Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan Addendum

Nevada Environmental Response Trust Site Henderson, Nevada

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July 22, 2021

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
amsl	above mean sea level
ASTM	ASTM International
bgs	below ground surface
BMI	Black Mountain Industrial (Complex)
COPC	chemical of potential concern
COD	chemical oxygen demand
DO	dissolved oxygen
DVSR	Data Validation Summary Report
EC	electrical conductivity
EDD	electronic data deliverable
EMD	EMD Acquisition, LLC – doing business as Borman Specialty Materials
EOS	emulsified oil substrate
ETI	Envirogen Technologies, Inc.
EVO	emulsified vegetable oil
FBR	fluidized bed reactor
ft/day	feet per day
ft/ft	foot per foot
g/L	grams per liter
gpm	gallons per minute
GWETS	groundwater extraction and treatment system
IDW	investigation-derived waste
ISB	in-situ bioremediation
lbs	pounds
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliter
NAC	Nevada Administrative Code
NAVD	North American Vertical Datum
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NERT or Trust	Nevada Environmental Response Trust
NMR	Nuclear Magnetic Resonance
NOI	Notice of Intent

Acronyms/Abbreviations	Definition
NTU	nephelometric turbidity units
nZVI	nano-scale zero-valent iron
O&M	operation and maintenance
ORP	oxidation-reduction potential
OU	operable unit
PLFA	phospholipid fatty acids
PVC	polyvinyl fluoride
Qal	Quaternary alluvium
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
pdf	portable document format
PEST	Parameter ESTimation (software)
psig	pounds per square inch-gauge
PVF	polyvinyl fluoride
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation and Feasibility Study
SEM	scanning electron microscopy
SLMW	stabilized Lake Mead water
TDS	total dissolved solids
Tetra Tech	Tetra Tech, Inc.
TOC	total organic carbon
UIC	Underground Injection Control
UMCf	Upper Muddy Creek formation
Unit Building 4	former Unit 4 building
UNLV	University of Nevada at Las Vegas
USCS	Unified Soil Classification System
VFD	variable frequency drive
Water Appropriation Permit	Permit to Appropriate the Public Waters of the State of Nevada for Environmental Purposes
Work Plan	*Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Revision 1*
XRD	x-ray diffraction

CERTIFICATION

Unit 4 Source Area In-Situ 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 systems(s) or those directly responsible for gathering the information or preparing the document, or the immediate supervisor of such person(s), the information submitted and provided herein is, to the best of my knowledge and belief, true, accurate, and complete in all material respects.

Office of the Nevada Environmental Response Trust

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

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

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

Title: Solely as President and not individually

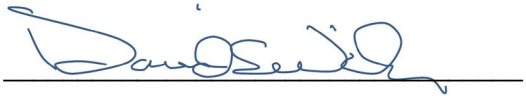
Company: Le Petomane XXVII, Inc., not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

Date: 7/22/21

CERTIFICATION

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

Description of Services Provided: Prepared Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan Addendum, Nevada Environmental Response Trust Site, Henderson, Nevada.



July 22, 2021

David S. Wilson, CEM
Principal Engineer
Tetra Tech, Inc.

Date

Nevada CEM Certificate Number: 2385
Nevada CEM Expiration Date: September 19, 2022

1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this Unit 4 Source Area In-Situ Bioremediation (ISB) Treatability Study (Unit 4 Treatability Study) Work Plan Addendum (Work Plan Addendum) containing the refined design and implementation plan for an ISB treatability study at the former Unit Building 4 (Unit Building 4) at the NERT site (Site). The Site is in Clark County, Nevada as shown on Figure 1. This Work Plan Addendum is being submitted to the Nevada Division of Environmental Protection (NDEP) under the Interim Consent Agreement effective February 14, 2011.

Prior planning documents related to the Unit 4 Treatability Study include the following:

- *Unit 4 Source Area In-Situ Bioremediation Treatability Study Bench-Scale Work Plan* (Tetra Tech, 2017), approved by NDEP on September 12, 2017
- *Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Revision 1* (Work Plan) (Tetra Tech, 2018a), approved by NDEP on February 21, 2018
- *Unit 4 Source Area In-Situ Bioremediation Bench-Scale Treatability Study Work Plan Modification No. 1* (Tetra Tech, 2018b), approved by NDEP on July 10, 2018
- *Treatability/Pilot Modification No. 4 – Unit 4 Source Area In-Situ Bioremediation Treatability Study* (Tetra Tech, 2018c), approved by NDEP on September 10, 2018
- *NERT Unit 4 Source Area In-Situ Bioremediation Treatability Study Modification 7* (Tetra Tech, 2019a), approved by NDEP on May 31, 2019

This Work Plan Addendum presents the results of the Phase 1 pre-design activities conducted in accordance with the planning documents listed above and the refined design and field implementation plan for the Phase 2 treatability study.

1.1 PROJECT OBJECTIVES

The Unit 4 Treatability Study is being conducted to support remedy selection as part of a Remedial Investigation and Feasibility Study (RI/FS) process for the Site. Currently, the RI is being conducted in four investigation sub-areas: the NERT Site; the NERT Off-Site Study Area; the Downgradient Study Area; and the Eastside Study Area. These investigation sub-areas are collectively referred to as the NERT RI Study Area. The study area for the Unit 4 Treatability Study (Unit 4 Treatability Study Area) is located within the NERT Study Area and is part of Operable Unit (OU) 1. Specifically, the Unit 4 Treatability Study Area is located within the footprint of Unit Building 4 on the portion of the Site that was formerly operated by multiple parties, was leased to and operated by Tronox, LLC (Tronox) upon inception of the Trust, and as of August 2018 is leased and operated by EMD Acquisition, LLC (EMD). Data collected from prior investigations, including the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020), demonstrated that soil and groundwater in this area contained very high concentrations of perchlorate, chlorate, chloroform, and hexavalent chromium, confirming that this area is a source of groundwater contamination for the Site.

The Remedial Action Objective (RAO) for OU-1 (Ramboll US Consulting, Inc., 2021) is as follows:

> ***Plume Containment and Source Control:*** The migration of COPCs present in groundwater within OU-1 will be mitigated. Specifically, on-site source control and containment at the downgradient property boundary of the NERT Site will be achieved through a combination of on-site vadose zone source control and the implementation (as required) of barrier groundwater control options (e.g., extraction, hydrogeologic barriers, or in-situ treatment).

The groundwater extraction and treatment system (GWETS), and specifically the Interceptor Well Field, were installed as a removal action to capture groundwater contaminants before migrating off site. However, additional source control and containment options will be considered in the forthcoming Feasibility Study to fully address the OU-1 RAO. Because the Unit 4 Treatability Study Area contains amongst the highest concentrations of COPCs

found at the Site, extraction or in-situ treatment and/or control of the source area groundwater in the Unit 4 Treatability Study Area may be necessary to achieve the OU-1 RAO. To support evaluation of potential technologies that may be used for source control and containment, the overall objective of this Unit 4 Treatability Study is to evaluate the effectiveness of an ISB approach to address impacted groundwater present in the Unit 4 Treatability Study Area. This treatability study will incorporate applicable results of the previous ISB treatability studies performed throughout the NERT RI Study Area; however, the conditions at the Unit 4 Treatability Study Area are significantly different from the conditions found in other areas of the NERT RI Study Area where ISB treatability studies were previously completed or are currently on-going. Primary differences include the following:

- Concentrations of the COPCs (perchlorate, chlorate, chloroform, and hexavalent chromium) present in groundwater in the Unit 4 Treatability Study Area are up to three orders-of-magnitude higher than the concentrations present in other treatability study areas.
- Total dissolved solids (TDS), which can inhibit biological activities at high concentrations, are present in groundwater in the Unit 4 Treatability Study Area at up to 58,000 milligrams per liter (mg/L), approximately six times higher than at other treatability study areas. In addition, the TDS present in the Unit 4 Treatability Study Area is largely comprised of the primary COPCs, whereas the TDS present at other treatability study areas is largely comprised of dissolved mineral salts such as sodium, calcium, chloride, magnesium, potassium, sulfate, bicarbonate, carbonate, and nitrate.
- The Unit 4 Treatability Study will evaluate the effectiveness of ISB to treat COPCs in the Upper Muddy Creek formation (UMCf) and use groundwater extraction to assist with carbon substrate distribution and reduce the number of injection wells required. The use of groundwater extraction to assist with the distribution of carbon substrate has not been tested in other treatability study areas and was selected in the NDEP-approved Work Plan (Tetra Tech, 2018a) over alternatives such as standard injection techniques and injections enhanced with hydraulic/pneumatic fracturing as it is anticipated to be a more cost-effective approach and have a higher likelihood of success given the depths at which the COPCs are present within the UMCf. The decision to use groundwater extraction also considered how the approach might be evaluated as part of the Feasibility Study for application to the UMCf elsewhere in the NERT RI Study Area.
- The Unit 4 Treatability Study will have daily pulsed injections of a carbon substrate solution over the duration of the treatability study rather than performing periodic injection events as have been conducted in the other treatability study areas. The use of daily pulsed injections of a carbon substrate solution was included to provide sufficient carbon substrate over an extended period to meet the carbon substrate demand for the high concentrations of COPCs present and to assist with the distribution of the carbon substrate through the Unit 4 Treatability Study Area to reduce the number of injection wells required.

Upon completion of the OU-1/OU-2 RI, risk assessments, and treatability studies, the FS for OU-1 and OU-2 will consider all findings and complete technology and alternative screening in accordance with the criteria established in 40 CFR 300.430.e.7 (implementability, effectiveness, and cost) to produce an array of remedies for OU-1/OU-2. This Unit 4 Treatability Study is intended to provide key information needed for the FS evaluation of the effectiveness and implementability of ISB to reduce COPC concentrations present in the source area, and thereby to support achievement of the OU-1 RAO. In the event ISB proves effective and implementable and is retained as an alternative in the FS, this approach will meet the requirements of 40 CFR 300.430.e.3.i for the FS to evaluate a source control treatment alternative.

1.2 WORKPLAN ADDENDUM ORGANIZATION

This Work Plan Addendum is organized as follows:

- **Introduction (Section 1.0):** Provides the objectives of the treatability study.
- **Phase 1 Pre-Design Field Activities and Results (Section 2.0):** Provides a summary of the field activities completed to date and discussion of the corresponding results.

- **Phase 1 Bench-Scale Testing Activities and Results (Section 3.0):** Provides a summary of the bench-scale testing activities and discussion of the corresponding results.
- **Phase 2 Treatability Study Considerations and Modifications (Section 4.0):** Provides a summary of the relevant findings from the Phase 1 pre-design activities, modifications to the conceptual design, and refined objectives of the field treatability study.
- **Phase 2 Treatability Study Design (Section 5.0):** Presents the revised field treatability study design including well layout, injection system, groundwater extraction system, and system operation.
- **Phase 2 Effectiveness Monitoring Plan (Section 6.0):** Presents the effectiveness monitoring program for the field treatability study, including groundwater monitoring, extraction system monitoring, and data validation requirements.
- **Phase 2 Administrative and Permitting Requirements (Section 7.0):** Summarizes administrative documentation and permitting requirements for the field treatability study implementation.
- **Phase 2 Reporting (Section 8.0):** Summarizes reporting related to design, execution, and evaluation of the field treatability study.
- **Phase 2 Schedule (Section 9.0):** Summarizes the schedule for conducting the field treatability study and associated reporting.
- **References (Section 10.0):** Lists the documents referenced in this Work Plan Addendum.

2.0 PHASE 1 PRE-DESIGN FIELD ACTIVITIES AND RESULTS

The Phase 1 pre-design activities were conducted to obtain data and information necessary for the design of the Phase 2 treatability study. The field activities and results of these Phase 1 pre-design activities are described in the following subsections.

2.1 TREATABILITY STUDY LOCATION

The location of the Unit 4 Treatability Study Area was selected to evaluate the effectiveness of ISB to achieve source reduction of Unit 4 COPCs (specifically perchlorate, chlorate, hexavalent chromium, chloroform, and nitrate; herein referred to as COPCs) within an area where some of the highest concentrations of COPCs in soil and groundwater have been identified at the Site. As shown in Figure 2, the Unit 4 Treatability Study Area is approximately 80 feet wide and 160 feet long within the basement of the Unit Building 4 and is a subset of the Unit 4 and 5 Buildings Investigation Area. The basement location of the Unit 4 Treatability Study Area allows for sufficient space to install the wells and infrastructure to implement the Phase 2 treatability study while minimizing potential impacts to the existing infrastructure and operations conducted by EMD. The Unit 4 Treatability Study Area is divided into two smaller study areas (Areas 1 and 2) to assess the effectiveness of ISB within areas with differing contaminant ranges that represent the contaminant ranges of source areas at the Site. The size of the Unit 4 Treatability Study Area was selected to allow enough space to account for heterogeneity and varying hydrogeologic conditions on the zone of influences from injection and extraction wells, evaluate the distribution of carbon substrate solution, and assess reduction of COPCs under varying contaminant and geochemical conditions. More details regarding the conditions present within the Unit 4 Treatability Study Area are presented in Section 2.4.

2.2 PLANNED FIELD ACTIVITIES AND MODIFICATIONS

The following planned Phase 1 pre-design field activities were described in the NDEP-approved *Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Revision 1* (Tetra Tech, 2018a).

- Geotechnical and structural evaluation to evaluate the potential impact of soil flushing on adjacent structures and utilities prior to implementing soil flushing activities;
- Soil flushing testing including injection well tests, infiltration and perforation spacing tests, lysimeter installation, and baseline pore water sampling to evaluate soil flushing design requirements if the geotechnical and structural evaluation indicated that soil flushing could be performed;
- Well installations and initial sampling activities including the installation of select wells, soil sampling, well development, well survey, and groundwater sampling to support the other Phase 1 pre-design activities and provide additional characterization of the Unit 4 Treatability Study Area;
- Aquifer testing consisting of single-borehole dilution tests, slug tests, step-drawdown pumping tests, constant-rate pumping tests, and nuclear magnetic resonance (NMR) logging to obtain area-specific aquifer property data; and
- Groundwater modeling consisting of updating and calibrating the groundwater flow model for the Unit 4 Treatability Study Area and running modeling simulations to evaluate the number and location of injection, extraction, and monitoring wells.

In addition, the following modifications to the planned Phase 1 pre-design field activities were proposed and subsequently approved by NDEP:

- Extended Groundwater Extraction Test
    - A technical memorandum (Treatability Study Modification No. 4) was submitted to NDEP on August 23, 2018, followed by revisions submitted on August 28, 2018 (Tetra Tech, 2018c), to recommend an extended groundwater extraction test to evaluate if short-term groundwater

extraction (up to 3 months) would reduce TDS concentrations to levels at which bioremediation has been successful in the bench-scale testing (further discussed in Section 3.0). NDEP approved the modification in a letter dated September 10, 2018, with comments noted for the administrative record.

- Removal of Soil Flushing
    - As summarized in Section 2.6, the results of the geotechnical and structural evaluation conducted as part of the planned Phase 1 pre-design activities suggested that collapsible soils are present within the planned soil flushing area, which could result in collapse of soils and damage to existing structures and utilities in the area, if soil flushing were implemented. As such, NERT recommended eliminating the soil flushing component from the treatability study in an email dated April 4, 2019. NDEP approved removal of the soil flushing component in an email dated April 10, 2019 and required documentation of the relevant details in this Work Plan Addendum.

Details of the specific Phase 1 pre-design field activities conducted in accordance with the approved Work Plan and subsequent NDEP-approved modifications are described in the following sections.

2.3 PHASE 1 PROCEDURES

The Phase 1 pre-design field activities (Figure 3) were conducted in accordance with the following procedural documents:

- *Field Sampling Plan, Revision 1* (ENVIRON, 2014),
- *Quality Assurance Project Plan, Revision 2* (QAPP) (Ramboll Environ, 2017a),
- *Site Management Plan, Revision 3* (Ramboll Environ, 2017b),
- *Health and Safety Plan for Site-Wide Investigations and Remedial and Construction Operations* (Tetra Tech, 2018d), and
- *Contingency Plan for Unit 4 Source Area In-Situ Bioremediation Treatability Study, Pre-Implementation Field Activities* (Tetra Tech, 2018e).

Details of the data management and investigation-derived waste (IDW) management practices are described below. Procedural details for other activities are described in each section for the individual Phase 1 pre-design field activities.

Sampling and analytical methods were selected to meet the project data quality objectives and quality control criteria. Samples were sent to laboratories identified in the approved QAPP and/or Work Plans for analysis. Laboratories provided data in portable document format (PDF) and in electronic data deliverables (EDDs) that contain sufficient and appropriate data to allow verification and validation at the required levels. Validated results have been uploaded to the NERT database. A Data Validation Summary Report (DVSR) will be prepared and presented with the Unit 4 Source Area In-Situ Bioremediation Treatability Study Results Report following completion of Phase 2.

IDW was managed according to applicable state, federal, and local regulations and as described in the *Field Sampling Plan, Revision 1* (ENVIRON, 2014). IDW generated included soil cuttings, concrete debris, used personal protective equipment, equipment decontamination water, and groundwater. Soil cuttings were stored in plastic-lined roll-off bins with proper labeling. Solids were characterized to determine disposal options. The IDW was disposed of and documented under a Trust-approved waste profile. IDW generated during purging or decontamination activities for drilling and sampling was temporarily stored in 250-gallon poly-totes and transferred into the GW-11 Pond. Extracted groundwater from the step-drawdown and constant-rate aquifer tests was accumulated in a 5,000-gallon tanker truck staged within the Unit 4 basement. The tanker truck was emptied each day by transporting the extracted groundwater from the tanker truck to the GW-11 Pond using a vacuum truck. Both the vacuum truck and the tanker truck were triple-rinsed using stabilized Lake Mead water (SLMW), and the decontamination water was placed in the GW-11 Pond.

Groundwater derived from the extended groundwater extraction test was accumulated in a 21,000-gallon frac tank located to the east of the Unit 4 basement. The frac tank was certified as a Resource Conservation and Recovery Act (RCRA) compliant tank prior to use and was inspected daily. The frac tank was placed within a secondary containment berm capable of containing 110 percent of the tank volume in compliance with RCRA requirements. The extracted groundwater was transported from the frac tank to the GW-11 Pond via an on-site haul route using a vacuum truck as-needed. The vacuum truck and the frac tank were triple-rinsed using SLMW prior to leaving the Site, and the decontamination water was placed in the GW-11 Pond.

2.4 SUMMARY OF CURRENT SITE CONDITIONS

As part of the Remedial Investigation of OU-1, NERT completed a detailed source characterization of the Unit Buildings 4 and 5 since perchlorate and chlorate manufacturing occurred in these buildings for over 50 years. The findings of the source characterization are presented in the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020). In support of the Phase 2 treatability study design, the understanding of the Unit 4 Treatability Study Area was refined based on an evaluation of the data presented in the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020), information provided in the *Annual Remedial Performance Report for Chromium and Perchlorate* (Ramboll US Corporation, 2018) (Ramboll US Corporation, 2019), and results from the Phase 1 pre-design field activities. The refined understanding of the site conditions in the Unit 4 Treatability Study Area support a better understanding of the geology, hydrogeology, geotechnical conditions, and distribution of COPCs in the Unit 4 Treatability Study Area as discussed in the following sections.

2.5 UPDATED UNIT 4 TREATABILITY STUDY AREA GEOLOGY AND HYDROGEOLOGY

The geology and hydrogeology encountered within the Unit 4 Treatability Study Area during the pre-design activities are consistent with the descriptions provided in the Work Plan and the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020). The depth to groundwater within the Unit 4 Treatability Study Area ranges from approximately 35 to 39 feet bgs. The horizontal direction of groundwater flow in the Unit 4 Treatability Study Area is generally toward the north following the slope of the ground surface. A potentiometric surface map of groundwater is provided as Figure 4, based on groundwater elevation data collected from wells screened at depths from 75 to 100 feet bgs. The flow direction is northwesterly, and the gradient is approximately 0.018 foot per foot (ft/ft). Within the Unit 4 Treatability Study Area, the vertical gradient as measured between the intermediate and deep well pairs is consistently downward, ranging from approximately 0.03 ft/ft to 0.07 ft/ft. Conversely, the vertical gradient in the well pairs surrounding the Unit 4 Treatability Study Area (M-247-100 and M248; M-249-100 and M-250; M-253-100 and M-254; and M-256-100 and M-257) is consistently upward, ranging from 0.1 ft/ft to 0.15 ft/ft.

Updated geologic cross sections of the Unit 4 Treatability Study Area are presented on Figures 5 through 8. The lithology encountered beneath the Unit 4 area consisted of approximately 20 to 25 feet of alluvium below the basement of Unit Building 4 or 35 feet below land surface. The alluvial deposits consisted primarily of sand and silty sand that transitioned to interbedded sandy silt and silt near the top of the UMCf. In the vicinity of the Unit 4 Treatability Study Area, the contact with the UMCf generally coincided with a change from sandy silt/silty sand to silt. The UMCf generally became finer-grained with depth, transitioning from the coarse-grained UMCf (UMCf-cg1) to the fine-grained UMCf (UMCf-fg1), as shown on Figures 6 through 8. Both the intermediate and the deep zones were logged as predominantly clay to silty clay with varying degrees of cementation present and are interpreted to be within the UMCf-fg1 formation. However, there were some sandy zones locally present in the vicinity of Unit Building 4. The most laterally extensive of these occurs at about 79 to 84 feet bgs, or 1735 to 1740 ft above mean sea level (amsl), just above the intermediate zone. These sandy zones have been interpreted as anastomosing stream deposits and are observed throughout the NERT Site (Ramboll US Corporation, 2020a). Within the

intermediate and deep zones, there are smaller and less extensive discontinuous sand stringers, which locally may serve as preferential flow pathways.

2.6 GEOTECHNICAL AND STRUCTURAL EVALUATION

In accordance with the NDEP-approved Work Plan, a geotechnical and structural evaluation was performed within the Unit 4 Treatability Study Area to evaluate the potential impact of soil flushing on adjacent structures and utilities prior to implementing the planned soil flushing activities. The evaluation included a field exploration program, laboratory testing, and data evaluation to assess potential total and differential settlement due to consolidation of the unsaturated soil column upon wetting and the potential reduction in the soil-bearing capacity below Unit Building 4 due to saturation of the soils. Details of the evaluation are presented in the *Unit 4 Source Area In-Situ Bioremediation Treatability Study Geotechnical and Structural Evaluation* (Tetra Tech, 2019b) included as Appendix A. A summary is provided in this section.

Six exploration borings were advanced using a hollow-stem auger rig under oversight of a geotechnical engineer to obtain information on subgrade soil conditions and soil samples for laboratory testing. The field exploration was conducted between May 16 and May 18, 2018. Prior to advancing the geotechnical borings, utility clearance was conducted. Five of the six geotechnical borings were advanced through the existing basement floor slab within the Unit Building 4 (Figure 3) to depths ranging from 56.5 to 58.5 feet below the basement surface. The sixth boring was located southeast of the Unit Building 4 within the nearby parking lot to evaluate soil conditions outside of the basement and in the vicinity of other structures (Figure 3) and was drilled to a depth of 56.5 feet below ground surface (bgs).

Soil samples were collected to determine the physical and engineering characteristics of the soils. Samples were analyzed for moisture content, grain-size distribution, Atterberg limits, dry density, consolidation/swell, and direct shear. Data evaluation yielded the recommendations below regarding the soil flushing and injection activities planned as part of the treatability study. These recommendations were summarized in the NDEP-approved *Unit 4 Source Area In-Situ Bioremediation Treatability Study Geotechnical and Structural Evaluation* (Tetra Tech, 2019b) that was prepared to support this project and is included as Appendix A.

- **Recommendation on Soil Flushing**: Based on laboratory test data and local site information (such as soil hazards information, including hydro-collapsible potential, illustrated on local soil maps), there is potential for upper soils in the Unit 4 Treatability Study Area to experience collapse when wetted, also known as hydro-collapse. The presence of hydro-collapsible soils is a naturally occurring condition that is typical in arid and semi-arid environments. When wetted, these soils containing minute pores and voids, partially supported by clays and silts or chemically cemented with carbonates, can undergo a rearrangement of their grains and removal of the cementing material, causing potentially rapid and significant settlement. The collapse of soils can be detrimental to buildings, utilities, and other structures in the immediate area of collapse. Water inundation from both soil flushing at the surface and injection well operations within the vadose zone are likely to produce significant settlement of these soils, and potentially large and differential settlements of adjacent structures, utilities, and other current infrastructure. Mitigation of potential settlement impacts associated with soil flushing to the structures around Unit Building 4 and nearby utilities would be difficult and impractical based on current operations of these facilities. Given the age and condition of the existing structures, it did not appear that ground improvement or underpinning to support the Unit Building 4 would be practical. Accordingly, the surface soil flushing component was recommended to be eliminated from the treatability study.
- **Recommendation on Injections**: Injections below the water table at a rate that does not create significant mounding into the vadose zone are unlikely to pose a significant risk of settlement from hydro-collapse. Accordingly, the planned injection activities can proceed; however, the sensitivity of the upper soils needs to be considered. Multiple monitoring techniques were recommended to be utilized during the treatability study to evaluate settlement risk from the injection activities. The recommended monitoring techniques included the following:

- Use of monitoring wells to verify groundwater levels do not rise more than 5 to 6 feet into the unsaturated zone (or an elevation of 1,783 feet amsl) during injections;
- Installation of magnetic extensometers to assess settlement during the treatability study; and
- If the basement concrete slab is removed prior to the implementation of the treatability study, a level survey of the existing soil surface should be conducted daily during the treatability study.

2.7 WELL INSTALLATIONS AND INITIAL SAMPLING

To provide additional characterization of the Unit 4 Treatability Study Area, well installation and soil and groundwater sampling were conducted as part of the Phase 1 pre-design activities as described below.

2.7.1 Soil Sampling

Soil samples were collected from the UMCf at 5-foot intervals from 78 to 123 feet bgs, the depth where the highest concentrations and mass of COPCs were present, as described in the Work Plan to supplement the data obtained as part of the Unit 4 and 5 Buildings investigation, where soil samples were collected at 10-foot intervals. These samples were collected during the drilling for the four deep injection/extraction wells (U4-E-01D, U4-E-02D, U4-E-04D, and U4-E-05D) to provide refinement of the vertical and lateral distribution of COPCs and geochemistry within the Unit 4 Study Area. In addition, soil samples were collected to evaluate the native microbial populations present and for use in bench-scale laboratory studies to support the implementation of ISB within the Unit 4 Study Area. Soil sampling equipment was decontaminated between samples. Soil samples were collected in laboratory-supplied containers, labeled, placed in plastic bags, and stored in a cooler on ice for transport to Test America. The soil samples were analyzed for a variety of chemical and microbial parameters, with the analytical methods listed in ***Table 1*** below. The analyses for perchlorate reductase and chlorite dismutase genes were performed as part of the bench-scale laboratory studies (see Section 3.0).

Table 1. Soil Sampling Protocol

Parameter	Analytical Method
Perchlorate	E314.1
Chlorate	E300.1
Chlorite	E300.1
Hexavalent Chromium	SW7199
Total Chromium	SW6010B
Total Organic Carbon	SM5310B
Soil pH	SW846 9045C
Soluble Cations and Anions [1,2]	See Notes 1 and 2
Total Dissolved Solids [2]	SM2540C
Metals [3]	SW 846 6010/6020/7471A
Perchlorate Reductase and Chlorite Dismutase Genes [4]	Microbial Insights Method

Notes:

1. Soluble cations and anions via analysis of leachate [cations include calcium, magnesium, potassium, and sodium (Method SW6010B); anions include chloride, sulfate, and nitrate (Method 300.0), chlorate (Method E300.1), and carbonate alkalinity (Method SM2320B)].
2. Analysis performed on water extract prepared per method SW9056.
3. Metals include boron, iron, manganese, and titanium (Method SW6010B); antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, selenium, silver, and zinc (Method 6020); and mercury (Method SW7471A).
4. Microbial analysis of the soil collected during the pre-design investigation activities was performed as part of the bench-scale testing activities.

A summary of the analytical results for the chemical parameters is provided in Appendix C. The analytical results from the soil samples were used to refine mass estimates and COPC distribution in the vicinity of the Unit 4 Treatability Study Area as presented in Section 2.12.

In general, soil concentrations of COPCs within the Unit 4 Treatability Study Area were consistent with the results from the Unit 4 and 5 Buildings investigation (Tetra Tech, 2020) in terms of distribution and range of concentrations. Soil concentrations of COPCs increased with depth from 78 to 88 feet bgs and then decreased with depth from approximately 118 to 123 feet bgs, the maximum depth of sample collection. Hexavalent chromium concentrations in soil samples ranged from 0.45 milligrams per kilogram (mg/kg) to 110 mg/kg with the highest hexavalent chromium concentrations observed in soil samples collected from 98 to 113 feet bgs. Chlorate concentrations in soil samples ranged from 15 mg/kg to 19,000 mg/kg with the highest chlorate concentrations observed in soil samples collected from 88 to 113 feet bgs. Chloroform concentrations in soil samples ranged from 5.4 micrograms per kilogram (µg/kg) to 7,100 µg/kg, with the highest chloroform concentrations observed in soil samples collected from 88 to 118 feet bgs. The maximum chloroform concentration of 7,100 µg/kg exceeded the maximum chloroform concentration of 5,800 µg/kg observed in soil samples collected during the Unit 4 and 5 Buildings investigation (Tetra Tech, 2020). Perchlorate concentrations in soil samples ranged from 1.6 mg/kg to 3,100 mg/kg with the highest perchlorate concentrations observed in soil samples collected from 88 to 118 feet bgs.

Soil samples were also analyzed for a suite of analytes that are non-COPCs (as listed in ***Table 1***) to provide additional characterization of the subsurface conditions. These additional analyses included anions and cations (alkalinity, bicarbonate, carbonate, calcium, chloride, magnesium, nitrate, potassium, and sulfate), dissolved metals, soil pH, TDS, and total organic carbon (TOC). These analyses were performed to evaluate the soil geochemistry and determine whether the conditions are suitable for ISB and how the conditions may affect the implementation of ISB within the Unit 4 Treatability Study Area. A brief summary of these results is presented below.

- Soluble anions and cations were analyzed to assess the salt loading in the soil. Predominant among the anions were chloride (maximum of 230 mg/L), nitrate (maximum of 12 mg/L), and sulfate (maximum of 69 mg/L).
- Dissolved metals were analyzed to assess potential secondary impacts of bioremediation. Results indicate that arsenic concentrations in soil range generally from 12 to 35 mg/kg, with one estimated soil sample result of 87 mg/kg (collected at 93 feet bgs from boring location U4-E-05D). Iron concentrations in soil samples ranged from 9,800 mg/kg to 27,000 mg/kg. Manganese concentrations in soil samples ranged from 150 mg/kg to 870 mg/kg.
- Soil pH ranged from 7.4 to 9.2 standard units.
- TDS was analyzed on the water extract, with results indicating the highest concentration of 2,300 mg/L detected in a soil sample collected at 103 ft bgs.
- TOC was detected at concentrations ranging up to 2.2 mg/L, indicating very little organic carbon is naturally available for microorganisms.

2.7.2 Well Installation

Prior to the drilling and well installation activities, Nevada Administrative Code (NAC) 534.320 Notice of Intent (NOI) Cards #40106 and #40116 were obtained from the Nevada Division of Water Resources (NDWR) with the approval for the NAC 534.441 Monitor Well Drilling Waiver MO-3457 for the planned Phase 1 pre-design wells. Groundbreaking permits were also obtained from Tronox for all drilling locations.

The drilling and well installation activities were conducted between May 3 and May 16, 2018, using rotosonic drilling methods. Five well clusters were installed in the northwest portion of the original ISB area presented in the Work Plan to support the other Phase 1 pre-design activities and provide additional characterization of the Unit 4 Treatability Study Area. The following wells were installed and labelled based on the original well layout provided in the Work Plan (Figure 3):

- Four intermediate injection/extraction wells (U4-E-01I, U4-E-02I, U4-E-04I, and U4-E-05I)
- Four deep injection/extraction wells (U4-E-01D, U4-E-02D, U4-E-04D, and U4-E-05D)
- One intermediate monitoring well (U4-MW-02I)
- One deep monitoring well (U4-MW-02D)

Continuous soil cores were logged by a geologist from ground surface to total depth in accordance with the Unified Soil Classification System (USCS) and utilized the modified American Society for Testing and Materials (ASTM) Standard D-2488-09a (ASTM International, 2009). Field equipment used during logging included the following items: Munsell™ color chart, USCS classification chart, grain size chart, and sample collection bags. Before the drill rig mobilized to another soil boring location, downhole drilling equipment was cleaned with a high-pressure, high-temperature water spray. The soil boring logs are provided in Appendix B.

Screen intervals of 15 feet were selected to target vertical zones with the UMCf containing the most mass of COPCs (see discussion in Section 2.12) to provide versatility for use as an injection or groundwater extraction well. The intermediate wells were screened to target the interval between 83 and 98 feet bgs while the deep wells were screened to target the interval between 103 and 118 feet bgs. The monitoring wells were constructed in a similar fashion to the injection/extraction wells in the event they would need to be used as injection/extraction wells based on the aquifer conditions. The wells were constructed with 4-inch Schedule 80 polyvinyl chloride (PVC) casing and 0.010-inch slotted wire-wrapped 304 stainless-steel well screens. A #2/16 sand was used as a filter pack from approximately 2 feet below to 2 feet above the screened interval. Wells were completed with an 18-inch flush-mounted, tamper-resistant, traffic-rated well box, set at an elevation approximately 0.5 inch above surrounding grade. The well construction details are provided in Appendix B.

Following the completion of well construction, but no sooner than 48 hours after well construction was complete, the newly installed wells were developed. A surge block and bailer were used to swab and surge the filter pack and remove sediment from the well. This process was followed by pumping with a submersible pump. Well development was considered complete when 3 to 10 casing volumes of water had been removed from the well, and index parameters consisting of pH, specific conductivity, turbidity, and temperature were stable (pH within 0.1, turbidity less than 5 nephelometric turbidity units (NTUs) or stable, and other parameters generally within 10 percent) over three consecutive measurements. Groundwater sampling, discussed in Section 2.7.3, was conducted not less than 72 hours following completion of the well development.

Once all well installation and development activities were completed, a Nevada-licensed land surveyor 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 measuring point relative to North American Vertical Datum (NAVD) 88 with accuracies of 0.1 foot and 0.01 foot, respectively. The well survey data are provided in Appendix B.

2.7.3 Groundwater Sampling

Prior to groundwater sample collection, groundwater levels were gauged in wells located within and adjacent to the Unit 4 Treatability Study Area for potentiometric surface mapping (Figure 4). Groundwater samples were collected from the newly installed wells from June 19 to June 20, 2018, to supplement the data obtained as part of the Unit 4 and 5 Buildings investigation that provided water quality data and concentrations of COPCs from several discrete-depth groundwater samples (i.e. temporary wells) and one groundwater monitoring well (M-251-100) within the targeted treatment zone within the Unit 4 Treatability Study Area.

Groundwater samples were collected using low-flow purging and sampling techniques. Filtering for dissolved metals was conducted in the field using a 0.45-micron filter. A pump capable of purging between approximately 0.1 and 0.13 gallon per minute (gpm) was used to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water passed through a flow-through cell field water analyzer for continuous monitoring of field parameters (temperature, pH, turbidity, electrical conductivity [EC], dissolved oxygen [DO], and oxidation-reduction potential [ORP]). Field parameters were monitored and recorded. Well purging was considered complete when the field parameter readings and water levels stabilized. Groundwater samples were then

collected at each well. Groundwater samples were analyzed for the chemical parameters listed in ***Table 2*** below to provide water quality data and concentrations of COPCs from monitoring wells screened within the intermediate and deep zones at the Unit 4 Treatability Study Area for use in the design of the Unit 4 Treatability Study, as described further below.

Table 2. Groundwater Sampling Protocol

Parameter	Analytical Method
Perchlorate	E314.0
Chlorate/Chlorite	E300.1B
Chloride/Nitrate/Sulfate	E300.0
Hexavalent Chromium	218.6
VOCs	8260B
Nitrogen	350.1/351.2
Total Phosphorous	365.3
Total Organic Carbon	SM 5310B
Alkalinity	SM 2320B
Total Hardness	SM 2340B
Methane	RSK175
TDS	SM 2540C
TSS	SM 2540D
Metals[1]	6010B/6020
VFAs	VFA-IC

Notes:

1. Total recoverable and dissolved metals include aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, potassium, selenium, silver, sodium, thallium, uranium, vanadium, and zinc.

Table 3 presents a summary of the groundwater concentrations of COPCs and TDS for the intermediate and deep wells installed within the Unit 4 Treatability Study Area. In general, the concentrations in groundwater samples collected from the intermediate and deep wells within the Unit 4 Treatability Study Area were consistent with the concentrations in groundwater samples collected from temporary and permanent wells during the Unit 4 and 5 Buildings investigation (Tetra Tech, 2020) in terms of distribution. However, the maximum concentrations of chlorate, hexavalent chromium, chloroform, nitrate, and TDS were higher in the groundwater samples collected from the deep wells within the Unit 4 Treatability Study Area than observed in groundwater samples collected during the Unit 4 and 5 Buildings investigation (Tetra Tech, 2020). COPC concentrations in groundwater samples collected from the deep wells were significantly higher than in groundwater samples collected from the intermediate wells. In the intermediate wells, the highest COPC concentrations were present in groundwater samples collected from well U4-E-01I, and the lowest COPC concentrations were present in groundwater samples collected from well U4-E-04I. In the deep wells, the COPC concentrations in the groundwater samples collected from all of the wells were high compared to the COPC concentrations in the intermediate zone and elsewhere at the Site and did not have as high a variability as was present in the groundwater samples collected from the intermediate wells.

Table 3. Concentration Ranges in Groundwater

Analyte	Concentrations in the Intermediate Wells (83 – 98 ft bgs)	Concentrations in the Deep Wells (103 – 118 ft bgs)
Perchlorate (µg/L)	84,000 – 2,100,000	1,700,000 – 5,300,000
Chlorate (µg/L)	1,200,000 – 13,000,000	20,000,000 – 33,000,000
Hexavalent Chromium (µg/L)	5,000 – 50,000	78,000 – 140,000
Chloroform (µg/L)	450 – 2,800	4,300 – 11,000
Nitrate (mg/L)	20 - 160	230 - 390
TDS (mg/L)	3,900 – 22,000	36,000 – 58,000

Notes:
ft bgs – feet below ground surface
µg/L – micrograms per liter
mg/L – milligrams per liter
TDS – total dissolved solids

The following is a brief summary of non-COPC analytical and field parameter results:

- Total phosphorous levels ranged up to 0.046 mg/L. Concentrations at these low levels indicate the likely need to add this macronutrient for the growth and development of microorganisms for biodegradation of the COPCs.
- TOC ranged from 0.85 mg/L to 1.6 mg/L, indicating very little organic carbon is naturally available for microorganisms.
- Dissolved metals were analyzed to establish baseline concentrations such that potential metals mobilization during bioremediation can be assessed. Results indicate that arsenic concentrations ranged from less than 5 µg/L to 42 µg/L.
- The pH ranged between 7 and 9 standard units, except for groundwater samples collected from U4-E-02I where the pH was approximately 11 standard units. Due to concerns that residual grout may have entered the well during installation activities, well U4-E-02I was redeveloped. Groundwater sampling was conducted at Well U4-E-02I on July 5, 2018, and the pH reading of the new groundwater sample was 8.6 which is consistent with groundwater samples collected from the other wells.
- DO levels ranged from 0.57 to 5.6 mg/L and the redox potential ranged from -40 to 156 mV indicating a range of aerobic and reducing conditions are present. In general, the DO levels measured in groundwater from the intermediate wells were higher than the DO levels measured in groundwater from the deep wells.

The results of the groundwater monitoring, including both laboratory analytical results and field parameters, are included in Appendix C.

2.8 AQUIFER TESTING

Aquifer testing in the Unit 4 Treatability Study Area was performed from May 2018 through March 2019 to obtain area-specific aquifer property data to update the preliminary groundwater flow model presented in the Work Plan (Section 2.10) and support the subsequent design of the Phase 2 treatability study. The aquifer testing consisted of single-borehole dilution tests, slug tests, step-drawdown pumping tests, constant-rate pumping tests, and downhole NMR surveys. An overview of the testing performed is provided below, with details in Appendix D.

- **Single-Borehole Dilution Test:** A single-borehole dilution test was performed between June 22 and 25, 2018, to estimate groundwater velocity at U4-E-01I, a newly installed intermediate injection/extraction well. However, a localized diurnal water level fluctuation resulted in variable gradients during the test and

invalidated the assumptions inherent to the borehole dilution test analysis, rendering estimates of groundwater flow velocity unreliable. Additional information regarding the localized diurnal water level fluctuations is provided in Appendix D. As such, groundwater velocity was not estimated at this well, and no additional borehole dilution tests were attempted. Data obtained from the other aquifer tests provided sufficient information on the aquifer characteristics in the Unit 4 Treatability Study Area for the purpose of updating the groundwater model and developing the proposed injection and extraction scenarios as described in this Work Plan Addendum.

- **Slug Tests:** Slug tests were performed between June 25 and July 3, 2018, to provide estimates of near-well hydraulic conductivity at all 10 newly installed wells.
- **Step-Drawdown Pumping Tests:** Four step-drawdown pumping tests were performed between July 16 and July 19, 2018, at four newly installed injection/extraction wells (U4-E-01I, U4-E-01D, U4-E-02I, and U4-E-05D). All four wells were pumped using at least three different pumping rates ranging from approximately 0.3 to 8 gpm for a targeted 2 hours each to determine a sustainable pumping rate for the subsequent constant-rate pumping tests.
- **Constant-Rate Pumping Tests:** Two constant-rate pumping tests were conducted from July 24 through July 26, 2018, and from July 30 through August 1, 2018, for characterization of hydraulic conductivity and storage coefficients. A 48-hour test was conducted at U4-E-02I and a 60-hour test was conducted at U4-E-01D. As part of the extended groundwater extraction test, long-term constant-rate pumping tests (authorized by NDEP under Modification No. 4 (Tetra Tech, 2018c) and described further in Section 2.9) were performed between December 2018 and March 2019 at wells U4-E-01I, U4-E-01D, and U4-E-05D.
- **NMR Logging:** NMR logging was performed between June 18 and June 21, 2018, in seven deeper wells within and near the Unit 4 Treatability Study Area (U4-E-01D, U4-E-02D, U4-E-04D, U4-E-05D, U4IS-MW-02D, MW-252, and MW-254) to provide high-resolution downhole estimates of hydraulic conductivity, water content, and total and mobile porosity. NMR logging could not be performed in the stainless-steel screened intervals of the wells as metal interferes with the magnetic signal. The high-resolution downhole estimates were also used to assess potential localized preferential flow pathways. The NMR logging indicated that the hydraulic conductivity generally decreases with depth. However, relatively thin preferential flow pathways are present even in the deep zone of the UMCf.

Methods, field activity descriptions, analysis, and results of the aquifer testing are detailed in Appendix D. ***Table 4*** provides a summary of the aquifer property values derived from the testing.

Table 4. Summary of Aquifer Testing Results

Testing	Intermediate Wells (83 to 98 ft bgs)				Deep Wells (103 to 118 ft bgs)			
	K (ft/day)	T (ft^2/day)	Q (gpm)	S	K (ft/day)	T (ft^2/day)	Q (gpm)	S
Slug Testing and Step-Rate Pumping Tests	1.2 - 1.8	--	2.9 and 6	--	0.06 – 0.5	--	0.38 and 1.3	--
Short-Term Constant- Rate Pumping Tests	6.7	794	6.38	0.0078	0.54	63	0.38	0.003
Long-Term Constant- Rate Pumping Tests	--	--	2.9	--	--	--	0.29 and 1.7	--

Acronyms and Abbreviations:
K: Hydraulic Conductivity
T: Transmissivity
Q: Pumping Rate
S: Storage Coefficient
ft bgs: feet below ground surface
ft/day: feet per day
ft^2/day: square feet per day
gpm: gallons per minute

As indicated in ***Table 4***, the hydraulic conductivities and groundwater extraction rates in the deep wells tested were less than half of those from the intermediate wells tested. In addition, there was more variability in the hydraulic conductivities and groundwater extraction rates in the deep wells tested than in the intermediate wells tested. However, the overall hydraulic conductivities and groundwater extraction rates were higher than would be expected for a clayey to silty material and may indicate a higher percentage of fine sand than logged, the presence of relatively thin preferential flow pathways, and/or that the sediments are relatively loosely compacted.

2.9 EXTENDED GROUNDWATER EXTRACTION TEST

Initial findings of the bench-scale testing (described in Section 3.0) suggested that TDS concentrations greater than approximately 21,000 mg/L may be inhibiting bioremediation of the COPCs. Based on this initial finding, NDEP approved Modification No. 4, which consisted of an extended groundwater extraction test as part of the Phase 1 pre-design field activities. The purpose of the extended groundwater extraction test was to evaluate if groundwater extraction (up to approximately 3 months) would reduce TDS concentrations to levels at which bioremediation had been successful in the bench-scale testing (i.e., 21,000 mg/L).

The extended groundwater extraction test was initially performed at intermediate well U4-E-01I and deep well U4-E-05D. Intermediate well U4-E-01I was selected for this test because the TDS concentration in the groundwater sample collected from U4-E-01I contained 22,000 mg/L and was the only intermediate well where groundwater had a TDS concentration above 21,000 mg/L. Deep well U4-E-05D was selected for the extended groundwater extraction test because the TDS concentration in the groundwater sample collected from U4-E-05D was 42,000 mg/L and the well was located the farthest distance away from U4-E-01I to minimize potential influence that groundwater extraction at U4-E-01I may have at U4-E-05D. After a TDS concentration reduction was achieved at U4-E-01I, the extraction test was extended to the deep well U4-E-01D, where the TDS concentration in the groundwater sample was 58,000 mg/L, the highest concentration in any of the groundwater samples collected from the Phase 1 pre-design field activities. Details of the extended groundwater extraction test are provided in Appendix E. A summary of the activities and results is provided in this section.

2.9.1 System Design and Installation

Installation of an extended groundwater extraction system and associated conveyance was completed from November 19 to November 29, 2018. The extended groundwater extraction system consisted of the following:

- A 21,000-gallon RCRA-compliant frac tank, for temporary storage of extracted groundwater;
- Secondary containment for the frac tank constructed using concrete K-rail barriers and a 60-mil liner with padding and geotextile fabric underneath;
- Two ¾-horsepower submersible pumps installed in extraction wells;
- Above-ground extraction wellheads featuring pressure gauges, sample ports, digital totalizing flow meters, and valves encapsulated in dedicated 100-gallon capacity spill control containers;
- Conveyance for the extracted water to the frac tank consisting primarily of industrial-grade nitrile rubber hosing;
- Electrical conduits and associated wiring to power the pumps and connect to a control panel;
- Leak detection switches installed at the frac tank secondary containment and the wellhead secondary containments;
- Float switches installed in the frac tank connected to relays to turn off power to the pumps (if activated); and
- A control panel.

A licensed electrician connected the pumps to the EMD power grid as well as installed float switches and leak detection sensors. Seven pressure transducers were also installed in nearby intermediate and deep wells for the duration of the pumping to record changes in water elevations throughout the extended groundwater extraction test.

2.9.2 System Operation and Monitoring

The extended groundwater extraction test began on December 5, 2018, with groundwater initially being extracted from intermediate well U4-E-01I and deep well U4-E-05D. The intermediate well U4-E-01I operated until January 18, 2019, when the pump was shut off due to the observed decrease in TDS concentrations to desired levels. The pump was then transferred to deep well U4-E-01D, which operated from January 18, 2019, until the end of the extraction period on February 28, 2019. Overall, the extended groundwater extraction test operated for a period of 85 days from December 5, 2018, until February 28, 2019. Operational field data are provided in Appendix E.

Groundwater samples were collected periodically at seven extraction and observation wells (U4-E-01I, U4-E-05D, U4-E-01D, U4-IS-MW-02I, U4-IS-MW-02D, U4-E-02I, and U4-E-04D) located within the Unit 4 basement to evaluate the change in groundwater concentrations over time. Groundwater samples were generally collected from each groundwater extraction well at the start of the test, every other day for the first week, and then on a weekly basis thereafter. Groundwater samples were generally collected from the observation wells at the start of the test, one week later, and monthly thereafter. The groundwater samples were analyzed for TDS and COPCs relevant to the in-situ biodegradation pathway (i.e., perchlorate, chlorate, nitrate, total chromium, hexavalent chromium, and chloroform). Additionally, field parameters consisting of pH, temperature, ORP, DO, turbidity, and specific conductivity were monitored and recorded during each sampling event. The analytical data and the field parameter values are provided in Appendix E.

At the end of the extended groundwater extraction test, the extraction and observation wells were monitored over a 2-week recovery period to evaluate potential rebound of water levels and TDS and COPC concentrations. During the recovery period, the extraction and observation wells were gauged daily to record water levels, and the data from the water level pressure transducers were downloaded on a weekly basis. At the end of the recovery period, a final sampling event of the extraction and observation wells was performed on March 13, 2019. Groundwater samples were analyzed for the same analytical suite as for the samples collected during the extraction period.

2.9.3 Summary of Results

The results of the extended groundwater extraction test are summarized below to describe the observed impact of the extended extraction on extraction rates, TDS concentrations, COPC concentrations, and field parameters. Additional details of the results and comprehensive summary data tables for the extended groundwater extraction test are provided in Appendix E.

Extraction Rates: The following sustained extraction rates were achieved at the three wells tested (also summarized in ***Table 4***):

- U4-E-01I: 2.9 gpm (operated from December 5, 2018, to January 12, 2019)
- U4-E-01D: 0.29 gpm (operated from January 18, 2019, to February 28, 2019)
- U4-E-05D: 1.7 gpm (operated from December 5, 2018, to February 28, 2019)

Total Dissolved Solids: TDS concentrations in groundwater samples collected from all three wells decreased during the extended groundwater test. A summary of the TDS concentration results is presented in ***Table 5*** with all TDS data tabulated in Appendix E. As indicated, TDS concentrations were successfully reduced to below 21,000 mg/L in groundwater samples collected from the intermediate well U4-E-01I and the deep well U4-E-05D by the end of the recovery period. At U4-E-01D, where the extraction test was only performed for half as long as the test for U4-E-05D and groundwater samples indicated a higher baseline TDS concentration, the TDS concentration in groundwater samples was reduced from approximately 52,000 mg/L to 39,000 mg/L in 41 days of extraction, and rebounded to 41,000 mg/L after recovery. If the TDS concentration in groundwater extracted from U4-E-01D continued to decrease at the rate observed during the test, the TDS concentrations in the extracted groundwater could have reached 21,000 mg/L after approximately 98 days of extraction.

Table 5. TDS Concentrations in Groundwater Samples Collected from Extraction Wells

Well ID	TDS Concentration at Beginning of Extraction (mg/L)	TDS Concentration at End of Extraction (mg/L)	# of Days of Extraction	TDS Concentration at End of 2-Week Recovery Period (mg/L)
U4-E-01I	31,000	4,800	34	6,300
U4-E-01D	52,000	39,000	41	41,000
U4-E-05D	36,000	24,000	85	16,000

Groundwater samples collected from four selected observation wells (U4-E-02I, U4-E-04D, U4-IS-MW-02I, U4-IS-MW-02D) indicated TDS concentrations remained generally stable throughout the extraction period and after the 2-week recovery period within the intermediate zone but fluctuated within the deep zone. The TDS concentrations in groundwater samples from the intermediate observation wells ranged between 2,500 mg/L and 3,000 mg/L at U4-E-02I, and between 2,200 mg/L and 2,600 mg/L at U4-IS-MW-02I. TDS concentrations in groundwater samples collected at deep observation well U4-E-04D fluctuated throughout the extraction period with concentrations ranging from a low of 7,300 mg/L to a high of 28,000 mg/L and a concentration of 33,000 mg/L reported after the 2-week recovery period. TDS concentrations in groundwater samples collected at deep observation well U4-IS-MW-02D decreased throughout the extraction period from a high of 38,000 mg/L to a low of 24,000 mg/L, with an increase to 30,000 mg/L on the last day of extraction. TDS concentrations in the groundwater sample collected at U4-IS-MW-02D on March 14, 2019, after the 2-week recovery period had a reported concentration of 52,000 mg/L.

Chemicals of Potential Concern: The COPCs analyzed periodically during the test included perchlorate, chlorate, nitrate, total chromium, hexavalent chromium, and chloroform. Overall, the COPC concentration trends observed indicate those concentrations generally exhibited similar trends as the TDS concentration trends. Groundwater samples collected from the three extraction wells indicated a concentration reduction for the COPCs

analyzed, with the exception of chloroform concentrations in extracted groundwater from U4-E-01D and U4-E-05D. This indicates that higher chloroform concentrations were present in groundwater at locations adjacent to the extraction well. As the extraction test was implemented, the capture zone expanded and drew in higher chloroform concentrations from these adjacent areas. ***Table 6*** provides a brief summary of the changes in the COPC concentrations for each extraction well.

Table 6. COPC Concentrations in Groundwater Samples Collected from Extraction Wells

Analyte	Concentration at Beginning of Extraction	Concentration at End of Extraction	Percent Reduction
U4-E-01I			
Perchlorate (µg/L)	2,200,000	40,000	98%
Chlorate (µg/L)	10,000,000	270,000	97%
Hexavalent Chromium (µg/L)	62,000	1,400	98%
Chloroform (µg/L)	1,400	84	94%
Nitrate (mg/L)	180	12	93%
U4-E-01D			
Perchlorate (µg/L)	3,000,000	2,700,000	10%
Chlorate (µg/L)	26,000,000	22,000,000	15%
Hexavalent Chromium (µg/L)	120,000	91,000	24%
Chloroform (µg/L)	7,200	8,100	-13%
Nitrate (mg/L)	340	250	26%
U4-E-05D			
Perchlorate (µg/L)	3,300,000	2,000,000	39%
Chlorate (µg/L)	17,000,000	13,000,000	24%
Hexavalent Chromium (µg/L)	88,000	57,000	35%
Chloroform (µg/L)	4,300	4,900	-14%
Nitrate (mg/L)	240	140	42%

Notes:
ft bgs – feet below ground surface
µg/L – micrograms per liter
mg/L – milligrams per liter

At the observation wells, COPC concentrations generally exhibited trends that reflected corresponding changes in TDS concentrations throughout the extraction period and after the 2-week recovery period. COPC concentration trends in groundwater at monitoring wells were inconsistent during the monitoring period with some decreasing, some remaining stable, and some increasing over time.

Field Parameters: Field parameters measured during sample collection included pH, temperature, ORP, DO, turbidity, and specific conductivity.

- pH remained generally stable with fluctuations more significant in deep wells.
- Temperature remained generally stable in the groundwater samples collected from the extraction wells with slight fluctuations observed in the groundwater samples collected from the observation wells, attributed to the sample collection process.
- ORP generally decreased with time in groundwater samples collected from the extraction wells U4-E-01I and U4-E-05D and fluctuated in groundwater samples from extraction well U4-E-01D. ORP in groundwater samples at the observation wells generally exhibited increasing trends.
- DO remained relatively stable in groundwater samples collected from extraction well U4-E-01I while extraction was occurring then decreased after the pump was transferred to U4-E-01D. DO readings in

groundwater samples collected from extraction wells U4-E-01D and U4-E-05D exhibited an overall decreasing trend while groundwater extraction was occurring in each respective well. DO readings generally remained stable with slight fluctuations in the groundwater samples collected from the intermediate observation wells. In groundwater samples collected from the deep observation wells, DO decreased sharply and remained low once pumping began at the extraction wells.

- Turbidity remained relatively stable with slight fluctuations in groundwater samples collected from the extraction wells and the observation wells throughout the extended groundwater extraction test.
- Specific conductivity remained generally stable in groundwater samples collected from U4-E-01I during extraction and decreased after extraction at the well ended. Specific conductivity in groundwater samples collected from U4-E-01D and U4-E-05D remained generally stable with slight overall decreasing trends and some occasional fluctuations. Specific conductivity in groundwater samples collected from the intermediate observation wells remained generally stable while exhibiting more pronounced fluctuations in groundwater samples collected from the deep observation wells.

The significance of findings from the groundwater extraction test on the Phase 2 treatability study is discussed in Section 4.0.

2.10 GROUNDWATER MODEL UPDATE

A preliminary three-dimensional numeric model was constructed to inform the preliminary injection and extraction design in the Work Plan. This model was updated and calibrated as part of the Phase 1 pre-design activities using the aquifer testing and the extended groundwater extraction test results. The updated and calibrated model was used to support the design of the Phase 2 treatability study. Details of the model update and calibration are provided in Appendix F. A summary is provided in this section.

The model was constructed and updated using MODFLOW 2000 including updates on grid, aquifer properties, and boundary conditions. The updated model now has a grid of 112 rows, 137 columns, and 7 model layers. A heterogeneous hydraulic conductivity field was set for each of the model layers based on the aquifer testing results and model calibration. The model boundary conditions were set far enough from the Unit 4 Treatability Study Area to not influence modeled water level changes at the Unit 4 Treatability Study Area. No recharge was applied to the model as soil flushing was removed from the Phase 2 treatability study and no significant recharge is anticipated based on local climate and surface drainage features. A combined steady-state and transient model was constructed.

The model was calibrated using the results from the extended groundwater extraction test, in particular the groundwater elevations observed from 32 nearby wells. Both a steady-state and transient calibration were performed to match groundwater elevation observations before and during the extended groundwater extraction testing. Calibration of the groundwater flow model was performed both manually and with the assistance of the Parameter ESTimation (PEST) software (Watermark Numerical Computing, 2016). PEST was also used to conduct a sensitivity analysis during calibration to evaluate which parameters had the most influence on the hydraulic head and drawdown observations. The model calibration statistics are within industry standards and are included in Appendix F.

2.11 DISTRIBUTION OF COPCS

The distribution of COPCs within soil and groundwater at the Unit Building 4 and 5 source area was presented in the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020). The 3-D visualization model prepared for the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* was updated using the soil and groundwater data collected from the Phase 1 pre-design field activities prior to the implementation of the extended groundwater extraction test.

Additional horizontal slices were generated from the updated 3-D visualization model at 90 and 110 feet bgs to depict the distribution of COPCs in groundwater at depths that correspond with the intermediate UMCf interval

(approximately 88 to 103 feet bgs) and the deep UMCf interval (103 to 118 feet bgs) within the Unit 4 Treatability Study Area (Figures 9 to 18). As observed previously, the highest groundwater concentrations of COPCs and TDS are present in the northwestern portion of the Unit 4 Treatability Study Area and the groundwater concentrations at 110 feet bgs are higher than the groundwater concentrations at 90 feet bgs. It should be noted that there are no additional data available immediately north of the Unit 4 Treatability Study Area, and the projected concentration contours indicating that higher COPC concentrations are present north of the Unit 4 Treatability Study Area are based on interpolation/extrapolation of available data.

The following presents a summary of the groundwater concentrations of COPCs within the Unit 4 Treatability Study Area.

- Perchlorate concentrations in groundwater at 90 feet bgs range from approximately 100 mg/L at the southern boundary to above 2,000 mg/L at the northern boundary (Figure 9). Perchlorate concentrations in groundwater at 110 feet bgs range from approximately 100 mg/L at the southern boundary to above 2,000 mg/L at the central portion and increase further to above 5,000 mg/L at the northeast boundary (Figure 10).
- Hexavalent chromium concentrations in groundwater at 90 feet bgs range from approximately 0.1 mg/L at the southern boundary to above 50 mg/L at the northwest boundary (Figure 11). Hexavalent chromium concentrations in groundwater at 110 feet bgs range from approximately 0.5 mg/L in the southeast corner to above 100 mg/L in the northern portion (Figure 12).
- Chloroform concentrations in groundwater at 90 feet bgs range from approximately 0.1 mg/L at the southern boundary to above 2 mg/L at the northern boundary (Figure 13). Chloroform concentrations in groundwater at 110 feet bgs range from approximately 0.02 mg/L in the southeast corner to 10 mg/L at the northern portion (Figure 14).
- Chlorate concentrations in groundwater at 90 feet bgs range from approximately 1,000 mg/L at the southern boundary to above 5,000 mg/L at the northern boundary (Figure 15). Chlorate concentrations in groundwater at 110 feet bgs range from approximately 500 mg/L at the southern boundary to 33,000 mg/L in the northern portion (Figure 16).
- TDS concentrations in groundwater at 90 feet bgs range from approximately 5,000 mg/L at the southern boundary to over 20,000 mg/L at the northern boundary (Figure 17). TDS concentrations in groundwater at 110 feet bgs range from approximately 5,000 mg/L at the southeast corner to 58,000 mg/L at the northern portion (Figure 18).

2.12 REFINED MASS ESTIMATES

Mass estimates for the Unit Buildings 4 and 5 investigation area were quantified in the *Unit 4 and 5 Buildings Investigation Source Area Characterization Report* (Tetra Tech, 2020) and are summarized in ***Table 7***.

Table 7. Mass Estimate in Soil within the Unit Buildings 4 and 5 Investigation Area

Zone	Perchlorate (lbs)	Chlorate (lbs)	Hexavalent Chromium (lbs)	Chloroform (lbs)	Nitrate (lbs)
Qal	103,000	577,000	1,600	10	2,160
UMCf	581,000	3,300,000	15,600	870	8,070
Total	**684,000**	**3,877,000**	**17,200**	**880**	**10,230**

Notes:
1. The contact between the Quaternary alluvium (Qal) and UMCf was assumed to be at 38 feet bgs (1,776 feet amsl).
2. The mass within the UMCf was estimated down to 158 feet bgs (1,656 feet amsl).

Even though the concentrations of COPCs within the Unit 4 Treatability Study Area are among the highest observed within the Unit Buildings 4 and 5 investigation area, the mass of COPCs present within the Unit 4 Treatability Study Area represents approximately 5% to 8% of the total mass of COPCs present within the Unit

Buildings 4 and 5 investigation area. This is because the Unit 4 Treatability Study Area comprises approximately 2% of the Unit Buildings 4 and 5 investigation area (Figure 2).

In accordance with the Work Plan, refined mass estimates for the Unit 4 Treatability Study Area have been calculated using all soil and groundwater data collected to date, including the data obtained during the source characterization investigation and the Phase 1 pre-design field activities. The approach to developing the mass estimates was generally consistent with the approach presented in the *RI Study Mass Estimate and Expanded Performance Metrics Technical Approach* (Ramboll Environ, 2017c), which was approved by NDEP on October 20, 2017. Variations to that approach were the use of a more refined grid using soil concentrations and an average bulk soil density value of 1.67 grams per cubic centimeter for the Qal and 1.23 grams per cubic centimeter for the UMCf. The supporting data for the refined mass estimates is provided in Appendix G.

Based on the results from the Phase I pre-design field activities and a Trust-directed treatability study optimization exercise, two smaller study areas have been selected for the Phase 2 treatability study implementation instead of the single, larger area originally identified in the Work Plan. This optimization was conducted to the ensure the scope of the treatability study was adequate to capture the data necessary to support the forthcoming Feasibility Study. The two areas were defined in support of the Phase 2 treatability study design as follows:

- Area 1: 80 feet by 80 feet area in the northern portion of the Unit 4 basement where TDS concentrations in the deep zone (103 to 118 ft bgs) are greater than 21,000 mg/L (Figure 18).
- Area 2: 80 feet by 80 feet area in the central portion of the Unit 4 basement where TDS concentrations in the deep zone are expected to be lower than 21,000 mg/L (Figure 18).

Using the soil data, the mass estimates show that within Area 1 and Area 2, greater than 80 percent of the total mass of perchlorate is present within the UMCf (***Table 8***). Further vertical discretization (Appendix G) shows that within the UMCf, greater than 90 percent of the perchlorate mass and total COPC mass is present between 83 and 118 feet bgs within Area 1, and greater than 80 percent of the perchlorate mass and total COPC mass is present between 83 and 118 feet bgs within Area 2.

Table 8. Mass Estimate in Soil Beneath the Unit 4 Treatability Study Area

Zone	Perchlorate (lbs)	Chlorate (lbs)	Hexavalent Chromium (lbs)	Chloroform (lbs)	Nitrate (lbs)
Area 1					
Qal	1,317	22,738	93	3	16
UMCf	28,658	160,141	779	32	331
Total	**29,975**	**182,879**	**872**	**35**	**347**
Area 2					
Qal	1,329	59,817	40	1	15
UMCf	5,886	44,218	255	14	99
Total	**7,215**	**104,035**	**295**	**15**	**114**

Notes:
1.The contact between the Quaternary alluvium (Qal) and UMCf was assumed to be at 38 feet bgs (1,776 feet amsl).
2. The mass within the UMCf was estimated down to 158 feet bgs (1,656 feet amsl).

The mass estimates were also prepared using groundwater data to compare the difference between the two mass estimating methodologies (***Table 9***; Appendix G).

Table 9. Mass Estimate in Groundwater Beneath the Unit 4 Treatability Study Area

Zone	Perchlorate (lbs)	Chlorate (lbs)	Hexavalent Chromium (lbs)	Chloroform (lbs)	Nitrate (lbs)
Area 1					
Qal	Unsaturated Zone				
UMCf	24,303	137,782	501	35	389
Total	**24,303**	**137,782**	**501**	**35**	**389**
Area 2					
Qal	Unsaturated Zone				
UMCf	4,660	43,076	77	100	159
Total	**4,660**	**43,076**	**77**	**100**	**159**

Notes:
1. The saturated zone was assumed to be at 38 feet bgs (1,776 feet amsl).
2. The mass within the UMCf was estimated down to 158 feet bgs (1,656 feet amsl).
3. Average porosity of 0.51 used for the UMCf between 38 to 88 feet bgs and 0.58 between 89 and 149 feet bgs.

In general, the groundwater data-based mass estimates were less than the mass estimates using soil data for all COPCs except for the mass estimates for chloroform and nitrate. This difference indicates that preparing mass estimates from groundwater data alone within the Unit Buildings 4 and 5 source area may significantly underestimate the amount of mass present.

3.0 PHASE 1 BENCH-SCALE TESTING ACTIVITIES AND RESULTS

The University of Nevada at Las Vegas (UNLV) initiated bench-scale studies in October 2017 as described in the NDEP-approved *Unit 4 Source Area In-Situ Bioremediation Treatability Study Bench-Scale Work Plan* (Bench-Scale Work Plan) (Tetra Tech, 2017). On June 29, 2018, a technical memorandum (Treatability Study Modification No. 1) was submitted to NDEP recommending additional bench-scale laboratory studies (Tetra Tech, 2018b) to examine the impact of nano-scale zero-valent iron (nZVI) on the reduction of hexavalent chromium and other COPCs; to evaluate the degradation of chloroform with other COPCs; and to evaluate the effectiveness of citric acid as a carbon source (as recommended by NDEP in comments to the Work Plan). NDEP approved the modification in a letter dated July 10, 2018. On May 15, 2019, a technical memorandum (Treatability Study Modification No. 7) was submitted to NDEP to summarize the citric acid testing results and recommend elimination of further citric acid testing (Tetra Tech, 2019a). The citric acid testing results suggested that the amount of carbon that can be provided by citric acid is much less than that from other carbon sources in testing with equivalent weight, making citric acid a less effective/efficient carbon source. In addition, a substantial amount of buffering would be required to maintain a neutral pH. As such, further citric acid testing was not recommended. NDEP approved the modification in a letter dated May 31, 2019. This section presents a summary of the bench-scale study objectives, procedures, results, and key findings from the bench-scale studies. The UNLV reports for the microcosm, column, and nZVI studies are provided in Appendix H.

3.1 BENCH-SCALE STUDY OBJECTIVES

The overall objective of the bench-scale studies was to provide data necessary for the design of the Unit 4 Treatability Study. Specific objectives of the bench-scale studies as outlined in the *Bench-Scale Work Plan and Treatability Study Modification No. 1* were to:

- Determine the impact of high COPC and TDS concentrations on the biodegradation kinetics of the COPCs using groundwater and soil collected from the Unit 4 Treatability Study Area.
- Examine the impact of bioaugmentation, along with adding nutrients and vitamins, on the biodegradation of the COPCs.
- Determine the rate at which chloroform is degraded along with other COPCs; evaluate potential chloroform toxicity to microorganisms; and identify intermediate and final degradation products associated with biodegradation of chloroform.
- Examine the impact of nZVI on the reduction of hexavalent chromium and other COPCs, and evaluate the degradation kinetics of a selected organic carbon source with and without the addition of nZVI to determine if the addition of nZVI influences biological reduction of COPCs.
- Evaluate the effectiveness of citric acid as a carbon source for ISB in the source area relative to molasses or emulsified vegetable oil (EVO).

3.2 COLLECTION AND EVALUATION OF SOIL AND GROUNDWATER

Soil cuttings were collected for use in the bench-scale studies (1) from boring locations M-251 (from 60 to 120 feet bgs) and M-253 (from 60 to 108 feet bgs) during the Unit Buildings 4 and 5 source characterization investigation from September 2017 to October 2017; and (2) from boring locations U4-E-01D, U4-E-02D, U4-E-04D, and U4-E-05D (from 75 to 115 feet bgs) during the Phase 1 pre-design field activities for the Unit 4 Treatability Study in May 2018. Groundwater was collected from wells M-251-100, M-253-100, U4-E-01I, U4-E-02I, and U4-E-05D from October 2017 through February 2020 for use in the bench-scale tests. UNLV tested and analyzed the collected soils and groundwater for various parameters including moisture content, contaminant concentrations, mineralogical composition, and microbial populations prior to use in the bench-scale tests.

In general, the moisture content and contaminant concentrations in soil increased with depth. The moisture content ranged from 32 percent by weight from soils collected from 60 to 70 feet bgs at boring location M-251 to 76 percent by weight from soils collected from 110 to 120 feet bgs at boring location M-251. The maximum concentrations of COPCs detected in soil for the bench-scale studies were in the soil samples collected from 90 to 100 feet bgs at boring location M-251. The maximum hexavalent chromium, nitrate, chlorate, and perchlorate concentrations in soil were approximately 55 mg/kg, 76 mg/kg, 7,570 mg/kg, and 1,141 mg/kg, respectively. The maximum concentrations of COPCs detected in groundwater for the bench-scale studies were in groundwater samples collected from monitoring well M-251-100. The maximum hexavalent chromium, nitrate, chloroform, chlorate, perchlorate, and TDS concentrations in groundwater were 112 mg/L, 378 mg/L, 8.3 mg/L, 32,000 mg/L, 4,730 mg/L, and 52,000 mg/L, respectively.

X-ray diffraction analysis of the soils collected from depths from 90 to 110 feet bgs at boring location M-251 identified that the soil within the UMCf is primarily composed of a smectite-group clay, montmorillonite (ranging from 29 to 42 percent). The remaining portion of the soil is composed of the following minerals, listed in decreasing percentages: quartz; illite/muscovite; andesine; orthoclase; calcite; kaolinite; dolomite; actinolite; clinoptilolite; and hematite.

Microbial analysis using Next Generation Sequencing and quantitative PCR revealed a relatively high diversity/low population profile of bacteria in soil and groundwater. The bacteria present were primarily protobacteria (approximately 54 to 57 percent) and actinobacteria (approximately 16 to 35 percent). Testing for genes encoding nitrate and perchlorate reducing enzymes revealed no detectable presence of perchlorate-reducing bacteria and only a limited number (up to 25 cells/mL) of denitrifying bacteria.

3.3 BATCH MICROCOSMS

UNLV conducted numerous sets of batch microcosm tests to achieve the bench-scale study objectives. A summary of the purpose, test variables, and major findings from each set of batch microcosm tests are provided below.

3.3.1 Preliminary

The purpose of the preliminary microcosm tests was to evaluate whether bioaugmentation is required to promote reduction of the COPCs. A secondary purpose was to provide a preliminary evaluation of the toxicity of high TDS concentrations to the microbiota. The microcosms contained soil from borings M-251 and M-253, groundwater collected from wells M-251-100 and M-253-100, nutrients (ammonia and phosphate), and a carbon substrate (EOS-PRO® or a mixture of EOS-PRO® and acetate). Unfiltered biosolids from the fluidized bed reactors (FBRs), part of the Site GWETS, were added to half of the microcosms during the testing for purposes of evaluating the necessity of bioaugmentation. The preliminary microcosm testing revealed that bio-augmentation and dilution of the high TDS concentrations are required to promote reduction of the COPCs. Reduction of COPC concentrations was observed in microcosms that had been bioaugmented and contained TDS concentrations ranging from approximately 12,000 mg/L to 18,000 mg/L. Reduction of COPCs did not occur in microcosms without bio-augmentation or with TDS concentrations at 46,000 mg/L.

3.3.2 Phase I

The purpose of the Phase I microcosm tests was to evaluate the performance of different carbon substrates, specifically EOS-PRO® and molasses, and to evaluate the effect of TDS concentrations on the degradation of COPCs. Molasses was evaluated as an alternative soluble substrate to acetate and was selected based on previous experience. The microcosms contained soil from boring M-251, groundwater from well M-251-100, SLMW, a mixed bacterial culture (consisting of lab-grown culture and unfiltered biosolids from the FBRs), nutrients (ammonia and phosphate), and carbon substrates (EOS-PRO® or molasses). The TDS concentrations within the microcosms ranged from approximately 19,000 mg/L to 45,000 mg/L.

Except for hexavalent chromium reduction in microcosms containing molasses, limited reduction of COPC concentrations was observed in the microcosms and was largely attributed to the high TDS concentrations. However, several important discoveries were made during the Phase I microcosm testing. Despite adding an excess amount of EVO (EOS-PRO®) to the microcosms, only a small amount of carbon substrate was observed in the dissolved phase. Based on this finding, UNLV conducted an oil sorption test with EOS-PRO® and the soils collected from the Unit 4 Treatability Study Area.

UNLV laboratory batch sorption testing of EVO on soil and groundwater from the Unit 4 Treatability Study Area indicated a relatively high retention capacity for these soils. Estimated retention values developed from sorption isotherms were one- to two- orders of magnitude higher compared to typical values reported in the literature and EVO protocol for similar soils. One reason for the higher retention capacities for the soil within the UMCf at the Unit 4 Treatability Study Area is likely the type of fines and clays that comprise the soil in this vicinity. Some clays, because of their structure, tend to retain higher quantities of organic compounds, including EVO. The type of clay and fines in the UMCf within the Unit 4 Treatability Study Area also differ from those in off-site areas, which had an EVO retention capacity approximately half of those from soil from the UMCf within the Unit 4 Treatability Study Area. A second factor for the higher retention capacity for the UMCf soil is the presence of high calcium in these soils. Calcium not only could serve as a flocculant agent for the EVO (similar to the role that trivalent ions serve in flocculation processes for water treatment), but also could result in the formation of calcium oleate (oleate is one of the major components of EVO). These properties of calcium result in an unusually high measured retention capacity for EVO. Finally, the extreme ionic strength present within the groundwater collected from the Unit 4 Treatability Study Area due to the high COPC concentrations may have induced micelle formation resulting in less EVO in the dissolved phase. It should be noted that the EVO that becomes sorbed to the soil is not lost, but the amount of EVO available in the dissolved phase for bacteria to utilize for biodegradation of the COPCs may be too low to meet the electron donor (or carbon substrate) demand based on the current concentrations of these contaminants. Molasses was able to provide sufficient soluble substrate to meet the electron donor demand and to also abiotically reduce hexavalent chromium, so it was selected over EVO for use in subsequent bench-scale tests. Given the beneficial slow-release properties of EVO, it may still have potential for use in the Unit 4 Treatability Study as TDS and COPC concentrations decrease. Further use of EVO in field application would be supplemental to the planned Phase 2 treatability study field implementation described in this Work Plan Addendum. If NERT decides to test the effectiveness of EVO at this location, a Treatability Study Work Plan Modification will be prepared and submitted to NDEP for approval prior to initiating work.

The presence of precipitates was also observed during the Phase I microcosm testing. UNLV conducted scanning electron microscopy (SEM) and x-ray diffraction (XRD) analyses to determine the nature of the precipitates, and the results indicated the presence of salt-like structures primarily comprised of sodium chlorate, sodium chloride, gypsum, and dolomite. The implications of this finding are further discussed in Section 3.5.

In addition, UNLV performed preliminary testing of citric acid as part of Treatability Study Modification No. 1 to evaluate if it would be a suitable carbon substrate for use in subsequent microcosm testing and potential use in the Unit 4 Treatability Study. The results of the preliminary testing, including chemical oxidation demand (COD) testing and performing a titration curve with citric acid, sodium bicarbonate, and groundwater from well M-251-100, indicated that the citric acid would not be further considered as a suitable carbon substrate for the Unit 4 Treatability Study due to the low chemical oxygen demand (COD) (maximum of 444 grams per liter [g/L] compared to approximately 1,000 g/L for molasses and approximately 2,000 g/L for EOS-PRO®) and the substantial amount of buffering solution (i.e., sodium bicarbonate) that would be required to maintain a neutral pH. Therefore, as agreed to by NDEP, no microcosm tests were performed using citric acid.

3.3.3 Salinity

Salinity microcosms were performed to determine the level of dilution required to reduce TDS concentrations to levels where biodegradation can occur. The microcosms contained soil from M-251, groundwater from well M-251-100, SLMW, unfiltered biosolids from the FBRs, nutrients (ammonia and phosphate), and a carbon substrate (molasses or acetate). For this microcosm test, UNLV used unfiltered biosolids from the FBRs to evaluate if the

biosolids provided the bacteria required for biological reduction of the COPCs. The groundwater from well M-251-100 was diluted with deionized water at ratios of 1:1, 1:2, 1:3, 1:4, and 1:9, prior to being added to the microcosms to evaluate TDS concentrations ranging from approximately 4,600 mg/L to 23,000 mg/L. In general, hexavalent chromium and nitrate concentrations were reduced in all microcosms containing molasses and were reduced to a lesser extent in microcosms containing acetate. However, minimal reduction in chlorate and perchlorate concentrations were observed in the microcosms regardless of the TDS concentration. The lack of chlorate and perchlorate degradation in microcosms containing molasses is attributed to pH reduction to approximately 4 pH units after the addition of the molasses, indicating the need to buffer the solution. The lack of chlorate and perchlorate degradation in microcosms containing acetate is attributed to the significant increase in TDS concentration following the addition of the sodium acetate to the microcosms. Because the dilution required to reduce TDS concentrations to levels where biodegradation can occur could not be determined through the salinity microcosms, the Phase II microcosms also tested a range of TDS concentrations to determine the appropriate range for biodegradation to occur.

3.3.4 Phase II

The purpose of the Phase II microcosm tests was to evaluate degradation rates of the COPCs at TDS concentrations near the anticipated limits where biodegradation could occur utilizing the knowledge gained from the previous microcosm tests. Molasses was selected as the primary carbon substrate for the microcosm test based on the results from the previous microcosm tests and the ability of molasses to degrade hexavalent chromium both abiotically and biotically. The addition of acetate with molasses was evaluated to determine if a more soluble substrate would enhance the biodegradation of the COPCs. The Phase I microcosms tested the use of molasses at initial TDS concentrations of approximately 24,000 mg/L and 45,000 mg/L. Due to the limited reduction in COPCs observed during the Phase I microcosms, the Phase II microcosms were conducted at lower initial TDS concentrations, ranging from approximately 15,200 mg/L to 21,000 mg/L. The Phase II microcosms also used sodium bicarbonate as a pH buffer so a neutral pH range was maintained throughout the testing. The microcosms contained soil collected from boring M-251, groundwater collected from M-251-100, SLMW, biosolids from the FBRs (filtered through a coffee filter), urea-diammonium phosphate solution, vitamin B12, sodium bicarbonate, and a carbon substrate (molasses alone or molasses with acetate). In addition, a trace mineral solution was added along with additional biosolids from the FBRs to four of the replicate microcosms after 253 days to evaluate if the slow rate of degradation was related to a lack of an essential trace mineral. The groundwater from well M-251-100 was diluted at varying ratios prior to being added to the microcosms to evaluate TDS concentrations at approximately 15,200 mg/L, 17,400 mg/L, and 21,000 mg/L.

The following is a brief summary of the COPC reductions observed within the microcosms containing molasses only:

- Hexavalent chromium concentrations reduced from a maximum concentration of 50 mg/L to less than 0.1 mg/L within 22 days in all TDS ranges evaluated (Figure 19);
- Nitrate concentrations reduced from a maximum concentration of 130 mg/L to less than 4 mg/L within 77 days in all TDS ranges evaluated (Figure 20);
- Chlorate concentrations reduced from a maximum concentration of 10,379 mg/L to less than 2.5 mg/L within 267 days in all TDS ranges evaluated (Figure 21);
- Perchlorate concentrations reduced significantly in some, but not all, the microcosms. In microcosms containing an initial TDS concentration of approximately 15,200 mg/L, perchlorate concentrations decreased from approximately 1,507 mg/L to 945 mg/L after 554 days. In microcosms containing an initial TDS concentration of approximately 17,400 mg/L, perchlorate concentrations decreased from an initial concentration of approximately 1,646 mg/L to less than 0.02 mg/L after 267 days. In microcosms containing an initial TDS concentration of approximately 21,000 mg/L, perchlorate concentrations decreased from 1,878 mg/L to 0.33 mg/L after 554 days (Figure 22).

The average perchlorate reduction rates in the Phase II microcosms ranged from 4 mg/L per day to 22 mg/L per day. It should be noted that the maximum perchlorate reduction rate was 76.5 mg/L per day in the replicate microcosm with an initial TDS concentration of 21,000 mg/L and where a trace mineral solution and additional biosolids were added after 253 days. This indicates that supplemental bioaugmentation and/or the addition of a trace mineral solution may increase the perchlorate reduction rate.

Significantly slower degradation rates were observed in microcosms containing molasses and acetate than those containing molasses alone. The faster degradation rates of the COPCs in microcosms containing molasses alone is attributed to the capability of molasses to reduce hexavalent chromium through both biotic and abiotic reduction. As detailed in the UNLV report (Appendix H), the abiotic reduction of hexavalent chromium with molasses has been previously reported in scientific papers and was also demonstrated in bench-scale microcosm tests conducted by UNLV. The reduction of hexavalent chromium is the first step in the biological degradation pathway of the COPCs, as it is the most thermodynamically favorable for the bacteria, followed by nitrate, chlorate, and then perchlorate. Another potential reason for the slower degradation rates in microcosms containing molasses and acetate is that the addition of acetate as sodium acetate contributes to the overall TDS concentration in the microcosm, which may further inhibit the biological reduction of the COPCs.

At the conclusion of the microcosm testing, the soil and liquids remaining in the microcosms were sampled and analyzed to further evaluate the degradation of the COPCs and potential causes for inhibition of COPC reduction in select microcosms. Hexavalent chromium, nitrate, and chlorate concentrations in the remaining liquid and soil were below the detection limits for all the microcosms where degradation in the liquid phase was observed. The average perchlorate concentrations in the remaining liquid in microcosms containing molasses and an initial TDS concentration of 15,200 mg/L, 17,400 mg/L, and 21,000 mg/L were 945 mg/L, 0.001 mg/L, and 0.2 mg/L, respectively, and the average perchlorate concentrations in the remaining soil were 915 mg/kg, less than 0.04 mg/kg, and 1.3 mg/kg, respectively. Similarly, the concentrations of the COPCs in the remaining soil correlated with the final liquid concentrations in the microcosms. Microcosms containing higher concentrations in the remaining soil also had higher concentrations in the remaining liquid. This result indicates that reduction in COPC concentrations observed from sampling the liquid in a mixed soil and water matrix provides a good approximation of the overall reduction of the COPC. The final TDS concentrations in the remaining liquid in microcosms containing molasses and an initial TDS concentration of 15,200 mg/L, 17,400 mg/L, and 21,000 mg/L were 12,600 mg/L, 11,600 mg/L, and 14,300 mg/L, respectively. In general, the COPCs were reduced faster in microcosms containing a lower final TDS concentration. However, this does not fully explain why perchlorate degradation was the slowest in the microcosms containing an initial TDS concentration of 15,200 mg/L. Nevertheless, these microcosm results indicated that in-situ bioremediation of the key COPCs can be accomplished using molasses alone and justifies the completion of a field implementation to further explore the success of this technology within a highly contaminated source area.

Microbiological evaluation of the soil remaining in the microcosms revealed several important genera, *Arcobacter, Azoarcus* and *Pseudomonas,* which include species reported to reduce nitrate, chlorate, and perchlorate. These genera are major components of the biosolids collected from the FBRs that were added to the microcosms and were also found in the soil and groundwater collected from the Unit 4 Treatability Study Area. *Flavobacterium* and *Rhodobacter*, which includes species reported to reduce nitrate, chlorate, and perchlorate, were also present in microcosms using molasses as the carbon substrate. Of the genera identified, only *Bacteroides* was found in microcosms using molasses as the carbon substrate but not in the soil and groundwater collected from the Unit 4 Treatability Study Area. *Bacteroides* is a primarily a genus of anaerobes, which ferment complex polysaccharides. Based on comparisons of bacteria identified in the soil and groundwater collected from the Unit 4 Treatability Study Area and the remaining soil present in the microcosms, the major contributions of the microbial culture to the microcosms are the introduction of *Bacteroides* and an increase in the amount of *Arcobacter*, *Azoarcus*, and *Pseudomonas* that are concentrated in the biosolids collected from the FBRs. These findings provide insight on what genera are introduced with the biosolids from the FBRs and which of these genera are important for the reduction of nitrate, chlorate, and perchlorate within the microcosms.

A total of 12 control microcosm tests were conducted for the Phase II microcosm testing: three control microcosm tests with no vitamin B12 added, three control microcosm tests with no biosolids from the FBRs added, and six control microcosm tests with no carbon substrate added. The control microcosms with a carbon substrate either contained molasses alone or molasses and acetate, similar to the test microcosms. Only the control microcosm test containing molasses and no vitamin B12 was able to reduce concentrations of all of the COPCs; hexavalent chromium concentrations reduced from approximately 32 mg/L to less than 0.05 mg/L, nitrate concentrations reduced from approximately 100 mg/L to less than 2.65 mg/L, chlorate concentrations reduced from approximately 8,200 mg/L to less than 10 mg/L, and perchlorate concentrations reduced from approximately 1,700 mg/L to 0.0013 mg/L within 554 days. This indicates that vitamin B12 is not needed to degrade hexavalent chromium, nitrate, chlorate, and perchlorate. However, it should be noted that the reduction of chloroform was not monitored in these control microcosms, and numerous scientific papers indicate vitamin B12 can assist in the reduction of chloroform. Results of the chloroform degradation testing are documented in the UNLV bench-study reports covering the column testing studies and the nZVI microcosm testing, both located in Appendix H.

In the control microcosms with molasses and acetate and no vitamin B12, hexavalent chromium, nitrate, and chlorate were reduced. At the end of the 554 day test, perchlorate concentrations reduced from 1,640 mg/L to 1,230 mg/L in one set of microcosms and from 1,340 mg/L to 1,110 mg/L in another set of microcosms and appeared to still be degrading with a declining trend in perchlorate concentrations. This finding confirmed the results from the Phase II microcosms that indicated COPCs are degraded faster in microcosms with molasses alone than in microcosms containing molasses and acetate and that vitamin B12 does not appear to be needed to degrade hexavalent chromium, nitrate, chlorate, and perchlorate.

In the control microcosms with no microbial culture added, hexavalent chromium was reduced from concentrations of 32 mg/L to less than 0.05 mg/L. Nitrate concentrations reduced from approximately 70 mg/L to 3 mg/L and chlorate concentrations reduced from approximately 6,400 mg/L to less than 5 mg/L within 554 days in the control microcosm test containing a TDS concentration of approximately 15,200 mg/L. No significant reduction of perchlorate concentrations was observed in this control microcosm test. No significant reduction of nitrate, chlorate, or perchlorate concentrations were observed in the other control microcosm tests with no microbial culture added. These control microcosms indicate that native bacteria present in the soil collected from the Unit 4 Treatability Study Area are capable of reducing the COPCs (with the exception of perchlorate); however, bio-augmentation allows the COPCs to be degraded faster and may allow all of the COPCs to be degraded where TDS concentrations exceed 15,200 mg/L. As expected, no significant reduction of COPC concentrations was observed in the control microcosm tests containing no carbon substrate, therefore indicating that there is not a sufficient carbon source in the soil, water, or other amendments to allow biodegradation to occur.

3.3.5 nZVI

The purpose of the nZVI microcosm tests was to evaluate the effect of nZVI on the reduction of COPCs and evaluate if the addition of nZVI influences the biological reduction of COPCs, including the reduction of chloroform. The nZVI microcosms contained combinations of groundwater collected from well U4-E-01D, blended soil collected from U4-E-01D (from 75 to 115 feet bgs), molasses, nutrients, vitamin B12, sodium bicarbonate, biosolids from the FBRs, and nZVI. The nZVI used in the microcosms was a 25S nZVI solution provided by NanoIron Future Technology and was added to the microcosms at dosages of 3 g/L, 30 g/L, 50 g/L, 60 g/L, 90 g/L, and 100 g/L.

Hexavalent chromium concentrations reduced from approximately 22 mg/L to non-detect within 4 days with the addition of nZVI at a dosage of 3 g/L. Hexavalent chromium concentrations reduced from approximately 22 mg/L to 0.035 mg/L within 4 hours with the addition of nZVI at a dosage of 30 g/L. Nitrate and chlorate concentrations in microcosms containing soil and nZVI at a dosage of 30 g/L were degraded to a lesser extent than microcosms containing soil with no nZVI added. However, the use of nZVI at high dosages (greater than 30 g/L) resulted in rapid degradation of hexavalent chromium, nitrate, chloroform, and chlorate. The following provides a brief

summary of the reduction in other COPC concentrations in microcosms containing nZVI dosages between 50 g/L and 100 g/L:

- Nitrate concentrations reduced from approximately 62 mg/L to approximately 5 mg/L within 35 days.
- Chloroform concentrations reduced from approximately 1 mg/L to 0.01 mg/L within 56 days.
- Chlorate concentrations reduced from approximately 3,000 mg/L to less than 1 mg/L within 7 days.
- Perchlorate concentrations did not significantly reduce within the 56-day test regardless of the nZVI dosage.

In summary, nZVI can degrade hexavalent chromium very quickly, even at dosages as small as 3 g/L. nZVI, at dosages greater than 30 g/L, was also able to degrade chlorate very quickly compared to biological reduction. As expected, perchlorate concentrations did not significantly reduce with addition of nZVI, regardless of the dosage, and therefore, perchlorate does not appear amenable to abiotic reduction with nZVI. In microcosms without nZVI, chloroform degraded from approximately 1 mg/L to 0.12 mg/L within 56 days, and formaldehyde and formic acid were detected, but not chlorocarbenes, suggesting that chloroform is biologically reduced to methane via the hydrolysis pathway. Within the biological degradation pathway for the COPCs, chloroform degradation was found to occur after the degradation of nitrate.

3.3.6 Summary of Microcosm Testing

The results of the microcosm testing justifies the completion of a field study to further explore the use of ISB within a highly contaminated source area. Specifically, the Phase II microcosm tests successfully demonstrated that bioremediation of the COPCs can be accomplished with TDS concentrations as high as 21,000 mg/L using molasses as a carbon substrate along with bioaugmentation using biosolids from the FBRs, nutrients, and sodium bicarbonate. The use of molasses allowed hexavalent chromium to degrade through abiotic and biotic pathways allowing the other COPCs to start degrading earlier and decreasing the overall timeframe for the degradation of the COPCs. Therefore, molasses is the preferred carbon substrate for use in field testing. The use of nZVI is not recommended for field testing as it did not improve the degradation rates of the COPCs compared to ISB unless high dosages (greater than 50 g/L) were used.

3.4 COLUMN TESTING

UNLV performed column testing from February 12, 2019, through February 29, 2020, under several simulated conditions guided by the information gathered from the batch microcosm testing and initial simulations. The purpose of the column tests was to evaluate COPC reduction and obtain other operational data under continuous flow-through conditions that more closely represent field hydrogeologic conditions that would be encountered within the Unit 4 Treatability Study Area. UNLV prepared four columns (each 2 inches in diameter and approximately 50 inches long) to conduct column testing. Two columns were packed with a mixture of soil collected from the intermediate zone (75 to 85 feet bgs) and sand (labeled Columns C and D; hereafter referred to as “intermediate columns”), and two columns were packed with soil collected from the deep zone (95 to 105 feet bgs) and sand (labeled Columns A and B; hereafter referred to as “deep columns”). The columns were packed with a mixture of soil and sand to achieve the desired flowrate that simulates groundwater flow velocities within the intermediate and deep zones within the Unit 4 Treatability Study Area. Soil collected from boring locations U4-E-01D, U4-E-02D, U4-E-04D, and U4-E-05D, and groundwater collected from wells U4-E-01I, U4-E-02I, and U4-E-05D were used in the column studies.

The columns were operated in a recirculation mode for 25 days with water collected from U4-E-01I (for the intermediate columns) and U4-E-01D (for the deep columns) to flush the soil in the columns and obtain consistent effluent concentrations. Following the recirculation period, the columns were operated under five simulations at various feed conditions. During each of the simulations, the input solution was continuously pumped through the columns from the top down and the effluent water was collected for analysis. The influent and effluent COPC concentrations for the two intermediate columns (Columns C and D) and the two deep columns (Columns A and

B) during the first four simulations are depicted in Figures 23 through 30 and during all five simulations are depicted in Figures 31 through 38.

3.4.1 Simulation #1

The purpose of Simulation #1 was to acclimate the columns and evaluate COPC reduction using diluted groundwater. During this simulation, the influent to the columns was a solution consisting of diluted groundwater collected from the Unit 4 Treatability Study Area (diluted with SLMW at a 1:3 ratio), molasses (0.4 percent solution by volume), vitamin B12, diammonium phosphate, sodium bicarbonate, and biosolids collected from the FBRs. Bioaugmentation with the biosolids collected from the FBRs was performed during the initial simulation period based on the findings from the batch microcosms which indicated that bioaugmentation was required to stimulate biodegradation of the COPCs. The calculated flow rates through the columns varied during the simulation but were generally around 0.05 mL/min for the intermediate columns and 0.1 mL/min for the deep columns. This simulation ran for 156 days to allow enough time for the COPCs to degrade in the columns. It should be noted that the influent COPC concentrations and TDS concentrations varied during this simulation as the groundwater used to formulate the feed solution was collected at different times over the study period and from different wells to provide a sufficient quantity of groundwater to keep the columns running. The feed solution for the intermediate columns used groundwater collected from well U4-E-01I, except from days 73 to 130, when groundwater collected from well U4-E-02I was used as U4-E-01I was being used for the extended groundwater extraction test. The TDS concentration in the feed solution ranged from 2,331 to 5,348 mg/L for the intermediate columns and from 4,308 to 4,550 mg/L for the deep columns during Simulations #1 through #4.

The following provides a brief summary of the COPC degradation rates for the intermediate columns during this simulation:

- Hexavalent chromium concentrations reduced from approximately 23 mg/L to less than 0.02 mg/L within 2 days, when the first effluent sample was collected, and remained reduced throughout Simulation #1 (Figure 23).
- Nitrate concentrations reduced from approximately 10 mg/L to less than the detection limit of 0.884 mg/L within 2 days, when the first effluent sample was collected, and remained reduced throughout Simulation #1 (Figure 24).
- Chlorate concentrations in the column effluent initially increased following the recirculation period to near the concentration in the feed solution of 2,150 mg/L after 18 days and then began reducing to an average concentration of approximately 1,650 mg/L after 43 days. On day 73, the chlorate concentration in the feed solution significantly reduced from 2,150 mg/L to 110 mg/L due to a change in the groundwater used to formulate the feed solution. Chlorate concentrations in the column effluent reduced to below 1 mg/L by day 90 and remained reduced throughout the remainder of Simulation #1, even when the chlorate concentration in the feed solution increased from 110 mg/L to 597 mg/L on day 131 (Figure 25).
- Perchlorate concentrations in the column effluent initially increased following the recirculation period to near the concentration in the feed solution of 875 mg/L after 33 days and then began reducing to an average concentration of 570 mg/L after 43 days. On day 73, the perchlorate concentration in the feed solution significantly reduced from 875 mg/L to 18 mg/L due to a change in the groundwater used to formulate the feed solution. Perchlorate concentrations in the column effluent reduced to below the detection limit of 0.05 mg/L by day 100 and remained reduced throughout the remainder of Simulation #1, even when the perchlorate concentration in the feed solution increased from 18 mg/L to 68 mg/L on day 131 (Figure 26).

The following provides a brief summary of the COPC degradation rates for the deep columns during this simulation:

- Hexavalent chromium concentrations reduced from approximately 25 mg/L to less than 0.02 mg/L within 4 days and remained reduced throughout the remainder of Simulation #1 (Figure 27).

- Nitrate concentrations reduced from approximately 35 mg/L to less than the detection limit of 0.884 mg/L within 2 days, when the first effluent sample was collected, and generally remained reduced throughout the remainder of Simulation #1 (Figure 28).
- Chlorate concentrations in the column effluent initially increased following the recirculation period to near the concentration in the feed solution of 2,000 mg/L after 18 days and then reduced to less than 0.2 mg/L after 100 days (Figure 29).
- Perchlorate concentrations reduced from 850 mg/L to an average concentration of 385 mg/L after 43 days. After 74 days, the perchlorate concentration in the feed solution reduced from 850 mg/L to 420 mg/L and the perchlorate concentrations in the column effluent reduced to less than 0.05 mg/L within 149 days (Figure 30).

The results of Simulation #1 demonstrated that the COPCs present in the diluted groundwater from both the intermediate and deep zones could be degraded with the addition of molasses, nutrients, and biosolids from the on-site FBRs under dynamic flow-through conditions without clogging the columns.

3.4.2 Simulation #2

During this simulation, the column influent was a solution of diluted groundwater, vitamin B12, and diammonium phosphate. No carbon substrate, sodium bicarbonate, or biosolids from the FBRs were added to the column influent during this simulation to evaluate how COPC concentrations would rebound. This simulation was run for 16 days. Hexavalent chromium, nitrate, chlorate, and perchlorate concentrations at the effluent of the intermediate columns remained reduced and did not increase throughout this simulation period (Figures 23 through 26), indicating there were sufficient bacteria and carbon substrate present in the columns from Simulation #1 to degrade the COPCs. For the deep columns, effluent concentrations of hexavalent chromium remained reduced but had a slight increase to a maximum concentration of 5.2 mg/L, compared to an influent concentration of approximately 15 mg/L (Figure 27). Effluent concentrations of nitrate, chlorate, and perchlorate in the deep columns increased to near the influent concentrations with maximum concentrations of approximately 29 mg/L, 2,700 mg/L, and 510 mg/L, respectively (Figures 28 through 30), indicating that there was insufficient carbon substrate remaining in the columns to continue reducing the COPCs.

3.4.3 Simulation #3

The purpose of this simulation was to evaluate whether COPC reduction could be achieved without the addition of biosolids from the FBRs and with a reduced amount of carbon substrate. During this simulation, the column influent was a solution consisting of diluted groundwater collected from the Unit 4 Treatability Study Area, a reduced amount of molasses (0.2 percent solution by volume), vitamin B12, diammonium phosphate, and sodium bicarbonate. This simulation was run for 19 days. In the intermediate columns, hexavalent chromium, nitrate, chlorate, and perchlorate concentrations in the effluent of the columns remained reduced and did not increase throughout this simulation period (Figures 23 through 26), indicating there were sufficient bacteria and carbon substrate present in the columns to degrade the COPCs. For the deep columns, effluent concentrations of hexavalent chromium concentrations reduced from 15 mg/L to less than 0.01 mg/L at the start of the simulation (Figure 27), nitrate concentrations reduced from 35 mg/L to less than 1 mg/L within 5 days (Figure 28), chlorate concentrations reduced from 2,000 mg/L to an average concentration of 1,040 mg/L within 19 days (Figure 29), and no perchlorate degradation was observed during the 19-day period (Figure 30). During this simulation, the chlorate and perchlorate degradation in the deep columns appeared to stall and little COD was observed in the effluent of the columns. Therefore, the amount of molasses added to the columns was increased to a 0.4 percent solution by volume for Simulation #4.

3.4.4 Simulation #4

This simulation was the same as Simulation #3, except the concentration of molasses was increased (0.4 percent solution by volume) to provide additional carbon substrate for the bacteria. This simulation was run for 67 days to allow sufficient time to observe degradation of the COPCs.

The following provides a brief summary of the COPC degradation rates for the intermediate columns during this simulation:

- Hexavalent chromium concentrations reduced from approximately 23 mg/L to generally less than 0.02 mg/L throughout the entire simulation (Figure 23).
- Nitrate concentrations reduced from approximately 10 mg/L to less than the detection limit of 0.884 mg/L throughout the entire simulation (Figure 24).
- Chlorate concentrations reduced from approximately 597 mg/L to generally less than 1 mg/L throughout the entire simulation (Figure 25).
- Perchlorate concentrations reduced from approximately 68 mg/L to generally less than 0.05 mg/L throughout the entire simulation (Figure 26).

The following provides a brief summary of the COPC degradation rates for the deep columns during this simulation:

- Hexavalent chromium concentrations reduced from approximately 15 mg/L to generally less than 0.02 mg/L throughout the entire simulation (Figure 27).
- Nitrate concentrations reduced from approximately 6.5 mg/L to less than the detection limit of 0.884 mg/L throughout the entire simulation (Figure 28).
- Chlorate concentrations reduced from approximately 2,000 mg/L to less than 0.1 mg/L after 44 days (Figure 29).
- Perchlorate concentrations reduced from approximately 420 mg/L to less than 0.05 mg/L after 63 days (Figure 30).

The results of this simulation indicate that: 1.) once the bacterial population has been established, bioaugmentation may no longer be required; and 2.) that a molasses solution of at least 0.4 percent by volume is required to provide sufficient carbon substrate for the microorganisms to degrade the COPC concentrations present in the column influent. There was no significant reduction in flow rates observed during this simulation, indicating that the accumulation of biomass in the columns did not significantly impact the soil permeability.

3.4.5 Simulation #5

The purpose of this simulation was to evaluate COPC reduction without bioaugmentation for undiluted groundwater collected from the intermediate and deep zone within the Unit 4 Treatability Study Area. During this simulation, the columns ran for 98 days with an influent solution consisting of undiluted groundwater, molasses (0.4 percent by volume), vitamin B12, diammonium phosphate, and sodium bicarbonate. No biosolids from the FBRs were added. The TDS concentration in the feed solution was 17,223 mg/L for the intermediate columns and ranged from 17,726 to 23,810 mg/L for the deep columns during Simulation #5.

The following provides a brief summary of the COPC degradation rates for the intermediate columns during this simulation:

- Hexavalent chromium concentrations reduced to generally less than 0.2 mg/L throughout the simulation even though the concentration in the feed solution increased from 23 mg/L to 100 mg/L (Figure 31).

- Nitrate concentrations increased at the start of the simulation to an average concentration of 84 mg/L, as the concentration in the feed solution increased from 10 mg/L to 130.8 mg/L, but then decreased to an average concentration of 55 mg/L at the end of the simulation (Figure 32).
- Chlorate concentrations increased at the start of the simulation to an average concentration of 12,000 mg/L, as the concentration in the feed solution increased from 597 mg/L to 14,000 mg/L, but then decreased to an average concentration of 8,100 mg/L at the end of the simulation (Figure 33).
- Perchlorate concentrations increased at the start of the simulation to an average concentration of 1,400 mg/L, as the concentration in the feed solution increased from 68 mg/L to 1,400 mg/L, but then decreased to an average concentration of 980 mg/L at the end of the simulation (Figure 34).

The following provides a brief summary of the COPC degradation rates for the deep columns during this simulation:

- Hexavalent chromium concentrations reduced to generally less than 0.2 mg/L throughout the simulation even though the concentration in the feed solution increased from 15 mg/L to 60 mg/L (Figure 35).
- Nitrate concentrations in the column effluent fluctuated throughout the simulation. Initially, nitrate concentrations increased to an average concentration of 67 mg/L as the concentration in the feed solution increased from 35 mg/L to 140 mg/L but then reduced to below 5 mg/L within 45 days. The nitrate concentrations in the column effluent then increased to an average concentration of 50 mg/L after 66 days, and then reduced to an average concentration of 15 mg/L at the end of the simulation (Figure 36). The fluctuations in nitrate concentrations in the column effluent indicate incomplete nitrate degradation and is likely associated with biological growth and carbon substrate availability as the influent COPC concentrations were increased.
- Chlorate concentrations increased at the start of the simulation to an average concentration of 9,500 mg/L 66 days after the concentration in the feed solution increased from 2,000 mg/L to 11,000 mg/L. Chlorate concentrations then remained relatively stable with an average concentration of 7,800 at the end of the simulation (Figure 37). It should be noted that the chlorate concentration of 12,000 mg/L in one sample collected from the effluent of Column A on day 324 exceeded the concentration in the feed solution (11,000 mg/L). This is likely due to variability in the feed solution concentration or variability in the analytical testing.
- Perchlorate concentrations reduced from approximately 1,800 mg/L to 1,500 mg/L after 98 days (Figure 38).

The results of this simulation indicated that degradation of the COPCs was observed even with TDS concentrations up to 23,810 mg/L after an acclimation period where the microbiota were able to adjust to the significantly higher COPC and TDS concentrations present in the feed solution. However, the full degradation of the COPCs was not achieved likely due to the limited contact time available between the microorganisms and contaminants within the relatively short columns; and there wasn't sufficient time (or column length) for the microorganisms to reduce all of the COPCs.

3.4.6 Post-Treatment Column Analysis

Following the completion of the column testing, UNLV opened the columns to evaluate conditions and analyze the chemical and microbiological content. Microbiological evaluation of the column contents revealed that approximately 70 percent of the bacteria present in the soils from the intermediate column and 50 percent of the bacteria present in the soils from the deep columns were the phylum proteobacteria, which are known nitrate and perchlorate reducers. The soils contained very high levels of genes corresponding to nitrate-reducing bacteria and low levels of genes related to perchlorate-reducing bacteria. However, it is important to note that the samples were collected at the end of the column testing, after the columns were running for more than 100 days without bioaugmentation and with undiluted groundwater, and limited perchlorate reduction was taking place at the time the simulation was completed. Hexavalent chromium was not detected in the soil from the intermediate or deep

columns. In the intermediate columns, the average soil concentrations of nitrate, chlorate, and perchlorate were 0.02 µg/kg, 1.7 µg/kg, and 0.4 µg/kg, respectively. In the deep columns, the average soil concentrations of nitrate, chlorate, and perchlorate were 0.013 µg/kg, 1.63 µg/kg, and 0.67 µg/kg, respectively. Concentrations of COPCs in the remaining soil generally correlated with the effluent sample results at the end of the column testing. For instance, in the intermediate column, where hexavalent chromium and nitrate degraded, hexavalent chromium was not detected in the soil and the nitrate concentration was only detected at 0.02 µg/kg. Therefore, the reduction of COPC concentrations in the liquid phase is a good indicator that biodegradation occurred in both the soil and liquid within the columns.

3.4.7 Summary of Column Testing

The results of the column testing supplement the results of the microcosm testing and further justifies the completion of a field study of ISB within a highly contaminated source area. COPCs were continuously degraded under conditions generally representing field hydrogeologic conditions that would be encountered within the Unit 4 Treatability Study Area. Simulation 1 demonstrated that the COPCs could be degraded over a period of 156 days with TDS concentrations up to 5,348 mg/L using a continuous feed solution of molasses, biosolids from the FBRs, nutrients, and sodium bicarbonate with no significant reduction in flow conditions. Simulations 3 and 4 demonstrated once the microbial populations were acclimated, the COPCs could be degraded without the need for further bioaugmentation. Simulation 5 demonstrated that COPCs at concentrations present within the Unit 4 Treatability Study Area could be degraded with TDS concentrations up to 23,810 mg/L, although some acclimation time is required and additional contact time between the microorganisms, COPCs, and the carbon substrate solution would be necessary for complete degradation.

3.5 PRECIPITATES

During the bench-scale testing activities, UNLV researchers noticed precipitates were present in soil and groundwater collected from the Unit 4 Treatability Study Area and that precipitates formed when adding molasses to the groundwater collected from the Unit 4 Treatability Study Area for use in the batch microcosms and column studies. UNLV directed a preliminary investigation on a blended soil sample collected from depths ranging from 60 to 120 feet bgs at boring location M-251, using an SEM and XRD to evaluate the nature of the precipitates. The results indicated the presence of halite and sodium chlorate in addition to the minerals expected to be present in the soil (clay minerals, dolomite, and gypsum). The presence of salts in the soil, specifically sodium chlorate, and the precipitate formation when adding molasses to the groundwater, are important findings for the Phase 2 treatability study, as it indicates that some of the chlorate within the Unit 4 Treatability Study Area is present as a salt and that the addition of molasses can cause precipitates to form. Additional work will be performed as a separate task to complete a study to better understand the implications of this issue.

4.0 PHASE 2 TREATABILITY STUDY CONSIDERATIONS AND MODIFICATIONS

The overall objective of the Unit 4 Treatability Study is to evaluate the effectiveness of an ISB approach to address impacted groundwater present in the vicinity of the Unit 4 Treatability Study Area, which as previously described is a source area containing the highest contaminant concentrations found at the Site. The ISB approach will combine daily pulsed carbon substrate solution injections with groundwater extraction to enhance distribution of the carbon substrate solution. This study will provide information to support technology screening and remedy selection as part of the FS process. The Phase 2 treatability study design and objectives presented herein build upon the conceptual design and objectives that were presented in the Work Plan and incorporate key findings of the Phase I results described in Sections 2.0 and 3.0.

Phase 1 of the Treatability Study (pre-design activities) was implemented to obtain soil and hydrogeologic information necessary to design the planned soil flushing, injection, and extraction activities, and to complete bench testing to evaluate the biodegradation limitations associated with high contaminant concentrations present in soil and groundwater in the Unit 4 Treatability Study Area. The bifurcation of the study into two distinct phases is consistent with the approach taken for other treatability studies across the NERT RI Study Area and affords the opportunity to evaluate newly available data to determine the optimal strategy for the Phase 2 efforts. The Phase 1 pre-design activities have produced valuable information that has significantly expanded the understanding of the Unit 4 Treatability Study Area. Additionally, since the conceptual treatability study design in the Work Plan was submitted, other NERT RI Study Area bioremediation treatability studies (both completed and on-going) have provided key data to support preparation of this Work Plan Addendum.

This section presents a summary of the relevant discoveries since submittal of the Work Plan (data collected during Phase 1 pre-design field activities and bench-studies), a discussion of the current modified treatability study approach for Unit 4, and a presentation of the updated Phase 2 treatability study objectives.

4.1 RELEVANT FINDINGS

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

As described in Sections 2.0 and 3.0, completion of the Phase 1 pre-design activities and bench-scale studies produced findings that altered the Unit 4 Treatability Study approach originally described in the Work Plan. Section 4.2 presents a revised concept of the Unit 4 Treatability Study. Key changes from the original treatability study approach include the following:

- The geotechnical and structural evaluation conducted as part of the Phase 1 pre-design field activities identified the presence of hydro-collapsible soils in the vadose zone. As a result of identifying this soil condition, the soil flushing component in the originally planned approach has been removed from the Phase 2 treatability study.
- The bench-scale testing activities demonstrated successful degradation of COPCs at TDS concentrations up to 21,000 mg/L; TDS concentrations higher than 21,000 mg/L may inhibit biological activities. Implementation of the extended groundwater extraction test indicated that groundwater extraction can reduce TDS to concentrations amenable to biodegradation of COPCs in the intermediate zone in a short time frame and in the deep zone in a relatively short time frame (approximately 3 months). The original treatability study concept included groundwater extraction to improve vertical and horizontal distribution of substrate in the subsurface. The current approach expands the use of groundwater extraction to also reduce TDS concentrations where necessary to assist in creating conditions suitable for biodegradation.
- Based on the bench-scale testing results, molasses is the recommended carbon substrate for the Phase 2 treatability study. Although EOS-PRO® has been used extensively in other treatability studies at the

Site, molasses performed better than EOS-PRO® in bench-scale testing to degrade COPCs at the current conditions present in the Unit 4 Treatability Study Area. Given the beneficial slow-release properties of EOS-PRO®, it may still have potential for use in the Unit 4 Treatability Study as TDS and COPC concentrations decrease.

- Since this treatability study involves groundwater extraction, this water must be disposed of in accordance with state and Federal regulations. Accordingly, NERT will transfer the extracted groundwater to the GWETS for treatment under the existing NPDES permit. Based on data obtained during the extended groundwater extraction test, it was determined that offsite disposal was cost prohibitive and that using vacuum trucks to transport extracted groundwater to a repurposed Process Tank[1] will provide more flexibility and potential cost savings. In addition, the costs relative to using a conveyance pipeline to transport extracted groundwater to the GWETS was also considered. Given the expected variability in flow and COPC concentrations in extracted groundwater over the course of the Unit 4 Treatability Study, using the designated Process Tank as a surge/equalization tank for the extracted groundwater was also determined to be beneficial for treatment of the extracted water via the GWETS. Therefore, the use of a conveyance pipeline to transport extracted groundwater directly to the GWETS was eliminated from the Phase 2 treatability study.
- Based on the findings from the Phase 1 pre-design activities and a Trust-directed optimization exercise (described in Section 2.12 above), the Unit 4 Treatability Study Area has been modified from the single 120-foot by 120-foot area described in the Work Plan to two separate 80-foot by 80-foot areas. Details of the optimized Unit 4 Treatability Study Area are described in Section 4.2.

As a result of the changes to the Phase 2 treatability study based on the Phase 1 findings, the Phase 2 treatability study objectives have been revised to align with the revised treatability study approach. Specific objectives of the Phase 2 treatability study are described in Section 4.3.

4.2 MODIFICATIONS TO CONCEPTUAL DESIGN

This section presents an overview of the revised approach for the Phase 2 treatability study. The original conceptual design included a soil flushing component to evaluate the effectiveness of soil flushing to remove the very high COPC concentrations present in the vadose zone of the Unit 4 Treatability Study Area and subsequently treat the flushed contaminants in shallow groundwater via ISB. The planned soil flushing area was located to the immediate east of the Unit Building 4 basement in an area with the highest vadose zone COPC concentrations as noted in the previous investigations. Based on the discovery of collapsible soils in the Unit 4 Treatability Study Area and the successful implementation of a soil flushing treatability study in a separate part of the Site, the soil flushing component was eliminated from the Phase 2 Unit 4 Treatability Study. Additionally, the conceptual design for the remaining ISB portion of the study was based on a single 120-foot by 120-foot treatment area, which has been optimized to two separate but adjacent treatment areas. Removal of the soil flushing component also eliminated the need for injection and extraction wells located in the eastern portion of the basement intended to capture the soil flushing waters so the treatability study was refocused in the central portion of the Unit 4 basement in the vicinity of the injection and extraction wells installed as part of the Phase 1 pre-design field activities.

Based on the variability in hydrogeology and COPC concentrations present with the Unit Buildings 4 and 5 Source Area, it was determined that the Unit 4 Treatability Study Area should consist of two smaller 80-foot by 80-foot treatment areas, referred to herein as Areas 1 and 2, rather than one large area to assess the effectiveness of ISB within areas with differing contaminant ranges that represent the contaminant ranges of source areas at the Site. Area 1 is centered around the existing extraction and injection wells installed during the Phase 1 pre-design activities. Area 2 is located to the south and directly upgradient of Area 1. The two treatment areas are depicted in Figure 39. The Trust may elect to reduce the scope of the Unit 4 Treatability Study by eliminating ISB within Area

[1] Three Process Tanks were originally constructed as part of the AP-5 Pond closure for solids treatment.

1 or Area 2 based on the outcome of the TDS reduction efforts in Area 1 and the initial pilot wells testing in Area 2. These scenarios are further discussed in Sections 4.2.4 and 4.2.5. Any material change to the scope of this treatability study will be submitted to NDEP for approval via a Treatability Study Modification. The targeted treatment interval for both treatment areas is from 83 to 118 ft bgs, where the highest soil and groundwater concentrations of COPCs have been detected within the UMCf. The targeted treatment interval has been further subdivided into the intermediate zone from 83 to 98 ft bgs and the deep zone from 103 to 118 ft bgs based on the distinct contaminant and hydraulic characteristics encountered in each zone during the Phase 1 pre-design activities.

4.2.1 Areas 1 and 2 Characteristics

The division of the Unit 4 Treatability Study Area into two smaller treatment areas will allow for evaluation of the ISB approach under varying contaminant, geochemistry, and hydrogeologic conditions. ***Table 10*** summarizes the differences in TDS concentrations, COPC concentrations, and hydraulic conductivity between the areas.

Table 10. Area 1 and Area 2 Characteristics

Parameter Range			Area 1		Area 2	
			Intermediate (83-98 ft bgs)	Deep (103-118 ft bgs)	Intermediate (83-98 ft bgs)	Deep (103-118 ft bgs)
TDS	Moderate	5,000 - 10,000 mg/L	X		X	
	High	10,000 - 20,000 mg/L				X
	Extreme	>20,000 mg/L		X		
Perchlorate	Moderate	40 - 400 mg/L	X		X	
	High	400 - 4,000 mg/L				X
	Extreme	>4,000 mg/L		X		
Chlorate	Moderate	100 - 1,000 mg/L			X	
	High	1,000 - 10,000 mg/L	X			X
	Extreme	>10,000 mg/L		X		
Chromium	Moderate	1 - 5 mg/L			X	
	High	5 - 50 mg/L	X			X
	Extreme	>50 mg/L		X		
Chloroform	Moderate	0.04 - 0.4 mg/L			X	
	High	0.4 - 4 mg/L	X			X
	Extreme	>4 mg/L		X		
Hydraulic Conductivity	Moderate	1 - 10 ft /day	X		X	
	Low	<1 ft/day		X		X

Note:
TDS and COPC concentrations and hydraulic conductivities in Area 1 are known based on the Phase 1 pre-design activities. The TDS and COPC concentrations in Area 2 are extrapolated from the data obtained in the Unit 4 and 5 Buildings investigation as shown in the isoconcentration mapping and horizontal distribution of mass figures in Appendix G. Additional data will be collected to confirm these conditions.

4.2.1.1 Intermediate Zone

As presented in ***Table 10***, hydraulic conductivity in the intermediate zone in both Areas 1 and 2 is expected to be higher than in the deep zone. COPC concentrations are high in the Area 1 intermediate zone, likely similar to the COPC concentrations in the Area 2 deep zone. However, the TDS concentrations in the Area 1 intermediate zone are lower than the Area 2 deep zone and the hydraulic conductivity is higher; thus, the Area 1 intermediate zone represents unique characteristics for testing.

COPC concentrations in the Area 2 intermediate zone are expected to be somewhat lower relative to the other Unit 4 Treatability Study testing areas, yet still high relative to the other ISB studies conducted at the Site. With hydraulic conductivity and TDS concentrations expected to be similar to the Area 1 intermediate zone, the primary characteristic differentiating the Area 1 and Area 2 intermediate zones are that Area 2 COPC concentrations are expected to be lower than Area 1. Given the somewhat more favorable conditions present, it is anticipated that biologically active conditions and resulting degradation of COPCs are likely to occur fastest in the Area 2 intermediate zone.

4.2.1.2 Deep Zone

As indicated in ***Table 10***, the hydraulic conductivity in the deep zone in both Areas 1 and 2 is expected to be low and the COPC concentrations very high. The Area 1 deep zone represents extreme conditions for testing the limits of the ISB approach. Perchlorate and chlorate are present at concentrations of up to three orders of magnitude higher than the highest concentrations tested in the other treatability or pilot studies conducted within the NERT RI Study Area. Chromium and chloroform concentrations are the highest reported for the Unit 4 Treatability Study Area and are much higher than the concentrations tested in other studies. With TDS concentrations greater than 20,000 mg/L and as high as 58,000 mg/L, it is expected that a combination of injections with SLMW only and groundwater extraction will be required to reduce the TDS in the Area 1 deep zone to establish conditions amenable to biodegradation prior to injecting a carbon substrate solution and implementing ISB.

Perchlorate and chlorate concentrations in the Area 2 deep zone are not expected to be as high as the Area 1 deep zone yet are still expected to be one- to two-orders of magnitude higher than the highest concentrations tested in the other site treatability studies elsewhere within the NERT RI Study Area. Although still very high, TDS concentrations are expected to be less than 20,000 mg/L and in a range where bench-scale studies have shown successful biological degradation of the COPCs.

4.2.2 Areas 1 and 2 Treatability Study Operations

Operationally, the two areas will be treated similarly during the Phase 2 treatability study implementation. Groundwater modeling was used to evaluate well locations and various injection and extraction scenarios for each treatment zone. Due to the varying hydraulic conductivities between the intermediate and deep zones, the well layout and proposed injection/extraction strategies are different for both the intermediate and deep zones. Details of the modeling are presented in Section 5.2. In the intermediate zone, shown in Figure 40, two upgradient injection wells will be used to apply donor, and two downgradient extraction wells will be used to increase donor distribution. In the deep zone, shown in Figure 41, four injection wells will be used to inject substrate in the corners of each area, and a central extraction well will be used to pull donor toward the center of the deep treatment zone in both Areas 1 and 2. With all extraction wells operating, it is estimated that the average extracted groundwater flow rate will be in the range of 12 gpm. As further discussed in Section 5.1, the injection and extraction systems will be designed to allow flexibility: wells may be converted from extraction to injection mode, or vice versa. The wells selected for injection or extraction may be modified at times over the course of the treatability study based on the performance monitoring results. Based on the groundwater modeling, it is estimated that the maximum total extraction flow rate from the Unit 4 Treatability Study Area will be approximately 30 gpm; however, the highest likely injection/extraction scenario is expected to produce approximately 20 gpm.

The Area 1 injection and extraction wells were all installed during the Phase 1 pre-design activities. Injection/extraction wells in Area 1 are spaced on approximately 45-foot centers. All wells in Area 2 will be installed as part of the Phase 2 treatability study. Based on modeling, and to account for noted variability in the hydraulic conductivity results determined in the Phase 1 pre-design activities, injection/extraction wells in Area 2 will be installed on 30-foot centers.

4.2.3 Groundwater Treatment via the GWETS

As noted above, it is anticipated that the groundwater extraction rates will range from 12 to 20 gpm during implementation of the Unit 4 Treatability Study. Water management will be a necessary component of this treatability study. Accordingly, water will be collected in temporary tanks in the Unit 4 area, and regularly transported via tanker truck to the designated GWETS Process Tank located to the south of the GW-11 Pond. The three Process Tanks were originally constructed as part of the AP-5 Pond closure for solids treatment, and each has a nominal capacity of 600,000 gallons. Water will be routed from the designated Process Tank through the existing groundwater treatment system.

When Phase 2 of the Unit 4 Treatability Study is initiated, extracted groundwater will contain high concentrations of chromium; thus, water from the designated Process Tank will be routed through chromium treatment first and then routed to the FBRs for perchlorate and chlorate treatment. Chloroform concentrations will be reduced by the granulated activated carbon treatment in the EQ Area and to a lesser degree by the FBRs. Over the duration of the treatability study, chromium concentrations are expected to be reduced in-situ both abiotically and biotically. As the treatability study progresses, it may be possible to bypass the ex-situ chromium treatment step and route water directly from the designated Process Tank to the FBRs. NERT will perform a more detailed analysis of the required treatment and/or disposal options. The information presented in this subsection is for background purposes only. NERT will be preparing design packages for modifications to the existing GWETS that will be submitted to NDEP, Bureau of Water Pollution Control (BWPC) for approval under the NPDES permit.

Because they function primarily to support on-going groundwater treatment, the FBRs have limits on both hydraulic and mass loading to support this study. Although flow from the Unit 4 Treatability Study is relatively low compared to the overall flow handled by the FBRs, perchlorate and chlorate concentrations in groundwater extracted from the Unit 4 area are expected to be very high initially. Perchlorate, chlorate, and nitrate each contribute to the mass loading in the FBRs, and their concentrations are combined into an equivalent loading metric based on the following equation:

$$\text{FBR Load} = [(0.9*NO_3 \text{ as } N + 0.17 * ClO_3 + 0.18*ClO_4)*\text{Flow}*1440/1000000*8.34]$$

The planned initial 12 gpm flow rate and the estimated COPC concentrations were used to calculate the Unit 4 Treatability Study's contribution to the equivalent loading to the FBRs. It is estimated the Unit 4 Treatability Study will initially contribute a load of 80 pounds per day (lbs/day) to the FBRs. For comparison, the wash water from the AP-5 solids treatment process had an initial equivalent load of approximately 375 lbs/day. Therefore, it is expected that the FBRs have sufficient mass loading capacity to treat the estimated equivalent load of 80 lbs/day.

As noted above, the maximum groundwater flow from the Unit 4 Treatability Study Area is predicted by the groundwater model at approximately 30 gpm. It is not expected that the system will operate at these rates; however, a worst-case equivalent load was calculated for comparison with the FBR capacity. Based on a flow of 30 gpm and the initial estimated COPC concentrations, the estimated equivalent load is 295 lbs/day, approximately 78 percent of the equivalent load that was initially contributed by wash water from the AP-5 solids treatment process.

The equivalent load calculations presented here use the estimated initial COPC concentrations from the Area 1 dataset, or the Area 2 extrapolated data obtained in the Unit 4 and 5 Buildings investigation as shown in the isoconcentration mapping figures and horizontal distribution of mass presented in Appendix G. Note that as the Unit 4 Treatability Study progresses, COPC concentrations will be treated and reduced in-situ, thus the equivalent loading to the FBRs is expected to decrease over the life of the treatability study.

4.2.4 Area 1 TDS Reduction

TDS concentrations in groundwater in the Area 1 deep zone significantly exceed 21,000 mg/L. Based on the bench-scale study, this was determined to be the upper threshold for TDS concentrations where the COPCs were successfully reduced using bioremediation. As a result, a preliminary step is required to reduce TDS prior to injection of carbon substrate. The extreme TDS concentrations present in the Area 1 deep zone will be reduced via groundwater-only circulation consisting of injecting SLMW in a pulsed manner and continuous groundwater extraction to establish conditions amenable to biodegradation prior to the implementation of ISB. Reduction in TDS concentrations via groundwater extraction may also affect COPC concentrations. After TDS concentrations are reduced to appropriate levels in the Area 1 deep zone, COPC concentrations will be evaluated to confirm the remaining COPC concentrations are substantially higher than those in Area 2. Carbon substrate injections would only be performed in Area 1 if the following conditions are met:

1. TDS concentrations in the Area 1 deep zone are reduced to approximately 21,000 mg/L or less, as determined by the average concentration at four monitoring wells located in between the injection and extraction wells (M-251-100, U4-MW-02D, U4-MW-05D, and U4-MW-07D); and,
2. COPC and TDS concentrations in the Area 1 deep zone are sufficiently different than the Area 2 deep zone after TDS concentrations have been reduced to justify inclusion of Area 1 in the study.

In the event that TDS concentrations in the Area 1 deep zone cannot be reduced in a reasonable amount of time or COPC and TDS concentrations in Area 1 are not sufficiently different than the concentrations present in Area 2 following the TDS reduction period, the Trust may elect to reduce the scope of the Unit 4 Treatability Study in Area 1 because performance of such efforts would not be required to achieve study objectives. Any material change to the scope of this treatability study will be submitted to NDEP for approval via a Treatability Study Modification.

4.2.5 Area 2 Pilot Borings and Monitoring Wells

As noted above, TDS and COPC concentrations and hydraulic conductivities in Area 1 are known, as is the well spacing because the Area 1 extraction wells were installed as part of the Phase 1 pre-design activities. Conditions in Area 2 are estimated based on modeling and extrapolation of data from other nearby wells and on data from one-time groundwater grab samples analyzed as part of the Unit 4 and 5 Buildings investigation. As an initial step in the Phase 2 treatability study, several wells will be installed and tested in Area 2 to confirm the characteristics of the intermediate and deep zones in Area 2. Assuming the results of the planned Area 2 pilot wells are consistent with expectations, substrate injections will commence in Area 2 while TDS reduction activities are active in Area 1. If the COPC concentrations, geochemistry, or hydrogeologic conditions discovered in Area 2 are not sufficiently different from Area 1 to warrant testing, the Trust may elect to reduce the Unit 4 Treatability Study Area by eliminating all or a portion of Area 2. The planned sequential pilot well approach is discussed in Section 5.1.1.2.

4.2.6 Treatability Study Duration

It is anticipated that the active ISB operations (carbon substrate injections and groundwater extraction) in Area 1 and Area 2 will be implemented over a 12 to 18-month period. However, as noted above, SLMW injections and groundwater extraction will be performed in Area 1 prior to implementation of ISB. It is expected to take approximately 6 months to reduce TDS concentrations within the Area 1 deep zone to levels where bench-scale studies have shown biological degradation of the COPCs to be possible, or approximately 21,000 mg/L, based on the positive results from the extended groundwater extraction test and the fact that SLMW will also be injected to dilute the groundwater and assist in the reduction of TDS concentrations. The goal of the treatability study is to obtain data to support technology and alternative evaluation in the FS, not to treat or fully remediate the Unit 4 Treatability Study Area. As noted in Section 4.3, key objectives for the study are to show that that the approach can be effective to reduce COPCs in the source area, and to operate the treatability study long enough to be able to evaluate COPC degradation under the varying conditions present in the intermediate and deep zones.

As described in Section 3.3.4 and shown in Figure 22, in the bench study microcosms containing an initial TDS concentration of approximately 17,400 mg/L, perchlorate concentrations decreased from an initial concentration of approximately 1,646 mg/L to less than 0.02 mg/L after 267 days (approximately 9 months). In microcosms containing an initial TDS concentration of approximately 21,000 mg/L, perchlorate concentrations decreased from 1,878 mg/L to 0.33 mg/L after 554 days (approximately 18.5 months), but also showed significant reduction (approximately 56 percent) after 337 days (approximately 11 months). Under dynamic operating conditions in the field, the reduction rate of the COPCs are expected to increase, as simulated by the column tests. Assuming it will take approximately 2 to 4 months to distribute carbon substrate and establish biologically active conditions within the Unit 4 Treatability Study Area, 12 to 18 months of active operations would allow approximately 8 to 16 months to observe meaningful and measurable reduction of all the COPCs.

4.3 REVISED TREATABILITY STUDY OBJECTIVES

The Unit 4 Treatability Study design has been modified based on information obtained during the Phase 1 pre-design activities. The design now focuses solely on testing the effectiveness and implementability of an ISB treatment approach in the Unit 4 Treatability Study Area. Phase 2 treatability study objectives presented in the original Work Plan have been modified or replaced to be specific to the revised Phase 2 treatability study design. The overall objective of the Unit 4 Treatability Study is to develop data necessary to support technology screening and remedial alternative evaluation as part of the FS process. Specific objectives of the Phase 2 treatability study are as follows:

- Determine if an ISB approach can effectively create a biologically active zone for remediation of source area COPCs under varying conditions present in the intermediate and deep treatment zones in Area 1 and Area 2.
- Verify bench-study results that show that biological degradation is effective for treatment of high COPC concentrations when high TDS concentrations (greater than 10,000 mg/L) are present.
- Evaluate the carbon substrate longevity within the source area and related effects on the dose and frequency of substrate injections.
- Evaluate the ability to inject and distribute bacteria, promote bacterial growth, and maintain bacterial populations capable of degrading the COPCs within the Unit 4 Treatability Study Area.
- Evaluate lateral and vertical distribution of a carbon substrate solution within the Unit 4 Treatability Study Area.
- Evaluate COPC reduction and biological degradation under the varying conditions present in the intermediate and deep treatment zones in Area 1 and Area 2 to develop a basis for estimating the time and associated costs required to meet various remedial action goals that will be established in the FS.
- Evaluate ISB implementation and operational components including injection protocols, achievable injection rates, subsurface distribution of injectate, and injection and extraction well spacing.
- Determine the necessity for and frequency of well maintenance activities.
- Assess secondary effects of an ISB approach both within and in the vicinity of the Unit 4 Treatability Study Area such as changes in hydrologic conditions, geochemistry, dissolved metal concentrations, and presence of degradation byproducts.

The well layout, injection and extraction system, and effectiveness monitoring program for the Phase 2 treatability study has been designed consistent with these objectives.

5.0 PHASE 2 TREATABILITY STUDY DESIGN

This section presents the revised design of the Phase 2 treatability study including the well layout, injection system, extraction system, system operation and maintenance, and management of the extracted groundwater and investigation-derived waste.

5.1 SYSTEM DESIGN AND INSTALLATION

This section describes the design for the ISB system for the Phase 2 treatability study. An injection system will be used to mix and inject the carbon substrate solution into the targeted treatment zone within both Areas 1 and 2 of the Unit 4 Treatability Study Area through injection wells to support in-situ bioremediation. A groundwater extraction system will be used to extract groundwater from extraction wells within the treatment areas to assist with the distribution of the carbon substrate solution, maintain hydraulic control, and reduce TDS concentrations to levels where bioremediation has proven to be successful in the bench-scale testing. The extracted groundwater will be pumped to an above-ground holding tank located near the Unit 4 Treatability Study Area and then conveyed via the use of vacuum trucks to a designated Process Tank (T-201) for equalization and temporary storage before being treated by the GWETS. NERT will be preparing design packages for modifications to the existing GWETS that will be submitted to NDEP, BWPC for approval under the NPDES permit.

5.1.1 Well Layout and Design

The well construction and layout design for the injection and extraction wells are based on the results of the Phase I pre-design activities and groundwater modeling simulations described in Section 2.0. The monitoring well network was designed to collect the required data for evaluation of the Phase 2 treatability study objectives. The planned well layout is provided in Figure 42.

5.1.1.1 Pre-Drilling Activities

Prior to conducting drilling activities, all necessary permits (as described in Section 7.1) will be obtained, USA North Utility Locating Services will be contacted, utility maps will be reviewed, and the services of a geophysical locator will be retained to check for underground utility lines. Boreholes will be advanced using a hydrovac unit up to 12 feet bgs, or the depth required by the EMD groundbreaking permits, to clear for subsurface utilities. The hydrovac unit will inject pressurized water through a handheld wand and extract the resulting slurry by a powerful vacuum. Boring locations may be adjusted in the field to avoid existing utilities, structures, or other site features.

5.1.1.2 Well Locations

The number and location of the wells for each treatment area were selected based on existing well locations, contaminant distribution, groundwater modeling, and for the purpose of obtaining data to achieve one or more treatability study objectives. The injection, extraction, and monitoring well layout for Areas 1 and 2 are presented in Figure 42.

As previously discussed in Section 4.2.5, conditions in Area 2 are estimated based on modeling and extrapolation of data from other nearby wells and on one-time groundwater grab samples analyzed as part of the Unit 4 and 5 Buildings investigation. Therefore, as an initial step in the Phase 2 treatability study, a total of four pilot wells will be installed to confirm the characteristics of the intermediate and deep zones in Area 2. As part of this initial phase, two intermediate and two deep injection/extraction wells (U4-E-06I, U4-E-06D, U4-E-07I, and U4-E-07D) will be installed and developed. Upon completion of installation activities, groundwater sampling and aquifer testing using the methods described in Section 5.1.1.4 will be performed at each of the newly installed wells. If the COPC concentrations, geochemistry, or hydrogeologic conditions discovered in Area 2 are not sufficiently different from Area 1 to warrant testing, the Trust may elect to reduce the scope of the Unit 4 Treatability Study (via Modification) by eliminating all or a portion of Area 2 or propose additional pilot wells to evaluate alternative locations for Area 2. The data collected from the pilot well installation and testing activities will be used to update

the existing groundwater model. The updated groundwater model will be used to adjust the planned well layout for Area 2, if necessary.

The injection/extraction and monitoring well layout for Area 1 and the planned layout for Area 2 are described below.

- **Area 1:**
  - Injection/Extraction Wells:
    - Four existing intermediate wells (U4-E-01I, U4-E-02I, U4-E-04I, and U4-E-05I), screened from 83 to 98 feet bgs and spaced approximately 40 feet apart, will be used as injection/extraction wells.
    - Four existing deep wells (U4-E-01D, U4-E-02D, U4-E-04D, and U4-E-05D) and one new deep injection/extraction well (U4-E-03D), screened from 103 to 118 feet bgs and spaced approximately 30 feet apart, will be used as injection/extraction wells.
  - Monitoring Wells:
    - One existing intermediate/deep monitoring well cluster (U4-MW-02I/D), screened from 83 to 98 feet bgs and 103 to 118 feet bgs, will be used as monitoring wells.
    - Existing dual-nested monitoring well (M-251-60 and M-251-100), screened from 52.3 to 62.3 feet bgs and 92.5 to 102.5 feet bgs, will be used as monitoring wells.
    - Existing monitoring well M-252, screened from 132.3 to 142.3 feet bgs, will be used as a monitoring well.
    - Two new dual-nested monitoring wells (U4-MW-05I/D and U4-MW-07I/D), screened from 83 to 98 feet bgs and 103 to 118 feet bgs, will be used as monitoring wells.
- **Area 2:**
  - Pilot Wells:
    - Two new intermediate wells (U4-E-06I and U4-E-10I), screened from 83 to 98 feet bgs and spaced approximately 30 feet apart, will be used as pilot wells.
    - Two new deep injection/extraction wells (U4-E-06D and U4-E-10D), screened from 103 to 118 feet bgs and spaced approximately 30 feet apart, will be used as pilot wells.
  - Injection/Extraction Wells:
    - Two new intermediate and two new deep injection/extraction wells (installed initially as pilot wells as described above) will be used as injection/extraction wells.
    - Two new intermediate wells (U4-E-07I and U4-E-09I), screened from 83 to 98 feet bgs and spaced approximately 30 feet apart, will be used as injection/extraction wells; three new deep injection/extraction wells (U4-E-07D, U4-E-08D, and U4-E-09D), screened from 103 to 118 feet bgs and spaced approximately 22 feet apart, will be used as injection/extraction wells.
  - Monitoring wells:
    - Three new dual-nested wells (U4-MW-11I/D, U4-MW-12I/D, and U4-MW-13I/D), screened from 83 to 98 feet bgs and 103 to 118 feet bgs, will be used as monitoring wells.

Additional new wells will be installed around the perimeter of the study areas to evaluate the vertical and horizontal effects on groundwater from the implementation of the proposed ISB approach as described below.

  - Eight new dual-nested intermediate and deep wells (U4-MW-01I/D, U4-MW-03I/D, U4-MW-04I/D, U4-MW-06I/D, U4-MW-08I/D, U4-MW-09I/D, U4-MW-15I/D, and U4-MW-16I/D), screened from 83 to 98 feet bgs and 103 to 118 feet bgs, will be used as monitoring wells.
  - Six new dual-nested shallow and deeper wells (U4-MW-01S/DD, U4-MW-03S/DD, U4-MW-08S/DD, U4-MW-09S/DD, U4-MW-15S/DD, and U4-MW-16S/DD), screened from 63 to 73 feet bgs and 128 to 138 feet bgs, will be used as monitoring wells.

The number of wells, well spacing and/or screen intervals may be adjusted based on field conditions, additional aquifer testing, and any updated groundwater modeling. Trust and NDEP approval will be obtained through a Treatability Study Modification prior to adjusting the number of wells installed.

5.1.1.3 Well Design and Installation

The injection and extraction wells will be constructed with 4-inch Schedule 80 PVC casing, and screened with a 4-inch diameter 0.010 slotted wire-wrapped 304 stainless-steel well screen. The monitoring wells will be dual-nested and constructed using 2-inch Schedule 80 PVC casing, and screened with either a 2-inch diameter 0.010 slotted wire-wrapped 304 stainless-steel or 0.010 slotted PVC well screen. A sand filter pack will be installed in the annular space around the well screens and extended up to 2 feet above the top of each screen interval. The remainder of the annular space will be sealed using a combination of attapulgite clay and/or cement grout. The wells installed within the treatment areas will be completed with flush-mounted, tamper-resistant, traffic-rated well boxes, at an elevation approximately 0.5 inch above surrounding grade. Wellhead fittings with appropriate valves and meters will be installed on the injection and extraction wells to allow for the well to be used for either injection or extraction purposes and to easily switch use throughout the Phase 2 treatability study, as needed. Planned well construction diagrams are provided in Appendix I. Management of investigation-derived solid waste and decontamination fluids is discussed in Section 5.3.

Following the completion of well construction, but no sooner than 48 hours after well construction is complete, each of the newly installed wells will be developed. A surge block and bailer will be used to swab and surge the filter pack and remove sediment from the well. This process will be followed by pumping with a submersible pump. Well development will be considered complete when three to ten casing volumes of water have been removed from the well, and index parameters consisting of pH, specific conductivity, turbidity, and temperature are stable over three consecutive measurements. All index parameter readings will be recorded on well development logs.

Once all well installation and development activities are completed, a Nevada-licensed land surveyor will survey the horizontal coordinates of each well relative to North American Datum 83 with an accuracy of 0.1 foot, and the elevation of the ground surface and top of well casing measuring point relative to North American Vertical Datum (NAVD) 88 with accuracies of 0.1 foot and 0.01 foot, respectively.

5.1.1.4 Aquifer Testing

Aquifer testing will be performed on the injection and extraction wells to determine baseline hydraulic conditions. Specifically, aquifer testing will consist of slug tests, step-drawdown pumping tests, and step-rate injection tests. The slug tests and step-drawdown pumping tests will be conducted as described in Section 2.8 and Appendix D to evaluate baseline hydraulic conductivity and groundwater extraction rates. Step-rate injection tests will also be performed to determine the maximum injection flow rates and pressures possible prior to implementation of the Phase 2 treatability study. The injection test will be performed by injecting SLMW at three flow rates for approximately 2 hours each. Wellhead fittings will be used to control injection flow rates into the well. Flow rates and wellhead pressures will be monitored throughout each test with a direct reading rotameter-type flow meter and pressure gauge. All flow rate changes and interruptions will be recorded, and the causes for such changes will be noted, if known. Injection flow rates will be increased in a step-wise fashion to evaluate the maximum achievable injection rate for each well while maintaining pressures within the allowable limit of 80 pounds per square inch-gauge (psig) provided in the Underground Injection Control (UIC) General Permit GU07RL-51060 previously issued by NDEP for both the Phase 1 and 2 field activities. Water level indicators and pressure transducers will be placed in nearby wells to evaluate changes in water levels during the testing. In addition, magnetic extensometers, discussed in the following section, will be monitored for potential settlement. The results of the aquifer testing will be used to update the three-dimensional groundwater model and revise the planned system operation if necessary.

5.1.1.5 Magnetic Extensometers

As discussed in Section 2.6, there is potential for upper soils in the Unit 4 Treatability Study Area to experience collapse when wetted, also known as hydro-collapse. Per the recommendation provided in the *Treatability Study Geotechnical and Structural Evaluation* (Tetra Tech, 2019b), included as Appendix A, magnetic extensometers

will be installed in the Unit 4 Treatability Study Area to monitor for settlement during Phase 2 treatability study operations as there is a potential for subsurface injections to cause groundwater to mound into the upper soils. A magnetic extensometer consists of several magnets (i.e., spider magnets and a datum magnet) installed at pre-determined depth intervals. The spider magnets will be attached to a 1-inch diameter access tube. A total of six 4-inch diameter boreholes will be installed to a depth of approximately 48 feet bgs using a hollow-stem auger rig for the installation of the magnetic extensometers in the Unit 4 Treatability Study Area. It is anticipated that 4 spider magnets will be installed per borehole, spaced approximately every 8 feet from 16 ft bgs to 40 ft bgs. The casing of the boreholes will be removed after placement of the access tube to allow the spider magnets to contact the native soil. A datum magnet that will be used as the reference point for any potential movement of the soil column will be installed at approximately 46 ft bgs, 2 feet above the bottom of the 1-inch access tube. A diagram depicting the planned magnetic extensometer is provided in Appendix I.

A reed switch probe will be used to monitor the magnets for movement. As the reed switch probe passes by the magnets, it activates, and these readings will be recorded in the field. The readings will be recorded during the step-rate injection tests and daily during the first week of injections and will continue until the completion of this study for comparison to the initial installed depths of the magnets. The monitoring frequency will be adjusted based on the results of the first week of monitoring. A tracking spreadsheet will be prepared to monitor for any trends which may be indicative of settlement. A geotechnical engineer will be consulted in the event of recorded settlement of more than 0.01 feet to determine if injection activities may safely proceed.

5.1.2 Injection System

The carbon substrate solution will be pressure-injected into injection wells using an injection system consisting of skid-mounted mixing and holding tanks, transfer pumps, mixers, and a manifold piping system and hoses supplied with valves and regulators for controlling and monitoring the rates of injection. This system will be similar to what has been used at both the Seep Well Field Area Bioremediation and Las Vegas Wash Bioremediation Treatability Studies but will allow for mixing and injecting smaller batches of carbon substrate solution on a daily basis. The carbon substrate solution will be prepared by thoroughly mixing the carbon substrate, additional amendments, and SLMW in the mixing tanks. The carbon substrate solution will then be pressure-injected into the injection wells on a pulsed daily basis through a manifold with hoses equipped with quick disconnect fittings. Pressure gauges and a flow totalizer will be used to monitor the pressure and flow rates during injection. Appendix J presents the process flow diagram for the injection system. Additional details of the injection system and the mixing and injection procedures will be provided in a Field Guidance Document that will be prepared prior to system start-up.

5.1.2.1 Carbon Substrates/Amendments

The bench-scale testing conducted by UNLV has been instrumental in determining the preferred type and quantity of carbon substrate, nutrients, vitamins, and bioaugmentation cultures to be injected during the Phase 2 treatability study. Based on the results of the bench-scale testing conducted to date, molasses was selected as the primary carbon substrate for use in the Unit 4 Treatability Study Area. Prior to performing the injections, the carbon substrate will be prepared by diluting with SLMW to the desired concentration. The following amendments will also be blended into the carbon substrate solution as needed to promote conditions that will enhance biodegradation:

- Diammonium phosphate – to provide macronutrients to support bacterial growth;
- Trace minerals – to provide micronutrients to support bacterial growth;
- Vitamin B12 – added as a co-factor to speed up anaerobic degradation and minimize the effects of chloroform toxicity;
- Biosolids from the FBRs – the biosolids from the on-site FBRs will be used to bioaugment the naturally occurring bacterial populations with additional quantities and genera of bacteria to allow for and enhance the in-situ biological reduction of COPCs; and

- Sodium bicarbonate – to provide pH buffering capacity to the aquifer

Preliminary carbon substrate quantities have been estimated based on the stoichiometric demand of the estimated mass of COPCs present within the intermediate and deep zones for Areas 1 and 2, and include a safety factor of 50 percent to account for uncertainties in the mass present and other factors such as incomplete in-situ mixing. Preliminary quantities are presented in ***Table 11***.

Table 11. Preliminary Carbon Substrate Quantities and Injection Volumes

Study Area	Approximate Volume of Molasses[1] (gallons)	Approximate Injection Volume of Molasses Solution[2] (gallons)
Area 1 – Intermediate Zone	8,300	838,000
Area 1 – Deep Zone	7,150	722,000
Area 2 – Intermediate Zone	1,500	152,000
Area 2 – Deep Zone	2,250	227,000

Notes:
1. Preliminary estimates of the volume of molasses required for the intermediate and deep zones are based on the stoichiometric demand of the COPC mass estimated between depths of 83 and 103 feet bgs and from 103 to 118 feet bgs and includes a safety factor of 50%.
2. Preliminary volume estimates of the injection solution is based on a dilution ratio of 100:1 for SLMW to molasses; the dilution ratio will be adjusted based on field conditions and results of the effectiveness monitoring.

The estimated amounts of carbon substrate and amendments and supporting calculations are provided in Appendix L. The final quantities of the carbon substrate and associated amendments to be injected may be modified based on the following:

- Lithological and soil characteristics of the UMCf including data collected from the planned new extraction/injection and monitoring wells;
- Changes in well locations and screened intervals;
- Chemistry and geochemistry of the groundwater collected during the baseline groundwater sampling event following the installation and development of the remaining injection/extraction and monitoring wells; and
- Stoichiometric requirements for the carbon substrate based on the estimated mass of COPCs and other electron acceptors.

The carbon substrate solution will be followed by the injection of distribution water to flush the lines and assist with the distribution of the carbon substrate solution after the injection of each carbon substrate solution batch. The distribution water will be a combination of SLMW, an oxygen scavenger to minimize the addition of oxygen into the subsurface, and sodium bicarbonate to provide pH buffering capacity. Details regarding carbon substrate solution injections will be provide to NDEP in monthly progress reports.

5.1.2.2 Tracer Dyes

Tracer dyes will be injected and periodically monitored to provide additional data to aid in the evaluation of study objectives. Specific objectives of the tracer study are to accomplish the following:

- Assess the horizontal and vertical distribution of the injectate/dye.
- Evaluate travel times of the injectate/dye.

To collect data to evaluate the objectives described above, two separate fluorescent dye tracers will be used during the study. One dye will be introduced into the intermediate zone of Area 1 along with the SLMW during the TDS reduction period, while a different dye will be introduced into the intermediate zone of Area 2 along with the

carbon substrate solution. The selected dyes are expected to be fluorescein and rhodamine WT so that commercially available field probes can be used to perform field assessment of tracer dye concentrations during the Phase 2 treatability study. Dye will be added to the injection solution during the first week of injections into the two upgradient intermediate injection wells within each Area (U4-E-04I, U4-E-05I, U4-E-09I, and U4-E-10I). A sample of each injectate solution will be collected and analyzed for dye to confirm the injection dye concentration. Field and laboratory testing will be periodically conducted throughout the Phase 2 treatability study from both monitoring wells and extraction wells from the intermediate and deep zones to determine the horizontal/vertical distribution and travel times of the dye. Dye testing will be performed during the planned groundwater monitoring and extraction system monitoring schedule as provided in Section 6.0. During groundwater monitoring and extraction system monitoring activities, field personnel will visually observe the water and use a handheld fluorometer calibrated to the injected dyes to evaluate if the dye is present. In addition to the field monitoring for the dye, water samples will be collected from each operating extraction well and performance monitoring well on a monthly basis and sent for laboratory analysis. The results of the dye testing will be used to evaluate the distribution of the injectate and update the groundwater model.

5.1.2.3 Injection System Components

The carbon substrate will be pressure-injected into the injection wells using a prefabricated injection system, consisting of tanks, transfer pumps and a manifold piping system installed on an equipment skid. The injection skid will be sized to allow for the placement of a bag filter system, mixing tanks, transfer piping and manifold on the same skid and will be placed in secondary containment with leak detection. The injection system will be capable of pumping a predetermined volume of carbon substrate solution simultaneously to up to 12 injection wells. Appendix J presents the injection process flow diagram that consists of the following primary components:

- Bag Filter System - A bag filter system will be installed on the SLMW water supply connection line to remove any sediment from the SLMW supply line. The bag filtration unit will have a differential pressure transmitter to monitor for pressure increase across the bag filter housing to determine the need for bag replacement. The bag filter housing system will have the ability to be bypassed, via valves, if it is no longer needed.
- Carbon Substrate/Amendments – The carbon substrate and amendments will be delivered to the Site and stored next to the injection system skid. These amendments will be staged in secondary containment with leak detection.
- Carbon Substrate/Amendment Transfer Pump – A carbon substrate/amendment transfer pump equipped with a VFD will be used to transfer substrate/amendments from the totes/drums to the mixing tanks. The pump will be capable of up to 10 gpm. The VFD will be used to adjust the dosing rate to achieve the desired ratio of substrate/amendment in water. For redundancy purposes, a second transfer pump will be provided.
- Mixing Tanks – Two cone-bottom tanks will be used for mixing and the temporary storage of the injection solution. The mixing tanks will have a top-mounted blind flange port for the introduction of dry (powder) substrate and/or amendment. Each mixing tank will have a mixer supported by mounting rack assembly.
- Injection Solution Transfer Pump – An injection solution transfer pump equipped with a VFD will be used to transfer the injection solution from the mixing tanks to the injection manifold piping system. The pump will be rated for a minimum of 12 gpm. For redundancy purposes, a second transfer pump will be provided.
- Injection Manifold Piping System – An injection manifold will be used to control the flow to the injection wells. The injection manifold piping system will also consist of valves, flow meters, pressure gauges, and high-pressure switches for control and monitoring the rates of injection. The injection pressure will be monitored and controlled to ensure the maximum injection pressure of 80 psig specified in the UIC permit is not exceeded. The manifold piping system will have cam lock fittings for injection hosing connections.

5.1.3 Groundwater Extraction System

A groundwater extraction system will be installed to assist in the distribution of the carbon substrate solution and assist in the reduction of TDS concentrations. The extraction system will have submersible pumps, an extraction manifold, and an extracted groundwater holding tank. Totalizing flow meters, flow control valves, and sample ports will be installed on an extraction system manifold to monitor the extraction flow rate and total amount of water extracted, adjust extraction flow rates, and allow for sample collection. Refer to Appendix J for the extraction system process flow diagram that consists of the following primary components:

- Submersible Pumps – The groundwater will be pumped from each extraction well using submersible pumps. Each pump will have a power cable and a pump control unit. The pump control units will be located on the extraction system skid.
- Extraction Manifold– An extraction manifold will be incorporated into the system and consist of a control panel and flow meters to monitor the flow from the extraction wells. The manifold piping system will have cam lock male fittings for extraction hose connections and will be placed inside secondary containment.
- Extracted Groundwater Holding Tanks – Two closed-top, epoxy-lined 21,000-gallon frac tanks will be used for the temporary storage of extracted groundwater. The frac tank will have level switches and will be placed inside secondary containment.

The extracted groundwater will be conveyed from the holding tank to Process Tank T-201 via vacuum trucks. Additional details of the extraction system, monitoring, and conveyance procedures will be provided in a Field Guidance Document that will be prepared prior to system start-up. Additionally, design packages will be prepared for NDEP, BWPC approval regarding GWETS modifications necessary to store and treat this water under NERT's NPDES permit.

5.2 SYSTEM OPERATION AND MAINTENANCE

A preliminary three-dimensional groundwater flow model was developed as part of the Work Plan to inform preliminary injection and extraction design presented in the Work Plan. This model has been updated and calibrated as part of the Phase 1 pre-design activities, using the results from Phase 1 pre-design field activities (as described in Section 2.0). This calibrated groundwater flow model was utilized to assist in determining the number of injection and extraction wells, well spacing, and injection and extraction rates in Areas 1 and 2 of the Unit 4 Treatability Study Area. A series of predictive scenarios was conducted to aid in developing a more optimal well layout and design for the Unit 4 Treatability Study assuming ISB proceeds in both Areas 1 and 2 based on the decision logic presented in Sections 4.2.4 and 4.2.5. As previously described, the Area 1 wells have been installed and aquifer testing has been completed, whereas Area 2 wells have not been installed onsite.

Results of these modeling scenarios estimate that cumulative injection and extraction rates of approximately 11.7 and 12 gpm, respectively, can be sustained over at least 60 days for the intermediate and deep zones of Areas 1 and 2. The modeling scenarios suggest that the use of an additional injection well in the center of Area 1 would provide better distribution of carbon substrate within the intermediate zone given the current 45-foot well spacing. This will be evaluated as part of the Phase 2 treatability study if ISB is implemented within Area 1. If insufficient carbon substrate is observed within the central portion of the intermediate zone in Area 1 as part of the effectiveness monitoring, an additional injection well may be added to provide better distribution of the carbon substrate as a treatability study modification. The location of this additional well, if required, will be specified in a Treatability Study Modification and submitted to NDEP for approval. In Area 2, since there are no hydrogeologic data available, the well spacing is recommended to be reduced to 30 feet in both the intermediate and deep zones to account for uncertainty in material properties of the UMCf. The data obtained from the installation of the pilot wells will be used to update the groundwater model and re-evaluate the planned well spacing for Area 2 assuming the conditions are sufficiently different than Area 1 as described in Section 4.2.5.

The initial plan for implementing ISB in Areas 1 and 2 during the Phase 2 treatability study is based on the groundwater modeling presented in Appendix K. For the intermediate zones, the carbon substrate solution will be

injected into the two upgradient wells in both Areas 1 and 2 while simultaneously extracting from the two downgradient wells in both Areas 1 and 2 (Figure 40). For the deep zones, the carbon substrate solution will be injected into the four perimeter wells in Area 1 and Area 2 while simultaneously extracting from the two central wells (Figure 41). This configuration of injection and extraction wells for the intermediate and deep zones was selected to maximize the carbon substrate distribution and maintain hydraulic control throughout the Unit 4 Treatability Study Area. The well layout, injection system, and extraction system were designed to allow operational flexibility to adjust for changes observed as part of the effectiveness monitoring plan. Such changes may include the wells used for injection or extraction, the addition of injection wells, the duration of injection and extraction, and/or amendments used.

Duration of the initial injection and extraction operations is currently anticipated to be a minimum of 60 days for both intermediate and deep zones given the lack of hydrogeologic information in Area 2. After the completion of the 60-day injection/extraction period and hydrogeologic data analysis, different injection/extraction well configurations (see Appendix K) could be selected to redistribute the injectate to enhance in-situ bioremediation in the intermediate and deep zones. This data assessment will consist of evaluating groundwater levels and concentrations, injection and extraction rates, and performing additional groundwater model simulations. Additional details regarding the planned injection and extraction system operations and maintenance for the Phase 2 treatability study will be provided in a Field Guidance Document following the installation and testing of the pilot wells in Area 2 and prior to system start-up.

5.2.1 Injection System

Injections will be performed daily throughout the active operations of the treatability study in pulsed operation, consisting of injecting SLMW or a carbon substrate solution for a period of up to 12 hours per day. During the Area 1 TDS reduction period, SLMW will be mixed with an oxygen scavenger in a mixing tank and injected into selected Area 1 injection wells for a period of up to 12 hours per day. Once TDS concentrations in the Area 1 deep zone have reduced to approximately 21,000 mg/L or below and the COPC and TDS concentrations are determined to be sufficiently different than the Area 2 deep zone, daily pulsed injections of a carbon substrate solution will commence. Within Area 2, where TDS concentrations are anticipated to already be below 21,000 mg/L, daily pulsed injections of a carbon substrate solution will commence concurrently with the Area 1 TDS reduction period. Batches of carbon substrate solutions will be mixed daily using multiple mixing tanks and will be adjusted based on observed substrate distribution and analytical results from performance monitoring events. Distribution water, consisting of SLMW with an oxygen scavenger and sodium bicarbonate, will be injected following the injection of each batch to flush the mixing tank and injection lines and improve the subsurface distribution of the carbon substrate. Transfer pumps will be used to add carbon substrate/amendments to the mixing tanks and inject the carbon substrate solution to the injection wells via the injection manifold. Under normal operating conditions, the field personnel will monitor the flow of SLMW to the mixing tank(s), the amount of carbon substrate and, amendments to the mixing tank(s), the flow of the injection solution to the injection wells, the manifold pressure for each injection well, and the volume of distribution water injected. The mixing tanks will have mechanical mixers to ensure proper mixing of the carbon substrate/amendments and water for the injection solution. The transfer pumps and mixers will have hand-off-auto switches located at the control panel. The operating levels within the mixing tanks will be monitored to ensure an ample supply of injection solution for the injection system.

5.2.2 Extraction System

The groundwater extraction system is planned to be operated continuously (24-hours per day) during the Phase 2 treatability study. The wells used and extraction rates will be determined based on performance monitoring results to ensure adequate distribution of the carbon substrate/amendments. The submersible pumps will extract the groundwater from the extraction wells through individual above-ground piping or hoses connected to the extraction manifold piping system. The extraction manifold will be connected to the groundwater holding tanks.

Water will be transferred from the holding tanks to AP Tank T-201 via tanker truck. Flow meters will be provided on the extraction manifold to allow adjustment of flow.

The submersible pump controls will be located on the groundwater extraction system skid. The submersible pump controls will be used to adjust the flow rates from the extraction wells. The extracted groundwater holding tank, leak detection, and level switches will be interlocked and alarmed to ensure that the extraction system operates as designed.

5.2.3 Well and System Maintenance

The injection and extraction wellhead pressures and flow rates will be monitored daily during the Phase 2 treatability study to evaluate the need for well maintenance. In addition, periodic down-hole camera inspections may be performed to evaluate well screen conditions. Wells that continue to exhibit signs of bioaccumulation or chemical precipitation that inordinately restricts injection, extraction, or monitoring activities will be subjected to well maintenance by mechanical scrubbing, surging, jetting, addition of reagents such as antiscalant chemicals or biocides, and/or the use of increased injection pressures not greater than the allowable pressure of 80 psig included in the UIC permit (See Section 7.0).

The injection and extraction systems will be maintained as necessary based on field observations and manufacturer recommendations. System monitoring will be performed daily and will be used to evaluate the need for system maintenance or replacement of parts. General maintenance activities will consist of filter replacements, cleaning pumps, cleaning flow meters, and daily flushing of the injection system with SLMW. The mixing tanks and extracted groundwater storage tanks will be inspected daily for accumulation of precipitates or significant bacterial growth and may be subject to mechanical scrubbing, pressure washing, and extraction via a vacuum truck. Spare parts will be available to replace items that are damaged or no longer functioning as intended. Additional details regarding the planned injection and extraction system maintenance for the Phase 2 treatability study will be provided in a Field Guidance Document.

5.2.4 Record Keeping

System operational parameters and operation and maintenance (O&M) tasks will be recorded daily on an O&M form, which will be prepared following installation of the system and included as part of the forthcoming Field Guidance Document. The injection and extraction systems--including the wellhead piping and secondary containment, injection and extraction hoses, and injection and extraction systems with secondary containment--will be monitored daily by field personnel and documented on a field inspection form.

5.3 MANAGEMENT OF INVESTIGATION-DERIVED WASTE

IDW generated during the Phase 2 treatability study will be managed according to applicable state, federal, and local regulations and as described in Field Guidance Document No. 001, Managing Investigation-Derived Waste (ENVIRON, 2014). The IDW generated will include soil cuttings, concrete debris, personal protective equipment, decontamination water, and groundwater generated during groundwater sampling and well development. Soil cuttings will be stored in plastic-lined roll-off bins. Solids will be characterized by collecting representative samples to determine disposal requirements. Water generated during purging or decontamination activities will be added to the extracted groundwater holding tank and transported to Process Tank T-201 with the extracted groundwater, as discussed in Section 5.1.3. All above-ground injection and extraction system components will be cleaned and removed from the Site at the conclusion of the Phase 2 treatability study. Wells and the magnetic extensometers will be retained for potential future use by the Trust.

6.0 PHASE 2 EFFECTIVENESS MONITORING PLAN

This section describes the monitoring program that will be implemented during the Phase 2 treatability study, which will consist of performance groundwater monitoring and extraction system monitoring. The data collected will be used to assess the objectives presented in Section 4.3.

6.1 GROUNDWATER MONITORING

A groundwater monitoring program will be implemented to evaluate the effectiveness of ISB at reducing contaminant concentrations in groundwater within the Unit 4 Treatability Study Area. This section presents the details of the anticipated monitoring program, which include monitoring wells to be sampled, groundwater sampling procedures to be implemented, and laboratory analysis to be performed. The actual selected monitoring wells, frequency of sampling, and specific parameters to be analyzed during each individual event may be adjusted after consultation with NDEP based on the results from the Phase 2 treatability study effectiveness monitoring events.

6.1.1 Monitoring Well Network

The monitoring well network consists of both existing and new wells located within and surrounding the Unit 4 Treatability Study Area which will be used to evaluate the following:

- Changes in COPC concentrations
- Changes in geochemistry, including TDS concentrations
- Carbon substrate distribution
- Microbial diversity and population size
- Changes in hydrologic conditions
- Vertical and horizontal migration of COPCs, daughter compounds, degradation by-products, and metals from the Unit 4 Treatability Study Area

A total of 47 monitoring wells have been incorporated into the monitoring program (as described in Section 5.1.1 and shown in Figure 42). The monitoring wells to be sampled during the Phase 2 treatability study may be adjusted based on the results from the injection groundwater effectiveness monitoring events. In addition, existing wells located outside the Unit 4 Treatability Study Area may be used to monitor for long-term changes in the hydrogeologic environment following the implementation of the Phase 2 treatability study as part of the Site-wide groundwater monitoring program (Figure 42).

6.1.2 Sampling Frequency

During the Area 1 TDS reduction period, a baseline groundwater monitoring event and monthly groundwater monitoring events will be performed to evaluate changes in COPC and TDS concentrations within Area 1. The baseline groundwater monitoring event will include sampling the 7 monitoring wells and 9 injection/extraction wells screened within the treatment zones within Area 1. The monthly groundwater monitoring events will include sampling the 7 monitoring wells screened within the treatment zones within Area 1.

The ISB injection activities within Areas 1 and 2 may not be completed at the same time due to the expected time required to reduce TDS in Area 1 prior to initiating carbon substrate injections, thus the monitoring events associated with each area may be staggered. However, separate mobilizations for monitoring will be minimized to the extent possible. A comprehensive groundwater sampling event will be performed within Area 1 following the TDS reduction period to evaluate if the COPC concentrations in Area 1 are sufficiently different than Area 2 to proceed with commencing carbon substrate injections and within Area 2 prior to commencing carbon substrate injections to establish baseline concentrations. Groundwater samples will be collected from all monitoring wells in the monitoring well network and injection/extraction wells. Following the start of injection and extraction activities, groundwater samples will be collected from the monitoring well network. The planned frequency for the

effectiveness groundwater monitoring events includes sampling 13 monitoring wells screened within the treatment zones of Areas 1 and 2 biweekly during the first month after the injections, followed by monthly sampling for the expected 12 to 18-month duration of the Phase 2 treatability study. In addition, the remaining wells in the monitoring well network will be sampled on a quarterly basis. Post-treatment monitoring events will be conducted 3 months and 6 months following completion of active injection and extraction operations in each test area to evaluate long-term changes in COPC concentrations and geochemical conditions. During the post-treatment groundwater monitoring events, groundwater samples will be collected from all monitoring wells in the monitoring well network and injection/extraction wells. The frequency of groundwater sampling may be adjusted based on the results of the monitoring events.

6.1.3 Effectiveness Monitoring Parameters

Groundwater samples will be collected and analyzed for a variety of field, laboratory, and microbial parameters as listed in ***Table 12***. The groundwater samples will be collected using low-flow purging and sampling techniques. Groundwater sampling activities will follow the guidance of the *Field Sampling Plan, Revision 1* (ENVIRON, 2014). A low-flow pump will be used to purge the monitoring well at a rate between approximately 0.1 to 0.13 gpm to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water will be passed through a flow-through cell for continuous monitoring of field parameters (temperature, pH, turbidity, EC, DO, and ORP) using a handheld water quality meter. Field parameters will be monitored and recorded on field sampling forms during purging. Purging will be considered complete and the wells will be sampled when the field parameter readings and water levels have stabilized, or after a maximum of 1 hour of purging. Groundwater samples will generally be analyzed for the parameters outlined in ***Table 12***, except for the microbial analyses, which will be analyzed via Bio-traps®.

Bio-Traps® will be deployed in three dual-nested monitoring wells within Area 1 and three dual-nested monitoring wells within Area 2 (total of twelve locations) during the baseline sampling event and on a quarterly basis thereafter. The Bio-Traps® will remain in the monitoring wells for approximately 30 days. These Bio-traps® will evaluate the microbial response to carbon substrate addition. Once retrieved, the Bio-traps® will be sent to Microbial Insights for analysis of phospholipid fatty acids (PLFA) and the presence and quantification of the perchlorate and nitrate reductase enzymes and sulfate reducing bacteria.

In addition, multiparameter sondes will be placed in select monitoring wells to provide real-time field parameter monitoring throughout the Phase 2 treatability study. The downhole transducers will continuously record water pressure and field parameters (EC, pH, DO, ORP, temperature, and turbidity). The actual frequency of sampling, selected monitoring wells, and specific parameters to be collected during each sampling event may be adjusted based on the results of the effectiveness monitoring events.

Table 12. In-Situ Bioremediation Effectiveness Monitoring Sampling Protocol

Parameter	Analytical Method	Purpose
Field Parameters		
EC	Field Meter	Assess geochemical conditions
pH	Field Meter	
DO	Field Meter	
ORP	Field Meter	
Temperature	Field Meter	
Turbidity	Field Meter	
Tracer Dye	Field Meter	Assess vertical and horizontal distribution of the tracer dye over time to evaluate hydraulic properties of the aquifer
Ferrous Iron	HACH Field Kit	Assess effect of reducing conditions on iron
Sulfide	HACH Method 8131	Examine secondary geochemical impacts

Parameter	Analytical Method	Purpose
Laboratory Parameters		
Perchlorate	E314.0/6860[1]	Assess treatment effectiveness
Chlorate/Chlorite	E300.1B	Assess treatment effectiveness
Chloride	E300.0	Assess treatment effectiveness
Hexavalent Chromium	SW7199	Assess treatment effectiveness
VOCs	8260B	Assess treatment effectiveness
TOC	SM5310B	Assess carbon substrate distribution in the aquifer
TDS	SM2540C	Assess any impact of salts on delayed or slower perchlorate biodegradation in the flow-through mode
Alkalinity	SM2320B	Assess geochemical conditions
Nitrate	E300.0	Assess nitrate as the most likely competing electron acceptor and carbon substrate consumer
Sulfate	E300.0	Assess sulfate as an electron acceptor and potential carbon substrate consumer
Ammonia as N	E350.1	Examine the need for micronutrients
Total Kjeldahl Nitrogen	E351.2	Examine the need for micronutrients
Dissolved Phosphorus	E365.2	Examine the need for micronutrients
Dissolved Methane	RSK-175	Examine secondary geochemical impacts
Dissolved Metals[2]	6010B/6020	Assess secondary impacts of treatment
VFAs	AM 23G	Assess surrogate carbon substrate
PLFA	Microbial Insights PLFA	Examine microbial response to carbon substrate addition
Perchlorate Reductase Enzyme	Microbial Insights Census-DNA	Examine microbial response to carbon substrate addition
Nitrate Reductase Enzyme	Microbial Insights Census-DNA	Examine microbial response to carbon substrate addition
Sulfate Reducing Bacteria	Microbial Insights Census-DNA	Examine microbial response to carbon substrate addition
Tracer Dyes	Ozark Underground Laboratory	Assess vertical and horizontal distribution of the tracer dye over time to evaluate hydraulic properties of the aquifer

Notes:
EC: Electrical conductivity
DO: Dissolved Oxygen
ORP: Oxidation-reduction potential
PLFA**: Phospholipid Fatty Acids**
TOC: Total organic carbon
TDS: Total dissolved solids
VOCs: Volatile Organic Compounds
VFAs: Volatile Fatty Acids
1. Based on results the bench-scale testing, the high TDS concentrations present at the Unit 4 Treatability Study Area interfere with the detection of perchlorate at low concentrations (<500 mg/L) using analytical method 314.0; therefore, method 6860 will be used when perchlorate concentrations are expected to be below 500 mg/L.
2.Dissolved metals includes the following: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, potassium, selenium, silver, sodium, thallium, uranium, vanadium, and zinc.

All field samples and field quality assurance/quality control (QA/QC) samples will be evaluated for quality and usability. Field QA/QC samples will include equipment blanks, field blanks, field duplicates, trip blanks, 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.

6.2 EXTRACTION SYSTEM MONITORING

Extraction system sampling will be used to evaluate the effectiveness of the groundwater extraction in reducing the TDS and COPC concentrations, evaluate carbon substrate distribution, as well as to provide data for treatment of the extracted groundwater during the Phase 2 treatability study. Effluent groundwater samples will be collected from the sample ports on the extraction system manifold and on the conveyance piping at system start-up on a monthly basis for the parameters outlined in ***Table 13***.

Table 13. In-Situ Bioremediation Extraction System Sampling Protocol

Parameter	Analytical Method
Tracer Dye	Field Meter/Ozark Underground Laboratory
Perchlorate	E314.0/ 6860
Chlorate/Chlorite	E300.1B
Chloride	E300.0/SW9056
Hexavalent Chromium	SW7199
VOCs	8260B
TOC	SM 5310B
TDS	SM2540C

Notes:
TOC: Total organic carbon
TDS: Total dissolved solids
VOCs: Volatile Organic Compounds

6.3 DATA VALIDATION

Field sampling will be conducted in accordance with the existing *Site Management Plan, Revision 3* (Ramboll Environ, 2017b), *Quality Assurance Project Plan, Revision 4* (Ramboll Environ, 2019), and *Field Sampling Plan, Revision 1* (ENVIRON, 2014). Sampling and analytical methods are selected to meet the project data quality objectives and quality control criteria. Analytical data collected during the completion of the Unit 4 Treatability Study will be verified and validated in accordance with procedures described in the QAPP, *NDEP Data Validation Guidance* (NDEP, 2018), and the references contained therein. Groundwater samples will be sent to a qualified laboratory for analysis. Water samples will be validated to Stage 2A. Laboratories will provide data in PDF and in EDDs that contain sufficient and appropriate data to allow verification and validation at the required levels. At the completion of data validation, validated results will be uploaded to the NERT database. A Data Validation Summary Report will be prepared and presented with the Unit 4 Source Area In-Situ Bioremediation Treatability Study Report.

7.0 PHASE 2 ADMINISTRATIVE AND PERMITTING REQUIREMENTS

This section presents a summary of the administrative and permitting requirements for the planned Phase 2 treatability study activities.

7.1 WELL INSTALLATION PERMITTING

Phase 2 treatability study activities will require a NAC 534.441 Monitoring Well Drilling Waiver and a NAC 534.320 NOI Card prior to installation of injection, extraction, and monitoring wells. The Monitoring Well Drilling Waiver also requires a completed, signed, and notarized Affidavit of Intent to Plug a Monitoring Well as an attachment. As required, all 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 wells associated with this treatability study are to be abandoned, well abandonment will be performed 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.

Groundbreaking permits will be obtained prior to performing any subsurface disturbance activities on the EMD-leased property, including the installation of the magnet extensometers, injection/extraction wells, and monitoring wells.

7.2 NDEP – UNDERGROUND INJECTION CONTROL PROGRAM

An NDEP Long-Term UIC General Permit is required for the injection of carbon substrates, amendments, and water into the saturated subsurface. During the Phase 1 pre-design activities, a long-term UIC general permit application was submitted to NDWR-Bureau of Water Pollution Control for all anticipated amendments and quantities (with a safety factor) that may be needed for the treatability study. This application was approved, with a long-term UIC general permit issued on August 16, 2018 (Permit # GU07RL- 51056). This permit will be amended to include additional chemicals for well maintenance. Additionally, the UIC permit requires injection reports to be submitted on a semi-annual basis.

7.3 WATER APPROPRIATION PERMIT

A Permit to Appropriate the Public Waters of the State of Nevada for Environmental Purposes (permit number 87707E) was issued by the NDWR on February 26, 2018, as part of the Phase 1 pre-design activities. This permit includes a sufficient number of extraction wells and extraction volume for the implementation of the Phase 2 treatability study. The Water Appropriation Permit requires extraction reports to be submitted on an annual basis to present total water extracted during the calendar year.

7.4 ELECTRICAL PERMIT

A licensed electrical contractor will obtain an electrical permit for all applicable electrical work associated with providing electrical service from an existing power supply at the EMD property to power the injection system, extraction system, office trailer, and controls. Applicable electrical design drawings and specifications will be prepared to obtain the electrical permit.

7.5 CONTINGENCY PLAN

In accordance with the *Site Management Plan, Revision* 6 (Ramboll US Corporation, 2020b), a Contingency Plan will be prepared to address protection measures and response procedures for the GWETS components located within 50 feet of Phase 2 treatability study activities. The Phase 2 treatability study activities conducted in the Unit 4 Treatability Study Area will not occur within 50 feet of GWETS components. However, extracted

groundwater will be transported via vacuum trucks to the designated Process Tank and hence to the GWETS for treatment.

7.6 HAZARDOUS WASTE MANAGEMENT PLAN

The Hazardous Waste Management Plan for the Site will be updated to include information for the Phase 2 treatability study activities including container accumulation areas, satellite accumulation areas, and emergency equipment.

8.0 PHASE 2 REPORTING

A Field Guidance Document will be prepared for the operation and maintenance activities associated with the injection and extraction systems prior to the system start-up.

Required documents and reports will be prepared for the permits obtained.

Monthly progress reports will be provided to the Trust and NDEP summarizing the progress and results of the Phase 2 treatability study. The monthly progress reports will include updated figures depicting well locations and system components along with summary data tables of the well details, injection details, groundwater extraction flow rates, and monitoring data.

Following completion of the Phase 2 treatability study, a final Unit 4 Source Area In-Situ Bioremediation Treatability Study Results Report will be prepared for NDEP review and comment. The report will include the following:

- Final Phase 2 treatability study implementation details, including injection, extraction, and monitoring well layout, targeted treatment depths and intervals in the UMCf, injection protocol for carbon donor and distribution water source, extracted groundwater treatment, and effectiveness monitoring program;
- Results of any additional groundwater modeling simulations performed based on the results of the Phase 2 treatability study activities;
- Analytical results summary of groundwater samples collected during Phase 2 treatability study;
- Summary of field measurements, including groundwater elevation, groundwater quality parameters, and system operation parameters;
- Summary of costs incurred to implement the treatability study for Area 1 and for Area 2; and,
- Summary of preliminary cost considerations for further evaluation in the FS regarding ISB implementation scenarios in the Unit Building 4 and 5 source area, including factors such as access restrictions around existing infrastructure, lithology, COPC concentrations, and potential future remedial action goals.

9.0 PHASE 2 SCHEDULE

Table 14 provides the anticipated general durations for the primary activities associated with implementing this Work Plan Addendum. This schedule is contingent upon Trust and NDEP approval of this Work Plan Addendum, Trust approval of funding and notice to proceed, and access to EMD and the Department of Homeland Security Restricted Area.

Based on the preliminary results from the bench-scale testing and groundwater modeling, it is anticipated that 6 months of SLMW injections and groundwater extraction will be required to reduce TDS concentrations within Area 1 and 12 to 18 months of system operations will be required to establish trends regarding the effectiveness of the combined ISB and groundwater extraction approach. The 12 to 18 months of operation will allow time for bioaugmentation, carbon substrate and nutrient distribution in the subsurface, and evaluation of COPC and TDS reductions in groundwater.

Table 14. Estimated Key Task Duration

Task/Milestone	Estimated Time to Complete
Pilot Well Installation and Testing	2 Months
Well Installations	3 Months
Injection/Extraction System Design and Installation	4 to 6 Months
Area 1 TDS Reduction	6 Months
Area 1 ISB	12 to 18 Months
Area 2 ISB	12 to 18 Months
Post-Treatment Monitoring	6 Months
Final Report	3 Months

10.0 REFERENCES

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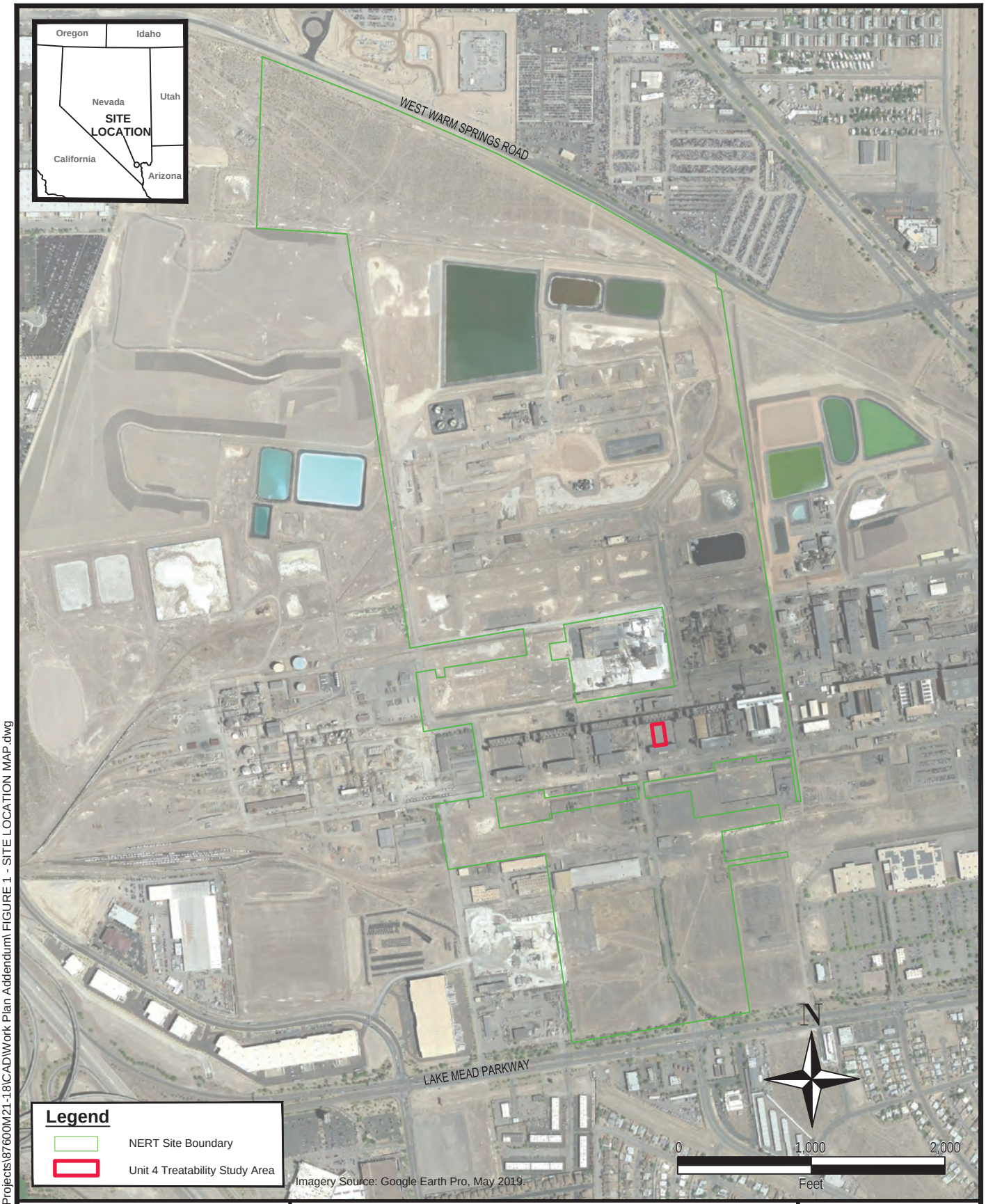
Figures



\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\ FIGURE 1 - SITE LOCATION MAP.dwg

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

SITE LOCATION

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
1

Legend

- NERT Site Boundary
- Unit 4 & 5 Buildings Investigation Area
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.

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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY LOCATION

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.

2

\\tts318fs3.ttlocal\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 2 - UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY LOCATION.dwg

M-12A
M-241
M-255
Unit 4 Chlorinator Building
G-1
G-2
G-3
U4-E-01D
M-251
M-252
U4-E-02D
U4-E-01I
U4-E-02I
U4-MW-02I
U4-MW-02D
AREA 1
M-250
M-249
U4-E-04D
U4-E-05D
U4-E-04I
U4-E-05I
M-191
M-192
M-253
M-254
AREA 2
G-6
G-4
G-5
Unit 4 Substation Building
M-189
M-247
M-248
N
0
40
80
Feet

Legend

- Existing Third Mobilization Monitoring Well
- Pre-Design Investigation Monitoring Well (I - Intermediate; D - Deep)
- Pre-Design Investigation Injection/Extracton Well (I - Intermediate; D - Deep)
- Pre-Design Investigation Geotechnical Soil Boring Location
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.
3. Existing well location source: Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Tetra Tech, 2017.

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 3 - PRE-DESIGN INVESTIGATION BORING AND WELL LOCATIONS.dwg

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

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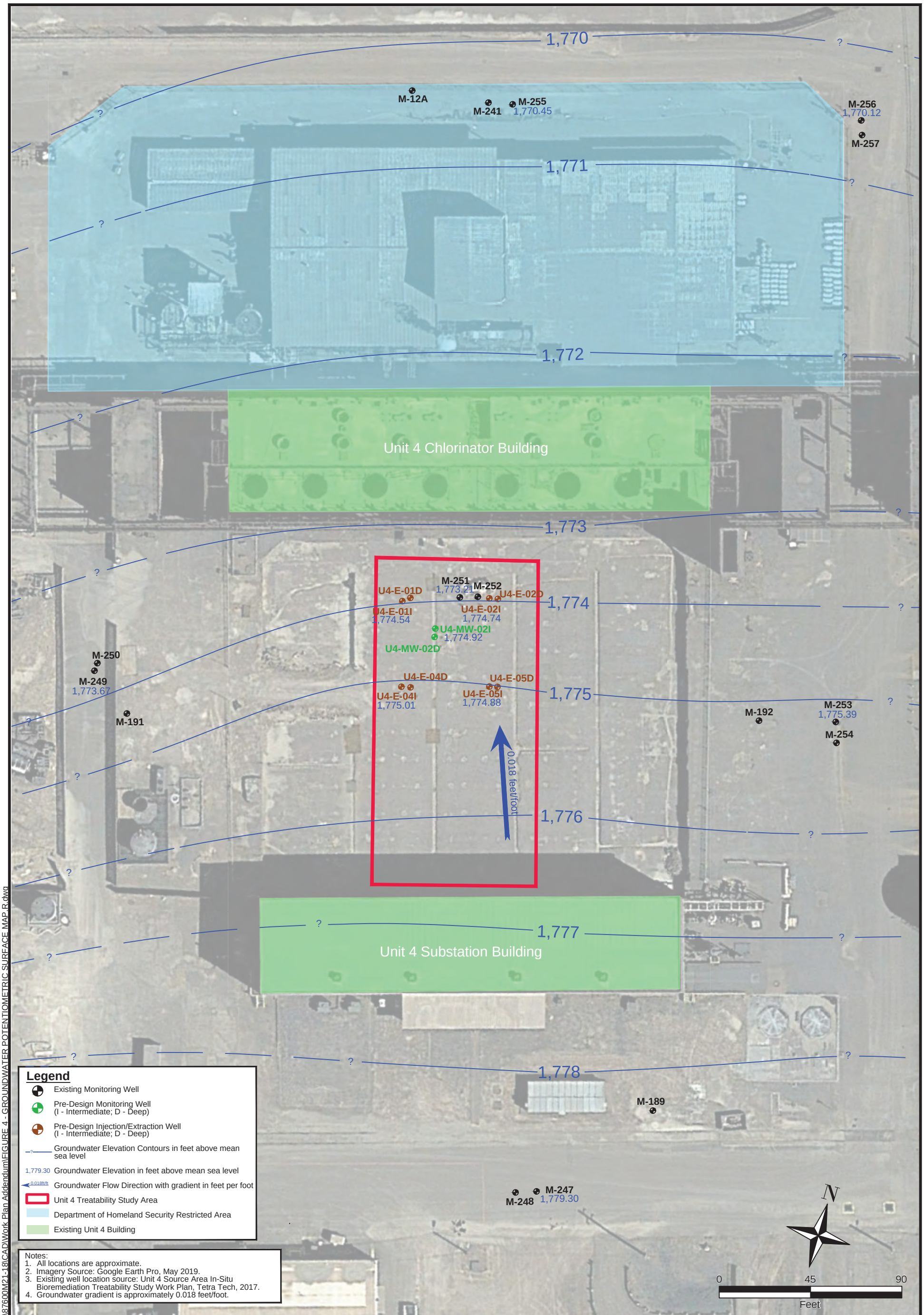
HENDERSON, NEVADA

PRE-DESIGN INVESTIGATION BORING AND WELL LOCATIONS

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.

3



Legend

- Existing Monitoring Well
- Pre-Design Monitoring Well (I - Intermediate; D - Deep)
- Pre-Design Injection/Extraction Well (I - Intermediate; D - Deep)
- Groundwater Elevation Contours in feet above mean sea level
- 1,779.30 Groundwater Elevation in feet above mean sea level
- 0.018ft/ft Groundwater Flow Direction with gradient in feet per foot
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.
3. Existing well location source: Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Tetra Tech, 2017.
4. Groundwater gradient is approximately 0.018 feet/foot.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
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GROUNDWATER POTENTIOMETRIC SURFACE MAP UNIT 4 AREA UPPER MIDDLE WATER BEARING ZONE SCREENED DEPTHS OF 75-100 FEET BGS JUNE 2018

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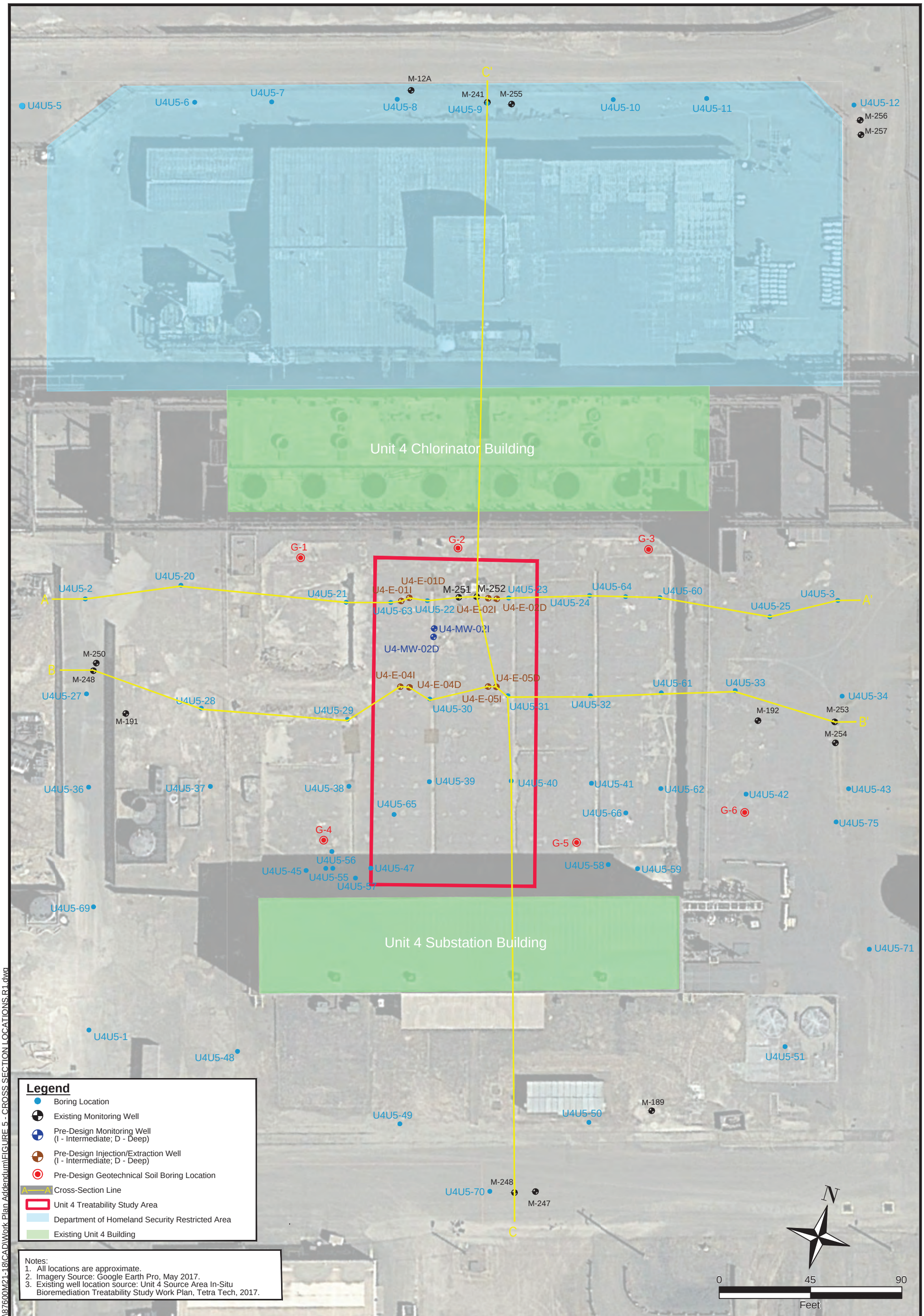
Figure No.

4

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CADWork Plan Addendum\FIGURE 4 - GROUNDWATER POTENTIOMETRIC SURFACE MAP R.dwg



Legend

- Boring Location
- Existing Monitoring Well
- Pre-Design Monitoring Well (I - Intermediate; D - Deep)
- Pre-Design Injection/Extraction Well (I - Intermediate; D - Deep)
- Pre-Design Geotechnical Soil Boring Location
- A—A' Cross-Section Line
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.
3. Existing well location source: Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Tetra Tech, 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

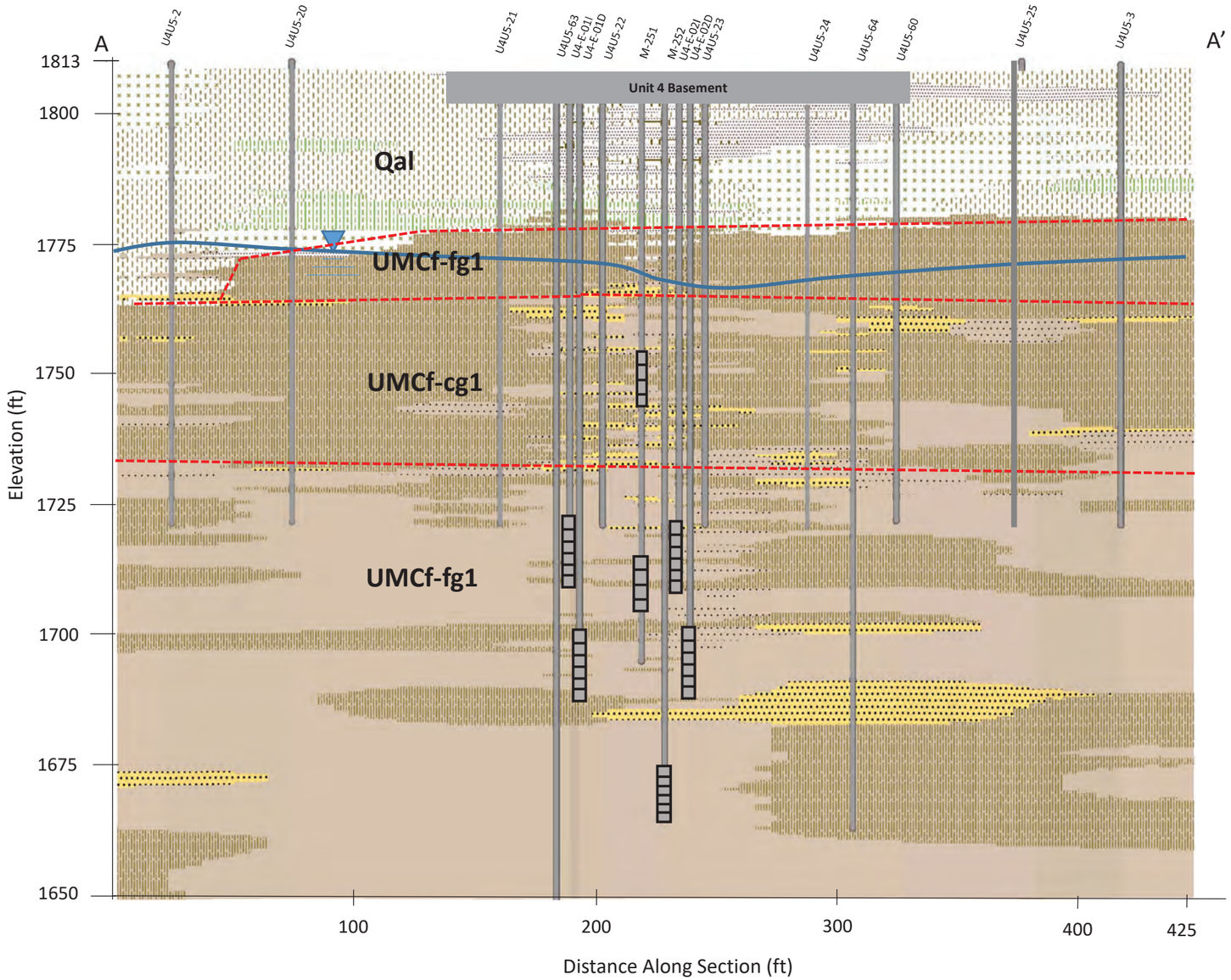
CROSS-SECTION LOCATIONS

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

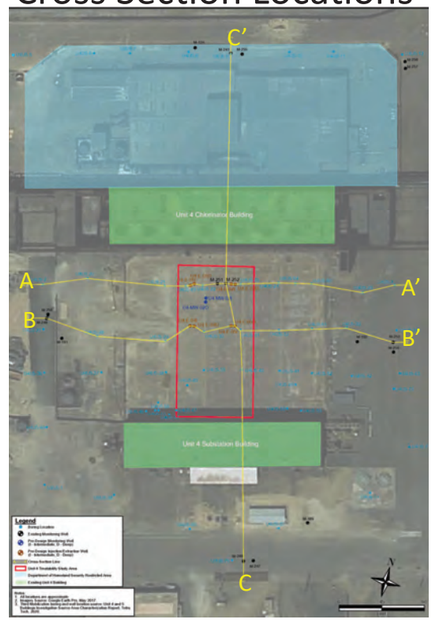
Figure No.

5

\\tts318fs3.ttlocal\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 5 - CROSS SECTION LOCATIONS.R1.dwg



Cross Section Locations



Well Screen

Water Table

Lithologic Contact

Soil Types in Alluvium (Qal)

- SILTY SAND / SILTY GRAVEL
- SAND / SAND WITH GRAVEL
- GRAVEL/ SANDY GRAVEL
- SILTY SAND
- CLAYEY SAND
- SANDY SILT

Soil Types in Upper Muddy Creek Formation (UMCf)

- SILTY CLAY/ CLAYEY SILT
- SANDY SILT (fine to very fine sand)
- SILTY SAND/ SANDY BED
- SILTY SAND/ GRAVEL

Other Soil Types

- FILL
- CALICHE

Notes:
1. Vertical exaggeration: 2:1.
2. Sections are shown looking North.
3. Data interpolation truncated below 163 ft bgs (below ground surface) due to insufficient data.
4. Ground surface elevation is assumed to be 1,813 ft amsl (above mean sea level) for the purposes of illustrated depth.
5. M-251 Monitoring well location and designation.
6. U4U5-20 Borehole location and designation.
7. Fine and coarse grained facies of the Upper Muddy Creek formation are designated as UMCf-fg1 and UMCf-cg1, respectively.

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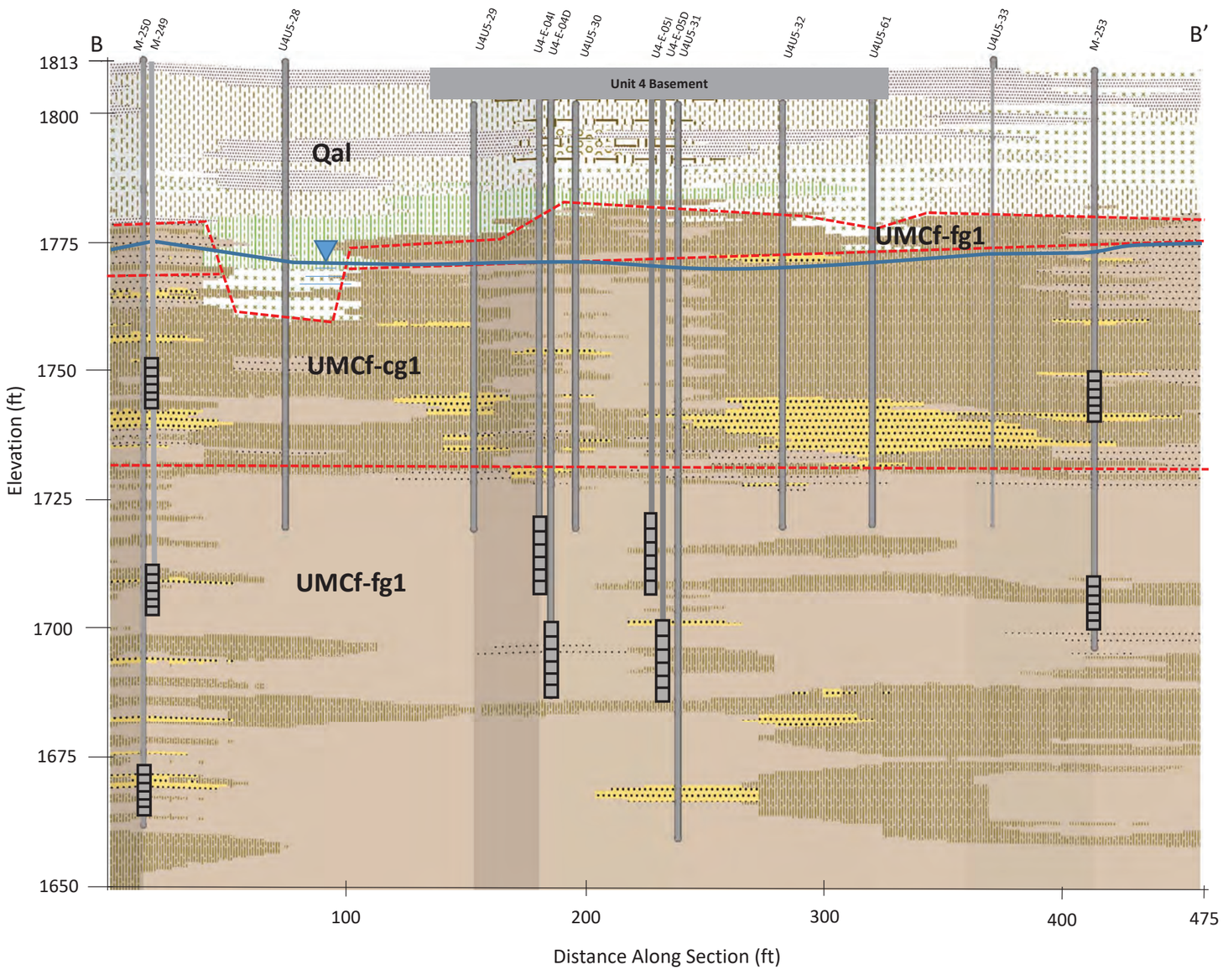
NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

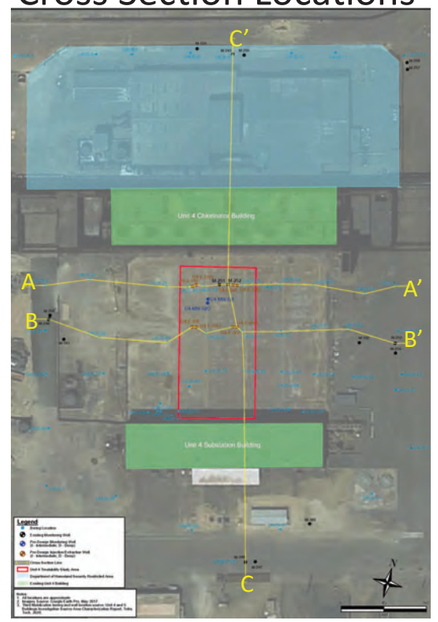
UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY
WORK PLAN ADDENDUM
HENDERSON, NEVADA

CROSS SECTION A-A'

Project No.:	117-7502018
Date:	JULY 8, 2021
Designed By:	MRB
Figure No.	6



Cross Section Locations



Well Screen

Water Table

Lithologic Contact

Soil Types in Alluvium (Qal)

- SILTY SAND / SILTY GRAVEL
- SAND / SAND WITH GRAVEL
- GRAVEL/ SANDY GRAVEL
- SILTY SAND
- CLAYEY SAND
- SANDY SILT

Soil Types in Upper Muddy Creek Formation (UMCf)

- SILTY CLAY/ CLAYEY SILT
- SANDY SILT (fine to very fine sand)
- SILTY SAND/ SANDY BED
- SILTY SAND/ GRAVEL

Other Soil Types

- FILL
- CALICHE

Notes:

1. Vertical exaggeration: 2:1.
2. Sections are shown looking North.
3. Data interpolation truncated below 163 ft bgs (below ground surface) due to insufficient data.
4. Ground surface elevation is assumed to be 1,813 ft amsl (above mean sea level) for the purposes of illustrated depth.
5. M-253 Monitoring well location and designation.
6. U4U5-28 Borehole location and designation.
7. Fine and coarse grained facies of the Upper Muddy Creek formation are designated as UMCf-fg1 and UMCf-cg1, respectively.

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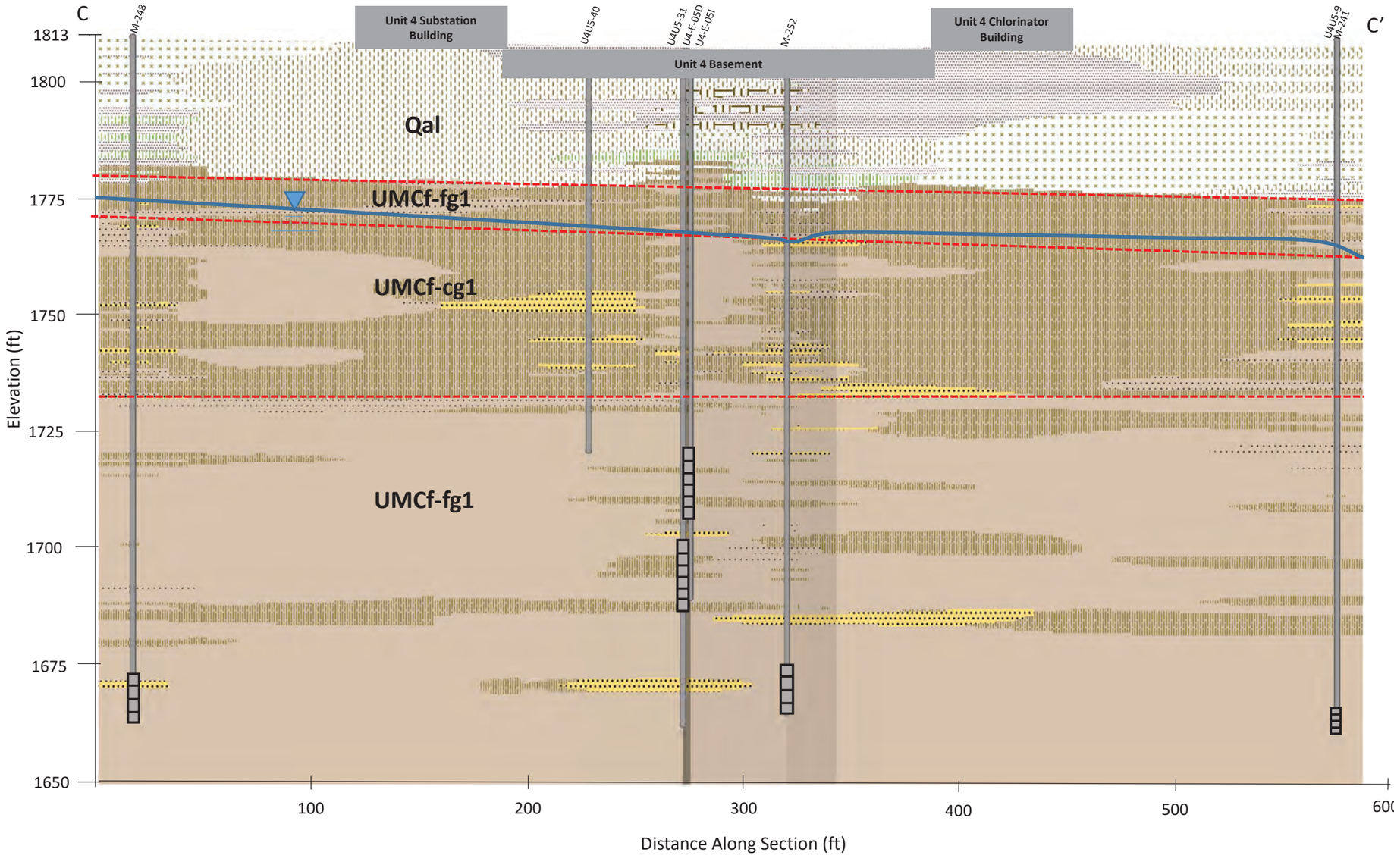
UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY
WORK PLAN ADDENDUM
HENDERSON, NEVADA

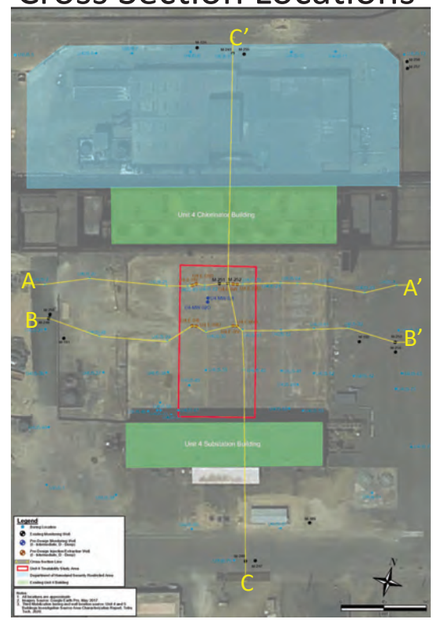
CROSS SECTION B-B'

Project No.:	117-7502018
Date:	JULY 8, 2021
Designed By:	MRB

Figure No.
7



Cross Section Locations



Well Screen

Water Table

Lithologic Contact

Soil Types in Alluvium (Qal)

- SILTY SAND / SILTY GRAVEL
- SAND / SAND WITH GRAVEL
- GRAVEL/ SANDY GRAVEL
- SILTY SAND
- CLAYEY SAND
- SANDY SILT

Soil Types in Upper Muddy Creek Formation (UMCf)

- SILTY CLAY/ CLAYEY SILT
- SANDY SILT (fine to very fine sand)
- SILTY SAND/ SANDY BED
- SILTY SAND/ GRAVEL

Other Soil Types

- FILL
- CALICHE

Notes:

1. Vertical exaggeration: 2:1.
2. Sections are shown looking West.
3. Data interpolation truncated below 163 ft bgs (below ground surface) due to insufficient data.
4. Ground surface elevation is assumed to be 1,813 ft amsl (above mean sea level) for the purposes of illustrated depth.
5. M-252 Monitoring well location and designation.
6. U4U5-40 Borehole location and designation.
7. Fine and coarse grained facies of the Upper Muddy Creek formation are designated as UMCf-fg1 and UMCf-cg1, respectively.

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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY
WORK PLAN ADDENDUM
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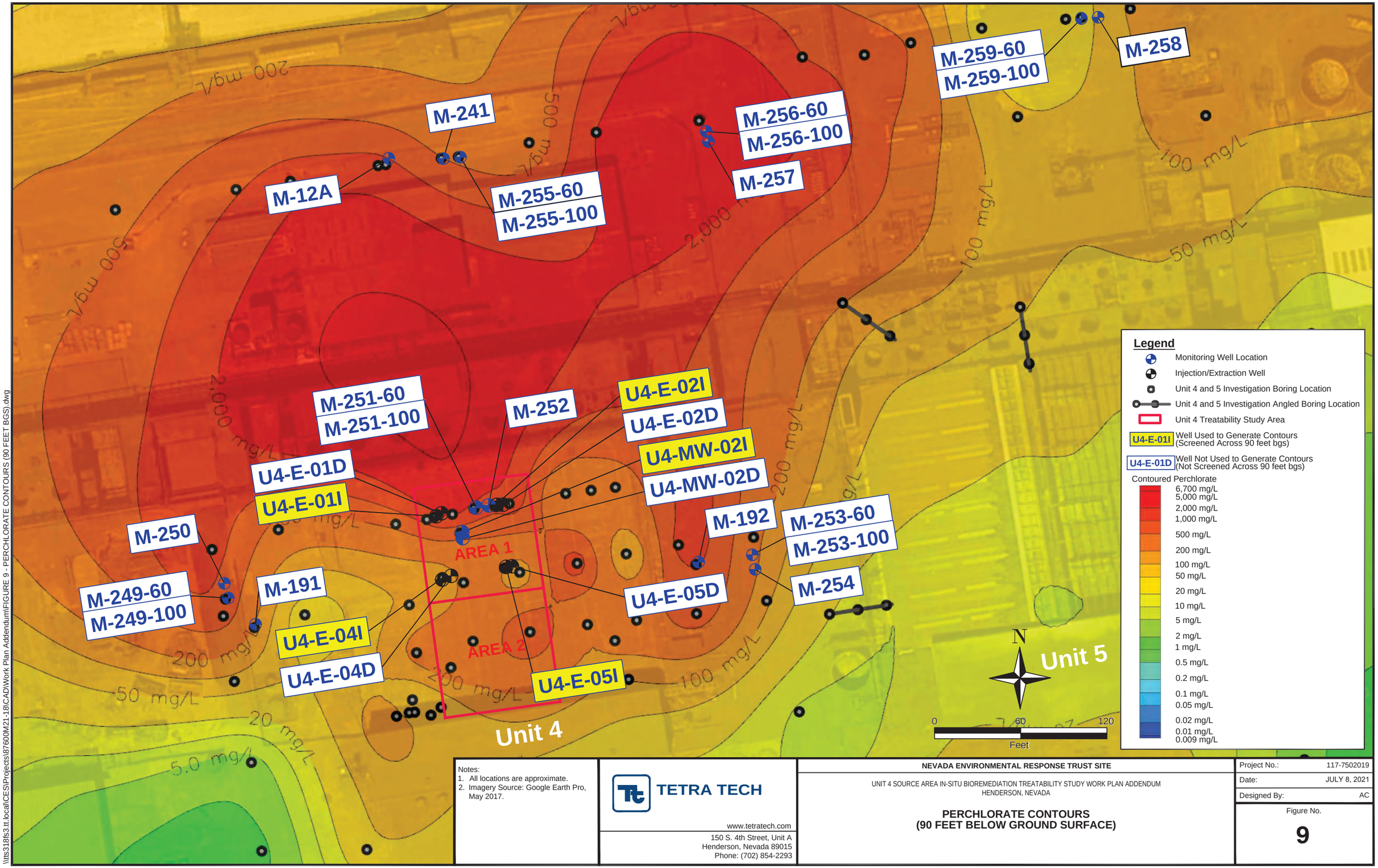
CROSS-SECTION C-C'

Project No.:	117-7502018
Date:	JULY 8, 2021
Designed By:	MRB

Figure No. **8**



\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 9 - PERCHLORATE CONTOURS (90 FEET BGS).dwg

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

PERCHLORATE CONTOURS (90 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.

9

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
U4-E-05I
U4-E-05D
M-192
M-253-60
M-253-100
M-254
AREA 1
AREA 2
Unit 4
Unit 5
N
0
60
120
Feet

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Not Used to Generate Contours (Not Screened Across 110 feet bgs)
- U4-E-01D — Well Used to Generate Contours (Screened Across 110 feet bgs)

Contoured Perchlorate

- 6,700 mg/L
- 5,000 mg/L
- 2,000 mg/L
- 1,000 mg/L
- 500 mg/L
- 200 mg/L
- 100 mg/L
- 50 mg/L
- 20 mg/L
- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.009 mg/L

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

PERCHLORATE CONTOURS (110 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
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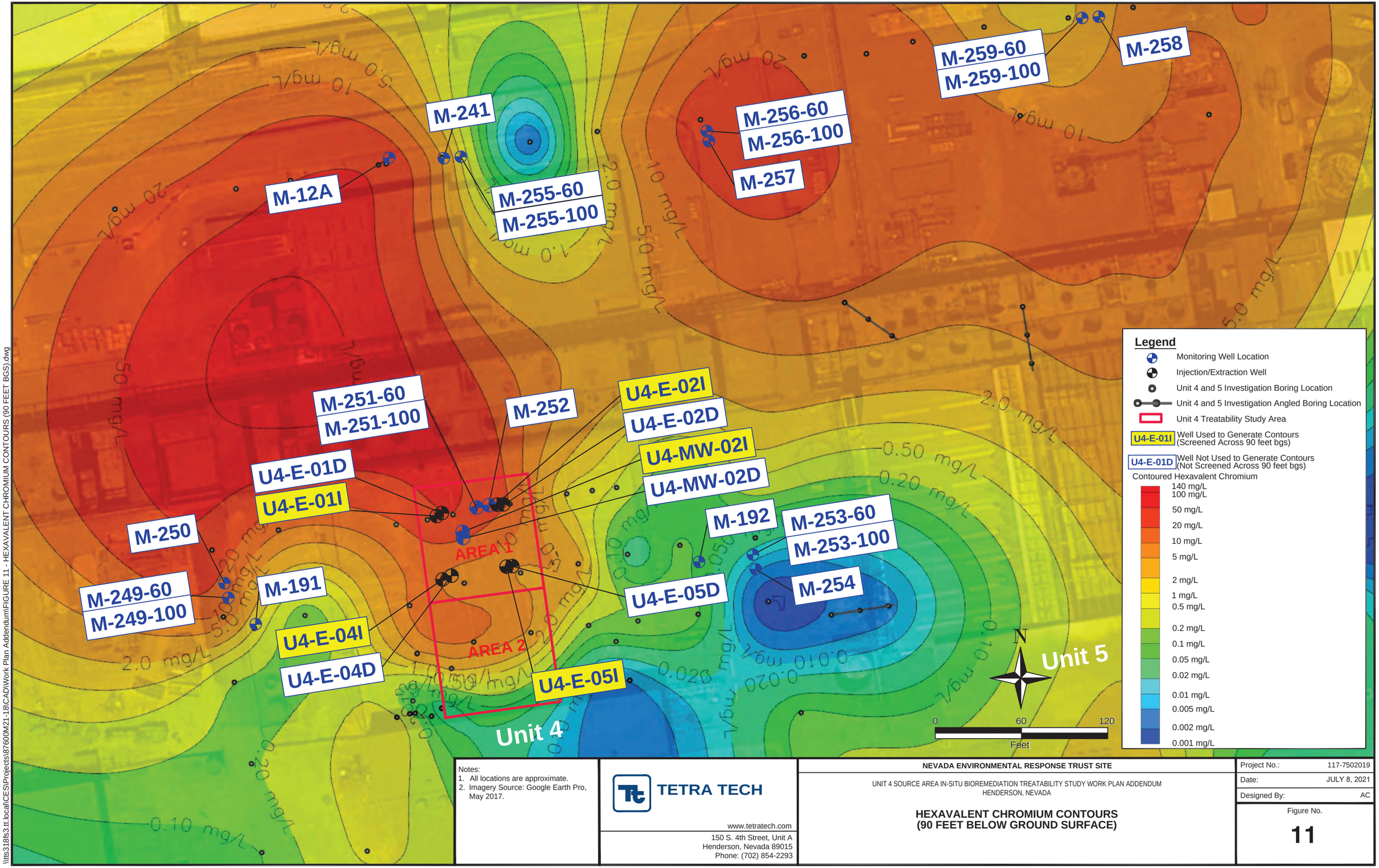
Figure No.
10

\\tts318fs3.ttl.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 10 - PERCHLORATE CONTOURS (110 FEET BGS).dwg

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 11 - HEXAVALENT CHROMIUM CONTOURS (90 FEET BGS).dwg



Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

HEXAVALENT CHROMIUM CONTOURS (90 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.

11

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
U4-E-05I
U4-E-05D
M-192
M-253-60
M-253-100
M-254
AREA 1
AREA 2
Unit 4
Unit 5
50 mg/L
20 mg/L
10 mg/L
5.0 mg/L
1.0 mg/L
0.50 mg/L
0.20 mg/L
0.10 mg/L
0.050 mg/L
N
0
60
120
Feet

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Not Used to Generate Contours (Not Screened Across 110 feet bgs)
- U4-E-01D — Well Used to Generate Contours (Screened Across 110 feet bgs)

Contoured Hexavalent Chromium

- 140 mg/L
- 100 mg/L
- 50 mg/L
- 20 mg/L
- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.005 mg/L
- 0.002 mg/L
- 0.001 mg/L

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

HEXAVALENT CHROMIUM CONTOURS (110 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
12

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 12 - HEXAVALENT CHROMIUM CONTOURS (110 FEET BGS).dwg

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
M-192
M-253-60
M-253-100
M-254
U4-E-05D
U4-E-05I
AREA 1
AREA 2
Unit 4
Unit 5
0.50 mg/L
2.0 mg/L
1.0 mg/L
0.20 mg/L
0.50 mg/L
0.50 mg/L
0.20 mg/L
2.0 mg/L
0.50 mg/L
0.50 mg/L
0.10 mg/L
0.050 mg/L
0.010 mg/L
0.020 mg/L
0.10 mg/L
0.050 mg/L

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Used to Generate Contours (Screened Across 90 feet bgs)
- U4-E-01D — Well Not Used to Generate Contours (Not Screened Across 90 feet bgs)

Contoured Chloroform

- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.005 mg/L
- 0.002 mg/L
- 0.001 mg/L
- 0.0005 mg/L
- 0.0002 mg/L
- 0.0001 mg/L

N

0 60 120
Feet

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

CHLOROFORM CONTOURS
(90 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
13

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 13 - CHLOROFORM CONTOURS (90 FEET BGS).dwg

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
U4-E-05I
U4-E-05D
M-192
M-253-60
M-253-100
M-254
AREA 1
AREA 2
Unit 4
Unit 5
N
0
60
120
Feet

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Not Used to Generate Contours (Not Screened Across 110 feet bgs)
- U4-E-01D — Well Used to Generate Contours (Screened Across 110 feet bgs)

Contoured Chloroform

- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.005 mg/L
- 0.002 mg/L
- 0.001 mg/L
- 0.0005 mg/L
- 0.0002 mg/L
- 0.0001 mg/L

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

CHLOROFORM CONTOURS (110 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
14

\\tts318fs3.tt.local\CES\Projects\87600M21-18CAD\Work Plan Addendum\FIGURE 14 - CHLOROFORM CONTOURS (110 FEET BGS).dwg

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
U4-E-05I
U4-E-05D
M-192
M-253-60
M-253-100
M-254
AREA 1
AREA 2
Unit 4
Unit 5
200 mg/L
500 mg/L
1,000 mg/L
5,000
1.0 mg/L
100 mg/L

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Used to Generate Contours (Screened Across 90 feet bgs)
- U4-E-01D — Well Not Used to Generate Contours (Not Screened Across 90 feet bgs)

Contoured Chlorate

- 33,000 mg/L
- 20,000 mg/L
- 10,000 mg/L
- 5,000 mg/L
- 2,000 mg/L
- 1,000 mg/L
- 500 mg/L
- 200 mg/L
- 100 mg/L
- 50 mg/L
- 20 mg/L
- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.005 mg/L
- 0.002 mg/L
- 0.001 mg/L

N

0 60 120
Feet

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

CHLORATE CONTOURS
(90 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
15

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 15 - CHLORATE CONTOURS (90 FEET BGS).dwg

M-259-60
M-259-100
M-258
M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
U4-E-04I
U4-E-04D
U4-E-05I
U4-E-05D
M-192
M-253-60
M-253-100
M-254
AREA 1
AREA 2
Unit 4
Unit 5
200 mg/L
500 mg/L
1,000 mg/L
2,000 mg/L
5,000 mg/L
10,000 mg/L
50 mg/L
100 mg/L
N
0
60
120
Feet

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Not Used to Generate Contours (Not Screened Across 110 feet bgs)
- U4-E-01D — Well Used to Generate Contours (Screened Across 110 feet bgs)

Contoured Chlorate
- 33,000 mg/L
- 20,000 mg/L
- 10,000 mg/L
- 5,000 mg/L
- 2,000 mg/L
- 1,000 mg/L
- 500 mg/L
- 200 mg/L
- 100 mg/L
- 50 mg/L
- 20 mg/L
- 10 mg/L
- 5 mg/L
- 2 mg/L
- 1 mg/L
- 0.5 mg/L
- 0.2 mg/L
- 0.1 mg/L
- 0.05 mg/L
- 0.02 mg/L
- 0.01 mg/L
- 0.005 mg/L
- 0.002 mg/L
- 0.001 mg/L

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

CHLORATE CONTOURS
(110 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
16

\\tts318fs3.ft.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 16 - CHLORATE CONTOURS (110 FEET BGS).dwg

M-241
M-12A
M-255-60
M-255-100
M-256-60
M-256-100
M-257
M-259-60
M-259-100
M-258
10,000 mg/L
10,000 mg/L
10,000 mg/L
5,000 mg/L
20,000 mg/L
M-251-60
M-251-100
M-252
U4-E-02I
U4-E-02D
U4-MW-02I
U4-MW-02D
U4-E-01D
U4-E-01I
M-250
M-249-60
M-249-100
M-191
M-192
M-253-60
M-253-100
M-254
U4-E-04I
U4-E-04D
U4-E-05D
U4-E-05I
AREA 1
AREA 2
10,000 mg/L
5,000 mg/L
Unit 4
Unit 5
N
0
60
120
Feet

Legend

- Monitoring Well Location
- Injection/Extraction Well
- Unit 4 and 5 Investigation Boring Location
- Unit 4 and 5 Investigation Angled Boring Location
- Unit 4 Treatability Study Area
- U4-E-01I — Well Used to Generate Contours (Screened Across 90 feet bgs)
- U4-E-01D — Well Not Used to Generate Contours (Not Screened Across 90 feet bgs)

Contoured Total Dissolved Solids

- 58,000 mg/L
- 50,000 mg/L
- 20,000 mg/L
- 10,000 mg/L
- 5,000 mg/L
- 2,000 mg/L
- 1,000 mg/L
- 500 mg/L
- 430 mg/L

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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HENDERSON, NEVADA

TOTAL DISSOLVED SOLIDS CONTOURS (90 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
Date:	JULY 8, 2021
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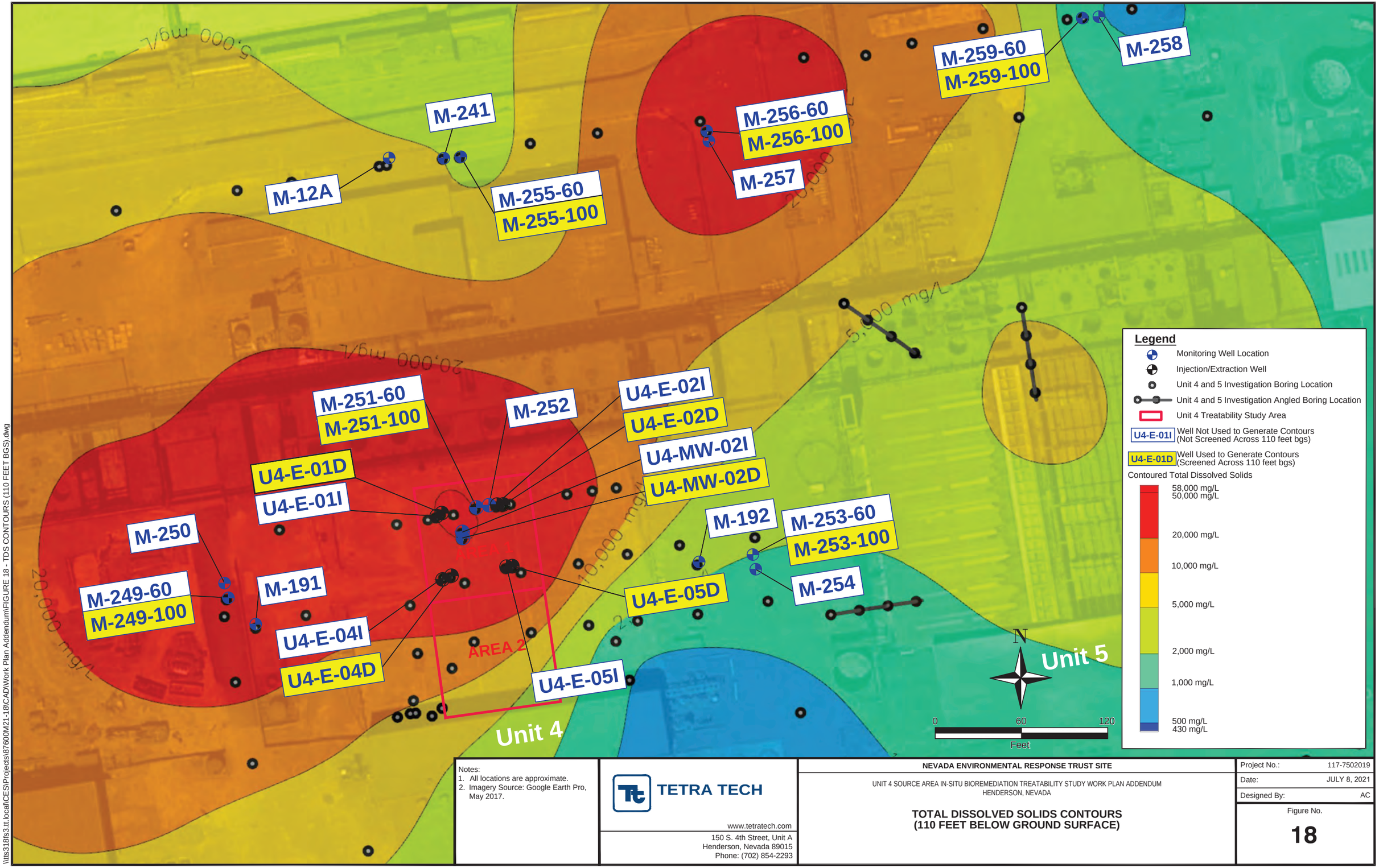
Figure No.
17



\\tts318fs3.ttl.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 18 - TDS CONTOURS (110 FEET BGS).dwg

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2017.

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TOTAL DISSOLVED SOLIDS CONTOURS (110 FEET BELOW GROUND SURFACE)

Project No.:	117-7502019
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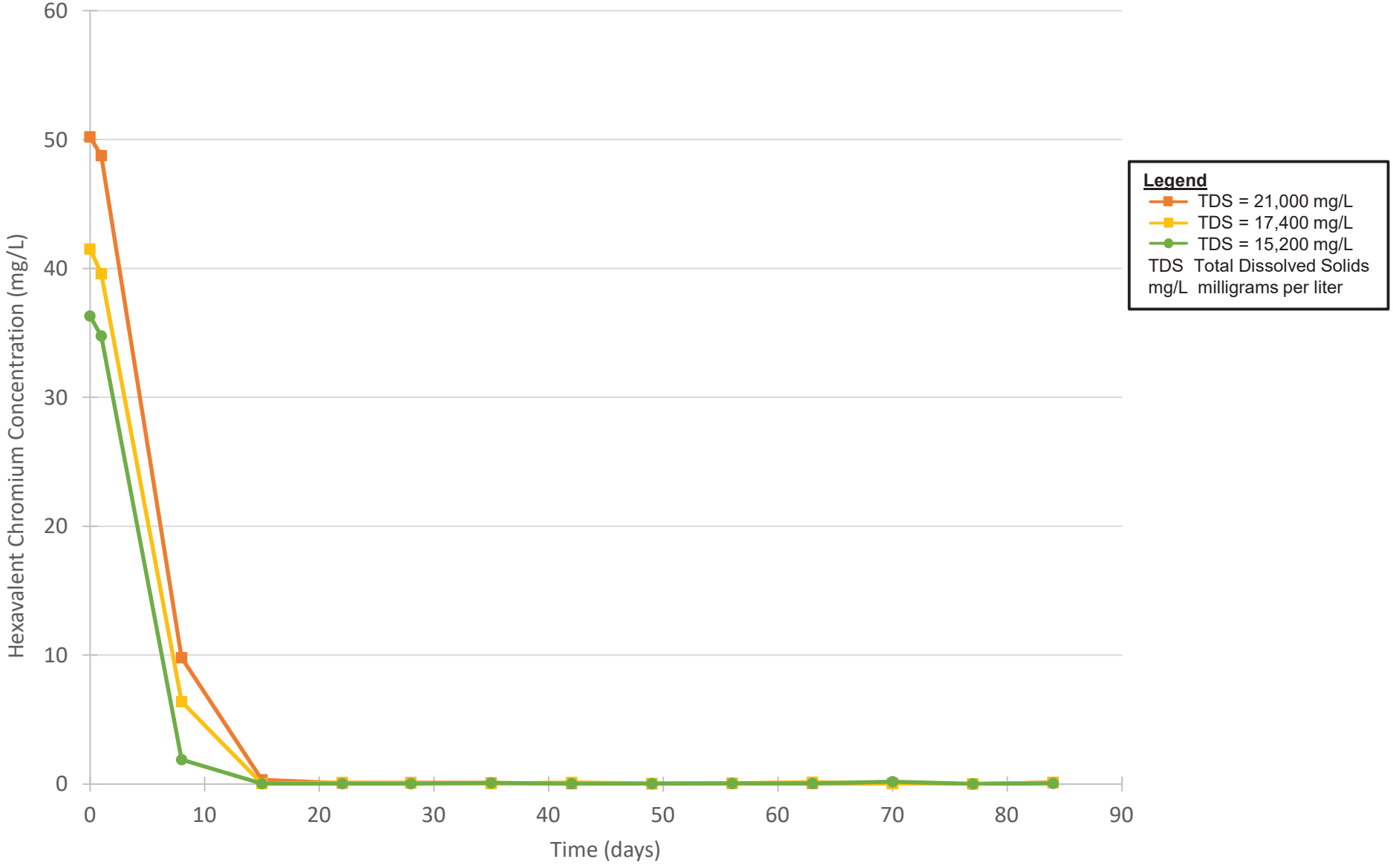
Figure No.

18



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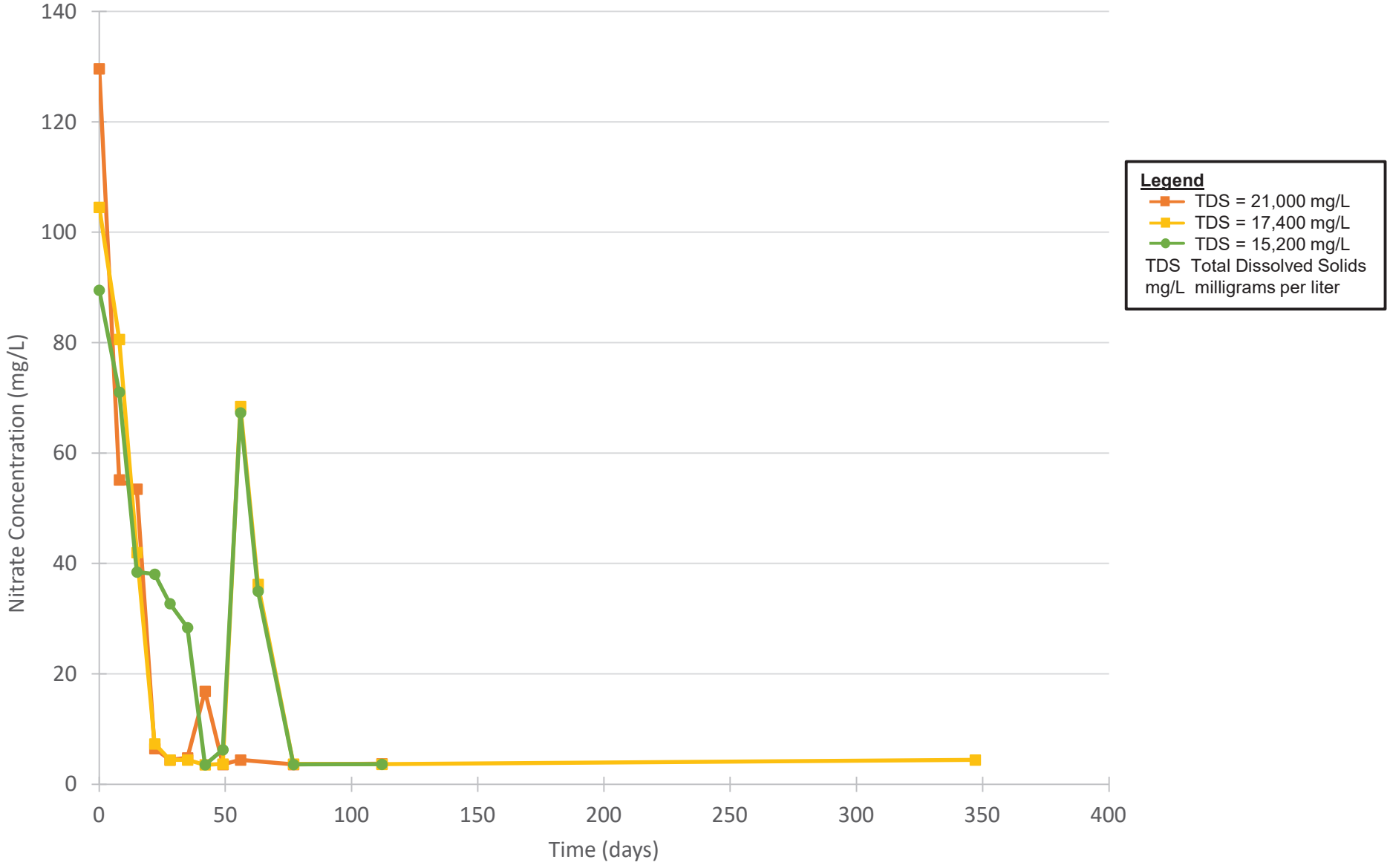
HENDERSON, NEVADA

HEXAVALENT CHROMIUM CONCENTRATIONS IN PHASE II MICROCOSMS WITH MOLASSES

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	DVK

Figure No.
19



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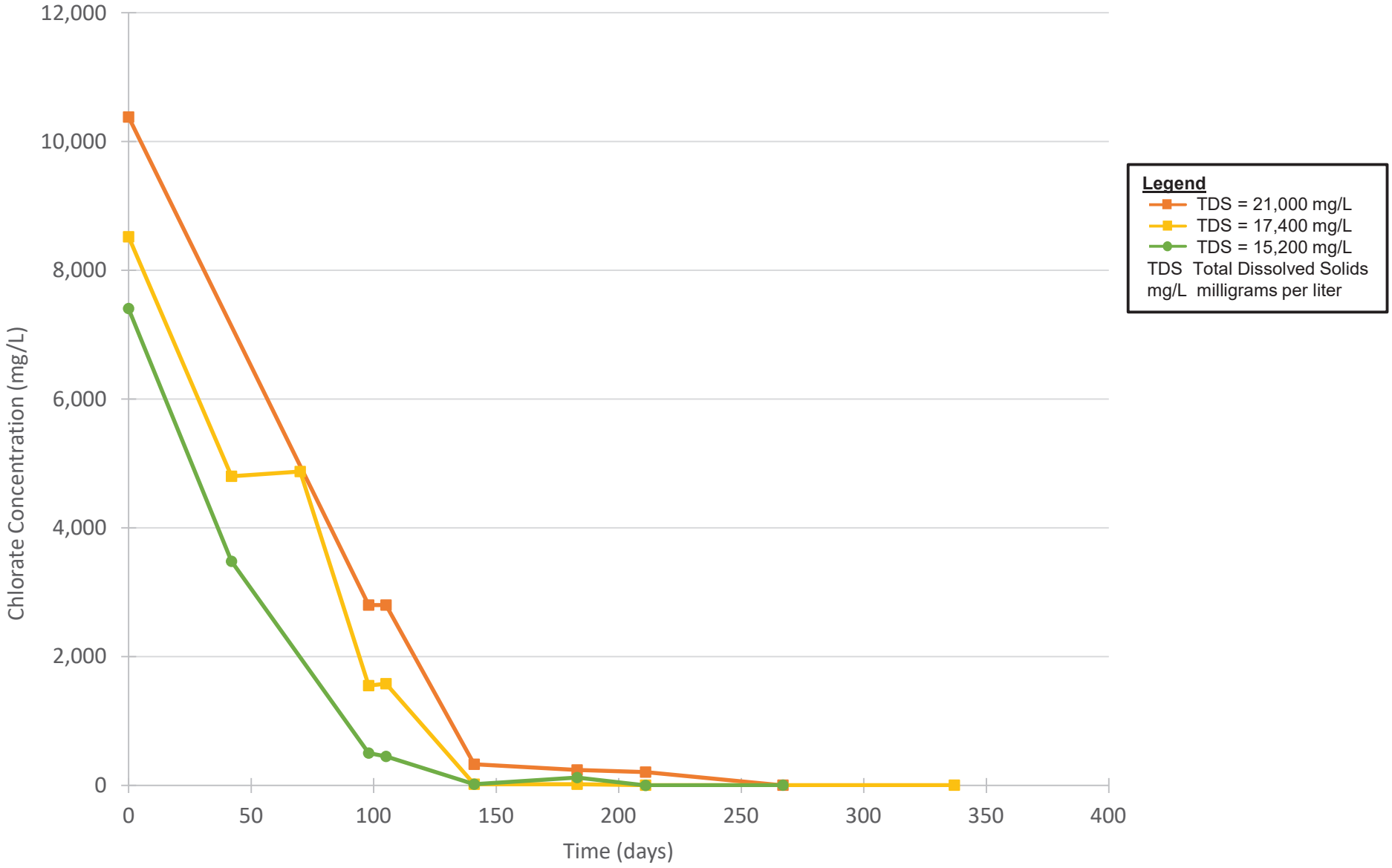
UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

NITRATE CONCENTRATIONS IN PHASE II MICROCOSMS WITH MOLASSES

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	DVK

Figure No.
20



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

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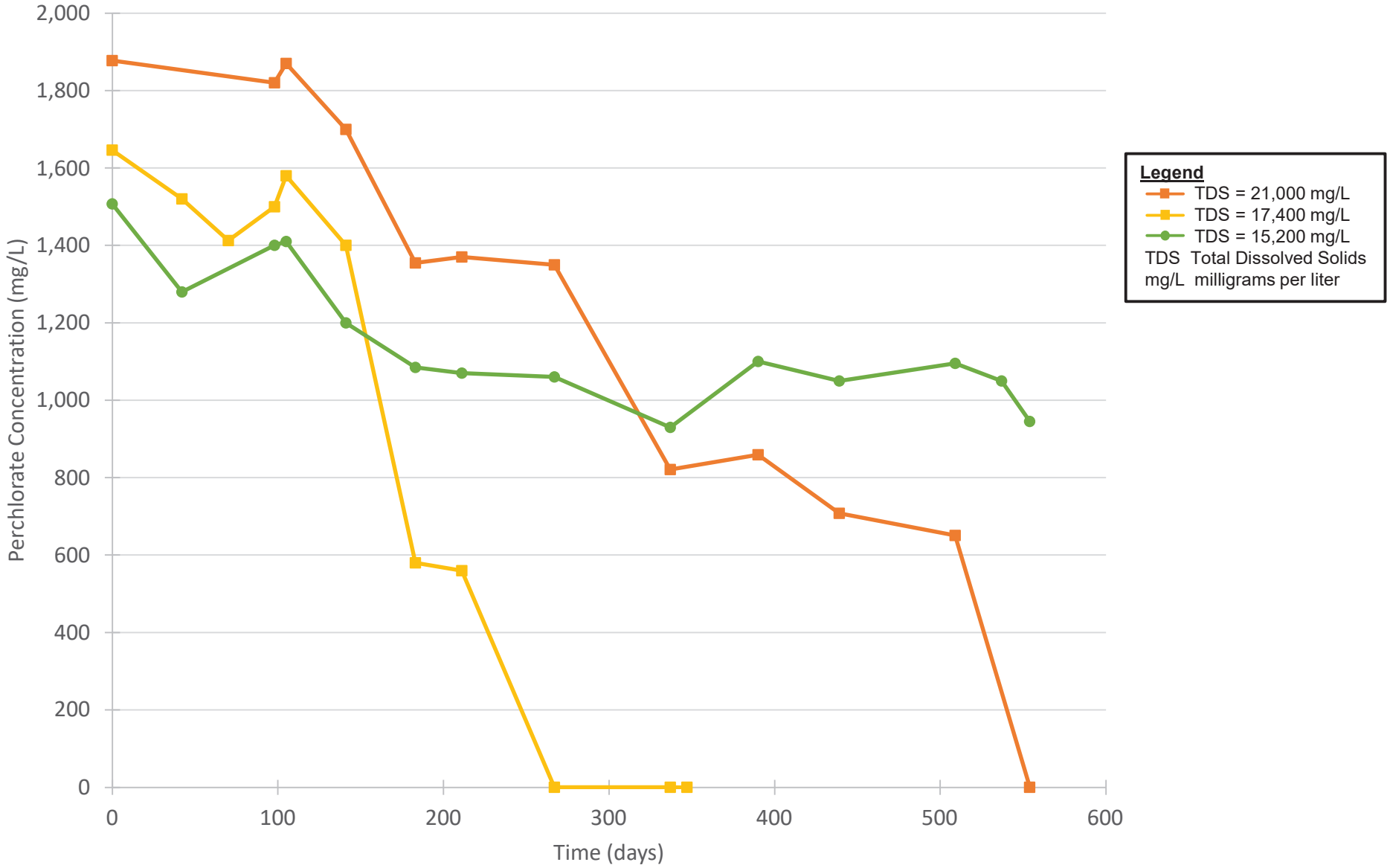
HENDERSON, NEVADA

CHLORATE CONCENTRATIONS IN PHASE II MICROCOSMS WITH MOLASSES

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	DVK

Figure No.
21



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

PERCHLORATE CONCENTRATIONS IN PHASE II MICROCOSMS WITH MOLASSES

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	DVK

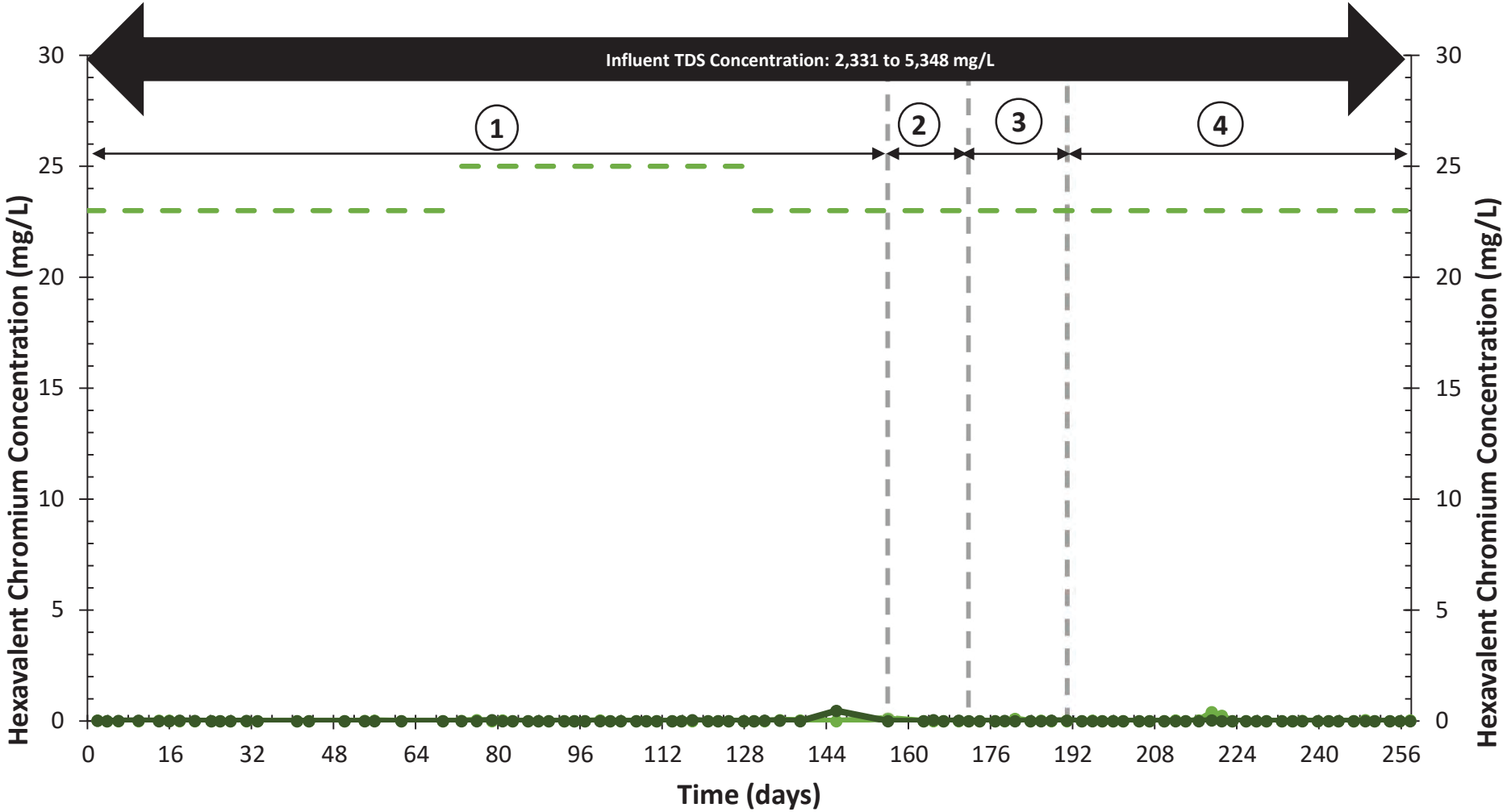
Figure No.
22

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column C
Effluent Column D
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

HEXAVALENT CHROMIUM CONCENTRATIONS FOR INTERMEDIATE COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
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Figure No.
23

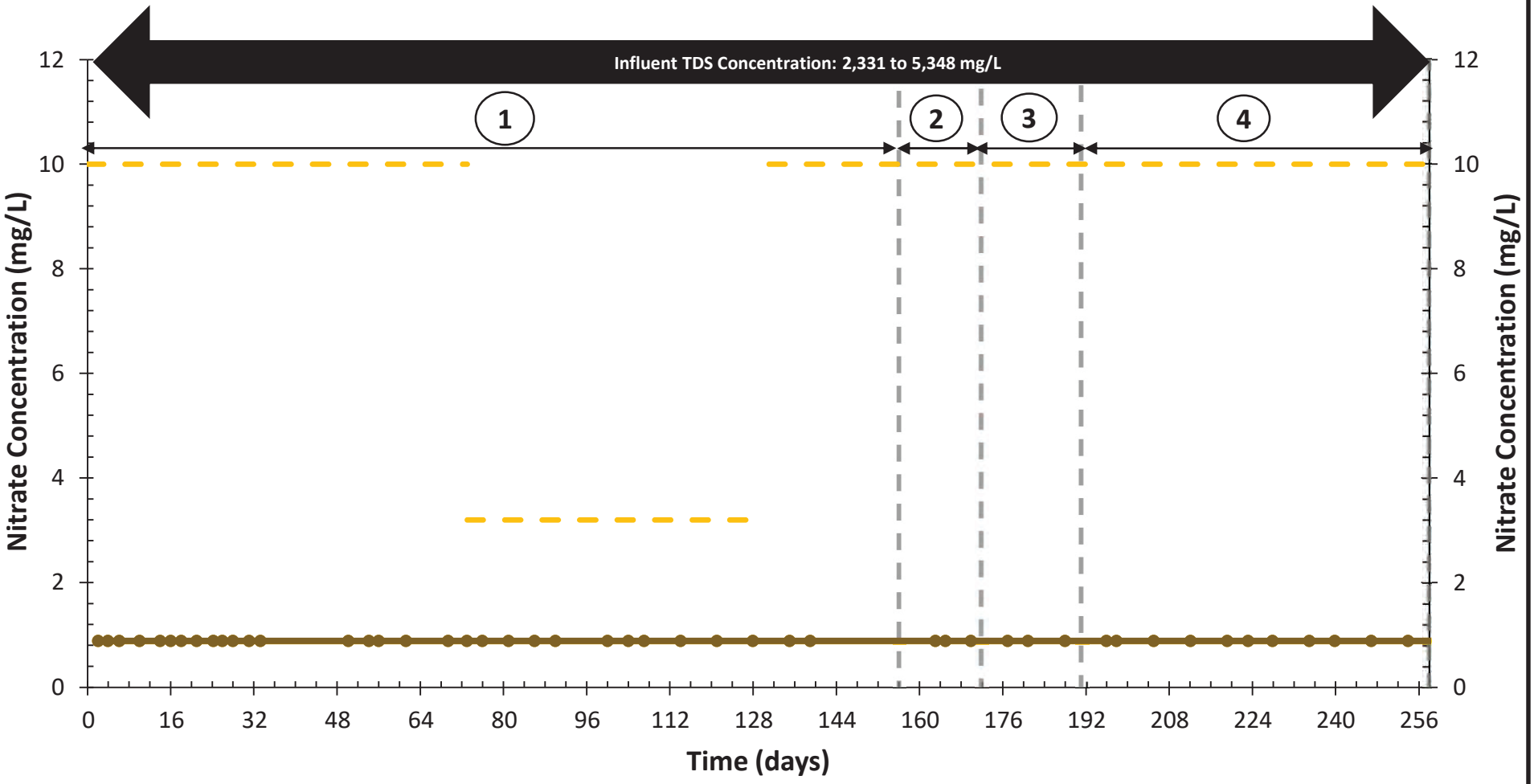
\\tts318fs3.tt.local\CES\Projects\87600M21-18\Working\Treatability Study Work Plan Addendum\Figures\Figures 9-20 - Microcosm and Column Charts.pptx

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column C
Effluent Column D
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

NITRATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
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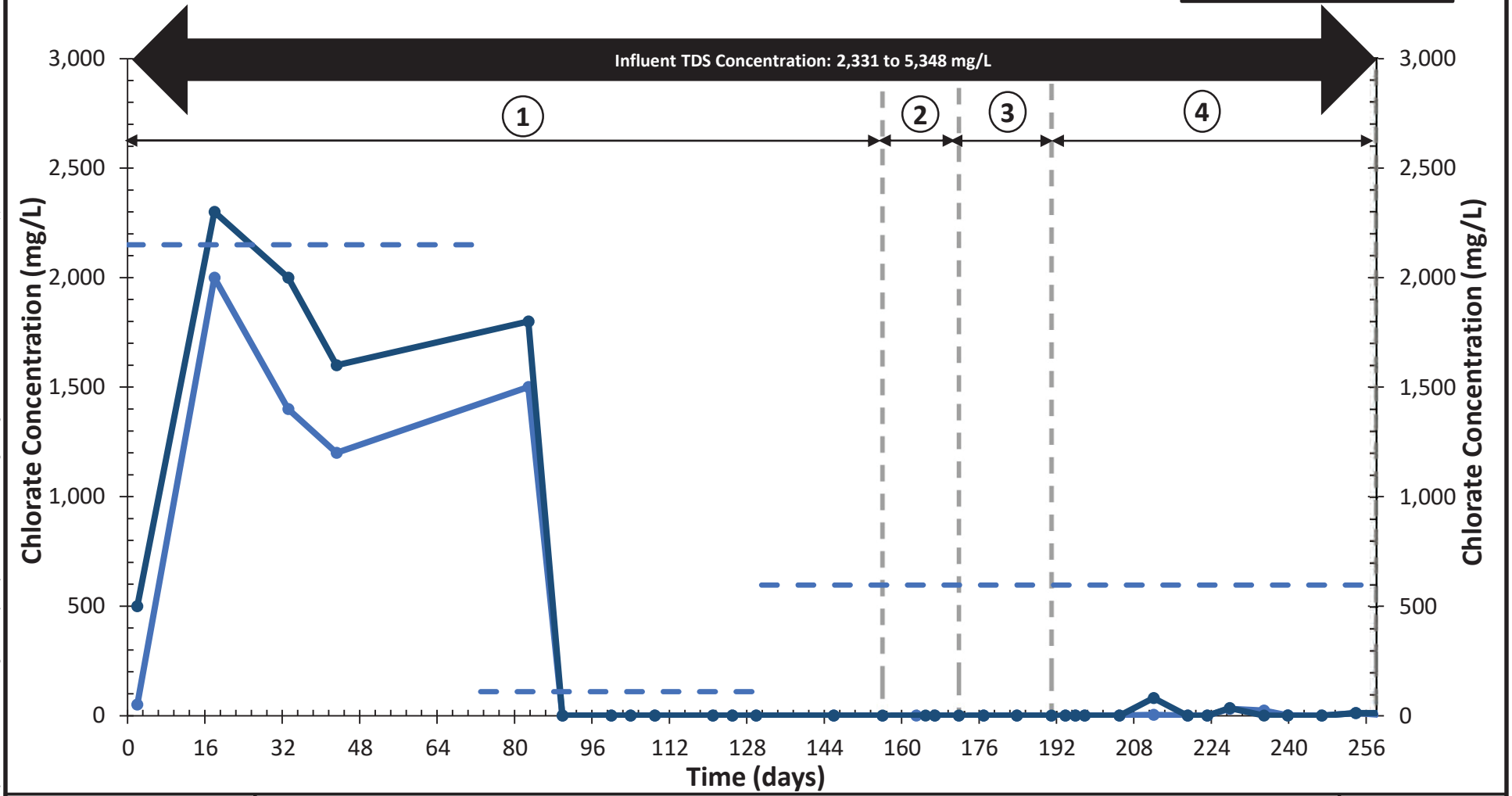
Figure No.
24

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column C
Effluent Column D
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

CHLORATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
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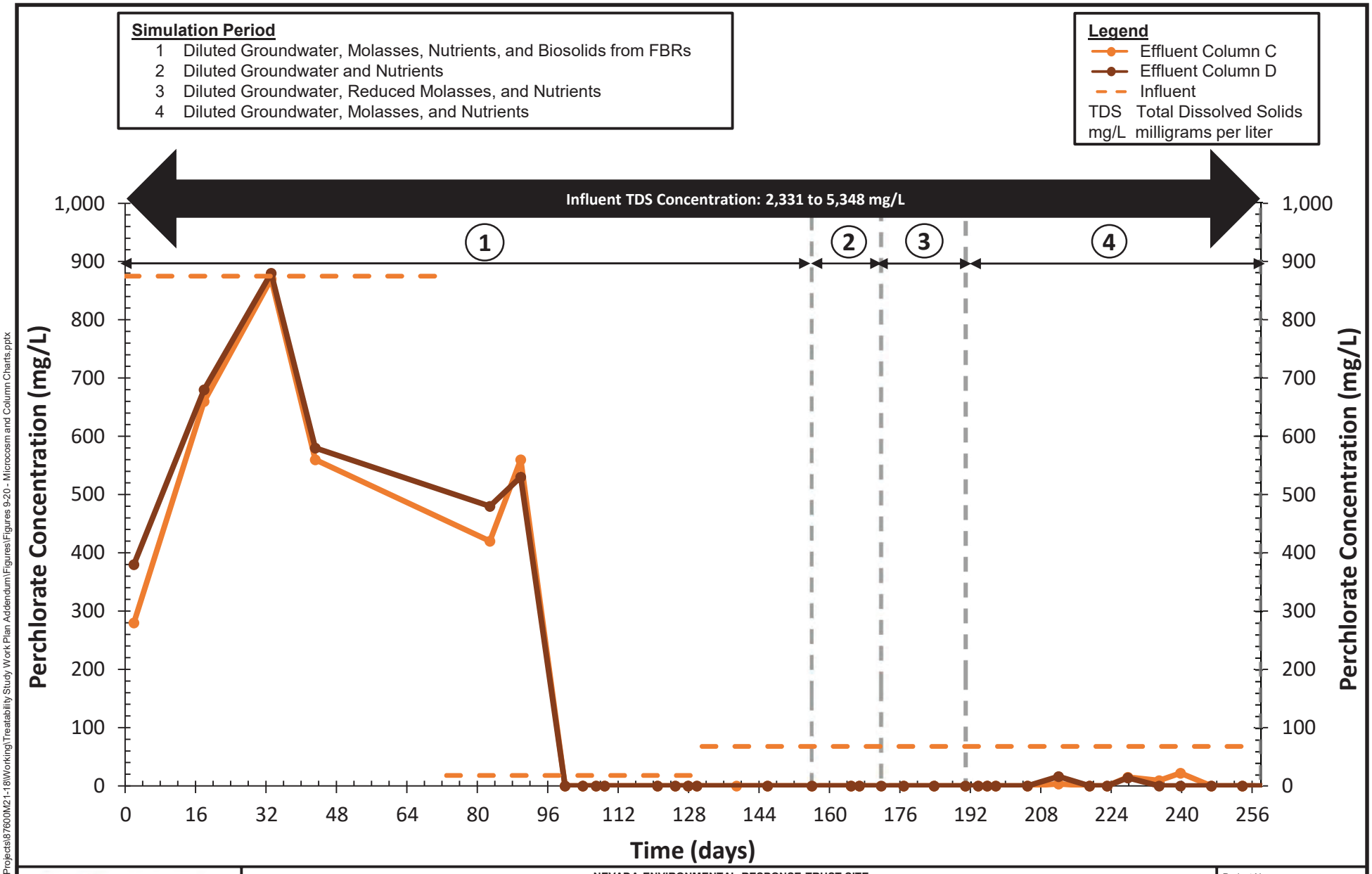
Figure No.
25



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
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PERCHLORATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

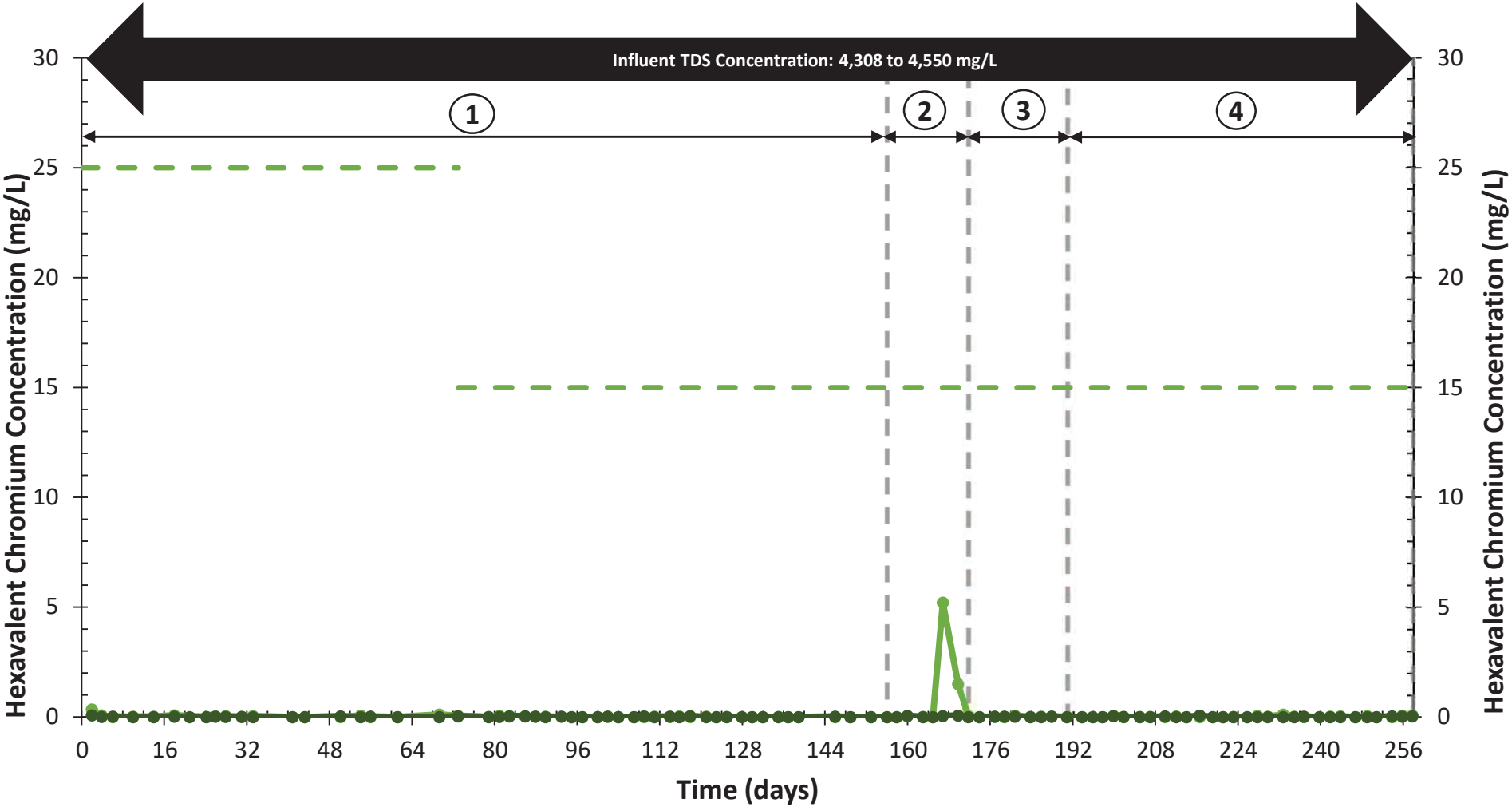
Figure No.
26

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

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HENDERSON, NEVADA

HEXAVALENT CHROMIUM CONCENTRATIONS FOR DEEP COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
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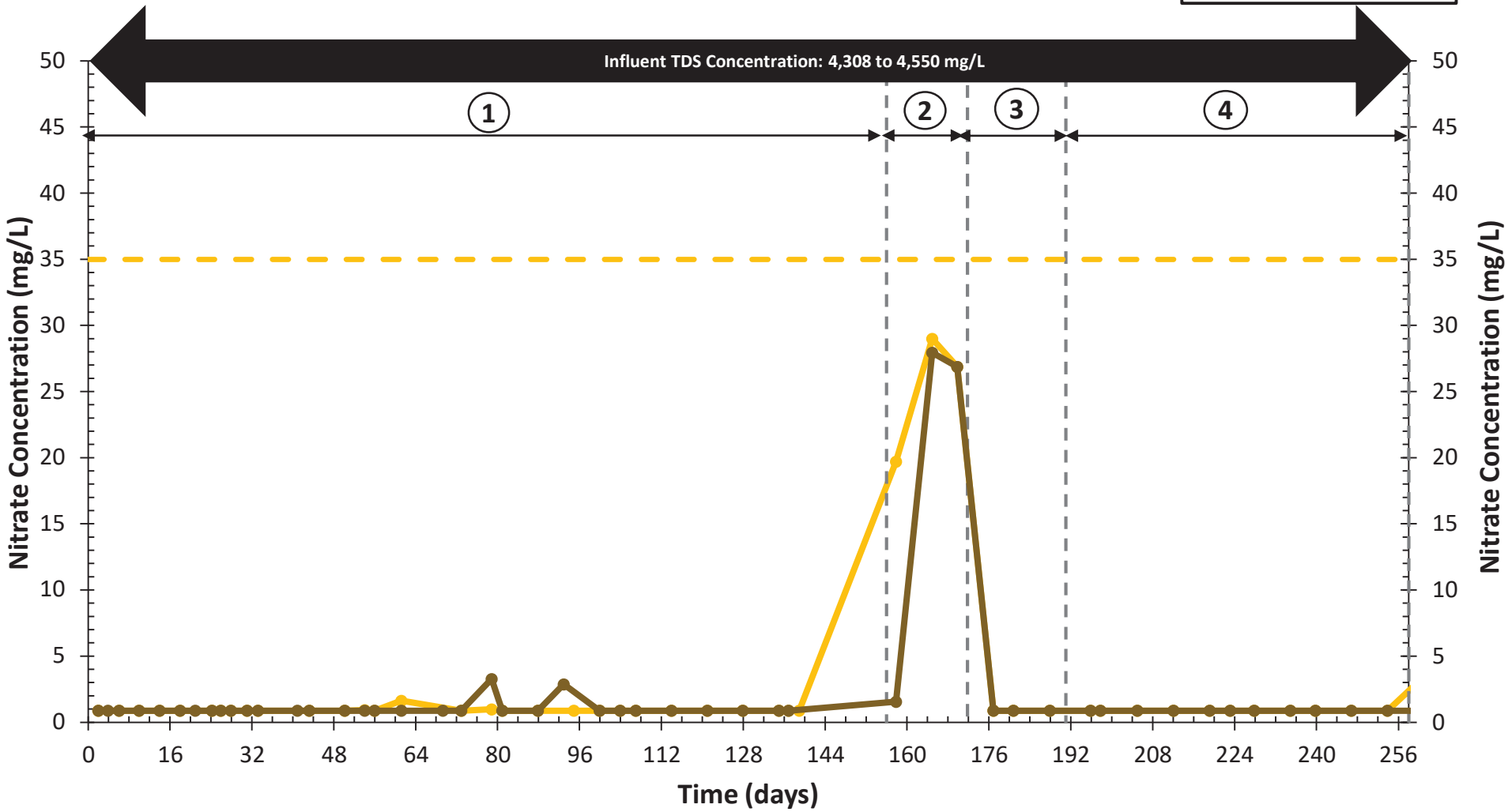
Figure No.
27

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

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HENDERSON, NEVADA

NITRATE CONCENTRATIONS FOR DEEP COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
28

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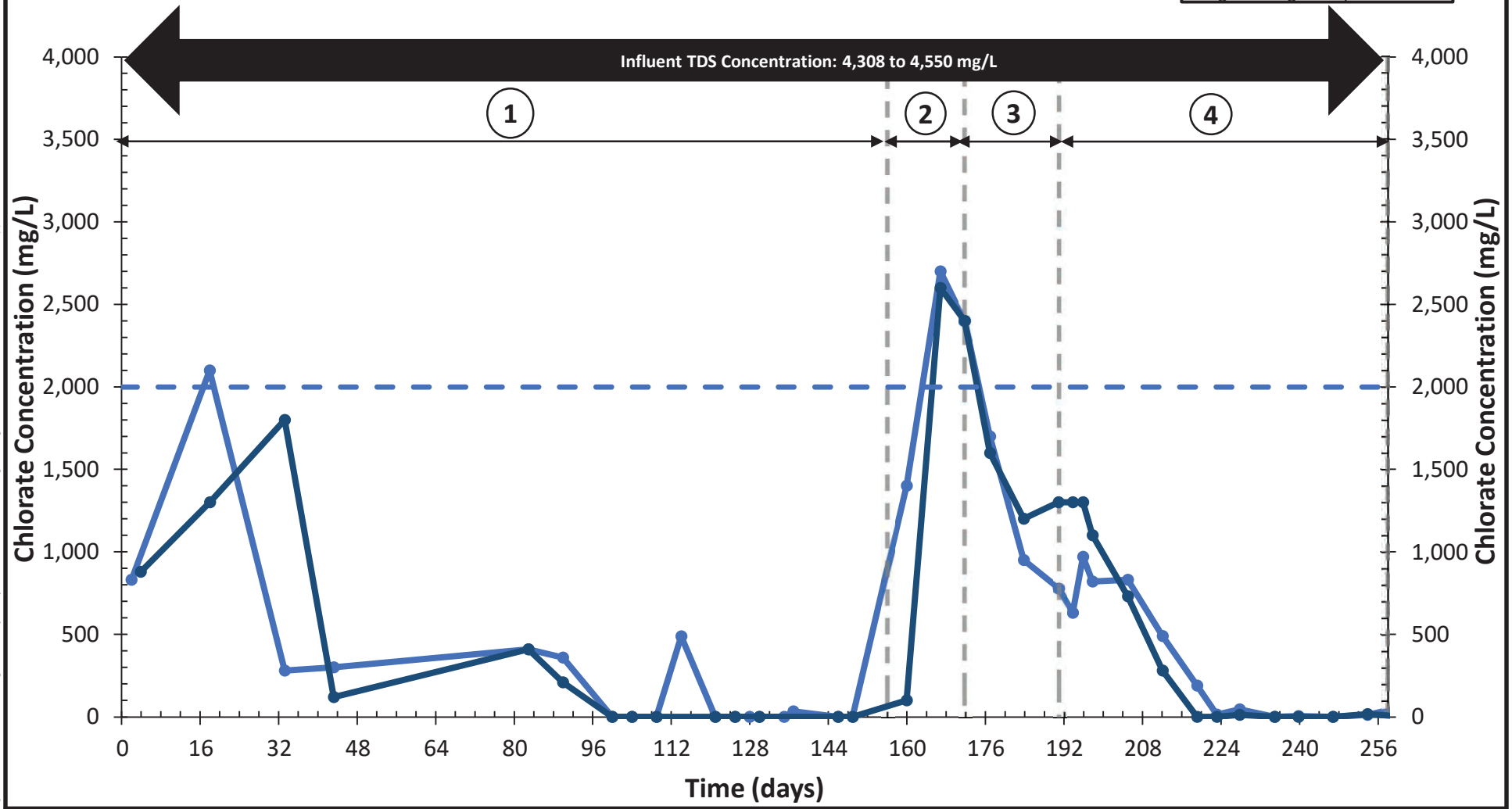
Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NEVADA ENVIRONMENTAL RESPONSE TRUST SITE

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HENDERSON, NEVADA

CHLORATE CONCENTRATIONS FOR DEEP COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
29

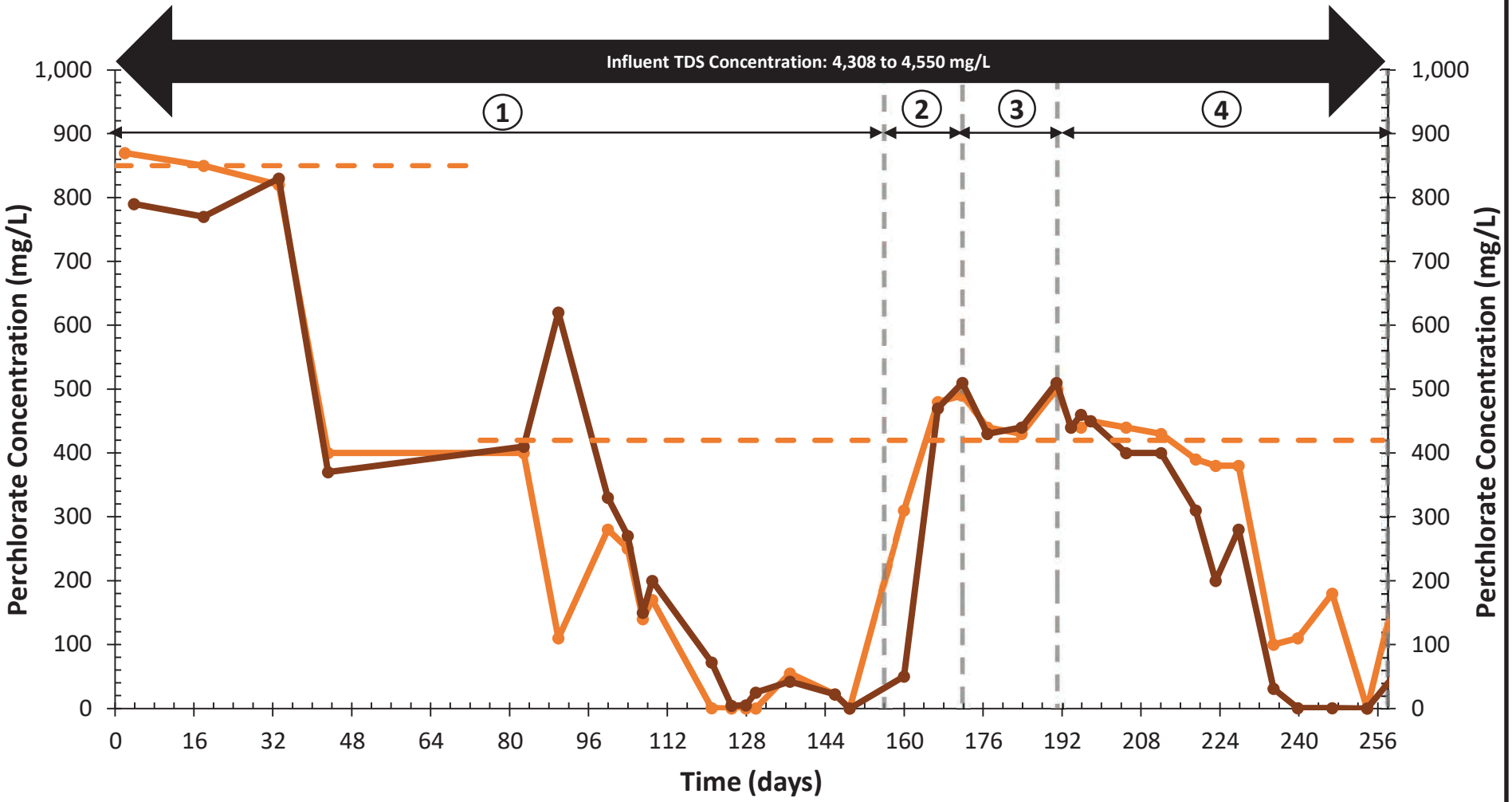
\\tts318fs3.tt.local\CES\Projects\87600M21-18Working\Treatability Study Work Plan Addendum\Figures\Figures 9-20 - Microcosm and Column Charts.pptx

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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UNIT 4 SOURCE AREA IN-SITU BIOREMEDIATION TREATABILITY STUDY WORK PLAN ADDENDUM
HENDERSON, NEVADA

PERCHLORATE CONCENTRATIONS FOR DEEP COLUMNS (SIMULATIONS 1 TO 4)

Project No.:	117-7502019
Date:	JULY 8, 2021
Designed By:	AC

Figure No.
30

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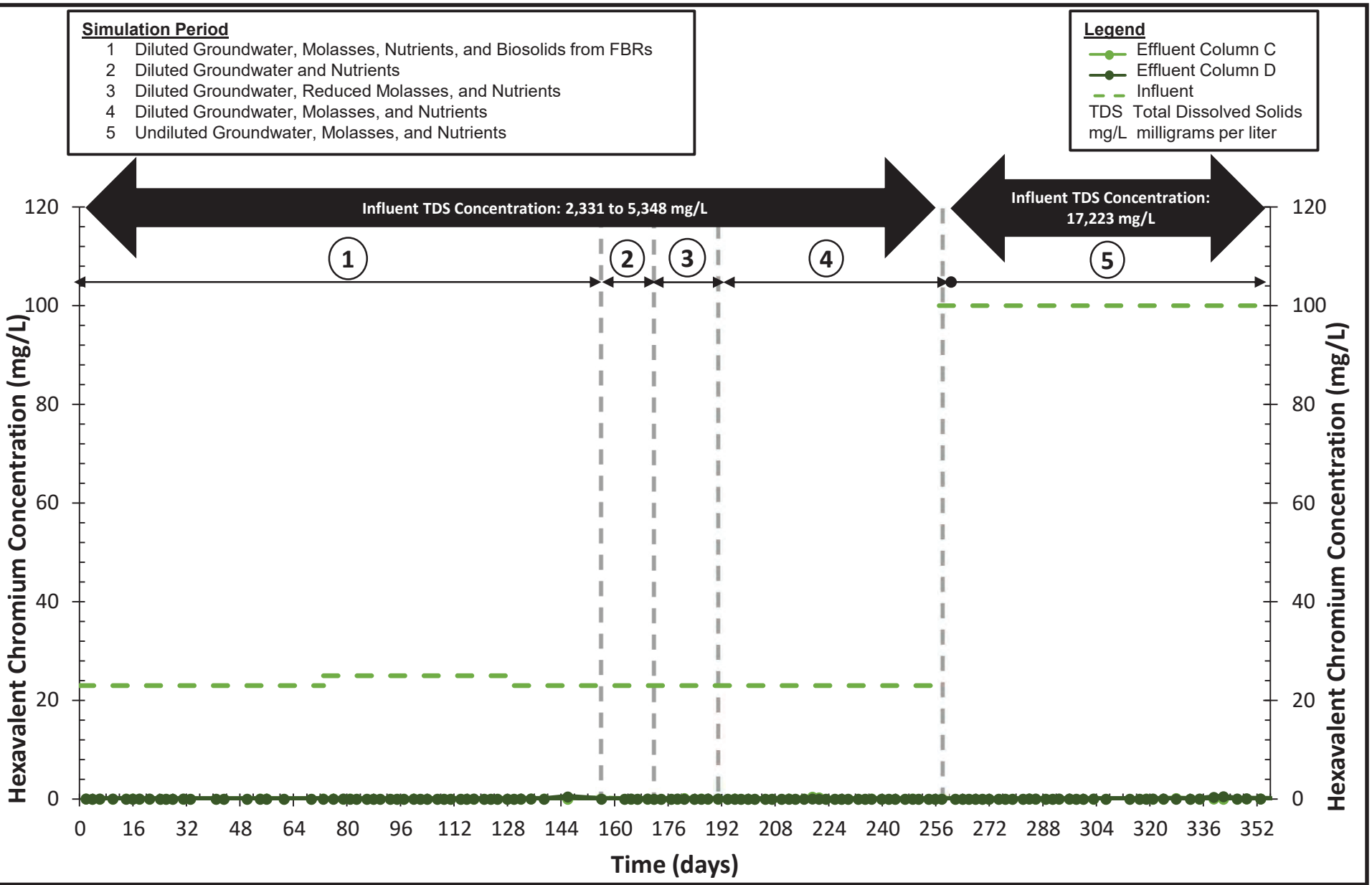

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HEXAVALENT CHROMIUM CONCENTRATIONS FOR INTERMEDIATE COLUMNS (ALL SIMULATIONS)

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Date:	JULY 8, 2021
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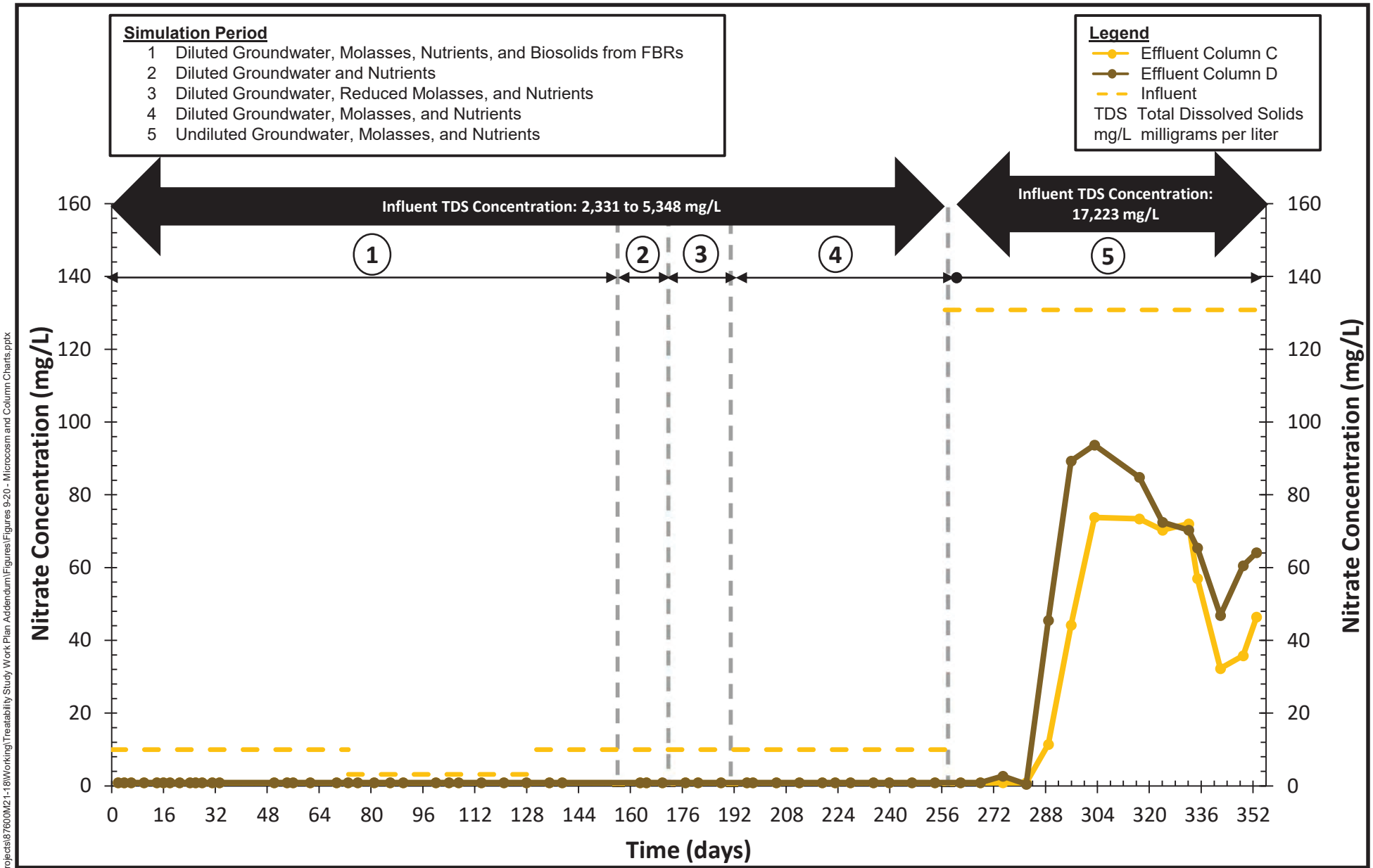
Figure No.
31



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NITRATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
Date:	JULY 8, 2021
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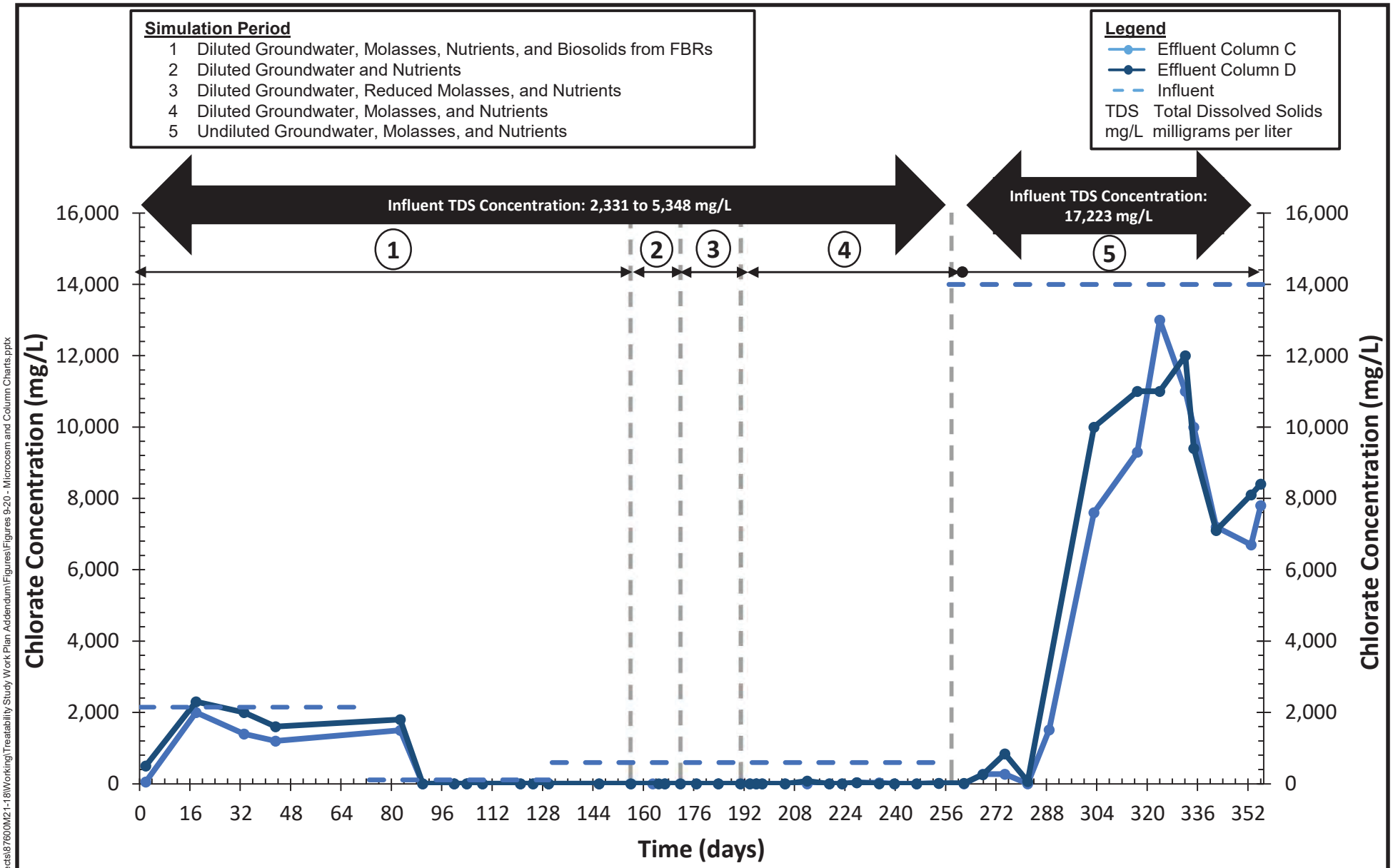
Figure No.
32



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CHLORATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
Date:	JULY 8, 2021
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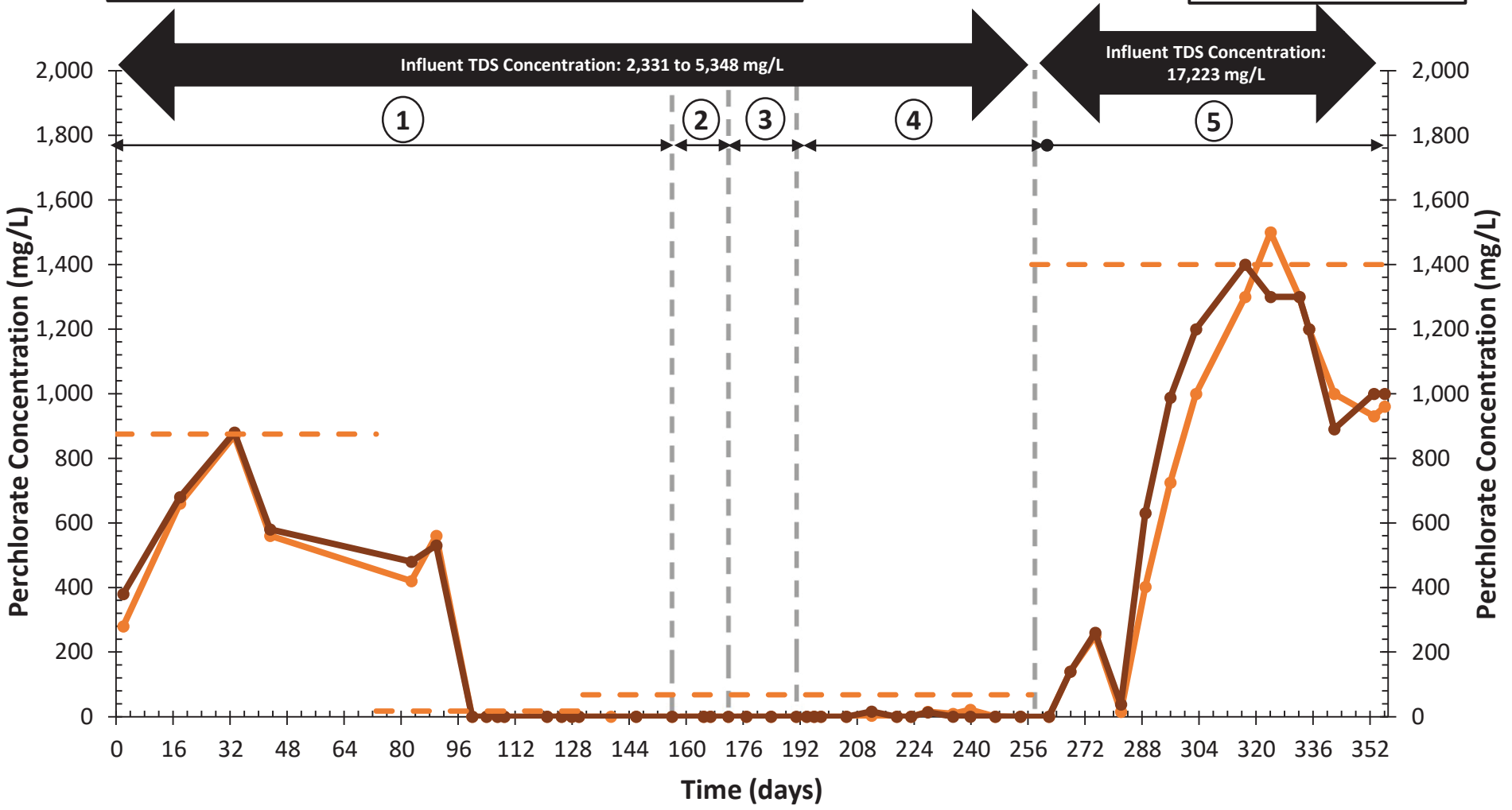
Figure No.
33

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients
5 Undiluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column C
Effluent Column D
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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PERCHLORATE CONCENTRATIONS FOR INTERMEDIATE COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
Date:	JULY 8, 2021
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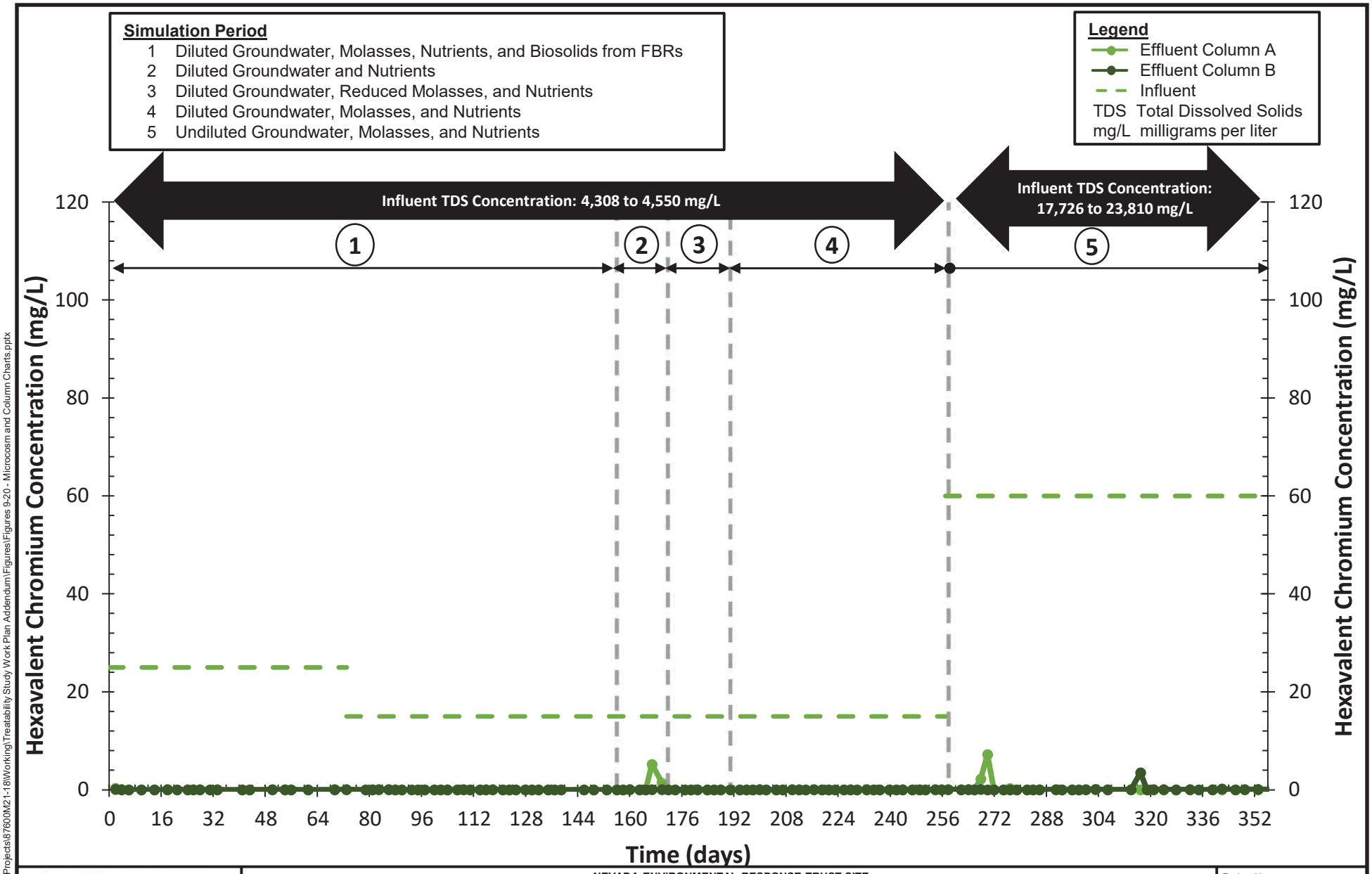
Figure No.
34



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HEXAVALENT CHROMIUM CONCENTRATIONS FOR DEEP COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
Date:	JULY 8, 2021
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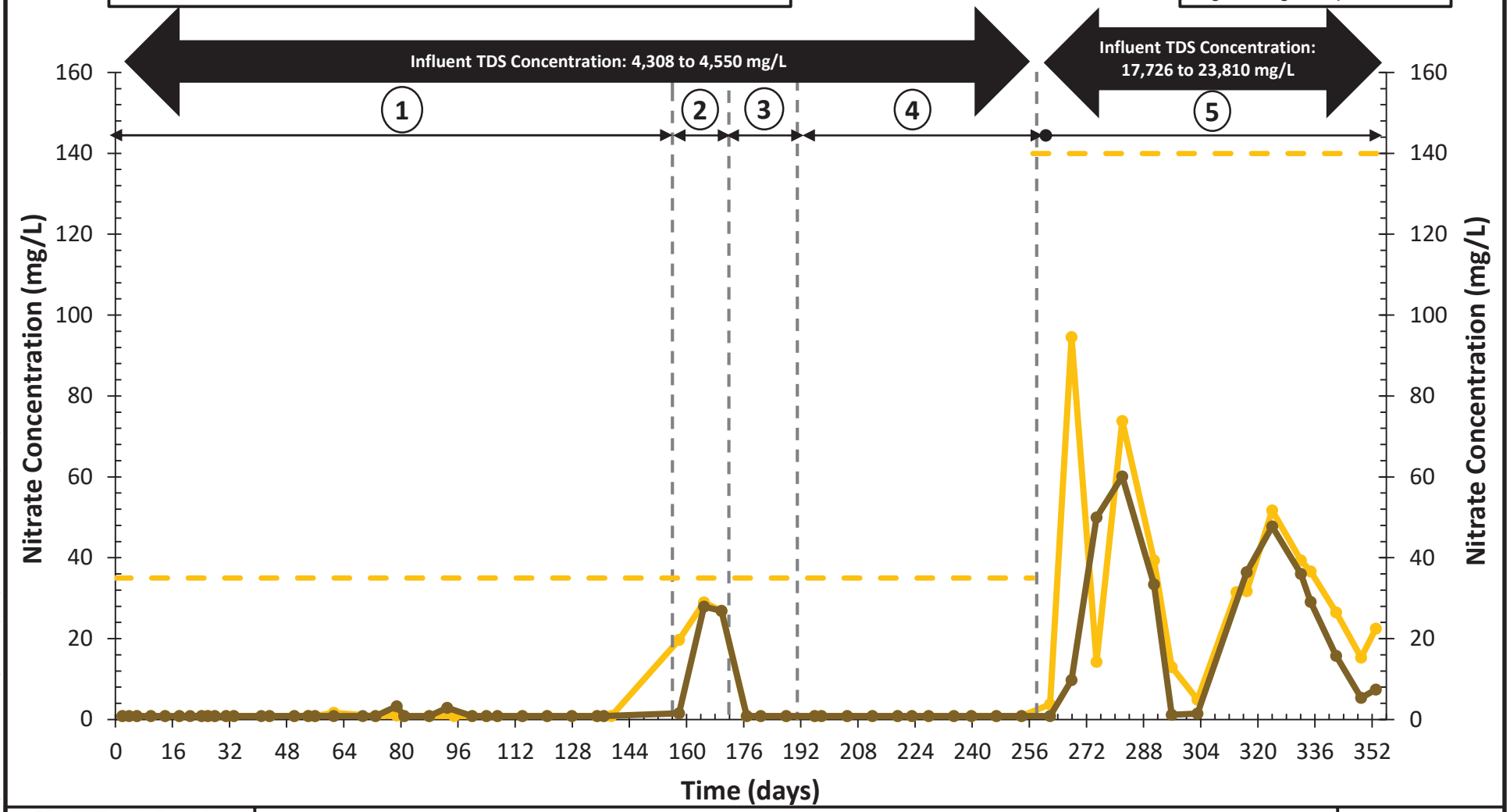
Figure No.
35

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients
5 Undiluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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NITRATE CONCENTRATIONS FOR DEEP COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
Date:	JULY 8, 2021
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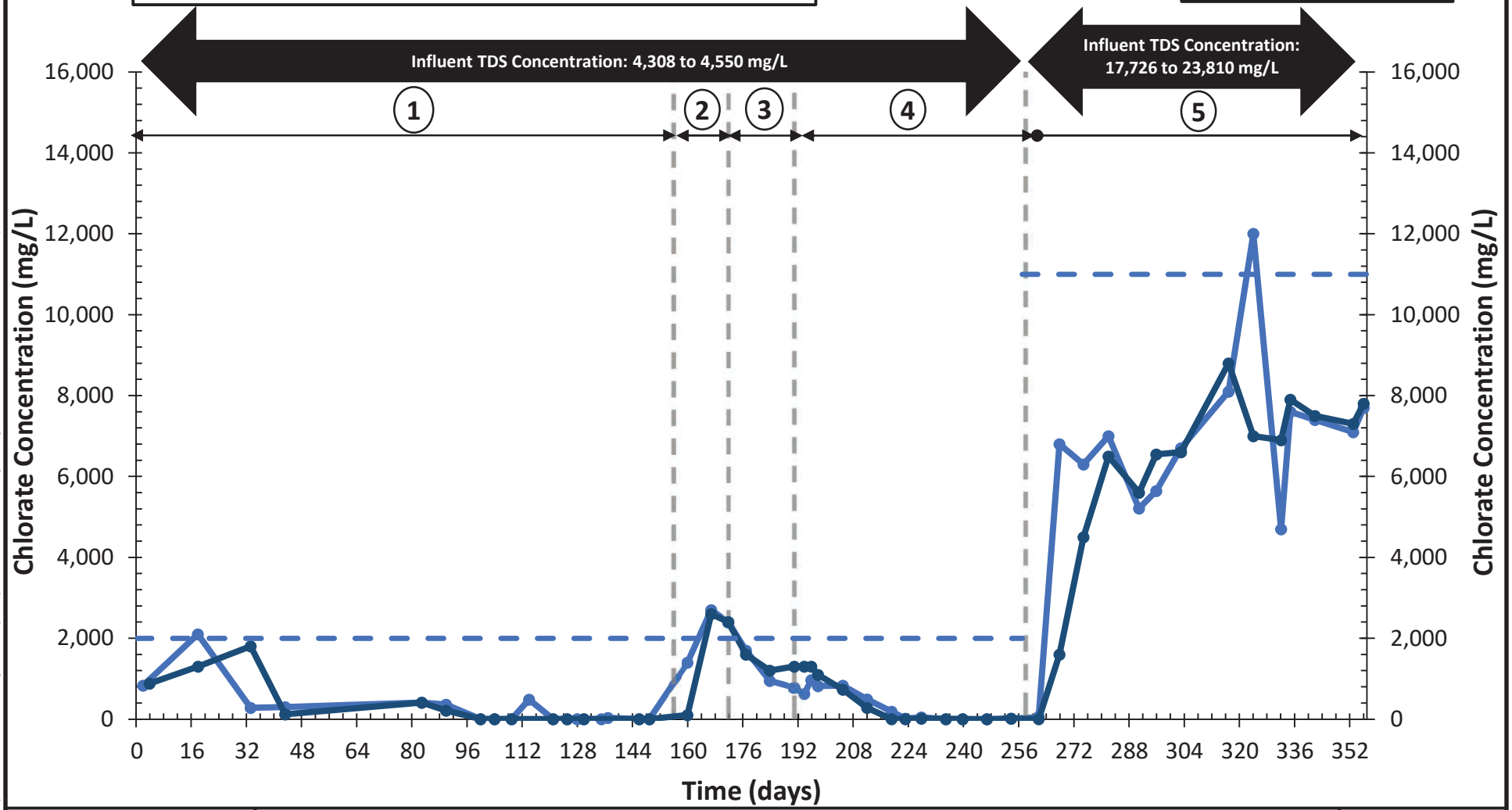
Figure No.
36

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients
5 Undiluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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CHLORATE CONCENTRATIONS FOR DEEP COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
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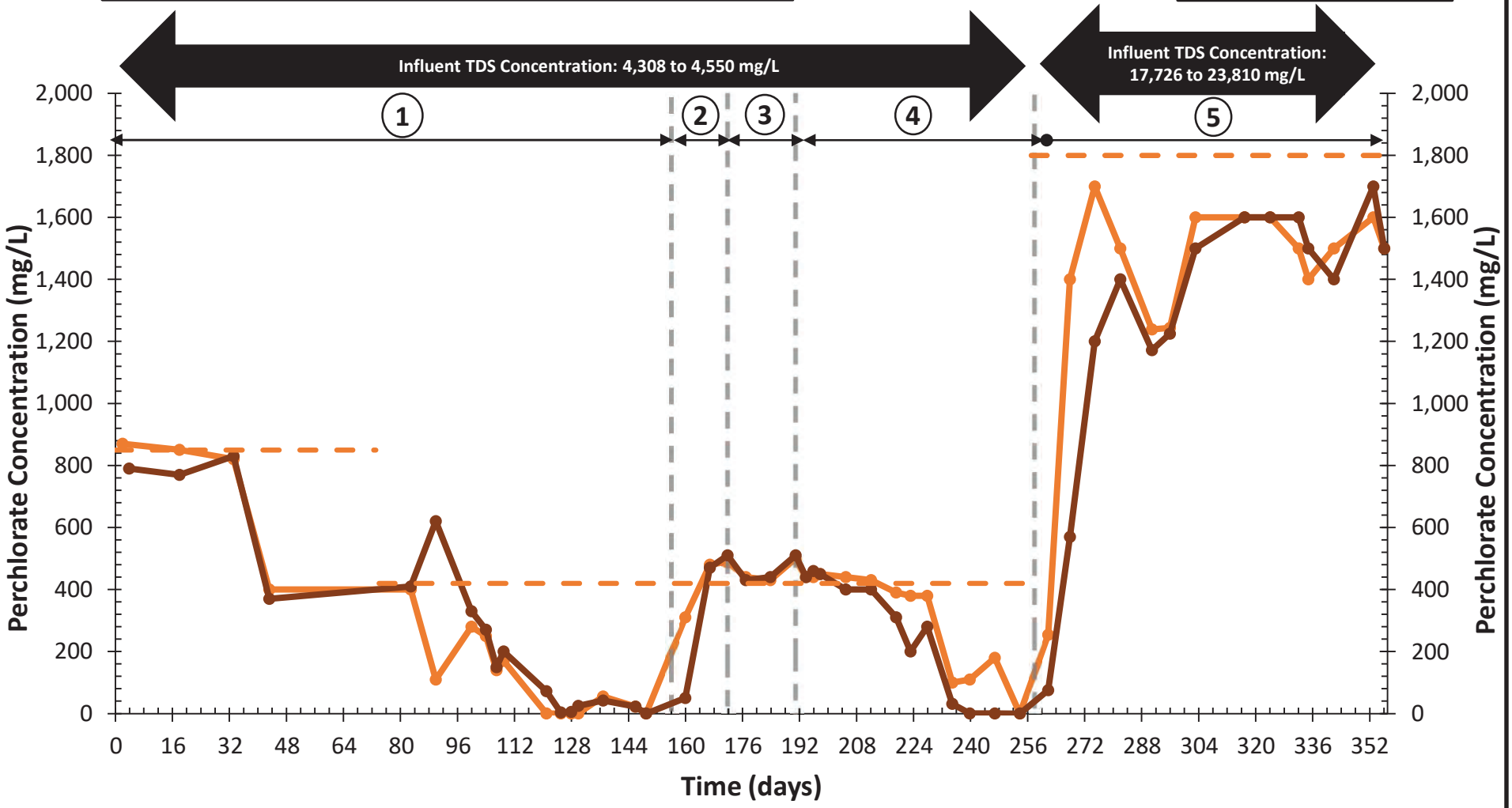
Figure No.
37

Simulation Period

1 Diluted Groundwater, Molasses, Nutrients, and Biosolids from FBRs
2 Diluted Groundwater and Nutrients
3 Diluted Groundwater, Reduced Molasses, and Nutrients
4 Diluted Groundwater, Molasses, and Nutrients
5 Undiluted Groundwater, Molasses, and Nutrients

Legend

Effluent Column A
Effluent Column B
Influent
TDS Total Dissolved Solids
mg/L milligrams per liter



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PERCHLORATE CONCENTRATIONS FOR DEEP COLUMNS (ALL SIMULATIONS)

Project No.:	117-7502019
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Figure No.
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M-12A
M-241
M-255
M-256
M-257
Unit 4 Chlorinator Building
80 ft
80 ft
U4-E-01D
M-252
U4-E-02D
U4-E-01I
M-251
U4-E-02I
U4-MW-02I
U4-MW-02D
AREA 1
U4-E-04D
U4-E-05D
U4-E-04I
U4-E-05I
M-250
M-249
M-191
M-192
M-253
M-254
AREA 2
80 ft
80 ft
Unit 4 Substation Building
M-189
M-247
M-248

Legend

- Existing Monitoring Well
- Pre-Design Monitoring Well (I - Intermediate; D - Deep)
- Pre-Design Injection/Extracton Well (I - Intermediate; D - Deep)
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.
3. Existing well location source: Unit 4 and 5 Buildings Investigation Source Area Characterization Report, Tetra Tech, 2020.

N

0 60 120
Feet

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 31 - TREATABILITY STUDY AREAS.dwg

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TREATABILITY STUDY AREAS

Project No.:	117-7502019
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Figure No.

39

Unit 4 Chlorinator Building

AREA 1

AREA 2

Unit 4 Substation Building

Legend

- Injection Location
- Extraction Location
- Particle Not Captured by Well
- Particle Captured by Well
- Water Elevation Contours (feet above mean sea level)
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.

N

0 20 40

Feet

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 32 - PLANNED INJECTION-EXTRACTION SCENARIO INTERMEDIATE ZONE.dwg

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PLANNED INJECTION AND EXTRACTION SCENARIO FOR THE INTERMEDIATE ZONE

Project No.:	117-7502019
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Figure No.

40

Unit 4 Chlorinator Building

AREA 1

AREA 2

Unit 4 Substation Building

Legend

- Injection Location
- Extraction Location
- Particle Not Captured by Well
- Particle Captured by Well
- Water Elevation Contours (feet above mean sea level)
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building

Notes:
1. All locations are approximate.
2. Imagery Source: Google Earth Pro, May 2019.

N

0 20 40

Feet

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 33 - PLANNED INJECTION-EXTRACTION SCENARIO DEEP ZONE.dwg

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PLANNED INJECTION AND EXTRACTION SCENARIO FOR THE DEEP ZONE

Project No.:	117-7502019
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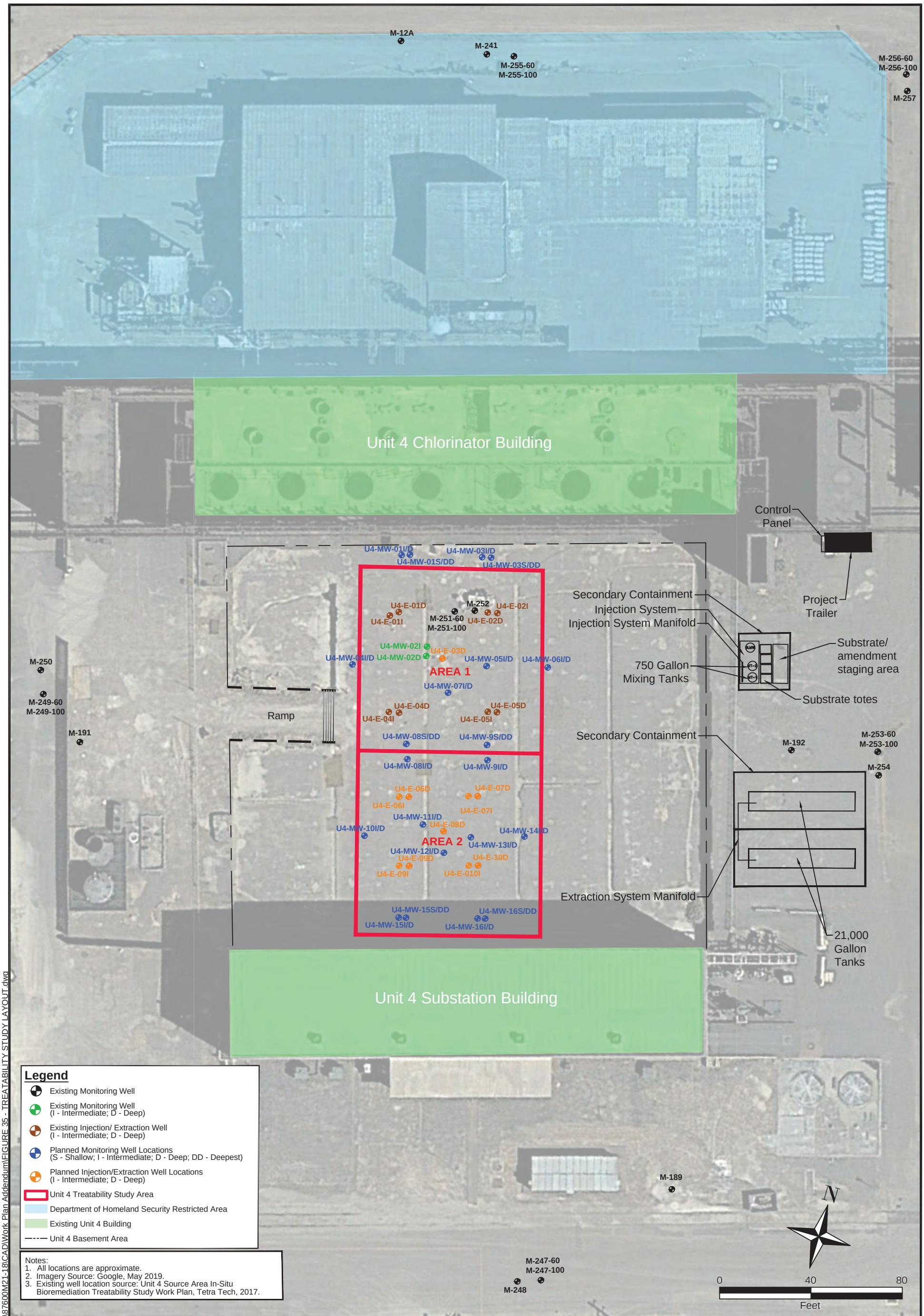
Figure No.

41



Legend

- Existing Monitoring Well
- Existing Monitoring Well (I - Intermediate; D - Deep)
- Existing Injection/ Extraction Well (I - Intermediate; D - Deep)
- Planned Monitoring Well Locations (S - Shallow; I - Intermediate; D - Deep; DD - Deepest)
- Planned Injection/Extraction Well Locations (I - Intermediate; D - Deep)
- Unit 4 Treatability Study Area
- Department of Homeland Security Restricted Area
- Existing Unit 4 Building
- Unit 4 Basement Area

Notes:
1. All locations are approximate.
2. Imagery Source: Google, May 2019.
3. Existing well location source: Unit 4 Source Area In-Situ Bioremediation Treatability Study Work Plan, Tetra Tech, 2017.

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TREATABILITY STUDY LAYOUT

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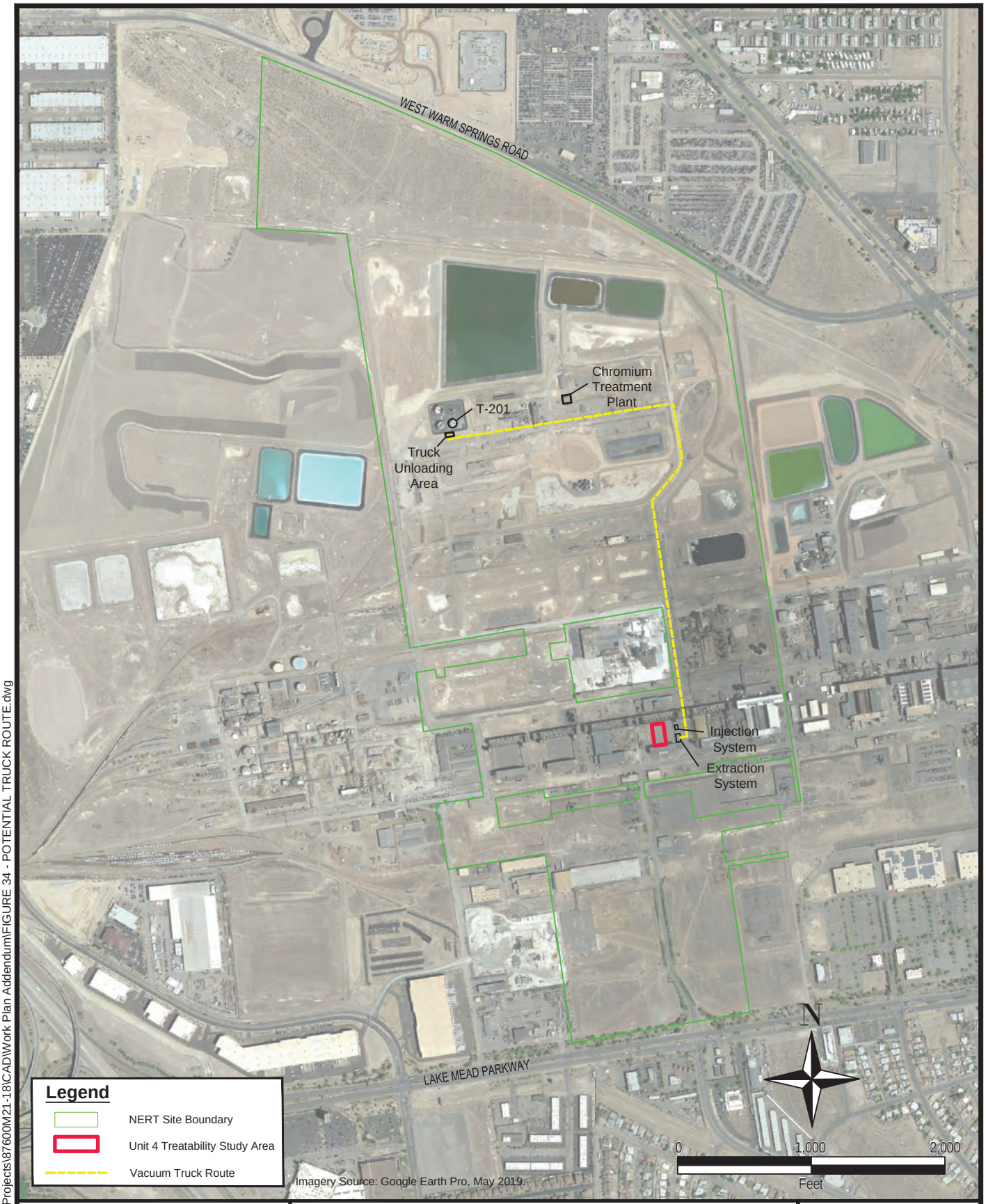
Figure No.

42

\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 35 - TREATABILITY STUDY LAYOUT.dwg



\\tts318fs3.tt.local\CES\Projects\87600M21-18\CAD\Work Plan Addendum\FIGURE 34 - POTENTIAL TRUCK ROUTE.dwg

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VACUUM TRUCK ROUTE

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Figure No.
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