses determined through stoichiometric analysis. The stoichiometric equations for reduction of nitrate, chlorate, and perchlorate with hydrogen as the electron donor were considered in conjunction with the stoichiometric equations for anaerobic corrosion of ZVI (i.e., hydrogen production). Through this stoichiometric analysis, UNLV calculated that approximately 0.12 grams (g) of ZVI would be required to degrade the nitrate, chlorate, perchlorate, and DO in one liter of representative site groundwater, assuming the groundwater contained 20 mg/L nitrate, 10 mg/L chlorate, 5 mg/L perchlorate, and 4 mg/L DO. To ensure that ZVI dose would not be a limiting factor, the tests described in subsequent sections were run at the following theoretical stoichiometric ratios: 20X (~2.4 g ZVI/L), 100X (~12 g ZVI/L), 200X (~24 g ZVI/L), 400X (~48 g ZVI/L), or 800X (~96 g ZVI/L).

A total of 128 microcosms were set up and run as described below. After each microcosm was filled with the selected ZVI material, the bottles were purged with nitrogen to remove oxygen, then capped tightly and placed in a rotary shaker at 30 rotations per minute (rpm) at ambient room temperature (~20°C). Microcosms were removed from the rotary shaker for analysis at various intervals, depending on the experiment. Sampling consisted of centrifuging the microcosm contents then filtering the liquid portion. The filtered liquid was then analyzed to determine the dissolved concentrations of each analyte. Additional details on the test setup are available in the final UNLV report (Appendix E).

5.1.2.2 Preliminary Batch Microcosm Tests

Four preliminary tests (referred to as 1a through 1d) were conducted to evaluate the impact of ZVI grain size on contaminant reduction. Since smaller ZVI particle sizes will have higher surface areas, these products should support faster degradation for those contaminants degraded via abiotic reactions on the material surface. Since perchlorate reduction is a biological process driven by the hydrogen produced by ZVI corrosion rather than direct contact with the ZVI, it is not expected to be impacted by grain size; therefore, these tests were primarily evaluating ZVI grain size effects on the reduction of nitrate and chlorate, which degrade abiotically.

Tests were performed using CC-1107, CC-1101, ETI CC-1004, and CC-1200 ZVI materials along with site groundwater at the highest ZVI loading level of 800X (96 g ZVI/L). These represented ZVI samples with the largest and smallest particle size distributions (CC-1190 had an intermediate particle size distribution and was not tested in this step). In each case, small (40 milliliter [mL]) vials were filled with ZVI and site groundwater, sealed with the plastic cap, and placed on a rotary shaker at 30 rpm at ambient room temperature. Vials were sacrificially sampled after four hours and 48 hours of run time in the rotary shaker.

Preliminary tests 1a through 1d showed notable chlorate and nitrate reductions in all the vials (Figure 5-1). Chlorate had the fastest reaction rates and chlorate concentrations were reduced by at least 97.5 percent in all tests after 48 hours of run time. Nitrate had slower reaction rates and while concentrations were also reduced in all tests, there was more variation among the different ZVI types. Nitrate concentrations were reduced by 58 and 72 percent after 48 hours in tests performed with the CC-1107 and CC-1101 ZVI, respectively, and were reduced by 95.3 percent in the ETI CC-1004 test and 98.3 percent in the CC-1200 test. In general reaction rates were observed to be marginally faster in tests with smaller ZVI grain size (i.e., CC-1200) or higher ZVI content in relation to iron oxide (i.e., ETI CC-1004), but no ZVI grade tested significantly outperformed the ETI-CC-1004 material. As expected, perchlorate reduction was not observed during these short-duration tests because perchlorate is not rapidly reduced on the ZVI surface.

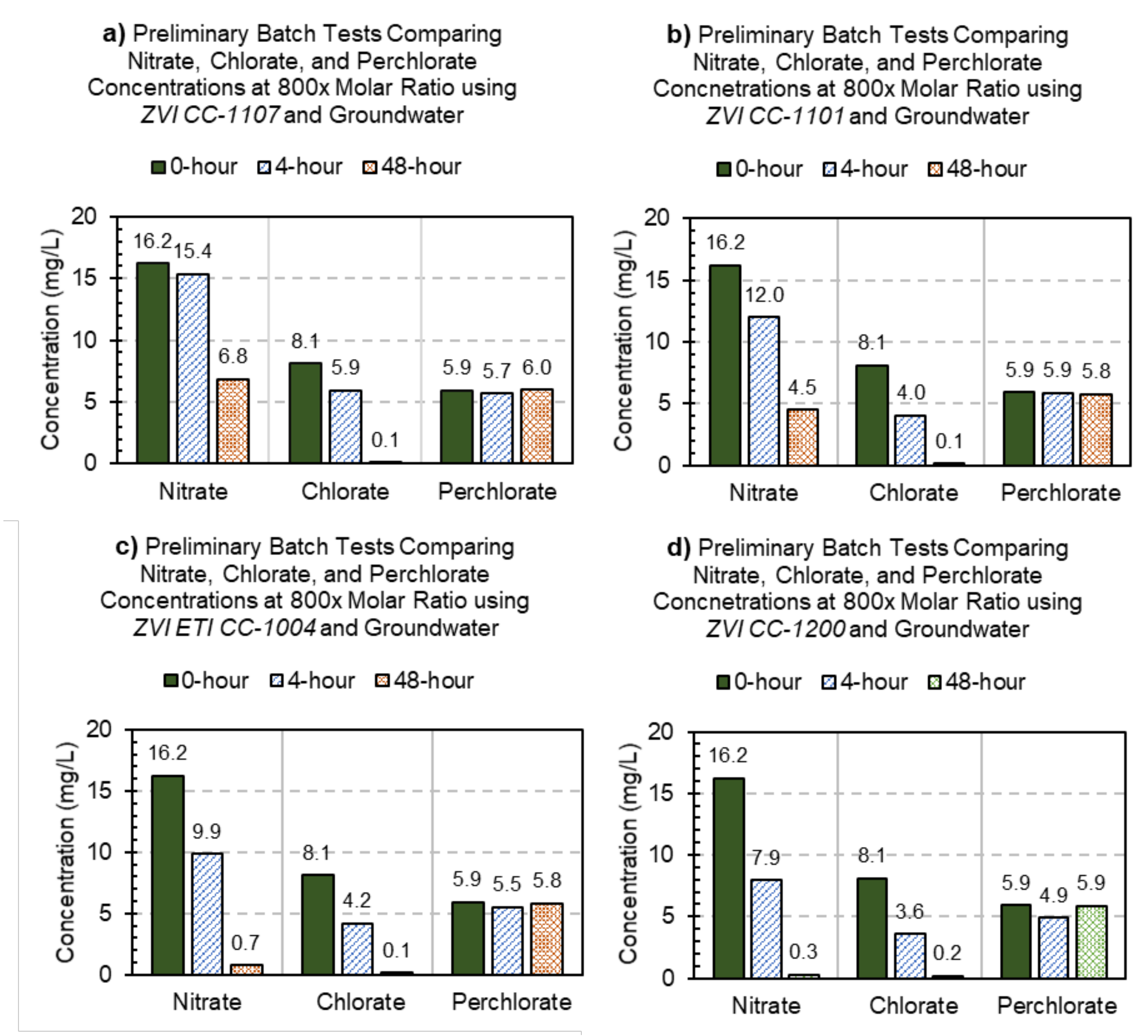

Figure 5-1: Impact of ZVI type on the reduction of nitrate, chlorate, and perchlorate present in groundwater measured after 4 hours and 48 hours using a ZVI to contaminant molar ratio of 800x

For the next round of preliminary batch microcosm testing, eight tests were conducted to evaluate ZVI loading. Preliminary tests 2a through 2d and 3a through 3d were conducted using ETI CC-1004 and CC-1190, respectively. The objective of these tests was to compare the performance of CC-1190 to the standard product, ETI CC-1004 over a larger range of ZVI loadings and experimental run times. Both products were tested at 20X (~2.4 g ZVI/L), 100X (~12 g ZVI/L), 200X (~24 g ZVI/L), and 400X (~48 g ZVI/L) doses. Vials were set up as previously described and were sacrificially sampled after four, 24, 48, and 72 hours of run time. Thus, the ZVI loadings were lower in this round of testing, but the test was run for a longer time.

Preliminary tests 2a through 2d (ETI CC-1004) and 3a through 3d (CC-1190) performed similarly, with reductions of at least 96 percent for chlorate and 80 percent for nitrate after 72 hours of run time. Microcosms with higher ZVI loadings in the range of 100X (~12 g ZVI/L) to 400X (~48 g ZVI/L) performed considerably better than those with the 20X (~2.4 g ZVI/L) loading. There were smaller differences in degradation rates when the ZVI loading was above 100X, indicating that ZVI surface area is not the primary driver for nitrate and chlorate reduction rates when the loading rate is above 100X. The results of preliminary tests run with ETI CC-1004 are shown in Figure 5-2 below as an example. Similar to the previous test and as expected, no perchlorate reduction was observed during these short-duration tests.

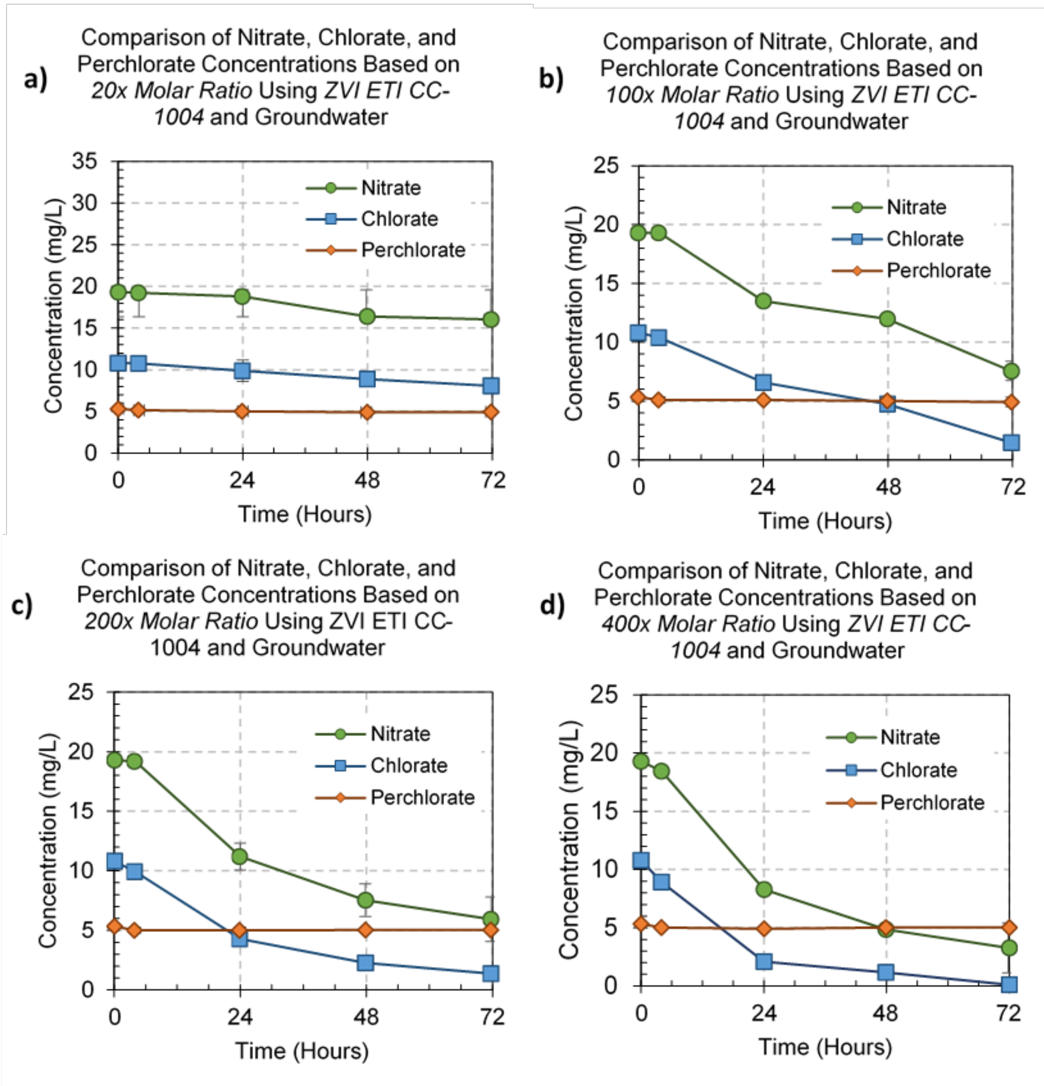

Figure 5-2: Nitrate, chlorate, and perchlorate reduction for (a) 20x molar ratio, (b) 100x molar ratio, (c) 200x molar ratio, and (d) 400x molar ZVI to contaminant molar ratios using ETI CC- 1004 in Phase 1 batch microcosm tests

5.1.2.3 Phase 1 Batch Microcosm Tests

Results from the preliminary rounds of testing were verified in Phase 1 batch microcosm tests run in larger (i.e., 125 mL) microcosm bottles and for longer periods (eight days) using site groundwater and ETI CC-1004 ZVI at ZVI loadings of 100X (~12 g ZVI/L) and 400X (~48 g ZVI/L) established to be optimal for nitrate and chlorate reduction during the preliminary testing. ETI CC-1004 was carried forward into this phase because it is the standard Connelly-GPM product and performed equivalent to or better than the other ZVI materials in the preliminary testing. Each microcosm bottle contained ZVI and 100 mL of site groundwater, was sealed with a butyl rubber stopper, and incubated on a rotary mixer at 30 rpm at ambient room temperature. Microcosms bottles were sacrificially sampled after one, two, three, five, and eight days of run time.

The results of the Phase 1 batch microcosm tests are shown in Figure 5-3. Chlorate was completely reduced within two days in microcosms loaded with 400X (~48 g ZVI/L) of ETI CC-1004 ZVI and within five days with a 100X (~12 g ZVI/L) loading. Nitrate was reduced by 95 percent after 5 days in microcosms with 400X (~48 g ZVI/L) of ZVI, and after 8 days in microcosms dosed at 100X (~12 g ZVI/L). Similar to previous experiments and as expected, no perchlorate reduction was observed during these short-duration tests.

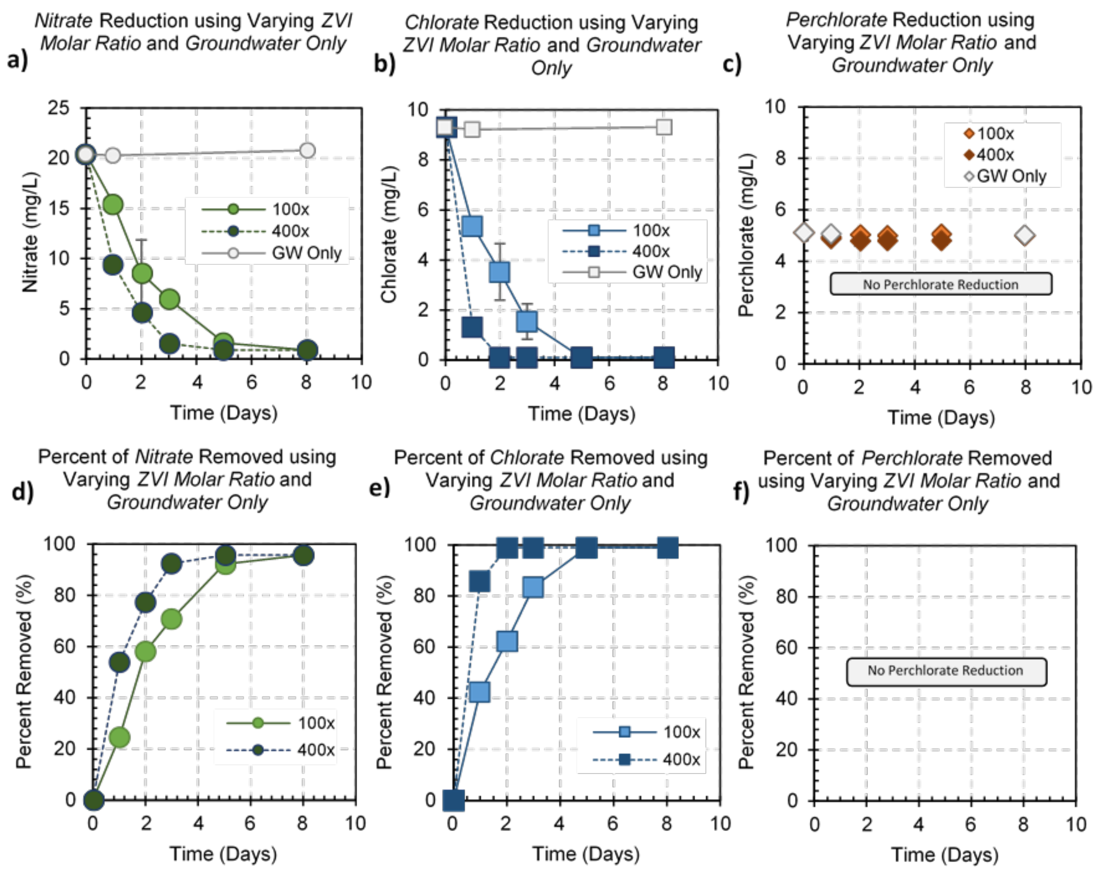

Figure 5-3: Impact of ZVI to contaminant molar ratios and longer reaction times on (a)nitrate, (b) chlorate, and (c) perchlorate reduction and percent of (c) nitrate, (d) chlorate, and perchlorate using ETI CC-1004 in groundwater only

5.1.2.4 Phase 2 Batch Microcosm Tests

Phase 2 batch microcosm tests were similar to Phase 1, except that site soil was added in addition to site groundwater and ZVI and the test was run over a longer time to determine if the presence of soil would impact the transformation rate of chlorate and nitrate or stimulate perchlorate reduction. Each microcosm bottle contained ZVI and 30 grams of wet soil and 100 mL of site groundwater. The bottles were sealed with a butyl rubber stopper and incubated on a rotary mixer at 30 rpm at ambient room temperature. Microcosms were sacrificially sampled after two, four, six, eight, 12, 17, and 21 days of run time in the rotary shaker.

The results of Phase 2 batch tests with site soil were roughly similar to those observed during Phase 1 without site soil (Figure 5-4). Complete reduction of chlorate was observed after two days in microcosms dosed with 400X (~48 g ZVI/L) of ETI CC-1004, and after seven days with the lower 100X (~12 g ZVI/L) dose. Nitrate was reduced by 95 percent after seven days in both cases. However, one difference was noted in the nitrate degradation. In the absence of soil, all the nitrate was degraded abiotically, as evidenced by the accumulation of stoichiometrically equivalent amounts of ammonia in the bottles (see the UNLV report in Appendix E for ammonia data). With soil presence, the molar balance could not be closed, indicating that some of the degradation was occurring via reduction of nitrate to nitrogen gas by nitrate-reducing bacteria present in the soil. Similar to previous experiments, no perchlorate reduction was observed during these tests.

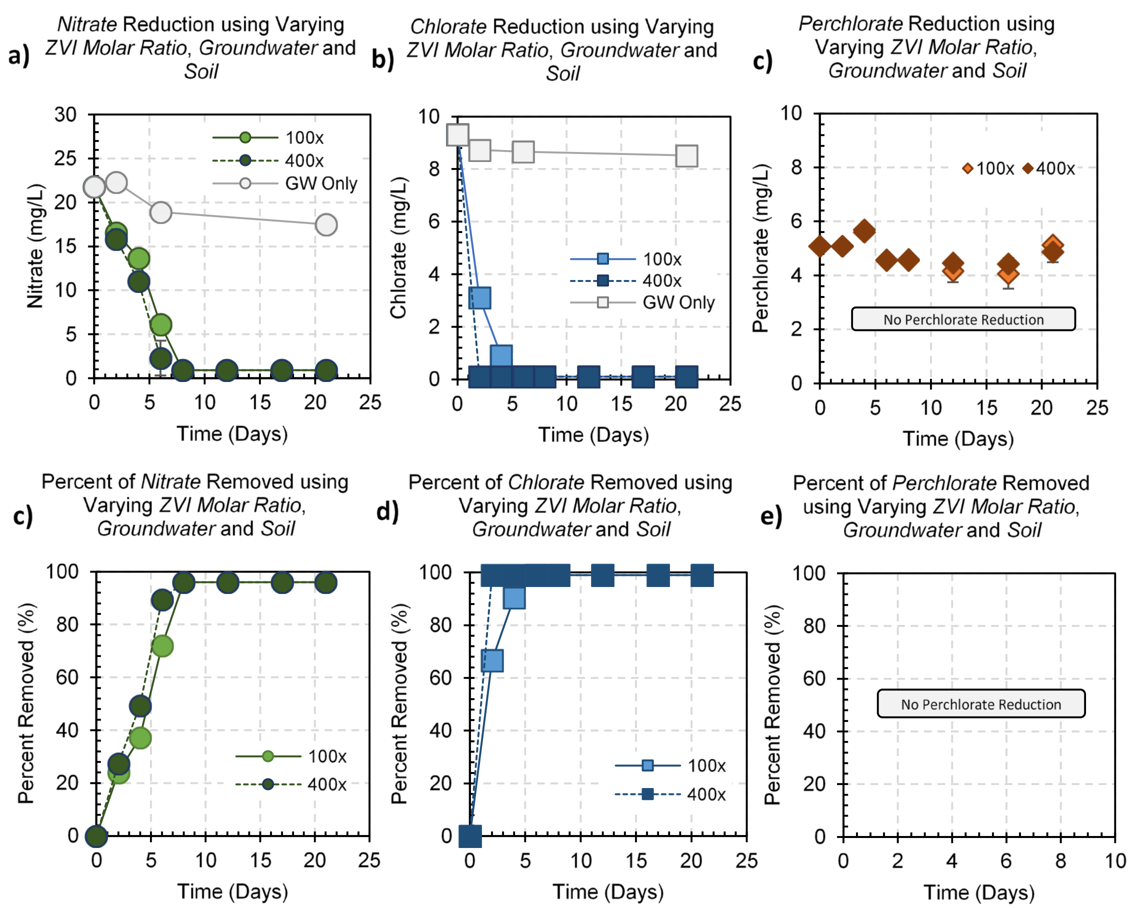

Figure 5-4: Impact of ZVI to contaminant molar ratios and longer reaction times on (a) nitrate, (b) chlorate, and (c) perchlorate reduction and percent of (c) nitrate, (d) chlorate, and (e) perchlorate using ETI CC-1004 with groundwater and soil

The rapid degradation of chlorate and nitrate observed in these batch tests is consistent with the literature cited in Section 2. Chlorate and nitrate are both degraded abiotically, while nitrate is also reduced biologically by nitrate-reducing bacteria using hydrogen generated by ZVI corrosion. The absence of perchlorate reduction is attributed to the low numbers of perchlorate-reducing bacteria present in the soil and groundwater (see Section 4) and the short duration of the batch tests. The results achieved supported proceeding with column tests, where the incubation times would be substantially longer than in the bottles.

5.1.3 Column Testing

Flow-through column testing was conducted using soil and groundwater obtained from the Galleria parcel. The primary objectives of column testing were as follows:

- Assess the effectiveness of a flow-through ZVI system in reducing the contaminants of interest using ZVI as a reactive material and source of hydrogen. The column tests were run for a longer period of time than the microcosm tests in order to stimulate perchlorate reduction.
- Assess of the impact of residence time on the reduction of perchlorate, chlorate, and nitrate in a flow-through system, as well as observation of the sequence of contaminant reduction under simulated field conditions.
- Provide an initial opportunity to evaluate the hydraulic behavior of groundwater in the ZVI treatment matrix and assess the potential for permeability decreases due to secondary mineral precipitation and/or biofouling.
- Measure mobilization or immobilization of metals due to the ZVI treatment to anticipate what metals need to be monitored during a field test.

Column testing methods, materials, and results are summarized in the following sections. All results are presented in the detailed report prepared by UNLV and provided in Appendix E. Five columns were constructed using ZVI as a matrix. Two of the five columns received no organic carbon amendment, while three columns received organic carbon amendment consisting of EVO or EHC™. The carbon-amended columns were added in the unlikely event that the columns with ZVI alone did not reduce perchlorate. All the ZVI columns receiving organic carbon amendments showed near complete reduction of the nitrate, chlorate, and perchlorate. The results from the columns containing ZVI without organic carbon are the focus of the following sections because organic carbon will not be added in the field. The results of all of the column tests are described in detail in Appendix E.

5.1.3.1 Methods and Materials

The column testing program was conducted in two phases, consisting of preliminary and secondary column tests. The preliminary column was built as a prototype to assist in the design of the secondary column test.

Column tests were conducted using groundwater extracted from well ES-34 and delivered to UNLV every two weeks. With the exception of the initial batch of groundwater, which had lower constituent concentrations, the groundwater contained an average of 55 mg/l nitrate, 50 mg/L chlorate, and 7.8 mg/L perchlorate. TDS ranged from 8,000 to 10,000 mg/L, sulfate ranged from 2,000 to 4,000 mg/L, and sodium and chloride averaged 1,000 and 1,500 mg/L, respectively. In addition, calcium and magnesium were present at approximately 500 mg/L each and alkalinity concentrations were approximately 60 mg/L (as $CaCO_3$). The influent pH ranged from 7 to 8, with an average of 7.5.

The two column tests containing ZVI without organic carbon amendment are described in the following sections.

5.1.3.2 Preliminary Column A1

Preliminary Column A1 was built as a prototype to assist in the design of the rest of the column tests. It was built using a two-foot length of 1-inch diameter transparent PVC tube to allow for visual observation of column contents during testing. The base of the column consisted of washed gravel and glass beads of varying sizes to keep column materials in-place and plugging the column inlet. On top of the base, a mixture of 1 g ZVI and 100 g of sand was added as a means to remove any DO present in the water and control iron hydroxide formation due to the rapid corrosion of ZVI in the presence of oxygen. Next, approximately two inches of site soil was added. Finally, a layer of 30 percent ETI CC-1004 and 70 percent sand was placed to build the ZVI reactive zone.

Column A1 was fed groundwater with no amendments for 140 days, after which nutrients (diammonium phosphate [DAP] and urea) and vitamin B12 were added until the test was completed on Day 180. This is indicated by the dashed line in Figure 5-5 below. DAP and urea were chosen because they are used to support the growth and activity of perchlorate-reducing bacteria in the FBRs currently operating at the NERT Site and together provide a near optimal ratio of nitrogen and phosphate for bacterial growth. The urea contains 20% by weight carbon, but is naturally broken down by bacteria utilizing a urease enzyme to form ammonia and carbon dioxide. The resulting ammonia can be used as a source of nitrogen for both autotrophic and heterotrophic bacteria. However, while the carbon dioxide can provide a source of carbon for autotrophic perchlorate-reducing bacteria, it cannot be used as an election donor for perchlorate reduction. Feed water was pumped into the column in an upward flow direction using a Cole-Parmer peristaltic pump plumbed to the influent valve at the base of the column. Influent and effluent samples were collected for nitrate, chlorate, and perchlorate analysis approximately three times per week. A wide range of other inorganic constituents were measured weekly or more intermittently.

Column A1 was operated with an initial target flow rate of 0.70 milliliters per minute (mL/min), which resulted in an empty bed contact time (EBCT) of approximately six hours. Actual flow rates measured during the first 55 days of operation generally varied from approximately 0.60 to 0.85 mL/min, with the occasional dip as low as 0.14 mL/min or spike as high as 1.50 mL/min. Plugging of the influent and effluent valves (and associated tubing) began to occur after approximately 50 days of operation, resulting in unsteady flow conditions for the remainder of the 180-day operational period (average values for EBCT are shown in Figure 5-5). It is important to note that the plugging took place in the valves and tubing outside of the soil column and not in the porous matrix inside. This is often the result of the diffusion of oxygen through the thin walls of the tubing, causing precipitation of minerals inside the tubing.

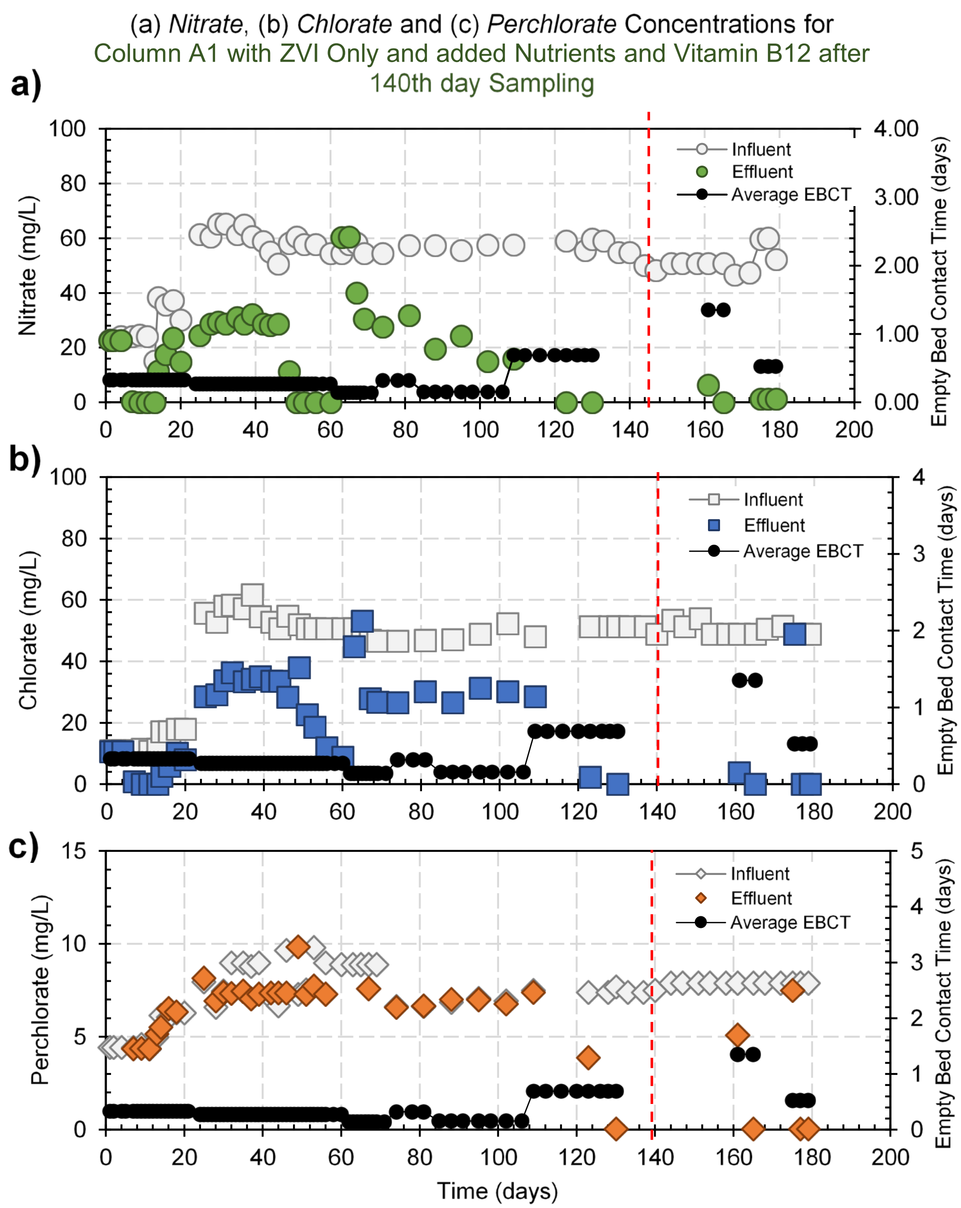

Figure 5-5: Conversion of nitrate, chlorate, and perchlorate in preliminary column A1. The dashed red line indicates when nutrients were added to the influent groundwater.

As a result of the tubing issues, between Day 51 and Day 180, the actual measured flow rates varied from 0.01 to 2.26 mL/min. The representativeness of EBCTs calculated during this unsteady operational period is questionable due to the rapid fluctuations in flow rate that occurred as the tubing and valves became clogged, which were subsequently cleared using a fine wire. EBCTs are calculated based on instantaneous flow rate measurements, so they are only accurate and representative when the flow rate remains relatively steady.

Consistent with the batch testing results, nitrate and chlorate were partially reduced during the first 110 days of the Preliminary Column A1 test when the EBCT ranged from 5.8 to 7.2 hours (Figure 5-5). It is likely most of the reduction was due to abiotic degradation on the ZVI surface and the extent of reduction was limited by contaminant residence time in the reactive zone. After Day 110, the EBCT was increased to above 15 hours and complete reduction of nitrate and chlorate was observed. No perchlorate reduction was observed in the column prior to increase in EBCT at 110 days. However, after that point perchlorate reduction was observed and complete reduction was noted in a single measurement on Day 130. Since both nitrate and chlorate are preferred electron acceptors relative to perchlorate, it is likely that both compounds needed to be removed before perchlorate reduction could commence.

Nutrients in the form of DAP, urea, and vitamin B12 were added to the column on Day 140. In general, the near complete removal of nitrate, chlorate, and perchlorate was observed after that point, although there was some variability in removal related to the difficulty in maintaining steady flow rates in the column.

Because the complete reduction of all constituents was observed prior to nutrient addition, it is not possible to assess the role that nutrients played in supporting the reduction of perchlorate from these results. However, samples were collected for microbiological analysis on Day 133 (before the addition of nutrients) and again at the end of the test. The results indicated that high levels of nitrate-reducing bacteria existed in the column at both time points, but perchlorate reductase, the enzyme response for perchlorate reduction, was only present in measurable quantities at the end of the testing. This result suggests that nutrient addition may help support the presence of perchlorate-reducing bacteria.

The pH in the effluent of Preliminary Column A1 increased from roughly 7.5 to 8.0 relative to influent values. This increase in pH is common in ZVI systems and did not exceed the optimal range for perchlorate-reducing bacteria. With respect to concentrations of dissolved metals in Preliminary Column A1, effluent concentrations decreased relative to the influent concentrations for arsenic, chromium, and cadmium and increased for manganese and iron. These results are typical for ZVI systems.

There was no evidence of significant loss of permeability in the ZVI reactive zone within any of the columns tested. As previously described, plugging issues were encountered in the column valves and tubing, most likely due to diffusion of oxygen through the tubing resulting in precipitation of minerals inside the tubing. There was observation of cementation of the ZVI and sand mixture in Preliminary Column A1 (refer to the UNLV report in Appendix E). This is likely due to mineral precipitation, but did not result in loss of permeability during the column testing.

5.1.3.3 Secondary Column A2

Secondary Column A2 was five feet long in order to provide a longer residence time in the column and was fed groundwater amended with nutrients (DAP and urea) and vitamin B12 from the beginning of the test. Sampling ports were installed in the sides of the column to provide data on contaminant transformation within the column.

Similar to Preliminary Column A1, the column was constructed with a base layer of washed gravel and an oxygen removal layer. A one-inch layer of site soil was placed above the oxygen removal layer, followed by 36 inches of a mixture of 30 percent ETI CC-1004 ZVI and 70 percent washed Cemex 30 mesh Monterey sand. Column A2 was operated in an upward flow direction for 176 days. At 145 days, the nutrients were removed from the influent groundwater and the remainder of the test was run without nutrients.

Also similar to Preliminary Column A1, the column was fed with groundwater extracted from well ES-34 and delivered to UNLV every two weeks. The chemical composition of the groundwater was as previously described in Section 5.1.3.1. Influent and effluent samples were collected for nitrate, chlorate, and perchlorate analysis approximately three times per week, and a wide range of other inorganic constituents were monitored weekly or more intermittently. Samples from the side ports were obtained and analyzed for nitrate, chlorate, and perchlorate every 1 to 2 weeks.

The target groundwater pumping rate through Secondary Column A2 was 0.20 mL/min, designed to provide an EBCT of approximately 2 days, or 8 times longer than in the preliminary column. In practice, the column was operated at instantaneous flow rates ranging from approximately 0.0004 to 0.57 mL/min, with fluctuations caused by plugging of influent/effluent tubing as previously observed in Preliminary Column A1. The average EBCT for Column A2 is shown in Figure 5-6 and ranged from 2 to 15 days.

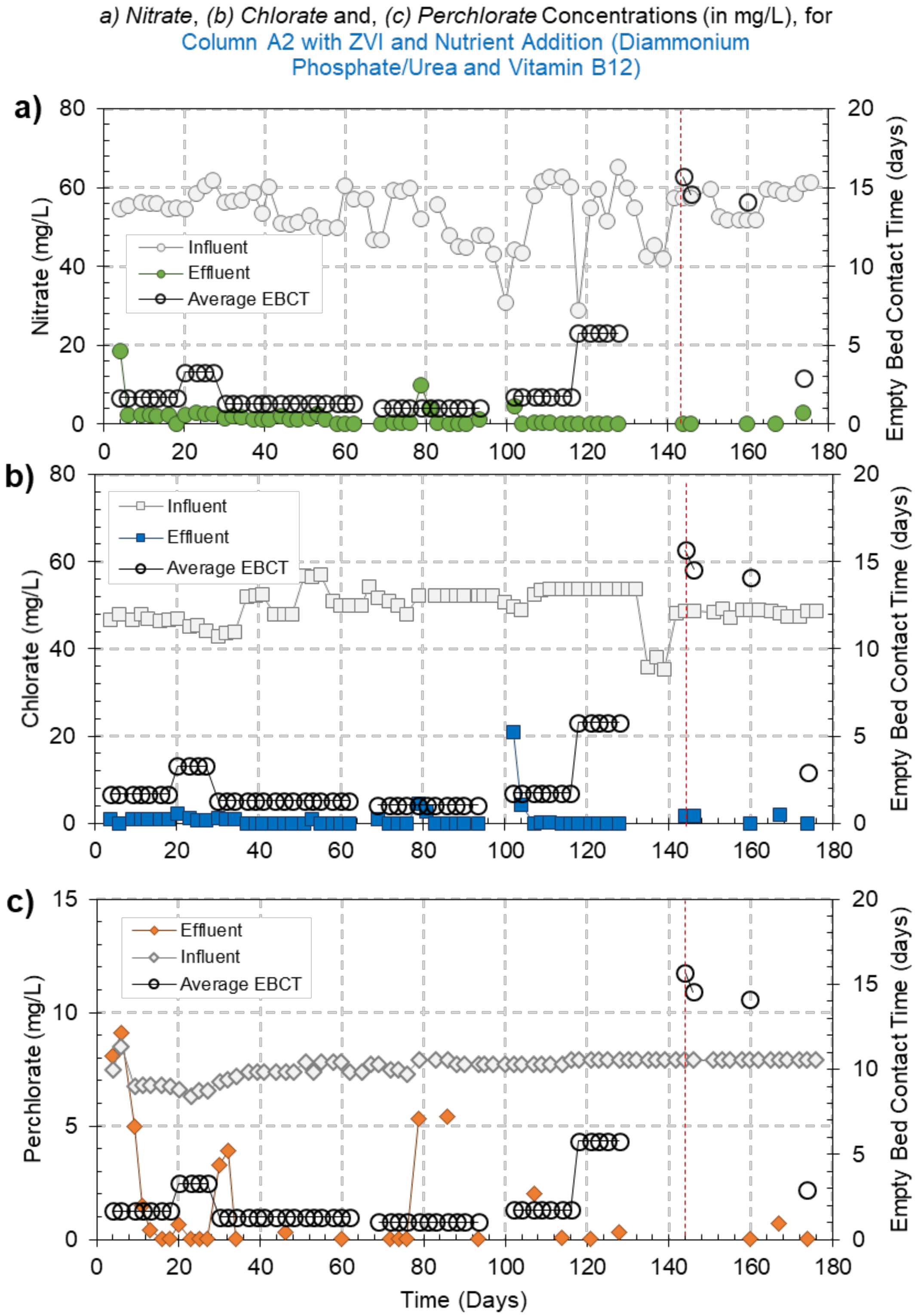

Figure 5-6: Conversion of nitrate, chlorate, and perchlorate in preliminary column A2. The dashed red line indicates when nutrient addition was stopped.

Column A2 showed notable reductions in effluent perchlorate, chlorate, and nitrate concentrations within the first few days of operation (Figure 5-6). Nitrate in the effluent was reduced by approximately 90% in the first 6 days of column operation and was fully degraded by 60 days, while chlorate was reduced by 95% in only four days. These results indicate that the majority of the initial removal observed for nitrate and chlorate was due to abiotic degradation at the ZVI surface, which is consistent with results observed in the batch tests. Perchlorate initially was the slowest to degrade, with approximately 80% removed after 12 days of operation and near complete removal observed after 16 days. Near complete removal of perchlorate, chlorate, and nitrate continued throughout most of the remainder of the test, except during short periods when the flow rate was temporarily increased following plugging incidents when the lines were cleared. The removal of these compounds did not change significantly after the nutrient addition was suspended on Day 145 (as indicated by dashed red line in Figure 5-6). However, these results may not be completely comparable to degradation in the presence of nutrients because the EBCT also increased during this latter period of column operation.

Sampling of the side ports in the column indicated that most of the contaminant removal occurred in the first 12 inches of the ZVI-sand mixture after Day 28 in the test. The residence time in the first 12 inches of the ZVI reactive zone is consistent with the 15 hours required for complete removal of nitrate and chlorate in the preliminary column. A few spikes in contaminant concentration were noted, but may relate to inconsistent flow due to the tubing plugging as previously described. Samples of the side ports were not collected after the nutrient addition was suspended.

Other significant results from the secondary column testing are summarized below.

- The pH in the effluent of Secondary Column A2 increased from roughly 7.5 to 8.3 relative to influent values. Thus, the pH increase once again did not exceed the optimal range for perchlorate-reducing bacteria. This suggests the site groundwater is sufficiently buffered to mitigate any detrimental pH excursions related to the ZVI.
- Sulfate was measured in both the column influent and effluent, but the levels were too high and the results too variable to make any determination about the extent of sulfate reduction in the column. Hydrogen sulfide was not measured in this test.
- Dissolved metals concentrations in Secondary Column A2 were similar to that observed in the preliminary column and, once again, consistent with lower redox conditions created by the ZVI in the column. In this case, effluent concentrations decreased relative to the influent concentrations for arsenic, chromium, lead, copper, and selenium and increased for manganese and iron.
- Phosphate levels were also reduced in the effluent of Column A2. In this case, influent phosphate levels were greater than 25 mg/L due to nutrient addition but were non-detect in the effluent. This removal of phosphate from the groundwater can be due to precipitation of phosphate onto the soil matrix and the reaction of phosphate with the iron.

- Similar to the preliminary column, there was observation of cementation of the ZVI and sand mixture in the column (refer to the UNLV report in Appendix E). This is likely due to mineral precipitation, but did not result in loss of permeability during the column testing.

5.1.4 Galleria Bench-Scale Testing Conclusions

Consistent with the literature results cited in Section 2, initial bench-scale testing conducted by UNLV showed that nitrate, chlorate, and perchlorate can be removed by ZVI using soil and groundwater from the Galleria Parcel. This is significant given the high TDS and saline nature of the groundwater in the vicinity of the Galleria Parcel. Nitrate and chlorate appear to be removed predominantly on the ZVI surface, while perchlorate is removed by perchlorate-reducing bacteria.

The UNLV batch microcosm testing demonstrated the removal of nitrate and chlorate using ZVI but were not run long enough to demonstrate perchlorate removal. However, column tests showed that perchlorate reduction can be achieved in a ZVI system without the addition of a carbon source.

The parameters that appeared to impact perchlorate removal the most in the column tests were residence time and nutrient addition (DAP, urea, and vitamin B12). Residence time is important because the majority of nitrate and chlorate must be removed before biological perchlorate reduction will commence because nitrate and chlorate are preferred electron acceptors relative to perchlorate.

The importance of nutrients for biological perchlorate reduction has been established in the literature (Kucharzyk, et al., 2012) and the lack of perchlorate reduction in the microcosm tests compared to the sustained perchlorate reduction in the column tests suggests that nutrients may have been a limiting factor for perchlorate reduction. At a minimum, it is likely that nutrient addition will shorten the lag phase required to stimulate the natural perchlorate-reducing bacteria population following emplacement of ZVI in the field. These observations informed the design of subsequent bench-scale testing described in Section 5.2.

Mobilization of metals in the column tests followed the conventional pattern of ZVI systems, where metals such as arsenic, cadmium, and chromium were removed from solution while manganese and iron were liberated.

There was no evidence of significant loss of permeability in the ZVI within the columns. Plugging issues were encountered in valves and tubing, most likely due to diffusion of oxygen through the tubing resulting in precipitation of minerals inside the tubing. There was observation of cementation of the ZVI and sand mixture in the column tests likely due to mineral precipitation. Samples from these columns, which have been preserved at UNLV, will be analyzed by X-ray diffraction to determine the composition of the mineral precipitation as described in Section 7.6.5.

5.2 Las Vegas Wash Transect 1A Bench-Scale Testing

As discussed previously, the Trust determined it was necessary to relocate the treatability study to Transect 1A due to uncertainties with property access due to development in the area. Therefore, it was necessary to perform additional Phase 1 bench-scale testing using soil and groundwater from Transect 1A to inform the design of the Phase 2 field test. Accordingly, Ramboll collaborated with Prima to conduct streamlined bench-scale testing to build upon the results from the UNLV testing related to the Galleria Parcel and evaluate the performance of ZVI under conditions present at Transect 1A. The intent of this streamlined additional testing was to quickly and efficiently gather necessary data to augment the information gained from the Galleria Parcel testing and provide design information for a subsequent field test.

The Transect 1A bench-scale testing program consisted of baseline characterization of soil and groundwater collected from Transect 1A to compare concentrations of key chemical parameters with Galleria Parcel soil and groundwater and subsequent batch microcosm testing using that soil and groundwater to inform the design of the field test.

5.2.1 Objectives

The Transect 1A bench-scale testing program had the following objectives:

- Verify the efficacy of ZVI to promote the reduction of nitrate, chlorate, and perchlorate using soil from the UMCf and alluvium and groundwater from the alluvium in Transect 1A.
- Investigate the effects of adding a biological inoculum containing perchlorate-reducing bacteria on process performance.
- Evaluate the impact of nutrients (DAP and vitamin B12) on process performance.
- Evaluate the potential impacts of amendments related to emplacement of the ZVI on process performance. These amendments include guar (used as a stabilizer or carrier agent if used to enhance the injection of ZVI into the subsurface or to create slurries that support and stabilize open trench walls during excavation), sodium tetraborate (Borax, used to cross link the guar), and enzymes associated with breaking the guar once the ZVI is emplaced.

5.2.2 Baseline Characterization Testing

The following sections describe the methods, materials, and results of baseline characterization testing of soil and groundwater sourced from Transect 1A. Soil samples for use in the bench-scale tests were obtained by collecting roughly equal volumes of borehole cuttings from the saturated alluvium and UMCf at location ZTS-MW115. Approximately 30 gallons of groundwater was obtained from nearby alluvium monitoring well LVWPS-MW108B. Soil and groundwater samples were transported to Prima Environmental for processing. The samples were chilled and stored until testing commenced in a manner which preserved the physical, chemical, and biological integrity of the samples.

Prior to analysis, alluvium and UMCf soils were sieved to remove particles larger than 3/8 inch, then homogenized. The UMCF soil consisted of grayish silt and clay. The alluvium soil consisted of reddish-brown sand and gravel with some silt and clay.

Groundwater was homogenized in a large drum. Chemical analyses of soil and groundwater that could not be conducted by Prima were subcontracted to Eurofins Calscience.

A detailed analysis of the soil and groundwater is found in the Prima Final Report provided in Appendix F. To briefly summarize, nitrate levels were low in both soil types. The alluvium soil contained higher levels of chlorate and perchlorate at 2.3 and 3.3 mg/kg, respectively, which were 1 to 2 orders of magnitude higher than concentrations in the UMCf. However, the UMCf soil contained higher levels of sulfate than the alluvium soil (1,300 mg/kg versus 340 mg/kg, respectively). TKN, which is a general measure of bioavailable nitrogen, was 1.1 mg/kg in the UMCf soil and 4.0 mg/kg in the alluvium.

The groundwater sample contained 56 mg/L nitrate, 36 mg/L chlorate, and 9.4 mg/L perchlorate. Hexavalent chromium and arsenic were present at 0.048 mg/L and 0.058 mg/L, respectively. Sulfate was present at 2,900 mg/L and sodium and chloride were present at 970 and 1,400 mg/L, respectively. Calcium and magnesium were present at 590 and 390 mg/L, respectively. DOC was measured to be less than 1 mg/L and the pH was 7.9. With the exception of the lower DOC, the groundwater from Transect 1A is similar to groundwater from the Galleria Parcel.

5.2.3 Batch Microcosm Testing

The following sections summarize batch microcosm testing methods, materials, and results. The program was designed to have two phases. The first phase was designed to verify and enhance the UNLV results, while the second phase built on the Phase 1 results to evaluate the impact of amendments potentially to be used in the field test on the performance of nitrate, chlorate, and perchlorate reduction. Full results of the batch testing can be found in the Prima Final Report provided in Appendix F.

5.2.3.1 Phase 1 Evaluation of ZVI Amended with FBR Solids Only (Alluvium and UMCf Soils)

Phase 1 batch microcosm tests were performed to evaluate the ability of ZVI amended with Transect 1A soil to remove nitrate, chlorate, and perchlorate from site groundwater and to verify the amount of ZVI required for complete removal. In this phase, alluvium and UMCf soils were tested separately. All the bottles in this phase of the study were inoculated with solids from the FBR currently used to treat perchlorate in extracted groundwater from the Site. As such, the bacteria found in the solids should be highly adapted to site conditions. In addition to the amended bottles, control microcosms were set up without ZVI or FBR solids to provide time zero data for the tests.

The microcosms consisted of 1 L glass media bottles. Each bottle received 287 g of site soil and 945 mL of site groundwater. A total of 19 microcosms were set up to test alluvium soils and 19 microcosms to test UMCf soils (Table 5-2). In addition to control microcosms prepared for each soil type without ZVI, additional microcosms were prepared with Connelly ETI CC-1004 ZVI added at 100X (~32.5 grams per liter [g/L]), 200X (65 g/L), and 400X (~130 g/L) the stoichiometric electron donor demand for reduction of perchlorate, chlorate, nitrate, and DO. The ZVI loading based on stoichiometric demand was higher for the Prima testing (0.36 g/L) than for the UNLV testing (0.12 g/L) because the concentrations of nitrate, chlorate, and perchlorate were higher in the groundwater used for the Prima testing. To each non-control bottle 7.2 mL of FBR solids were added as a source of perchlorate-reducing bacteria. The FBR solids contained 860 mg/L of TOC, most of which (790 mg/L) was DOC. Thus, the total amount of DOC added to the bottles was less than 6 mg/L, which is too low to support and sustain a very large population of heterotrophic perchlorate-reducing bacteria. The bottles were statically incubated in a water bath at 30°C until sampled. Individual bottles were sacrificed and analyzed according the schedule shown in Table 5-2. The testing lasted 8 to 12 weeks.

Table 5-2: Design of Prima Phase 1 Microcosm Tests

Test Number	Soil	Number of Replicates	Treatment	Temperature (degrees Celsius)	Sample Times (weeks)
1A-T0	Alluvium	1	None	20	0
2	Alluvium	6	100X ZVI, FBR solids	30	2, 4, 8
3	Alluvium	6	200X ZVI, FBR solids	30	2, 4, 8, 12
4	Alluvium	6	400X ZVI, FBR solids	30	2, 4, 8
1B-T0	UMCf	1	None	20	0
5	UMCf	6	100X ZVI, FBR solids	30	2, 4, 8
6	UMCf	6	200X ZVI, FBR solids	30	2, 4, 8
7	UMCf	6	400X ZVI, FBR solids	30	2, 4, 8

With the exception of the control microcosms, nitrate, chlorate, and perchlorate were all rapidly degraded in these initial microcosm tests. Nitrate was removed to below method detection limits within 2 to 3 weeks in all of the bottles. 99.5% of the chlorate was removed in the first four weeks of the testing and, in most cases, was reduced by 99.9% by the end of the testing (Figure 5-7a). Perchlorate was also reduced by more than 99% by week four of the testing and to below method detection limits by the end of the testing (Figure 5-7b). There was very little difference in the rate of removal of any of the contaminants as a function of ZVI loading, indicating the lowest ZVI loading of 100X (32.5 g/L) was sufficient to support reduction of all constituents without the surface area becoming rate limiting. Removal of chlorate and perchlorate was slightly more rapid with the UMCf soil.

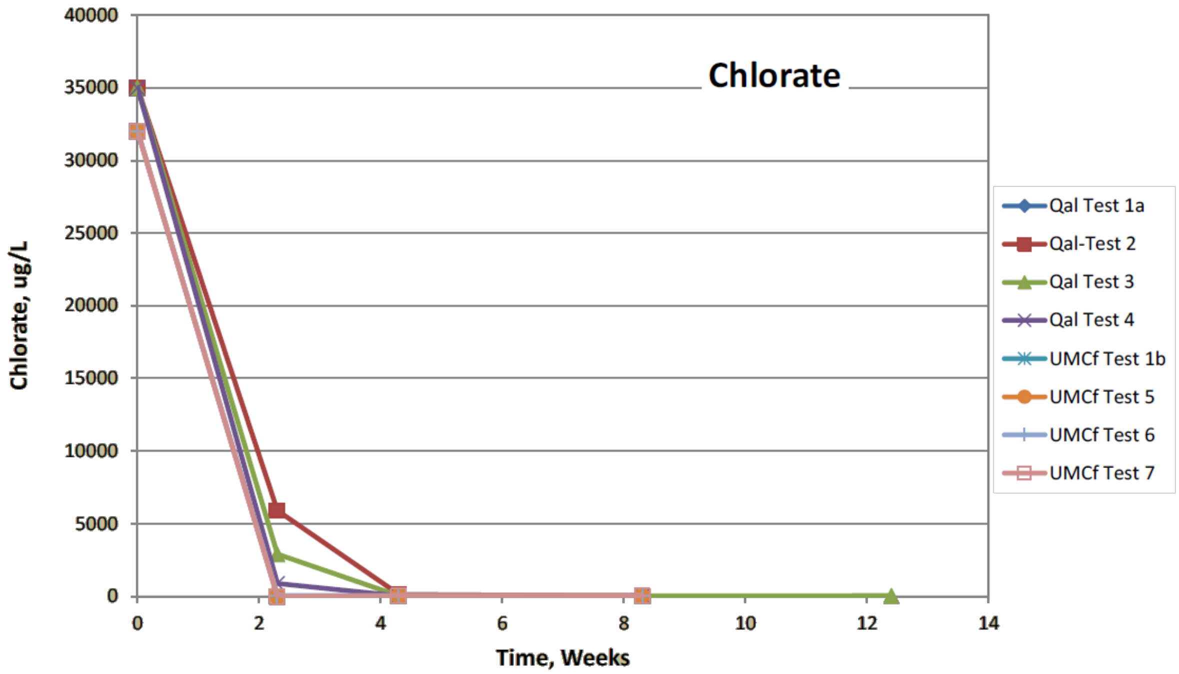

Figure 5-7a: Chlorate reduction in Prima Phase 1 testing.

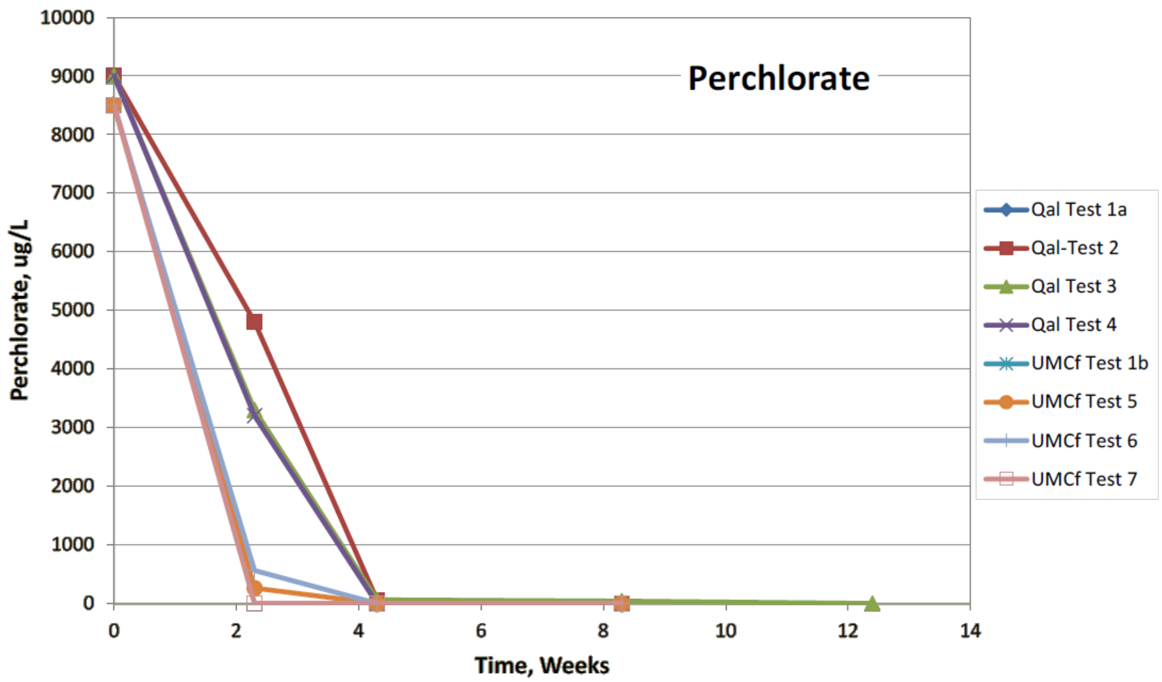

Figure 5-7b: Perchlorate reduction in Prima Phase 1 testing

The pH in the bottles did not change appreciably during the testing. Sulfate levels also did not change appreciably, and no hydrogen sulfide was observed during the testing. It should be noted that if hydrogen sulfide was produced, it would rapidly react with the reduced iron and be removed from solution. Similar to the UNLV column tests (as discussed in Sections 5.1.3.2 and 5.1.3.3), chromium and arsenic were removed from solution in the Prima bottles, while iron and manganese were liberated.

5.2.3.2 Phase 2 Evaluation of Effects of FBR Solids and Additives (Mixed Soil)

Phase 2 batch microcosm tests were performed to evaluate the impact on process performance of various additives that may be mixed with ZVI during field installation or added subsequently to enhance remedial performance. Additives and amendments tested included guar, borax, enzymes, DAP and vitamin B12, FBR solids, and EVO. As previously stated, guar is commonly used as a stabilizer or carrier agent when injecting ZVI into the subsurface or to create slurries that support and stabilize open trench walls during excavation. Borax is a cross-linker for the guar, while the enzymes are used to break the guar once the ZVI is in place.

The microcosms consisted of 1 L glass media bottles as previously described. A total of 56 bottles were set up in phase 2, as shown in Table 5.3 below. Each bottle received 287 g of site soil and 945 mL of site groundwater. In this case, the soil was a 50%-50% mix of alluvium and UMCf soils. The phase 2 microcosm test design is shown in Table 5-3. With the exception of control bottles (Test 1d) and bottles amended with EVO and nutrients, the bottles were prepared with Connelly ETI CC-1004 ZVI added at 100X (~32.5 grams per liter [g/L]) since this ZVI loading was sufficient to remove all of the contaminants in the previous testing. As previously described, 7.2 mL of FBR solids were added to select bottles as a source of perchlorate-reducing bacteria. Where utilized, guar was added to the bottles at a concentration of 65 mg/L. Guar is 22% carbon, so the total amount of carbon added to each bottle was less than 15 mg/L, and as such was likely inconsequential as an electron donor or source of carbon for the perchlorate-reducing bacteria. In this case the bottles were statically incubated at room temperature (20^{o}C), rather than at 30^{o}C as in phase 1, so as to better match field conditions. Individual bottles were sacrificed and analyzed according the schedule shown in Table 5-3. The tests lasted 8-12 weeks.

Table 5-3: Design of Prima Phase 2 Microcosm Tests

Test Number	Soil	Number of Replicates	Treatment	Temperature (Degrees Celsius)	Approximate Sample Times (weeks)
1c-T0	Mix	1	None	20	0
1d-Controls	Mix	7	None	20	1, 2, 4, 8, 14
8	Mix	6	ZVI, guar, FBR solids	20	1, 2, 4
9	Mix	6	ZVI, guar, Borax, FBR solids	20	1, 2, 4
10	Mix	6	ZVI, guar, Borax, enzyme, FBR solids	20	1, 2, 4
11	Mix	6	ZVI, guar, Borax, enzyme, B12, PO_4	20	1, 2, 4, 8, 14
12	Mix	6	ZVI, guar, Borax, enzyme, B12, PO_4, FBR solids	20	1, 2, 4
13	Mix	6	ZVI, guar, Borax, enzyme, B12, PO_4, EVO, FBR solids	20	1, 2
14	Mix	6	ZVI, guar, Borax, enzyme, B12*, PO_4*, EVO*, FBR solids*	20	1, 2, 4
15	Mix	6	B12, PO_4, EVO, FBR solids	20	1, 2

Notes:
* Amendments added at week 2, after nitrate had been reduced.

Perchlorate, chlorate, and nitrate were removed by all phase 2 test conditions except in the control bottles (Test 1d) containing no amendments. Contaminant removal was most rapid in the bottles containing ZVI and EVO (Tests 13 to 15; Figures 5-8a and 5-8b), with near complete removal of all contaminants occurring within 2 to 4 weeks. However, the bottles containing ZVI and FBR solids without EVO (i.e., Tests 8, 9, 10, and 12) also performed well, with near complete removal of all contaminants in 4 weeks. These bottles performed quite comparably, and the similarity in contaminant removal in these bottles suggests the amendments added (guar, borax, enzyme, vitamin B12 or DAP) neither inhibited nor accelerated process performance. The lack of impact of added nutrients in this case, as opposed to the UNLV testing, may be related to the presence of residual nutrients in the FBR solids or to the fact that the solids already contained significant numbers of perchlorate reducing bacteria so that nutrients were not required for growth.

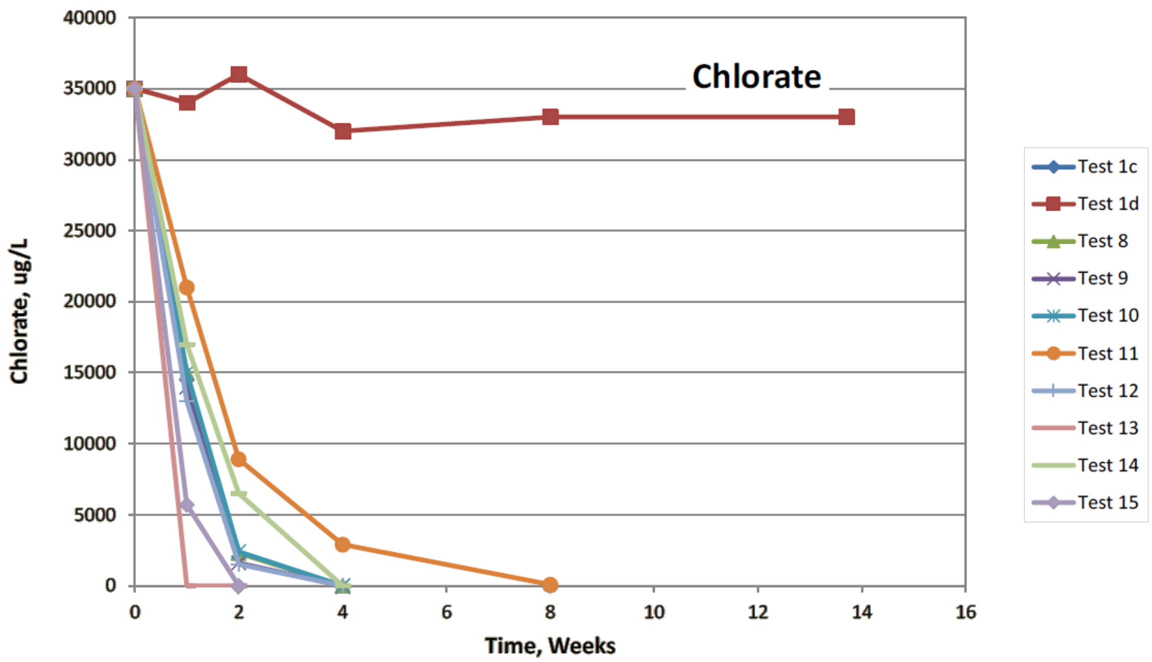

Figure 5-8a: Chlorate reduction in Prima Phase 2 testing

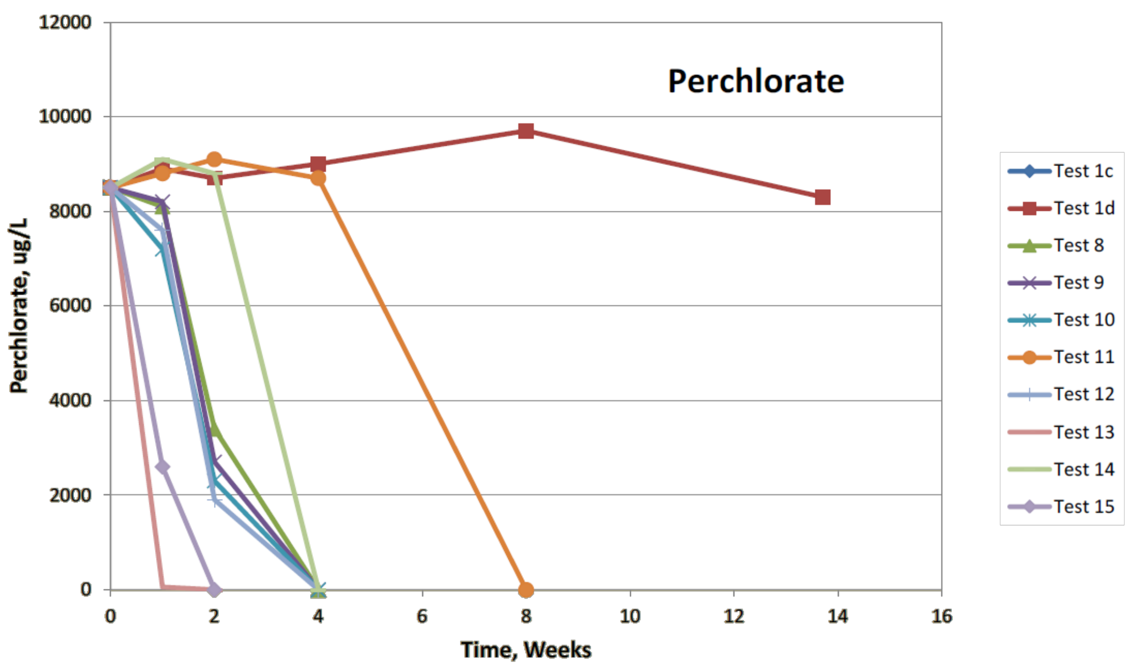

Figure 5-8b: Perchlorate reduction in Prima Phase 2 testing

It is significant to note the complete removal of contaminants was observed in bottles with ZVI but without inoculation with FBR solids (Test 11). Complete removal of chlorate and perchlorate took up to 8 weeks in this case but was still accomplished and was relatively rapid after a lag of about four weeks (Figure 5-8b). These bottles contained nutrients, and although a non-nutrient control was not run in these tests, the results are consistent with the UNLV testing in indicating that the natural perchlorate-degrading population can be stimulated in site soil by adding nutrients alone.

Other observations from the phase 2 tests were generally similar to those made in the phase 1 testing. A significant shift in pH was not noted in the bottles. Chromium was rapidly and completely removed in all the amended bottles, while arsenic was completely removed in Tests 8 through 13 and decreased in Tests 14 and 15. Ferrous iron and manganese increased in all the bottles except for iron in Test 15, primarily because ZVI was not added to that test. Hydrogen sulfide was only detected in Tests 13 and 15 and was particularly high (i.e., 11 mg/L) in Test 15. This may indicate that EVO may stimulate higher levels of sulfate reduction than does ZVI alone or that the lack of ferrous iron in solution in Test 15 eliminates the reaction with hydrogen sulfide that removes hydrogen sulfide from solution to produce insoluble iron sulfide minerals. Both may be true in this case.

5.2.4 Transect 1A Bench Testing Conclusions

Bench testing at Prima was conducted in two phases to both build upon the UNLV results and gather necessary data specific to design the field study at Transect 1A. The Phase 1 Prima microcosm tests showed the same rapid degradation of nitrate and chlorate as observed in the UNLV microcosm tests, consistent with surface-mediated reactions on the ZVI. In addition, all the bottles were inoculated with FBR solids and perchlorate was reduced by 99% by four weeks into the testing in all bottles, suggesting the FBR solids can be an effective source for perchlorate-reducing bacteria. The lack of dependence of perchlorate degradation rate on ZVI loading suggests that hydrogen production at the lowest ZVI loading is not limiting the perchlorate reduction process.

The Phase 2 Prima microcosm testing reinforced the importance of inoculation with FBR solids by demonstrating near complete perchlorate degradation in all inoculated bottles in 2 to 4 weeks. The addition of guar, borax, enzyme, or nutrients (vitamin B12 and DAP) did not appear to impact the rate of perchlorate degradation in either a positive or negative way. In this regard, the impact of nutrients was different than observed in the UNLV tests. However, this difference may be related to the presence of residual nutrients in the FBR solids or to the fact that the solids already contained significant numbers of perchlorate-reducing bacteria so that nutrients were not required for growth.

Bottles that were not inoculated also degraded perchlorate in 8 weeks, after a 4-week lag period, suggesting that the native bacteria population can also be stimulated over time. Importantly, these bottles also contained nutrients, so that these results were consistent with results from the UNLV column tests.

Other observations could be made from both tests. In general, chromium and arsenic concentrations decreased in groundwater, while levels of iron and manganese concentrations increased. A significant shift in pH was not noted in the bottles in either test. Sulfate reduction and associated sulfide precipitation was not observed in microcosm tests performed on Transect 1A soil and groundwater amended with ZVI in the absence of organic carbon.

5.3 Bench-Scale Testing Conclusions

In summary, bench-scale testing conducted by UNLV and Prima demonstrates the potential for ETI CC-1004 ZVI to support the complete removal of nitrate, chlorate, and perchlorate from NERT soil and groundwater without the addition of a carbon-based electron donor. The removal of nitrate and chlorate is rapid and is likely an abiotic process occurring primarily on the ZVI surface, while the reduction of perchlorate is performed predominantly by autotrophic perchlorate-reducing bacteria using hydrogen generated at the ZVI surface. The addition of nutrients (vitamin B12 and DAP) appears to be important in stimulating the growth of naturally occurring perchlorate-reducing bacteria, whereas these bacteria can also be added by inoculation with FBR solids. The latter appears to eliminate the lag phase associated with acclimation and growth of a community of perchlorate-reducing bacteria and may speed up the development of conditions necessary for a fully functioning remedy. ZVI also removes certain metals such as hexavalent chromium and arsenic from solution.

The residence time within the ZVI reactive zone must be long enough to remove most of the nitrate and chlorate so perchlorate reduction will occur. This was observed to be approximately 15 hours for the 30% ZVI in sand mixture utilized in the UNLV column tests. The pH will increase with residence time due to corrosion of the ZVI, so residence time cannot be so long that the pH rises above the optimum range for perchlorate reduction.

The Phase 1 bench-scale testing results demonstrate that ZVI-enhanced bioremediation is a viable technical option for in-situ treatment of nitrate, chlorate, and perchlorate in NERT groundwater, specifically in conditions present in the Transect 1A area which is generally representative of the northern third of the NERT RI Study Area. Accordingly, performance of a field test to evaluate ZVI-enhanced bioremediation is appropriate. Moreover, considering both the Phase 1 bench-scale conclusions along with the Phase 1 pre-design field investigation conclusions (discussed in Section 4.6), Transect 1A is an appropriate location for a Phase 2 field test of ZVI-enhanced bioremediation.

6. MODELING

This section describes the groundwater flow and geochemical modeling performed in support of the treatability study and development of the Phase 2 field test. Groundwater flow modeling was used to determine average seepage velocities and other aquifer characteristics in the Transect 1A Study Area in order to ensure proper residence times in the ZVI reactive zones. Geochemical modeling was used to estimate hydrogen generation from corrosion of the ZVI and model the degradation of nitrate, chlorate, and perchlorate, as well as to estimate changes in pH and ORP. The geochemical model was also used to estimate the rate that minerals will precipitate from groundwater as a result of changes in geochemical conditions. Both the flow and geochemical modeling results have been incorporated into the Phase 2 field test design described in Section 7.

The models will be further refined as additional information is collected during the Phase 2 pre-construction investigation, the construction of the field test, and the performance monitoring collected following construction. These refined models will continue to support the treatability study by assisting with the final field test design and the interpretation of monitoring results. Ultimately, to support the FS, the models will be used to extrapolate the results of the field test in order to provide an assessment of long-term performance (i.e., more than 10 years) and applicability of ZVI in different areas of the NERT RI Study Area.

6.1 Groundwater Flow Modeling

To support the treatability study, a focused groundwater flow model of the Transect 1A Study Area was developed based on the existing Phase 6 regional groundwater model developed for the RI/FS (Ramboll 2019b). The Phase 6 model is a comprehensive model of the southeastern portion of the Las Vegas Groundwater Basin that simulates hydrogeologic conditions during the period 2014 to 2018 (Ramboll 2019b). The regional model was designed to represent both the regional hydrogeologic system and the effects of groundwater remediation activities (e.g., groundwater extraction) performed by NERT and other neighboring parties to simulate groundwater flow and perchlorate discharge to Las Vegas Wash.

Due to the size of the Phase 6 model, a local-scale model was developed based on the Phase 6 model but modified with local-scale information collected during the Phase 1 pre-design field investigation. The local-scale model was used to evaluate the local groundwater flow conditions, which will be influenced by the installation of the proposed ZVI tests and may show some local deviation in gradient direction during treatability testing.

6.1.1 Flow Modeling Approach

The local scale model was developed for the Transect 1A Study Area using the approach of telescopic mesh refinement (TMR; Leake 1999). Figure 6-1 graphically illustrates the approximate geographic extent of the local-scale model within the existing Phase 6 model domain. Extraction well fields are shown in Figure 6-1 surrounded by red polygons. The only extraction well field in the vicinity of the Transect 1A Study Area is the NERT Seep Well Field (SWF). Given its proximity, the SWF is included in the ZVI model.

The local scale model was created using the TMR capabilities of Groundwater Vistas (Version 7.24) to create a new refined model covering a sub-region of an existing original model. The TMR technique applies boundary conditions from the original model to the local-scale model, which are interpolated from the larger-scale model automatically by Groundwater Vistas. The Phase 6 model grid size varies from 50 feet to 200 feet. The local-scale model was discretized into a horizontal grid with a cell size of 5 feet to capture the heterogeneity in the Transect 1A Study Area, while retaining the same vertical discretization as the regional model with 10 layers. The local-scale model captures the complexity of the regional model and preserves the regional flow effects at the local scale.

As described in Section 3, a Phase 1 pre-design field investigation was conducted at Transect 1A to supplement the characterization of this area and further refine the hydrologic, geologic, and chemical distribution parameters used in the model simulations. The hydraulic parameters for the local scale model have been updated using the new hydraulic data collected as part of the Phase 1 pre-design field investigation. These hydraulic parameters are described in Section 4.5 and in Appendix D. The main parameters updated as part of this refinement were the hydraulic conductivity and porosity values of the alluvium and UMCf.

6.1.2 Flow Modeling Results

The distribution of modeled groundwater velocities and groundwater elevations in Transect 1A in the alluvium and UMCf are shown on Figures 6-2 and 6-3, respectively. For comparison, the average groundwater velocity values and elevations from field data in the alluvium and UMCf are shown on Figures 4-7 and 4-8. Some inconsistencies remain between the local-scale flow model and the field data in the interpreted groundwater flow direction and velocity in the alluvium and UMCf. These inconsistencies will be resolved when the model is updated based on the Phase 2 pre-construction investigation results. The updated model will be used to predict the distribution of groundwater velocities under different ZVI field test scenarios in order to support the final design of the field tests.

The local-scale model will be further refined based on information collected during the field test construction and installation and monitoring of the performance monitoring well network, as discussed in Sections 7.6.5 and 8. As needed, the grid will be further refined horizontally in the location of field tests. The predicted flow velocities and directions will be used to assist in the interpretation of the performance monitoring data and to support the geochemical modeling described in the next section.

6.2 Geochemical and Reactive Transport Modeling

Geochemical and reactive transport modeling was conducted to describe processes occurring within and downgradient of a hypothetical ZVI wall and was built to aid in the design of the Phase 2 field test and inform the performance monitoring program. The following sections summarize the details and results of these modeling exercises. A more comprehensive discussion of the model is provided in Appendix G.

The simulations were based on the conceptual model developed by Bennett (1997) and Blowes et al. (1999b). ZVI corrosion by water is described by a rate expression with a first-order dependence on ZVI surface area (Reardon 1995). The effect of the reduction-corrosion reactions leads to a significant increase of pH values and causes the redox potential of the water passing through the ZVI wall to decrease (Blowes et al. 1999). High-pH conditions promote the precipitation of a number of secondary minerals throughout the treatment zone. Precipitation of secondary mineral phases within the ZVI wall were estimated by the model using published equilibrium equations from the WATEQ4F (Ball and Nordstrom 1991) and MINTEQA2 (Allison et al. 1991) databases. The reaction rates used in the simulations were calibrated to simulate site conditions, although under actual field conditions it can be anticipated that the precipitation of additional mineral phases may also occur.

In this model, chlorate reduction is assumed to occur abiotically by ZVI. Hydrogen gas, formed by the corrosion reaction, is utilized by nitrate- and perchlorate-reducing bacteria and the degradation of nitrate and perchlorate was modeled using Monod-type kinetics using a sub-model called MIN3P (Mayer 1999; Mayer et al. 2002, 2012). The dependence of the reduction reactions on hydrogen was included to provide for the likely case that microbial reductions are potentially faster than hydrogen production. The model does not account for the long-term passivation (reactivity decrease) of the granular ZVI material because representative passivation rates were not available at the time this model was constructed. However, the data necessary to estimate passivation rates will be collected in parallel with the pre-construction field activities (see Section 7.6.5).

6.2.1 Geochemical Modeling Approach

One-dimensional (1-D) reactive transport simulations were performed along the flow line carrying the highest contaminant concentrations toward a hypothetical ZVI wall. The solution domain extends 13 feet in the horizontal direction, including a 2-ft thick ZVI wall. For this exercise, the ZVI backfill was assumed to contain 30% granular ZVI and 70% sand (by weight). In terms of volume fractions, the ZVI reactive zone contains 20% ZVI, 30% sand, and 50% pore space. The domain was discretized using an interval of 1.5 inches. Simulations were performed for a time period of 10 years with results recorded at 0.5, 1, 2, 5, and 10 years in order to evaluate geochemical evolution of the system.

Initial concentrations for the modeling were assumed to be constant within the Transect 1A Study Area, as shown in Table 6-1. As a conservative approach, the maximum concentrations detected during the pre-design field investigation were used for each target contaminant and other relevant aqueous phase design parameters. Average values of hydraulic testing results measured in the alluvium from Table 4-9 were used for porosity and hydraulic conductivity. An engineering estimate was used for the porosity of the ZVI-sand mixture. The hydraulic gradient was selected so that the average groundwater velocity was approximately equal to the average measured in alluvium wells based on Darcy's Law of 1.8 ft/d reported in Table 4-9.

Table 6-1: Reactive Transport Model Inputs

Parameter	Value	Units
Aqueous phase parameters		
H^{+}	7.57	pH
CO_3^{-2}	330	mg/L
SO_4^{-2}	2,700	mg/L
Ca^{+2}	640	mg/L
Fe^{+2}	0.2	mg/L
NO_3^{-}	64	mg/L
ClO_4^{-}	7.9	mg/L
ClO_3^{-}	41	mg/L
DO	2.1	mg/L
ORP	82.3	mV
Physical parameters		
Porosity – Aquifer	0.10	[-]
Porosity – ZVI	0.30	[-]
Hydraulic conductivity – Aquifer	8.52×10^{-5}	m/s
Hydraulic conductivity – ZVI	7.06×10^{-4}	m/s
Hydraulic gradient	7.29×10^{-3}	[-]

6.2.2 Geochemical Model Results

The predicted performance of the hypothetical ZVI wall was evaluated based on estimated rate of ZVI consumption and porosity reduction from secondary mineral precipitation. Predicted mineralization profiles from the preliminary modeling are shown in Figure 6-4. Additional figures and discussion are provided in Appendix G.

The estimated hydrogen generation rate from preliminary results of the 1-D reactive transport model is 4.5×10^{-4} moles per liter per day, so that total hydrogen gas generation is 26.2 grams per day (g/d). Using maximum observed concentrations of nitrate, chlorate, and perchlorate within the Transect 1A Study Area, mass flux through the ZVI wall was calculated to determine hydrogen consumption rates. Total hydrogen consumption by all contaminants is 5.1×10^{-5} g/d, so that the generated hydrogen is several orders of magnitude greater than the hydrogen demand.

The simulation results illustrate that the reduction rates for nitrate and chlorate are fast in comparison to the transport velocity through the ZVI wall. Because of fast reaction kinetics, nitrate and chlorate reductions take place primarily in the entry area of the ZVI wall. Perchlorate reduction is somewhat slower and persists over a longer distance, but perchlorate is still completely degraded in the ZVI wall. These modeling results are consistent with the rapid loss of nitrate and chlorate observed in the laboratory results discussed in Section 4, along with the slower loss of perchlorate once nitrate and chlorate have been removed.

ZVI consumption due to corrosion and chlorate reduction was estimated to be 0.53% of total mass per year. In other words, the model estimates that the ZVI wall would lose approximately 5.3% of its total mass over 10 years of operation, which is acceptable for this application, but these estimates are preliminary.

The pH of the groundwater upgradient of the ZVI zone was set at 7.57 and simulations indicate that pH rises over time within the ZVI wall to a maximum of 10.9, which is common in ZVI remediation applications. However, the simulations also demonstrate that the buffering capacity in the native soil downgradient of the reactive zone decreases pH values rapidly, such that they approach background values within a short distance downgradient of the wall.

The simulations indicate that reduction-corrosion reactions and the associated pH increase lead to the precipitation of a number of secondary mineral phases across the width of the ZVI reactive zone. ZVI corrosion leads to elevated concentrations of Fe^{2+} within the reactive zone. However, most of Fe^{2+} mass is precipitated as siderite ($FeCO_{3(s)}$), amorphous iron hydroxide ($Fe(OH)_{2(am)}$), and mackinawite ($FeS_{(am)}$) to a lesser extent due to precipitation reactions. Results from the model indicate that the precipitation of carbonate minerals, such as calcite ($CaCO_3$) and siderite, takes place near the upgradient interface of the ZVI wall and aquifer and suggest that siderite is the dominant carbonate phase in the upgradient interface. Minerals such as mackinawite precipitate throughout the ZVI wall. Simulations over 10 years show a 7% loss in absolute porosity in the ZVI wall due to mineral precipitation, which is tolerable for this application. Although this loss in porosity occurs over a long time period, it will eventually affect the hydraulic properties of the ZVI wall.

Additional refinement of the 1-D model will follow collection of additional data during implementation of the Phase 2 field test. Future two-dimensional (2-D) simulations will address the effect of preferential flow and be used to illustrate ZVI performance in a 2-D cross-section. The modeling results will be used to examine the potential for porosity reduction in the ZVI reactive zones over time, which will provide necessary information to assess the longevity of ZVI compared with other remedial technologies to be evaluated during the FS.

7. PHASE 2 FIELD TEST DESIGN

This section describes the ZVI-enhanced bioremediation Phase 2 field test design, including field testing objectives, materials and emplacement methods, testing layouts and purposes, design considerations, and design details.

The Phase 2 field test design is based on currently available information resulting from the Phase 1 pre-design field investigations (Sections 3 and 4) and Phase 1 bench-scale testing (Section 5), flow and geochemical modeling (Section 6), and key assumptions presented herein. The Phase 2 field test design may be adjusted based on data collected from the pre-construction activities (described in Section 7.6.5) and/or field conditions encountered during construction. Any material adjustments to the Phase 2 field test design will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

7.1 Field Testing Approach and Objectives

As detailed in Section 5, Phase 1 bench-scale testing demonstrated that ZVI-enhanced bioremediation can successfully treat perchlorate, chlorate, and nitrate in NERT groundwater. Moreover, there were four observations from the Phase 1 bench-scale tests that are important for the Phase 2 field test design:

1. Nitrate and chlorate degrade rapidly in the presence of ZVI and the reaction is so rapid that it supports a conclusion that it is abiotic in nature.
2. Perchlorate removal requires development of a perchlorate-reducing bacterial population.
3. A one-time inoculation with FBR solids accelerates perchlorate removal by increasing the starting population of perchlorate-reducing bacteria and addition of nutrients accelerate the ZVI-enhanced biodegradation.
4. A low-cost, coarse-grain granular ZVI (Connelly ETI CC-1004) performs as well as any other ZVI grain size tested in removing nitrate and chlorate and providing hydrogen to perchlorate-reducing bacteria.

While the Prima Transect 1A bench-scale tests simulated conditions by using site soils and groundwater, to fully evaluate the applicability and assess the performance of ZVI-enhanced bioremediation, a Phase 2 field test is necessary to confirm the bench-scale results and collect data to understand performance under actual groundwater flow and geochemical conditions.

As presented in Section 1.2, the objectives for the field treatability study of ZVI-enhanced bioremediation are to:

- Confirm the results of the laboratory testing demonstrating that nitrate, chlorate, and perchlorate can be degraded in the field using ZVI, where ZVI acts as both a reactive media and source of hydrogen to support biological degradation.
- Evaluate the performance of two methods of emplacing ZVI as well as the impact of the ZVI dosage under field conditions.

- Assess the distribution of hydrogen and the associated biologically active zone generated by the ZVI inside and downgradient of the reactive zones under actual groundwater flow conditions.
- Evaluate methods of increasing and sustaining biological perchlorate reduction via inoculation and nutrient addition.
- Monitor the geochemical changes that take place inside and down-gradient of the ZVI treatment zones under actual groundwater flow conditions and model hydrogen production, ZVI mass loss, passivation, and precipitation of inorganic species to assess the potential longevity of granular ZVI in the NERT RI Study Area.
- Provide data to allow evaluation of ZVI-enhanced bioremediation treatment under field conditions and provide key design, performance, monitoring, and cost criteria for use during the FS for comparison of remedial alternatives.

The field test is not intended to achieve final water quality objectives as may be defined in the final remedy, but rather to provide data to allow evaluation of ZVI-enhanced bioremediation under field conditions and provide key design and performance criteria to inform the FS and future remedial design. Therefore, performance objectives are defined based on the technical design requirements, and not solely on water quality criteria consistent with potential clean up goals for target constituents.

To achieve these objectives, and as detailed in Sections 7.2 through 7.6, Ramboll proposes discrete field tests to evaluate two emplacement methods of granular ZVI dosages. The test areas will be constructed simultaneously and proximate to each other (see Figure 7-1) to allow a comparative evaluation of their performance in real time.

7.2 Field Test Materials

As detailed in Section 5, various materials and amendments were evaluated as part of the Prima Transect 1A bench-scale testing. Based on the results of these tests, a subset of these materials and materials tested in the Galleria Parcel bench-scale program were selected for the Phase 2 field test based on their applicability and value in achieving field test objectives. Following is a description of the materials and amendments that were evaluated during bench-scale testing and selected for the Phase 2 field test.

- **Granular ZVI** – As discussed in Section 5.1.2, all five bulk ZVI products (i.e., CC-1107, CC-1101, CC-1190, ETI CC-1004, and CC-1200) obtained from Connelly-GPM (Chicago, Illinois) were deemed to be similarly effective in treating perchlorate, chlorate, and nitrate. Ultimately, ETI CC-1004 (with a -8 +50 mesh specification and a density of 140 to 160 pounds per cubic foot) was selected for field testing due to its larger grain size, which is hydraulically more favorable, makes it longer lasting, reduces risks of clogging by mineral precipitation or biofouling, and has a lower life-cycle cost. This material is ideal for passive in-situ remediation because it has the potential to last for decades as a groundwater treatment media. The selected granular ZVI product is a recycled and an unrefined (except for baking to remove surface debris) granular iron aggregate product that is not trademarked; thus, the cost of this material is substantially less than other refined ZVI-based groundwater treatment amendments. A specifications sheet for ETI CC-1004 is provided in Appendix H.

- **PeroxyChem EHC** – EHC is an in-situ chemical reduction reagent manufactured and sold by PeroxyChem. The reagent is composed of micro-scale ZVI, controlled-release carbon, and nutrients. The proprietary blend is designed to create strong reducing conditions that stimulate both abiotic and biotic chemical reduction of contaminants mainly through the increased surface area provided by the micro-scale ZVI. However, the micro-scale ZVI in EHC does not have as long of a lifespan compared to granular ZVI due to its much greater surface area per unit mass, fine particle size and, thus, faster reaction time. While bench-scale column tests indicated that EHC could reduce nitrate, chlorate, and perchlorate (refer to Section 5.1), EHC was not selected for field testing.
- **Biological Inoculum** – As discussed in Section 5.2.3 and 5.2.4, addition of biological inoculum (i.e., FBR solids) was tested to accelerate the onset of perchlorate, chlorate, and nitrate reduction. Specifically, the results of bench-scale testing indicate that using the FBR inoculum will provide a functionally diverse microbial community that can minimize the lag time in the development of a robust perchlorate-reducing community. Thus, to accelerate the ZVI-enhanced bioremediation and reduce the overall duration of the field treatability study, a one-time injection of biological inoculum, a derivative of the FBR solids, will immediately follow installation of the ZVI walls (refer to Section 7.6.3 and Appendix I).
- **Nutrients and Micronutrients** – As presented in Section 5, several nutrient amendments (including DAP, urea, and vitamin B12) were evaluated in the bench-scale tests. The results indicate that the addition of vitamin B12 and DAP appear to be important in stimulating the growth of naturally occurring perchlorate-reducing bacteria in the subsurface or bacteria added by inoculation. Accordingly, to accelerate the ZVI-enhanced biodegradation and reduce the overall duration of the field treatability study, a one-time injection of vitamin B12 and DAP will immediately follow installation of the ZVI walls (refer to Section 7.6.3 and Appendix I).
- **Organic Carbon** – As discussed in Section 5, bench-scale testing demonstrated the ZVI-enhanced bioremediation of nitrate, chlorate, and perchlorate without the addition of a carbon-based electron donor. Therefore, organic carbon amendments will not be incorporated as part of the Phase 2 field test.
- **Guar and Associated Materials** – As described in Section 5.2.3, bench-scale testing included an evaluation of the effects of introducing guar and associated materials to the subsurface during construction. Guar is used as a "carrier agent" if used to enhance the injection of ZVI into the subsurface or to create slurries that support and stabilize open trench walls during excavation. Typically, biodegradable, food-grade guar gum is used to temporarily increase the viscosity of the slurry or injecting fluid to "carry" the ZVI particles further into the surrounding formation. The bench-scale testing concluded that, like other organic carbon sources, the addition of Guar (plus borax and a proprietary enzyme used to breakdown the guar) did not appear to affect perchlorate reduction. However, guar could cause fouling if not applied correctly. Therefore, to eliminate potential variables, guar and associated materials will not be incorporated as part of the Phase 2 field test. As explained in Section 7.3 below,

this exclusion also justified exclusion of certain emplacement methods for the field test (i.e., injection of ZVI and bio-polymer trenching).

In summary, the materials retained for field testing will be limited to: ETI-CC-1004 coarse-grained ZVI produced by Connelly-GPM or equivalent[5], inoculum produced from the FBR solids, and nutrients (DAP and vitamin B12).

7.3 ZVI Emplacement Methods

Once the field tests materials were defined for the Phase 2 field test, means for placement and construction of a subsurface wall were evaluated. The selection of the emplacement methods for the field test primarily considered ease of implementation and controlling quality of ZVI backfill, demonstrability, cost, and reducing the number of test variables that could interfere with the evaluation of performance monitoring data (until the technology has been demonstrated to perform successfully in the field). Following is a description of the ZVI emplacement methods that were evaluated and retained for the Phase 2 field test, as well as the rationale for selection.

7.3.1 ZVI Filled Trench

Trenching is the most commonly used method for the emplacement of ZVI in a continuous permeable wall configuration (see Figure 7-2). Trenches have been previously excavated within the NERT RI Study Area; therefore, they have demonstrated implementability. This emplacement method involves excavating a trench to the target treatment depth and backfilling it with reactive materials (e.g., ZVI and sand or gravel mixture). In some cases, portions of the trench are filled with impervious materials (e.g., soil-bentonite, soil-cement-bentonite) or sheet piles are driven to provide lateral hydraulic control and direct groundwater flow towards the permeable portion of the trench that contains the reactive media. The trench typically is oriented perpendicular to the approximate direction of groundwater flow to intersect the migration of contaminated groundwater.

[5] While Connelly-GPM was the source of the material used for lab testing, Ramboll will evaluate pricing for equivalent ZVI from other coarse aggregate ZVI sources (e.g., Peerless of Detroit, Michigan) during the procurement process.

Figure 7-2: Typical Trench Excavation

Three methods of trench installation were assessed: (a) traditional trenching using long-reach excavators and shoring and/or dewatering systems; (b) bio-polymer trenching (also known as slurry trenching), where the slurry supports and stabilizes open trench walls during excavation; and (c) one-pass trenching that simultaneously excavates the native soil and backfills with the emplacement material using specialized equipment in a single pass. Traditional trenching was eliminated from further consideration for this project because it is not capable of reaching the NERT field test target depth of 35 feet without complex shoring or trench wall support systems. Although bio-polymer trenching would likely be effective—and has been used successfully by Ramboll to construct ZVI walls at other sites using guar as the bio-polymer—it was eliminated from further consideration for the Phase 2 field test because it introduces a biodegradable material that (while broken down by enzymes and recirculation) could potentially interfere with the performance evaluation and adds complexities to the construction process. One-pass trenching was ultimately selected for the Phase 2 field test because it does not require stabilization of the trench walls or dewatering to reach the target depth and operations can be performed below the water table in soils with gravel and some cobbles[6]. However, one-pass trenching requires larger quantities of ZVI backfill

[6] While not anticipated at NERT, large and extensive cobbles (typically larger than the trench width) can limit the effectiveness of the one-pass trencher as it would require that these subsurface obstructions be removed using other equipment.

since, unlike other trenching methods that could allow layering of backfill materials, the ZVI backfill will need to extend to the ground surface the trencher is working from. With one-pass trenching, ZVI can be installed in a continuous wall to depths of up to 50 feet deep (35 feet with their conventional trencher), 1 to 4 feet wide, with a production rate of 200 to 400 linear feet per day (Dewind, 2020)[7].

7.3.2 ZVI-Filled Borings

ZVI filled borings would allow emplacement of ZVI to form a discontinuous wall. Similar to the arrays of "unpumped wells" described by Wilson, R., et al. (1997), arrays of closely spaced and staggered borings[8] would serve to emplace granular ZVI in selected depth intervals (i.e., the saturated zone) to support ZVI-enhanced bioremediation. Specifically, 12-inch diameter soil borings are advanced using traditional drilling techniques[9] (hollow-stem auger (HSA) or rotary sonic borings have been previously advanced at the NERT site; therefore, they have demonstrated implementability) to the bottom of the targeted treatment depth (see Figure 7-3). ZVI-filled borings typically can be employed when a trench installation is not feasible (e.g., installations deeper than approximately 50 feet or where difficult terrain or geologies such as high occurrences of large cobbles are present). This emplacement method would result in a discontinuous wall, which may achieve treatment performance similar to a continuous ZVI wall since, as explained in Section 1.1,

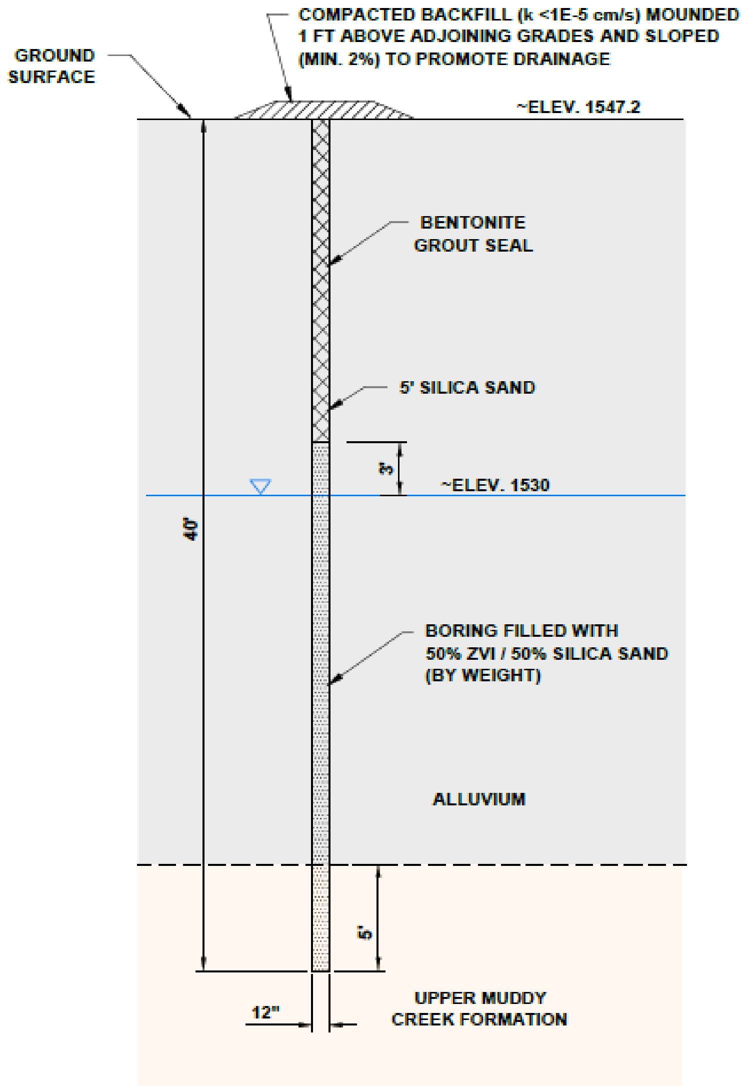

Figure 7-3: ZVI-filled Soil Boring Schematic

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[7] Given the depth limitation of the one-pass trencher to place ZVI (i.e., up to 50 feet), this emplacement method is not suitable for implementation in the UMCf at Transect 1A given the depths of contamination encountered in the UMCf extend to 80 feet.

[8] Staggering the ZVI-filled borings provides greater coverage by reducing gaps between adjacent boreholes.

[9] Larger diameter borings (typically up to about 12 feet) can be advanced using other drilling techniques such as bucket or core barrel.

ZVI-enhanced bioremediation does not require direct contact between the perchlorate and ZVI. Further, while it would take longer to implement, it would generate significant less quantity of soil spoils requiring management, can achieve great depths, does not require mobilization of specialized equipment, and as previously indicated, would be suitable for terrains or geology that may limit the applicability of other emplacement methods or where additional flexibility was required. Therefore, the boring emplacement method has also been selected for the Phase 2 field test.

7.3.3 In-Situ Soil/ZVI Mixing

Granular ZVI could be placed as a series of overlapping or adjacent large diameter columns using in-situ soil mixing (see Figure 7-4). This method uses a large diameter (1 to 3 meters) soil mixing rig to blend granular ZVI with the native soils, thereby eliminating the need for trenching and dewatering. However, to facilitate the delivery of ZVI, it is typically suspended in a biodegradable slurry (similar to that used in bio-polymer trenching previously described). Because mixing is performed in-situ, the generation of excess soils is limited (generally the volume of ZVI added plus some heaving due to the mixing increasing the volume of the subsurface material slightly). ZVI columns would require close placement or overlapping construction to assure general continuity of the wall. Although in-situ soil/ZVI mixing would likely be effective and could likely achieve the target depths, it (a) results in a less controlled in-place ZVI backfill than the trenched wall or ZVI-filled borings as it blends heterogenous site soils with ZVI instead of replacing site soils with a controlled ZVI backfill; (b) it introduces a biodegradable material that (while broken down by enzymes and recirculation) could potentially interfere with the performance evaluation; and (c) adds complexities to the

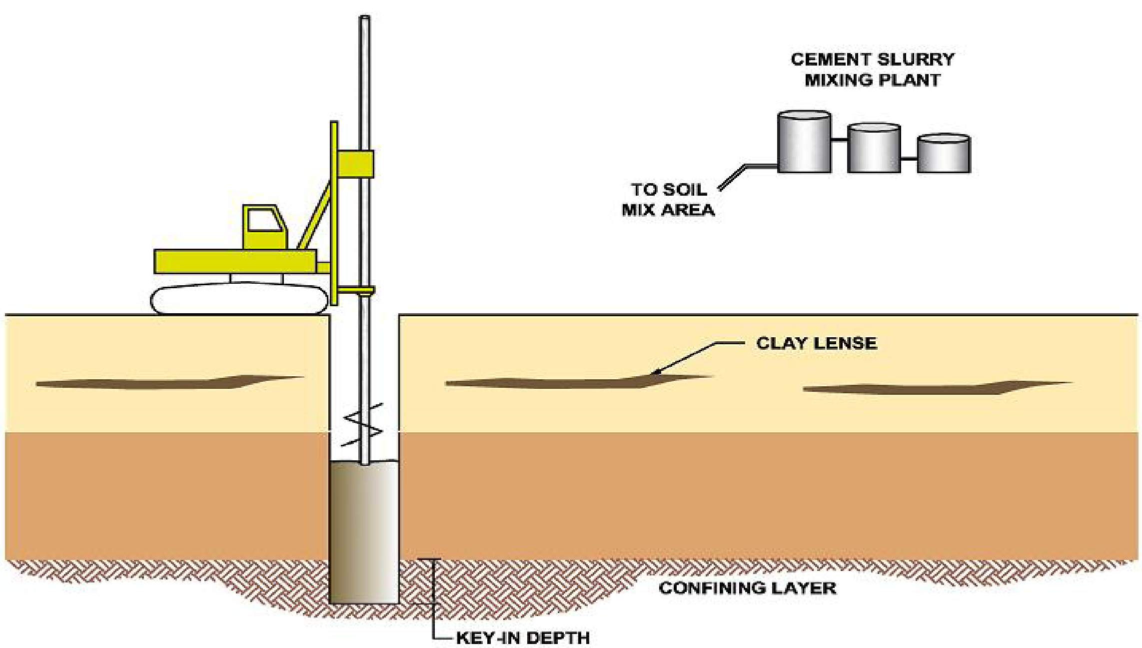

Figure 7-4: In-Situ Soil/ZVI Mixing Schematic

construction process. Therefore, in-situ soil/ZVI mixing was eliminated from further consideration for the Phase 2 field test.

7.3.4 Directional Jet Injection of ZVI

Jet injection applies injection pressures that overcome the overburden pressures and cohesive forces that hold the soil matrix together in the subsurface, allowing for direct injection of materials such as ZVI into the subsurface (see Figure 7-5). This method of emplacement can create a two-dimensional sheet-like structures radiating outward form the borehole. The orientation of the sheet-like structures is determined by the geometry of the hole or nozzle from which the fluid is forced into the formation, and the extent is determined by the pressure applied, the volume of material injected, and the degree of heterogeneity within the formation. The resulting sheet-like structures have a higher hydraulic conductivity than the surrounding formation (due to the granular nature of the proppant material), which tends to distort localized groundwater flow conditions and effectively increase the capture zone. Creating numerous such structures allows for emplacing large amounts of granular ZVI into low-permeability formations. It is likely that the injections of ZVI will not create a continuous ZVI wall, but rather a semi-continuous or discontinuous ZVI wall. Since, as explained in Section 1.1, ZVI-enhanced bioremediation does not require direct contact between the perchlorate and ZVI, directional jet injection may be a feasible alternative to the ZVI filled borings for targeting the UMCf; however, (a) the placement and distribution of ZVI backfill would be less controlled than the ZVI borings as subsurface heterogeneities will affect the configuration and distribution of ZVI-filled sheet-like structures; and (b) additional pre-design testing would be required to design the injection program and understand its applicability and limitations. Therefore, directional jet injection was not selected for the Phase 2 field test. Future testing may be considered based on the performance monitoring results for the Phase 2 field test.

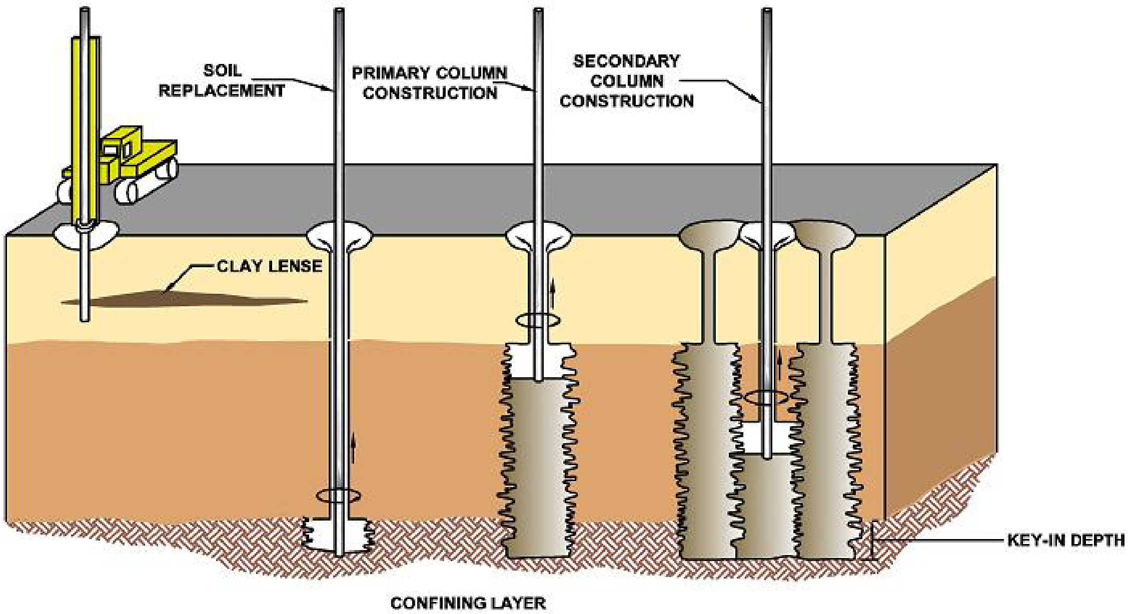

Figure 7-5: Directional Jet Injection Schematic

7.3.5 ZVI Emplacement Method Summary

While various emplacement methods have been considered and are implementable, the emplacement methods retained for field testing are:

- one-pass trenching for construction of a continuous ZVI wall; and
- HSA drilling[10] for construction of a discontinuous ZVI wall.

If the ZVI-enhanced bioremediation technology is successfully demonstrated in the Transect 1A Study Area, the means and methods excluded from the field tests (e.g., biopolymer trenches, in-situ soil/ZVI mixing, directional jet injection) may be reconsidered in the FS or as potential components of the final remedy. These other ZVI emplacement methods may be most suitable for specific conditions elsewhere at the site (e.g., directional jet injection to address perchlorate in the UMCf or biopolymer trenches where subsurface obstructions may be present or deep trenches are required).

[10] In cases where HSA drilling is ineffective in reaching the target depth, rotary sonic drilling will be used to advance the borings.

7.4 Field Test Layouts and Purposes

The Phase 2 field test will be conducted within the Transect 1A Study Area, which is on property owned by the COH[11]. Field testing will involve evaluating two of the emplacement methods identified above (continuous ZVI trenched wall using one-pass and discontinuous ZVI-filled borings using HSA drilling) in five discretely-monitored tests performed in two proximate areas collectively designed to address the objectives described in Sections 1.2 and 7.2. Four of the five tests will evaluate performance of ZVI-enhanced bioremediation in the alluvium while the fifth test will evaluate performance in the UMCf. The locations of the proposed field tests are shown on Figure 7-1.

In summary, two continuous ZVI walls with different ZVI dosages installed in the alluvium (Tests 1a and 1b) are proposed to evaluate performance of ZVI-enhanced bioremediation in the alluvium and assess the relationship between ZVI dosage and performance in the field. Similarly, two discontinuous ZVI walls with two- and three rows of ZVI borings installed in staggered arrays within the alluvium (Tests 2a and 2c) are proposed. These four test configurations will allow comparative evaluation of the performance of continuous and discontinuous ZVI walls installed in the alluvium. In addition, a third discontinuous ZVI wall with two rows of ZVI borings will be installed in the upper portion of the UMCf (Test 2b) to evaluate the performance of ZVI-enhanced bioremediation in the UMCf. Implementation of these five tests will:

a) maximize the cost-effectiveness of the Phase 2 field test (e.g., costs for mobilization of the one-pass trencher are significant, relative to costs for installation of the proposed continuous ZVI walls);

b) meet the study objectives (refer to Sections 1.2 and 7.2) through collection of the data required to demonstrate the effectiveness of ZVI-enhanced bioremediation in the alluvium and UMCf;

c) evaluate both the viability and performance of the technology as a full-scale option; and

d) generate data to evaluate key FS criteria (e.g., COPC reduction, long and short-term effectiveness, permanence, cost) and inform the design of ZVI-enhanced bioremediation as a potential component of the final remedy (e.g., production rates, optimum ZVI dosages, residence times, distribution of the bioactive zone, hydraulic responses, limitations, and applicability of emplacement methods).

Test locations, orientations, and configurations are subject to minor modifications and adjustments based on (a) the findings of the pre-construction investigation activities described in Section 7.5.1, (b) field conditions encountered at the time of implementation, and (c) by the requirements of the access agreement with COH. Each test will have its own monitoring program (further discussed in Section 8) to address the specific purposes of each test listed in Table 7-1.

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[11] An access agreement between the Trust and the City of Henderson will be required to allow implementation of the proposed Phase 2 field test. As of the date of this Work Plan Addendum, the COH has initially accepted the field test efforts presented herein and the Trust continues its efforts with the COH to procure access. Any material changes to the proposed Phase 2 field test which result from the finalization of the access agreement with the COH will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

Table 7-1: ZVI Field Test Summary

Test ID	Reactive Zone Type	Emplacement Method	Specific Purposes of Test
1a	Continuous ZVI Wall in the Alluvium (10% by weight)[a]	One-pass trenching to 35 feet	1. Evaluate performance of a continuous low-dose, coarse-grain granular ZVI wall in the alluvium for enhanced bioremediation of perchlorate, chlorate, and nitrate in groundwater. 2. Compare performance of lower ZVI dosage in continuous ZVI wall against higher ZVI dosage in continuous ZVI wall (i.e., Test 1b below). 3. Evaluate performance against discontinuous ZVI-filled boring wall in the alluvium (i.e., Test 2a and Test 2c below).
1b	Continuous ZVI Wall in the Alluvium (30% ZVI by weight)[a]	One-pass trenching to 35 feet	1. Evaluate performance of a continuous high-dose, coarse-grain granular ZVI wall in the alluvium for enhanced bioremediation of perchlorate, chlorate, and nitrate in groundwater. 2. Compare performance of higher ZVI dosage in continuous ZVI wall against lower ZVI dosage in continuous ZVI wall (i.e., Test 1a above). 3. Evaluate performance against discontinuous ZVI-filled boring wall in the alluvium (i.e., Test 2a and Test 2c below).

Table 7-1: ZVI Field Test Summary

Test ID	Reactive Zone Type	Emplacement Method	Specific Purposes of Test
2a	Discontinuous ZVI Two Boring Array Wall in the Alluvium (50% ZVI by weight)[a]	HSA drilling[b] of two arrays to 35 feet	1. Evaluate performance of a discontinuous low-dose, coarse-grain ZVI two boring array system in the alluvium for enhanced bioremediation of perchlorate, chlorate, and nitrate in groundwater. 2. Compare performance of lower ZVI dosage in discontinuous ZVI-filled two-boring array wall against the higher ZVI dosage (i.e., three boring array) in discontinuous ZVI wall (i.e., Test 2c below). 3. Evaluate performance against continuous trenched wall in the alluvium (i.e., Test 1a and 1b above) and/or for areas where a trench may not be implementable.
2b	Discontinuous ZVI Two Boring Array Wall in the UMCf (50% ZVI by weight)[a]	HSA drilling[b] of two arrays to 75 feet	1. Evaluate performance of a discontinuous low-dose, coarse-grain ZVI two boring array system in the UMCf for enhanced bioremediation of perchlorate, chlorate, and nitrate in groundwater.

Table 7-1: ZVI Field Test Summary

Test ID	Reactive Zone Type	Emplacement Method	Specific Purposes of Test
2c	Discontinuous ZVI Three Boring Array Wall in the Alluvium (50% ZVI by weight)[a]	HSA drilling[b] of three arrays to 35 feet	1. Evaluate performance of a discontinuous high-dose, coarse-grain ZVI three boring array system in the alluvium for enhanced bioremediation of perchlorate, chlorate, and nitrate in groundwater. 2. Compare performance of higher ZVI dosage in discontinuous ZVI-filled three boring array wall against the lower ZVI dosage (i.e., three boring array) in discontinuous ZVI wall (i.e., Test 2a above). 3. Evaluate performance against continuous trenched wall in the alluvium (i.e., Test 1a and 1b above) and/or for areas where a trench may not be implementable.

[a] The %ZVI by weight (dosage) refers to the weight of ZVI over the total weight of the backfill (ZVI plus sand and/or pea gravel). The rationale for selection of the ZVI dosages listed for Tests 1a and 1b is provided in Section 7.5.4.

[b] In cases where HSA drilling is ineffective in reaching the target depth, rotary sonic drilling will be used to advance the borings.

7.5 Field Test Design Considerations

Section 4 discusses the geologic, hydrogeologic, chemical, and biological conditions at the Transect 1A Study Area, which along with the bench-scale results discussed in Section 5 and the modeling discussed in Section 6, form the basis of the Phase 2 field test design.

As shown on Figure 7-1, Tests 1a and 1b are to be conducted perpendicular to groundwater flow and are located directly upgradient of the existing LVWPS-MW107 monitoring well cluster. Tests 2a, 2b and 2c are to be conducted perpendicular to groundwater flow and are located directly upgradient of the existing LVWPS-MW102 monitoring well cluster.

7.5.1 Hydrogeological Conditions and Contaminant Concentrations

The results of previous soil and groundwater sampling in the Transect 1A Study Area show that perchlorate contamination is largely limited to the saturated alluvium and the upper portion of the UMCf to a depth of between 70 and 80 feet bgs. Based the soil profiles defined by the LVWPS-MW107 and LVWPS-MW-102 monitoring well clusters, the contact between the alluvium and UMCf in the Test 1a/1b and Test 2a/2b/2c areas is approximately 30 and 35 feet bgs, respectively. Further, a gypsum-rich subunit is encountered at depths of about 70 feet bgs and perchlorate concentrations above the groundwater screening level of 0.015 mg/L extend to depths between 48 and 69 feet bgs. Therefore, the field testing program is focused on this shallow interval to a maximum depth of 75 feet bgs.

As presented in Sections 4.2 and 4.4, and summarized in Table 4-10, previous data from the saturated alluvium and the upper portion of the UMCf in and around the Transect 1A Study Area indicate contaminant concentrations have been relatively stable over time. Moreover, lateral variability in contaminant concentrations is not observed to be a primary factor in shallow groundwater conditions within the Transect 1A Study Area. As discussed in Section 6.3., the upper range concentrations of each target contaminant and other relevant aqueous phase design parameters were used in the preliminary modeling and for field test design purposes.

As presented in the Table 4-7, DO concentrations, ORP values and pH in the alluvium averaged 2.1 mg/L, 82.3 mV and 7.5, respectively. In the UMCf, DO concentrations, ORP values and pH averaged 1.2 mg/L, -95.4 mV and 7.8, respectively. These conditions represent a slightly oxic, circumneutral aquifer with varying redox conditions. Based on microbial results discussed in Section 4 and results of bench-scale testing discussed in Section 5, native perchlorate-reducing bacteria activity is very low, but is capable of being further stimulated through injection of inoculum following ZVI emplacement.

Similarly, the hydrogeological parameters summarized in Table 4-9 were used in the preliminary geochemical model (see Section 7.5.2) and ZVI wall design (see Section 7.5.3). Generally, groundwater elevations/gradients have been relatively stable over time; however, for design purposes maximum groundwater elevations were considered to address potential fluctuations that may be observed during implementation and monitoring of the field test. The mean groundwater velocity (1.8 ft/day and 0.29 ft/day for the alluvium and upper portion of the UMCf, respectively), hydraulic conductivity

(24.2 ft/day and 1.7 ft/day, respectively) and porosity (0.1 ft/day and 0.08 ft/day) were considered in the design of the field test.

7.5.2 Geochemical Modeling

As presented in Section 6, the 1-D reactive transport modeling defined hydrogen generation and demand rates assuming a ZVI dosage of 30% by weight and using the maximum observed concentrations of nitrate, chlorate, and perchlorate within the Transect 1A Study Area. The model concluded that the hydrogen generation rate (26.2 g/d) is several orders of magnitude greater than the expected hydrogen demand (5.1×10^{-5} g/d). The geochemical model estimated the ZVI consumption due to corrosion and chlorate reduction to be 0.53% of total ZVI mass per year, which is not significant at that ZVI loading. The amount of ZVI consumption should be similar at the various ZVI dosages proposed in the field test, but the percent reduction will vary as a function of the starting amount. These consumption rates will be further refined using the geochemical data derived during the Phase 2 field test.

The 1-D modeling also indicated that reduction-corrosion reactions and the associated pH increase lead to the precipitation of a number of secondary mineral phases across the width of the ZVI wall. The simulations indicate a loss in absolute porosity in the ZVI reactive zone due to mineral precipitation reactions of 0.7% per year (i.e., the assumed 30% porosity of the ZVI wall would be reduced to 29.3% after 1 year). Although this level of precipitation will not impact the field test, this annual loss in porosity will affect the hydraulic properties of the ZVI wall over time. Changes in hydraulic performance will be assessed during the field test.

7.5.3 Residence Time

As detailed in Section 5.1.3.2, UNLV Galleria Parcel bench-scale testing indicates that for a 30% ZVI design mix, a residence time of 15 hours is required to reduce all nitrate and chlorate. After this time, the biological reduction of perchlorate commences. Since the bench-scale tests were conducted under controlled conditions (e.g., temperature) and over relatively short time frames which do not account for potential longevity effects (see Section 7.5.5), design residence times are increased by a "factor of safety." As presented in Appendix J, assuming a porosity of the ZVI backfill of 0.3, the resulting groundwater velocity in the ZVI wall would be 0.6 ft/day (or three times lower than the 1.8 ft/day of the alluvium) and flow through a 30-inch wide wall would provide a residence time of over 100 hours. If the materials in the flow area consist of 30% ZVI, the factor of safety (or ratio of design residence time to the required residence time determined from column tests) would be about 6.7, meaning the proposed ZVI wall configuration provides 6.7 times the required residence time.

If the ZVI content was reduced to 10%, the required residence time would increase inversely proportional to the change in ZVI content (i.e., a decrease in the ZVI content by 1/3 would result in an increased residence time by a factor of 3). For a similarly configured flow wall width (i.e., 30 inches wide) the actual residence time would not change, but the factor of safety would decrease to about 2.2 (a decrease by a factor of 3 when compared to the 30% ZVI mix).

Similarly, flow through the core of a 12-inch diameter ZVI-filled boring would provide a residence time of about 28.3 hours. However, increasing the ZVI content to 50%, would results in a factor of safety of about 3.1 since the increased ZVI content would reduce the required residence time from 15 hours to 9 hours. For ZVI-filled borings installed in the upper portion of the UMCF, where the groundwater velocity is 0.29 ft/day, the residence time and factor of safety would be almost 220 hours and about 24.4, respectively.

7.5.4 ZVI Dosage and ZVI Design Mixes

As discussed in Section 5.2.3.1, bench scale testing results showed that a ZVI concentration equal to approximately 100X (~32.5 g ZVI/L) the molar ratio determined through stoichiometric analysis was sufficient to completely degrade chlorate and nitrate in site groundwater without the amount of ZVI limiting the degradation rate. These bench tests simulated static conditions and did not account for contaminant flux into the system. Although it is difficult to compare static and dynamic ZVI loadings, a 30% ZVI in sand mixture was used in the UNLV column studies and was able to remove all of the chlorate and nitrate in 15 hours of residence time. For the treatability test, ZVI dosages will range from 10% to 50% ZVI by weight, which represent the upper and lower bounds of what Ramboll considers to be reasonable for this field application based on available research and previous project experience. The balance of the ZVI design mix will consist of washed sand or pea gravel, which will provide an inert material that will help limit potential bridging of the ZVI and provide a porosity and hydraulic conductivity greater (i.e., 0.3 and 200 ft/day) than that of the native soils (i.e., 0.1 and 24.2 ft/day in the alluvium and 0.08 and 1.7 ft/day in the UMCf).

One of the objectives of the Phase 2 field test is to compare the performance of two methods of emplacing ZVI under field conditions as well as the impact of the ZVI dosage. This will involve comparing the continuous trenched walls (Tests 1a and 1b) and the discontinuous ZVI-filled boring walls (Tests 2a and 2c), where two ZVI dosages (10% versus 30%) will be tested in the continuous trench configuration and two versus three rows of borings containing 50% ZVI will be tested in the discontinuous boring walls. In order to compare these options, the total ZVI loading (i.e., ZVI mass per cross-sectional area of flow) for each option must be known and relatively similar. The calculations presented in Appendix J show that when considering the cross-sectional area in the direction of groundwater flow, the proposed ZVI dosages are within the same range. Specifically, the 10% and 30% ZVI in the continuous trenched wall will have an average loading of about 55 and 165 pounds per vertical square foot (lbs/VSF) of wall, while the 50% ZVI design mix in the 2-row ZVI-filled boring discontinuous wall and 3-row ZVI-filled boring discontinuous wall will have an average loading of about 58 and 86 lbs/VSF.

7.5.5 Longevity

Three primary factors can limit the life of a ZVI wall: mass loss of the ZVI due to corrosion (refer to Section 7.5.2), loss of hydraulic conductivity, and ZVI surface passivation. As previously stated, ZVI consumption was estimated by the preliminary geochemical model to be 0.53% per year for a reactive zone containing 30% ZVI in sand. This rate of ZVI mass loss is considered insignificant, particularly for the relatively short duration of this study.

Mineral precipitation and, to a lesser extent, biological fouling could result in loss of porosity. While the groundwater pH is circumneutral, the addition of ZVI will result in pH increases, which in turn could result in carbonate mineral precipitation when carbonate alkalinity is high. This mineral precipitation could lead to loss of porosity and reactivity of the ZVI wall. These precipitation reactions are common to all ZVI systems and have been considered in the preliminary geochemical model (see Section 7.5.2), where the loss in total porosity for a 30% ZVI in sand treatment zone was estimated to be 0.7% per year. Sulfate reduction and associated sulfide precipitation was not observed in microcosm tests performed on Transect 1A soil and groundwater amended with ZVI in the absence of organic carbon (see Section 5.2.4). Similarly, as detailed in Section 5.1.4, column tests did not show any evidence of biofouling even when carbon sources were added. While precipitation is not expected to be a concern for the five planned ZVI wall configurations, the potential for sulfide precipitation and other precipitating species will be assessed during the Phase 2 field test.

Passivation was not considered in the preliminary geochemical model because representative passivation rates were not available at the time the model was developed (see Section 6.3). The DO and nitrate concentrations are high in Transect 1A alluvium groundwater (8.4 mg/L and 64 mg/L, respectively, as shown in Table 4-5) and could lead to formation of oxide precipitates that could cause passivation of the ZVI surface. Site-specific passivation rates will be measured in a focused laboratory test during the pre-construction activities and incorporated into the updated geochemical model.

In addition, water quality, geochemistry, hydraulics, and biological activity will be monitored as part of the performance monitoring program (see Section 8) to inform the updated geochemical model and quantify potential precipitation and biofouling effects on remedy longevity for the FS in order to assess the suitability of ZVI-enhanced bioremediation as a potential component of the final remedy.

7.6 Proposed Field Test Design Details

This section describes the proposed Phase 2 field test locations and configurations, inoculum and nutrient injection, performance monitoring network, pre-construction activities, and planned site improvements for field test implementation. The location of the field tests is shown on Figure 7-1. The design drawings for tests areas are provided in Figures 7-6 through 7-12.

All fieldwork associated with the Phase 2 field test will be conducted in accordance with the Site-Wide Health and Safety Plan (Ramboll Environ 2017a, 2017b), an addendum to which will be added to address specific job hazards associated with implementation of this Work Plan Addendum. It is anticipated that modified Level D PPE will be required for all field activities. The pre-construction procedures, including utility surveys and filing of required permit applications (refer to Section 9), will be followed. Drilling, well installation, and well development procedures are provided in the Field Sampling Plan, Revision 1 (ENVIRON 2014a).

7.6.1 Tests 1a and 1b – Continuous ZVI Wall

As shown on Figure 7-6, two adjacent ZVI walls will be installed upgradient of the LVWPS-MW107 monitoring well cluster and oriented in a manner designed to intercept groundwater with similar contaminant concentrations and groundwater flow characteristics. The adjacent walls will be constructed as a single[12] ZVI-filled trench using one-pass trenching (described in Section 7.3), with the ZVI design mix being the only difference between the two wall segments. Test 1a will be used to evaluate a lower percentage by weight of ZVI (i.e., 10%) and Test 1b a higher percentage by weight of ZVI (i.e., 30%).

Each continuous ZVI wall will be approximately 100 feet long by 40 feet deep and keyed approximately 5 feet into the UMCf[13]. The width, and therefore the flow-through thickness, will be 2.5 feet to provide the required residence time (see Section 7.5.3)[14]. To achieve the target depth using the conventional one-pass trencher (with a reach of 35 feet), a working platform will be constructed by benching-down approximately five feet using a conventional excavator and placing a layer of quarried stone over a geosynthetic fabric. While one-pass trenchers with greater depth reaches and trench widths are available, the associated mobilization and demobilization costs are significantly greater than the costs of pre-trenching for this size field test. The excavated materials will be stockpiled in the staging area for use as backfill to restore site grades once the ZVI walls are constructed. The depth of and configuration of this excavation may be adjusted based on data collected from the pre-construction activities (described in Section 7.6.5) and actual field conditions encountered during construction.

To create the ZVI backfill, granular ZVI and sand and gravel[15] will be mixed on-site using weigh belts and hoppers, volumetric mixers, pugmills or similar equipment. This will allow for greater control on the uniformity of the backfill and limit potential segregation of materials during transport. The ZVI backfill will be designed to have a hydraulic conductivity and porosity of 30 ft/day and 0.3, respectively, which are greater than those of the native materials (1.7 ft/day and 0.1 for the alluvium and 0.2 ft/day and 0.1 for the UMCf). These hydraulic properties will ensure that the ZVI wall will not impede or divert water flow around it or cause groundwater mounding behind it, while providing adequate residence time and longevity (see Sections 7.5.3 and 7.5.5).

Figures 7-7 and 7-8 present cross-sections and profiles of the continuous ZVI walls during construction and post-construction. As shown in Figure 7-7, the one-pass trencher will operate within the benched down area, from where it will either directly load trucks or stockpile trench excavation materials for loading using a front-end loader or excavator onto site trucks for stockpiling in the staging area. Another excavator positioned above the benched down area will feed the ZVI backfill to the one-pass trencher's hopper to allow simultaneous excavation and backfilling of the ZVI wall. The trencher will be used to install a large diameter temporary well casing (typically 12 to 24 inches in diameter) at the leading edge of the trench. This temporary well will be used to extract groundwater, which will be reintroduced to the trench during ZVI backfill

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[12] As indicated in Section 7.3, the conventional one-pass trencher can install ZVI in a continuous wall to depths of up to 35 feet with a production rate of 200 to 400 linear feet per day. The proposed Test 1a and 1b continuous ZVI trench length was selected to optimize use of the specialized one-pass trencher.

[13] As indicated in Section 7.5.1, the contact between the alluvium and UMCf in the Test 1a/1b and Test 2a/2b/2c areas is approximately 30 and 35 feet bgs, respectively.

[14] Selection of the trench width also considered available standard trencher sizes and construction limitations due to the target trench depth.

[15] Approximately 10 to 25% of the backfill will consist of ¼- to ¾-inch diameter gravel to facilitate the delivery and placement of the backfill into the trench and limit potential ZVI bridging during placement.

placement to further stabilize the trench walls and facilitate material placement. The trenching will begin with the Test 1a continuous ZVI wall with a mixture of 10% ZVI and 90% sand or gravel until the mid-point of the 200-foot long trench. At this point, the backfilling mixture will be transitioned to 30% ZVI and 70% sand or gravel and trenching and backfilling will resume until completion of the Test 1b wall. Upon completion, the large diameter temporary well casing will then be removed and backfilled with previously excavated materials. The benched down excavation (upper five feet) will be then backfilled with the native soils removed during excavation, which will be compacted to achieve a hydraulic conductivity of less than 1×10^{-5} centimeters per second (cm/s) to prevent potential infiltration of stormwater through the ZVI-filled trench that could interfere with the evaluation of performance monitoring data. The specifications and compaction requirements and potential amendments[16] to achieve the target hydraulic conductivity will be defined from laboratory testing of the excavated materials performed during the pre-construction activities (refer to Section 7.5.1). If native soils cannot achieve the target hydraulic conductivity, a one-foot layer of hydrated bentonite will be placed over the backfilled trench and overlain by four-feet of compacted native soils removed during excavation. The Test 1a/1b area will then be mounded at least one foot to accommodate potential settlements and graded (at least 2%) to provide positive drainage away from and prevent ponding of stormwater over the area (see Figure 7-8).

The Test 1a/1b area will have a monitoring well network with a subset of wells focused on each of the two test areas to collect data for the purposes presented in Table 7-1. The completed Test 1a/1b continuous ZVI walls cross-section and profile also showing the relative position of monitoring wells are presented in Figure 7-8. The data collected from the pre-construction activities (described in Section 7.6.5) will be evaluated to determine final alignment and terminal depths of the Test 1a/1b ZVI walls.

A construction quality control (CQC) plan will be implemented to ensure that (a) implementation conforms to the design specification, permit conditions, and test objectives, (b) as-built conditions and potential field modifications that would inform the evaluation of performance monitoring data are documented; and (c) information relevant to the FS and future remedial design is gathered. As presented in Appendix K, this plan will include measures to confirm that the target trench depths have been achieved, document the verticality of the constructed wall, and ensure the homogeneity of the ZVI backfill and conformance to the ZVI design mix.

7.6.2 Test 2a, 2b and 2c – Discontinuous ZVI Boring Array Wall

As shown on Figure 7-9, three adjacent discontinuous walls of ZVI-filled borings will be installed upgradient of the existing LVWPS-MW102 monitoring well cluster and oriented in a manner designed to intercept groundwater with similar contaminant concentrations and groundwater flow characteristics. The discontinuous walls will be constructed using two or three staggered arrays of closely-spaced 12-inch diameter borings advanced using HSA drilling. The target depth intervals within each borehole will be backfilled with

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[16] The specified hydraulic conductivity of less than 1×10^{-5} cm/s for trench backfill is expected to be achievable using compacted sandy silts, as those that comprise the alluvium soils. However, should testing performed as part of the pre-construction activities indicate that the target hydraulic conductivity cannot be achieved, approximately 1% bentonite by weight would be mixed with the native soils to achieve the target hydraulic conductivity.

50% ZVI and 50% sand by weight. The upper portions of each boring will be backfilled with sand followed by neat cement grout to the ground surface. The spacing between borings in each array will be 3 feet on-center and the spacing between arrays will be 2 feet on-center. This spacing provides the tightest possible spacing while ensuring boring verticality and that adjacent completed borings are not compromised during installation. However, the boring spacing, configuration and target depths may need to be adjusted based on data collected from the pre-construction activities (described in Section 7.6.5) and actual field conditions encountered during construction.

The three walls will differ in the number of borings that comprise the wall (i.e., the ZVI dosage) and the depth of the borings. Specifically:

- The Test 2a array targets the alluvium and is comprised of seventeen 12-inch diameter ZVI-filled borings, advanced in two staggered rows to a target depth of 35 feet bgs.
- The Test 2b array targets the UMCf and is comprised of nine 12-inch diameter ZVI-filled borings, advanced in two staggered rows to a target depth of 75 feet bgs. These ZVI borings will be double-cased to isolate the alluvium and UMCf water bearing units.
- The Test 2c array targets the alluvium and is comprised of twenty-five 12-inch diameter ZVI-filled borings, advanced in three staggered rows to a target depth of 35 feet bgs.

As with the backfill for the continuous ZVI walls, to create the ZVI backfill, granular ZVI and sand will be mixed on-site using weigh belts and hoppers, volumetric mixers, pugmills or similar equipment. This will allow for greater control on the uniformity of the backfill and limit potential segregation of materials during transport. The ZVI backfill materials will be subject to CQC testing requirements, including sieve analyses, bulk density, and percent iron (refer to the CQC plan provided in Appendix K). The Test 2a/2b/2c area will be mounded at least one foot to accommodate potential settlements and graded (at 2% minimum) to provide positive drainage away from and prevent ponding of stormwater over the area.[17]

The boring arrays will have independent monitoring well networks to collect data for the purposes presented in Table 7-1. The proposed Test 2a/2b/2c discontinuous ZVI walls cross-section and profiles also showing the relative position of monitoring wells are presented in Figure 7-10.

A construction quality control plan will be implemented to ensure that implementation conforms to the design specification and test objectives. As presented in Appendix K, this plan will include measures to confirm that the target boring depths have been achieved and ensure the homogeneity of the ZVI backfill and conformance to the ZVI design mix.

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[17] The proposed site restoration and grading plans will be subject to the access agreement discussions between the Trust and the City of Henderson which will be finalized upon NDEP approval of this Work Plan Addendum.

7.6.3 Inoculum and Nutrient Injection Design

As discussed in Section 7.2, a biological inoculum and nutrients will be injected following construction of the ZVI walls. The purpose of this one-time injection is to accelerate the onset of biological perchlorate reduction and reduce the overall duration of the field test. The inoculum will be developed from the FBR solids and will accelerate the onset of perchlorate reduction by providing a functionally diverse microbial community that can avoid a lag in biological development. Refer to Appendix I for details on the inoculum culture development. The nutrients (i.e., vitamin B12 and DAP) will stimulate the growth of naturally occurring perchlorate-reducing bacteria in the subsurface or bacteria added by inoculation.

Addition of the inoculum and nutrients as part of the ZVI backfilling activities is not desirable for various reasons. Importantly, the inoculum may be sensitive to exposure to oxygen, which may kill some of the bacteria. Also, addition of inoculum and nutrients to the ZVI backfill, rather than injection at target depths would result in a less controlled placement and distribution of these materials (i.e., all backfill would be inoculated instead of only the portion that will be submerged resulting in loss of inoculum and nutrients). Further, for the one-pass emplacement method, backfill materials should be generally dry. Lastly, though not anticipated it would be necessary, addition of the inoculum and nutrients to the ZVI backfill would not allow future addition of nutrients.

As detailed in Appendix I and shown in Figure 7-6 and 7-9, subject to Underground Injection Control (UIC) permit requirements (see Section 9.2.4), inoculum and nutrients will be injected using 2-inch diameter injection wells spaced 20 foot on centers. Specifically, 10 shallow injection points will be installed in the Test 1a/1b area, two shallow injection points will be installed in both Test 2a and Test 2c areas, and one pair of deep injection points will be installed in the Test 2b area. The injection wells for Tests 1a, 1b, 2a and 2b will be screened in the saturated alluvium; for Test 2c, the upper portion of the UMCf will be screened. Inoculum will be added to each well followed by anaerobic chase water, and nutrients will be diluted in water prior to addition to each well. The water for the injections will be extracted from select wells installed as part of the monitoring network. As described in Section 9.2.5, this activity will require a Water Appropriation Permit. As stated in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019) there are several advantages of using extracted groundwater instead of public supply water (e.g., COH hydrant water):

- Using extracted water eliminates dilution effects on existing chemical concentrations in the immediate vicinity of the test area that could result from use of potable water from COH.
- It is more sustainable and less costly, as it does not deplete water from the supply system and avoids the need to procure and/or purchase water.
- Since water will only be used for the one-time injections, the quantity of water needed is very small and can be easily obtained from monitoring wells proximate to the injection wells.

The injection points will be constructed of 2-inch Schedule 40 PVC casing and screened with 2-inch diameter, slotted PVC well screen at varying intervals within the alluvium and UMCf. While the borings for the installation of injection points will be 6.2-inches in outside diameter, the total well depth, screened intervals, slot size of well screen, filter pack, and length of the well screens for each injection point will be selected based on lithology encountered during borehole drilling at each location. All deep borings will be double cased to isolate the alluvium and UMCf water bearing units. The injection points will be completed with a flush mount and concrete apron slightly above the surrounding grade. Following construction, but no sooner than 48 hours after construction is complete, each of the newly installed injection points will be developed using a surge block and bailer to swab and surge the filter pack and remove sediment from the wells.

7.6.4 Monitoring Network Layout and Design

As discussed in Section 8, a performance monitoring program will be implemented to assess the continuous and discontinuous ZVI walls in the context of the objectives listed in Sections 1.2 and 7.4. The monitoring networks associated with Tests 1a and 1b are shown on Figures 7-6 and 7-8 and for Tests 2a, 2b and 2c are shown in Figures 7-9 and 7-10. The monitoring well networks for all test areas are similarly designed (in layout, spacing, and depth). The monitoring well networks for Tests 2a and 2b include both existing and new monitoring wells. The networks incorporate the monitoring wells installed as part of pre-construction activities (refer to Section 7.6.5) and the existing monitoring well clusters in the Test 1a/1b area (LVWPS-MW107) and the Test 2a/2b/2c area (LVWPS-MW102). By incorporating existing wells in the monitoring program, the monitoring well network is expanded without the need for additional monitoring well installation.

The monitoring wells will be installed upgradient, downgradient, and within the ZVI walls and periodically sampled to evaluate performance as detailed in Section 8. Figures 7-6 and 7-9 show the approximate layout of the proposed monitoring well networks, including:

- For Test 1a, fifteen shallow monitoring wells (3 within the wall, 2 upgradient and 10 downgradient) and two deep downgradient monitoring wells will be installed for the performance monitoring network. The monitoring network incorporates the three upgradient and one downgradient well that will be installed as part of the pre-construction activities described in Section 7.6.5. Note that two additional deep monitoring wells (1 upgradient and 1 downgradient) will be installed between Test 1a and 1b as part of the pre-construction activities. The purpose of the deeper wells screened in the upper portion of the UMCf is to assess potential contaminant flux from the UMCf into the alluvium. Thus, a total of 23 monitoring wells will form the monitoring well network for the Test 1a area.
- For Test 1b, thirteen shallow monitoring wells (3 within the wall, 1 upgradient and 9 downgradient) and two deep monitoring wells (1 upgradient and 1 downgradient) will be installed for the performance monitoring network. The monitoring network incorporates the three upgradient and one downgradient well that will be installed as part of the pre-construction activities described in Section 7.6.5. The monitoring network will also incorporate the existing shallow and two deep monitoring wells in the LVWPS-MW107 cluster located downgradient of Test 1b. Thus, a total of 19 monitoring wells (of which 3 are existing wells) will form the monitoring well network for the Test 1b area.
- For Test 2a, eight shallow monitoring wells (1 within the wall, 2 upgradient and 5 downgradient) and two deep monitoring wells (1 upgradient and 1 downgradient)

will be installed for the performance monitoring network. The monitoring network incorporates the two upgradient and two downgradient wells that will be installed as part of the pre-construction activities described in Section 7.6.5. The monitoring network for Test 2a, will also incorporate the existing shallow and deep monitoring wells in the LVWPS-MW102 cluster located downgradient of Test 2a. Thus, a total of 16 monitoring wells (of which 2 are existing wells) will form the monitoring well network for the Test 2a.

- For Test 2b, eight downgradient monitoring wells will be installed for the performance monitoring network. Four of these wells will be screened in the upper portion of the UMCf and the remaining four will be screened in the lower portion of the UMCf. The monitoring network will incorporate the three upgradient and two downgradient wells that will be installed as part of the pre-construction activities described in Section 7.6.5. Thus, a total of 13 monitoring wells will form the monitoring well network for the Test 2b area.
- For Test 2c, nine shallow monitoring wells (1 within the wall, 2 upgradient and 6 downgradient) and two deep monitoring wells (1 upgradient and 1 downgradient) will be installed for the performance monitoring network. The monitoring network will incorporate the two upgradient and two downgradient wells that will be installed as part of the pre-construction activities described in Section 7.6.5. Thus, a total of 15 monitoring wells will form the monitoring well network for the Test 2c area.

Figures 7-6 and 7-9 also define the spacing and distances between monitoring wells. As shown in these figures, the placement of most monitoring wells is biased to be in close proximity to the ZVI wall because increased hydrogen concentrations will dissipate rapidly within a short distance of where it is generated. Figures 7-8 and 7-10 provide typical cross-sections of the performance monitoring network for the continuous and discontinuous ZVI walls, respectively.

Because the proposed monitoring well network will be installed in very close proximity to the ZVI walls or within the bench down area in the case of the continuous ZVI wall, the monitoring wells associated with each test will need to be installed immediately following construction of the Test 1a/1b and Test 2a/2b/2c ZVI reactive zones to protect their integrity. This will allow for the performance monitoring to commence immediately after ZVI emplacement.

Except for seventeen monitoring wells (which will be installed during the pre-construction activities), all monitoring wells will be constructed of 2-inch Schedule 40 PVC casing and screened with 2-inch diameter, slotted PVC well screen at varying intervals within the alluvium and UMCf. The seventeen pre-construction monitoring wells will be 4-inches in diameter instead of 2-inches to allow the performance of borehole dilutions tests (refer to Section 8). While the borings for the installation of the 2- and 4-inch diameter monitoring wells will be a nominal 6- and 8-inches in outside diameter, respectively, the total well depth, screened intervals, slot size of well screen, filter pack, and length of the well screens for each monitoring well will be selected based on lithology encountered during borehole drilling at each location. All borings and wells that extend into the UMCf will be double cased to isolate the alluvium and UMCf water bearing units. The monitoring wells will be completed with a flush mount and concrete apron slightly above the surrounding grade. Following monitoring well construction, but no sooner than 48 hours after construction is complete, each of 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. Following installation, all monitoring wells will be surveyed by a Nevada-licensed land surveyor.

7.6.5 Pre-Construction Activities

The pre-construction activities will include advancement of pilot borings, installation of monitoring wells, and laboratory testing. Initially, laboratory testing will be conducted to evaluate passivation and observed cementation in bench-scale testing. As indicated in Section 5.1.4, samples of the observed cementation of the ZVI and sand mixture in the column tests have been preserved at UNLV and will be analyzed by X-ray diffraction to determine the composition of the mineral precipitation. In addition, site-specific passivation rates will be measured in a focused laboratory test during the pre-construction activities and incorporated into the updated geochemical model.

The final alignment and subsurface design of the continuous ZVI walls of Test 1a/1b and the discontinuous ZVI walls of Test 2a/2b/2c will be informed by a series of pilot borings that will be advanced at the locations shown in Figures 7-6, 7-9 and 7-11. Specifically,

- Initially, seventeen pilot borings will be advanced at the locations shown in Figure 7-11, with six drilled to a depth of approximately 75 feet bgs or terminated five feet into the gypsum-rich subunit of the UMCf (saline lake sediments). The remaining eleven pilot borings will be drilled to a depth of approximately 40 feet bgs, or five feet below the UMCf contact. These initial borings will be used to define potential variations in the hydrogeologic profile in the area and select the final position of the Test 1a/1b and Test 2a/2b/2c ZVI walls and additional pre-construction pilot borings.
- Following confirmation of the Test 1a/1b area location, six pilot borings will be advanced at the at the locations shown in Figure 7-6 with four drilled to a depth of approximately 35 feet bgs and two to a depth of approximately 48 feet bgs, or twelve feet below the UMCf contact.
- Following confirmation of the Test 2a/2b/2c area location, ten pilot borings will be advanced at the locations shown in Figure 7-9 with six drilled to a depth of approximately 35 feet bgs. Two of the remaining pilot borings will be drilled to a depth of approximately 75 feet bgs or terminated five feet into the gypsum-rich subunit of the UMCf (saline lake sediments) and the remaining two pilot borings will be drilled to a depth of approximately 55 feet bgs.

Soil from the saturated alluvium and UMCf from each test area will be collected and sent to a laboratory for geotechnical testing. The undisturbed geotechnical samples will be collected using Shelby tubes from select initial pre-construction borings and will be subjected to specific gravity (ASTM D854), moisture content (ASTM D2216), hydraulic conductivity (ASTM D2434 or D5084), Atterberg limits (ASTM D4318), particle size distribution (ASTM D6913), and density testing (ASTM D2763). In addition, samples of the uppermost 5 feet of native soils will be collected for geotechnical testing (i.e., standard proctor testing [ASTM D698] and hydraulic conductivity testing [ASTM D5084]) to determine the compaction requirements and potential need for amendments to achieve the target hydraulic conductivity for the compacted backfill over the ZVI walls (refer to Section 7.6.1).

Monitoring wells will be constructed at each pilot boring location following the same methods and procedures described in Section 7.6.4. As shown in Figures 7-6, 7-9 and 7-11, seventeen of the preconstruction monitoring wells will be 4-inches in diameter and the remaining sixteen preconstruction monitoring wells will be 2-inches in diameter. These monitoring wells will be integrated into the performance monitoring network as described in Section 7.6.4.

Upon completion of installation activities, groundwater sampling, slug testing and borehole dilution testing will be performed at each[18] of the newly installed monitoring wells as described in Section 8 to establish baseline conditions prior to field test implementation. Groundwater samples will be analyzed for perchlorate, chlorate, and nitrate to refine and better establish contaminant distribution in the test areas. Borehole dilution and slug testing will be performed as part of the aquifer testing program to better define the hydrogeology of the Test 1a/1b and Test 2a/2b/2c areas and refine the final field treatability study design.

The data collected from the pilot boring installation and baseline testing activities will be evaluated to determine the alignment, configuration, and terminal depths of the 200-foot long Test 1a/1b and the approximately 60-foot long Test 2a/2b/2c. These data will also be used to define any potential adjustments to the ZVI backfill (e.g., if chemical concentrations are significantly different that evaluated in the bench scale testing).

7.6.6 Staging Area Construction and Site Improvements

To allow implementation of the field tests and protect the performance monitoring network, the site improvements listed below will be implemented. These proposed site improvements are subject to change pending the ongoing discussions between the Trust and the COH. Any material changes to the proposed Phase 2 field test which result from the finalization of the access agreement with the COH will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

- *Access Roads*. The existing access roads within the Transect 1A Study Area are unimproved dirt roads that, in select locations, are too soft and/or rutted to allow vehicles and equipment to safely access the injection well sites and other work areas. As a result, in order to implement the work described above, gravel will be placed in select locations to slightly raise the road elevation, provide a more robust driving surface, and/or create a stable working platform during drilling, construction, and/or monitoring activities.
- *Staging Area*. Two staging areas will be established for temporary storage of excavated materials, imported materials and equipment during drilling and construction activities, to park vehicles, and to perform other work activities. As shown in Figure 7-1, these staging areas will be located within close proximity to the Test 1a/1b and Test 2a/2b/2c areas depending on the outcome of access approvals. The staging areas were sized to provide adequate storage of

[18] Borehole dilution tests will only be performed on the 4-inch diameter monitoring wells.

excavated materials from the benching down for Test 1a/1b, backfill materials for test areas, and backfill mixing operations.

- *Soil Erosion and Dust Control*. Soil erosion and sediment control measures will be installed around work areas (see Figure 7-12 for typical details). Further, dust suppression measures (e.g., wetting of surface) will be employed (as needed) during construction to mitigate excessive dust generated by the construction activities.
- *Site Regrading*. The area within and around Test 1a/1b and Test 2a/2b/2c will be cleared and grubbed and then graded to ensure positive drainage away from the test areas and prevent ponding of stormwater over the test areas. Earthen berms may need to be constructed to divert stormwater, where grading alone cannot achieve the drainage requirements. In addition, temporary access roads will be constructed to provide one-way traffic within the work areas (see Figure 7-1). Access to the staging areas from off-site roads will be provided via two-way traffic temporary roads. Further, as detailed in Section 7.6.1, to allow construction of the continuous ZVI walls to the target depths, the work area will need to be benched down prior to trenching (see Figure 7-7) and, following ZVI wall construction, backfilled and compacted (see Figure 7-8). A working platform will be constructed in the benched down area by placing a layer of quarried stone over a geosynthetic fabric.
- *Site Restoration*. Subject to the currently assumed conditions of the access agreement as indicated by the Trust, only the ZVI wall, ZVI boring arrays and certain groundwater monitoring wells will remain in place following completion of the Phase 2 field test. Site restoration activities contemplated at this time will be limited to dismantling the staging areas and temporary roads, removing all excess materials, and grading the site to promote drainage away from the test area. No revegetation is included in the site restoration activities.

In addition—and limited to the pre-construction and field test implementation activities—security personnel will monitor the site during non-working hours (nights, weekends, and holidays).

8. PHASE 2 PERFORMANCE MONITORING PROGRAM

This section describes the performance monitoring program that will be implemented during the Phase 2 field test, which will consist of periodic groundwater monitoring, laboratory analyses, and field data collection. The data collected will be used to assess the performance of each discrete field test described in Section 7.4 with respect to four criteria: hydraulic performance, geochemical performance, COPC performance, and biological performance. This performance monitoring program has been designed to provide data and establish the performance criteria necessary to achieve the Phase 2 objectives described in Section 1.2.

It is important to point out that this is the first field test of ZVI-enhanced bioremediation in the NERT RI Study Area, therefore, there are more uncertainties regarding how best to design, construct, and monitor this field test compared with technologies that have been field tested previously. While Ramboll has experience designing and implementing similar ZVI systems, the site-specific performance of ZVI in the field is difficult to predict even with the benefit of bench-scale testing and modeling. Therefore, it is critical to employ a robust performance monitoring program which collects sufficient spatial and temporal data to successfully achieve test objectives. For ZVI-enhanced bioremediation, the data collected must have the following characteristics:

- Spatial data with representative locations upgradient, within, downgradient, below, and at the edges of each ZVI reactive zone. The spatial data must also include representative locations along the groundwater flow path to monitor groundwater as it successively moves from upgradient to downgradient locations. Locations must also allow for contour mapping of groundwater elevations to determine gradient directions and magnitudes.
- Temporal data of sufficient duration to monitor an equilibrium condition representing performance that is reasonably expected to be achieved and sustained during a full-scale application of the technology. In the case of ZVI-enhanced bioremediation and as discussed further in Section 8.1, this requires time to allow for the development of a robust perchlorate-reducing biological community. The temporal data must also be collected at a frequency sufficient to monitor the changes in conditions leading up to and into the equilibrium state, but also frequent enough to observe hydraulic responses to precipitation events (this is often achieved through deployment of remote logging pressure transducers).

The sections below describe how the performance monitoring program will collect data that meets the needs of the Phase 2 field test of ZVI-enhanced bioremediation.

8.1 Time-Dependence of Performance Criteria

ZVI-enhanced bioremediation begins with emplacement of ZVI in the subsurface to intercept free-flowing groundwater in a passive manner. Groundwater in contact with ZVI for a period of time (i.e., the residence time as discussed in Section 7.5.3) causes slow corrosion of ZVI and numerous other geochemical reactions, including the generation of dissolved hydrogen. In time, these geochemical reactions in turn cause chemical and biological changes in groundwater within, downgradient, and (in some cases) upgradient of the ZVI. Emplacement of ZVI can be accomplished by different means and methods, but it always involves temporary disruption to the subsurface equilibrium. It takes time for a new "steady-state" condition to be achieved where stabilized performance of the ZVI can be observed. Moreover, certain aspects of performance will be observable sooner than others. This dictates the duration of testing and the frequency of monitoring.

It is also important to note that with the exception of the one-time biological inoculum injection event, the ZVI-enhanced bioremediation field test operates passively (i.e., the only driving force for migration through the reactive zones and downgradient monitoring networks is the natural flow of groundwater). This is dramatically different from previous NERT treatability studies of ISB where routine injection of liquid organic carbon substrates and significant chase water drives amendments further and faster into the formation. The passive nature of ZVI-enhanced bioremediation further informs the duration of testing and the frequency of monitoring. As discussed further in Section 8.2, the passive operation also dictates monitoring well spacing that is in closer proximity to the reactive zones.

Based on Ramboll's previous experience with ZVI-enhanced bioremediation and similar technologies, and the lessons learned from each of the two Phase 1 bench-scale testing programs, the performance criteria are evaluated in stepwise fashion.

1. **Hydraulic performance criteria** will be first to stabilize following emplacement of ZVI. Groundwater flow through the ZVI reactive zone must be established in order for the subsequent geochemical reactions to take place.
2. **Geochemical performance criteria** are expected to stabilize next. Establishing the desired geochemical conditions within and downgradient of the ZVI reactive zones will subsequently stimulate the desired biological community and transformations of COPCs.
3. **COPC performance criteria**—the primary measure of performance—are next to be established. Based on bench-scale results, nitrate and chlorate concentrations decrease first because these chemicals are less dependent on biology, being abiotically reduced directly by ZVI. The reduction will be observed in wells proximate to the ZVI reactive zone, and with time, in wells further downgradient. However, perchlorate reduction is entirely dependent on biology and, therefore, performance with respect to perchlorate reduction will lag until a robust perchlorate-reducing biological community is developed.
4. **Biological performance criteria** will be the last to stabilize, and, in general, these performance criteria can be the most difficult to measure and evaluate in field tests. However, because perchlorate reduction only occurs when perchlorate-reducing bacteria are present and active, biological performance criteria are critical to understanding the performance of ZVI-enhanced bioremediation, or any ISB approach, for treating perchlorate.

Hydraulic performance criteria generally begin stabilizing within a matter of days following emplacement of ZVI. Geochemical performance criteria generally begin stabilizing within a matter of weeks thereafter. COPC performance criteria generally begin stabilizing within weeks or months. As discussed in Section 5.2.4, chlorate and nitrate are expected to be rapidly removed from groundwater through an abiotic process in the presence of ZVI while perchlorate removal requires time for the development of a robust community of perchlorate-reducing bacteria. Therefore, COPC performance will include a short-term and a longer-term component, with perchlorate reduction being tied to biological performance. Biological performance criteria are generally last to begin stabilizing and, in some cases, measurable changes to the biology can take 6 months or more to materialize. This understanding, and the critical dependence of the biology on perchlorate remediation as established in the Phase 1 bench-scale testing, led to the recommendation to inoculate during the Phase 2 field test as discussed in Section 7.6.3. Regarding the onset of biological perchlorate reduction, the critical information needed to inform remedy performance is not how long it takes for perchlorate reduction to begin, but the fact that it does occur and is sustained through the duration of the field test.

The time dependence of the performance criteria for ZVI-enhanced bioremediation has informed the planned duration and frequency of performance monitoring as described in Sections 8.3 and 8.4, respectively.

8.2 Performance Monitoring Network

A network of monitoring wells specifically designed for each of the five discrete ZVI emplacement tests will be the primary means of collecting data for the performance evaluations. The monitoring well network includes wells located upgradient, downgradient, and within each discrete test. The monitoring wells will be installed in two phases: during pre-construction activities as described in Section 7.6.5 to establish baseline conditions and following construction of the ZVI reactive zones as described in Section 7.6.4 to complete the monitoring network. The baseline monitoring wells (discussed in Section 8.4) are shown on Figure 8-1. The Test 1a/1b and Test 2a/b/c monitoring wells are shown on Figures 8-2 and 8-3, respectively.

The monitoring well network will be used to measure groundwater elevations and assess hydraulic gradients in the vicinity of the field tests. Upgradient monitoring wells will be used to assess the geochemical conditions and COPC concentrations in groundwater migrating into the ZVI reactive zones. Wells installed within the ZVI reactive zones will be used to monitor hydraulic and geochemical conditions within or in very close proximity to the ZVI. Monitoring wells installed immediately downgradient from the ZVI reactive zones will be used to monitor the biologically active zone where perchlorate reduction is expected to occur. Wells further downgradient will be used to assess the attenuation of the biologically active zone and COPC performance.

8.2.1 Groundwater Sampling and Analysis

Groundwater sampling activities will follow the guidance of the Field Sampling and Analysis Plan (ENVIRON 2014a). Prior to groundwater sample collection, groundwater levels will be gauged in all wells to be used in potentiometric contouring. Groundwater samples will be collected using low-flow purging and sampling techniques. During low-flow purging of the wells, a pump capable of purging between approximately 0.03 to 0.13 gpm will be used to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water will be passed through a flow-through cell field water analyzer for continuous monitoring of field parameters (temperature, pH, turbidity, electrical conductivity, 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. Consistent with previous investigations and treatability studies, 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 at the NERT Site for onsite treatment in the GWETS.

All samples for chemical analysis and field quality assurance/quality control (QA/QC) samples will be evaluated for quality and usability. 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 QAPP, Revision 6 (Ramboll Environ, 2021) and NDEP Data Verification and Validation Requirements (NDEP 2018).

8.3 Performance Monitoring Duration

Based on Ramboll's previous experience with ZVI-enhanced bioremediation, and consistent with the discussion of time-dependence of the performance criteria in Section 8.1, the proposed duration of the Phase 2 field test performance monitoring program is 16 months. This operation and performance monitoring period begins once the field test construction is complete (including construction of the monitoring network described in Sections 7.6.4 and 8.2 and the one-time injection of inoculum and nutrients described in Section 7.6.3). The 16-month performance monitoring does not include the comprehensive baseline groundwater monitoring event described in Section 8-3, which will occur prior to emplacement of ZVI.

The 16-month performance monitoring period is necessary to allow for evaluation of each of the field tests described in Section 7-4 with respect to the performance criteria described herein. The 16-month duration was selected to account for a 4 to 6 month acclimation period to allow for the onset of biological perchlorate reduction and a subsequent 10 to 12 month steady state period where performance can be monitored over approximately a seasonal cycle. These timeframe estimates are based on the bench-scale testing results and prior experience, but the planned 16-month monitoring duration is only an estimate of what is sufficient to collect the temporal data needed to evaluate performance. The monitoring duration may be extended if necessary to achieve the objectives of the field test or reduced if data sufficiently demonstrates objectives have been met in advance of the 16 month monitoring period.

8.4 Performance Monitoring Frequency

A comprehensive baseline groundwater monitoring event will be performed to establish baseline conditions prior to emplacement of ZVI. Groundwater samples will be collected from all monitoring wells installed as part of the Phase 2 pre-construction activities (described in Section 7.6.5) and from existing wells installed during Phase 1 pre-design field investigations (Figure 8-1).

Approximately, one month following emplacement of ZVI and construction of the performance network (described in Section 8.4), the first comprehensive monitoring event of all of the upgradient, cross-gradient, and downgradient monitoring wells within each test area will be conducted. Following this "month 1" sampling event, routine groundwater levels will be measured monthly and groundwater samples collected quarterly to generate time-series data for evaluation with respect to performance criteria. During each quarterly event, hydraulic, geochemical, and COPC performance parameters will be analyzed as specified in Sections 8.5, 8.6, and 8.7, respectively. The biological parameters specified in Section 8.8 will be analyzed on a subset of 7 monitoring wells during the baseline groundwater monitoring event and on a subset of 23 monitoring wells during every other quarterly event. The specific monitoring wells for biological analyses specified in Section 8.8 will be determined based on results of the hydraulic, geochemical, and COPC monitoring in order to assess the biological composition and function under varying subsurface conditions. The Test 1a/1b and Test 2a/b/c monitoring well networks are shown of Figures 8-2 and 8-3, respectively.

It should be noted that the frequency of groundwater monitoring may be adjusted based on the results of the performance monitoring events. Any material changes to the proposed Phase 2 field test monitoring frequency will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

8.5 Hydraulic Performance

The hydraulic performance parameters and the performance criteria that will be evaluated during the Phase 2 field test are presented in Table 8-1.

Groundwater levels are the primary hydraulic performance parameter. Groundwater levels will be monitored monthly in all monitoring wells located within the Transect 1A Study Area including all Phase 1 pre-design investigation wells, Phase 2 pre-construction wells, and Phase 2 performance monitoring wells. Pressure transducers will be deployed in 10 locations in each of Test 1a and Test 1b, in 7 locations in each of Test 2a and 2c, and 4 locations in Test 2b. The pressure transducers will collect both pressure head and temperature for real-time data acquisition. Based on the results of performance monitoring, the pressure transducers may be moved around to enhance data collection and characterization of hydraulic performance.

Table 8-1: Hydraulic Performance Parameters

Parameter	Performance Criteria	Method (Frequency)
Groundwater levels	Groundwater elevations are a primary indicator of the hydraulic performance of the ZVI reactive zones. Groundwater elevations will be measured in monitoring wells located upgradient, within, and downgradient of ZVI reactive zones to: • Estimate horizontal and vertical hydraulic gradients in the vicinity of the ZVI reactive zones to determine groundwater flow direction. • Assess groundwater mounding upgradient of ZVI reactive zone, which is an indicator of insufficient groundwater flow through the ZVI reactive zones. • Assess hydraulic effects of seasonal precipitation events and potential infiltration of surface water into ZVI reactive zones. • Assess potential non-uniform flow (as determined by an analysis of continuity of hydraulic gradients combined with analysis of geochemical parameters).	Field meter (Baseline and Monthly) Pressure transducers for real-time data acquisition (15-minute intervals)
Groundwater Temperature	Groundwater temperatures can be used as an indicator of infiltration of surface water or deionized water introduced during multi-well dilution testing. Groundwater temperatures will be measured in monitoring wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess potential for infiltration of surface water into ZVI reactive zones.	Temperature sensors integrated with pressure transducers for real-time data acquisition (15-minute intervals)
Hydraulic Conductivity	Hydraulic conductivity is a measure of porous materials to transmit groundwater and can indicate loss of permeability from accumulation of precipitates and/or biomass. Hydraulic conductivity will be estimated through slug testing of wells located upgradient, within, and downgradient of ZVI reactive zones to: • Evaluate baseline hydraulic conductivities and groundwater velocities (through Darcy's Law calculations). • Assess potential for biomass and/or precipitate accumulation through reductions in estimated hydraulic conductivities from baseline through end of field test.	Slug testing in accordance with American Society for Testing and Materials (ASTM) Standard D4044-96 (Baseline and end of field test)

Parameter	Performance Criteria	Method (Frequency)
Groundwater Velocity	Groundwater velocity is a measure of the rate at which groundwater moves and is used to design the size of ZVI reactive zones and spacing of monitoring wells. Groundwater velocity will be measured at the Test 1 and Test 2 transects during pre-construction activities to: • Confirm the residence times and monitoring well spacing. If measured groundwater velocities differ significantly from the prior estimates, the design of the ZVI reactive zones and monitoring well spacing will be refined using the new velocities.	Borehole dilution testing (Baseline only)

Baseline aquifer testing (consisting of slug tests and borehole dilution tests) will be performed using the same methods described in Section 3.2.5 in newly installed monitoring wells installed in the pre-construction pilot borings described in Section 7.5.1. Slug tests will be performed after developing newly installed monitoring wells installed in each test area to evaluate pre-construction 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 ZVI reactive zones. In order to directly measure effective porosity, the tracer released in the borehole dilution tests will be pumped back into the well it was released into using the approach of Hall et al. (1991). Borehole dilution and slug tests will be performed again at the end of the field testing to examine subsurface hydraulic conductivity and groundwater velocity changes following the field test.

8.6 Geochemical Performance

The geochemical performance parameters and the performance criteria that will be evaluated during the Phase 2 field test are presented in Table 8-2.

Based on Ramboll's experience with ZVI-enhanced bioremediation and other in-situ ZVI approaches, groundwater flowing through ZVI will undergo a predictable cascade of geochemical changes. These changes will, in turn, cause changes to the biology, and ultimately, removal of contaminants. The geochemical changes caused by ZVI will attenuate in groundwater as it flows downgradient. Ideally, at some distance downgradient, the geochemical shift caused by ZVI will return to the ambient conditions with the only change in groundwater being removal of contaminants. The geochemical parameters and performance criteria described in Table 8-2, as assessed through data collected from the performance monitoring network (described in Section 8.4), are designed to evaluate these shifts in geochemistry.

As described in Section 2.1, biological perchlorate reduction is a process comprised of a series of redox reactions mediated by bacteria, and ZVI can create the appropriate reduced redox state for it to occur. Moreover, the redox conditions of groundwater strongly affect the mobility and persistence of many constituents and dictate biogeochemical processes. Inferences to geochemistry and chemical speciation can be made from the redox conditions. Therefore, the redox state (as measured by ORP and DO) is an important geochemical performance parameter for ZVI-enhanced bioremediation. ORP and DO measured in a flow-through cell during low-flow groundwater sampling will be used to inform the overall understanding of redox conditions.

Another geochemical parameter important for evaluating the performance of ZVI-enhanced bioremediation is dissolved hydrogen. As discussed in Section 2, dissolved hydrogen, generated by corrosion of ZVI in groundwater, is the electron donor used by perchlorate-reducing bacteria. It is expected that a hydrogen-enriched zone will be generated in a zone up to 10 to 20 feet downgradient of the ZVI reactive zone. This "bio-active" zone is where the bulk of biological perchlorate reduction will occur; therefore, the measured distribution of dissolved hydrogen, along with other geochemical parameters, will be used to target biological monitoring locations as discussed in Section 8.8.

Table 8-2: Geochemical Performance Parameters

Parameter	Performance Criteria	Method (Frequency)
Oxidation Reduction Potential (ORP)	ORP is an indicator of the geochemical performance of ZVI. Once emplaced, ZVI will begin creating reducing conditions in the saturated zone, which can be estimated through measurement of ORP. ORP will be measured in a flow-through cell during quarterly groundwater monitoring events in wells located upgradient, within, and downgradient of ZVI reactive zones to: • Demonstrate the ability of ZVI to influence redox conditions. • Assess the horizontal distributions of ORP to evaluate potential for non-uniform flow through the ZVI reactive zones.	Field meter (Baseline plus month 1 and then Quarterly)
Dissolved Oxygen (DO)	DO is an indicator of the geochemical performance of ZVI. Once emplaced, ZVI will begin reducing DO levels. DO will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Determine whether aerobic or anaerobic conditions predominate. DO values <0.5 mg/L generally indicate anaerobic conditions are predominant.	Field meter (Baseline plus month 1 and then Quarterly)

Parameter	Performance Criteria	Method (Frequency)
Dissolved Hydrogen	Dissolved hydrogen, generated as part of the natural corrosion process of ZVI, is the electron donor used by perchlorate-reducing bacteria to reduce perchlorate to chloride. Dissolved hydrogen will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess the distribution of hydrogen to identify the extent of the bio-active zone where perchlorate reduction is expected to occur.	AM20GAX Bubble Strip Method (Baseline plus month 1 and then Quarterly)
pH	Perchlorate-reducing bacteria are sensitive to pH changes and pH is a fundamental geochemical parameter. ZVI reacts predictably with groundwater to raise pH within the ZVI reactive zone. Depending on the buffering capacity of native soils and groundwater, these conditions can persist some distance downgradient. pH will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Confirm the results from the bench-scale testing indicating strong buffering capacity within site groundwater and soils. • Assess the distribution of pH changes and the potential effects on biological perchlorate-reducing bacteria.	Field meter (Baseline plus month 1 and then Quarterly)
Nitrate	Nitrate is a competing electron acceptor that must be removed before perchlorate reduction will occur. Nitrate is expected to be removed within the ZVI reactive zone (and/or in close proximity downgradient) prior to the onset of perchlorate reduction. Concentrations of nitrate in groundwater collected from monitoring wells upgradient and downgradient of ZVI reactive zones will be used to: • Evaluate the performance of ZVI to reduce concentrations of nitrate as measured in downgradient wells compared to concentrations measured in corresponding upgradient wells.	EPA Method 300.0 for Nitrate-N (Baseline plus month 1 and then Quarterly)

Parameter	Performance Criteria	Method (Frequency)
Organic Carbon	Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC) are primary indicators of organic carbon available for heterotrophic cell growth. TOC/DOC can also act as electron donor for reductive biological processes such as perchlorate reduction. TOC and DOC will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess available organic carbon for biological cell growth. • Evaluate changes in TOC/DOC along with COPC data to assess predominant biological process. o Declining TOC/DOC concentrations in conjunction with declining perchlorate concentrations may indicate heterotrophic perchlorate reduction is occurring. o Alternatively, stable TOC/DOC concentrations in conjunction with declining perchlorate concentrations may indicate autotrophic perchlorate reduction is occurring.	EPA Method SM5310B (Baseline plus month 1 and then Quarterly)
Inorganic Carbon	Total inorganic carbon (TIC) includes aqueous carbon dioxide, carbonic acid, and total carbonate alkalinity. Along with TOC, TIC is a measure of total carbon available in groundwater. TIC will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess available inorganic carbon for biological cell growth.	Shimadzu TIC analyzer (Baseline plus month 1 and then Quarterly)
Sulfate and Sulfide	Sulfate is a competing electron acceptor and sulfide is the reduced form of sulfate. Sulfide reacts spontaneously with divalent metals, such as ferrous iron, and precipitates. Excessive sulfate reduction consumes electron donor and can cause loss of permeability. Concentrations of sulfate and sulfide in groundwater collected from monitoring wells upgradient and downgradient of ZVI reactive zones will be used to: • Evaluate the competition for electron donor from sulfate reduction compared with perchlorate, chlorate, and nitrate reduction. • Assess the generation of sulfide, which is an indicator of excess sulfate reduction.	EPA Method 300.0 for sulfate HACH Method 8131 for sulfide (Baseline plus month 1 and then Quarterly)

Parameter	Performance Criteria	Method (Frequency)
Dissolved Metals (full suite)	Metals behave differently to changes in redox conditions. For example, groundwater concentrations of manganese can increase in response to onset of reduced redox conditions stimulated by ZVI (and other ISB electron donors). However, dissolved metals concentrations typically return to ambient conditions a short distance downgradient of the reactive zones. Dissolved metals will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess secondary effects of remediation including potential for mobilization of metals in the field.	EPA Method 6010B/6020 (Baseline plus month 1 and then Quarterly)
Total Nitrogen	Bacteria require nitrogen for cell growth and can use nitrogen from a number of sources including endogenous decay of bacterial cells. Total nitrogen will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess total nitrogen concentrations to identify potential nutrient-limiting conditions.	EPA Method E351.2/E300.0 (Baseline plus month 1 and then Quarterly)
Total Phosphorus	Bacteria require phosphorous for cell growth and can use phosphorous from a number of sources including endogenous decay of bacterial cells. Total phosphorous will be measured in groundwater wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess total phosphorous concentrations to identify potential nutrient-limiting conditions.	EPA Method E365.3 (Baseline plus month 1 and then Quarterly)
Total Anions and Cations	Total anions and cations are necessary to inform the geochemical model and assess general geochemistry for assessing potential mineralization reactions. There are no specific performance criteria for total anions and cations.	Various EPA Methods (Baseline plus month 1 and then Quarterly)
Total Dissolved Solids (TDS)	Assess any impact of salts. There are no specific performance criteria for TDS.	EPA Method SM2540C (Baseline plus month 1 and then Quarterly)
Alkalinity	Assess geochemical conditions. There are no specific performance criteria for alkalinity.	EPA Method SM2320B (Baseline plus month 1 and then Quarterly)

Parameter	Performance Criteria	Method (Frequency)
Other General Water Quality	Electrical conductivity, temperature, and turbidity will be used to assess general water quality and determine stabilization during low-flow purging and sampling of groundwater wells. There are no specific performance criteria for these parameters.	Field meter (Baseline plus month 1 and then Quarterly)

8.7 COPC Performance

The COPC performance parameters and the performance criteria that will be evaluated during the Phase 2 field test are presented in Table 8-3. The COPCs for the Phase 2 field test are perchlorate and chlorate.

The proposed Phase 2 field test is not intended to achieve final water quality objectives with respect to COPCs as may be defined in the final remedy, but rather to provide data to allow evaluation of ZVI-enhanced bioremediation under field conditions and provide key design and performance criteria to inform the FS and future remedial design. Therefore, COPC performance criteria are defined based on the technical design requirements, and not solely on water quality criteria consistent with potential clean up goals for target constituents.

The performance criteria listed in Table 8-3 involve comparing contemporaneous concentrations of individual parameters measured in monitoring wells upgradient, within, and downgradient of ZVI reactive zones. Therefore, the performance criteria are designed to be relative measures of performance rather than establishing target concentrations. However, knowing what the remedial goals may ultimately be for the final remedy are important in designing a field test. The applicable or relevant and appropriate requirement (ARAR)/to be considered (TBC) criteria for perchlorate is currently the federal preliminary remedial goal (PRG) of 0.015 mg/L. The ARAR/TBC criteria for chlorate is currently the Residential Water Basic Comparison Level (BCL) of 1.0 mg/L (ENVIRON 2014b). However, the field test is not intended to achieve final water quality objectives as may be defined in the final remedy, but rather to provide data to allow evaluation of ZVI-enhanced bioremediation under field conditions and provide key design and performance criteria to inform the FS and future remedial design. Therefore, performance objectives are defined based on the technical design requirements, and not solely on water quality criteria consistent with potential clean up goals for target constituents.

Table 8-3: COPC Performance Parameters

Parameter	Performance Criteria	Method (Frequency)
Chlorate	Chlorate is a COPC and competing electron acceptor that must be removed before perchlorate reduction will occur. Chlorate is expected to be removed within the ZVI reactive zone (and/or in close proximity downgradient) prior to the onset of perchlorate reduction. Concentrations of chlorate in groundwater collected from monitoring wells upgradient and downgradient of ZVI reactive zones will be used to: • Evaluate the performance of ZVI to reduce concentrations of chlorate as measured in downgradient wells compared to concentrations measured in corresponding upgradient wells.	EPA Method 300.1 for Chlorate (Baseline plus month 1 and then Quarterly)
Perchlorate	Perchlorate is the primary COPC and acts as an electron acceptor that consumes electron donor when biological perchlorate reduction is occurring. Perchlorate reduction is expected to occur after chlorate and nitrate have been removed and after the development of a robust perchlorate-reducing microbial community. Concentrations of perchlorate in groundwater collected from monitoring wells upgradient and downgradient of ZVI reactive zones will be used to: • Evaluate the performance of ZVI to stimulate biological perchlorate reduction and reduce concentrations of perchlorate as measured in downgradient wells compared to concentrations measured in corresponding upgradient wells.	EPA Method 314.0 (Baseline plus month 1 and then Quarterly)

8.8 Biological Performance

The biological performance parameters and the performance criteria that will be evaluated during the Phase 2 field test are presented in Table 8-4.

While chlorate and nitrate degrade rapidly in the presence of ZVI, perchlorate degradation requires development of a perchlorate-reducing bacterial population. To achieve this in the field, an inoculum will be added as described in Section 7.6.3 to augment the initial population of perchlorate-reducing bacteria. Assessing the composition and functionality of the perchlorate-reducing bacterial community throughout the field test implementation is critical to understanding the performance of ZVI-enhanced bioremediation.

Bacteria require carbon, nutrients, energy, and reducing power (the ability to transfer electrons) in order to grow. The geochemical and COPC parameters described in Sections 8.6 and 8.7, respectively, are intended in part to assess these bacterial growth factors. The biological performance parameters described in Table 8-4 are intended to assess the actual composition and function of the biological community during the field test.

The biological parameters will be analyzed on a subset of 23 monitoring wells during every other quarterly event. The specific monitoring wells for biological analyses during each monitoring event will be determined based on prior results of hydraulic, geochemical, and COPC monitoring. The intent of this adaptive approach to biological monitoring is to assess the biological composition and function under varying subsurface conditions.

Table 8-4: Biological Performance Parameters

Parameter	Performance Criteria	Method (Frequency)
Viable Biomass and Community Structure	All bacterial cells have membranes which consist mainly of phospholipid fatty acids (PLFA). PLFA biomarkers break down quickly; therefore, their presence is a measure of living (viable) organisms and is expressed as cells per unit of sample. Moreover, chemical composition of the PLFA biomarkers differ depending on the type of bacteria and therefore can be used to generate a "fingerprint" of the microbial community composition. The change in microbial community composition will also help assess the shift in the redox state of groundwater. PLFA will be performed on samples from monitoring wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess the total viable biomass and how it changes in response to the field test implementation. • Evaluate changes in the microbial community composition over time and in response to field test implementation.	Lipid extraction followed by lipid separation; analysis by gas chromatography with flame ionization detection (GC-FID) (Baseline and then every other Quarterly event)

Parameter	Performance Criteria	Method (Frequency)
Microbial Community Composition	The inter-relationships between subsurface microbial ecology and engineering factors associated with ZVI reactive zones must be determined during the field test implementation. The use of high-throughput DNA sequencing to assign microbial taxonomy and community composition is a well-established, widely-available molecular technique that can provide critical insights regarding microbial community structure, diversity, stability, and resiliency. Microbial community composition analyses will be performed on samples from monitoring wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess the total microbial composition at the onset of the field test implementation. • Monitor overall changes in the microbial community structure over time and in response to field test implementation.	16S rRNA gene sequencing (Baseline and then every other Quarterly event)
Perchlorate-Reducing Bacteria	Perchlorate reducing bacteria harbor genes in their DNA that encode enzymes to convert perchlorate to innocuous chloride. The enzyme involved in reducing perchlorate to chlorate and subsequently chlorite is perchlorate reductase (encoded by the *pcrABCD* genes), while chlorite is further reduced to chloride by chlorite dismutase (encoded by the *cld* gene). Quantifying the abundance of these genes with respect to total bacteria present via quantitative polymerase chain reaction (qPCR) can provide insights into the overall number of perchlorate-reducing bacteria present at any given stage of ZVI reactive zone operation. qPCR will be performed on samples from monitoring wells located upgradient, within, and downgradient of ZVI reactive zones to: • Assess the relative abundance of perchlorate-reducing bacteria in response the field test implementation. • Monitor overall changes in the relative abundance of perchlorate-reducing bacteria over time in response to field test implementation.	qPCR targeting the *pcrA* and *cld* genes (Baseline and then every other Quarterly event)

9. PHASE 2 ACCESS AND PERMITTING

An access agreement and multiple permits will be required prior to performing the Phase 2 field test presented in Section 7 of this Work Plan Addendum. This section presents a summary of the access and permit requirements that are anticipated to be required.

9.1 Access Negotiations

Field work described in this Work Plan Addendum will be performed under an access agreement that is currently being discussed and negotiated between the Trust and the COH for the Transect 1A Study Area parcel (APN:160-31-501-005). This dialogue between the Trust and the COH has been happening in parallel with the development of this Work Plan Addendum to expedite implementation of the Phase 2 field test presented herein. Any material changes to the proposed Phase 2 field test which result from the finalization of the access agreement with the COH will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

9.2 Permitting

A series of permits will be required for the various activities that are being proposed as part of the treatability study, as discussed below.

9.2.1 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 field test indicates that the soil disturbance will be greater than 0.25 acres during construction activities. As a result, Ramboll, 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 equipment needed for their construction and operation that would trigger minor source permitting. Following completion of construction activities, the dust control permit will be closed as monitoring activities do not constitute construction disturbance.

9.2.2 Nevada Construction Stormwater General Permit

A Construction Stormwater General Permit is anticipated because cumulative disturbances associated with construction are expected to exceed 1 acre. As 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.

9.2.3 Well Installation Permitting

Field treatability study activities will require a NAC 534.441 Monitor Well Drilling Waiver and a NAC 534.320 Notice of Intent Card prior to installation of each groundwater well. The Monitoring Well Drilling Waiver also requires a completed, signed, and notarized Affidavit of Intent to Abandon a Well as an attachment for each well. 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 treatability study are to be abandoned[19], they would be done so 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.

9.2.4 NDEP – Underground Injection Control Program

The treatability study will require several permits administered by the UIC program at NDEP, as described in the following sections.

9.2.4.1 UIC Permitting for Emplacement of ZVI

Prior to emplacing ZVI in the subsurface at the Transect 1A Study Area, UIC permit authorization will be obtained from NDEP. It is anticipated that separate permits will be required for each of the ZVI emplacement methods described in Sections 7.6.1 and 7.6.2 (including the recirculation of groundwater) as well as for the injection of biological inoculum and nutrients discussed in Section 7.6.3.

9.2.4.2 UIC Permitting for Borehole Dilution Tests

As with the borehole dilution tests performed during the Phase 1 pre-design investigations discussed in Sections 3 and 4, NDEP U240 Chemical Use Request Forms will be completed and submitted as needed prior to performing the additional borehole dilution tests specified for the Phase 2 field test.

9.2.5 Water Appropriations 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 (a) the temporary large diameter well casing as part of the ZVI emplacement method described in Section 7.6.1 and (b) select monitoring wells for use as chase water during the injection operations described in Appendix I. The Water Appropriation Permit will require an extraction report to be submitted to present total water extracted for that calendar year.

[19] The proposed well abandonment will be subject to the access agreement discussions between the Trust and the City of Henderson which will be finalized upon NDEP approval of this Work Plan Addendum.

10. PHASE 2 REPORTING

Monthly treatability study progress reports will be prepared summarizing the progress of the Phase 2 field test implementation. In addition, this monthly reporting will include analytical results and preliminary analysis of select data to evaluate performance with respect to the hydraulic, geochemical, COPC, and biological monitoring criteria. If changes in monitoring or operation are deemed necessary based on the performance evaluations, these would also be communicated through the monthly progress reports.

Following completion of the Phase 2 field test, a final report summarizing the field test activities and results will be prepared for submittal to NDEP. This report will include the following:

- Field test implementation details based on the design presented herein and as modified following pre-construction activities, including presentation of the final test as-builts, configuration and monitoring well layouts, targeted depths and intervals, and a summary of monitoring activities within each test.
- Summary of the hydraulic, geochemical, chemical, and biological data collected as part of the performance monitoring program.
- Presentation and discussion of hydraulic and geochemical model refinements.
- Evaluation of the comparative performance of the discretely-monitored tests with respect to the performance criteria.
- Discussion of the technology’s effectiveness, implementability, applicability to other areas/conditions, estimated longevity, and a potential range of costs for full-scale scenarios and other relevant components required for proper evaluation in the FS.

11. PHASE 2 SCHEDULE

The schedule is contingent upon Trust, NDEP, and USEPA approval of this Work Plan Addendum, Trust budgetary approval and notice to proceed, completion of access agreements, and obtaining all necessary permits. The following figure presents a conceptual schedule once approvals and access are in place. It should be noted that while it is currently estimated that operation and monitoring will require 16 months, actual duration is dependent upon field conditions and results of the performance monitoring program. Any material changes to the proposed Phase 2 field test duration will be presented in a Treatability Study Modification which will be submitted to NDEP for approval.

Figure 11-1: Phase 2 Implementation Schedule

Months	1-4				5-8				9-12				13-16				17-20				21-24			
Pre-Construction	■	B																						
Procurement & Mobilization			■	■																				
Construction					■	■	■																	
Performance Monitoring								1	■	■	Q	■	■	Q	■	■	Q	■	■	Q	■	■	Q	

B = Baseline Sampling Event
1 = Month 1 Monitoring Event
Q = Quarterly Monitoring Event

The Trust has advised Ramboll that it is currently contemplated that the ZVI material will remain in the subsurface after the completion of the planned field test. The ZVI will continue to treat groundwater beyond the end of the study regardless of whether this technology is selected as a component of final remedy. Accordingly, the removal of the ZVI material has not been included in the scope of work for this Phase 2 field test. Unless the Trust advises to the contrary based upon its ongoing dialogue with NDEP and the COH, it is contemplated that performance monitoring would be streamlined and integrated with NERT's broader groundwater monitoring program through a future modification to the Sampling and Analysis Plan (SAP) for the NERT RI Study Area (Ramboll 2020).

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TABLES

TABLE 3-3: TRANSECT 1A MONITORING WELL CONSTRUCTION DETAILS
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Owner	Easting	Northing	Top of Casing Elevation (ft amsl)	Ground Surface Elevation (ft amsl)	Well Depth (ft bgs)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Casing Diameter (in)	Casing Material	Lithology
LVWPS-MW101A	NERT	832678.44	26732789.49	1549.34	1549.80	34	23	33	2	Sch. 40 PVC	Qal
LVWPS-MW101B	NERT	832686.18	26732788.37	1549.13	1549.57	65	45	65	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW102A	NERT	832965.93	26732606.35	1546.82	1547.23	67	47	67	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW102B	NERT	832973.68	26732605.06	1546.78	1547.14	97	77	97	2	Sch. 40 PVC	UMCf (saline lake sediments)
LVWPS-MW103A	NERT	833455.96	26732371.53	1548.39	1548.77	40	30	40	2	Sch. 40 PVC	UMCf (mudflat)
LVWPS-MW103B	NERT	833461.76	26732368.31	1548.68	1548.93	97	77	97	2	Sch. 40 PVC	UMCf (saline lake sediments)
LVWPS-MW104	NERT	832609.25	26732930.15	1547.69	1548.05	34	24	34	2	Sch. 40 PVC	Qal
LVWPS-MW105	NERT	833300.91	26732570.24	1547.32	1547.66	27	17	26	2	Sch. 40 PVC	Qal
LVWPS-MW106	NERT	833734.57	26732357.82	1548.62	1549.01	51	30	50	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW107A	NERT	833144.18	26732823.90	1547.58	1548.14	35	25	35	4	Sch. 40 PVC	Qal
LVWPS-MW107B	NERT	833144.44	26732816.68	1547.82	1548.20	66	46	66	4	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW107C	NERT	833138.10	26732819.93	1547.93	1548.33	121	100	120	2	Sch. 40 PVC	UMCf (saline lake sediments)
LVWPS-MW108A	NERT	832645.51	26733238.09	1543.56	1543.91	41	21	41	2	Sch. 40 PVC	Qal
LVWPS-MW108B	NERT	832652.04	26733242.52	1543.33	1543.85	67	46	66	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW108C	NERT	832645.33	26733245.54	1543.62	1544.05	120	100	119	2	Sch. 40 PVC	UMCf (saline lake sediments)
LVWPS-MW109	NERT	833034.22	26733119.00	1544.63	1544.91	52	37	52	2	Sch. 40 PVC	Qal
LVWPS-MW110	NERT	833593.18	26732788.02	1545.68	1545.95	68	48	68	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW111A	NERT	833424.95	26733253.38	1540.64	1541.06	41	21	41	2	Sch. 40 PVC	Qal
LVWPS-MW111B	NERT	833432.86	26733253.32	1540.22	1540.72	78	58	78	2	Sch. 40 PVC	UMCf (mudflat sediments)
LVWPS-MW112A	NERT	833795.12	26733137.42	1537.99	1538.61	49	29	48	2	Sch. 40 PVC	Qal
LVWPS-MW112B	NERT	833803.81	26733134.16	1538.24	1538.84	75	54	74	2	Sch. 40 PVC	UMCf (mudflat sediments)
ZTS-MW113	NERT	833008.97	26732606.59	1548.19	1548.26	30	20	30	4	Sch 40 PVC	Qal
ZTS-MW114	NERT	832602.28	26732910.14	1548.68	1548.69	70	50	70	4	Sch 40 PVC	UMCf (mudflat sediments)
ZTS-MW115	NERT	833595.72	26732796.12	1545.92	1546.03	30	20	30	4	Sch 40 PVC	Qal

Notes:
ft amsl = feet above mean sea level
ft bgs = feet below ground surface
in = inches
Qal = Alluvium
UMCf = Upper Muddy Creek formation
The UMCf mudflat sediments consist predominantly of silt, sandy silt, and silt with sand.
The UMCf saline lake sediments consist predominantly of silt and clayey silt with gypsum crystals.

TABLE 4-1: TRANSECT 1A GROUNDWATER ELEVATIONS
Nevada Environmental Response Trust Site
Henderson, Nevada

Well ID	Measurement Date	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Screened Lithology	Depth to Water (ft bgs)	Groundwater Elevation (ft amsl)
LVWPS-MW101A	12/6/2019	23	33	Qal	18.75	1531.05
LVWPS-MW101B	12/6/2019	45	65	UMCf (mudflat sediments)	9.34	1540.23
LVWPS-MW102A	12/3/2019	47	67	UMCf (mudflat sediments)	10.33	1536.90
LVWPS-MW102B	12/3/2019	77	97	UMCf (saline lake sediments)	5.39	1541.75
LVWPS-MW103A	12/3/2019	30	40	UMCf (mudflat sediments)	19.77	1529.00
LVWPS-MW103B	12/3/2019	77	97	UMCf (saline lake sediments)	12.08	1536.85
LVWPS-MW104	12/6/2019	24	34	Qal	17.17	1530.88
LVWPS-MW105	12/3/2019	17	26	Qal	20.99	1526.67
LVWPS-MW106	12/9/2019	30	50	UMCf (mudflat sediments)	20.83	1528.18
LVWPS-MW107A	12/9/2019	25	35	Qal	21.16	1526.98
LVWPS-MW107B	12/9/2019	46	66	UMCf (mudflat sediments)	17.31	1530.89
LVWPS-MW107C	12/9/2019	100	120	UMCf (saline lake sediments)	6.52	1541.81
LVWPS-MW108A	12/5/2019	21	41	Qal	12.72	1531.19
LVWPS-MW108B	12/5/2019	46	66	UMCf (mudflat sediments)	5.56	1538.29
LVWPS-MW108C	12/5/2019	100	119	UMCf (saline lake sediments)	6.35	1537.70
LVWPS-MW109	12/9/2019	37	52	Qal	17.04	1527.87
LVWPS-MW110	12/6/2019	48	68	UMCf (mudflat sediments)	19.02	1526.93
LVWPS-MW111A	12/5/2019	21	41	Qal	15.77	1525.29
LVWPS-MW111B	12/5/2019	58	78	UMCf (mudflat sediments)	12.02	1528.70
LVWPS-MW112A	12/5/2019	29	48	Qal	15.66	1522.95
LVWPS-MW112B	12/5/2019	54	74	UMCf (mudflat sediments)	16.31	1522.53
ZTS-MW113	12/3/2019	20	30	Qal	19.58	1528.68
ZTS-MW114	12/6/2019	50	70	UMCf (mudflat sediments)	8.63	1540.06
ZTS-MW115	12/6/2019	20	30	Qal	21.70	1524.33

Notes:

ft amsl = feet above mean sea level

ft bgs = feet below ground surface

Qal = Alluvium

UMCf = Upper Muddy Creek formation

The UMCf mudflat sediments consist predominantly of silt, sandy silt, and silt with sand.

The UMCf saline lake sediments consist predominantly of silt and clayey silt with gypsum crystals.

TABLE 4-3: TRANSECT 1A SOIL ANALYTICAL RESULTS

Nevada Environmental Response Trust Site

Henderson, Nevada

Location Name	Lithology	Sample Date	Start Depth (ft bgs)	End Depth (ft bgs)	Chlorate (mg/kg)	Chromium (total) (mg/kg)	Nitrate as NO3 (mg/kg)	Perchlorate (mg/kg)	Total Organic Carbon (mg/kg)	Moisture (%)
ZTS-MW113	Alluvium	11/22/2019	10.0	10.5	<0.021	15	3.7 UJ	<0.010	1,990	3.9
			15.0	15.5	0.11 J	14	4.2 J-	0.034	766	7.4
		11/23/2019	20.0	20.5	13	24	16 J-	1.2	1,730	21.8
			20.0 (FD)	20.5 (FD)	12	20	19 J-	2.0	2,450	21.6
			25.0	25.5	18	23	28 J-	2.7	3,120	31.3
ZTS-MW114	UMCf (mudflat sediments)	11/20/2019	45.0	45.5	<0.032	15	5.6 UJ	<0.015	36,500	35.0
ZTS-MW115	Alluvium	11/22/2019	35.0	35.5	1.4	51	10 J-	0.65	604 J	50.5
			40.0	40.5	2.8	30	18 J-	1.7	416 J	45.4

Notes:

FD = field duplicate

ft bgs = feet below ground surface

J = Concentration is estimated

J- = Estimated concentration, potential negative bias

J+ = Estimated concentration, potential positive bias

UJ = Concentration is less than estimated laboratory method reporting limit

< = Concentration is less than indicated laboratory method reporting limit

mg/kg = milligrams per kilogram

UMCf = Upper Muddy Creek Formation

TABLE 4-6: TRANSECT 1A GROUNDWATER ANALYTICAL RESULTS
Nevada Environmental Response Trust Site
Henderson, Nevada

Location Name	Lithology	Sample Date	Bicarbonate as HCO3 (mg/L)	Calcium (mg/L)	Carbon, Dissolved Organic (mg/L)	Carbon, Total Organic (mg/L)	Carbonate as CO3 (mg/L)	Chlorate (mg/L)	Chloride (mg/L)	Chromium (total) (mg/L)	Dissolved Hydrogen (nM)	Dissolved Solids (total) (mg/L)	Hydroxide (mg/L)	Iron (mg/L)	Iron, Ferric (mg/L)	Iron, Ferrous (mg/L)	Magnesium (mg/L)
LVWPS-MW101A	Qal	12/06/2019	130	540	1.3	0.94 J	<2.4	25	700	0.043	NA	4,900	<1.4	8.1	8.1 J-	0.10 UJ	220
LVWPS-MW101B	UMCf (mudflat sediments)	12/06/2019	110	530	<0.65	<0.65	<2.4	19	1,300	0.17	3.3	7,000	<1.4	4.4	4.4 J-	0.10 UJ	420
LVWPS-MW102A	UMCf (mudflat sediments)	12/03/2019	110	720	0.78 J	1.2	<2.4	8.6	2,000	0.37	NA	NA	<1.4	34	34 J-	0.10 UJ	1,100
LVWPS-MW102B	UMCf (saline lake sediments)	12/03/2019	130	140	3.8	3.4	<2.4	<0.10	11,000	<0.050	NA	NA	<1.4	14	14 J-	0.10 UJ	6,000
LVWPS-MW103A	UMCf (mudflat sediments)	12/03/2019	97	490	0.77 J	0.82 J	<2.4	<0.20	810	0.055	NA	NA	<1.4	0.064 J	0.064 J	0.10 UJ	320
		12/06/2019	NA	NA	NA	NA	NA	NA	NA	NA	2.6	NA	NA	NA	NA	NA	NA
LVWPS-MW103B	UMCf (saline lake sediments)	12/03/2019	200	590	6.8	7.0	<2.4	18	16,000	<0.25	NA	NA	<1.4	<5.0	0.10 UJ	0.10 UJ	14,000
LVWPS-MW104	Qal	12/06/2019	230	530	1.3	1.2	<2.4	11	860	0.025	NA	5,400	<1.4	3.7	3.7 J-	0.10 UJ	210
LVWPS-MW105	Qal	12/03/2019	100	640	1.2	1.2	<2.4	41	990	0.039	NA	NA	<1.4	0.29	0.29 J-	0.10 UJ	280
LVWPS-MW106	UMCf (mudflat sediments)	12/09/2019	120	660	1.5	1.4	<2.4	97	1,100	0.070	3.2	6,500	<1.4	0.24	0.24 J-	0.10 UJ	310
LVWPS-MW107A	Qal	12/09/2019	150	590	1.1	0.98 J	<2.4	13	790	0.026	4.9	5,800	<1.4	0.18	0.18 J-	0.10 UJ	280
LVWPS-MW107B	UMCf (mudflat sediments)	12/09/2019	110	240	<0.65	<0.65	<2.4	<0.010	1,000	<0.0025	NA	6,200	<1.4	0.23	0.23 J-	0.10 UJ	370
LVWPS-MW107C	UMCf (saline lake sediments)	12/09/2019	120	250	4.5	4.1	<2.4	<0.10	13,000	<0.025	NA	71,000	<1.4	1.1	1.1 J-	0.10 UJ	7,500
LVWPS-MW108A	Qal	12/05/2019	330	260	1.5	1.5	<2.4	11	860	0.0051	1.6	4,000	<1.4	0.11	0.11 J-	0.10 UJ	140
LVWPS-MW108B	UMCf (mudflat sediments)	12/05/2019	110	660	0.75 J	0.81 J	<2.4	34	1,400	0.11	1.7	7,800	<1.4	4.7	4.7 J-	0.10 UJ	510
		(FD)	NA	NA	NA	NA	NA	NA	NA	NA	2.0	NA	NA	NA	NA	NA	NA
LVWPS-MW108C	UMCf (saline lake sediments)	12/05/2019	130	350 J	4.9	5.1	<2.4	<0.10	11,000	<0.13	NA	61,000	<1.4	<2.5	0.10 UJ	0.10 UJ	5,400
		(FD)	130	250 J	4.9	5.1	<2.4	<0.10	11,000	<0.25	NA	60,000	<1.4	<5.0	0.10 UJ	0.10 UJ	6,000
LVWPS-MW109	Qal	12/09/2019	270	620	1.4	1.6	<2.4	12	830	0.099	3.3	4,500	<1.4	21	21 J-	0.10 UJ	220
LVWPS-MW110	UMCf (mudflat sediments)	12/06/2019	120	600	0.86 J	0.71 J	<2.4	<0.010	1,200	<0.0025	NA	7,200	<1.4	1.8	1.8 J-	0.10 UJ	410
LVWPS-MW111A	Qal	12/05/2019	240	630	1.7	2.2	<2.4	21	1,000	0.053 J	NA	5,000	<1.4	22 J	22 J	0.10 UJ	220
		(FD)	230	600	1.7	2.4	<2.4	21	980	0.082 J	NA	5,000	<1.4	41 J	41 J	0.10 UJ	230
LVWPS-MW111B	UMCf (mudflat sediments)	12/05/2019	110	500	<0.65	0.80 J	<2.4	6.8	1,300	0.067	NA	7,200	<1.4	2.8	2.8 J-	0.10 UJ	480
LVWPS-MW112A	Qal	12/05/2019	190	500	1.3	1.3	<2.4	19	790	0.022	NA	4,800	<1.4	0.98	0.98 J-	0.10 UJ	200
LVWPS-MW112B	UMCf (mudflat sediments)	12/05/2019	200	310	4.5	4.8	<2.4	<0.10	2,900	<0.13	NA	46,000	<1.4	5.1	4.5 J-	0.60 J-	5,900
ZTS-MW113	Qal	12/03/2019	130	670	1.2	1.3	<2.4	54	1,000	0.058	NA	NA	<1.4	<0.050	0.10 UJ	0.10 UJ	270
		12/06/2019	NA	NA	NA	NA	NA	NA	NA	NA	3.0	NA	NA	NA	NA	NA	NA
ZTS-MW114	UMCf (mudflat sediments)	12/06/2019	120	570	0.69 J	<0.65	<2.4	32	1,400	0.021	4.2	7,600	<1.4	0.33	0.33 J-	0.10 UJ	430
ZTS-MW115	Qal	12/06/2019	120	650	1.2	1.1	<2.4	20	1,000	0.0091	2.6	6,200	<1.4	1.1	1.1 J-	0.10 UJ	270

Notes:
[1] Where ferric iron was not calculated by the laboratory and provided in laboratory reports, ferric iron was calculated using the same calculation method used by the laboratory.
[2] Where nitrate as N was not calculated by the laboratory and provided in laboratory reports, nitrate as N was calculated using the same calculation method used by the laboratory.

FD = field duplicate
J = Concentration is estimated
J- = Estimated concentration, potential negative bias
J+ = Estimated concentration, potential positive bias
UJ = Concentration is less than estimated laboratory method reporting limit
< = Concentration is less than indicated laboratory method reporting limit
mg/L = milligrams per Liter
NA = Not Available
Qal = Alluvium
UMCf = Upper Muddy Creek Formation

TABLE 4-6: TRANSECT 1A GROUNDWATER ANALYTICAL RESULTS
Nevada Environmental Response Trust Site
Henderson, Nevada

Location Name	Lithology	Sample Date	Nitrate as N (mg/L)	Nitrate as NO3 (mg/L)	Perchlorate (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Total Alkalinity as CaCO3 (mg/L)
LVWPS-MW101A	Qal	12/06/2019	14	64	3.4	72	590	2,100	110
LVWPS-MW101B	UMCf (mudflat sediments)	12/06/2019	7	32	5.6	130	830	2,700	87
LVWPS-MW102A	UMCf (mudflat sediments)	12/03/2019	2.9 J	13 J	3.2	550	1,400	5,100	91
LVWPS-MW102B	UMCf (saline lake sediments)	12/03/2019	<5.5	<25	<0.095	4,800	7,400	31,000	100
LVWPS-MW103A	UMCf (mudflat sediments)	12/03/2019	11	49	6.7	540	790	3,300	80
		12/06/2019	NA	NA	NA	NA	NA	NA	NA
LVWPS-MW103B	UMCf (saline lake sediments)	12/03/2019	<5.5	<25	<0.095	11,000	14,000	88,000	160
LVWPS-MW104	Qal	12/06/2019	10	45	3.3	61	720	2,200	190
LVWPS-MW105	Qal	12/03/2019	12	55	5.9	190	620	2,400	86
LVWPS-MW106	UMCf (mudflat sediments)	12/09/2019	19	84	6.5	170	720	2,800	97
LVWPS-MW107A	Qal	12/09/2019	7.2	32	5.3	99	690	2,700	120
LVWPS-MW107B	UMCf (mudflat sediments)	12/09/2019	<1.1	<5.0	<0.0048	530	780	2,400	93
LVWPS-MW107C	UMCf (saline lake sediments)	12/09/2019	<5.5	<25	<0.019	6,500	9,500	36,000	95
LVWPS-MW108A	Qal	12/05/2019	7.3	32	4.3	41	780	1,300	270
LVWPS-MW108B	UMCf (mudflat sediments)	12/05/2019	11	48	9.4	120	980	2,900	87
		(FD)	NA	NA	NA	NA	NA	NA	NA
LVWPS-MW108C	UMCf (saline lake sediments)	12/05/2019	<5.5	<25	<0.019	2,400	7,600	28,000	110
		(FD)	<5.5	<25	<0.019	2,700	8,400	27,000	110
LVWPS-MW109	Qal	12/09/2019	8.5	38	3.9	55	670	1,700	220
LVWPS-MW110	UMCf (mudflat sediments)	12/06/2019	<1.1	<5.0	<0.0048	470	780	3,100	98
LVWPS-MW111A	Qal	12/05/2019	7.8	35	7.9	54	700	1,600	190
		(FD)	8.0	35	7.4	57	650	1,600	190
LVWPS-MW111B	UMCf (mudflat sediments)	12/05/2019	2.4	11	3.3	240	860	2,700	88
LVWPS-MW112A	Qal	12/05/2019	12	54	3.3	57	650	2,000	160
LVWPS-MW112B	UMCf (mudflat sediments)	12/05/2019	<5.5	<25	<0.019	1,800	3,600	26,000	170
ZTS-MW113	Qal	12/03/2019	13	58	8.7	160	700	2,500	110
		12/06/2019	NA	NA	NA	NA	NA	NA	NA
ZTS-MW114	UMCf (mudflat sediments)	12/06/2019	10	46	8.9	140	940	3,000	96
ZTS-MW115	Qal	12/06/2019	7.2	32	3.4	150	610	2,500	95

Notes:
[1] Where ferric iron was not calculated by the laboratory and provided in laboratory reports, ferric iron was calculated using the same calculation method used by the laboratory.
[2] Where nitrate as N was not calculated by the laboratory and provided in laboratory reports, nitrate as N was calculated using the same calculation method used by the laboratory.

FD = field duplicate
J = Concentration is estimated
J- = Estimated concentration, potential negative bias
J+ = Estimated concentration, potential positive bias
UJ = Concentration is less than estimated laboratory method reporting limit

< = Concentration is less than indicated laboratory method reporting limit
mg/L = milligrams per Liter
NA = Not Available
Qal = Alluvium
UMCf = Upper Muddy Creek Formation

TABLE 4-7: TRANSECT 1A FIELD PARAMETERS
Nevada Environmental Response Trust Site
Henderson, Nevada

Location Name	Lithology	Measurement Date	Purge Start Time	Purge Stop Time	Pump/Sample Depth (ft bRE)	Final Purge Rate (ml/min)	Volume Purged (L)	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	ORP (mV)	Turbidity (NTU)	Color	Odor (Y/N)
LVWPS-MW101A	Qal	12/06/2019	10:40	11:02	28.0	300.0	4.5	24.4	7.63	5730	8.36	158.0	901.0	partly cloudy	No
LVWPS-MW101B	UMCf (mudflat sediments)	12/06/2019	09:50	10:09	55.0	300.0	4.5	23.5	7.75	8060	0.67	60.0	--	mostly clear	No
LVWPS-MW102A	UMCf (mudflat sediments)	12/03/2019	10:35	10:51	57.0	300.0	5.5	21.7	7.78	12700	0.66	19.0	>1000	cloudy	No
LVWPS-MW102B	UMCf (saline lake sediments)	12/03/2019	10:00	10:26	87.0	100.0	5.5	21.6	7.90	56000	0.66	-291.0	>1000	mostly cloudy	No
LVWPS-MW103A	UMCf (mudflat sediments)	12/03/2019	12:00	12:26	35.0	300.0	5.5	22.1	7.72	7850	1.38	-66.0	71.2	mostly clear	No
LVWPS-MW103B	UMCf (saline lake sediments)	12/03/2019	13:10	13:55	87.0	100.0	4.5	19.8	7.90	85100	0.76	-87.0	106.0	mostly clear	No
LVWPS-MW104	Qal	12/06/2019	09:05	09:29	29.0	300.0	4.5	23.2	7.46	6310	2.60	102.0	718.0	mostly clear	No
LVWPS-MW105	Qal	12/03/2019	11:18	11:40	24.0	300.0	5.5	22.5	7.58	6860	0.56	51.0	>1000	cloudy	No
LVWPS-MW106	UMCf (mudflat sediments)	12/09/2019	12:45	13:25	40.0	300.0	10.5	23.2	7.73	7410	5.31	29.0	68.7	clear	No
LVWPS-MW107A	Qal	12/09/2019	08:35	09:09	30.0	500.0	5.5	22.0	7.47	6570	1.93	117.0	193.0	clear	No
LVWPS-MW107B	UMCf (mudflat sediments)	12/09/2019	09:35	10:11	56.0	300.0	5.5	22.3	7.75	7550	0.69	-232.0	90.9	clear	No
LVWPS-MW107C	UMCf (saline lake sediments)	12/09/2019	10:35	11:07	110.0	300.0	7.5	22.5	8.00	62400	0.68	-296.0	519.0	mostly cloudy	No
LVWPS-MW108A	Qal	12/05/2019	09:40	10:57	31.0	300.0	4.5	22.0	7.34	5700	1.31	79.0	184.0	mostly clear	No
LVWPS-MW108B	UMCf (mudflat sediments)	12/05/2019	08:55	09:15	56.0	300.0	4.5	22.8	7.84	8720	1.27	22.0	>1000	mostly clear	No
LVWPS-MW108C	UMCf (saline lake sediments)	12/05/2019	08:10	08:34	109.0	300.0	4.5	21.6	7.82	55400	1.32	-196.0	268.0	mostly clear	No
LVWPS-MW109	Qal	12/09/2019	11:40	12:02	44.0	500.0	5.5	26.7	7.51	5620	0.52	36.0	1000.0	cloudy brown	No
LVWPS-MW110	UMCf (mudflat sediments)	12/06/2019	13:15	13:40	58.0	300.0	4.5	22.3	7.68	8220	0.72	-182.0	679.0	mostly cloudy	No
LVWPS-MW111A	Qal	12/05/2019	11:45	12:02	31.0	300.0	4.5	23.5	7.38	6090	0.84	94.0	>1000	silty	No
LVWPS-MW111B	UMCf (mudflat sediments)	12/05/2019	12:20	12:39	68.0	300.0	4.5	23.5	7.82	8040	0.72	-74.0	--	clear	No
LVWPS-MW112A	Qal	12/05/2019	13:10	13:28	38.0	300.0	4.5	24.2	7.44	5720	1.92	101.0	--	mostly clear	No
LVWPS-MW112B	UMCf (mudflat sediments)	12/05/2019	13:45	14:15	64.0	100.0	4.5	23.6	7.48	33000	0.91	-120.0	420.0	mostly clear	No
ZTS-MW113	Qal	12/03/2019	08:30	08:56	25.0	300.0	6.5	21.6	7.59	7420	2.01	108.0	114.0	mostly clear	No
ZTS-MW114	UMCf (mudflat sediments)	12/06/2019	08:10	08:29	60.0	300.0	4.5	22.3	7.70	8810	0.91	78.0	237.0	clear	No
ZTS-MW115	Qal	12/06/2019	13:50	14:12	25.0	300.0	4.5	22.6	7.82	7050	0.82	-23.0	185.0	mostly clear	No

Notes:

-- = Not available
ft bRE = feet below reference elevation
ml/min = milliliter per minute
L = liter
µS/cm = microSiemens per centimeter
mg/L = milligrams per liter
mV = millivolts
NTU = nephelometric turbidity unit
Qal = Alluvium
UMCf = Upper Muddy Creek Formation

Table 4-8: Transect 1A Hydraulic Testing Results

Nevada Environmental Response Trust Site

Henderson, Nevada

Well ID	Screened Geologic Unit	Screen Interval (ft bgs)	Hydraulic Conductivity [a] (ft/d)	Effective Porosity [b]	Hydraulic Gradient [c]	Groundwater Velocity From Darcy's Law [d] (ft/d)	Groundwater Velocity From Borehole Dilution Testing (ft/d)
LVWPS-MW101A	Qal	23.3 - 33	22	0.1	0.013	2.9	--
LVWPS-MW101B	UMCf (mudflat sediments)	44.8 - 64.5	1.6	0.08	0.013	0.26	--
LVWPS-MW102A	UMCf (mudflat sediments)	47 - 66.6	3.5	0.08	0.014	0.61	0.85
LVWPS-MW102B	UMCf (saline lake sediments)	76.8 - 96.5	1.0	0.08	0.014	0.18	--
LVWPS-MW103A	UMCf (mudflat sediments)	29.8 - 39.5	0.4	0.08	0.015	0.075	--
LVWPS-MW103B	UMCf (saline lake sediments)	76.8 - 96.5	--	--	--	--	--
LVWPS-MW104	Qal	23.8 - 33.5	2.9	0.1	0.013	0.38	2.1
LVWPS-MW105	Qal	16.5 - 26.2	3.9	0.1	0.0075	0.29	0.28
LVWPS-MW106	UMCf (mudflat sediments)	30.4 - 50.1	1.3	0.08	0.015	0.24	--
LVWPS-MW107A	Qal	24.8 - 34.5	85	0.1	0.006	5.1	2.9
LVWPS-MW107B	UMCf (mudflat sediments)	46 - 65.8	0.02	0.08	0.015	0.0038	0.62
LVWPS-MW107C	UMCf (saline lake sediments)	100.3 - 120	1.4	0.08	0.015	0.26	--
LVWPS-MW108A	Qal	20.8 - 40.7	15	0.1	0.011	1.7	3.1
LVWPS-MW108B	UMCf (mudflat sediments)	46.3 - 66	4.5	0.08	0.013	0.73	1.6
LVWPS-MW108C	UMCf (saline lake sediments)	99.6 - 119.3	0.050	0.08	0.013	0.01	--
LVWPS-MW109	Qal	36.8 - 51.5	22	0.1	0.006	1.32	1.5
LVWPS-MW110	UMCf (mudflat sediments)	47.8 - 67.5	0.20	0.08	0.013	0.03	1.7
LVWPS-MW111A	Qal	20.8 - 40.5	2.5	0.1	0.006	0.15	2.9
LVWPS-MW111B	UMCf (mudflat sediments)	57.8 - 77.5	1.9	0.08	0.013	0.31	0.24
LVWPS-MW112A	Qal	28.8 - 48	72	0.1	0.006	4.3	4.1
LVWPS-MW112B	UMCf (mudflat sediments)	54.3 - 74	0.0010	0.08	0.013	0.00016	--
ZTS-MW113	Qal	20 - 30	14	0.1	0.010	1.4	6.3
ZTS-MW114	UMCf (mudflat sediments)	50 - 70	6.4	0.08	0.013	1.0	2.4
ZTS-MW115	Qal	20 - 30	2.9	0.1	0.006	0.18	2.6

Notes:

ft bgs = feet below ground surface
ft/d = feet per day
K = Hydraulic conductivity
Qal = Alluvium
UMCf = Upper Muddy Creek formation
-- = Not available

Table 4-8: Transect 1A Hydraulic Testing Results

Nevada Environmental Response Trust Site

Henderson, Nevada

Well ID	Screened Geologic Unit	Screen Interval (ft bgs)	Hydraulic Conductivity [a] (ft/d)	Effective Porosity [b]	Hydraulic Gradient [c]	Groundwater Velocity From Darcy's Law [d] (ft/d)	Groundwater Velocity From Borehole Dilution Testing (ft/d)

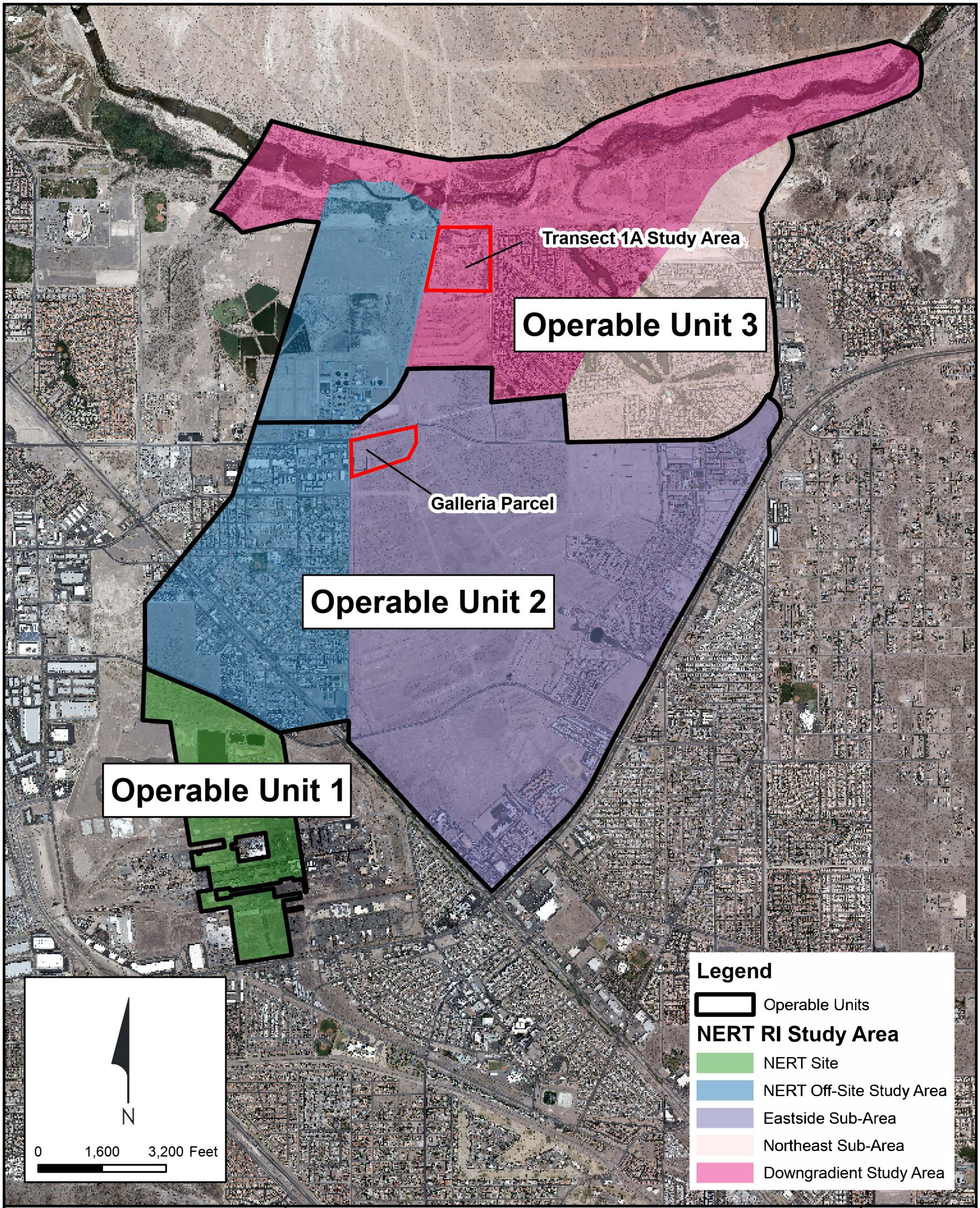
[a] Hydraulic conductivity from slug testing. Slug tests for ZTS-MW113, ZTS-MW114, and ZTS-MW115 were performed by Ramboll, as described in Appendix D. Slug tests for other wells were performed by Tetra Tech, as described in the Las Vegas Wash Bioremediation Pilot Study Work Plan Addendum (Tetra Tech 2019).

[b] Effective porosity based on average of laboratory results in the alluvium and UMCf measured in OU-2 as part of the draft RI for OU-1 and OU-2 (Ramboll 2021).

[c] Hydraulic gradient estimated from the potentiometric surface maps.

[d] Single-borehole dilution tests were performed by Ramboll at all wells except LVWPS-MW107A and LVWPS-MW107B, which were tested by Tetra Tech and re-analyzed by Ramboll.

FIGURES



RAMBOLL

Treatability Study Area Locations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **1-1**

Drafter: RS / JC Date: 04-May-21 Contract Number: 169001 1200-046 Approved: Revised:

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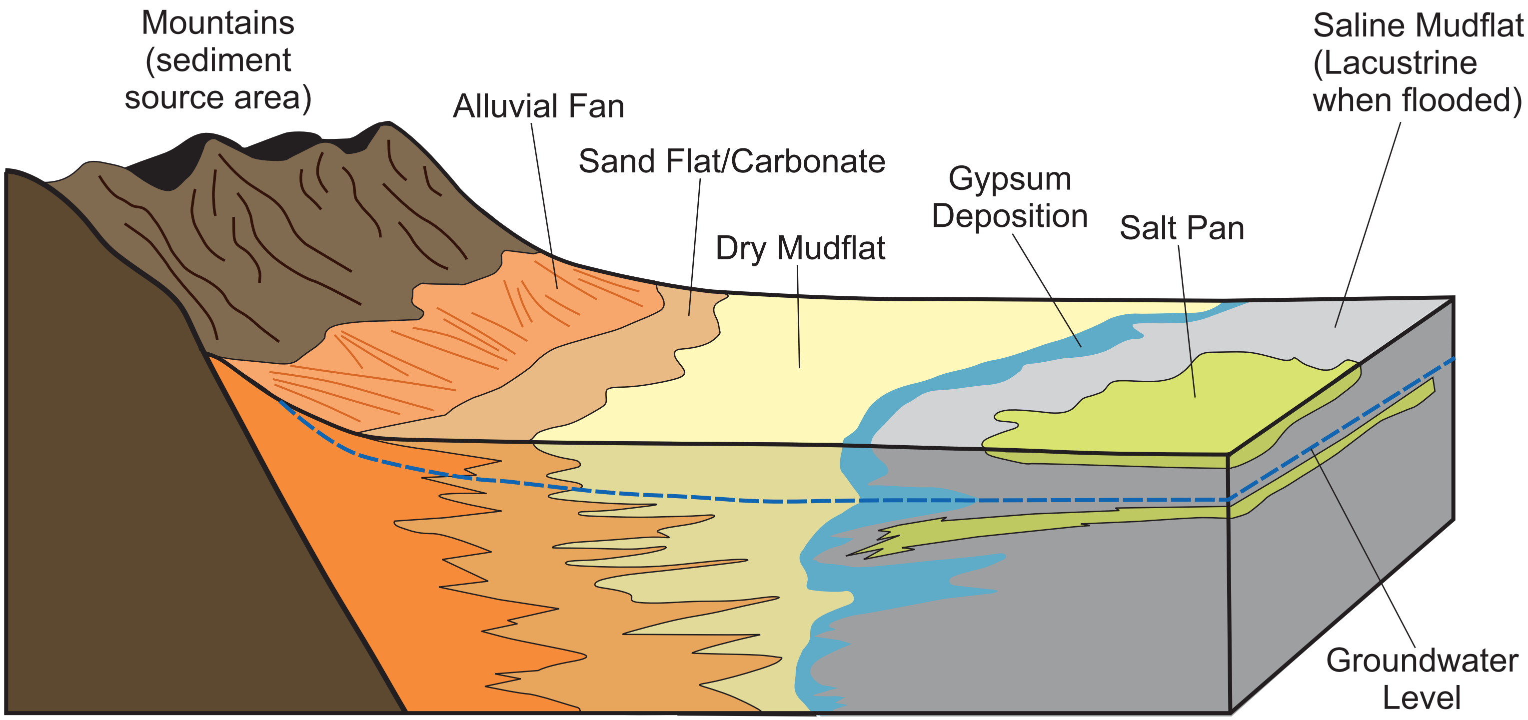
RAMBOLL

Transect 1A Study Area Layout
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
3-1

Drafter: JC | Date: 2021-09-03 | Contract Number: 1690016064-038 | Approved: | Revised:



Source: Faulds et al., 2016

Generalized Model for Closed-Basin Sedimentation

RAMBOLL

Conceptual Geologic Model for the Muddy Creek Formation
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure

4-1

Drafter: RS | Date: 5/4/2020 | Approved: | Contract Number: 169001 6064 | Revised:

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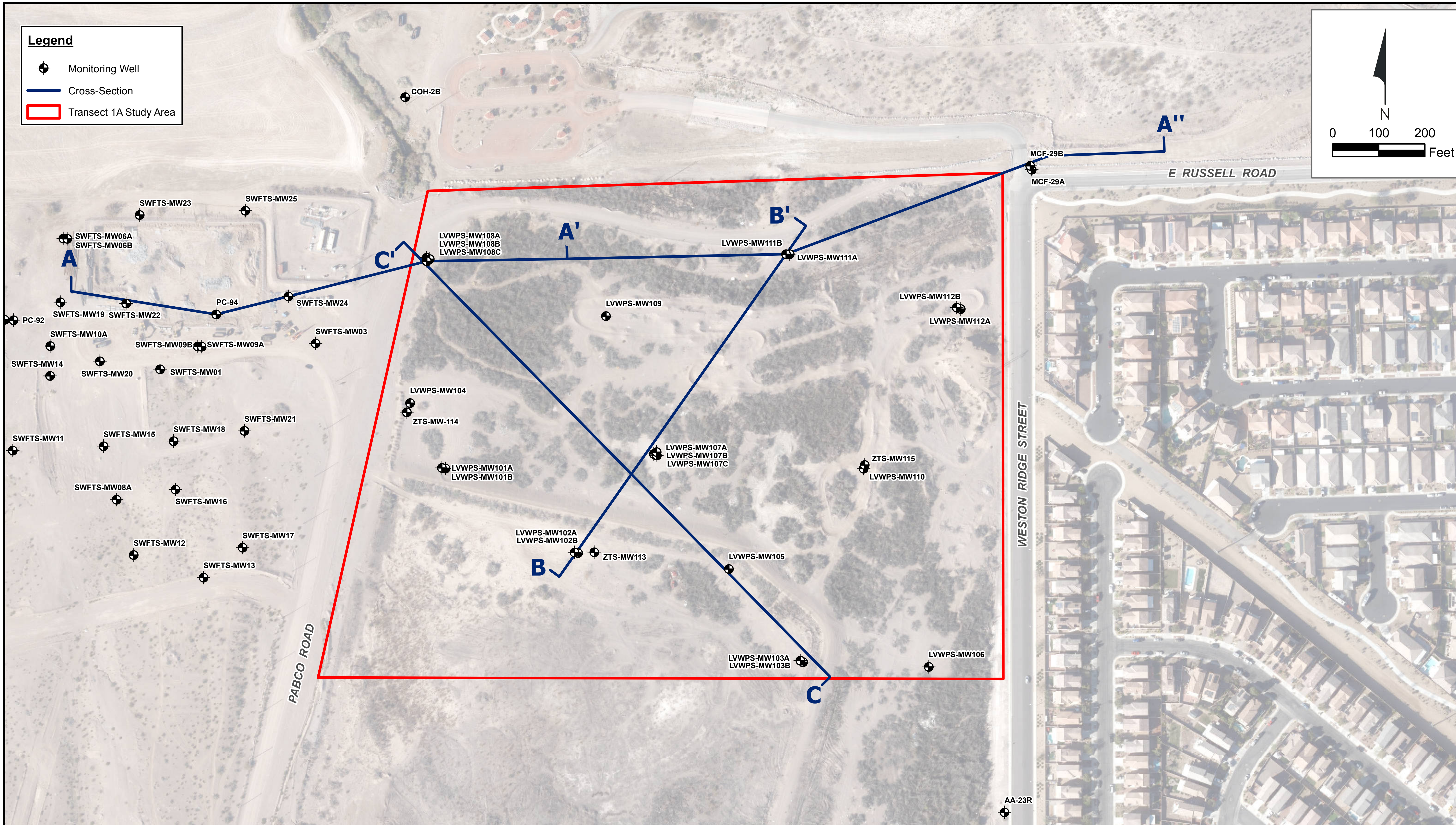

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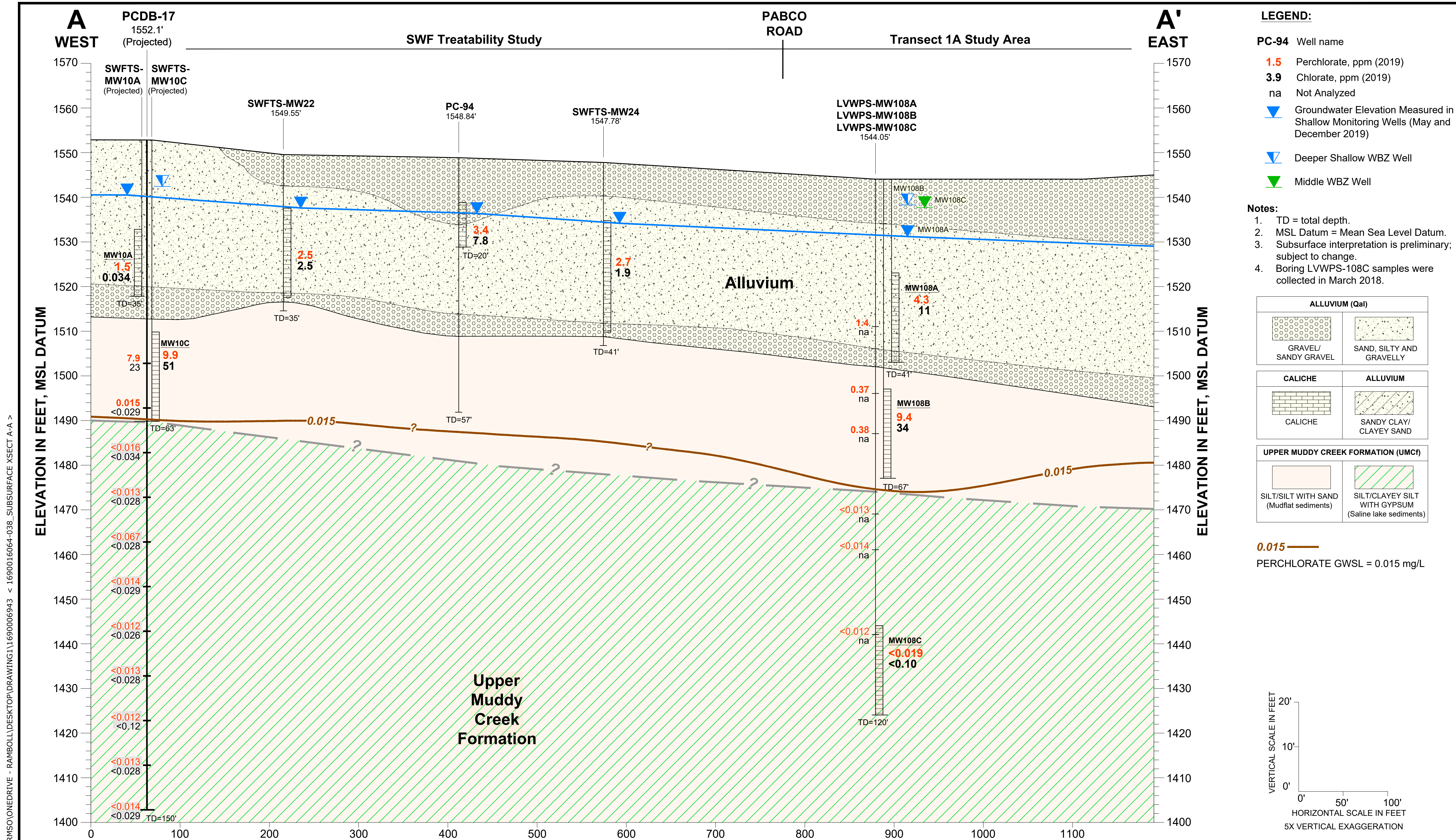
RAMBOLL

Transect 1A Cross-Section Layout
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-2

Drafter: RS | Date: 4/5/2021 | Contract Number: 1690020169-022 | Approved by: | Revised:



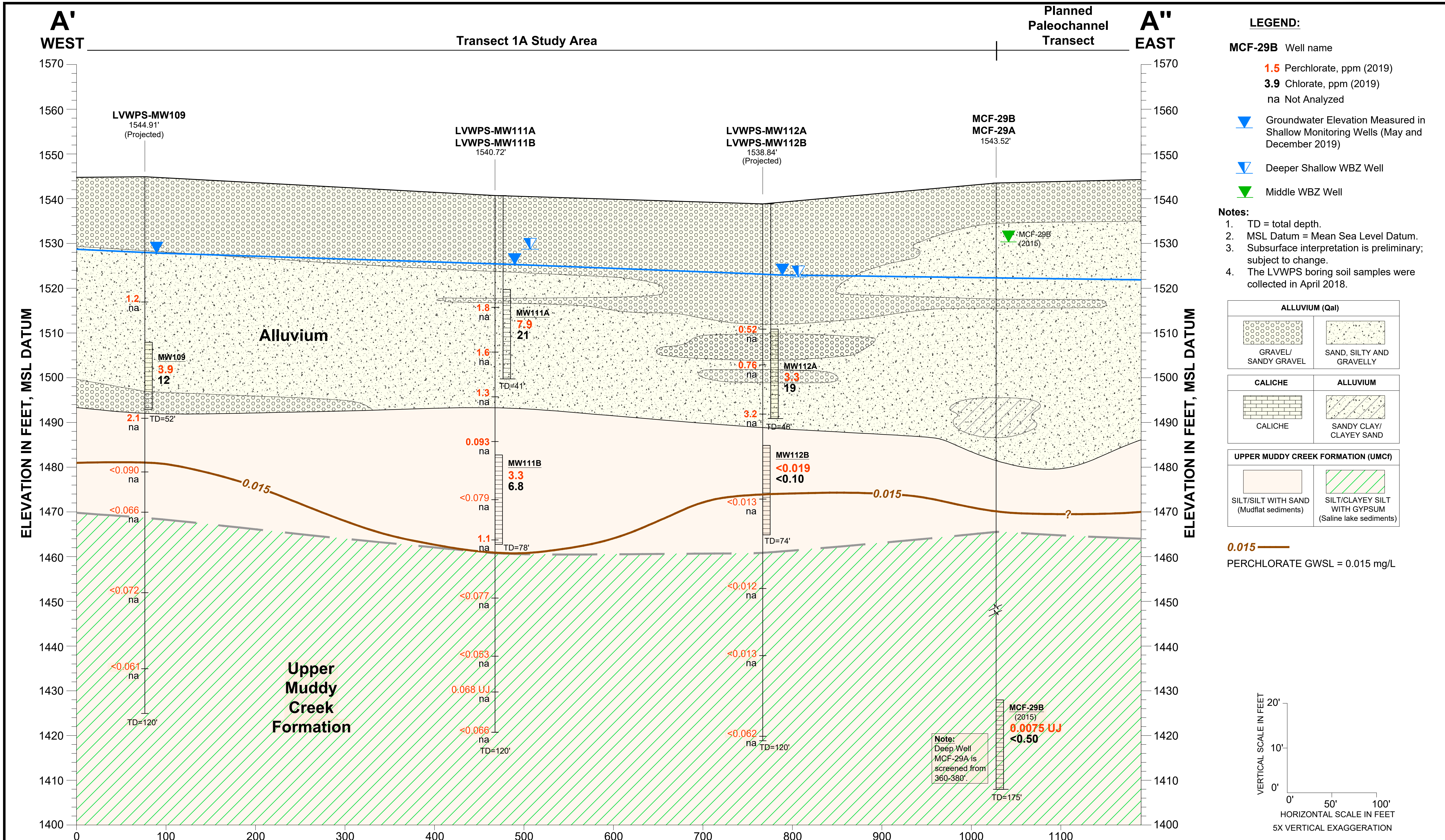
RAMBOLL

Schematic Subsurface Cross-Section A-A'

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-3

Drafter: RS | Date: 4/20/2021 | Contract Number: 169002 0169-022 | Approved by: | Revised:



RAMBOLL

Schematic Subsurface Cross-Section A'-A''

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-4**

Drafter: RS | Date: 4/20/2021 | Contract Number: 169002 0169-022 | Approved by: | Revised:

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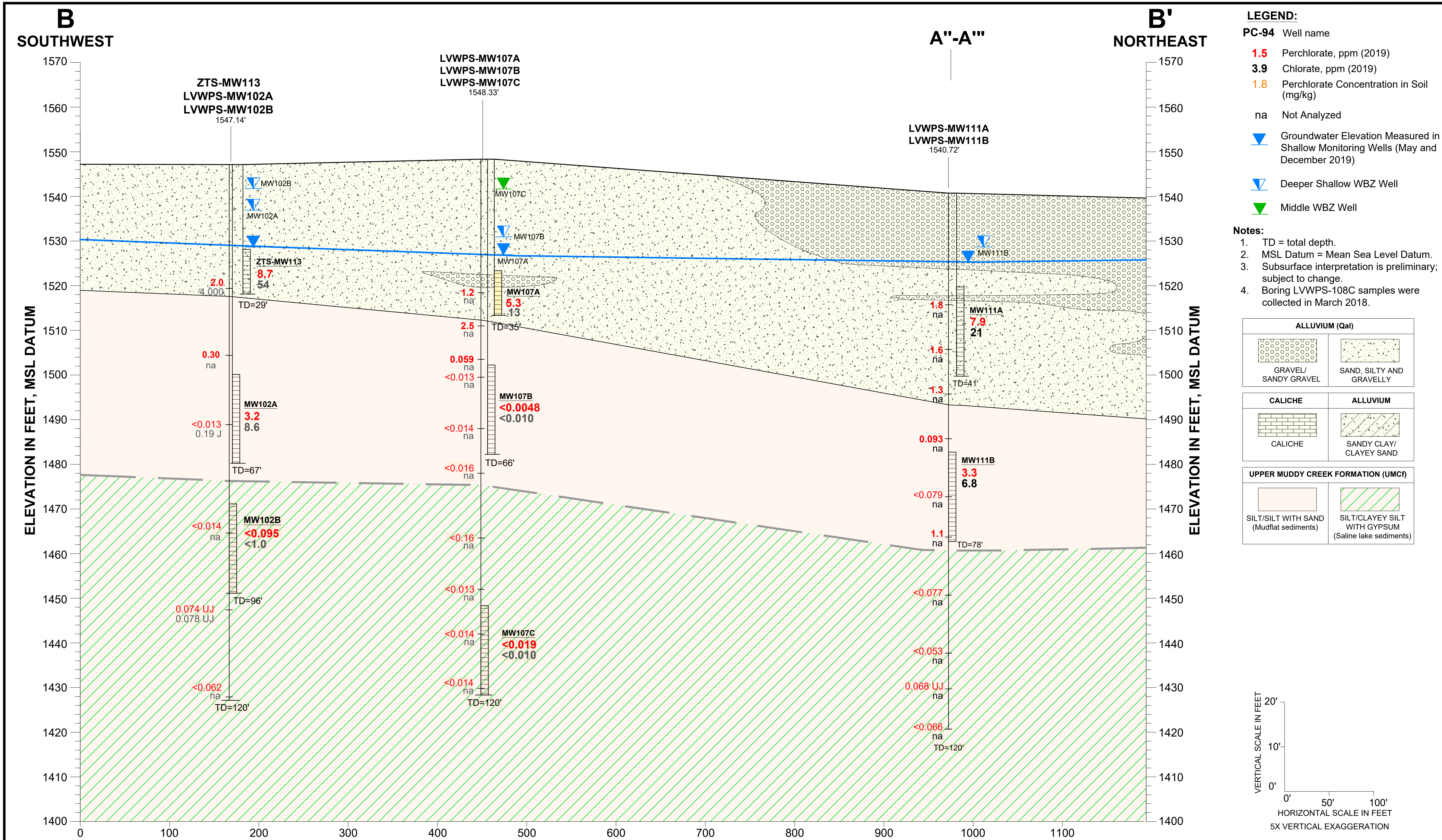


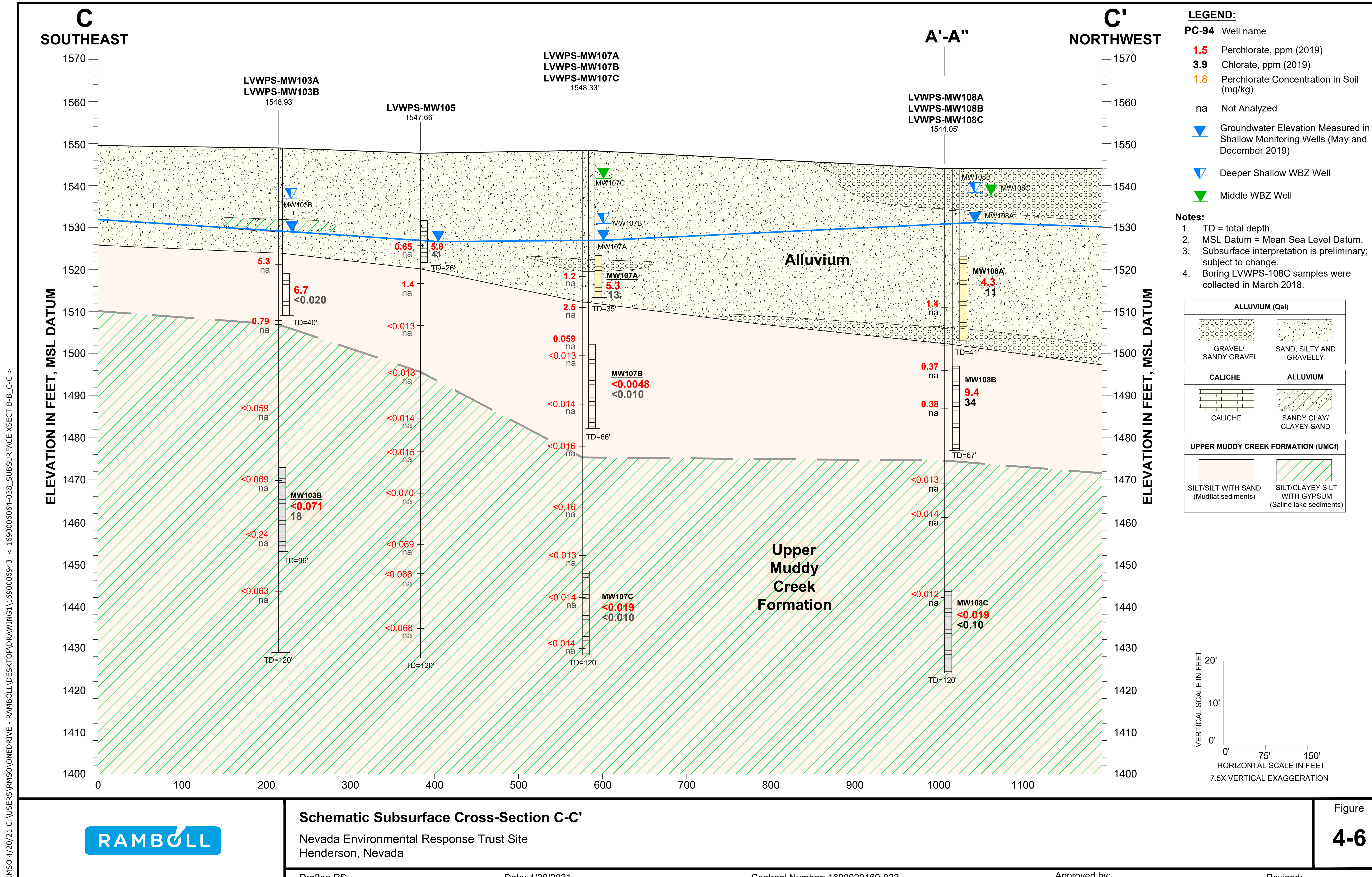
RAMBOLL

Schematic Subsurface Cross-Section B-B'

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-5**

Drafter: RS | Date: 4/20/2021 | Contract Number: 1690020169-022 | Approved by: | Revised:



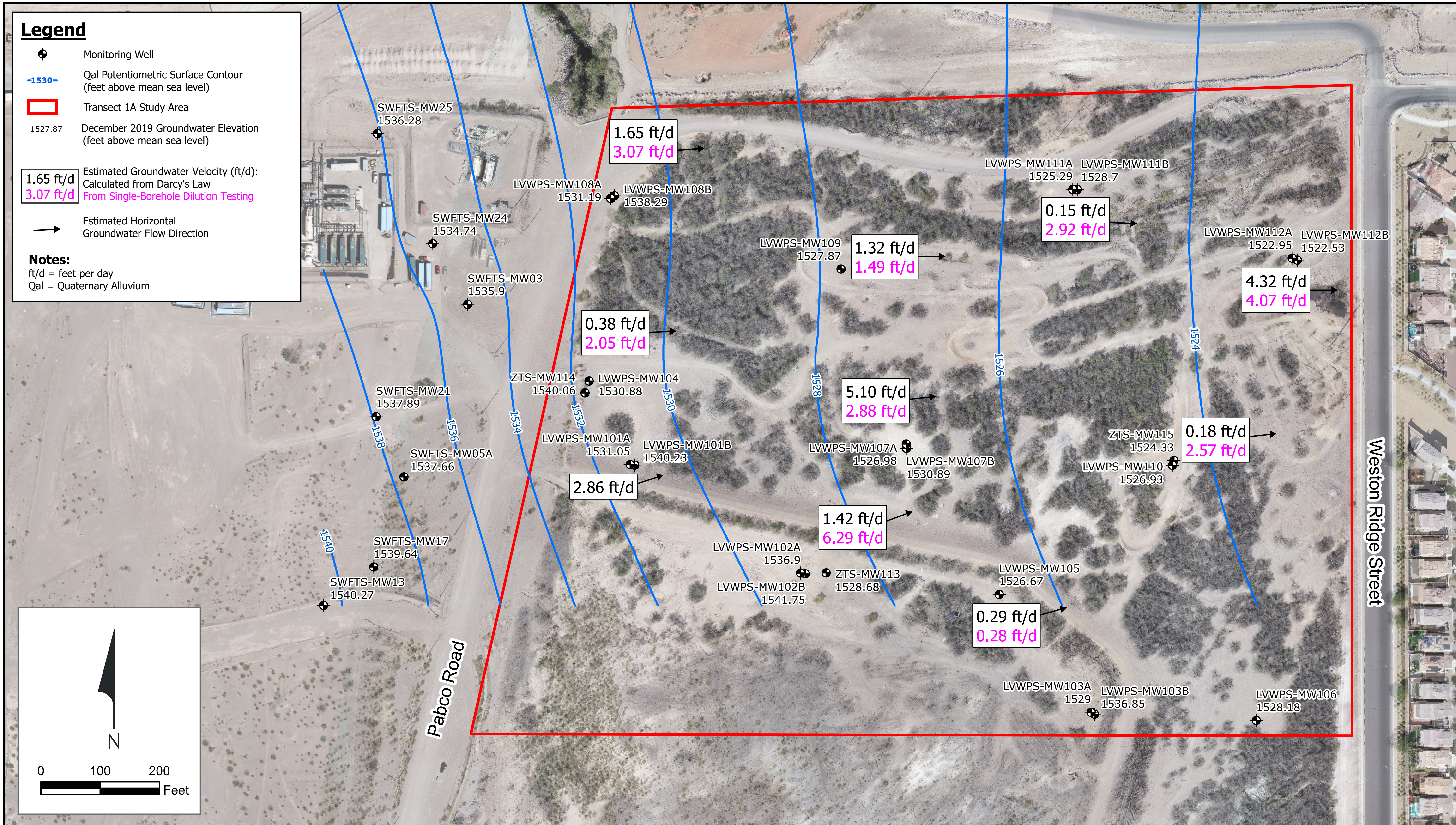
RAMBOLL

Schematic Subsurface Cross-Section C-C'

Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-6**

Drafter: RS	Date: 4/20/2021	Contract Number: 1690020169-022	Approved by:	Revised:



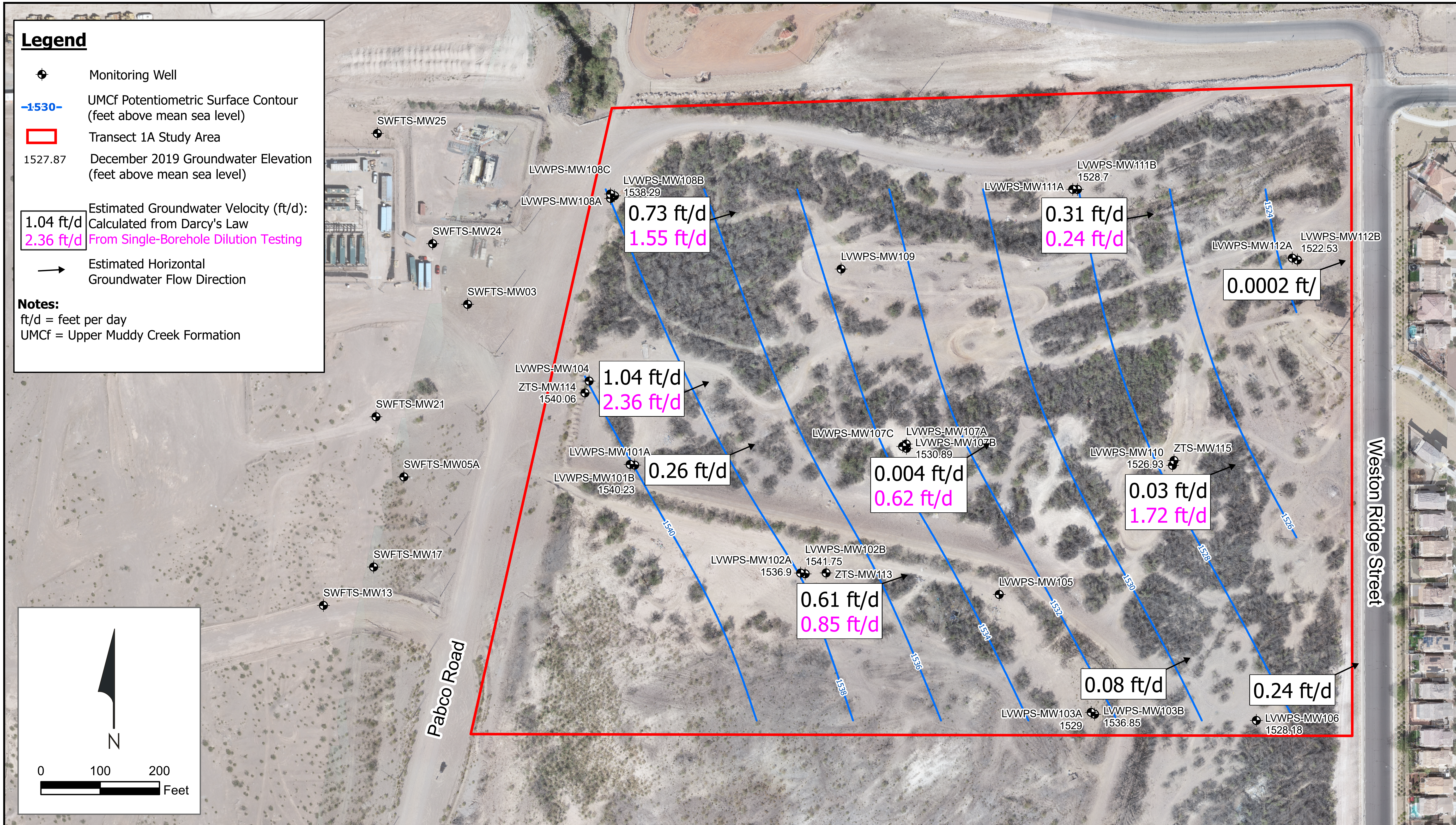
Path: H:\LePetomane\NERT\GIS\RI.FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx

RAMBOLL

Transect 1A Alluvium Groundwater Elevation Contours
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-7**

Drafter: JC/RS	Date: 2021-05-05	Contract Number: 169002 0169-022	Approved by:	Revised:



Transect 1A UMCf Groundwater Elevation Contours
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-8

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: H:\LePetomane\NERT\GIS\RI.FS_Treatability Studies\2V_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx\figure_4-8

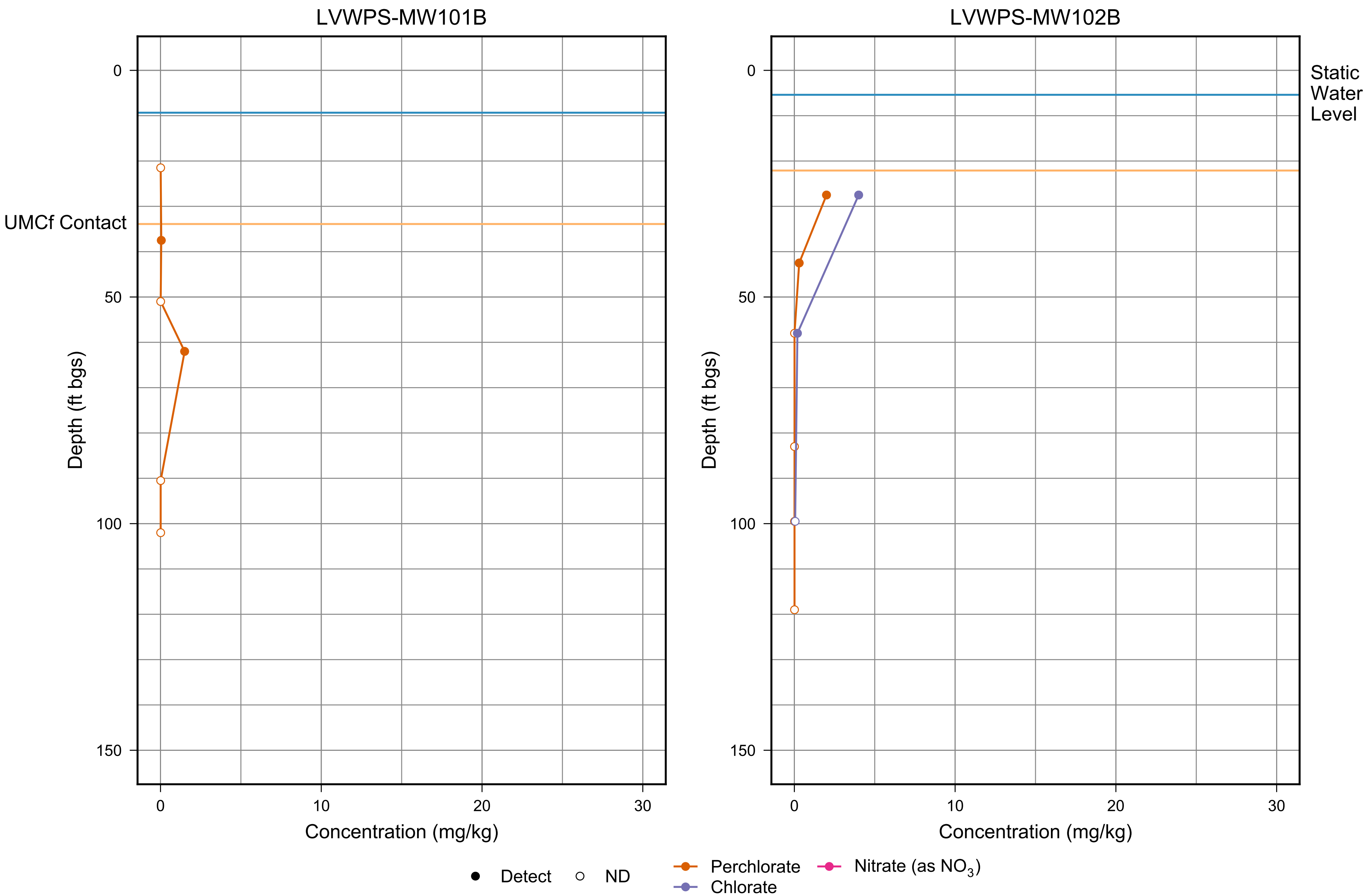
RAMBOLL

Transect 1A Vertical Groundwater Gradients
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-9**

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

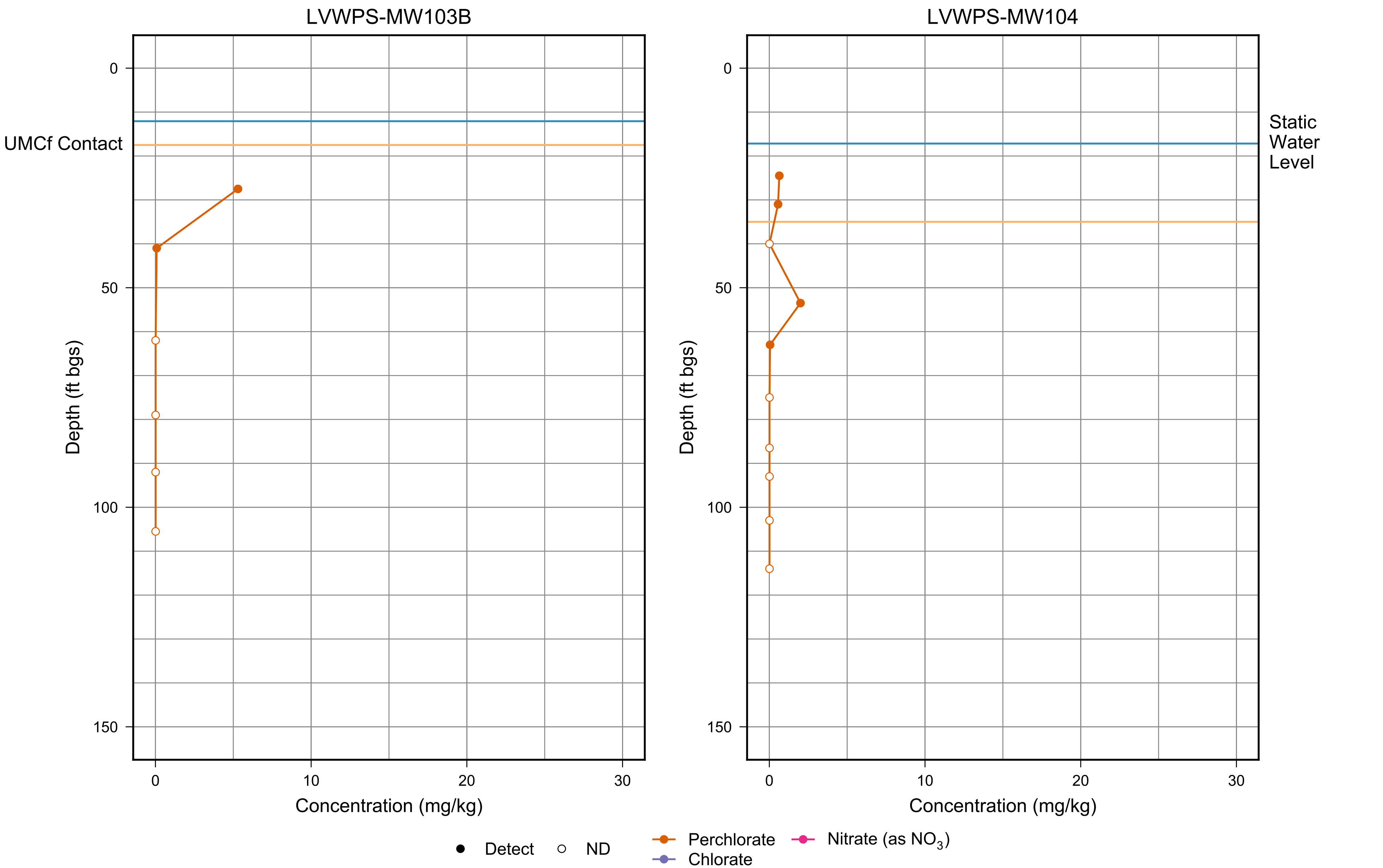


Soil Concentration Profiles for Borings LVWPS-MW101B and LVWPS-MW102B
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-10a**

Drafter: JH | Date: 05/05/20 | Contract Number: 169001 6064 | Approved: | Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

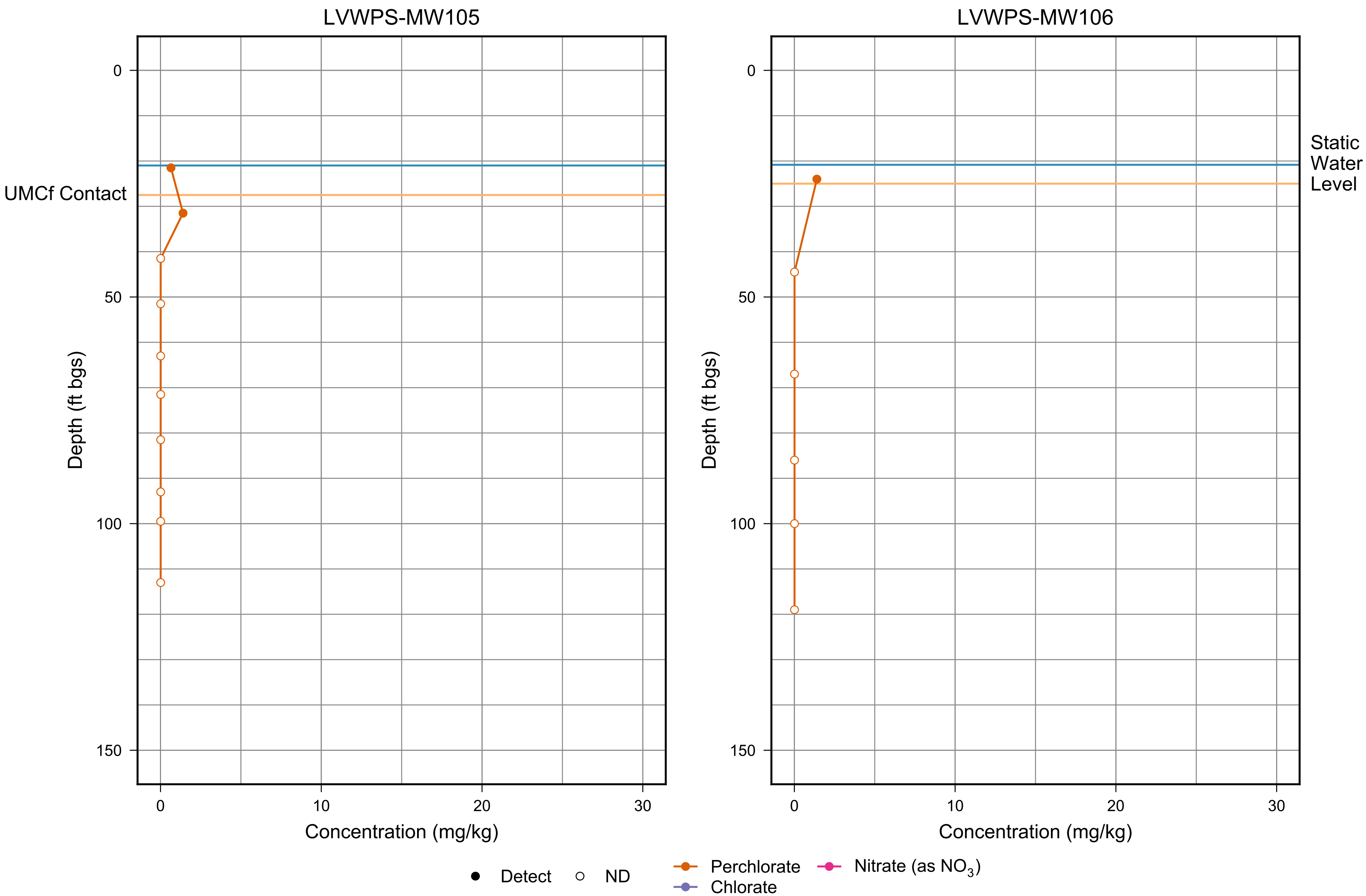


Soil Concentration Profiles for Borings LVWPS-MW103B and LVWPS-MW104
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-10b**

Drafter: JH	Date: 05/05/20	Contract Number: 169001 6064	Approved:	Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py



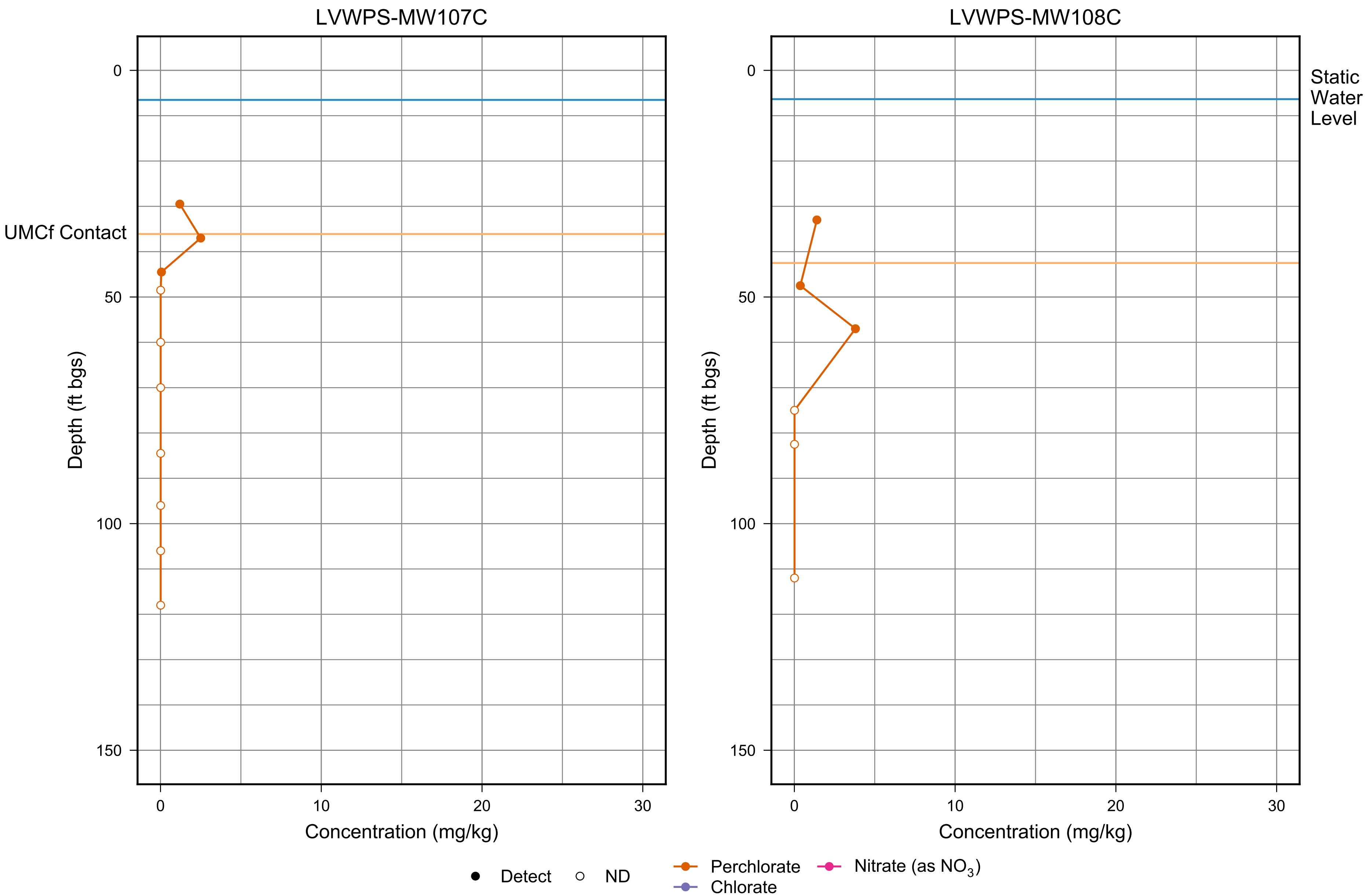
RAMBOLL

Soil Concentration Profiles for Borings LVWPS-MW105 and LVWPS-MW106
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-10c

Drafter: JH	Date: 05/05/20	Contract Number: 169001 6064	Approved:	Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py



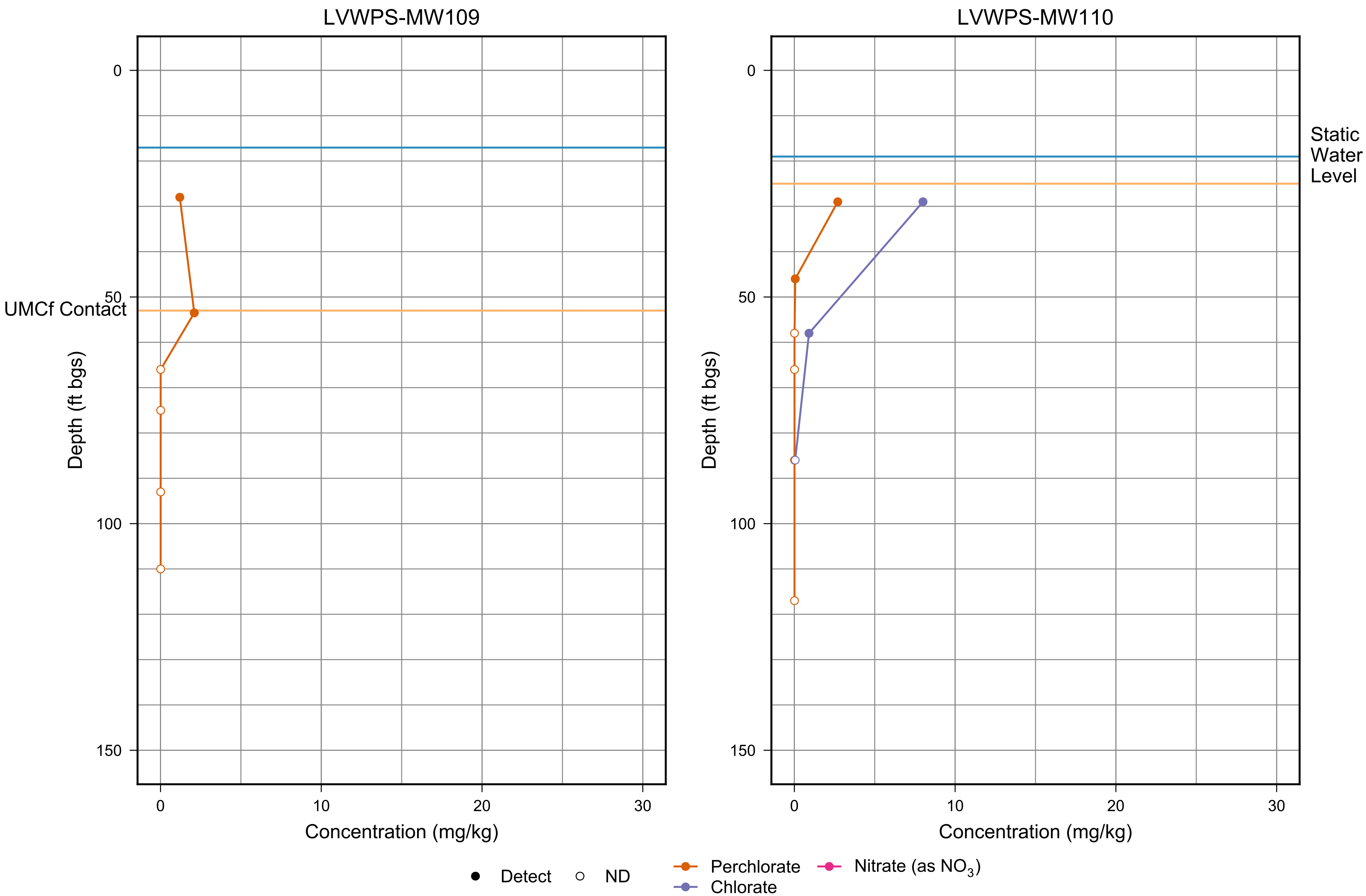
RAMBOLL

Soil Concentration Profiles for Borings LVWPS-MW107C and LVWPS-MW108C
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-10d

Drafter: JH	Date: 05/05/20	Contract Number: 169001 6064	Approved:	Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

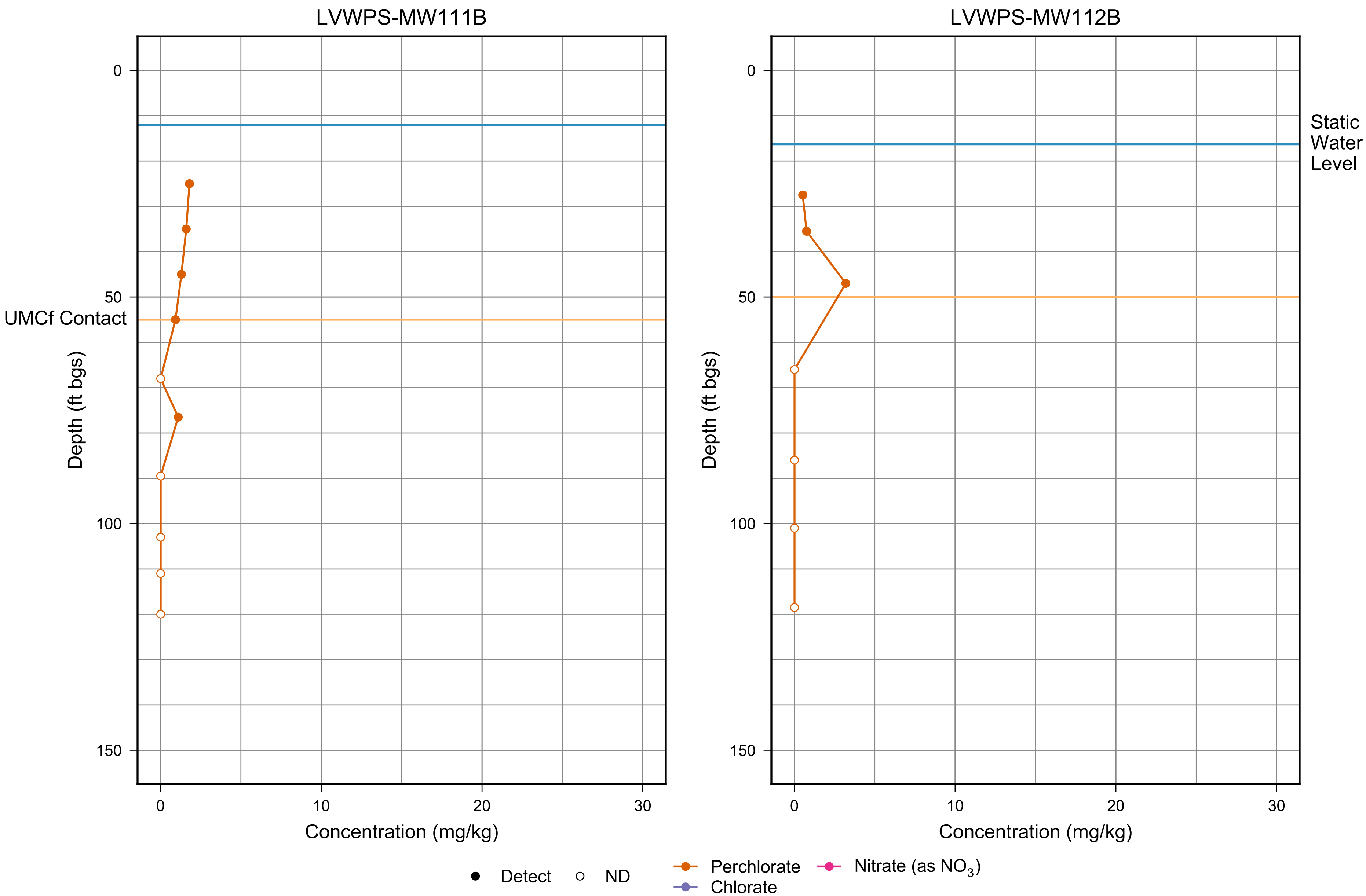


Soil Concentration Profiles for Borings LVWPS-MW109 and LVWPS-MW110
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-10e

Drafter: JH | Date: 05/05/20 | Contract Number: 169001 6064 | Approved: | Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

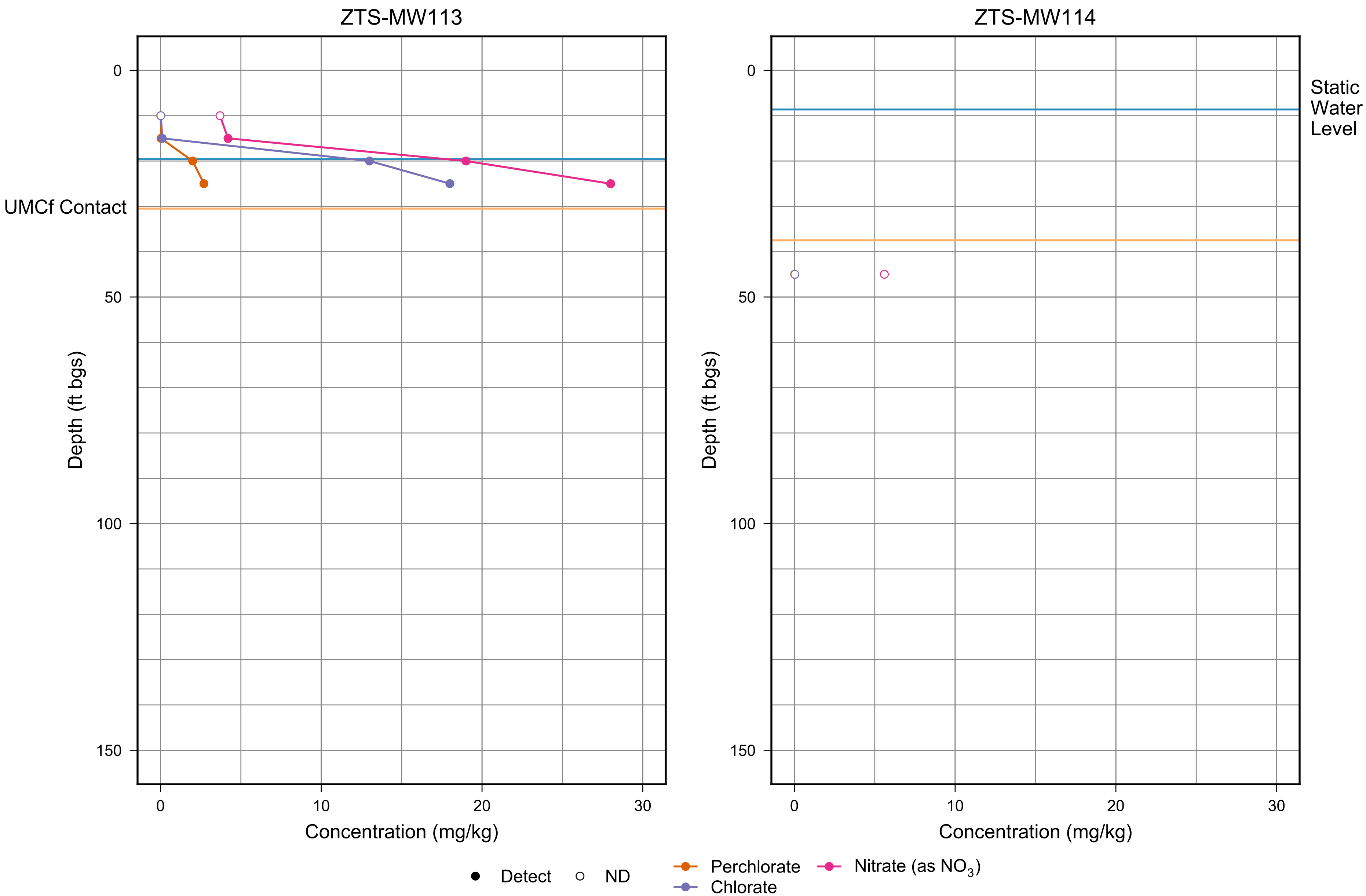


Soil Concentration Profiles for Borings LVWPS-MW111B and LVWPS-MW112B
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-10f**

Drafter: JH | Date: 05/05/20 | Contract Number: 169001 6064 | Approved: | Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

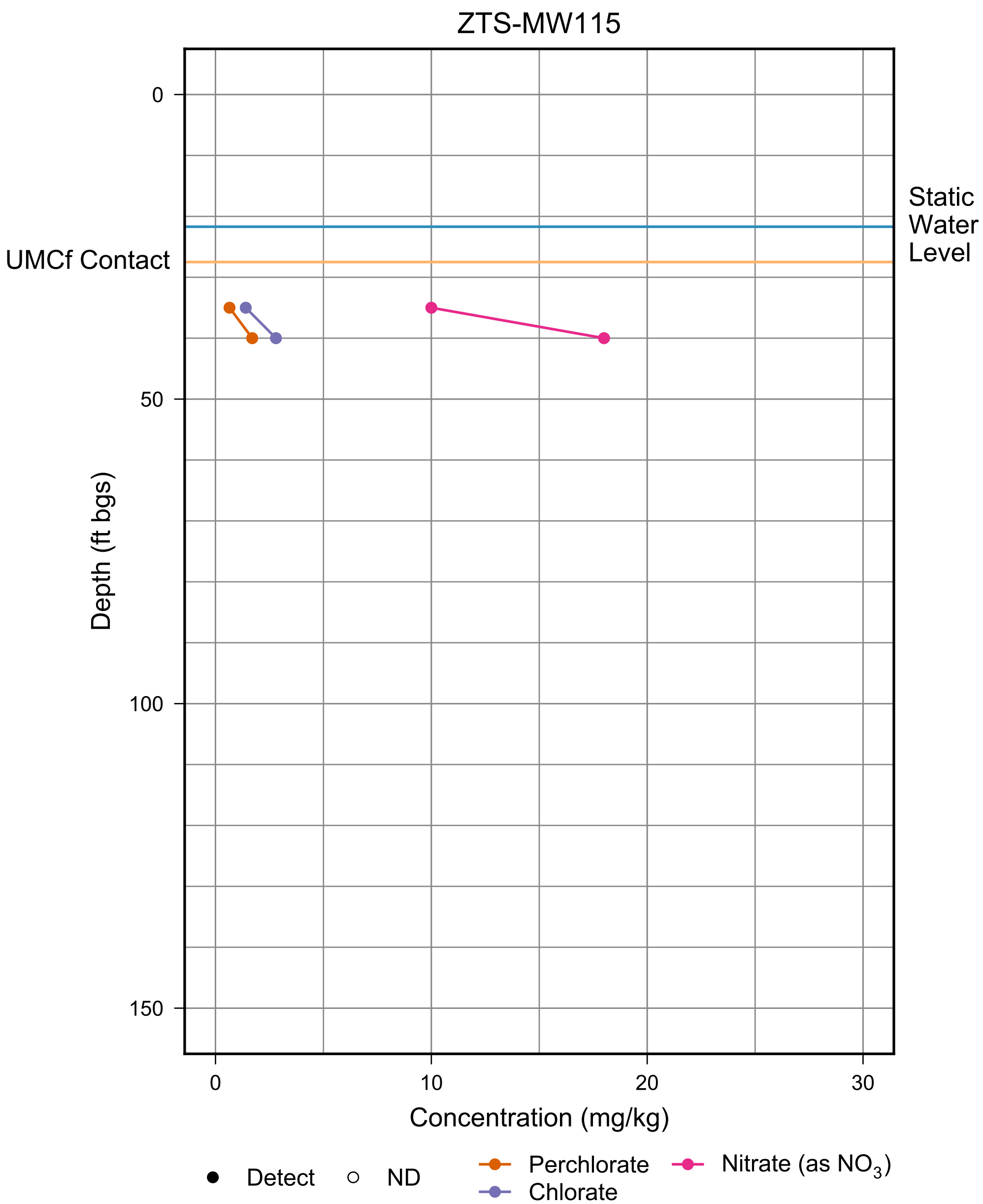


Soil Concentration Profiles for Borings ZTS-MW113 and ZTS-MW114
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-10g

Drafter: JH	Date: 05/05/20	Contract Number: 169001 6064	Approved:	Revised:

Path: rehemy2\projects\NERT\ZVI\SoilDepthProfilesTransect1A.py

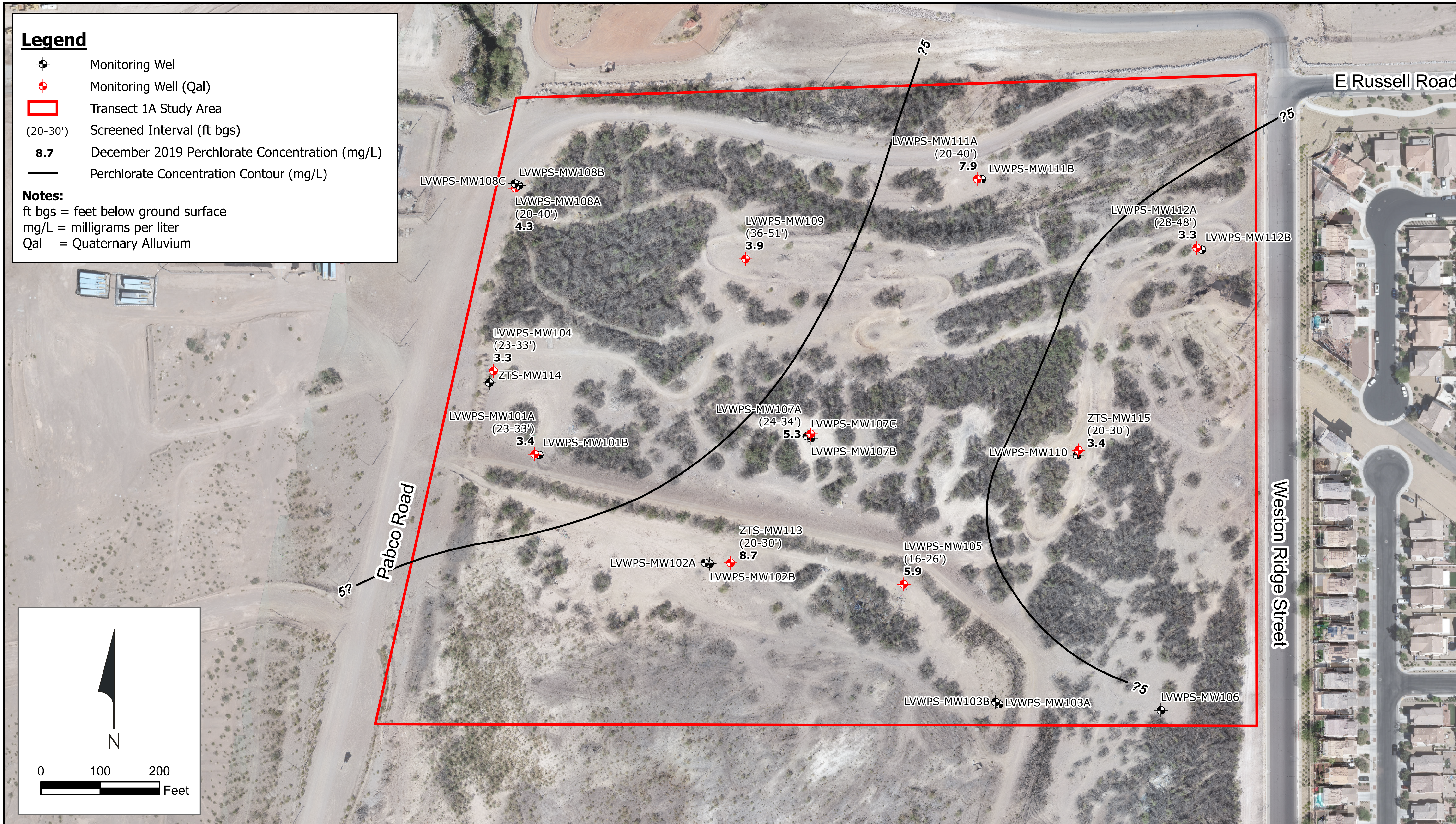


RAMBOLL

Soil Concentration Profile for Boring ZTS-MW115
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-10h

Drafter: JH	Date: 05/05/20	Contract Number: 169001 6064	Approved:	Revised:

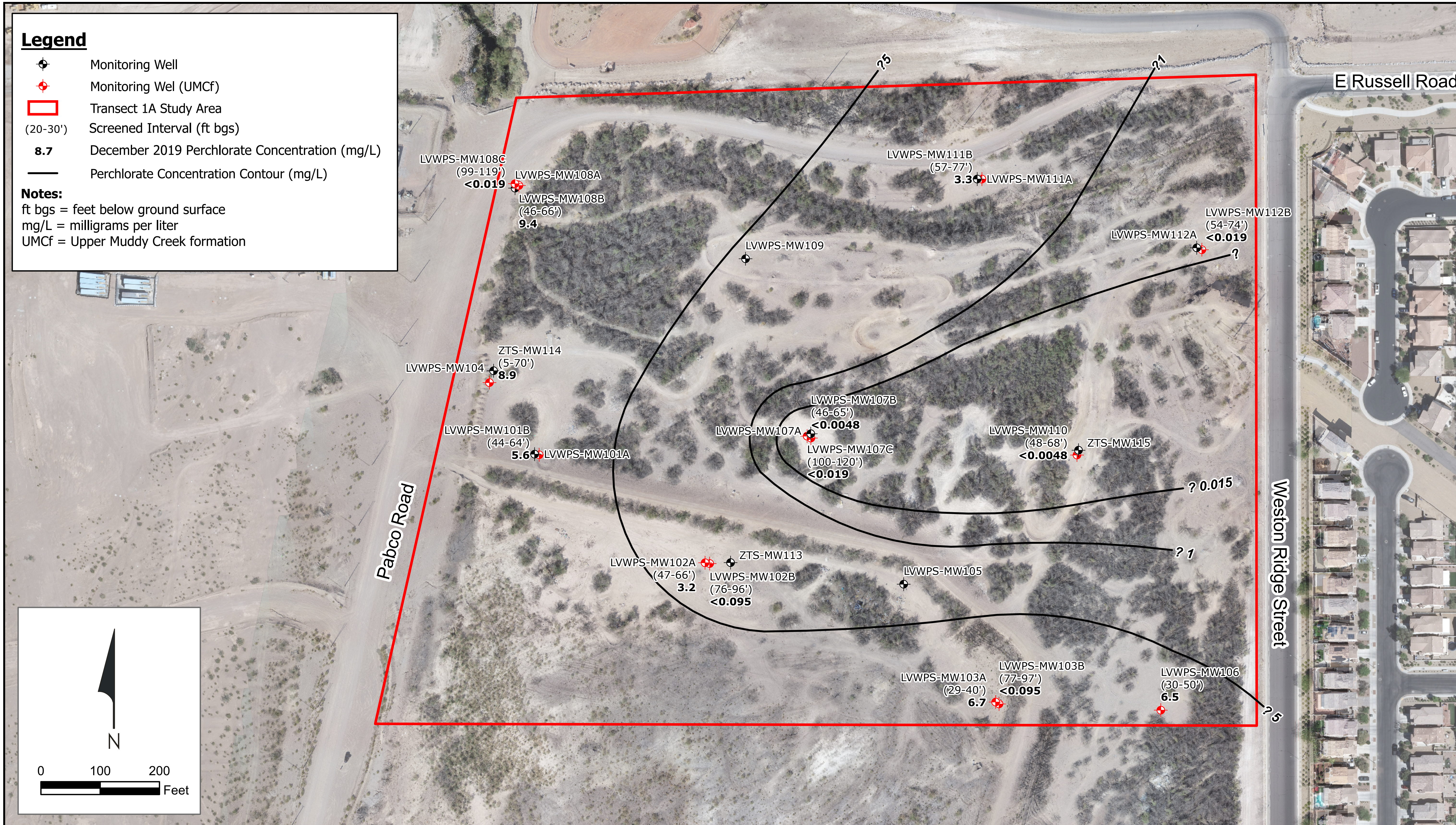


RAMBOLL

Alluvium Groundwater Perchlorate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-11**

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:



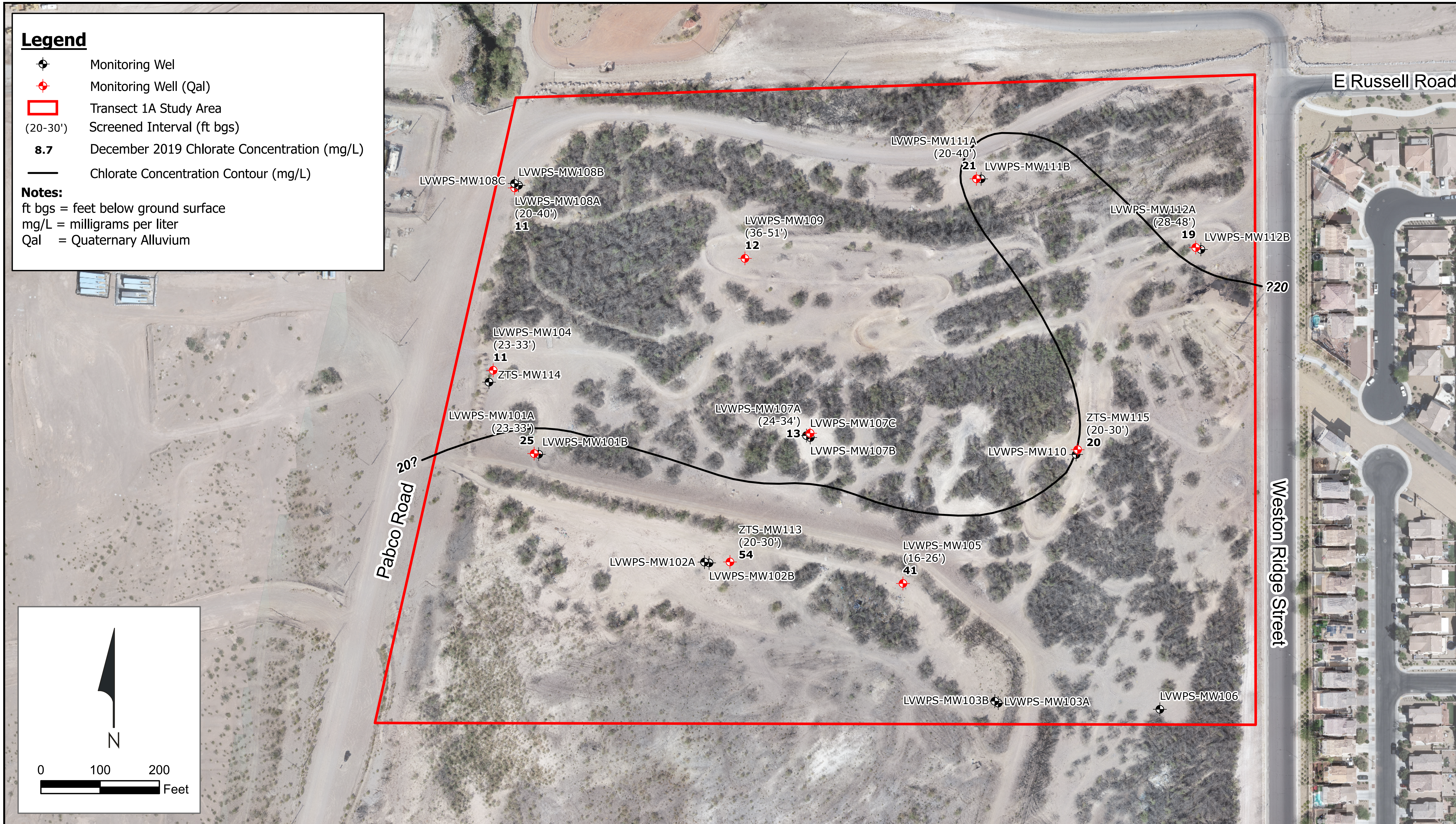
UMCf Groundwater Perchlorate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

RAMBOLL

Figure
4-12

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: H:\LePetomane\NERT\GIS\RI_FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx\figure_4-12



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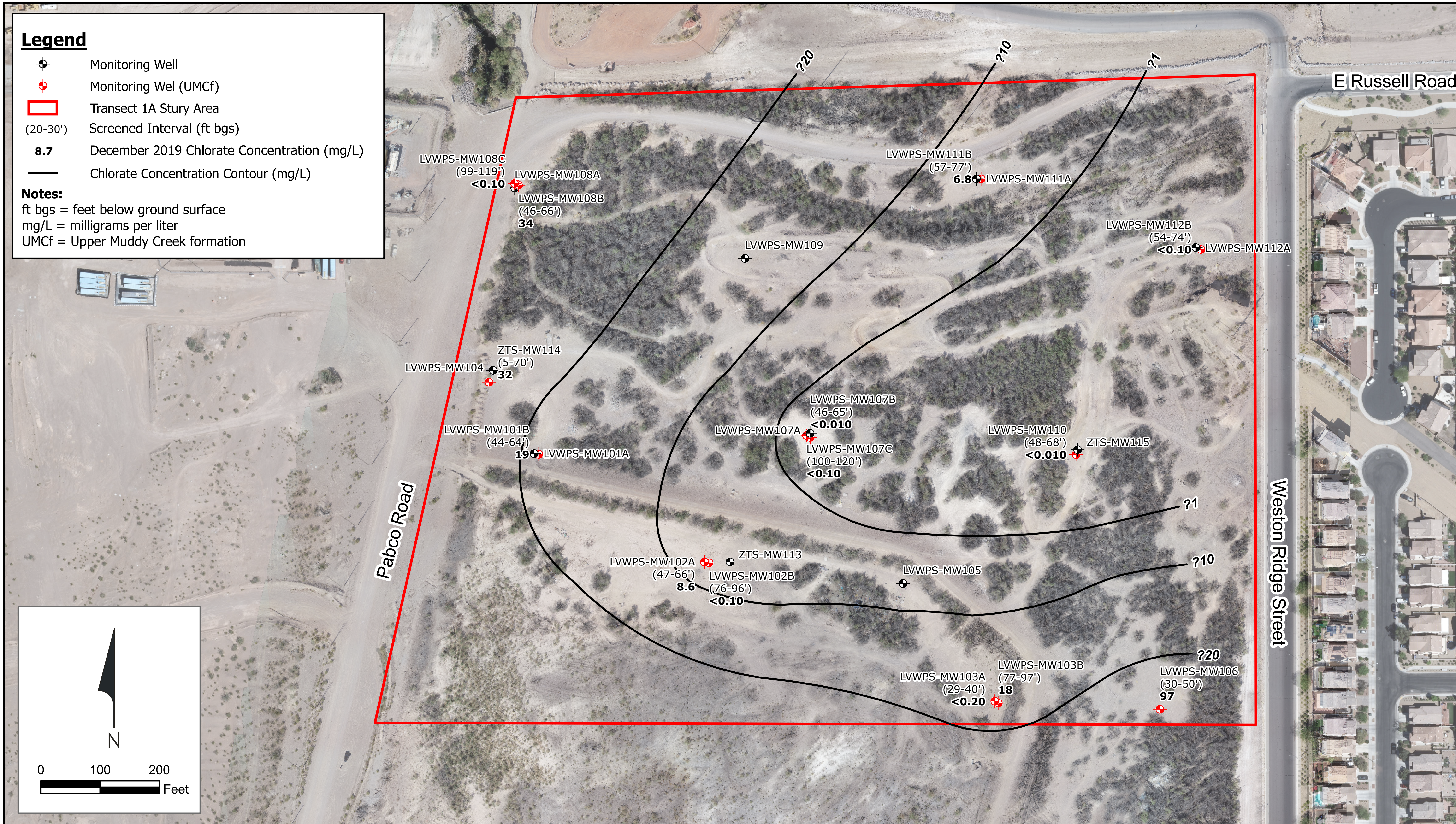
RAMBOLL

Alluvium Groundwater Chlorate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-13

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:



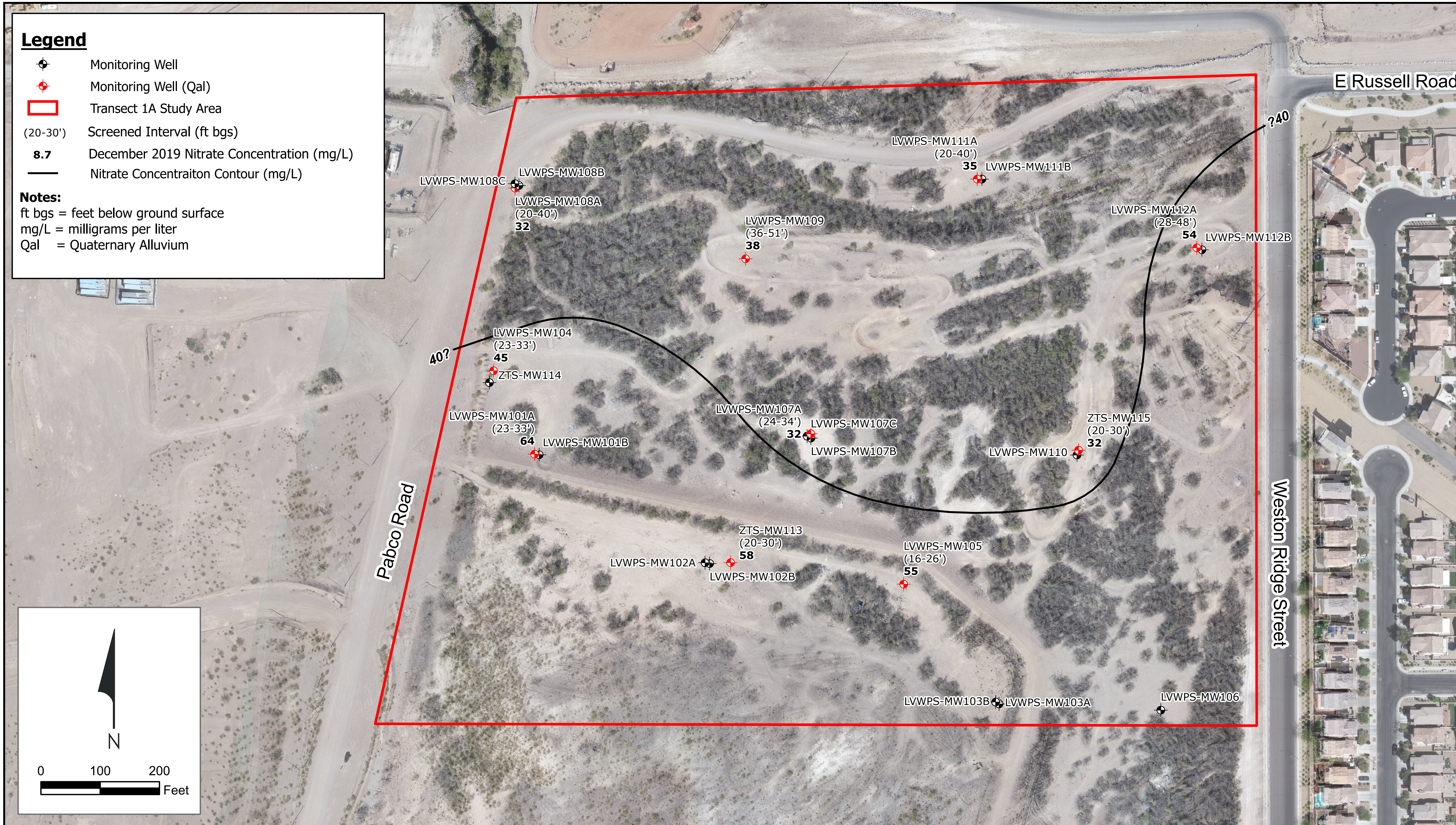
RAMBOLL

UMCf Groundwater Chlorate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-14

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: H:\LePetomane\NERT\GIS\RI\FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx\figure_4-14



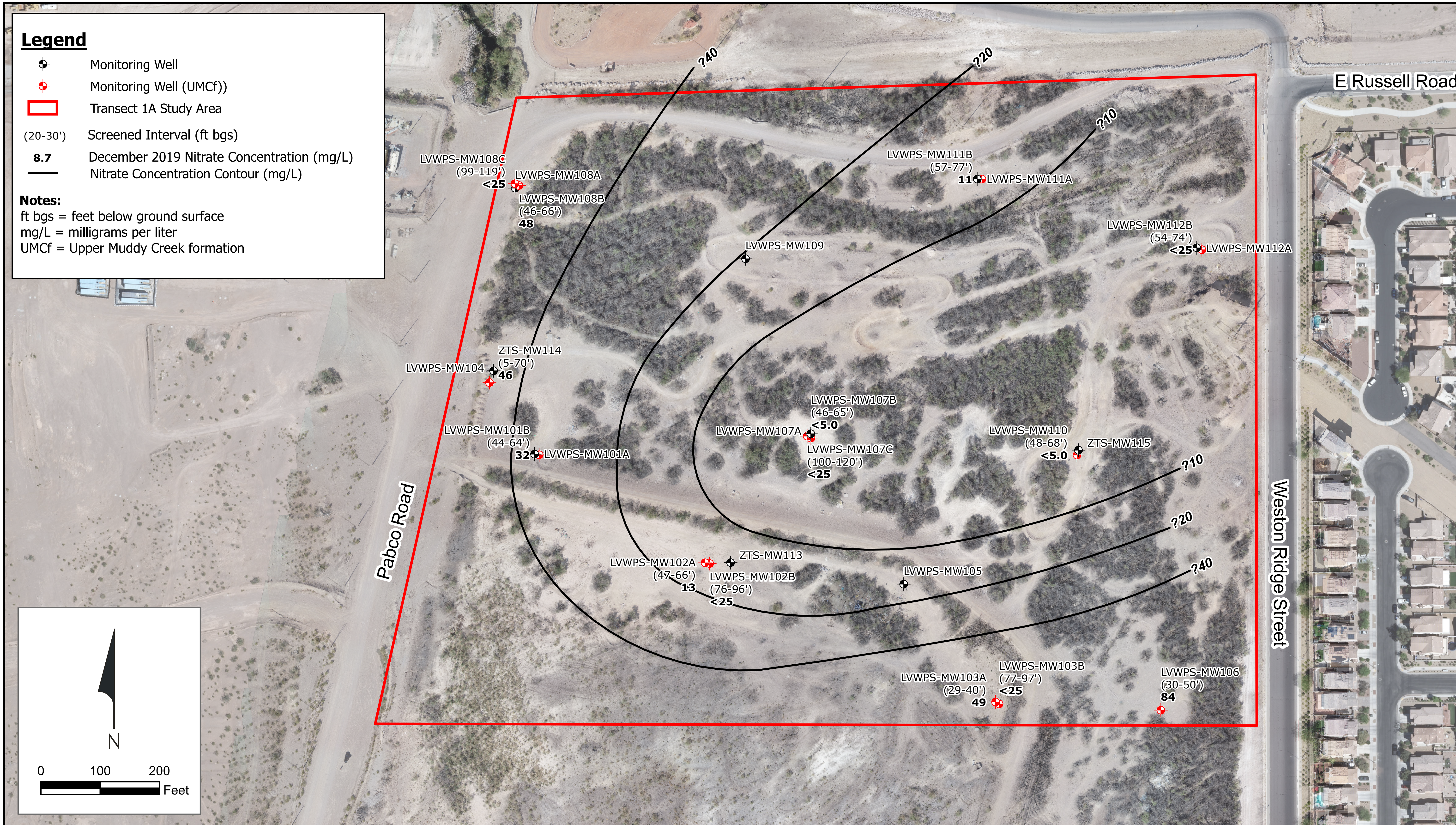
RAMBOLL

Alluvium Groundwater Nitrate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **4-15**

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: H:\LePetomane\NERT\GIS\RI\FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx\figure_4-15



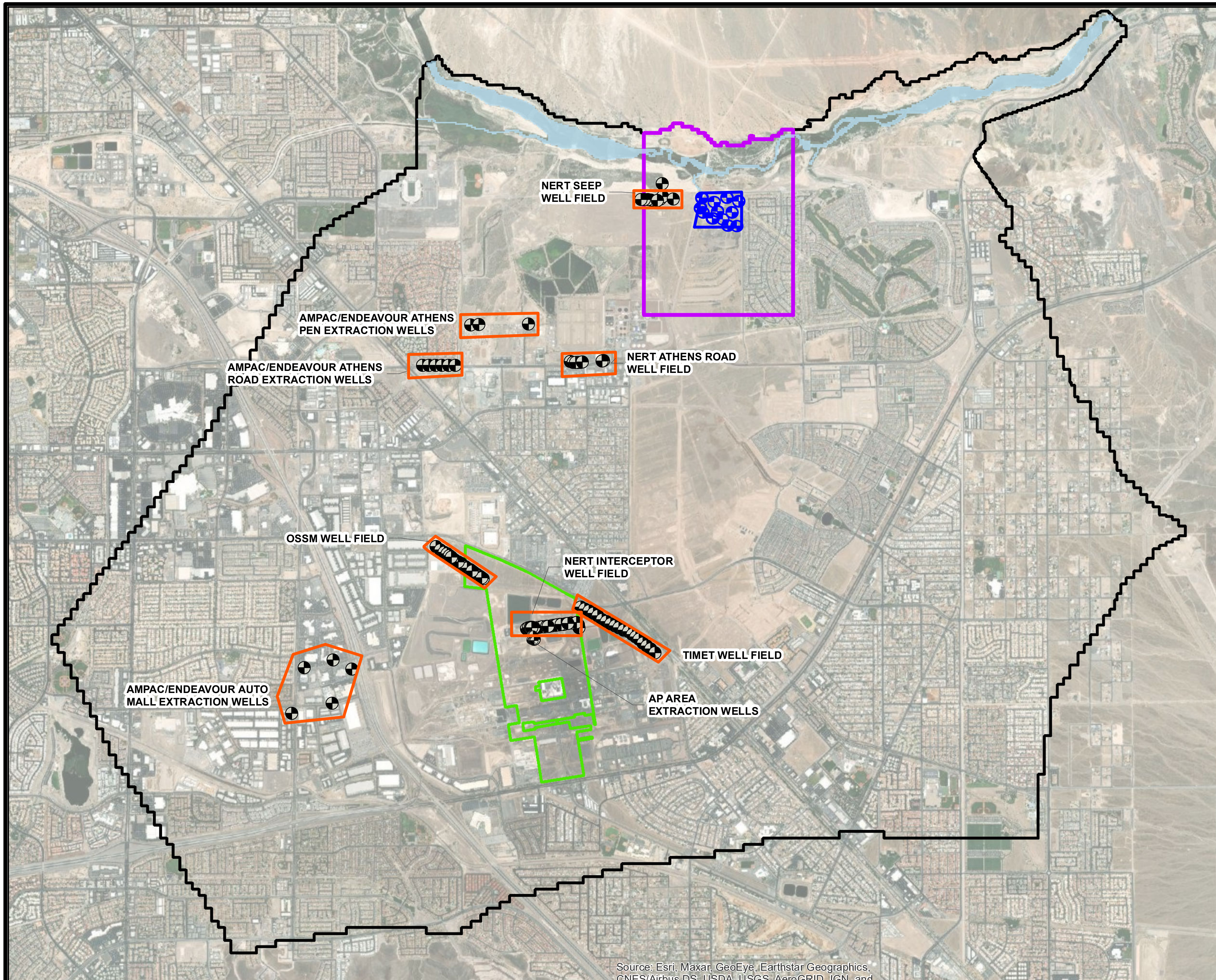
RAMBOLL

UMCf Groundwater Nitrate Concentrations
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure
4-16

Drafter: JC | Date: 2021-05-05 | Contract Number: 1690016064-038 | Approved: | Revised:

Path: H:\LePetomane\NERT\GIS\RI\FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\figures_20210505.aprx\figure_4-16



Legend

- Transect 1A Monitoring Well
- Extraction Well
- ZVI Treatability Study Area
- ZVI Area Model Extent
- Phase 6 Model Extent

Notes:

AMPAC/Endeavour: American Pacific Corporation now Endeavour LLC
NERT: Nevada Environmental Response Trust
OSSM: Olin/Stauffer/Syngenta/Montrose
TIMET: Titanium Metals Corporation

N

0 0.5 1 Miles

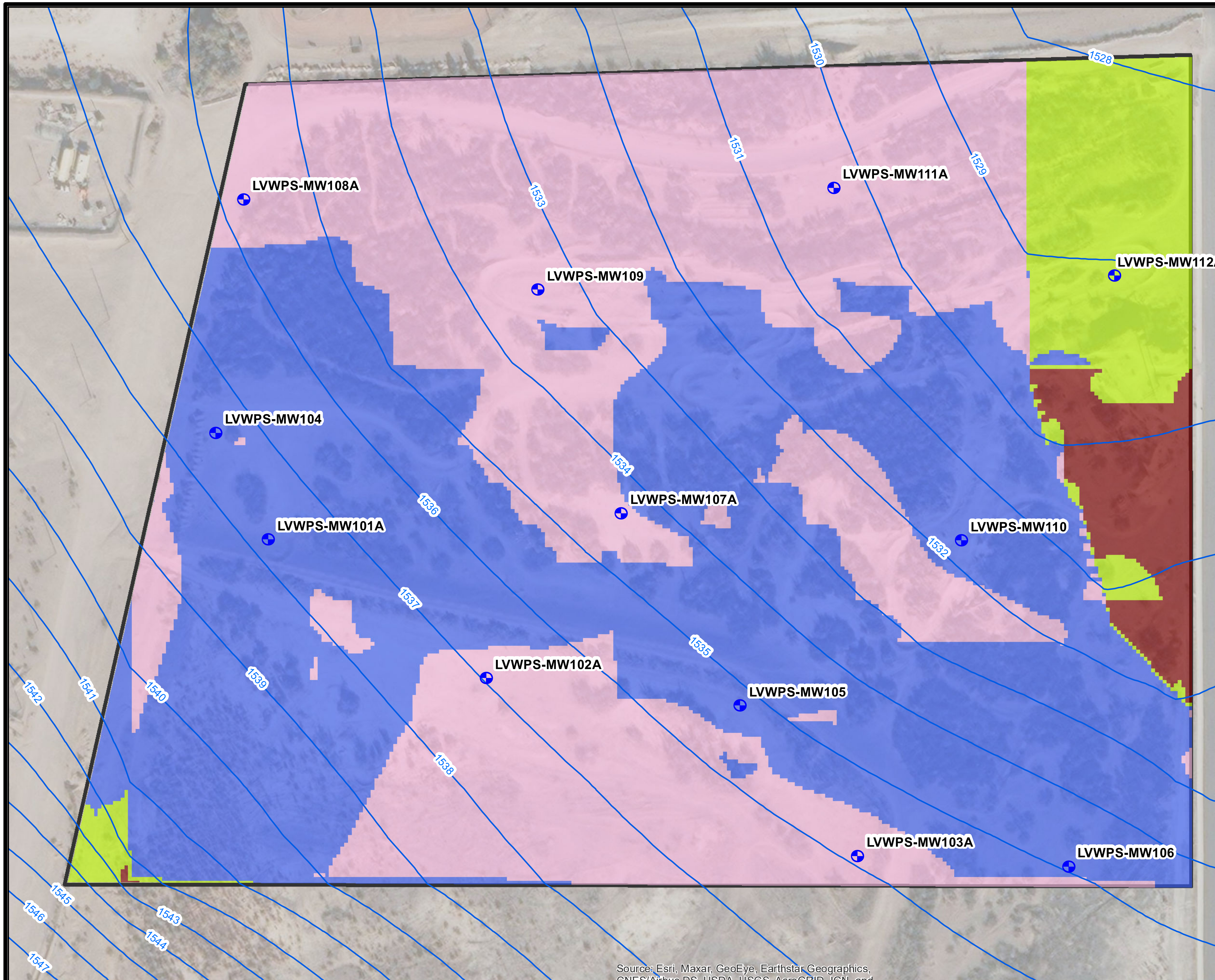
RAMBOLL

Proposed Extent of ZVI Area Model

Nevada Environmental Response Trust Site
Henderson, Nevada

Date:	Contract Number:		Figure
9/22/2021	1690016064-038		6-1
Drafter: AS	Approved:	Revised:	

Path: \\wcevfps1\ENG\LePetomane\NERT\GIS\RI\FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\Figure 6-1 - ZVI Model Extent within Phase 6 Model Area.mxd



Legend

- Transect 1A Monitoring Well
- Groundwater Elevation (ft amsl)
- ZVI Treatability Study Area

Groundwater Velocity (ft/d)

- <0.7
- 0.7-1.7
- 1.7-3.4
- >3.4

Notes:

ft/d = feet per day
ft amsl = feet above mean sea level

1. Groundwater velocities shown were estimated using a local scale model for the ZVI Treatability Study Area.

N

0 100 200 Feet

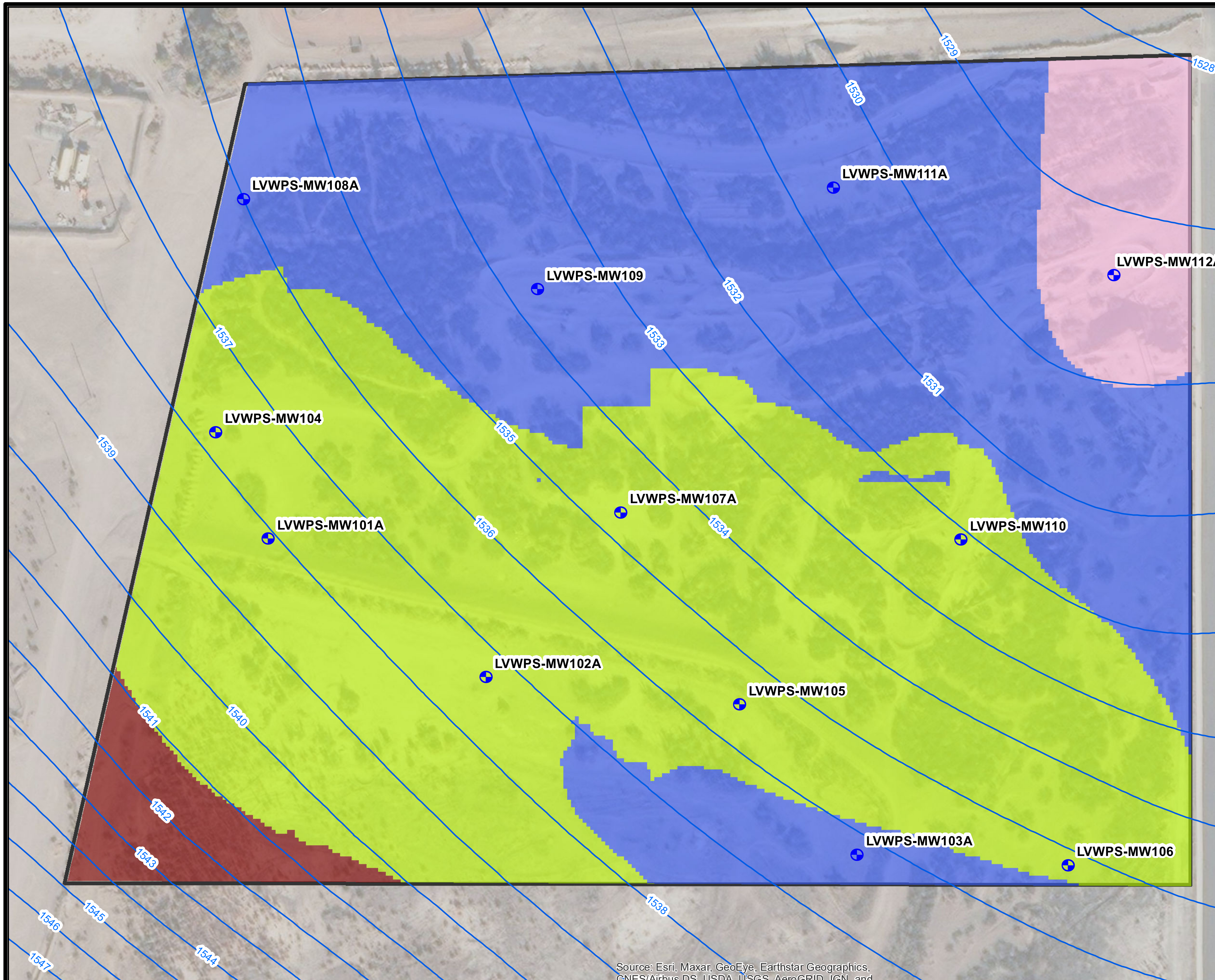
RAMBOLL

Estimated Groundwater Velocity Distribution in Alluvium

Nevada Environmental Response Trust Site
Henderson, Nevada

Date:	Contract Number:		Figure
9/22/2021	1690016064-038		6-2
Drafter: AS	Approved:	Revised:	

Path: H:\LePetomane\NERT\GIS\RI.FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\Figure 6-2 - Estimated GW Velocity Distribution_QAL.mxd



Legend

Transect 1A Monitoring Well

Groundwater Elevation (ft amsl)

ZVI Treatability Study Area

Groundwater Velocity (ft/d)

< 0.002

0.002 - 0.0035

0.0035 - 0.005

>0.005

Notes:

ft/d = feet per day

ft amsl = feet above mean sea level

UMCf = Upper Muddy Creek formation

1. Groundwater velocities shown were estimated using a local scale model for the ZVI Treatability Study Area.

N

0 100 200 Feet

RAMBOLL

Estimated Groundwater Velocity Distribution in UMCf

Nevada Environmental Response Trust Site
Henderson, Nevada

Date: 9/22/2021	Contract Number: 1690016064-038		Figure 6-3
Drafter: AS	Approved:	Revised:	

Path: H:\LePetomane\NERT\GIS\RI-FS_Treatability Studies\ZVI_TreatabilityStudy_NERT\Transect 1A\Figure 6-3 - Estimated GW Velocity Distribution_UMCf.mxd

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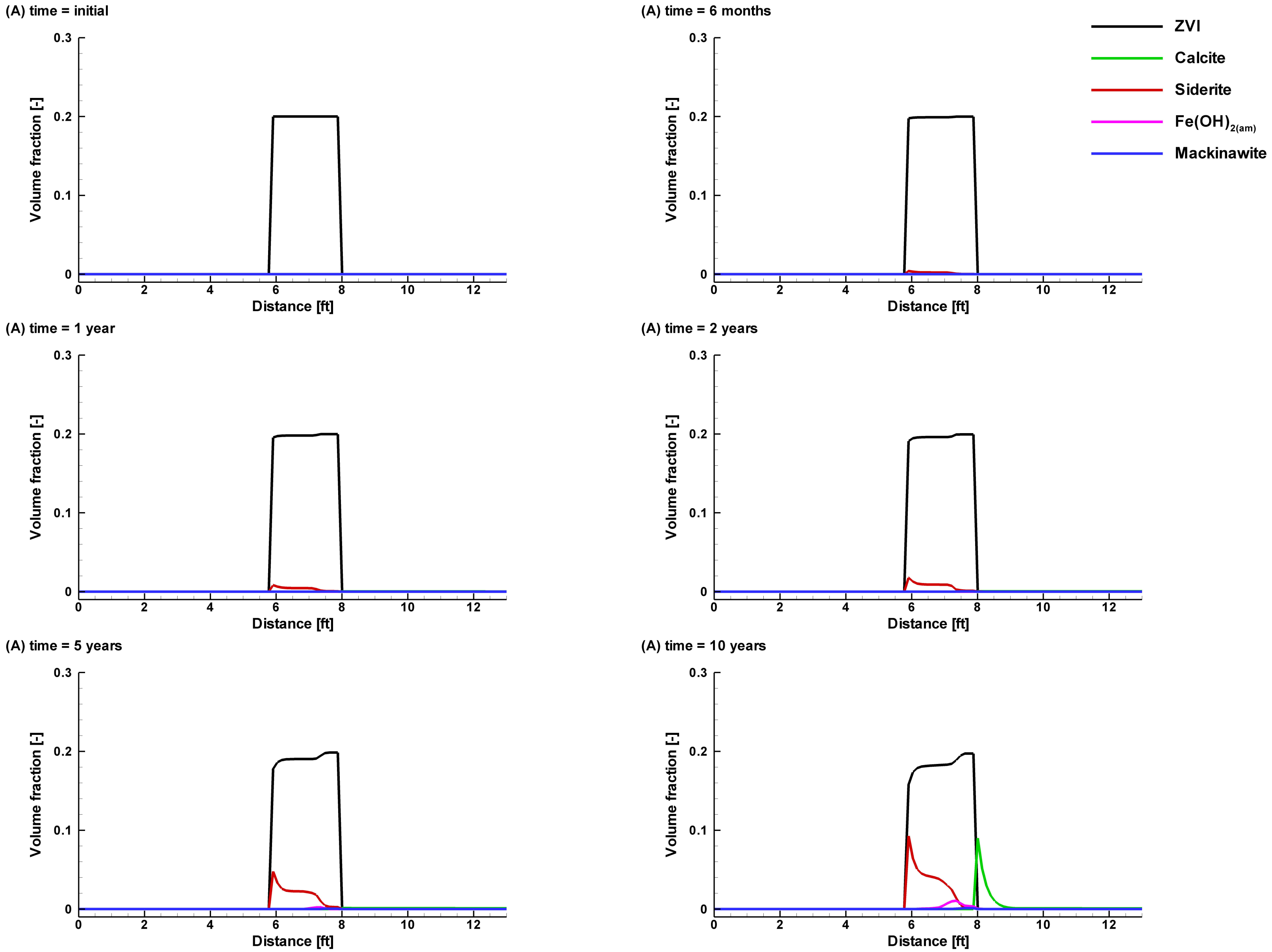


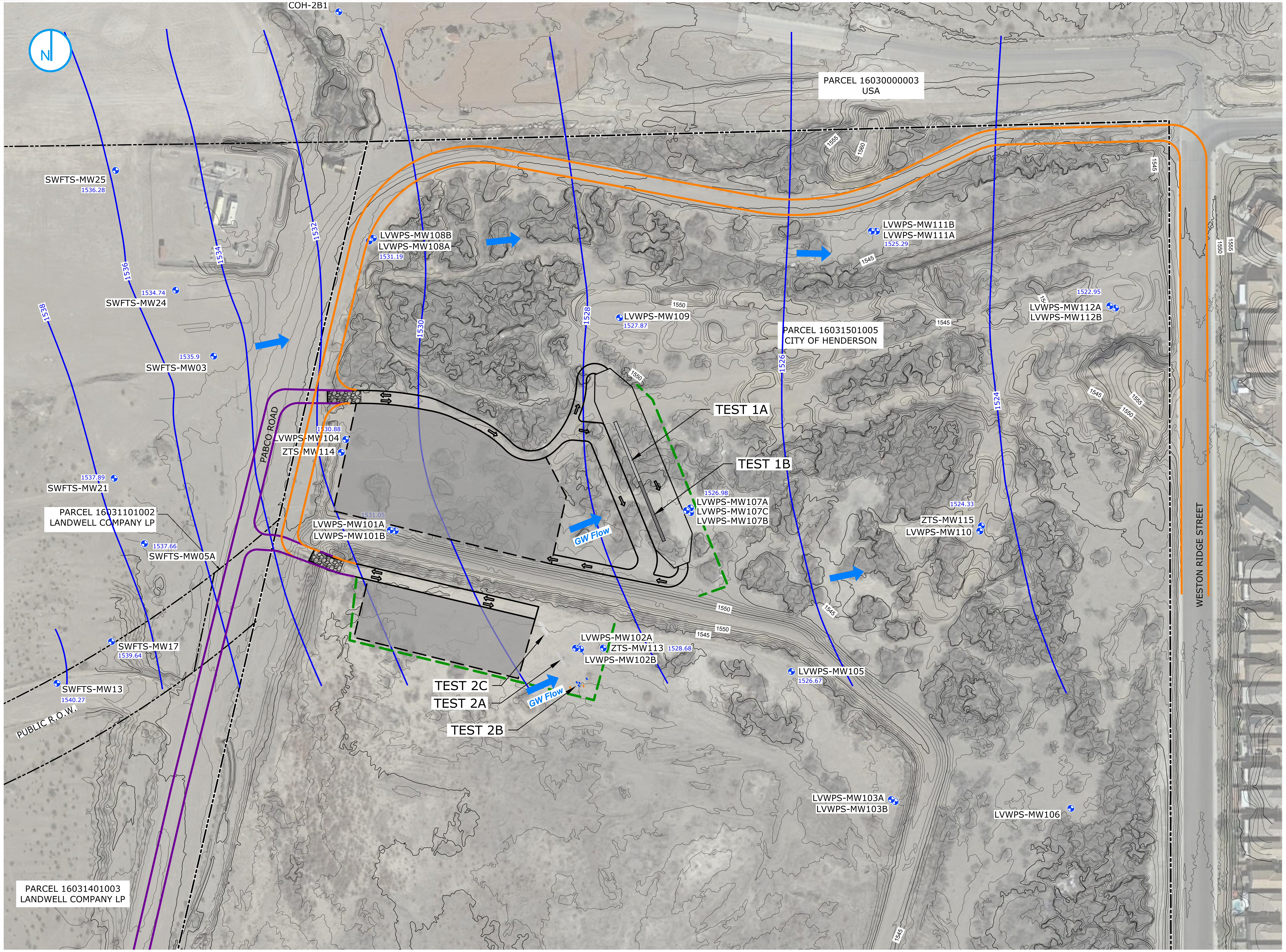
RAMBOLL

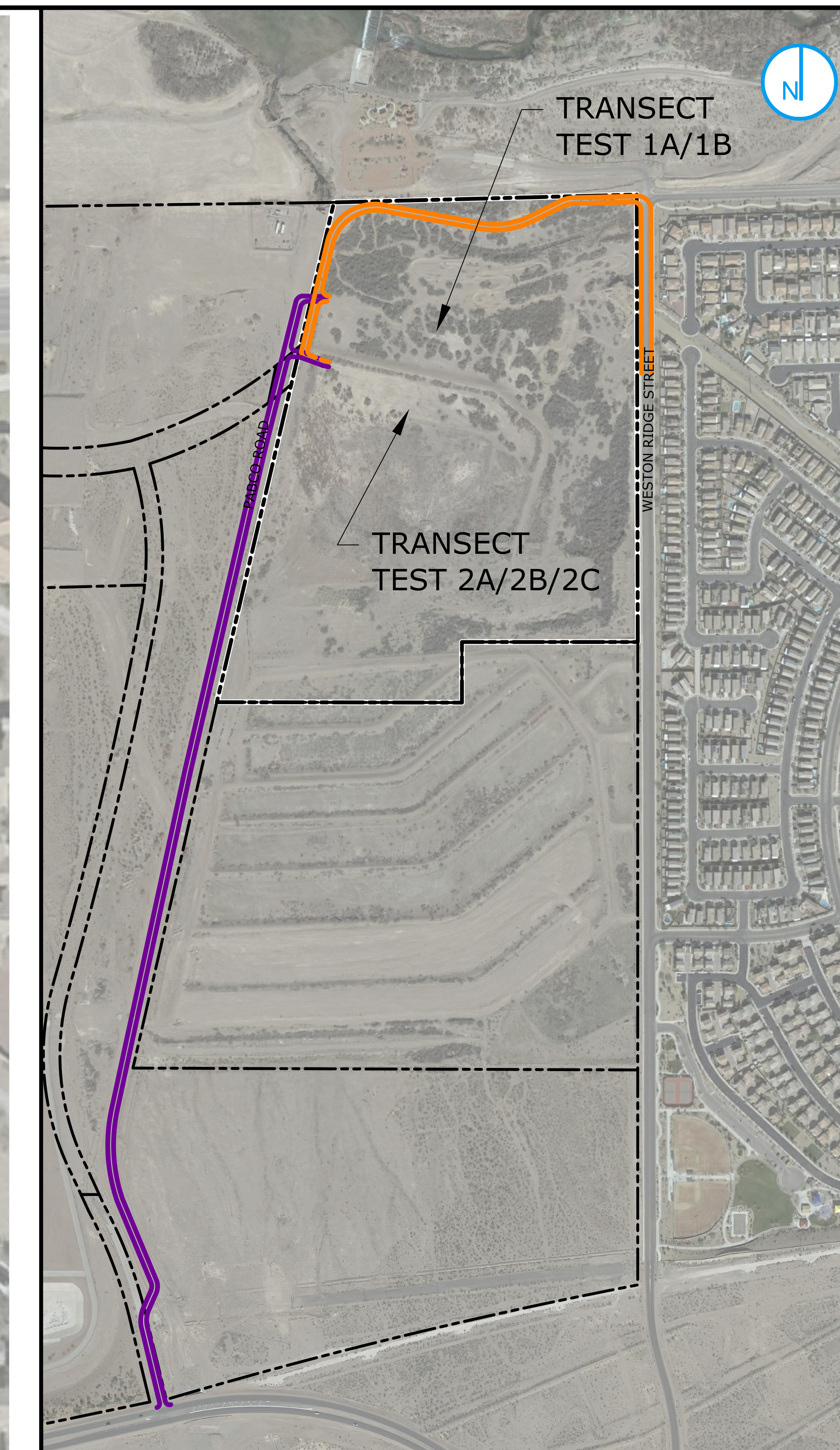
Reactive Transport Model Mineral Volume Fraction Profiles
Nevada Environmental Response Trust Site
Henderson, Nevada

Figure **6-4**

Drafter: PR | Date: 05/05/21 | Contract Number: 16900016064-038 | Approved: | Revised:

SAVED: 9/1/21 4:44 PM





KEY MAP
1"=500'

Legend:

- Property Boundary
- Existing Monitoring Well
- Silt Fence
- Alluvium Potentiometric Surface Contour (feet above mean sea level)
- Construction Traffic Direction
- Temporary Access Road During Construction or Other Access Provided Under Agreement with BEC
- Post Construction Temporary Access Road

80 0 80 160
SCALE IN FEET

SOURCE:
AERIAL IMAGERY: Google Earth. IMAGE DATE 02/12/2020.

F:\1690016064_NERT_WIP DRAFT\LAYOUT_PROPOSED.DWG

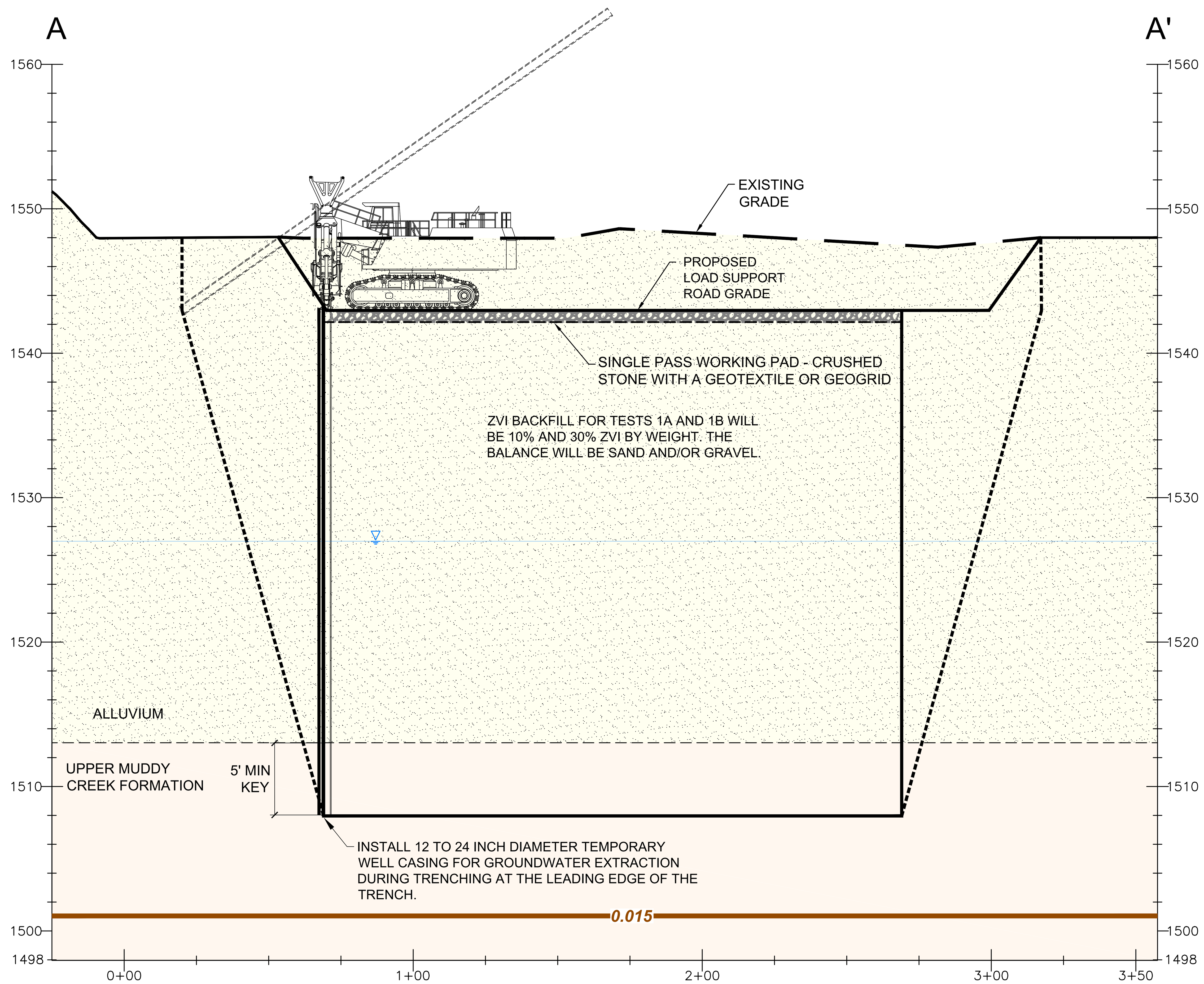
CLIENT	NO. / DATE / REVISION / INT.	DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE		PROJECT	SHEET DESCRIPTION	
NERT		DESIGNED BY: JS; CHECKED BY: JS; DRAWN BY: MB; PROJECT NO.: 1690016064; DATE: 09/01/2021	RAMBOLL US CONSULTING, INC. RAMBOLL	Nevada Environmental Response Trust (NERT); ADDRESS: HENDERSON, NEVADA	FIELD TEST LOCATIONS WITHIN THE TRANSECT 1A AREA	7-1

SAVED: 9/2/21 9:46 AM

CLIENT	DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE		PROJECT	SHEET DESCRIPTION	
NERT	DESIGNED BY: JS; CHECKED BY: JS; DRAWN BY: MB; PROJECT NO. 1690016064; DATE 09/01/2021	RAMBOLL US CONSULTING, INC. RAMBOLL	Nevada Environmental Response Trust (NERT); ADDRESS HENDERSON, NEVADA	FIELD TEST 1A AND 1B - LAYOUT AND ALIGNMENT OF ZVI CONTINUOUS WALLS	7-6

NO.	DATE	REVISION	INT.

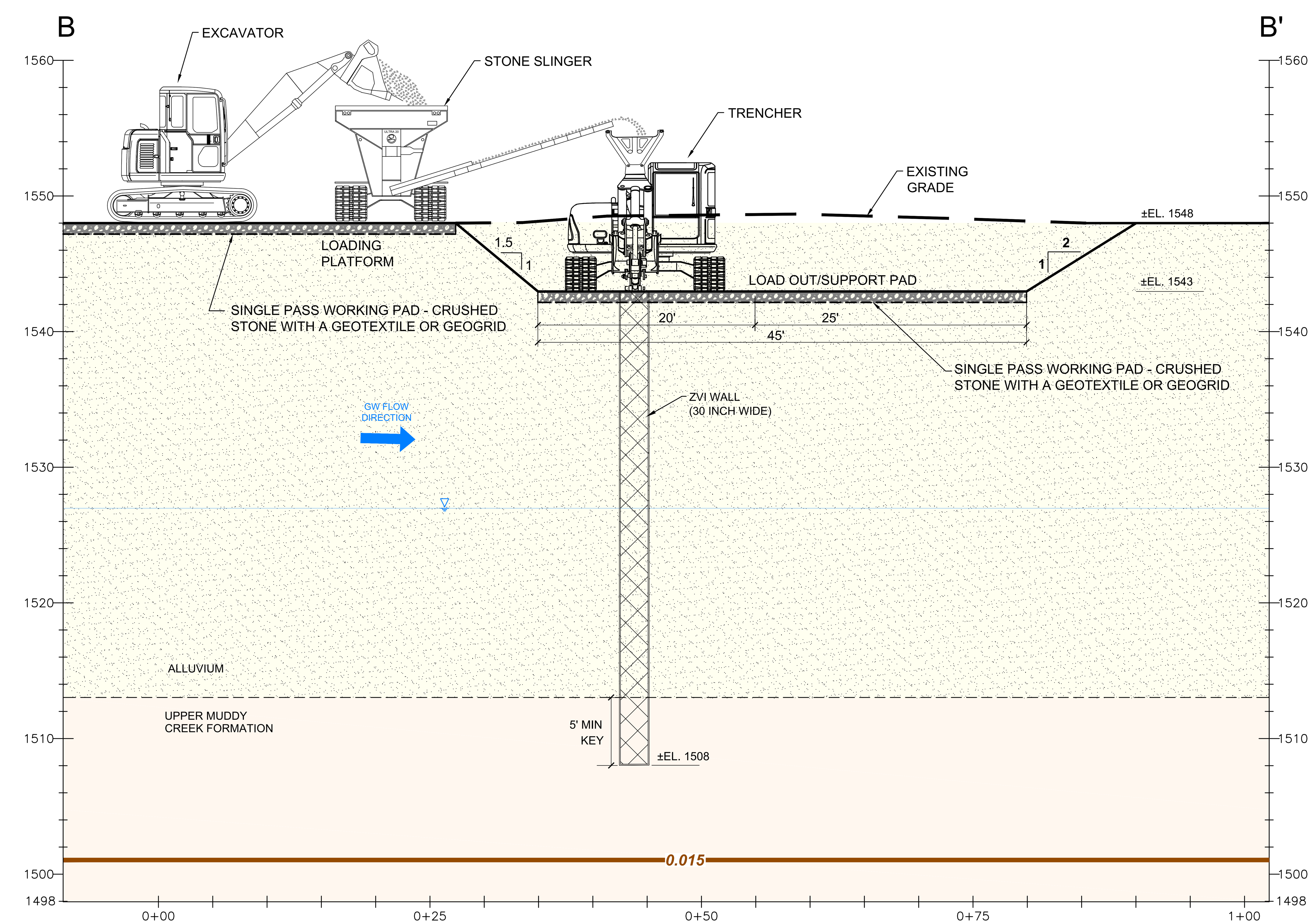
F:\1690016064_NERT_WIP DRAFT\LAYOUT_PROPOSED.DWG



CONTINUOUS ZVI WALL - PROFILE

HORIZ. SCALE: 1" = 30' (30' 0 30')

VERT. SCALE: 1" = 6' (6' 0 6')



CONTINUOUS ZVI WALL INSTALLATION - CROSS SECTION

HORIZ. SCALE: 1" = 7.5' (7.5' 0 7.5')

VERT. SCALE: 1" = 6' (6' 0 6')

LEGEND

0.015 mg/L — PERCHLORATE CONCENTRATION LIMIT

ALLUVIUM (Qal)	
GRAVEL/ SANDY GRAVEL	SAND, SILTY AND GRAVELLY

UPPER MUDDY CREEK FORMATION (UMCf)	
SILT/SILT WITH SAND (Mudflat sediments)	SILT/CLAYEY SILT WITH GYPSUM (Saline lake sediments)

NOTES:

1. THE ONE PASS TRENCHING SYSTEM SHALL BE USED TO INSTALL THE PERMEABLE ZVI WALL.
2. THE CONTINUOUS ZVI WALL PLAN AND PROFILE, INCLUDING, BUT NOT LIMITED TO, ALL UNDERGROUND AND ABOVE GROUND STRUCTURES AND UTILITIES ARE CONSIDERED APPROXIMATE ONLY.
3. THE SUBSURFACE PROFILE IS A INTERPRETATION OF THE STRATIGRAPHY ALONG THE HORIZONTAL PLAN VIEW OF THE CONTINUOUS ZVI WALL LOCATION. THE ACTUAL CONDITIONS ENCOUNTERED MAY DIFFER FROM THOSE SHOWN.
4. STATIONING SHOWN DOES NOT REFLECT THE LENGTH OF THE CONTINUOUS ZVI WALL AND IS SHOWN FOR REFERENCE PURPOSES ONLY.
5. THE DEPTH/ELEVATION TO THE CONTACT BETWEEN THE ALLUVIUM AND UMCF, DEPTH TO GROUNDWATER, AND THE BENCH-DOWN DEPTH IS FOR ILLUSTRATION PURPOSES. DESIGN DEPTHS/ELEVATIONS WILL BE DEFINED FOLLOWING THE PRE-CONSTRUCTION ACTIVITIES.

NO.	DATE	REVISION	INT.

CLIENT: NERT

DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE
DESIGNED BY: JS — PROJECT NO.: 1690016064
CHECKED BY: JS — DATE: 09/01/2021
DRAWN BY: MB

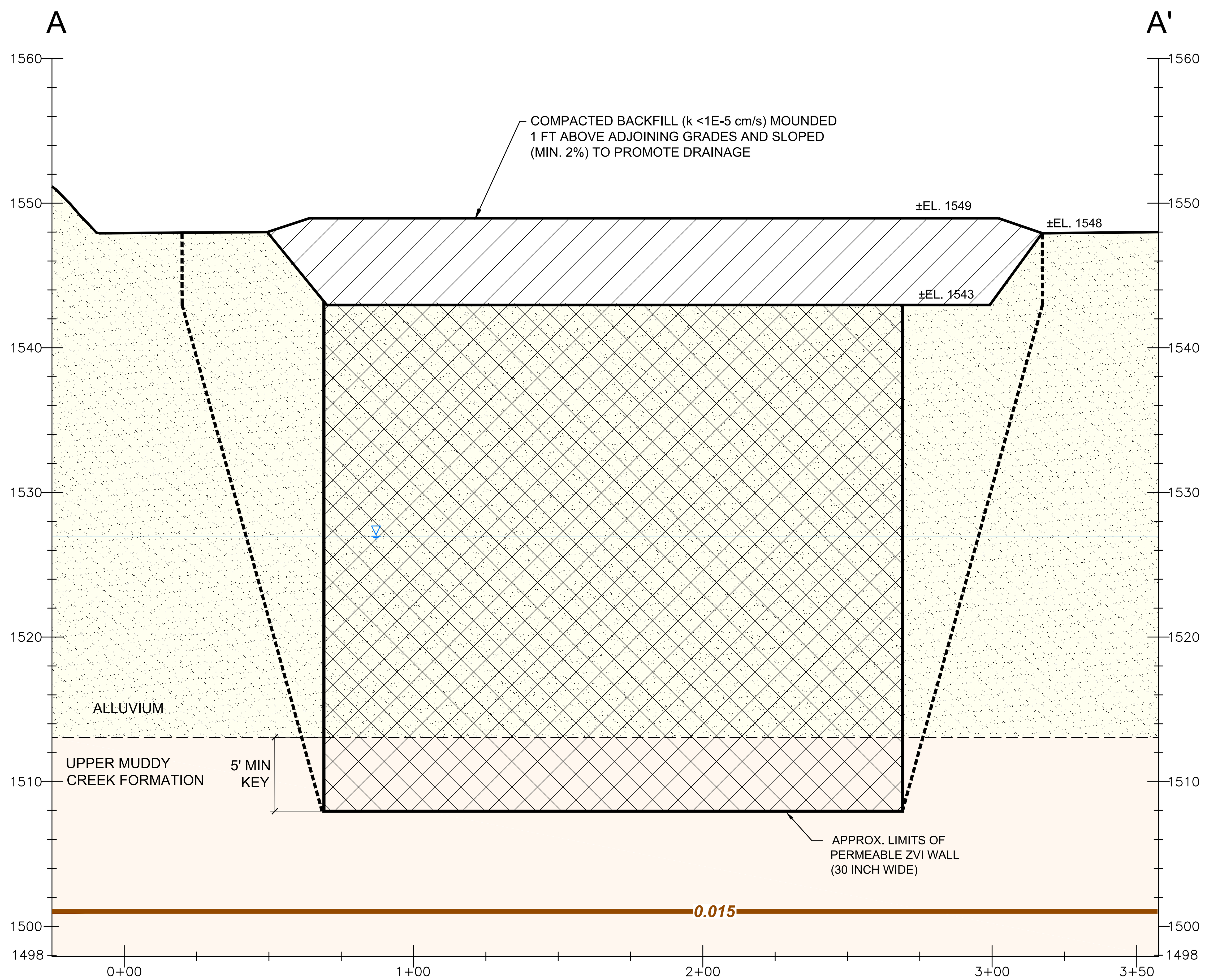
CERTIFICATE OF AUTHORIZATION: RAMBOLL US CONSULTING, INC.

PROJECT: Nevada Environmental Response Trust (NERT)
ADDRESS: HENDERSON, NEVADA

SHEET DESCRIPTION: FIELD TEST 1A AND 1B - CROSS-SECTION AND PROFILE OF CONTINUOUS ZVI WALLS DURING CONSTRUCTION

7-7

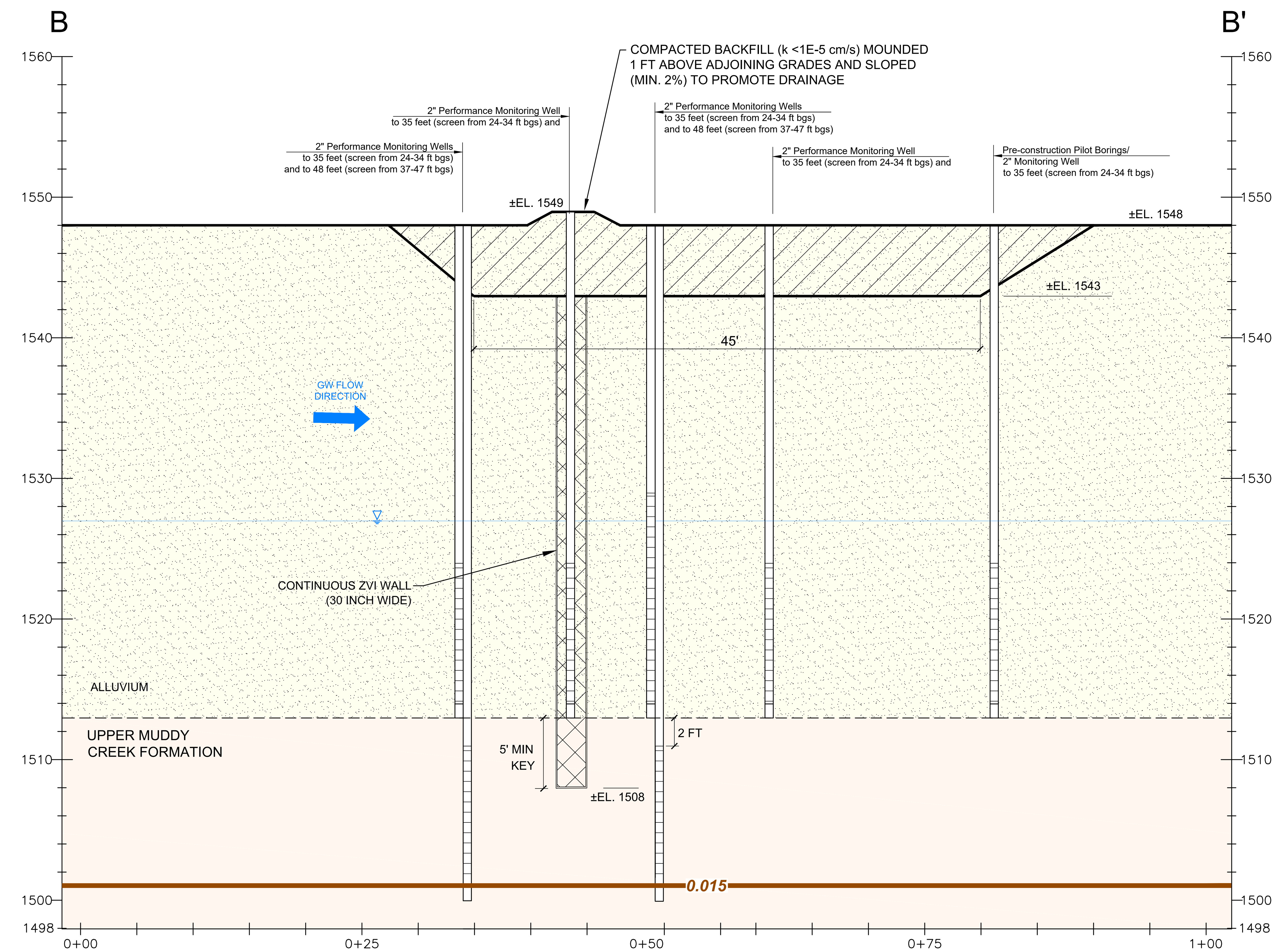
SAVED: 9/2/21 10:06 AM



CONTINUOUS ZVI WALL - PROFILE

HORIZ. SCALE: 1" = 30'

VERT. SCALE: 1" = 6'



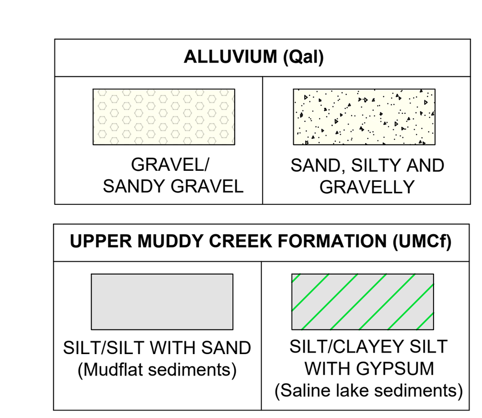
CONTINUOUS ZVI WALL INSTALLATION - CROSS SECTION

HORIZ. SCALE: 1" = 7.5'

VERT. SCALE: 1" = 6'

LEGEND

0.015 mg/L — PERCHLORATE CONCENTRATION LIMIT



NOTES:

1. THE ONE PASS TRENCHING SYSTEM SHALL BE USED TO INSTALL THE PERMEABLE ZVI WALL.
2. THE CONTINUOUS ZVI WALL PLAN AND PROFILE, INCLUDING, BUT NOT LIMITED TO, ALL UNDERGROUND AND ABOVE GROUND STRUCTURES AND UTILITIES ARE CONSIDERED APPROXIMATE ONLY.
3. THE SUBSURFACE PROFILE IS A INTERPRETATION OF THE STRATIGRAPHY ALONG THE HORIZONTAL PLAN VIEW OF THE CONTINUOUS ZVI WALL LOCATION. THE ACTUAL CONDITIONS ENCOUNTERED MAY DIFFER FROM THOSE SHOWN.
4. STATIONING SHOWN DOES NOT REFLECT THE LENGTH OF THE CONTINUOUS ZVI WALL AND IS SHOWN FOR REFERENCE PURPOSES ONLY.
5. THE DEPTH/ELEVATION TO THE CONTACT BETWEEN THE ALLUVIUM AND UMCF, DEPTH TO GROUNDWATER, AND THE BENCH-DOWN DEPTH IS FOR ILLUSTRATION PURPOSES. DESIGN DEPTHS/ELEVATIONS WILL BE DEFINED FOLLOWING THE PRE-CONSTRUCTION ACTIVITIES.

CLIENT
NERT

NO.	DATE	REVISION	INT.

DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE

DESIGNED BY: JS — PROJECT NO. 1690016064
CHECKED BY: JS — DATE 09/01/2021
DRAWN BY: MB

CERTIFICATE OF AUTHORIZATION:
RAMBOLL US CONSULTING, INC.

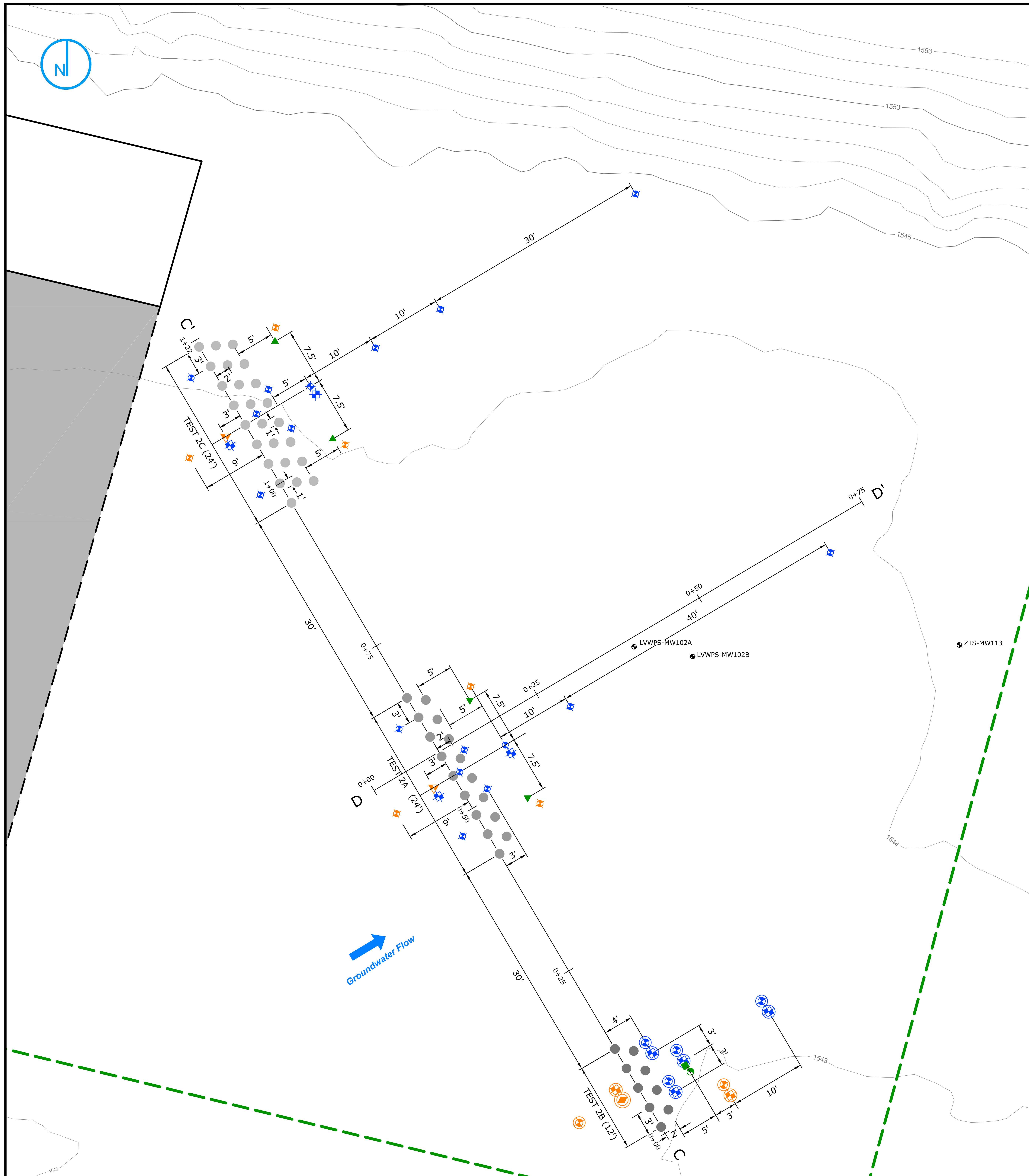
RAMBOLL

PROJECT
Nevada Environmental Response Trust (NERT)
ADDRESS
HENDERSON, NEVADA

SHEET DESCRIPTION
FIELD TEST 1A AND 1B - CROSS-SECTION AND PROFILE OF CONTINUOUS ZVI WALLS POST-CONSTRUCTION

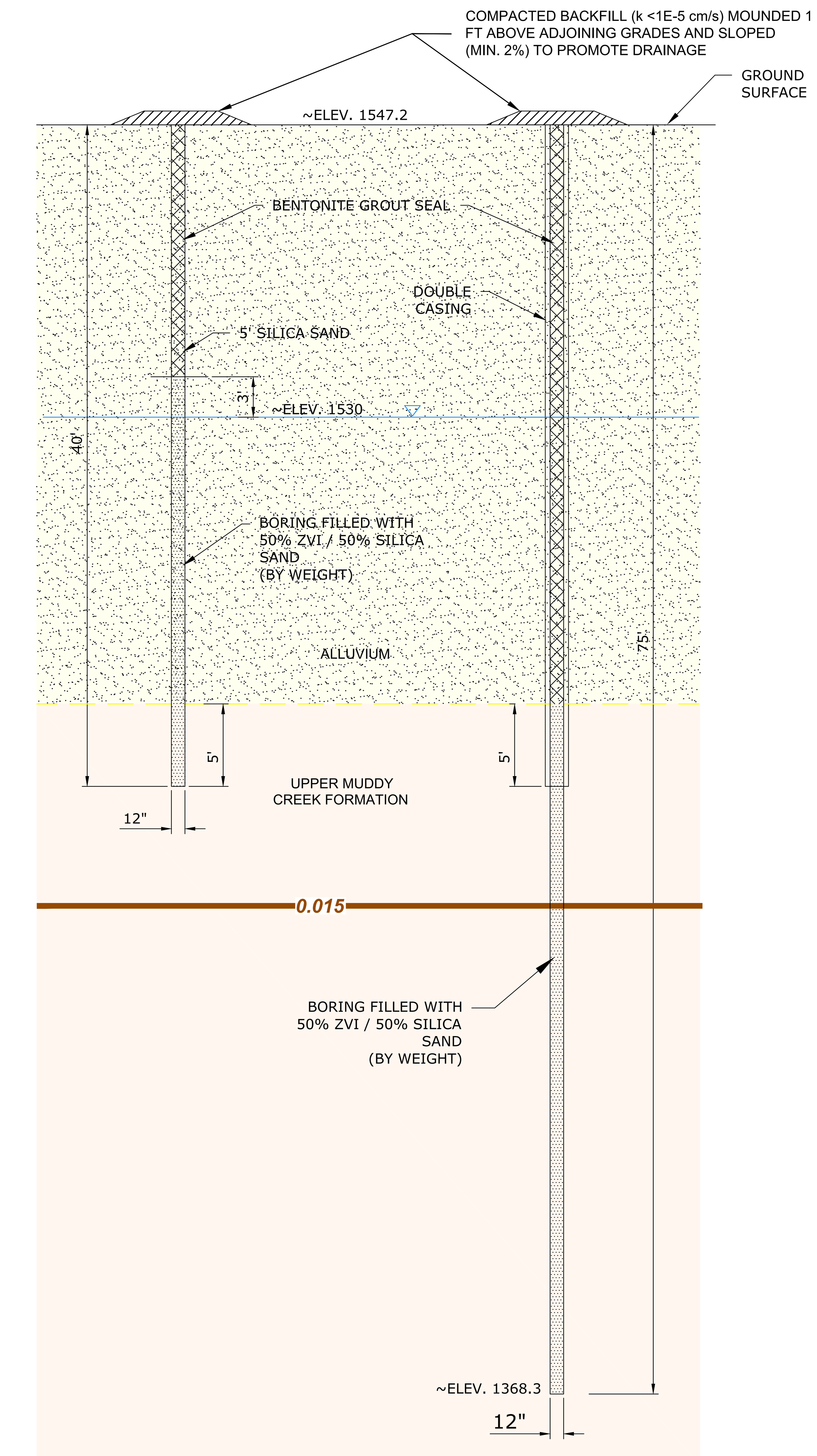
7-8

F:\1690016064_NERT_WIP DRAFT\PROFILE.DWG



Legend:

- Existing well
- 2" Performance Monitoring Well (Shallow) to 35 feet (screen from 24-34 ft bgs)
- 2" Performance Monitoring Well (Deep) to 48 feet (screen from 37-47 ft bgs)
- 2" Performance Monitoring Well (Deep) to 55 feet (screen from 39-54 ft bgs)
- 2" Performance Monitoring Well (Deep) to 75 feet (screen from 59-74 ft bgs)
- Pre-Construction Pilot Borings/2" Monitoring Wells (shallow) to 35 feet (screen from 24-34 ft bgs)
- Pre-Construction Pilot Borings/2" Monitoring Wells (deep) to 55 feet (screen from 39-54 ft bgs)
- Pre-Construction Pilot Borings/2" Monitoring Wells (deep) to 75 feet (screen from 59-74 ft bgs)
- Pre-Construction Pilot Borings/4" Monitoring Wells (shallow) to 40 feet (screen from 24-34 ft bgs)
- Pre-Construction Pilot Borings/4" Monitoring Wells (deep) to 75 feet (screen from 39-54 ft bgs)
- 2" Injection Well (alluvium) to 35 feet (screen from 19-34 ft bgs)
- 2" Injection Well (upper UMCf) to 56 feet (screen from 40-55 ft bgs)
- 2" Injection Well (lower UMCf) to 76 feet (screen from 60-75 ft bgs)
- Silt Fence
- Construction Traffic Direction
- *0.015 mg/L* Perchlorate Concentration Limit



A) TEST 2A/2C ZVI BORING

B) TEST 2B ZVI BORING

ZVI TEST 2 : TYPICAL COMPLETED ZVI BACKFILLED BORING CROSS SECTION

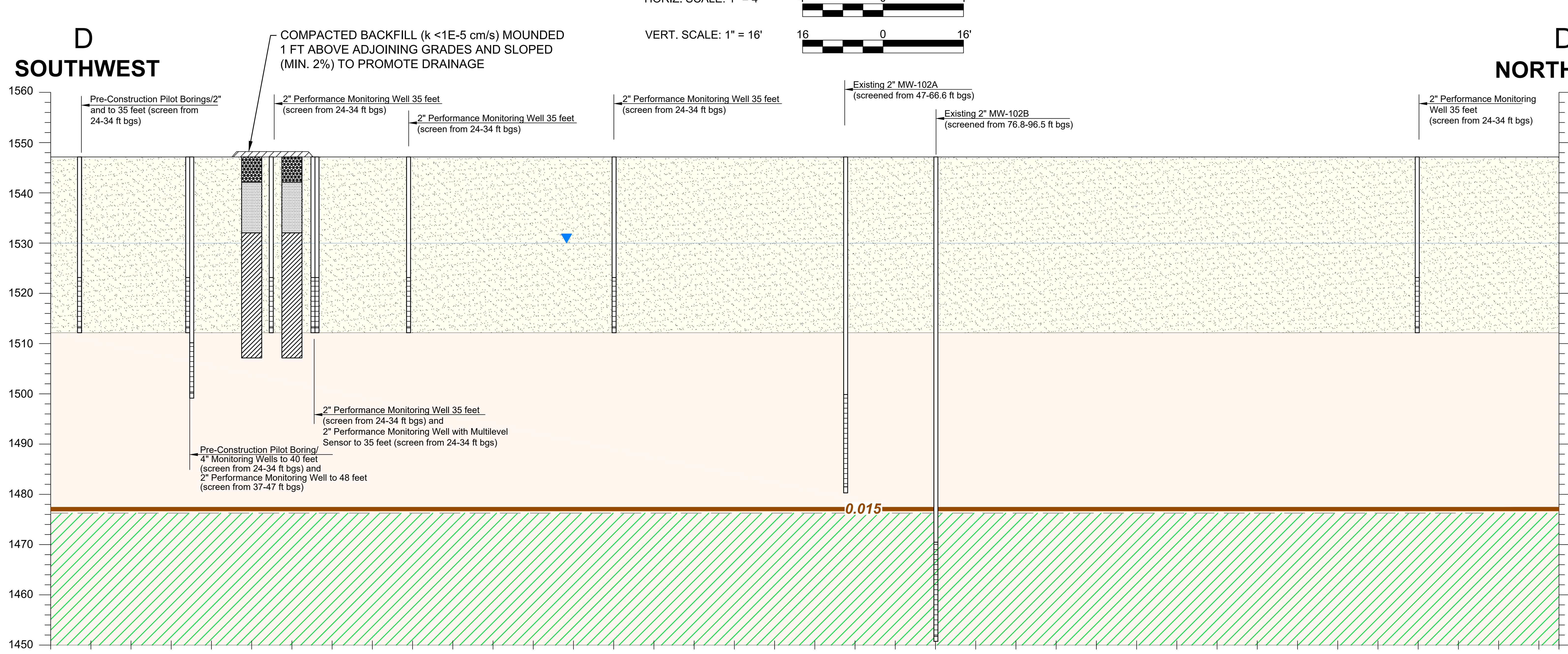
8 0 8 16
SCALE IN FEET

CLIENT	NO.	DATE	REVISION	INT.	DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE		PROJECT	SHEET DESCRIPTION	
NERT					DESIGNED BY: JS; PROJECT NO.: 1690016064; CHECKED BY: JS; DATE: 09/01/2021; DRAWN BY: MB	RAMBOLL US CONSULTING, INC. RAMBOLL	Nevada Environmental Response Trust (NERT); ADDRESS: HENDERSON, NEVADA	FIELD TEST 2A, 2B AND 2C - LAYOUT AND ALIGNMENT OF DISCONTINUOUS ZVI WALLS	7-9

DISCONTINUOUS ZVI WALL PROFILE

HORIZ. SCALE: 1" = 4' 4' 0 4'

VERT. SCALE: 1" = 16' 16 0 16'



DISCONTINUOUS ZVI WALL SECTION

HORIZ. SCALE: 1" = 4' 4' 0 4'

VERT. SCALE: 1" = 16' 16 0 16'

NOTES:

1. THE DISCONTINUOUS ZVI WALL PLAN AND PROFILE, INCLUDING, BUT NOT LIMITED TO, ALL UNDERGROUND AND ABOVE GROUND STRUCTURES AND UTILITIES ARE CONSIDERED APPROXIMATE ONLY.
2. THE SUBSURFACE PROFILE IS A INTERPRETATION OF THE STRATIGRAPHY ALONG THE HORIZONTAL PLAN VIEW OF THE ZVI WALL LOCATION. THE ACTUAL CONDITIONS ENCOUNTERED MAY DIFFER FROM THOSE SHOWN.
3. STATIONING SHOWN DOES NOT REFLECT THE LENGTH OF THE ZVI WALL AND IS SHOWN FOR REFERENCE PURPOSES ONLY.
4. THE DEPTH/ELEVATION TO THE CONTACT BETWEEN THE ALLUVIUM AND UMCF, DEPTH TO GROUNDWATER, AND THE BENCH-DOWN DEPTH IS FOR ILLUSTRATION PURPOSES. DESIGN DEPTHS WILL BE DEFINED FOLLOWING THE PRE-CONSTRUCTION ACTIVITIES.

LEGEND

- BENTONITE GROUT SEAL
- SILICA SAND
- 50% ZVI / 50% SILICA SAND (BY WEIGHT)
- *0.015 mg/L* PERCHOLORATE CONCENTRATION LIMIT

ALLUVIUM (Qal)
- GRAVEL/ SANDY GRAVEL
- SAND, SILTY AND GRAVELLY

UPPER MUDDY CREEK FORMATION (UMCf)
- SILT/SILT WITH SAND (Mudflat sediments)
- SILT/CLAYEY SILT WITH GYPSUM (Saline lake sediments)

CLIENT: NERT

NO.	DATE	REVISION	INT.

DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE
DESIGNED BY: JS — PROJECT NO.: 1690016064
CHECKED BY: JS — DATE: 09/01/2021
DRAWN BY: MB

CERTIFICATE OF AUTHORIZATION:
RAMBOLL US CONSULTING, INC.

RAMBOLL

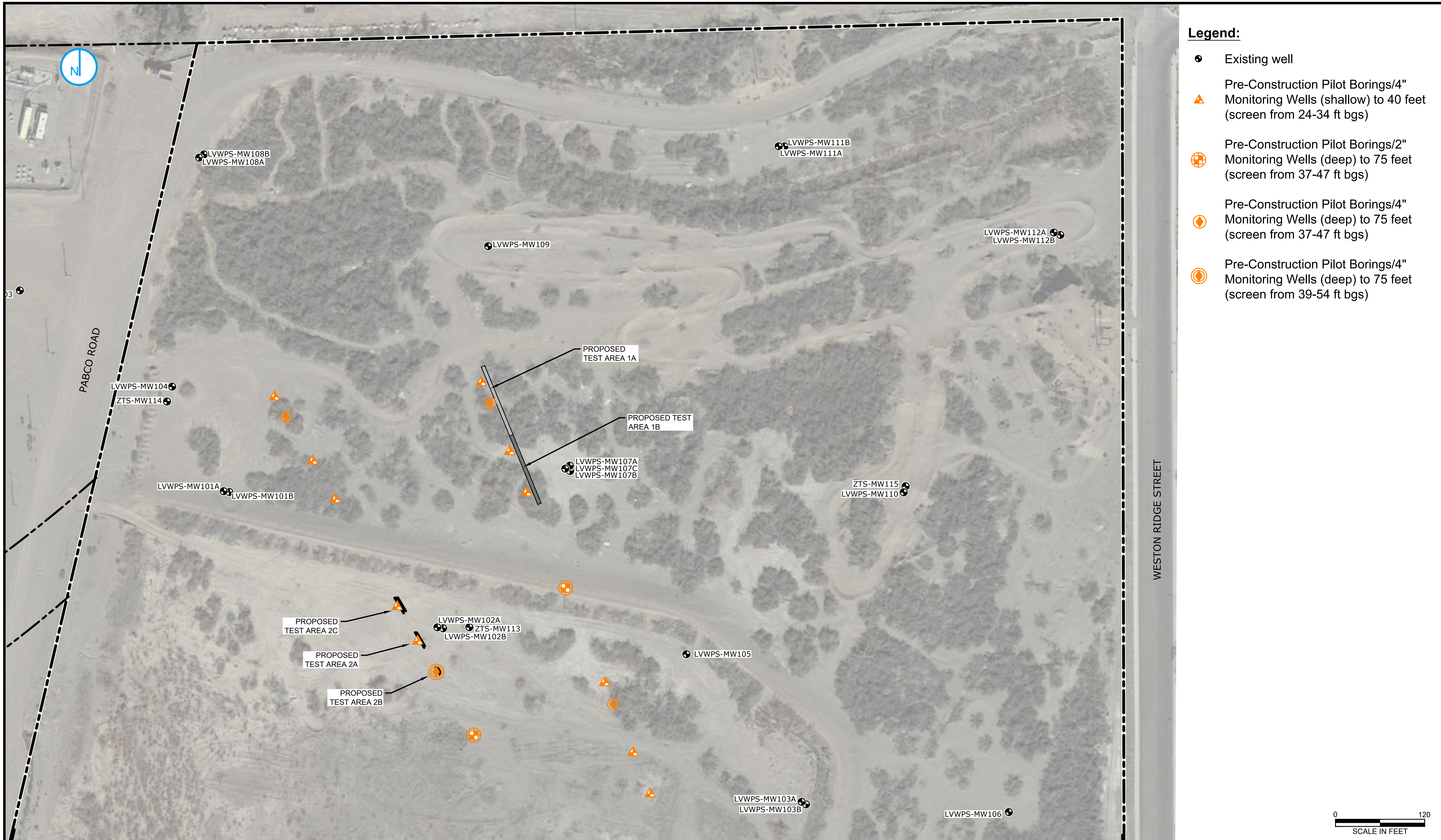
PROJECT: Nevada Environmental Response Trust (NERT)
ADDRESS: HENDERSON, NEVADA

SHEET DESCRIPTION: FIELD TEST 2A, 2B AND 2C - CROSS-SECTION OF DISCONTINUOUS ZVI WALLS

7-10

SAVED: 9/2/21 9:39 AM

F:1690016064_NERT_WIP DRAFT\PROFILE.DWG



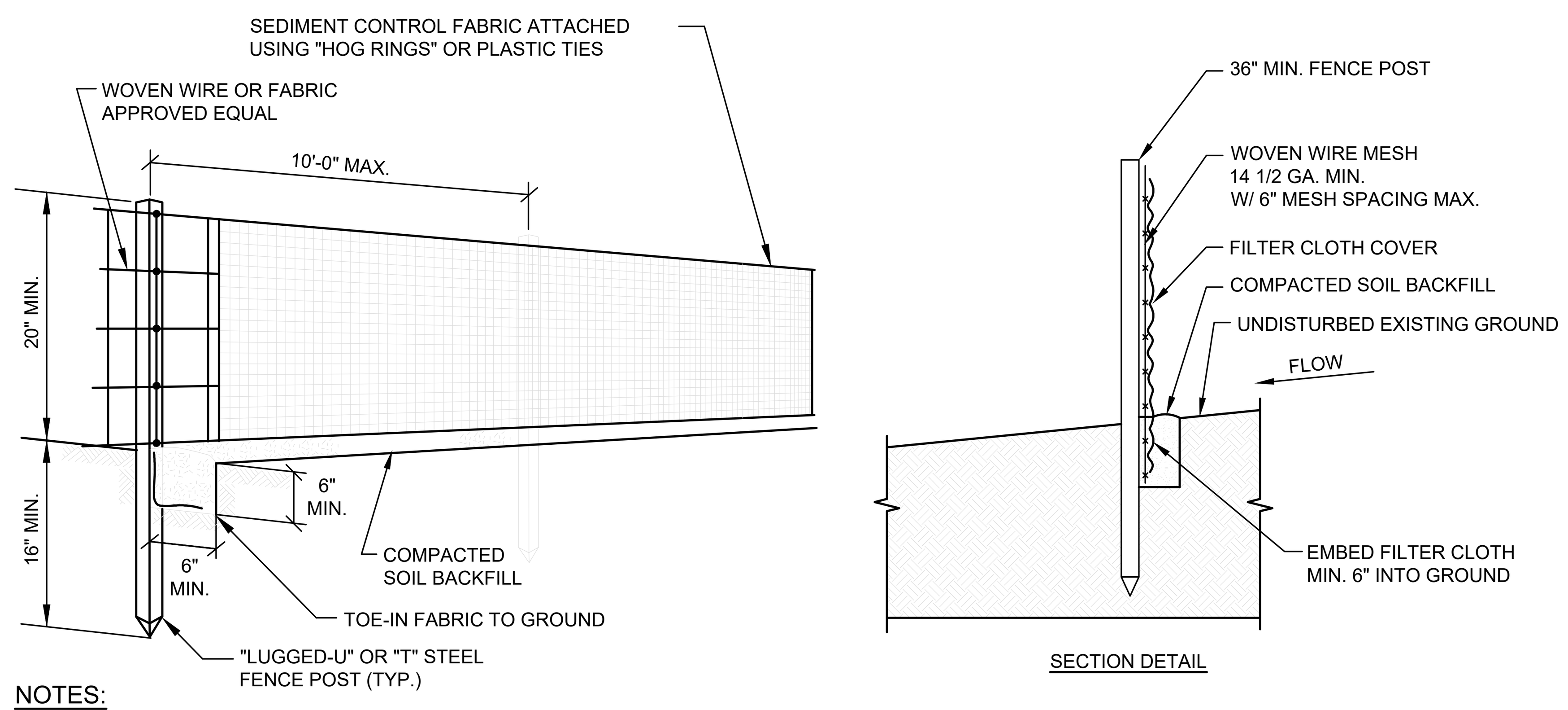
RAMBOLL

INITIAL PRE-CONSTRUCTION BORINGS AND MONITORING WELLS

Nevada Environmental Response Trust Site;
Henderson, Nevada

Figure **7-11**

Drafter: MB	Date: 07/09/2021	Contract Number: 1690016064	Approved by:	Revised:



NOTES:

1. WOVEN WIRE FENCE TO BE FASTENED SECURELY TO FENCE POSTS WITH WIRE TIES OR STAPLES.
2. FILTER CLOTH TO BE FASTENED SECURELY TO WOVEN WIRE FENCE WITH TIES SPACED EVERY 24" AT TOP AND MID SECTION.
3. WHEN TWO SECTIONS OF FILTER CLOTH ADJOIN EACH OTHER THEY SHALL BE OVER-LAPPED BY SIX INCHES AND FOLDED.
4. MAINTENANCE SHALL BE PERFORMED AS NEEDED AND MATERIAL REMOVED WHEN "BULGES" DEVELOP IN THE SILT FENCE.
5. FENCE TO BE ALIGNED ALONG CONTOUR AS CLOSELY AS POSSIBLE.
6. SILT FENCE MUST BE INSTALLED AT LEVEL GRADE. BOTH ENDS OF EACH FENCE SECTION MUST EXTEND AT LEAST 10 FEET UP SLOPE AT 45 DEGREES TO THE MAIN FENCE ALIGNMENT.
7. SEDIMENT MUST BE REMOVED WHERE ACCUMULATIONS REACH 1/2 THE ABOVE GROUND HEIGHT OF THE FENCE.
8. ANY FENCE SECTION WHICH HAS BEEN UNDERMINED OR TOPPED MUST BE IMMEDIATELY REPLACED.
9. COMPOSITE FILTER SOCK MAY BE USED IN LIEU OF PREFABRICATED SILT FENCE. SEE COMPOSITE FILTER SOCK DETAIL THIS SHEET.

POSTS : STEEL EITHER T OR U TYPE OR 2" HARDWOOD

FENCE : WOVEN WIRE 14.5 GAUGE 6" MAX MESH OPENING

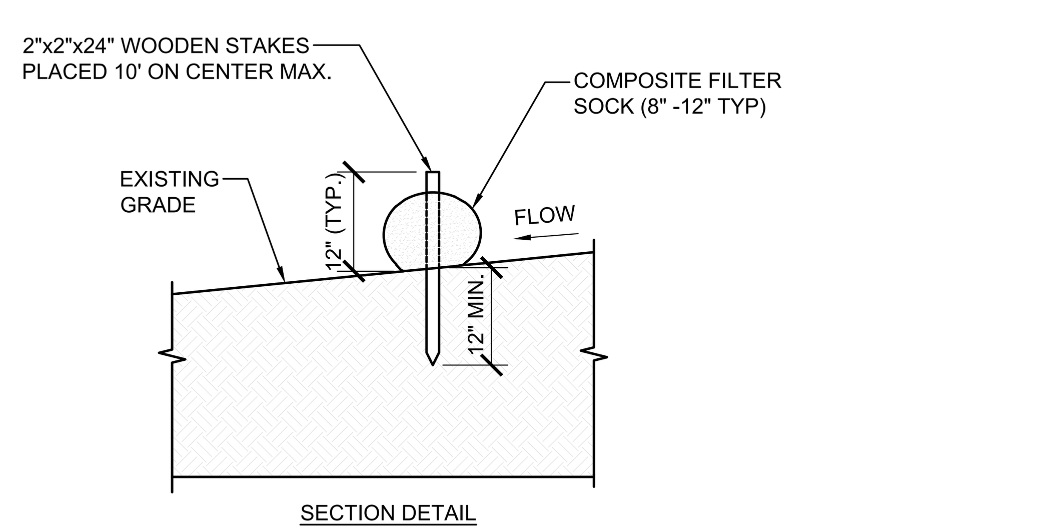
FILTER CLOTH : MINIMUM TENSILE STRENGTH OF 120 LBS. (ASTM D-16826)

PREFABRICATED UNIT : PREFABRICATED FENCE IS ACCEPTABLE OR APPROVED EQUAL.

STANDARD SYMBOL —— SF —— SF

A SILT FENCE DETAIL

NOT TO SCALE



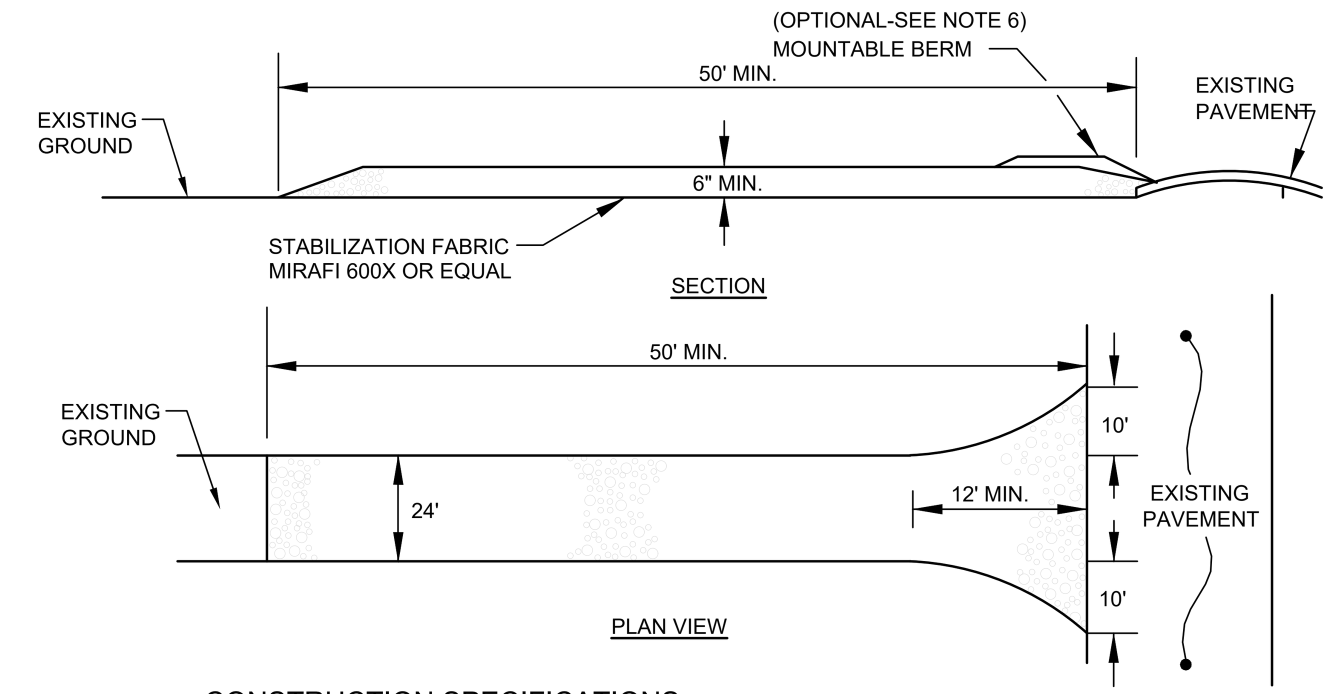
DETAIL NOTES:

1. STAKES SHALL BE INSTALLED THROUGH THE MIDDLE OF THE COMPOSITE FILTER SOCK AT 10' INTERVALS MAXIMUM USING HARDWOOD STAKES.
2. COMPOSITE FILTER SOCK TO BE ALIGNED ALONG CONTOUR AS CLOSELY AS POSSIBLE.
3. BOTH ENDS OF EACH COMPOSITE FILTER SOCK SECTION MUST EXTEND AT LEAST 10 FEET UP SLOPE AT 45 DEGREES TO THE MAIN COMPOSITE FILTER SOCK ALIGNMENT.
4. SEDIMENT MUST BE REMOVED WHERE ACCUMULATIONS REACH 1/2 THE ABOVE GROUND HEIGHT OF THE COMPOSITE FILTER SOCK.
5. ANY COMPOSITE FILTER SOCK SECTION WHICH HAS BEEN UNDERMINED OR TOPPED MUST BE IMMEDIATELY REPAIRED OR REPLACED AT NO ADDITIONAL COST TO THE OWNER.

STANDARD SYMBOL —— SB —— SB

B COMPOSITE FILTER SOCK DETAIL

NOT TO SCALE

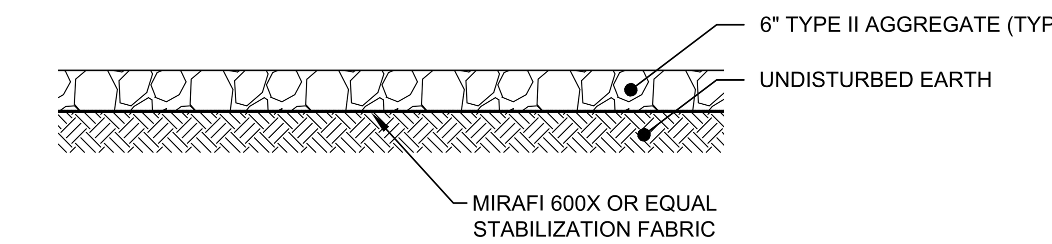


CONSTRUCTION SPECIFICATIONS:

1. STONE SIZE - USE 2" STONE.
2. LENGTH - AS REQUIRED, BUT NOT LESS THAN 50 FEET
3. THICKNESS - NOT LESS THAN SIX (6) INCHES
4. WIDTH-(24) TWENTY-FOUR FEET MINIMUM, BUT NOT LESS THAN THE FULL WIDTH AT POINTS WHERE EGRESS OCCURS.
5. STABILIZATION FABRIC (MIRAFI 600X OR EQUAL) - WILL BE PLACED OVER THE ENTIRE AREA PRIOR TO PLACING OF STONE.
6. SURFACE WATER - ALL SURFACE WATER FLOWING OR DIVERTED TOWARDS CONSTRUCTION ENTRANCES SHALL BE PIPED ACROSS THE ENTRANCE. IF PIPING IS NOT POSSIBLE, A MOUNTABLE BERM 3' WIDE (MIN.) WITH 5:1 SLOPES WILL BE PERMITTED.
7. MAINTENANCE - THE ENTRANCES SHALL BE MAINTAINED IN A CONDITION THAT WILL PREVENT TRACKING OR FLOWING OF SEDIMENT ONTO PUBLIC RIGHTS-OF-WAY. THIS MAY REQUIRE PERIODIC TOP DRESSING WITH ADDITIONAL STONE AS CONDITIONS DEMAND AND REPAIR AND/OR CLEANOUT OF ANY MEASURES USED TO TRAP SEDIMENT. ALL SEDIMENT SPILLED, DROPPED, WASHED OR TRACKED ONTO PUBLIC RIGHTS-OF-WAY MUST BE REMOVED IMMEDIATELY.
8. WASHING - WHEELS SHALL BE CLEANED TO REMOVE SEDIMENT PRIOR TO ENTRANCE ONTO PUBLIC RIGHTS-OF-WAY. WHEN WASHING IS REQUIRED, IT SHALL BE DONE ON AN AREA STABILIZED WITH STONE AND WHICH DRAINS INTO ADJACENT SEDIMENT BASINS.
9. PERIODIC INSPECTION AND MAINTENANCE SHALL BE PROVIDED AS REQUIRED AND/OR AS DIRECTED BY THE ENGINEER.

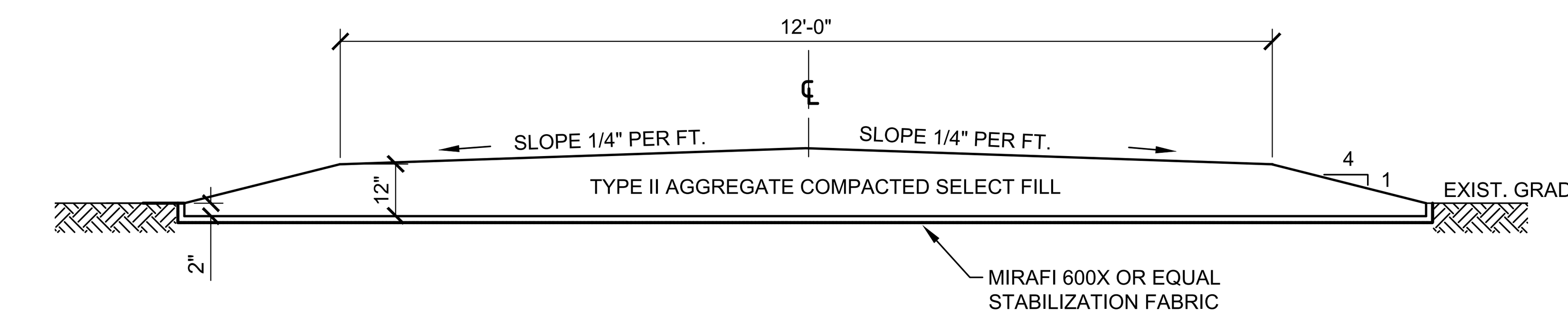
C STABILIZED CONSTRUCTION ENTRANCE DETAIL

NOT TO SCALE



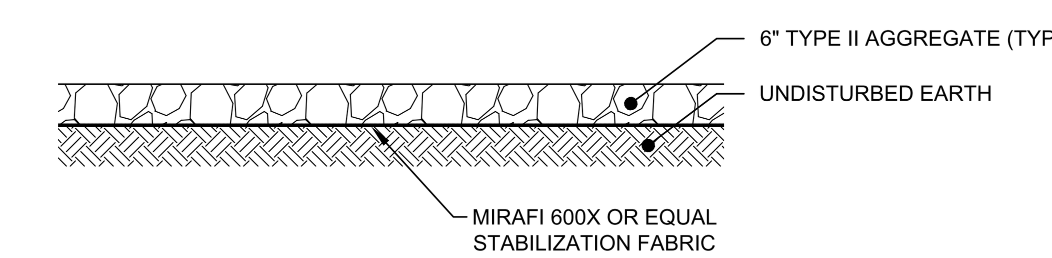
D ACCESS ROAD IMPOVEMENT DETAIL

NOT TO SCALE



E GRAVEL ACCESS DETAIL

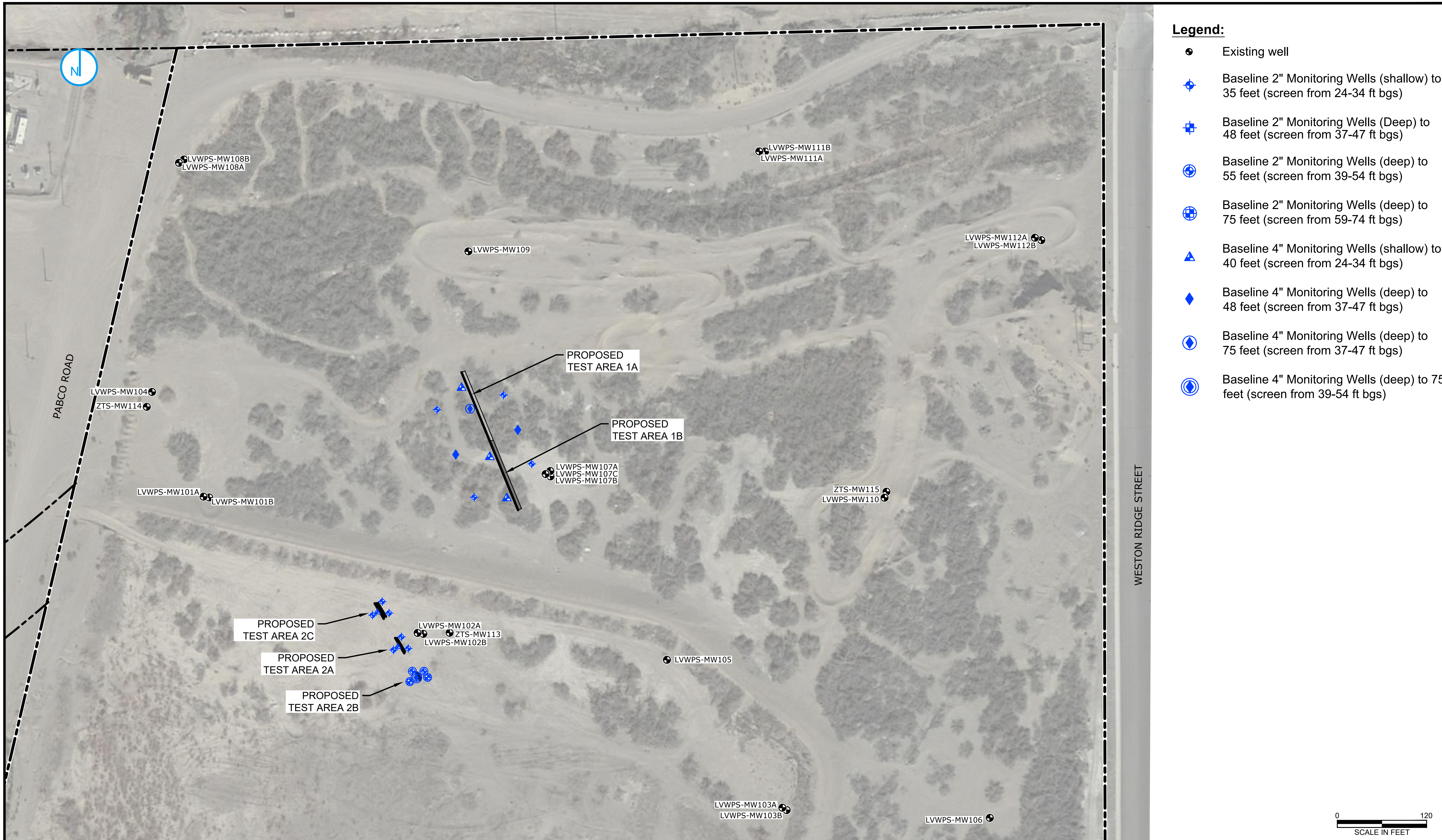
NOT TO SCALE



F MATERIAL STAGING PAD DETAIL

NOT TO SCALE

CLIENT	NO.	DATE	REVISION	INT.	DESIGNER / PROFESSIONAL ENGINEER RESPONSIBLE			PROJECT	SHEET DESCRIPTION	
NERT					DESIGNED BY JS	PROJECT NO. 1690016064	RAMBOLL US CONSULTING, INC.	Nevada Environmental Response Trust (NERT)	PRELIMINARY CONSTRUCTION DETAILS	7-12
					CHECKED BY JS	DATE 09/01/2021	RAMBOLL	ADDRESS HENDERSON, NEVADA		
					DRAWN BY MB					



RAMBOLL

FIELD TEST 1A, 1B, 2A, 2B, & 2C - BASELINE MONITORING PROGRAM

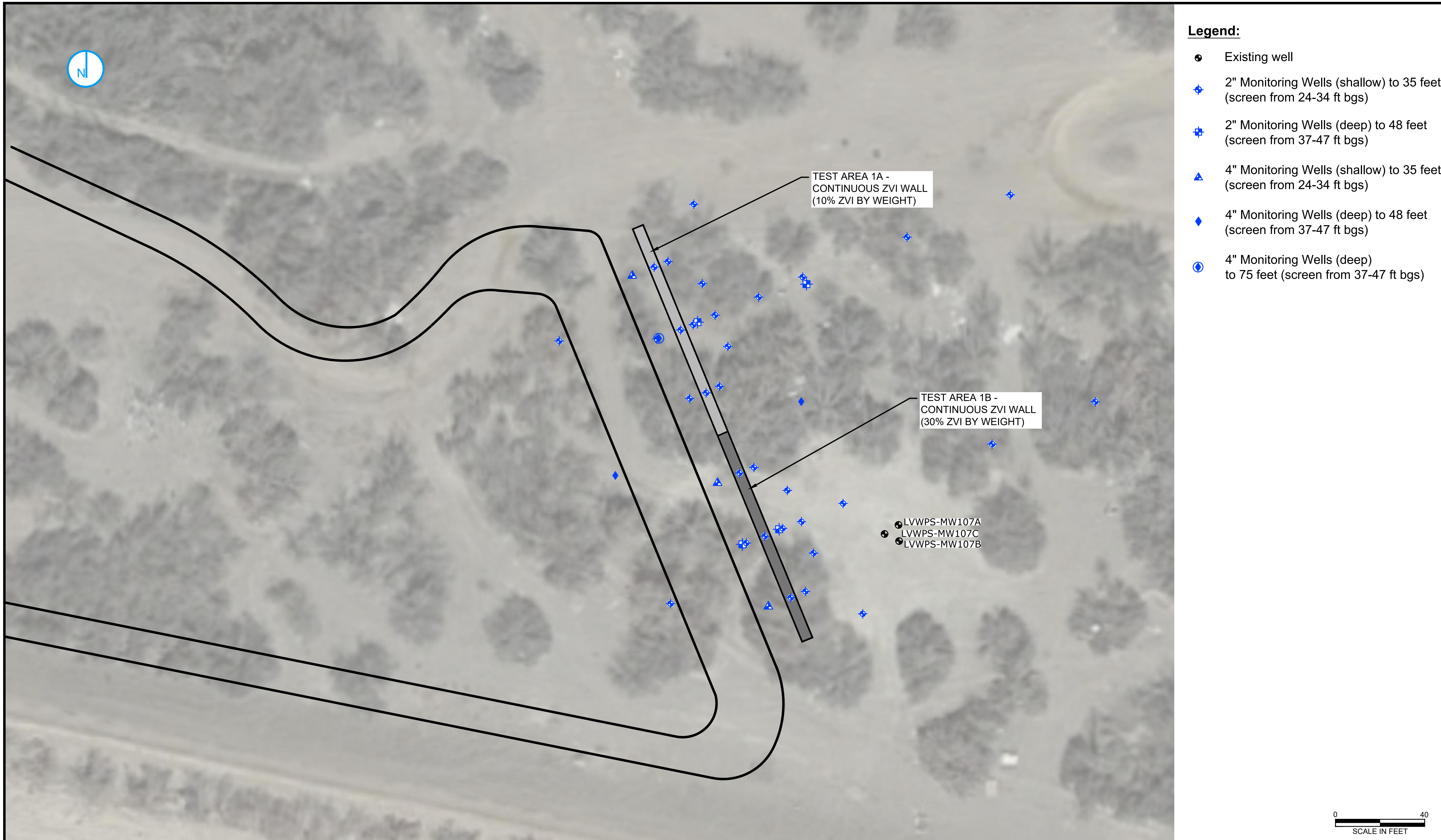
Nevada Environmental Response Trust Site;
Henderson, Nevada

Figure

8-1

Drafter: MB | Date: 09/01/2021 | Contract Number: 1690016064 | Approved by: | Revised:

MBLEI 9/2/21 F:\1690016064_NERT_WIP DRAFT < LAYOUT_BASELINE WELLS >



RAMBOLL

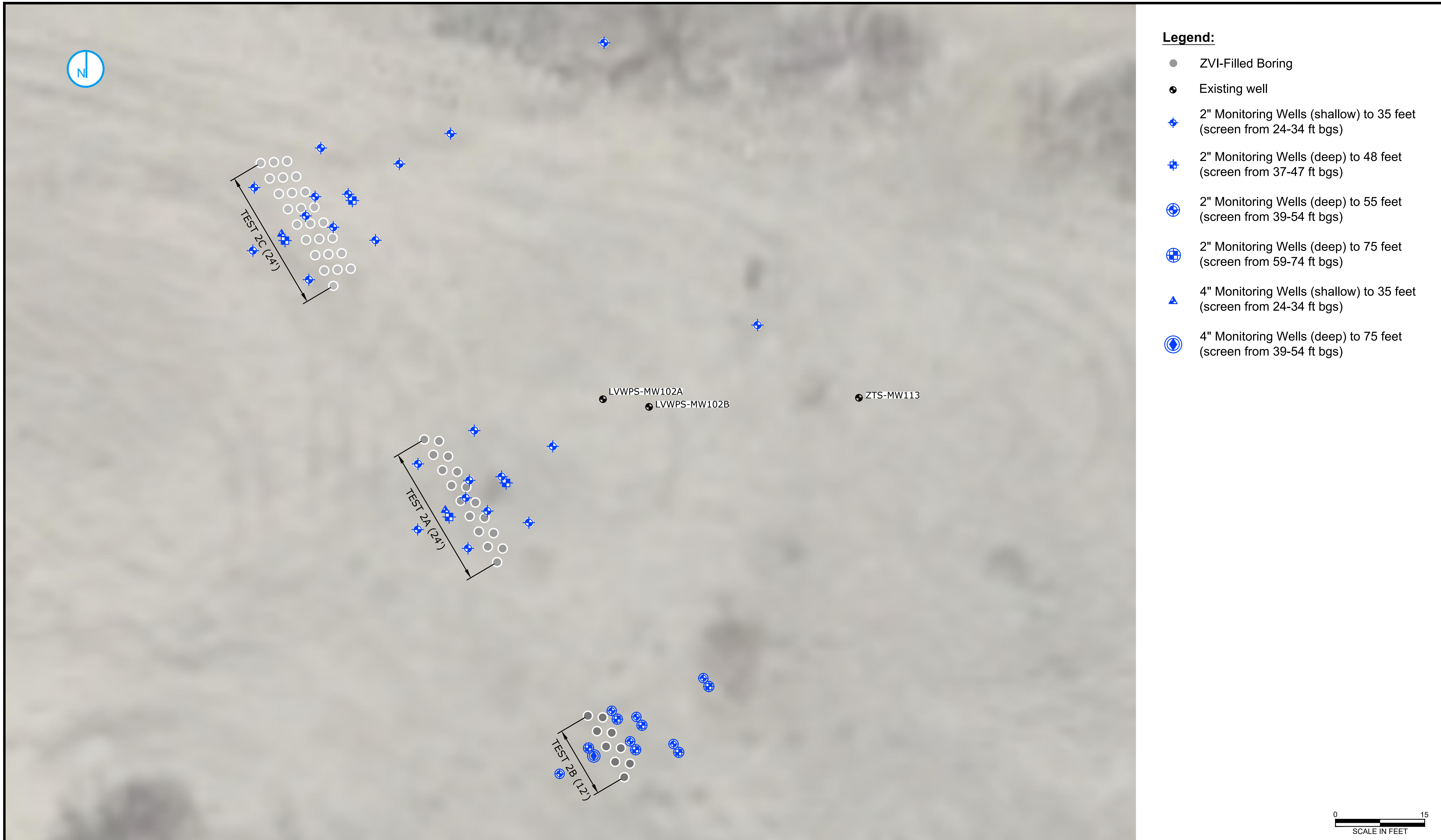
FIELD TEST 1A AND 1B - MONITORING NETWORK

Nevada Environmental Response Trust Site;
Henderson, Nevada

Figure **8-2**

Drafter: MB | Date: 09/01/2021 | Contract Number: 1690016064 | Approved by: | Revised:

MBLEI 9/2/21 F:\1690016064_NERT_WIP DRAFT < LAYOUT_MONITORING NETWORK >



RAMBOLL

FIELD TEST 2A, 2B AND 2C - MONITORING NETWORK

Nevada Environmental Response Trust Site;
Henderson, Nevada

Figure **8-3**

Drafter: MB | Date: 09/01/2021 | Contract Number: 1690016064 | Approved by: | Revised:

MBLEI 9/2/21 F:\1690016064_NERT_WIP DRAFT < LAYOUT_MONITORING NETWORK >

APPENDICES