Final Seep Well Field Area Bioremediation Treatability Study Work Plan

Nevada Environmental Response Trust Site
Henderson, NV

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ASTM	American Society for Testing and Materials
AWF	Athens Road Well Field
BAZE	Biologically Active Zone Enhancement
BL	baseline
COH	City of Henderson
DO	dissolved oxygen
EC	electrical conductivity
EOS®	emulsified oil substrate
FBR	Fluidized Bed Reactor
ft/day	feet per day
gpm	gallons per minute
GWETS	Groundwater Extraction and Treatment System
GWTP	Groundwater Treatment Plant
IWF	Interceptor Well Field
lbs/day	pounds per day
μg/L	micrograms per liter
mg/L	milligrams per liter
mV	milliVolts
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NERT or Trust	Nevada Environmental Response Trust
NMR	nuclear magnetic resonance
ORP	oxidation reduction potential
PLFA	phospholipid fatty acids
PVC	polyvinyl chloride
Site	Nevada Environmental Response Trust site
SWF	Seep Well Field
TDEM	Time Domain Electromagnetic
TDS	total dissolved solids
Tetra Tech	Tetra Tech, Inc.
TOC	total organic compound
UIC	Underground Injection Control

Acronyms/Abbreviations	Definition
UMCf	Upper Muddy Creek formation
UNLV	University of Nevada at Las Vegas
VFAs	volatile fatty acids
Work Plan	Bioremediation Treatability Study Work Plan

CERTIFICATION

I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been prepared in a manner consistent with the current standards of the profession, and to the best of my knowledge, comply with all applicable federal, state, and local statutes, regulations, and ordinances.

Description of Services Provided: Seep Well Field Area Bioremediation Treatability Study Work Plan, Nevada Environmental Response Trust Site, Henderson, Nevada

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09/06/2016

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

1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this Bioremediation Treatability Study Work Plan (Work Plan) for the Seep Well Field Area at the NERT site (Site), located in Clark County, Nevada (Figure 1). This Work Plan is being submitted to the Nevada Division of Environmental Protection (NDEP) under the Interim Consent Agreement effective February 14, 2011. The Work Plan presents the technical approach and scope of work for conducting bench and field tests for in-situ bioremediation of perchlorate in groundwater within the vicinity of monitoring well PC-94, located east of the Seep Well Field (SWF) and west of Aguila Road (Figure 1). Bench tests will be performed by the University of Nevada at Las Vegas (UNLV).

1.1 PROJECT OBJECTIVES

The overall objective of this treatability study is to demonstrate the effectiveness of using in-situ bioremediation to reduce the flux of perchlorate mass that is migrating off-Site and is not currently being captured by the existing extraction well network known as the SWF. Based on data from the second quarter of 2015, an estimated 3.5 pounds per day (lbs/day) of perchlorate is being discharged into the Las Vegas Wash from the NERT Downgradient Plume Area (Ramboll Environ, 2015a). The treatability study will build on the results of the on-going in-situ bioremediation treatability study being performed downgradient of the Athens Well Field (AWF) near the City of Henderson (COH) Bird Viewing Ponds. The on-going treatability study has demonstrated that sustained in-situ perchlorate biodegradation is achievable via the addition of a slow-release carbon substrate, namely, emulsified vegetable oil.

Groundwater is currently being extracted from three separate locations: the on-Site Interceptor Well Field (IWF), the off-Site AWF, and the off-Site SWF. Recovered groundwater is then treated in an aboveground treatment system located on-Site using fluidized bed bioreactors. If in-situ bioremediation can be demonstrated to be a successful treatment technology through this treatability study in the SWF Area, it has the potential to be a more efficient and cost-effective alternative to reduce the flux of perchlorate to the Las Vegas Wash, in comparison to expansion of the SWF. The proposed treatability study will evaluate the success of groundwater bioremediation approach in a slightly different geologic setting from the area where the treatability study was implemented.

1.2 WORK PLAN ORGANIZATION

This Work Plan is organized as follows:

- **Introduction (Section 1.0):** Provides the primary objectives of the bench and field test along with relevant background information, including regional geology and hydrogeology.
- **Technology Description (Section 2.0):** Provides an overview of bioremediation of perchlorate and provides a summary of the on-going in-situ bioremediation treatability study at the COH property.
- **Preliminary Field and Laboratory Activities (Section 3.0):** Provides a description of the field and laboratory activities to be completed prior to implementing the field test to optimize and finalize the field test design.
- **Field Test Conceptual Design (Section 4.0):** Describes the conceptual design of the field test including objectives, test location, conceptual layout, preliminary substrate injection design, permitting requirements, and health and safety.
- **Effectiveness Monitoring Plan (Section 5.0)**: Presents the conceptual effectiveness monitoring program for the field test, including the field, analytical, and microbial groundwater monitoring.
- **Reporting (Section 6.0):** Summarizes reporting related to design and execution of the preliminary field activities, bench tests, and field test.

- **Schedule (Section 7.0):** Summarizes the schedule for conducting the preliminary field activities, bench test, field test, and associated reporting.
- **References (Section 8.0):** Lists the documents referenced in this Work Plan.

1.3 BACKGROUND

1.3.1 General

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

1.3.2 Regional Geology

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

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

1.3.3 Local Geology and Hydrogeology

At and near the NERT Site, boring logs have encountered valley fill deposits including Quaternary alluvium, transitional Muddy Creek Formation, and the Pleistocene Upper Muddy Creek Formation (UMCf). The alluvium is generally described as reddish-brown discontinuous layers of sand and gravel with minor amounts of silt, clay, and caliche. The thickness of these alluvial deposits ranges from less than one foot to more than 50 feet beneath the Site (ENVIRON, 2014a). Thick deposits of alluvium that are structurally narrow and linear have been interpreted as stream-deposited sands and gravels that were deposited within paleochannels during flooding events. The paleochannel sand and gravel deposits often exhibit significantly greater permeability than the alluvium outside the paleochannels. At the base of the alluvium, the transitional Muddy Creek Formation is sometimes encountered. The transitional Muddy Creek Formation consists of reworked sediments derived from the Muddy Creek Formation. The UMCf underlies the transitional Muddy Creek Formation (if present) or alluvium, and consists of interbedded coarse-grained and fine-grained sediments that become progressively finer-grained to the north towards the central portion of the valley.

The UMCf subcrops beneath a thin veneer of Quaternary alluvium near the Site. In that area, the contact between the alluvium and the Muddy Creek Formation is typically marked by the appearance of a well-compacted, moderate brown silt-to-sandy silt or stiff clay to-sandy clay (ENVIRON, 2014a). However, in the vicinity of the Las Vegas Wash and the COH Bird Viewing Preserve (Bird Preserve), the contact is marked by light grey-green to yellow-green clays and silts.

Locally, the ground surface slopes north toward the Las Vegas Wash. Thus, surface water at the Site generally flows south to north toward the Las Vegas Wash. Surface water infiltrating into groundwater below the ponds of the Bird Preserve creates a groundwater high that diverts groundwater flowing north from the Site around the Bird Preserve. Subsurface paleochannels just south and east of the Bird Preserve also serve to direct impacted water from the Site toward the Las Vegas Wash. The on-going bioremediation treatability study targeted an area of paleochannel just south of the Bird Preserve. The current work plan will target an area just east of the same paleochannel, but further north near where the paleochannel intersects the sediments underlying the Las Vegas Wash.

The depth to water between PC-58 and PC-94 just south of the Las Vegas Wash tends to be less than 30 feet and averages around 15 feet, depending on the year. The horizontal groundwater gradient is approximately 0.01 feet/foot. The gradient between these two wells has remained relatively consistent over the past 10 years of monitoring. However, the actual groundwater elevation has decreased by about five feet since the nearby SWF began operating in 2001. The vertical gradient near the Las Vegas Wash is generally upward, with groundwater discharging into the wash and underlying alluvium (ENVIRON, 2014a).

1.3.4 Groundwater Extraction and Treatment System

Groundwater extraction has been implemented at the Site to address impacts to groundwater resulting from releases of perchlorate and hexavalent chromium, among other contaminants. Collectively, the entire system of extraction wells, water conveyances, and treatment plants is referred to as the Groundwater Extraction and Treatment System (GWETS).

The GWETS treats water from three groundwater extraction well fields: the IWF; AWF; and SWF (Figure 1). Pipelines and lift stations convey groundwater from the well fields to the Site to be treated by the on-site treatment plant. This treatment plant is comprised of the following components: the groundwater treatment plant to treat hexavalent chromium from the IWF; the Fluidized Bed Reactor (FBR) treatment plant to treat perchlorate in groundwater from all of the well fields; the GW-11 Pond, which is used for water storage and equalization; the Equalization Area, which includes equalization tanks and a granular activated carbon pretreatment system; and the effluent pump station and pipeline, which convey treated effluent from the FBR treatment plant to an outfall at the Las Vegas Wash (Tetra Tech, Inc., 2015a).

1.3.5 Seep Well Field

The SWF and the seep capture sump are located near the Las Vegas Wash, approximately 4,500 feet north of the AWF (Ramboll Environ, 2015a). Pumping operations at the SWF began in July 2002 and originally consisted of four extraction wells, (with two wells connected and operating as one), installed in the deepest part of the alluvial channel. In 2003/2004, six additional wells were installed. As a result, current operations consist of 10 extraction wells, with wells screened across the Quaternary Alluvium and across the deepest portion of an alluvial channel. Based on the 2015 Annual Remedial Performance Report, the combined discharge rate of the SWF averaged 536.0 gallons per minute (gpm) during the 2014-2015 reporting period, with average monthly extraction rates ranging from 517 gpm to 595.8 gpm (Ramboll Environ, 2015a).

The recent 2015 Annual Remedial Performance Report indicated that perchlorate plume configuration in the vicinity of the SWF has remained relatively stable over the past year and that perchlorate concentrations have significantly decreased since 2002. Perchlorate concentrations in the vicinity of the SWF ranged from 82 μg/L to 19,000 μg/L during the most recent sampling event reported in the 2015 Annual Remedial Performance Report. The most recent reported perchlorate concentration in monitoring well PC-94, which is located to the east of the SWF capture zone, was 23,000 μg/L in May-June 2015. Additionally, the 2015 Annual Remedial Performance Report estimated 3.5 pounds per day (lbs/day) of perchlorate is being discharged into the Las Vegas Wash from the NERT Downgradient Plume Area (Ramboll Environ, 2015a).

2.0 TECHNOLOGY DESCRIPTION

2.1 MICROBIOLOGY AND BIODEGRADATION OF PERCHLORATE

Perchlorate is the anionic component of ammonium perchlorate, a common solid rocket fuel booster. Perchlorate salts are very soluble in water, (approximately 200,000 milligrams per liter [mg/L] for ammonium perchlorate and approximately 2,100,000 mg/L for sodium perchlorate) and do not adsorb very strongly to most soils.

Perchlorate also tends to be biologically stable under aerobic conditions or when there is a limited source of organic carbon. However, in the presence of a carbon substrate and after dissolved oxygen (DO) and nitrate have been depleted, perchlorate can act as an electron acceptor for anaerobic respiration. The first step in perchlorate biodegradation is carried out by the enzyme perchlorate reductase, wherein perchlorate is sequentially converted to chlorate and then to chlorite. A second enzyme, chlorite dismutase further reduces the chlorite to chloride and oxygen (Interstate Technology & Regulatory Council [ITRC], 2008).

A variety of perchlorate-reducing bacteria have been isolated, with some of them being strict anaerobes, while others are facultative microbes. Generally, perchlorate-reducing microorganisms are known to be quite ubiquitous in the subsurface and are also quite versatile. As a result, the key to successful groundwater treatment is understanding the chemical, geochemical, physical, geological, and hydrogeological conditions at a site, and then devising a prudent approach to engineer a successful remedial strategy. Physical, geological, and hydrogeological conditions are commonly quite established and fixed, and therefore, a successful remedial strategy relies on the alteration and sustainment of the appropriate geochemical conditions for continual perchlorate biodegradation to occur. Favorable redox conditions that are appropriate for perchlorate biodegradation are less than 0 millivolts (mVs) and generally in the 0 to -100 mVs range. This range of redox is generally indicative of conditions wherein the aquifer is depleted of DO and nitrate itself gets consumed, leaving perchlorate the next preferred electron acceptor as the respiratory source for native microorganisms (ITRC, 2008).

2.2 PREVIOUS BIOREMEDIATION APPLICATION

An on-going groundwater bioremediation treatability study began in April 2015. The current study is being performed within the vicinity of the COH Water Treatment Facility, which is immediately upgradient of the Bird Viewing Preserve and mid-way between the AWF and SWF. The current field test is scheduled to be completed in August 2016. This section provides a brief summary of the on-going treatability study. Upon completion of all field work, a report will be written summarizing the laboratory bench-scale study, field carbon substrate injection design and details, and all the results and findings from the treatability study.

The main elements of the on-going treatability study are as follows:

- (i) Single borehole dilution and slug tests to determine site hydrogeologic characteristics of hydraulic permeability and groundwater velocity;
- (ii) Bench batch microcosm and column testing at UNLV;
- (iii) Installation of field test injection and monitoring wells;
- (iv) Two carbon substrate injection events; and
- (v) Periodic groundwater sampling, analyses, and evaluation of chemical, biochemical, and microbial parameters, which includes a baseline sampling event followed by weekly, biweekly, and monthly groundwater sampling events.

2.2.1 Summary of Treatability Study Activities

The single borehole dilution tests and slug tests performed in April 2015 resulted in a groundwater flow velocity estimate that ranged from 26 feet per day (ft/day) to 39 ft/day, with a geometric average at 32 ft/day. These velocities were higher than anticipated when compared to those used during work plan development, which assumed a maximum velocity of 15 ft/day (Tetra Tech, Inc., 2015b).

Soil and groundwater samples collected during the drilling of the borehole test well for hydrogeologic testing were transported to UNLV to perform soil physical testing and bench-scale batch and column bioremediation studies. These studies were performed between April 2015 and October 2015. Installation of injection and monitoring wells began in August 2015. Three injection wells were installed along a transect perpendicular to the groundwater flow. A suite of strategically located performance monitoring wells were also installed upgradient and downgradient of the injection wells. Following well completion and development, groundwater sampling was performed in all wells to establish baseline conditions before injections. Upon completion of the laboratory column testing and evaluation of results, designed quantities (based on overall stoichiometric demand and a factor of safety), of emulsified oil substrate (EOS®), followed by chase water obtained from a nearby COH hydrant, were injected into the groundwater during the first week of December 2015. Weekly groundwater sampling was performed thereafter for a one-month period, followed by bi-weekly sampling during the second month, and monthly sampling thereafter. After an evaluation of groundwater monitoring results from the first two months of the study, a second EOS® injection into the same injection wells was completed in early March 2016. One additional groundwater monitoring event will be completed in August 2016.

2.2.2 Bioremediation Treatability Study Results

The results of the bench batch microcosm tests indicated that the chosen carbon substrate, EOS®, a slow-release patented emulsified vegetable oil product, has the ability to create and sustain the reducing/anaerobic conditions in batch microcosms necessary to promote the biodegradations of both perchlorate and nitrate in groundwater. Results also indicated that native microorganisms have the ability to rapidly acclimate and biodegrade perchlorate in groundwater. Follow-up laboratory column testing simulated field flow-through conditions in the laboratory. Results indicated that biodegradation of perchlorate and nitrate could be sustained at the high groundwater flow velocities that are prevalent at the Site.

Groundwater sampling results from the field test and analyses that has been completed thus far have provided the following preliminary findings:

- An anaerobic zone which is basically devoid of DO, termed as a Biologically Active Zone Enhancement (BAZE), was created within two weeks following the first carbon substrate injection.
- Denitrification (biological consumption of nitrate) occurred within the first two weeks of the injection event, and perchlorate reduction via biodegradation was also observed within two weeks.
- Baseline DO concentrations were approximately 2.0 mg/L, but following substrate injection, reduced to below 0.2 mg/L in most wells, and these conditions have continued during the treatability study.
- Perchlorate concentrations also registered decreases of over 80 percent in several monitoring wells, and total organic carbon (TOC) increased from less than 5.0 mg/L in most wells to over 50 mg/L in several wells. One of the wells showed a decrease in perchlorate concentration from 25,000 micrograms per liter (μg/L) to less than the method detection level of 4.8 μg/L within four weeks.
- The influence of the BAZE was also observed in the farthest downgradient monitoring wells, which are located 250 feet from the injection well transect.
- Specialized microbial analyses of the perchlorate reductase gene, pcrA, (via the installation of Bio-Traps®) which is a strong indicator of the presence of perchlorate-reducing microorganisms, were as high as 6.41×10^5 cells per milliliter of groundwater.

Groundwater chemical, biochemical, and microbial data continue to be collected and analyzed in the treatability study field test area. However, the observations thus far have indicated that the injected carbon substrate, EOS®, has the strong ability to create, sustain, and rapidly carry out significant biodegradation of perchlorate in groundwater. Once all the data is collected and analyzed, a report will be written summarizing in detail the findings and applications of in-situ bioremediation of perchlorate in groundwater during the bench and field tests. Notable findings and inferences deciphered thus far, including the injection well set up, configuration, and spacing, optimal quantities of distribution or chase water during injections, and desired number of injection events will be incorporated into the current design and work plan for the proposed SWF treatability study.

3.0 PRELIMINARY FIELD AND LABORATORY ACTIVITIES

This section describes the various preliminary activities to be completed prior to the field test, including geophysical surveys, soil and groundwater sampling, single borehole dilution and slug tests, and laboratory bench tests. Results from these tasks will be used to finalize design details for field test implementation.

3.1 FIELD ACTIVITIES

All field work described herein will be conducted in general accordance with the existing Field Sampling Plan (ENVIRON, 2014b). Tetra Tech, on behalf of NERT, will prepare and submit all required applications and obtain required permits prior to the installation of any soil borings, injection wells, and monitoring wells. Once approval is granted, an underground utility survey will be performed before drilling commences. All wells will be drilled in accordance with the Nevada Division of Water Resources (NDWR) requirements, following submittal of a Notice of Intent to Drill.

3.1.1 Access Agreement

Due to the off-site location of the preliminary field activities and field test (described in Section 4.0), the Trust will acquire access and user agreements for all field activities and field test activities (including injections and monitoring) from the property owner, Basic Environmental Company, prior to installation.

3.1.2 Utility Clearance

Tetra Tech will review available utility maps and retain the services of a geophysical locator to check for underground utility lines prior to advancing the borings. Boring locations may be adjusted in the field to avoid existing utilities, structures, or other site features.

3.1.3 Geophysical Data Collection

Geophysical surveys will be performed as a cost-effective way to determine the optimum placement for the bioremediation field test. One of the lessons learned during the on-going COH treatability study (described in Section 2.2) was that improved definition of preferential flow pathways and paleochannel morphology was needed to better define original perchlorate mass and mass removal rates during bioremediation. Time domain electromagnetic (TDEM) soundings will be utilized to characterize the top of the UMCf and identify potential preferential flow pathways associated with paleochannels in the vicinity of monitoring well PC-94. The TDEM method has been used to successfully identify paleochannels in the UMCf at the Black Mountain Industrial Complex property southeast of the study area (GEOVision, 2003). Three lines of soundings, (one east-west and two northwest-southeast), will be performed in the vicinity of the proposed field test area, as presented in Figure 2. The results of the geophysical surveys will be used to select appropriate locations for boreholes and monitoring wells to further characterize the study area both lithologically and hydrogeologically.

3.1.4 Installation of Soil Borings and Monitoring Wells

3.1.4.1 Soil Borings

Based on the results of the geophysical data collection described in Section 3.1.3, soil borings and monitoring wells will be installed in strategic locations throughout the field test area to better characterize the study area and allow for selection of the best location for the bioremediation field test. As many as 20 soil borings may be installed throughout the field test area, although the locations and final quantity of soil borings and monitoring wells will be determined after the geophysical data collection has been completed. The purpose of the soil borings will be to obtain area-specific lithological information, physical parameters, and contaminant concentrations.

Additionally, during boring installation, soil will be collected and transported to the UNLV for use in the laboratory bench tests (described in Section 3.2).

Tetra Tech will retain a licensed drilling contractor to advance the soil borings using rotosonic drilling methods to allow for the collection of continuous soil cores for accurate lithologic logging and sampling. Before the drill rig mobilizes to each selected soil boring location, down-hole drilling equipment will be cleaned with a high-pressure, high-temperature water spray to avoid potential cross-contamination. Soil borings will be advanced through the alluvium to a depth that corresponds to the top of the UMCf to evaluate soil conditions within the alluvium and interface of the alluvium and UMCf. A select number of soil borings will also be advanced into the UMCf to evaluate soil conditions and perchlorate concentrations within the UMCf. The continuous soil cores will be logged by the on-site geologist from ground surface to total depth using the Unified Soil Classification System.

The drilling contractor will decontaminate soil collection equipment between samples. Soil samples for laboratory analysis will be collected in laboratory-supplied containers, labeled, placed in plastic bags, and stored in a cooler on ice for transport to the project analytical laboratory. Selected soil samples will be analyzed for soil grain size analysis. Upon reaching groundwater, a minimum of one undisturbed soil sample will be collected using a Shelby tube, or similar collection device, from each borehole, for physical parameter analysis including moisture content, porosity, and soil density. Soil samples will also be analyzed for a variety of chemical and biochemical parameters such as the ones listed in Table 1. A depth-discrete groundwater sample will be collected from select boreholes within the alluvium, just above the top of the UMCf, and within the UMCf to vertically profile the perchlorate extent.

Table 1 Example Soil Sampling Protocol

Parameter	Analytical Method	Purpose
Laboratory Parameters		
Perchlorate	E314.0	Estimate mass of perchlorate in saturated soil
TOC	SM5310B	Estimate available natural organic carbon
Soil pH	SW846 9045C	Assess geochemical conditions
Soluble Cations and Anions[1,2]	Notes 1 and 2	Asses salt loading
TDS[2]	SM2540C	Assess salt loading
Dissolved Metals[3]	SW 846 6010/6020	Assess potential secondary impacts of treatment
Hexavalent Chromium	SW 846 7199	Assess potential secondary impacts of treatment such as mobilization potential of chromium into the groundwater under reducing conditions
Total Kjeldahl Nitrogen	Modified EPA Method 351.2	Evaluate potential nutrient availability in soil
Total Phosphorus	EPA 6010B	Evaluate potential nutrient availability in soil
PLFA	Microbial Insights Method	Examine native/natural microbial characteristics
Perchlorate Reductase Gene	Microbial Insights Method	Examine native/natural microbial perchlorate degradation characteristics
Acronyms and Abbreviations:		

Parameter	Analytical Method	Purpose
PLFA: Phospholipid Fatty Acids TDS: Total dissolved solids TOC: Total organic carbon **Notes:** 1. Cations include sodium, potassium, calcium, and magnesium (Method SW6010). Anions include chloride, sulfate, nitrate (Method E300.0), carbonate, and bicarbonate (Method SM2320B). 2. Analysis to be performed on water extract prepared per method SW9056. 3. Metals include arsenic, chromium, iron, and manganese.		

3.1.4.2 Monitoring Wells

Monitoring wells will be installed to evaluate the before and after extent of perchlorate in the field test area and to monitor key parameters to help optimize the design and performance of the field test. As many as ten borings could be converted to permanent monitoring wells, some or all of which may be installed as paired wells with separate screened intervals in both the alluvium and UMCf. Decisions regarding which and how many borings to convert to monitoring wells and where paired wells will be installed will be based on geophysical survey data collected as described in Section 3.1.3 as well as review of the soil cores and lithology encountered during the soil boring field activities. Most wells will be constructed using 2-inch schedule 40 polyvinyl chloride (PVC) casing and screened with 2-inch diameter 0.020-inch slotted PVC well screen. Up to four wells will be installed with 4-inch diameter schedule 40 PVC casing and screened with 4-inch diameter slotted PVC well screen; these wells will be used for borehole dilution testing. The total depth and length of the well screens will be determined in the field based on the lithology and depth to groundwater. A washed #3/16 sand filter pack will be installed in the annular space around the well screens and extend up to two feet above the top of the screen intervals. The screen slot size and filter pack may be adjusted based on the lithology depth and results of depth-discrete sampling. The remainder of the annular space will be backfilled with two feet of hydrated bentonite, followed by neat cement grout. Wells will be completed with flush-mounted, tamper-resistant (locked), traffic-rated well boxes, at an elevation approximately one-half inch above grade.

Following the completion of well construction, but no sooner than 24 hours after well construction is compete, Tetra Tech will develop each of the newly installed wells. 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 to purge the well of fine-grained sediment. 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 (pH within 0.1 and other parameters within 10 percent) over three consecutive measurements. All index parameter readings will be recorded by Tetra Tech on well development logs.

Following well development, groundwater will be sampled and analyzed for a variety of field and laboratory parameters, described in more detail in Section 5.1, to establish baseline conditions of the soil and groundwater to be used in the laboratory bench studies. Collected groundwater will be transported to UNLV to be used in the bench studies described in Section 3.2.

Following installation of all groundwater monitoring wells, a land surveyor will survey the horizontal coordinates of each well relative to North American Datum 83 with an accuracy of 0.1 foot, and the elevation of the ground surface and top of well casing measuring point relative to North American Vertical Datum 88 with accuracies of 0.1 foot and 0.01 foot, respectively.

3.1.5 Single-borehole Dilution Test

A single-borehole dilution test will be performed in up to four of the newly installed wells to evaluate volumetric flow in the alluvium and UMCf within the field test area. Single-borehole dilution tests consist of mixing a tracer compound into the groundwater in a well, and then observing the decline in tracer concentration in the well as a function of time using downhole instruments (e.g., Pitrak et al., 2007). The decline in tracer concentration in the well is due to dilution by volumetric groundwater flow, and the results will be used to estimate groundwater velocity in the immediate vicinity of the well.

Tracers used in single-borehole dilution tests are typically chloride or bromide salts, or fluorescent dyes. During the current bioremediation treatability study's preliminary testing activities at the COH property, distilled water was successfully used as the tracer in well BHW-1. Based on the proximity of the test area to the Las Vegas Wash, the use of fluorescent dye tracers is not recommended. Furthermore, water quality results summarized in a previous Work Plan (ENVIRON, 2014a) indicate that groundwater near the proposed field test location has a specific conductance of 12,300 to 13,500 microsiemens per centimeter, suggesting that analytical interferences may be a problem if salt tracers are used in conjunction with conventional ion-specific electrodes for concentration measurement. However, the high specific conductance would support the potential use of distilled water as a tracer. Water samples collected after well installation will therefore be analyzed for major cations and anions to confirm the suitability of distilled water as a tracer prior to use. If the specific conductance is low enough that distilled water would not serve as an appropriate tracer, other appropriate tracers will be evaluated.

Results of the single-borehole dilution tests will be used to determine appropriate flow rates to be used in the field test design. All results will be provided in a final report which is further described in Section 6.0.

3.1.6 Slug Tests

Slug tests will be performed in select newly installed wells and existing well PC-94 to estimate location-specific aquifer hydraulic conductivity within the field test area and to confirm the results of the borehole dilution tests described in Section 3.1.5. The slug tests will be performed in general accordance with American Society for Testing and Materials (ASTM) Standard D4044-96 (ASTM International, 2008). Prior to conducting each slug test, the water level in the well will be measured manually with an electronic water level probe to determine the static groundwater level. An electronic pressure transducer/data logger will then be suspended in the well, and water levels will be monitored manually until static conditions are reestablished. A falling-head test will then be conducted by smoothly lowering a length of weighted and sealed PVC pipe (slug) into the well, securing it in place above the transducer, and recording the rate of water level decline. Once static conditions are reestablished, a rising-head test will be conducted by removing the slug and allowing the water level to again recover to static conditions while recording the rate of recovery. Barometric pressure changes during testing will be monitored and recorded using a pressure transducer placed above the water table.

At the end of each test, the pressure transducer will be removed from the well, and the water level displacement data will be downloaded to a laptop computer and corrected for barometric pressure effects. The corrected data will be interpreted using AQTESOLV for Windows (Duffield, 2014), or similar aquifer test analysis software. If possible, both the falling-head and rising-head data will be analyzed to cross-check the interpretation results.

3.1.7 Nuclear Magnetic Resonance Logging

Nuclear magnetic resonance (NMR) logging will be performed on the newly installed wells. This technology can be used in open or PVC-cased wells to provide high-resolution downhole estimates of hydraulic conductivity, total water content, and relative pore-size distributions below the water table (Walsh et al, 2013). Above the water table, NMR provides volumetric water content measurements. The specific tool used will depend on the diameter of the well, because larger diameter wells require a larger tool that has a larger radius of investigation. All tools are expected to provide a measurement approximately every 1.5 feet of depth. The high-resolution estimates of hydraulic conductivity will be compared to the lithologic logs and aquifer testing results for each well to assess the possibility of vertical preferential flow.

3.1.8 Management of Investigation-Derived Wastes

Investigation-derived waste generated during the soil and groundwater investigation will be managed according to applicable state, federal, and local regulations and as described in Field Guidance Document No.001, Managing Investigation-Derived Waste (ENVIRON, 2014b).

The investigation-derived waste that will be generated during the environmental investigation includes soil cuttings, personal protective equipment, equipment decontamination water, and groundwater generated during depth-discrete groundwater sampling and well development. Investigation-derived soil waste will be accumulated in plastic-lined roll-off bins. Solids will be characterized by collecting representative samples, as necessary, to determine disposal options. Depending upon the size of the container and quantity of material, one sample may be sufficient for characterization, or several samples may be composited in the field. Generally, a minimum of one sample will be collected for each 10 cubic yards of solid waste or each roll-off bin. Waste sample analysis will be determined by the receiving waste facility’s analysis requirements. Waste water generated during purging or decontamination activities will be temporarily stored in 55-gallon drums and transferred into the GW-11 Pond. Drums, bins, and tanks will be labeled with “pending analysis” labels, the date accumulation began, contents, source, and contact information, and stored in a designated area. Management of IDW will comply the requirements of the access agreement.

3.2 BENCH-SCALE SOIL AND GROUNDWATER STUDIES

Previous bioremediation bench-scale batch and microcosm studies performed at UNLV between April 2015 and October 2015 have already proven that perchlorate present in site groundwater will biodegrade via the action of native microorganisms and in the presence of the slow release carbon substrate, EOS®. The column tests demonstrated that perchlorate biodegradation can occur on a continual basis under the high groundwater flow rates that were estimated during the field study. For this proposed field test, additional targeted laboratory bench-scale studies with stated objectives and select analyses that will aid in its successful implementation will be performed at UNLV as described below:

(i) **Soil physical characterization analysis** – This includes grain size analysis, soil density, porosity, and moisture content and chemical/biochemical tests (listed in Table 1) from soil that is collected in conjunction with the soil boring tests described in Section 3.1.4. These tests will be used to understand soil type, screening and characterization of the fines, and chemical make-up in advance of the field test.

(ii) **EOS® adsorption and desorption tests on soil from the field test location –** Effective and optimal application of EOS® and its longevity requires an understanding of the interactions of the various soil types and the EOS®. The amount of EOS® that adsorbs and the nature of the desorption pattern is dependent on soil characteristics such as particle size, type of minerals present in the soil, soil pH, and soil structure. These tests will evaluate the adsorption of EOS® to the soil as a whole and to determine the adsorption of emulsified oil to the various independent soil fractions and fines determined from (i) above. Columns of different heights will be set up to establish oil movement and amount of EOS® that is desorbed over time to support biodegradation. As part of this testing, oil retention capacity tests will also be performed.

(iii) **Short-term batch microcosm perchlorate biodegradation tests** – Tests will be performed using groundwater from the field test location, hydrant water, effluent water from the COH Water Treatment Plant, and effluent water from the on-site GWETS. These tests will follow protocol similar to that established for the previous UNLV bench-scale testing (Tetra Tech, 2015b). Batch tests will reconfirm the application of EOS® to the soil and groundwater that will be encountered in the SWF vicinity and provide an estimate of the acclimation, lag time, and perchlorate biodegradation rates. The field test will require a source of water for distribution of the injected EOS®. While hydrant water is planned for the field test, the GWETS effluent, or effluent water from the COH Water Treatment Plant are available sources of water for future use. Because the GWETS water is known to be higher in TDS (> 5,000 mg/L), verification of biodegradation under these TDS conditions in the laboratory will be performed in batch microcosms.

4.0 FIELD TEST CONCEPTUAL DESIGN

This section describes the conceptual design for the field test, which includes specific objectives, field test location details, conceptual well layout, preliminary substrate design, permitting requirements, and health and safety requirements. The field test design, as well as the effectiveness monitoring program (described in Section 5), may be modified or refined based on the results of additional data collection described in Section 3.0.

4.1 OBJECTIVES

The objectives of the field test are to accomplish the following:

- Evaluate the feasibility of in-situ bioremediation to remediate perchlorate-contaminated groundwater in the vicinity of the PC-94, located east of the SWF;
- Estimate the lateral influence achieved in the subsurface during the field test;
- Estimate or extrapolate the longevity of the carbon substrate and the frequency of carbon substrate replenishment required to prevent perchlorate breakthrough immediately downgradient of the injection transect via the extensive collection of chemical and biochemical data listed in Table 2; and
- Examine the approach and feasibility for full-scale transect treatment including equipment, injection, and monitoring well layout; substrate addition and replenishment; and analytical sampling evaluation criteria.

4.2 FIELD TEST LOCATION

As shown in Figure 2, the proposed area for the field test is the area surrounding PC-94, which is approximately 500 feet east of the nearest extraction well (PC-133) associated with the SWF. This area was selected due to the elevated perchlorate concentrations of 23,000 μg/L in the May/June 2015 groundwater sampling event.

4.3 CONCEPTUAL LAYOUT

This section describes the details of the injection wells and surrounding monitoring wells that will be installed to evaluate the effectiveness of the in-situ bioremediation field test. The conceptual layout of the injection and monitoring well locations are provided in Figure 2.

Tetra Tech, on behalf of NERT, will prepare and submit all required applications for permitting and will work with the Trust attorneys to secure site access prior to the installation of any injection or monitoring well. Once approval is granted, an underground utility survey will be performed before drilling commences. All wells will be drilled in accordance with the NDWR requirements. Drilling, well installation, and well development procedures are provided in the *Field Sampling Plan, Revision 1* (ENVIRON, 2014b).

4.3.1 Injection Well Layout

Although the final quantity and location of the injection wells will be determined after completion of the preliminary field activities described in Section 3.0, it is anticipated that the injection wells will be installed within two transects located perpendicular to groundwater flow to intersect perchlorate-contaminated groundwater migrating towards the Las Vegas Wash. Preliminary analyses of the geochemical response and data collected at the on-going COH treatability study area have indicated that there is considerable heterogeneity in the lithology within relatively short distances. The soil grain type and thickness of the gravel and paleochannels vary in all three dimensions in the saturated sub-surface. Therefore, flow pathways and, thereby, the transport of organic carbon during injections appears to be non-uniform. To counter the impacts of heterogeneity and non-uniform flow, a prudent design approach is to install two transects of injection wells, rather than a single transect. The injection wells will also be staggered on these two transects in order to provide overlap and better distribution of the injected carbon substrate. Therefore, two transects would be placed upgradient of PC-94 and will consist of two separate rows of injection wells that are off-set to maximize subsurface distribution and overlap of the injection wells' lateral influence to curtail the potential for perchlorate breakthrough. The proposed transect layout should be sufficient to take into account subsurface variability as well as general effectiveness of bioremediation at remediating perchlorate-contaminated groundwater. The transects extend as far to the east as possible given access restrictions and as far to the west as possible without threatening to impact the operation of the SWF extraction well PC-133 and the other SWF extraction wells located further west.

The radius of influence of injection wells in most subsurfaces with coarser, gravely soil generally range from 30 feet to over 60 feet (AFCEE, 2004). For this treatability study, it is anticipated that injection wells will be spaced approximately 75 feet apart, with the injection rows spaced approximately 150 feet apart, for a total of up to 25 injection wells. Because the wells along the two transects will be staggered, the effective spacing of wells is 37.5 feet. This proposed and planned spacing is closer than the 60 feet spacing between injection wells that was implemented for the on-going treatability study, which will further address subsurface variability and non-uniform groundwater flow and lithology by improving contact of carbon substrate with perchlorate in the saturated matrix. Based on the known SWF area hydrogeological characteristics, higher permeability in the alluvium, and observations from the on-going treatability study, it is estimated that this spacing is sufficient to create lateral influence with a degree of overlap and factor of safety for carbon distribution in groundwater. The exact number and spacing of the injection wells, number of transects, and transect layout will be finalized based on the results of the preliminary field activities described in Section 3.0.

Injection wells will be constructed of 2-inch schedule 40 PVC casing and screened with 2-inch diameter 0.020-inch slotted PVC well screen and #3/16 filter pack, as discussed in Section 3.1.4.2. The slot size and filter pack may be adjusted based on the results of the soil physical parameter analyses. The depth of the well and length of well screen will be determined in the field based on lithology and depth to groundwater. Dual-nested or paired wells may be used to separate screened intervals within the alluvium to maximize subsurface distribution during substrate injections. Wells will be completed with flush-mounted, tamper-resistant (locked), traffic-rated well boxes, at an elevation approximately one-half inch above grade. As discussed in Section 3.1.4.2, following the completion of well construction, but no sooner than 24 hours after well construction is compete, Tetra Tech will develop each of the newly installed wells.

4.3.2 Performance Monitoring Wells

A monitoring well network, consisting of both upgradient and downgradient monitoring wells will be required to evaluate field test effectiveness. Upgradient monitoring wells will be used to determine the perchlorate concentrations in groundwater that are migrating into the injection well transect(s). Downgradient monitoring wells will be installed at strategic locations downgradient of the injection well transects to monitor for treatment effectiveness. In addition to the wells mentioned in Section 3.1.4.2, up to 15 additional monitoring wells may be installed at locations directly in-line and offset from the injection wells at varying distances upgradient and downgradient of the transects as shown in Figure 2. The exact number and location of performance monitoring wells may be modified based on the results of the slug tests and the single borehole test, estimations of groundwater velocity, and other geological characteristics in the area.

Monitoring wells will be constructed of 2-inch schedule 40 PVC casing and screened with 2-inch diameter 0.020-inch slotted PVC well screen and #3/16 filter pack, as discussed in Section 3.1.4.2. The slot size and filter pack may be adjusted based on the results of the soil physical parameter analyses. The depth of the well and length of well screen will be determined in the field based on lithology and depth to groundwater. Dual-nested or paired monitoring wells may be used to separate screened intervals, if conditions warrant. Wells will be completed with flush-mounted, tamper-resistant (locked), traffic-rated well boxes, at an elevation approximately one-half inch above grade. As discussed in Section 3.1.4.2, following the completion of well construction, but no sooner than 24 hours after well construction is compete, Tetra Tech will develop each of the newly installed wells.

4.4 PRELIMINARY INJECTION DESIGN

Results of the on-going treatability study and analyses performed thus far have provided preliminary findings on the longevity of each carbon substrate injection event, lateral and downgradient coverage or influence of the injections, and impact of the chase water distribution. As these results continue to be evaluated and finalized, the findings will be utilized for the final design of the proposed treatability study. Preliminary evaluation and findings of the on-going COH treatability study (described in Section 2.0) have indicated that the stoichiometric estimates (with a factor of safety of five) for the first carbon injection event was sufficient for a period between two and three months. The on-going study had a second injection event, in which half the quantity of carbon substrate was added to the groundwater in comparison to the first event. The reason for adding only half the quantity was to examine the lower threshold of the substrate that would be required for bioremediation. Secondly, the UNLV bench-scale column study indicated that aquifer clogging could be an issue if excess carbon substrate was added. The second carbon substrate addition appeared to be sufficient for less than two months, despite the observation that perchlorate continued to degrade and very little DO was present. Based on this current evaluation of the on-going COH treatability study, it appears that to ensure continuous availability of organic carbon and perchlorate biodegradation in the groundwater in this high velocity aquifer, injection events could possibly be required every two months for future efforts. Furthermore, for subsequent events following the first event, it is proposed that three-quarters of the original quantity, rather than half the original quantity would provide a sufficient factor of safety for continuous and sustained biodegradation of perchlorate. Therefore, based on the results of the previous laboratory bench-scale tests performed at the UNLV and on-going COH treatability study, up to three separate injection events may be required during the proposed six-month field test.

Additional factors that will be considered when determining the quantity of carbon substrate that will be injected into the subsurface for this treatability study include the proposed field activities outlined in Section 3.1 (including the slug tests and the borehole dilution tests), laboratory bench-scale studies outlined in Section 3.2, the known chemistry and geochemistry of the groundwater, stoichiometric requirements for the EOS® (based on the mass of perchlorate and other electron acceptors that will migrate through the transects in the field test timeframe), and EOS® Remediation vendor design tools.

Prior to actual carbon substrate injections, slug tests will also be performed on a select number of the injection wells and downgradient monitoring wells to determine pre-injection hydraulic conditions. Step-rate injection tests will also be performed prior to carbon substrate injections to establish well injection rates and pressures in the injection wells. Slug tests will continue to be performed periodically throughout the treatability study as they have been shown to provide valuable information on subsurface conductivity changes following carbon substrate injections in the on-going COH treatability study described in Section 2.2.

The EOS® will be pressure injected into injection wells using a mobile injection system consisting of a tanker or trailer unit with a manifold piping system and hoses supplied with valves and regulators for control and monitoring rates of injection. Prior to each injection, the injection solution will be prepared in a truck-mounted batch tank. Water for dilution of the EOS® product (generally diluted at a ratio of 1:4 parts of EOS®: water for sandy/gravelly soils) will likely be obtained from a hydrant source and transported to the field test area via water tanker truck, which will transfer the water into frac tanks used for water storage for the duration of the field test. The injection solution will be prepared by thoroughly mixing the carbon substrate, additional amendments such as micronutrients, and water using the electric mixer in the trailer-mounted mixing tank. The injection solution will then be pressure-injected into the injection wells through a manifold with hoses equipped with quick disconnect fittings. Pressure gauges and a flow totalizer will be used to monitor the pressure and flow rates during injection at each injection well. A designated quantity of chase or distribution water (determined based on results from the preliminary field activities described in Section 3) will be injected into each well following EOS® injection to obtain even distribution of the carbon substrate within the transects. Based on a preliminary review of the impact of chase water during the two injection events in the on-going COH treatability study, it is believed that larger amounts of chase water would be required to obtain enhanced distribution of the carbon substrate in vicinity of the injection wells. It appears that up to two-thirds of a single pore volume of chase water could be required for each well. Preliminary findings also indicate that alternating the chase water between wells or injecting into alternatively spaced wells provides better distribution of carbon substrate that was injected. These findings will be incorporated into the final chase water protocol for the SWF area treatability study.

4.5 ECOLOGICAL REVIEW AND PROTECTION MEASURES

Tetra Tech reviewed 2015 National Agriculture Imagery Program (NAIP) aerial photographs to assess current habitat conditions. Habitat at the field test location is currently disturbed due to previous activities. The ground surface around PC-94 has been graded and is devoid of vegetation. Patchy desert shrub communities are present to the east of the project. Other suitable wildlife habitat near PC-94 is located approximately 0.2 mile (1,056 feet) to the north along the Las Vegas Wash and 0.7 mile (3,696 feet) to the southwest at the Henderson Bird Viewing Preserve. Water and riparian vegetation in these areas attract a diversity of wildlife, particularly birds (SNWA-LVWPCT, 2008). Riparian habitat along the Las Vegas Wash is in various stages of restoration, involving removal of non-native vegetation (e.g. tamarisk), planting of native seedlings, and installation of weirs (SNWA-LVWPCT, 2008). Habitat north of the Las Vegas Wash is desert scrub.

Implementation of the field test would not result in direct impacts to wildlife or suitable habitat. The area is disturbed and is not expected to support wildlife or native vegetation. A larger area around PC-94 was considered for potential indirect impacts to wildlife from noise and human activity. Specifically, species protected under the Migratory Bird Treaty Act and listed under the Endangered Species Act were evaluated because they are protected on both public and private land. Migratory birds are considered within a 300-foot buffer of the project. Threatened and endangered species are considered within 0.5 mile of the project. It is unlikely migratory birds would occur within 300 feet of the field test area as habitat for foraging and nesting does not occur. Therefore, no nest clearance survey would be required prior to implementing the work. Impacts to migratory birds are not expected.

There is no designated critical habitat for threatened or endangered species within 0.5 mile of the project (USFWS, 2016). However, threatened and endangered species have occasionally been documented along the Las Vegas Wash, including Yuma clapper rail (*Rallus longirostris yumanensis*), southwest willow flycatcher (*Empidonax traillii extimus*), and yellow-billed cuckoo (*Coccyzus americanus*) (last recorded in 1998) (SNWA-LVWPCT, 2008). However, no nesting by these species has been documented and the project would not directly impact riparian vegetation along the Las Vegas Wash; therefore, no protection measures are expected to be required for these species. Desert tortoise (*Gopherus agassizii*) has also been recorded on the north side of the Las Vegas Wash. Because there is potential for desert tortoise to occur in the project area, protection measures may be implemented (SNWA-LVWPCT, 2008), if warranted. Potential protection measures are provided in Appendix A.

4.6 PERMITTING REQUIREMENTS

4.6.1 NDEP – Underground Injection Control Program

The field test will require an underground injection control (UIC) permit for the injection of the carbon substrate and amendments into the saturated subsurface. Specifically, for short term field tests (less than six months), a Class V General Short-Term Remediation UIC permit is typically required. The UIC short-term general permit falls under NAC 445A.891 and is valid for a period of six months. The permit application requires completion of UIC Form U200 – Permit Application and UIC Form U210 – Notice of Intent. The NDEP states that UIC permits will be generally issued within 30 days of receipt of a complete application.

Assuming injections may continue after the six-month timeframe due to the success of the field test, an application for a UIC General Permit for Long-Term Remediation may be prepared prior to expiration of the short-term permit. Alternatively, based on the on-going discussions with NDEP, a long-term application could be obtained at the beginning of the treatability study itself and suitable modifications can be instituted after the six-month testing period, as deemed necessary. As with the short-term permit application, the General Permit for Long-Term Remediation also requires completion of UIC Form U200 - Permit Application and UIC Form U210 – Notice of Intent, as well as periodic injection/monitoring reports.

4.6.2 Nevada Division of Water Resources

The field test will also require a NAC 534.441 Monitor Well Drilling Waiver and a NAC 534.320 Notice of Intent Card prior to installation of injection wells and monitoring wells. The Monitoring Well Drilling Waiver also requires a completed, signed, and notarized Affidavit of Intent to Abandon a Well as an attachment. As required, the injection and monitoring wells will be drilled by a licensed well driller pursuant to Nevada Revised Statutes 534.160 and will be constructed pursuant to NAC Chapter 534 – Underground Water and Wells. All injection and monitoring wells associated with this treatability study will be abandoned 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 upon completion of the treatability study.

4.6.3 Ecological Permits

No ecological permits are required for work associated with the field test activities. However, the U.S. Fish and Wildlife Service will be contacted to obtain concurrence with Tetra Tech's effects determinations for migratory birds and threatened and endangered species, as well as the proposed desert tortoise protection measures, if warranted, which are provided in Appendix A.

4.7 HEALTH AND SAFETY

Fieldwork will be conducted in accordance with an Activity Hazard Analysis and other elements of the Site-wide Health and Safety Plan (Tetra Tech, Inc., 2015c), which addresses potential chemical and physical hazards associated with the field test. It is anticipated that modified Level D personal protective equipment will be required for all field activities.

5.0 EFFECTIVENESS MONITORING PLAN

This section describes the conceptual groundwater monitoring program to determine treatment effectiveness.

5.1 GROUNDWATER SAMPLING PROCEDURES

General groundwater sampling activities will follow the guidance of the Field Sampling and Analysis Plan (ENVIRON, 2014b). Prior to groundwater sample collection, groundwater levels will be gauged in all wells to be used in potentiometric contouring. Groundwater samples will be collected using low-flow purging and sampling techniques. During low-flow purging of the wells, a pump capable of purging between approximately 0.1 to 0.13 gpm will be used to minimize drawdown and induce inflow of fresh groundwater. The pump discharge water will be passed through a flow-through cell field water analyzer for continuous monitoring of field parameters (temperature, pH, turbidity, electrical conductivity, dissolved oxygen, and oxidation reduction potential). Field parameters will be monitored and recorded on field sampling forms during purging. The wells will be sampled when purging is complete, which is when the field parameter readings and water levels have stabilized

5.1.1 Performance Monitoring

Groundwater samples will be collected from all injection and monitoring wells in the vicinity of the field test area to establish baseline conditions prior to the injections. After injections have occurred, groundwater samples will be periodically collected from both upgradient and downgradient monitoring wells. A variety of field, laboratory, and microbial parameters that may be evaluated during the study are listed in Table 2, which presents the parameters, associated methods, purpose, and potential sampling frequency. Effectiveness monitoring wells will include newly installed monitoring wells as well as existing monitoring wells COH-1A, PC-91, PC-92, PC-94, PC-97, and/or PC-133, as access to wells is permitted. Additionally, some or all of the monitoring wells installed during the preliminary field investigation may be sampled during the treatability study to assist in determining remedial effectiveness. The actual frequency of sampling, selected wells, and specific parameters to be sampled during each individual event will be determined during the study and based on the results from prior events. In addition, slug tests will be repeated periodically during the field test to examine any changes in hydraulic conductivity as a result of carbon injections and geochemical processes. Specialized microbial analyses, namely, PLFA analyses and the presence of the perchlorate reductase gene will be determined via the employment of Bio-Traps® in select wells during the study.

Table 2 Example Performance Monitoring Sampling Protocol

Parameter	Analytical Method	Purpose	Potential Frequency
Field Parameters			
EC	Field Meter	Assess geochemical conditions	Baseline, Weekly, Biweekly, Monthly
pH	Field Meter		
DO	Field Meter		
ORP	Field Meter		
Temperature	Field Meter		
Turbidity	Field Meter		
Laboratory Parameters			
Perchlorate	E314	Assess treatment effectiveness	Baseline, Weekly, Biweekly, Monthly
TOC	SM5310B	Assess carbon substrate distribution in the aquifer	Baseline, Weekly, Biweekly, Monthly

Parameter	Analytical Method	Purpose	Potential Frequency
TDS	SM2540C	Assess any impact of salts on delayed or slower perchlorate biodegradation in the flow through mode	Baseline, Monthly
Alkalinity	SM2320B	Assess geochemical conditions	Baseline, Monthly
Hexavalent Chromium	SW846 7199	Assess secondary impacts of treatment	Baseline, Monthly
Nitrate	E300.0	Assessment of nitrate as the most likely competing electron acceptor and carbon substrate consumer	Baseline, Weekly, Biweekly, Monthly
Sulfate	E300.0	Assessment of sulfate as an electron acceptor and potential carbon substrate consumer	Baseline, Weekly, Biweekly, Monthly
Sulfide	HACH Method 8131	Examine secondary geochemical impacts	Baseline, Monthly
Total Nitrogen	E351.2	Examine the need for micronutrients	Baseline, Monthly
Total Phosphorus	E365.3	Examine the need for micronutrients	Baseline, Monthly
Ferrous Iron	HACH Field Kit	Assess effect of reducing conditions on iron	Baseline, Monthly
Manganese	SW846 6010B	Assess potential for biologically-driven dissolution of manganese	Baseline, Monthly
Methane	EPA Method RSK175	Examine secondary geochemical impacts	Baseline, Monthly
Dissolved Metals(1)	SW6010/6020	Assess secondary impacts of treatment (includes arsenic)	Baseline, Monthly
VFAs	BF-MB-009, Rev 3	Surrogate carbon substrate assessment	Baseline, Monthly
Chlorate/Chlorite	E300.1	Assess treatment effectiveness and examination as intermediate by-product of perchlorate biodegradation	Baseline, Monthly
Chloride	E300.0	Potential estimation of conservative end-product of biodegradation	Baseline, Monthly
PLFA	Microbial Insights Method	Examine microbial response to carbon substrate addition	Baseline, Month 2
Perchlorate Reductase Gene	Microbial Insights Method	Examine microbial response to carbon substrate addition	Baseline, Month 2

Acronyms and Abbreviations:

BL: Baseline
EC: Electrical conductivity
DO: Dissolved Oxygen
ORP: Oxidation-reduction potential
PLFA: Phospholipid Fatty Acids
TOC: Total organic carbon
TDS: Total dissolved solids
VFAs: Volatile Fatty Acids

(1) Metals include arsenic, chromium, iron, and manganese.

6.0 REPORTING

Monthly status updates will be provided to both the Trust and NDEP summarizing the progress and results of the preliminary field activities, laboratory, and field testing, as needed.

Following completion of the field test, a Seep Well Field Area Bioremediation Treatability Study Report will be prepared for NDEP and US EPA review. The report will include the following:

- Results of geophysical analyses, soil borings, single borehole dilution tests, and slug tests;
- Analytical results summary of soil and groundwater samples collected during the preliminary field activities;
- Summary of bench testing results;
- Evaluation of effectiveness in reducing perchlorate-contaminated groundwater in the vicinity of monitoring well PC-94, including an estimate of the perchlorate mass reduction;
- Estimation of perchlorate degradation kinetics that are attainable in the field from trend graphs of individual monitoring wells, and
- Evaluation of the technology's feasibility and effectiveness for full-scale application and to identify a preliminary design and layout that is most feasible.

7.0 SCHEDULE

The following table provides the general schedule for the primary deliverables and activities associated with implementing the bench and field tests. This schedule is contingent upon Trust, NDEP, and US EPA approval of this Work Plan, Trust approval of funding and notice to proceed, and completion of access agreement.

Table 3 Preliminary Project Schedule

Task/Milestone	Estimated Start Date	Estimated Completion Date
Preliminary Field Activities	September 2016	December 2016
Bench Tests	November 2016	January 2017
Detailed Field Test Design	November 2016	January 2017
Field Test Installation	January 2017	March 2017
Injection Event 1	April 2017	May 2017
Injection Event 2*	July 2017	August 2017
Injection Event 3*	October 2017	November 2017
Effectiveness Monitoring	April 2017	December 2017
Treatability Study Report	October 2017	February 2018

Note:

* - Dates projected for injection events 2 and 3 are tentative dates based on observations from the ongoing bioremediation treatability study described in Section 2.0. Actual dates for these subsequent injection events will be decided based on effectiveness monitoring data from this treatability study following the first injection event.

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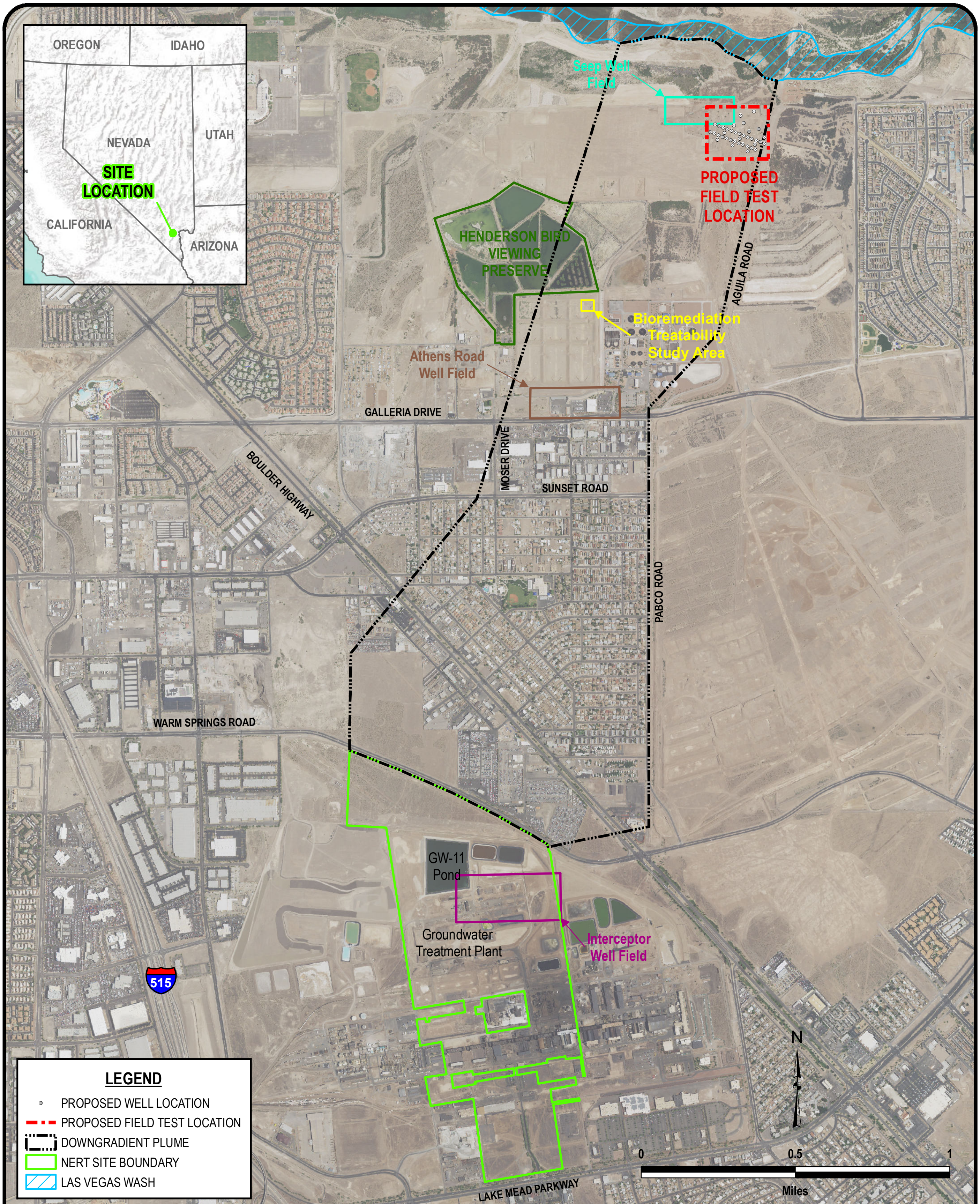

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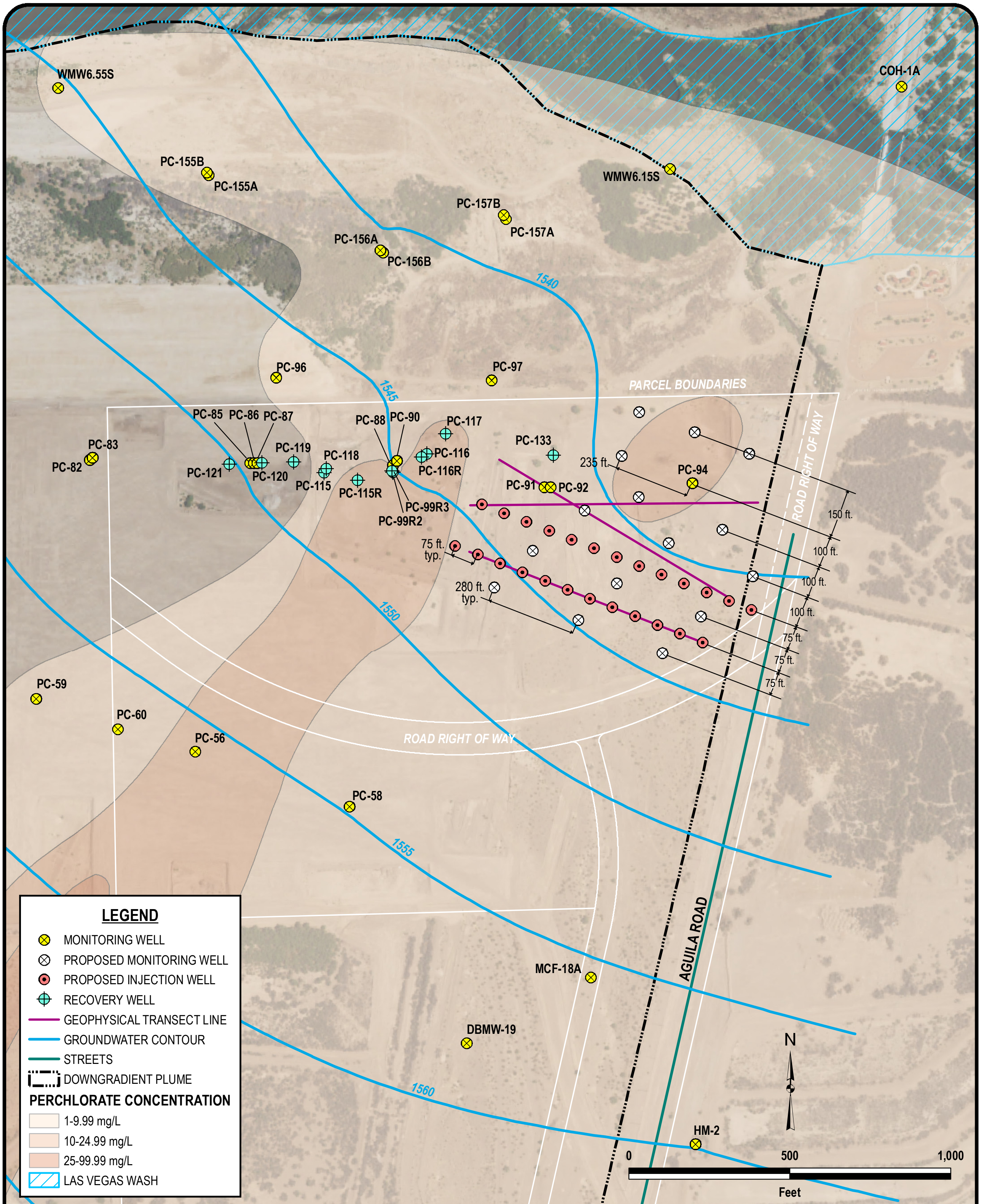
NEVADA ENVIRONMENTAL RESPONSE TRUST

SITE MAP

Project No.:	114-520225
Date:	APRIL 21, 2016
Designed By:	JWR

Figure No.
1

APR 21, 2016 N:\PROJECTS\NERT\GIS FIGURE DATABASE\MXD\FIGURE 1 - SITE MAP.MXD



MAY 26, 2016 N:\PROJECTS\NERT\GIS FIGURE DATABASE\MXD\FIGURE 2 - FIELD TEST CONCEPTUAL LAYOUT.MXD

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NEVADA ENVIRONMENTAL RESPONSE TRUST

FIELD TEST CONCEPTUAL LAYOUT

Project No.:	114-520225
Date:	JUNE 29, 2016
Designed By:	SRA
Figure No.	2

Appendix A
Desert Tortoise Protective Measures

APPENDIX A – DESERT TORTOISE PROTECTIVE MEASURES

Strategies used to avoid the take of desert tortoises are included in the United States Fish and Wildlife Services' (USFWS) 2009 Biological Opinion (USFWS, 2009a) and are also found in the Desert Tortoise (Mojave population) Field Manual (Gopherus agassizii) (USFWS, 2009b). In the event that protective measures are warranted at the site, several strategies could be implemented, if warranted, which include:

- Maintain a maximum speed of 15 miles per hour while traveling on the roads that access the Las Vegas Wash field test location.
- Present a desert tortoise education program to all relevant personal on Site prior to well installation and sampling activities. The program will include information on the biology and distribution of the desert tortoise, its legal status and occurrence in the Las Vegas Wash project location, the definition of "take" and associated penalties, the measures and reporting procedures to be used when desert tortoises are encountered. The program shall instruct participants to report all observations or signs of listed species during construction activities to an authorized biologist.
- All potential desert tortoise burrows found within areas of ground disturbance, whether occupied or vacant, will be excavated by an authorized biologist and collapsed or blocked to prevent tortoise re-entry. All such burrows will be excavated with hand tools to allow removal of desert tortoises, and any desert tortoise handling will be in accordance with the USFWS-approved desert tortoise handling protocol.
- If a desert tortoise appears in the Wash Location, project activities that threaten the desert tortoise will cease immediately until the desert tortoise moves out of harm's way or is moved out of harm's way by an authorized biologist. Such authorized desert tortoise biologist shall be familiar with the 2009 biological opinion (USFWS, 2009a).
- Desert tortoises will be treated in a manner to ensure that they do not overheat, exhibit signs of overheating (e.g., gaping, foaming at the mouth, etc.) or be placed in a situation where they cannot maintain surface and core temperatures necessary to their well-being. Unless the tortoise is in imminent danger, no desert tortoise shall be captured, moved, transported, released or purposefully caused to leave its burrow for whatever reason when the ambient air temperature is above 95 degrees, or if the ambient air temperature is anticipated to exceed 95 degrees before handling can be completed.
- Conduct a desert tortoise survey by an authorized biologist of the area 30 feet from the centerline of any access roads that are to be cleared and from the edge of the well installation footprint no more than 24 hours prior to surface disturbance activities that take place within upland habitat areas suitable for the desert tortoise. The authorized desert tortoise biologist will act as a biological monitor and will be present during all activities that require the use of heavy equipment or that may result in ground disturbance.
- While a temporary USFWS-approved tortoise-proof fence may be installed as an option to protect desert tortoises in the vicinity prior to ground-disturbing activities, the certified biologist would have to evaluate whether this is a viable option for the Las Vegas Wash field test location and planned project activities.
- Project activities that involve ground disturbance will be avoided during the desert tortoise active season which typically spans from the Spring into early Summer. Desert tortoises can also be active following rain events and unseasonably warm periods during the fall and winter.
- Litter will be controlled to reduce the attractiveness of the Las Vegas Wash project location to opportunistic predators such as desert kit fox, coyotes, and common ravens.
- Any fuel or hazardous waste leaks or spills shall be contained immediately and cleaned up at the time of occurrence. Contaminated soil will be removed and disposed of at an appropriate facility.
- The onsite biologist will record each observation of desert tortoise handled and details about the event and the specimen. A report of any observed desert tortoise will be submitted to the USFWS' Nevada Fish and Wildlife Office in Las Vegas within 90 days of completion of installation of the new wells.