In-Situ Chromium Treatability Study Work Plan
Nevada Environmental Response Trust Site Henderson, NV

PREPARED FOR

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ASTM	American Society for Testing and Materials
AWF	Athens Road Well Field
bgs	below ground surface
COD	chemical oxygen demand
COP	Continuous Optimization Program
CPS	calcium polysulfide
Cr(III)	Chromium trivalent state
Cr(VI)	Chromium hexavalent state
EOS®	emulsified oil substrate
FBR	Fluidized Bed Reactor
ft/d	feet per day
g	grams
gpm	gallons per minute
GWETS	Groundwater Extraction and Treatment System
GWTP	Groundwater Treatment Plant
IRM	interim remedial measure
IWF	Interceptor Well Field
mg/L	milligrams per liter
ml	milliliters
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NERT or Trust	Nevada Environmental Response Trust
PVC	polyvinyl chloride
Qal	Quaternary alluvial
Site	Nevada Environmental Response Trust site
Tetra Tech	Tetra Tech, Inc.
UIC	Underground Injection Control
UMCf	Upper Muddy Creek formation
UNLV	University of Nevada at Las Vegas
WBZ	water-bearing zone
Work Plan	In-Situ Chromium 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: In-Situ Chromium Treatability Study Work Plan, Nevada Environmental Response Trust Site, Henderson, Nevada

_____ 5/25/2016

Kyle Hansen, CEM
Field Operations Manager/Geologist
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Date

Nevada CEM Certificate Number: 2167
Nevada CEM Expiration Date: September 18, 2016

1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this In-Situ Chromium Treatability Study Work Plan (Work Plan) for the NERT site (Site), located in Clark County, Nevada (Figure 1). This Work Plan is being submitted to the Nevada Division of Environmental Protection (NDEP) as part of the Remedial Investigation consistent with the Interim Consent Agreement effective February 14, 2011. The Work Plan presents the technical approach and scope of work for conducting bench-scale and field-scale tests for hexavalent chromium reduction in groundwater. The bench-scale tests will be performed by the University of Nevada at Las Vegas (UNLV) to evaluate several chemicals and biological carbon substrates. After the completion of the bench-scale test, the selected biological carbon substrate will be injected as part of a field test that will be performed approximately 640 feet upgradient of the Interceptor Well Field (IWF) at the Site (Figure 2). Field testing of in-situ chemical treatment will be evaluated as part of an interim remedial measure (IRM) currently planned in the former ammonium perchlorate manufacturing area (AP Area) as shown in Figure 2. This Work Plan is organized as follows:

- **Introduction (Section 1.0):** Provides the primary objectives of the bench-scale and field tests along with relevant background information, including regional geology and hydrogeology.
- **Technology Description (Section 2.0):** Provides an overview of chromium treatment technologies along with their relative advantages and disadvantages for application at the Site.
- **Preliminary Field and Laboratory Activities (Section 3.0):** Provides a description of the field activities and laboratory activities to be completed prior to implementing the field test, including the bench-scale test objectives, set-up, effectiveness monitoring, and evaluation of results.
- **Field Test Conceptual Design (Section 4.0):** Describes the conceptual design of the field test including objectives, test location, conceptual layout, preliminary injection design, effectiveness monitoring plan, permitting requirements, and health and safety.
- **Reporting (Section 5.0):** Summarizes reporting related to design and execution of the preliminary field activities, bench-scale tests, and field test.
- **Schedule (Section 6.0):** Summarizes the schedule for conducting the preliminary field activities, bench-scale test, field test, and associated reporting.
- **References (Section 7.0):** Lists the documents referenced in this Work Plan.

1.1 PROJECT GOAL

The goal of performing the bench-scale and field-scale tests is to evaluate the feasibility of, and the optimal approach for, achieving in-situ reduction of hexavalent chromium in groundwater at the Site. If in-situ treatment of hexavalent chromium is demonstrated to be successful, the results could be used in the Feasibility Study to evaluate a full-scale application to reduce the mass of chromium that is extracted by the IWF and treated by the Groundwater Treatment Plant (GWTP). The GWTP pre-treats chromium in the IWF discharge which is subsequently treated for perchlorate by the Fluidized Bed Reactor (FBR) portion of the Groundwater Extraction and Treatment System (GWETS).

An additional goal of the treatability study is to understand how to implement in-situ treatment of chromium without negatively impacting the operation of the IWF. One of the common means of achieving in-situ treatment of chromium is biological reduction. This requires injection of a carbon substrate as an electron donor. However, if carbon substrate were to migrate into the IWF extraction wells, it is possible that biofouling of the extraction wells could occur. For this reason, the biological field test will be conducted with additional precautions to minimize the potential for biofouling the IWF wells. The abiotic approaches, such as using calcium polysulfide or ferrous

sulfate, will be evaluated in the bench-scale test and the use of calcium polysulfide will be further evaluated as part of the soil flushing IRM planned to be completed immediately upgradient of the IWF.

1.2 BACKGROUND

1.2.1 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 producing manganese and boron products (Figure 2). 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 (Ramboll Environ, 2015a).

1.2.2 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. Collectively, the entire system of extraction wells, water conveyances, and treatment plants is referred to as the GWETS.

The GWETS treats water from three groundwater extraction well fields: the IWF; Athens Road Well Field (AWF); and the Seep Well Field (Figure 1). Pipelines and lift stations convey groundwater from the well fields to the Site to be treated by the on-site treatment plant. This treatment plant is comprised of the following components: the GWTP to treat hexavalent chromium from the IWF; the 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).

1.2.3 Interceptor Well Field

The IWF was installed in the shallow water bearing zone starting in 1986. The IWF extracts contaminated groundwater immediately down-gradient from the on-site source areas. The IWF now consists of 30 wells, 27 of which are currently active (as of June 2015). The wells were installed in 1986 (10 wells), 1993 (4 wells), between 1998 and 2000 (11 wells), 2003 (1 well), and between 2007 and 2010 (4 wells). Well depths range from 35 feet to 51 feet below ground surface (bgs). The IWF has been operating at approximately 69 gpm with average discharge for individual IWF wells ranging from 0.4 to 5.4 gpm (Tetra Tech, Inc., 2015a).

To further enhance groundwater capture, a physical barrier wall was constructed in the ground, across the higher concentration portion of the chromium and perchlorate plume in 2001 (Figure 2). The barrier wall is approximately 1,600 feet in length, 60 feet deep, and constructed to tie into approximately 30 feet of the Upper Muddy Creek formation (UMCf) (Ramboll Environ, 2015a).

1.2.4 Groundwater Treatment Plant

The GWTP, located adjacent to the IWF and barrier wall (Figure 2), has been treating IWF extracted groundwater since its construction in 1986-87. Envirogen Technologies, Inc. (ETI) has operated and maintained the GWTP and the rest of the GWETS since July 25, 2013.

The chromium-impacted groundwater extracted by the IWF is treated by first chemically reducing the hexavalent chromium by addition of ferrous sulfate and then removing the resulting trivalent chromium through chemical precipitation. The precipitated solids settle in a clarifier and are pumped periodically into a filter press where a final sludge cake is produced and disposed of off-site. The treated groundwater effluent is pumped to either the GW-11 Pond or the equalization tanks before it enters the FBR biological treatment plant. From July 2014 through June 2015, the GWTP removed approximately 2,270 pounds of chromium (Ramboll Environ, 2015a).

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

1.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

1.3.1 Regional Geology

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

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

1.3.2 Alluvium

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

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

1.3.3 Muddy Creek Formation

The Muddy Creek Formation represents deposition in an alluvial apron environment from the Spring Mountains to the west, grading into fluvial, paludal (swamp), playa, and lacustrine environments further out into the valley center (ENVIRON, 2014a). The UMCf underlies the transitional Muddy Creek Formation or alluvium, and consists of interbedded fine-grained sediments (clay and silt representing the first and second fine-grained facies) and

coarse-grained (sand, silt, and gravel representing the first and second coarse-grained facies) that become progressively finer-grained to the north towards the central portion of the Las Vegas Valley.

1.3.4 Hydrogeology

According to previous work performed around the region, the depth to groundwater ranges from approximately 27 to 80 feet bgs, and is generally deepest in the southern portion of the Site and becomes shallower to the north toward the Las Vegas Wash. The average groundwater gradient ranges from 0.015 to 0.020 feet/foot, south of the AWF, and decreases to approximately 0.007 to 0.010 feet/foot to the north of the AWF (ENVIRON, 2014a). The direction of groundwater flow on the Site is generally north to north-northwest and then changes slightly to the northeast towards the Las Vegas Wash.

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

- Shallow WBZ – The first occurrence of groundwater in the area occurs within either the alluvium or the Upper Muddy Creek Formation. Groundwater in the Shallow WBZ occurs under unconfined to partially confined conditions and is considered the "water table aquifer." At the Site, the Shallow WBZ is comprised of the saturated portions of the alluvium and the uppermost portion of the UMCf to depths of approximately 90 feet bgs (ENVIRON, 2014a).
- Middle WBZ – Groundwater in the Middle WBZ generally occurs between 90 and 300 feet bgs. Water-bearing units in the Middle WBZ are confined (ENVIRON, 2014a). Groundwater in the Middle WBZ exhibits an upward vertical gradient (Ramboll Environ, 2015a).
- Deep WBZ – Groundwater in the Deep WBZ generally occurs between 300 and 400 feet bgs. Water-bearing units in Deep WBZ are confined. Groundwater in the Deep WBZ exhibits an upward vertical gradient (Ramboll Environ, 2015a).

1.4 EXTENT OF CHROMIUM IMPACTS

Since the early 1980s, subsurface investigations have identified chromium impacts in groundwater north of the Unit Buildings and extending as far north as the City of Henderson Bird Viewing Preserve. The highest concentrations of chromium in groundwater at the Site have been historically reported south (upgradient) of the IWF and the barrier wall. NDEP identified 70 contaminant source areas for the Site, including process chemicals suspected to have leaked to soil through cracks in the basements of Units 4, 5 and 6 (ENVIRON, 2014a).

In the most recent Annual Remedial Performance Report dated October 30, 2015, the maximum total chromium concentrations in groundwater were reported in monitoring wells M-65 and M-66 (22 and 23 milligrams per liter [mg/L], respectively) and in extraction wells I-H, I-Q, I-T, and I-U (ranging from 21 to 25 mg/L) (Ramboll Environ, 2015a). Immediately upgradient of the IWF, chromium appears to primarily be in the hexavalent state with a maximum hexavalent chromium concentration of 18 mg/L at M-38 (total chromium concentration reported as 17 mg/L). While these wells are screened across both the alluvium and UMCf, groundwater elevations at most of these monitoring and extraction wells are below the UMCf contact (M-65, I-H, I-Q, I-T, I-U), indicating significant hexavalent chromium concentrations are present within the UMCf. Additionally, as presented in Table 10 of the Annual Remedial Performance Report dated October 30, 2015, it is estimated that approximately 98.5% of the chromium mass on-site is currently present in the UMCf with only 1.5% present within the alluvium (Ramboll Environ, 2015a).

As noted in Section 1.2, the goal of a full-scale in-situ chromium treatment program would be to reduce the majority of the mass flux of chromium from the IWF to the GWETS such that the GWTP could be bypassed and the FBR portion of the GWETS could handle the treatment of any residual chromium. In consideration of this goal, the chromium mass flux rate has been evaluated based on the combination of chromium concentration and groundwater flow rate for each IWF extraction well from May 2015 (Ramboll Environ, 2015a). As shown on

Figure 3, Extraction Well I-F has the highest mass flux rate for chromium at approximately 0.9 lbs/day. This well represents approximately 15% of the total 5.8 lbs/day mass flux of chromium extracted by the IWF.

2.0 TECHNOLOGY DESCRIPTION

2.1 HEXAVALENT CHROMIUM TREATMENT

Chromium is generally found in the trivalent state [Cr(III)] in nature and is largely immobile in the environment. Under strong oxidizing and alkaline conditions, chromium is present in the hexavalent state [Cr(VI)] and persists in anionic form as chromate or dichromate, which are water soluble. The primary goal of chromium remediation is to reduce the carcinogenic, soluble, and mobile Cr(VI) to the less toxic and less mobile Cr(III), which forms minimally soluble precipitates (U.S. Environmental Protection Agency, 2000).

Traditionally, groundwater extraction and treatment has primarily been used to remediate chromium-contaminated plumes. While providing interception and hydraulic containment of the plume, this approach will likely require long-term operation and may not effectively remediate the source zone. Other remedial approaches for Cr(VI) include in-situ chemical reduction, monitored natural attenuation, and bioremediation (Guertin et al., 2005). In this Work Plan, Tetra Tech proposes to evaluate the use of chemical reduction and biological reduction for in-situ hexavalent chromium treatment at the Site. General technical descriptions of the chemical reduction and biological reduction technologies are described below. The field test design and methodology are described in Section 4.

2.2 CHEMICAL REDUCTION

Chemical reduction of Cr(VI) to Cr(III) refers to abiotic reduction via an electron donor such as sulfur (S), or iron [Fe(II)] and [Fe(0)]. From this reduction, Cr(III) precipitates out of solution and Cr toxicity is reduced. Examples of engineered chemical reduction technologies include in-situ injection of an electron donor such as calcium polysulfide (CPS), ferrous sulfate, and other sulfate-based reductants. During injection, the pH level is optimized to facilitate electrostatic surface interactions between Cr(VI) anionic species and the electron donor. In areas that exhibit high Cr(VI) concentrations, pH is increased so that Cr(III) forms precipitates (Guertin et al., 2005). While numerous chemicals are capable of achieving chemical reduction of Cr(VI) to Cr(III), CPS and ferrous sulfate were selected for further evaluation due to their relative ease of use, availability, documented effectiveness, and relative costs.

2.2.1 Calcium Polysulfide

CPS is used extensively as an agricultural soil amendment, a fungicide at vineyards, and for removal of metals in water treatment systems (Padzadeh & Batista, 2011). It has more recently been found to be capable of fixating many heavy metals (e.g., arsenic, lead, copper, cadmium) in the environment. There have been numerous successful applications of CPS to treat Cr(VI) in groundwater over that last 15 years (Freedman, et al., 2005; Graham, et al., 2006; Storch, et al., 2002; Messer et al., 2003; Yu & Tremaine, 2002) and at industrial sites with Cr(VI) concentrations as high as 240 mg/L (Blessing & Rouse, 2002).

Once CPS is mixed with water, polysulfide dissociates to form bisulfide (HS-) and aqueous hydrogen sulfide ($H_2S_{(aq)}$), which can react directly with Cr(VI) to form Cr(III). Alternatively, the sulfide can reduce Fe(III) present in the aquifer to Fe(II), which reduces Cr(VI) to Cr(III). In the pH range of 4 to 10, Cr(III) will precipitate as $Cr(OH)_3$. If reduction is by Fe(II), Cr(III) will co-precipitate with Fe(III) to form the less soluble $Fe_{0.75}Cr_{0.25}(OH)_3$ (Sass & D. Rai, 1987). In summary, calcium polysulfide can reduce Cr(VI) to (Cr(III) to form a non-toxic, low solubility form of chromium, chromium hydroxide, as generally described by the following chemical equation:

$$2\ CrO_4^{2-} + 3\ CaS_5 + 10\ H^+ \text{-->} 2\ Cr(OH)_3 + 15\ S + 3\ Ca^{2+} + 2H_2O$$

CPS is typically more stable and persistent in groundwater than other reductants and is relatively safe to handle. Tetra Tech proposes to utilize CPS for a bench-scale test to evaluate dosage and expected treatment times.

2.2.2 Ferrous Sulfate

The ability of iron (both in its zero-valent form Fe(0) and as Fe(II)) to reduce redox sensitive elements such as chromium or to dechlorinate various organic groundwater contaminants has been demonstrated at both laboratory scale and in the field (Puls, Paul, & Powell, 1999) (Ludwig, et al., 2001). Iron can be used for reduction and immobilization of chromium by the following reaction:

$$Fe^{2+} + CrO_4^{2-} + 4\ H_2O + 2\ H^+ \text{-->}\ (Fe_x\ Cr_{1-x})(OH)_3 + 5\ OH^-$$

in which Cr(VI) is reduced to the less toxic Cr(III), which readily precipitates as $Cr(OH)_3$ or as the solid solution $Fe_x\ Cr_{1-x}(OH)_3$ (Puls, Paul, & Powell, 1999).

Ferrous sulfate is a traditional reducing agent for the treatment of metal industry process effluents and has more recently been successfully applied as an in-situ groundwater treatment method with hexavalent concentration reductions from 85 mg/L to 0.05 mg/L (Brown, Leaby, & Pyrih, 1998). Ferrous sulfate is currently used in the GWTP. The use of ferrous sulfate for in-situ treatment of chromium will be evaluated in a bench-scale test.

2.3 BIOLOGICAL REDUCTION

In-situ microbial reduction of Cr(VI) to Cr(III) can be enhanced by injecting a carbon substrate (carbohydrate) solution, such as a dilute molasses solution. The carbohydrates, primarily sucrose, are readily degraded by heterotrophic microorganisms present in the aquifer. This process depletes the available dissolved oxygen and causes reducing conditions within the aquifer. Various mechanisms of Cr(VI) to Cr(III) include: (1) the direct enzymatic reduction of Cr(VI) by numerous bacteria species, such as *Bacillus subtilis* (Fredrickson et al., 2000; Lovely, D. R., 1993; Lovely & Coates, 1997; Tebo & Obraztsova, 1998); (2) an extracellular reaction with byproducts of sulfate reduction such as H_2S; and (3) abiotic oxidation of the organic compounds including soil organic matter such as humic and fulvic acids. Microbial reduction of Cr(VI) primarily occurs under anaerobic conditions. In addition, microbial reduction of Fe(III) and $SO4^{2-}$ creates chemical reductants, Fe(II) and sulfide respectively, which can reduce Cr(VI) to Cr(III) (Fendorf et al., 2002; Wielinga et al., 2001).

As shown in the following chemical equation, the primary end product of hexavalent chromium reduction is chromic hydroxide [$Cr(OH)_3$], which readily precipitates out of solution under alkaline to moderately acidic and alkaline conditions:

$$\text{Carbon Substrate} + 4\ CrO_4^{2-} + 8\ H^+ \rightarrow 3\ CO_2 + 4\ Cr(OH)_3 + H_2$$

The chromium precipitates remain immobilized within the soil matrix of the aquifer, ensuring short-term and long-term effectiveness (Sass & D. Rai, 1987; Pettinea et al., 1998).

Adding a carbon substrate to the subsurface can sustain the appropriate redox range (approximately -200 to -300 millivolts) in aquifers with limited supply of natural organic carbon. Numerous carbon donors are available and the selection is based on several physical, chemical, geochemical, and economic factors. At the Site, the objective is to examine the feasibility of bioremediation, which requires the engineered addition of a carbon substrate to the groundwater to optimize and sustain in-situ biodegradation of hexavalent chromium in groundwater.

As favorable redox conditions for perchlorate biodegradation are generally in the 0 to -100 millivolts range, perchlorate degradation is likely to occur prior to the reduction of Cr(VI), which would be a beneficial byproduct of using biological reduction for in-situ treatment of chromium.

2.3.1 Industrial Sugar Wastewater

Various organic wastes have been evaluated and used as a carbon substrate for microbes for the in-situ anaerobic bioremediation of perchlorate as well as hexavalent chromium by providing suitable conditions for microbial growth and creating a reducing environment (Perlmutter, 2001). As the cost of the carbon substrate is one of the primary costs for implementing biological reduction, finding a cost-effective, local supply of carbon

substrate is preferable. A facility located within approximately 1.5 miles of the Site generates a substantial quantity of wastewater containing sugars. In 2015, UNLV analyzed a representative sample of the wastewater and determined that it contained a chemical oxygen demand (COD) of 26,880 mg/L, a pH at 5.5, and ammonia concentration of 10 mg as nitrogen per liter. While the pH is on the slightly acidic side, the groundwater at the Site is known to have a high buffering capacity. Tetra Tech will evaluate using the industrial sugar wastewater as potential carbon substrate in the bench-scale test.

2.3.2 Emulsified Vegetable Oil

Emulsified vegetable oil is prepared by mixing edible oils with emulsifying agents and water, yielding a smooth blend oil-in-water emulsion. The small, uniform emulsion droplets can transport in most aquifers and have a negative surface charge to reduce droplet capture by the solid surfaces (Solutions-IES, Inc., 2006). Oil droplets can collide with sediment surfaces and coat them with a thin layer of oil droplets when they migrate through the aquifer pore spaces, which provides a carbon source for long-term biodegradation. A single injection can provide sufficient carbon to drive biodegradation for several years, which significantly lowers operational and maintenance costs compared to aqueous-phase injection of soluble carbon sources. The small oil droplets of emulsified vegetable oil can be transported substantial distances (up to 45 feet depending on the geological conditions) with low to moderate oil retention and little permeability loss. Therefore, the major advantage of these carbon substrates is their longevity in the subsurface, less frequent injection intervals, and less likelihood of biofouling.

Emulsified Oil Substrate (EOS®) (a product of EOS® Remediation, LLC) has a well-documented history of treating recalcitrant compounds through enhanced reductive processes. Injection of EOS® into aquifers creates highly reducing conditions caused by the fermentation of soybean oil and other carbon substrates present in its proprietary formulations. During fermentation, hydrogen and acetate are released which decrease the oxidation-reduction potential (ORP). Subsequently hydrogen can be used as an electron donor by other microorganisms to degrade contaminants of concern. Hexavalent chromium [Cr(VI)] has been demonstrated to convert to trivalent chromium [Cr(III)], a much less soluble and non-toxic species, under highly reducing aquifer conditions. EOS® serves as an electron donor source, enabling direct electron transfer to Cr(VI) and resulting in oxidation by microbial respiration. Simultaneously the reduction of any iron or sulfate present in the aquifer can provide a secondary mechanism to reduce Cr(VI) to Cr(III). Producing electron donor equivalence from a long-lasting carbon source, such as EOS®, allows Cr(VI) reduction to continue for several years. EOS® has previously been evaluated for the Site and is currently being used for the groundwater bioremediation treatability test located approximately 2,000 feet downgradient of the AWF (Figure 1) (Tetra Tech, Inc., 2015b). Therefore, EOS® will also be used in the bench-scale test for comparison purposes to the other carbon substrates.

2.3.3 Molasses

Molasses is a viscous by-product of the refining of sugarcane or sugar beets into sugar. It has been used for chromium remediation for over 10 years with a high degree of success. Molasses is a water-soluble carbon substrate that provides an electron donor and carbon source for native bacteria present in the aquifer. The increased activity of the bacteria will rapidly utilize any dissolved oxygen and any other electron acceptors present in the groundwater, driving conditions to be anaerobic and causing hexavalent chromium to be reduced to trivalent chromium (Chen et al., 2015). The advantage of this soluble carbon substrate is that it is a low-cost alternative, is food-grade, and is easy to handle and use. However, it also has a shorter half-life, can alter the groundwater pH, and may require multiple rounds of injection depending upon the groundwater conditions. Blackstrap molasses will be used in the bench-scale test due to the additional nutrients present that help promote biological growth. During the bench-scale test, the pH will be carefully monitored to evaluate the need to add a pH buffer such as sodium bicarbonate.

3.0 PRELIMINARY FIELD AND LABORATORY ACTIVITIES

This section describes the various preliminary activities to be completed prior to the field test, including soil and groundwater sampling, slug tests, and bench-scale tests. Results from these tasks will be used to finalize design details for field test implementation.The chemical field test will be conducted in the AP Area as part of the IRM planned for this area and the biological field test will be conducted in the Central Retention Basin to the east of the existing soil flushing treatability test cells as shown on Figure 4.

3.1 FIELD ACTIVITIES

All field work described herein will be conducted in accordance with the existing Site Management Plan, Revision 2 (Ramboll Environ, 2015b) and Field Sampling Plan (ENVIRON, 2014b). Tetra Tech, on behalf of NERT, will prepare applications and obtain required permits prior to the installation of the injection and monitoring wells. The injection and monitoring wells will be drilled in accordance with the Nevada Division of Water Resources requirements, following submittal of a Notice of Intent to Drill.

3.1.1 Utility Clearance

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

3.1.2 Soil Borings and Grab Groundwater Samples

Two soil borings will be drilled within the test plot shown on Figure 4 to obtain lithologic information, physical parameters, and contaminant concentrations as well as soil for use in the bench-scale tests. The test plot area was selected based on several factors including chromium mass flux, hydrogeology, as well as other practical considerations (See Section 4.2). Tetra Tech will retain a qualified, licensed drilling contractor to advance the soil boring using a hollow-stem auger or rotary vibratory drill, if deemed necessary, 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.

The soil borings will be advanced through the alluvium and top of the UMCf up to a total depth of 55 feet, the approximate depth of the IWF, to evaluate soil conditions within the alluvium and UMCf. Continuous soil samples will be collected utilizing split-spoon samplers, or similar, from ground surface to total depth and logged using the Unified Soil Classification System by the on-site geologist. To evaluate vadose zone impacts in the area, soil samples will be collected every 5 feet as well as at lithologic or color changes for laboratory analysis. The drilling contractor will decontaminate soil collection equipment between samples. Soil samples for laboratory analysis will be collected in laboratory-supplied containers, labeled, placed in plastic bags, and stored in a cooler on ice for transport to the project analytical laboratory. Upon reaching groundwater, a minimum of one undisturbed soil sample will be collected using a Shelby tube, or similar, from each borehole for physical parameter analysis. Additional soil will be collected in the targeted remediation zones for use in the bench-scale tests.

A depth-discrete groundwater sample will be collected within the alluvium, if sufficient water is present, and at the top of the UMCf at each boring location to vertically profile the chromium and perchlorate impacts. Groundwater samples will be collected using a depth-discrete groundwater sampling tool (e.g., Hydropunch™ or Simulprobe™) or from temporary 2-inch wells. If temporary wells are installed, a minimum of three casing volumes of water will be purged prior to sampling, if the formation allows. Groundwater samples, collected with a small diameter

disposable bailer, will be tested for general water quality parameters (temperature, pH, conductivity, and turbidity) using a portable water quality meter and then transferred into clean laboratory-supplied containers for laboratory analysis.

3.1.3 Initial Well Installation

Once collection of the soil and groundwater samples is complete, a dual-nested well will be installed within each borehole to perform a slug tests and obtain representative groundwater for use in the bench-scale tests. The wells will be constructed with two-inch diameter, Schedule 40 polyvinyl chloride (PVC) and 0.010-inch slot size well screen. A washed #2/16 sand filter pack will be installed in the annular space around the well screen and extended up to two feet above the top of the screen interval. The screen slot size and filter pack may be adjusted based on the lithology encountered. The remainder of the annular space will be backfilled with two feet of hydrated bentonite, followed by neat cement grout. At each boring location, one well will be installed with a screened interval within the alluvium, from approximately 30 to 35 feet bgs, and the other well will be installed with a screened interval within the UMCf, from approximately 40 to 45 feet bgs, with a bentonite-cement grout seal placed in between the two screened intervals. The depth and length of the well screens will be determined in the field based on the lithology and depth to groundwater. The surface completions for the wells may vary based on whether they are located in vehicle traffic areas. In traffic areas, flush-mounted, tamper-resistant, traffic-rated well boxes will be installed, at an elevation approximately one-half inch above grade. In areas where there is no vehicle traffic, the top of the casing will extend approximately three feet above surrounding grade. If needed, three bollards surrounding the monitoring well casing may be installed.

3.1.4 Well Development

Following the completion of well construction, but no sooner than 24 hours after well construction is compete, Tetra Tech will develop the newly installed wells. Well development will consist of using a surge block and bailer to swab and surge the filter pack and remove sediment from the wells. This process will be followed by pumping with a submersible pump to purge the well of fine-grained sediment. Well development will be considered complete 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. At the completion of the well development, groundwater will be collected using clean, disposable bailers for use in the bench-scale test as described in Section 3.2.

3.1.5 Slug Test

Due to variable hydraulic conductivities reported in the vicinity of the field test area and the relatively limited information available for the UMCf, slug tests will be performed in the newly installed wells to obtain location-specific hydraulic conductivity. 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 Aquifer Test Solver (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.

3.1.6 Well Survey

Following installation of the all of the injection and 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.

3.1.7 Laboratory Analysis

Selected soil samples will be submitted to the project analytical laboratory for analysis of hexavalent chromium, total chromium, and perchlorate. Selected saturated soil samples will also be analyzed for physical parameters, total organic compound, pH, soluble cations and anions, total dissolved solids, and various metals. Grab groundwater samples will be analyzed for hexavalent chromium, total chromium, and perchlorate to evaluate the vertical extent of primary chemicals of concern. Additional analyses will be performed on the soil and groundwater samples collected for use in the bench-scale test (Section 3.2).

Table 1 Baseline Soil and Groundwater Sampling Protocol

Parameter(s)	Method	Purpose
Soil Analyses		
Hexavalent Chromium	SW7199	Estimate mass of chromium in saturated soil
Total Chromium	SW-6010 or 6020	Estimate mass of chromium in saturated soil
Perchlorate and Chlorate	E314	Assess potential secondary impacts of treatment
Total Organic Compound	E415	Estimate available natural organic carbon
Soil pH	SW9045	Assess geochemical conditions
Soluble Cations and Anions	See Note 1	Assess salt loading
Total Dissolved Solids[2]	E160.1	Assess salt loading
Metals[3]	SW6020	Assess potential secondary impacts of treatment
Physical Parameters[4]	API RP40 ASTM D2216 EPA 9100	Assess geophysical properties, porosity and hydraulic conductivity of soil
Grab Groundwater Analyses		
Hexavalent Chromium	SW7199	Assess vertical extent of chromium impacts
Total Chromium	SW-6010 or 6020	Assess vertical extent of chromium impacts
Perchlorate and Chlorate	E314	Assess vertical extent of perchlorate impacts

Notes:

1. Cations include sodium, potassium, calcium, and magnesium (Method SW6020). Anions include chloride, sulfate, nitrate (Method E300/SW9056), carbonate, and bicarbonate (Method E2320B).
2. Analysis to be performed on water extract prepared per method SW9056.
3. Metals include arsenic, iron, and manganese.
4. Physical parameters include native-state permeability to water (hydraulic conductivity), grain density, dry bulk density, total porosity, air-filled porosity, moisture content and total pore fluid saturation (reported as water only).

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 stored in plastic-lined roll-off bins. Solids will be characterized by collecting representative samples, as necessary, to determine disposal options. Depending upon the size of the container and volume of material, one sample may be sufficient for characterization, or several samples may be composited in the field. Generally, a minimum of one 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.

3.2 BENCH-SCALE TESTS

3.2.1 Objectives

The objectives of the bench-scale tests are to accomplish the following:

- Determine the most appropriate chemical and biological carbon substrate amendments to promote hexavalent chromium reduction under site-specific conditions;
- Evaluate chemical and biological carbon substrate dosage;
- Determine chemical and biological carbon substrate persistence;
- Evaluate impact of chemical and carbon substrate type on degradation kinetics; and
- Evaluate impact of pH on degradation kinetics.

3.2.2 Soil and Groundwater Samples

Soil and groundwater samples from the test plot will be collected, as discussed in Section 3.1, for use in the bench-scale tests.

The groundwater at the Site has many oxidized ions that will be competing for the added chemical and biological carbon substrate including perchlorate, chlorate, nitrate, and chromium. Therefore, it is necessary to determine the amount of each ion present to compute the amount of chemical and biological carbon substrate to be added in the bench-scale test. Determination of the total and hexavalent chromium concentrations is also important for the chemical bench-scale test. To evaluate the ions present along with the baseline concentrations of the chemicals of concern, groundwater samples collected from the Site will be analyzed for parameters listed in Table 2.

In addition, the soil at the Site also contains some of these ions that will compete for the chemical and biological carbon substrate. In order to account for this demand, the soil samples will also be extracted to determine the concentrations of these ions that are present in the soils. Extraction will be performed by adding sequential amounts of deionized water to the samples and extracting the water using a centrifuge. The decanted water from the centrifugation steps are combined into one sample that is then analyzed for the contaminants of interest (Table 2).

Table 2 Soil Extract and Groundwater Testing

Parameter	Method
Hexavalent Chromium	SW7199
Total Chromium	SW6010 or 6020
Perchlorate and Chlorate	E314
Electrical Conductivity	USDA-Saturated Paste
Chemical Oxygen Demand	Hach 8000
Nitrate/Nitrite	Hach 10206/352.1
Total Nitrogen	Hach 20106
Ferric/Ferrous Ions	Hach 8008/8147
Sulfate	Hach 8051
Sulfide	Hach 8131
pH	9045 D
Phosphate	E365.1
Total Dissolved Solids	SM 2540/E160.1

3.2.3 Chemical Reduction Test

The objective of the chemical reduction bench-scale test is to assess whether calcium polysulfide and ferrous sulfate can be used as reducing agents for in-situ chromium reduction at the Site. As ferrous sulfate is currently used in the existing GWTP, a comparison of dosage requirements to achieve chromium reduction will be performed. Two types of tests are proposed, batch tests to determine the optimum dosage to be used and column tests to mimic field conditions. The results of this testing will inform the chemical reduction field test currently being planned as part of the IRM.

Batch tests will be performed using a batch jar apparatus with 500 ml of groundwater collected from the proposed IRM area. Stoichiometric ratios of 1:1 to 3:1 will be used for both the calcium polysulfide and ferrous sulfate tests. The potential amount of sludge formed will be measured using a graduated cylinder and suspended solids testing to evaluate the potential for clogging during field testing. The turbidity of the resulting effluent will be measured to gauge the settling properties of the sludge, such as settling velocity. The samples will then be centrifuged and filtered to generate a clear concentrate that will be analyzed to determine the remaining concentrations of unreacted total chromium and hexavalent chromium in the pore water. The concentrations of calcium, alkalinity, sulfide, sulfate, and pH will be measured as well. There is potential for scale formation when adding calcium polysulfide because the groundwater has high sulfate and calcium concentrations. The beaker walls and the jar apparatus blade will be inspected for scale formation. If scale is formed, samples will be sent for X-ray diffraction to determine its composition. The potential for scale formation is important to understand so appropriate mitigation measures can be implemented during field testing to limit scale build-up on injection and monitoring wells.

Once the desired ratio of calcium polysulfide is established, column testing using these ratios will be performed to mimic conditions in the field. A column test using ferrous sulfate will be performed if results of calcium polysulfide testing indicate that it is not a viable option for use at the Site. The column testing will use the existing PVC columns at UNLV that were built for previous testing of biodegradation of perchlorate and nitrate. Two columns will be used; one will be filled with soil from the proposed IRM area to mimic site conditions, and the other will use plastic media to mimic locations where the flowrates are high (e.g. paleochannels). The column study will

evaluate the flow conditions within the alluvium and UMCf. The columns will be fed by two containers, one with groundwater from the Site containing chromium and the other with calcium polysulfide at computed desired ratios and based on the results of the batch tests. The influent and effluent will be analyzed for total chromium and hexavalent chromium. Of major interest in the column testing is whether any scale is formed or whether the resulting sludge will result in clogging. Flow rate and pressure will be monitored during the column tests to evaluate whether clogging is formed. Degradation kinetics will also be evaluated by periodically sampling the water for chromium and perchlorate along three ports drilled in the columns.

3.2.4 Biological Reduction Test

Tetra Tech has selected emulsified oil (EOS®), blackstrap molasses, and industrial sugar wastewater as the three carbon substrates to be tested in the bench-scale biodegradation tests. Tetra Tech will coordinate the collection of a representative sample of the industrial sugar wastewater with a facility representative. Once the concentrations of chromium, perchlorate, nitrate, and chlorate are determined in the soil and groundwater, the amount of carbon substrate needed can be computed from stoichiometric biodegradation reactions. The presence of oxygen will also be measured and included in the stoichiometric demand calculations. The amount of nitrate and phosphate measured will be used to determine whether there are enough macronutrients to sustain biodegradation.

PRIMA (2011) reports that as much as 0.02 g EOS®/g of soil can be adsorbed to soils at the Site. Testing at UNLV has also resulted in similar values for some areas of the Site. The retention capacity of EOS® will be tested during the bench-scale test. There is currently no data on the use of molasses or industrial sugar wastewater at the Site. However, several reports note that chromium reduction requires the presence of relatively high concentrations of biomass (Wang & Changsong, 1995), and large additions of carbon substrate may be required to lower chromium concentrations at the Site to desired levels. In the screening test, an amount of electron donor equivalent to 100 times the stoichiometric demand (to provide a conservative safety factor) will be used. If the phosphate and nitrate concentrations measured are not sufficient, the test will modified to include a nutrient amendment.

Moisture needed for biodegradation is expected to be 35-45% by weight, based on the presence of silty soil. UNLV has previously performed batch testing for perchlorate degradation to support the groundwater bioremediation treatability test, using 30 g wet saturated soil and 100 g of water; or a water to soil ratio of 3.3:1. Therefore, the same ratio will be used for the biodegradation bench-scale test for chromium.

Batch biodegradation tests will be performed using blended soil and groundwater from the Site where the field biodegradation test will take place. No additional nutrients, nitrogen or phosphorus, will be added to the microcosms, except for the nutrient control to which only phosphorus will be added. Nitrate concentrations naturally present are likely sufficient to support the microbial nitrogen need for biodegradation. Nutrient requirement calculations will assume a typical bacterial cell composition of $C_5H_7O_2N$. Electron donor addition will be based on the relative COD of molasses, EOS® and industrial sugar wastewater. The COD of each electron donor will be measured before testing is performed. In the batch degradation tests, 30 g of wet soil, 100 ml of groundwater and the desired amount of electron donor (up to 100 times stoichiometric need) will be added to each bottle. The electron donor will be mixed with water to obtain the appropriate concentration. A suitable chemical agent, such as sodium metabisulfite, will be evaluated and utilized to scavenge the oxygen from water used to mix with the electron donor. The bottles will then be closed with a butyl rubber cap and crimped sealed with an aluminum ring.

At the established time intervals, the bottles will be taken out of the shaker, opened, and their contents will be extracted and analyzed for the contaminants of interest. The contents of each bottle will be transferred to a refrigerated centrifuge and extracted. Total and hexavalent chromium will be measured in all samples. Nitrate and perchlorate will only be measured during selected days.

Once it is determined which electron donor best promotes the degradation of chromium, a column test will be performed to determine the most suitable amount of electron donor to be added and evaluate the potential for

clogging. Three different ratios will be tested using the batch testing methods described above to determine the optimal ratio for the preferred carbon substrate. The optimal ratio will be used in the subsequent field test described in Section 4.0.

4.0 FIELD TEST CONCEPTUAL DESIGN

The conceptual design for the field test includes 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, may be modified or refined based on the results of the data collection and bench-scale testing described in Section 3.0. At the completion of the bench-scale test, one biological carbon substrate will be selected for further evaluation in the field test based on the overall effectiveness and feasibility (cost, hexavalent chromium reduction, limited scale/sludge formation, etc.).

The results of the chemical reduction bench-scale test will be used to design and implement a field test conducted as part of the soil flushing IRM.

4.1 OBJECTIVES

The objectives of the proposed chemical and biological field test are to accomplish the following:

- Evaluate the feasibility of chemical reduction to remediate hexavalent chromium-contaminated groundwater;
- Evaluate the amount of chemical injection required, injectability of the chemical solution into the different formations, the potential for scaling to occur, changes to pH in groundwater, and chemical mixing ratios;
- Evaluate the feasibility of in-situ bioremediation to remediate hexavalent chromium-contaminated groundwater;
- Estimate the zone of influence achieved in the subsurface during the field test;
- Evaluate the kinetics of contaminant degradation;
- Estimate or extrapolate the longevity of the biological carbon substrate and the frequency of carbon substrate replenishment, if required;
- Examine the approach for full-scale transect or grid treatment including equipment, injection, and monitoring well layout; substrate addition and replenishment; and analytical sampling evaluation criteria;
- Evaluate the proximity to the IWF that will allow in-situ treatment of chromium to be effective while avoiding biofouling or scaling of the IWF wells, and
- Estimate preliminary costs for full-scale implementation, if the field test is effective.

4.2 FIELD TEST LOCATION

The chemical reduction field test as currently envisioned will be located northwest of the AP-5 pond and approximately 200 feet upgradient of the IWF wells I-B, I-R, I-Y, I-L, I-S, and I-C. The final field test location along with the well layout will be determined as part of the AP Area IRM. Currently, four triple-nested injection wells located on approximately 40 feet centers are proposed as part of the soil up-flushing portion of the IRM, along with three triple-nested groundwater monitoring wells located approximately 40 feet downgradient of the injection wells. The triple-nested injection wells will be installed with one well screened within the alluvium, from approximately 30 to 35 feet bgs, and two wells screened within the UMCf, from approximately 40 to 45 feet bgs and 50 to 55 feet bgs, to allow for evaluating injection conditions in both formations. The exact number, locations, and well construction details of the proposed monitoring wells may be modified based on the results of slug tests, estimations of groundwater velocity, and other geological characteristics in the area.

The proposed bioremediation field test location is east of the Soil Flushing Treatability Test Area and approximately 640 feet upgradient of the IWF (Figure 4). This area was selected for the following reasons:

- Sufficient distance from the IWF to minimize potential for unintended migration of the carbon substrate (potential biofouling of the wells);
- Not located within a reported paleochannel (Figure 5) (Ramboll Environ, 2015a);
- High hexavalent chromium concentrations are expected to be present (Figure 6);
- Approximately 4.5 to 5 feet of groundwater is expected to be present within the alluvium based on recent borings located within the Soil Flushing Treatability Test Area (Tt-TP4-B1; Tt-TP4-B2; Appendix A);
- No significant structures are present;
- Located cross-gradient from the Soil Flushing Treatability Test Area; and
- Located within the area that will likely require full-scale treatment if the GWTP is bypassed.

The remainder of Section 4 presents the approach for the biological field testing.

4.3 LOCAL GEOLOGY AND HYDROGEOLOGY

4.3.1 Local Geology

There are two reported paleochannels within the alluvial deposits that cross the IWF in a north-northeast direction (Figure 5). Similar to the other reported paleochannels throughout the region, these paleochannels are inferred to have eroded into the surface of the Muddy Creek Formation during infrequent flood runoff periods with stream-deposited sands and gravels. The generally uniform sand and gravel deposits are narrow, vary in thickness, and exhibit higher permeability than the adjacent well-graded deposits. The two on-site paleochannels are presumed to meet together north of the Site and continue through the region towards the Las Vegas Wash. The nearest reported paleochannels appear to be approximately 200 feet to the east of the test plot (Ramboll Environ, 2015a).

The alluvial deposits generally range between 20 to 30 feet bgs at the Site (Ramboll Environ, 2015a). Soil types identified in on-site soil borings include poorly sorted gravel, silty gravel, poorly sorted sand, well sorted sand, and silty sand. The transitional Muddy Creek Formation is encountered at the base of the alluvium at some locations, and consists of reworked sediments derived from the Upper Muddy Creek Formation.

Similar to the regional Muddy Creek Formation lithology, the UMCf underlies the alluvium, and consists of interbedded fine-grained sediments (clay and silt representing the first and second fine-grained facies) and coarse-grained sediments (sand, silt, and gravel representing the first and second coarse-grained facies). The first fine-grained facies (UMCf-fg1) separates the first coarse-grained facies (UMCf-cg1) from the overlying alluvium at the Site. The Muddy Creek Formation subcrops beneath a veneer of Quaternary alluvium. The on-site borings have exhibited an appearance of a well-compacted, moderate brown silt-to-sandy silt or stiff clay-to-sandy clay between the Qal and UMCf-fg1 (Ramboll Environ, 2015a).

4.3.2 Local Hydrogeology

The depth to groundwater ranges from about 11 to 43 feet bgs and is generally deepest in the southern portion of the Site and becomes shallower to the north, toward the AWF (Ramboll Environ, 2015a). The direction of groundwater flow on the Site is generally north to north-northwest and then changes slightly to the northeast offsite. Local groundwater flow may be altered due to the subsurface paleochannels cutting into the underlying UMCf, the on-site barrier wall, and the IWF.

Groundwater in the proposed field test area flows generally north-northwest, following the slope of the ground surface (Figure 5). The average hydraulic gradient calculated in the area of the field test area for wells screened in the alluvium and/or UMCf was calculated to be 0.024 feet per foot.

Based on data collected from boreholes advanced at the Soil Flushing Treatability Test Area, groundwater in the vicinity of the biological test plot occurs in the alluvium and UMCf at depths ranging from 22 feet to 29 feet bgs (Tt-TP4-B1; Tt-TP4-B2; Appendix A).

Several hydrogeologic investigations have been performed at the Site since the early 1980s to obtain aquifer data (i.e. hydraulic conductivity [K], transmissivity [T], and storativity [S]) in support of groundwater remediation efforts. Aquifer tests performed include slug and baildown tests, constant rate pumping tests, step-drawdown tests, and recovery tests. Based on the results of these tests, the average hydraulic conductivity for the alluvium and UMCf was calculated to be 38.5 feet per day (ft/d) and 3.2 ft/d, respectively (Tronox, LLC, 2010) with hydraulic conductivity at wells in the immediate vicinity of the field test area ranging from 0.6 ft/d (extraction well I-G) to 55 ft/d (extraction well I-V).

The groundwater flow velocity was estimated for the alluvium and UMCf in the vicinity of the field test area in order to evaluate how quickly the proposed biological carbon substrate may pass through each area and subsequently design the monitoring well layout. Using the K values for nearby groundwater wells (M-15, M-17, I-N and I-X), a hydraulic gradient value of 0.024 feet per foot, and a porosity value ranging from 20% (KMCC, 1987) to 48% (ULNV; USDA soil textural classification look-up table values); (Clapp & Hornberger, 1978) (Rawls, Gimenez, & Grossman, 1998) (Saxton & Rawls, 2006)), the calculated groundwater velocity in the vicinity of the field test area varies from 0.49 ft/d to 5.0 ft/d. Based on groundwater wells with a saturated zone across both alluvium and UMCf (I-N and I-X) or mostly in the alluvium (M-15 and M-17), the groundwater velocity for the alluvium/UMCf and alluvium for the area is estimated to be approximately 0.49 to 3.4 ft/d and 1.2 to 5.0 ft/d, respectively.

The large variability of estimated groundwater flow velocity values indicates the large variability in lithology and physical soil properties within the vicinity of the field test area. Therefore, the preliminary well layouts will be adjusted as necessary after obtaining hydraulic conductivities through the slug tests and physical soil properties from soil sampling within the test plot.

4.4 CONCEPTUAL LAYOUT

This section describes the details of the injection wells and downgradient monitoring wells that will be installed to evaluate the effectiveness of the biological carbon substrate. The conceptual layouts and injection and monitoring well locations are provided in Figures 4 through 6. Well layout adjustments will be made, as necessary, following the completion of the initial slug tests and bench-scale tests.

4.4.1 Injection Well Layout

Currently, two dual-nested injection wells are proposed to be installed within the test plot, approximately 20 feet apart to allow for sufficient biological carbon substrate injection and horizontal spread across the test plot. The depth of the well screens will be determined in the field based on the lithology and depth to groundwater. At the test plot, the dual-nested injection wells will be installed with separate screened intervals in the alluvium and in the UMCf, if sufficient water is present, to allow for evaluating injection conditions in both formations. The injection wells will be constructed with two-inch diameter, Schedule 40 PVC with 0.010-inch slot size well screen and #2/16 filter pack, as discussed in Section 3.1.3; however, the slot size and filter pack may be adjusted based on the results of the soil physical parameter analyses. The number of injection wells and distances between injection wells will be finalized based on the results of the slug tests, bench-scale tests, geological characteristics in the area, and soil physical parameter analyses.

4.4.2 Performance Monitoring Wells

A monitoring well network will be installed within the test plot to evaluate the effectiveness of the biological carbon substrate at achieving the primary objective of reducing hexavalent chromium concentrations. Five monitoring

wells are proposed to be installed at various distances downgradient of the injection wells at the test plot to monitor for influence of the substrate injection, substrate travel time, chromium concentration reduction, and general groundwater parameters. The proposed well layout includes installation of monitoring wells located at distances of approximately 8, 15, 30, and 50 feet downgradient of the injection wells. These downgradient wells will be used to monitor the substrate travel time and remedy effectiveness. The field study should have minimal/negligible impact in the side-gradient directions and more impact in the downgradient direction. The exact number, locations, and well construction details of the proposed monitoring wells may be modified based on the results of the slug tests, estimations of groundwater velocity, and other geological characteristics in the area.

The monitoring wells will be constructed and screened similarly as the injection wells with two-inch diameter, Schedule 40 PVC and 0.010-inch slot size well screen (Figure 7). The slot size and filter pack may be adjusted based on the results of the soil physical parameter analyses. If conditions warrant the installation of dual-nested injection wells, as described in Section 4.4.1, some or all of the corresponding monitoring wells will also be dual nested. As discussed in Section 3.1.4, 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.

4.5 PRELIMINARY INJECTION DESIGN

The quantity of biological carbon substrate that will be injected within the test plot will be determined based on the results of the bench-scale tests, the known chemistry and geochemistry of the groundwater, and stoichiometric demand. The selected biological carbon substrate will be injected via gravity flow or pressure injected, if deemed necessary, using a mobile injection system consisting of a truck or trailer unit with storage tanks, a mixing tank, a manifold piping system and hoses supplied with valves and regulators for control and monitoring rates of injection (Figure 7). More specifically, the injection system will generally consist of the following:

- Storage tank(s) with approximately 500-gallon capacity;
- Trailer/truck-mounted mixing tank (approximately 500 to 1,000-gallon capacity) with an industrial-grade electric mixer;
- A transfer pump;
- Portable generator; and
- Associated piping/hoses, fittings, valves and instrumentation.

Prior to each injection, the injection solution will be prepared in a truck-mounted batch tank. A specified volume of stabilized Lake Mead water will be obtained from an on-site hydrant and pumped into the trailer mounted mixing tank along with a corresponding volume of biological carbon substrate to make the desired injection concentration. The injection solution will be prepared by thoroughly mixing the biological carbon substrate and water using the electric mixer in the mixing tank. The injection solution will then be gravity fed or pumped with a transfer pump to the injection wells through a manifold with hoses equipped with quick disconnect fittings. Chase water (stabilized Lake Mead water) may be used if necessary depending upon the carbon substrate selected. Injections will be performed within the UMCf prior to injecting into the Qal. Pressure gauges and a flow totalizer will be used to monitor the pressure and flow rates during injection. Based on the results of the bench-scale tests and performance monitoring, multiple injections may be required during the field test.

4.6 EFFECTIVENESS MONITORING PLAN

4.6.1 Baseline Monitoring

This section describes the conceptual monitoring program associated with groundwater monitoring to determine treatment effectiveness. Groundwater samples will be collected from the injection wells and monitoring wells in the test plot, and from nearby monitoring wells, to establish baseline conditions prior to the injections.

When development of the wells in the test plot is complete, the water level in each well will be allowed to recover to at least 90 percent of the static water level prior to collecting a groundwater sample. 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. 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 one hour of purging. Groundwater samples will be analyzed as outlined in Table 3.

4.6.2 Performance Monitoring

After injections have occurred, groundwater samples will be periodically collected from downgradient monitoring wells and analyzed for a variety of field and laboratory parameters. The proposed groundwater sampling protocol is summarized in Table 3 including the parameters to be analyzed, frequency, and methods. The monitoring frequency may be adjusted based on the results of the bench-scale and hydraulic conductivity testing. In addition, slug tests will be repeated at the end of the field test to examine any changes in hydraulic conductivity as a result of injections and geochemical processes.

Table 3 Biological Performance Monitoring Sampling Protocol

Analytical Requirements		Week								
Parameter	**Analytical Method**	**BL**	**1**	**3**	**5**	**7**	**12**	**16**	**20**	**24**
Field Parameters										
EC	Field Meter	X	X	X	X	X	X	X	X	X
pH	Field Meter	X	X	X	X	X	X	X	X	X
DO	Field Meter	X	X	X	X	X	X	X	X	X
ORP	Field Meter	X	X	X	X	X	X	X	X	X
Temperature	Field Meter	X	X	X	X	X	X	X	X	X
Turbidity	Field Meter	X	X	X	X	X	X	X	X	X
Laboratory Analyses										
Hexavalent Chromium	SW7199	X	X	X	X	X	X	X	X	X
Total Chromium	SW6010B or 6020	X	X	X	X	X	X	X	X	X
Alkalinity	E310.2	X	X	X	X	X	X	X	X	X
TOC	E415	X	X	X	X	X	X	X	X	X
Nitrate	E300/SW9056	X	X	X	X	X	X	X	X	X
Sulfate	E300/SW9056	X	X	X	X	X	X	X	X	X
Sulfide	HACH Method 8131	X	X	X	X	X	X	X	X	X
Total Nitrogen	E351.1	X	X	X	X	X	X	X	X	X
Total Phosphorus	E365.1	X	X	X	X	X	X	X	X	X
TDS	E160.1	X	X	X	X	X	X	X	X	X
Ferrous and Ferric Iron	HACH Method 8008 & 8147	X	X	X	X	X	X	X	X	X
Hardness	E130.1	X	X	X	X	X	X	X	X	X
Manganese	SW6010B	X	X	X	X	X	X	X	X	X
Dissolved Methane	EPA Method RSK175	X	X	X	X	X	X	X	X	X
Dissolved Metals	SW6010/6020	X	X	X	X	X	X	X	X	X

Analytical Requirements		Week								
Parameter	Analytical Method	BL	1	3	5	7	12	16	20	24
Volatile Fatty Acids	SW8015-Modified	X	X	X	X	X	X	X	X	X
Perchlorate	E314	X	X	X	X	X	X	X	X	X
Chlorate/Chlorite	E300.1	X	X	X	X	X	X	X	X	X
Chloride	E300/SW9056	X	X	X	X	X	X	X	X	X
PLFA	Microbial Insights Bio-Traps®	X				X				

Acronyms and Abbreviations:

BL: Baseline
EC: Electrical conductivity
DO: Dissolved Oxygen
ORP: Oxidation-reduction potential
TOC: Total organic carbon
TDS: Total dissolved solids

Dissolved metals includes the following: aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, uranium, vanadium, and zinc

4.6.3 Effectiveness Evaluation

The effectiveness of the treatability tests will be evaluated using the following factors:

- Hexavalent chromium concentration reduction;
- Redox potential;
- pH;
- Metal mobilization;
- Injection rates; and
- Changes in hydraulic conductivity.

4.7 PERMITTING REQUIREMENTS

4.7.1 NDEP – Underground Injection Control Program

The field test will require a Class V General Short-Term Remediation Underground Injection Control (UIC) permit, which will be necessary for the injection of the biological carbon substrate into the saturated subsurface. The UIC short-term general permit is issued by NDEP under Nevada Administrative Code (NAC) Section 445A.891 and is valid for a period of six months.

The permit application requires the 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.

As discussed in Section 4.5, more than one injection event may be required to demonstrate remedial effectiveness. If more than one injection event is anticipated, based on the results of the bench-scale tests, the biological reduction test may extend past 6 months and an application for a UIC General Permit for Long-Term Remediation may be necessary.

4.7.2 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 to install injection wells and monitoring wells. 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.

4.8 HEALTH AND SAFETY

Field work will be conducted in accordance with an Activity Hazard Analysis and other elements of the site-wide Health and Safety Plan, which will address potential chemical and physical hazards associated with the field test. It is anticipated that modified Level D personal protective equipment will be required for all field activities. Available chemical fact sheets and safety data sheets are provided in Appendix B and will be incorporated into the Health and Safety Plan.

5.0 REPORTING

Monthly status updates with detailed figures, tables, and schedules will be provided to the Trust summarizing the progress and results of the preliminary field and laboratory testing described in Section 3.0 along with refinement of the field test design, as needed.

Following completion of the field test, an In-situ Chromium Treatability Study Test Report will be prepared for NDEP and US EPA review and comment. The results of both the biological reduction testing described in this Work Plan and the chemical reduction field testing conducted as part of the IRM will be presented in the report. The report will include the following:

- Summary of soil and groundwater analytical results;
- Summary of bench-scale testing results;
- Evaluation of effectiveness in reducing hexavalent chromium-contaminated groundwater;
- Determination of degradation kinetics; and
- Preliminary cost-benefit analysis to determine the technology's feasibility and cost effectiveness for full-scale application and to identify a preliminary design and layout that is most feasible.

6.0 SCHEDULE

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

Table 4 Preliminary Project Schedule

Task/Milestone	Estimated Start Date	Estimated Completion Date
Initial Well Installation/Sample Collection	June 2016	June 2016
Bench-Scale Tests	July 2016	November 2016
Detailed Field Test Design	November 2016	December 2016
Biological Field Test	December 2016	July 2017
Treatability Study Test Report	July 2017	December 2017

7.0 REFERENCES

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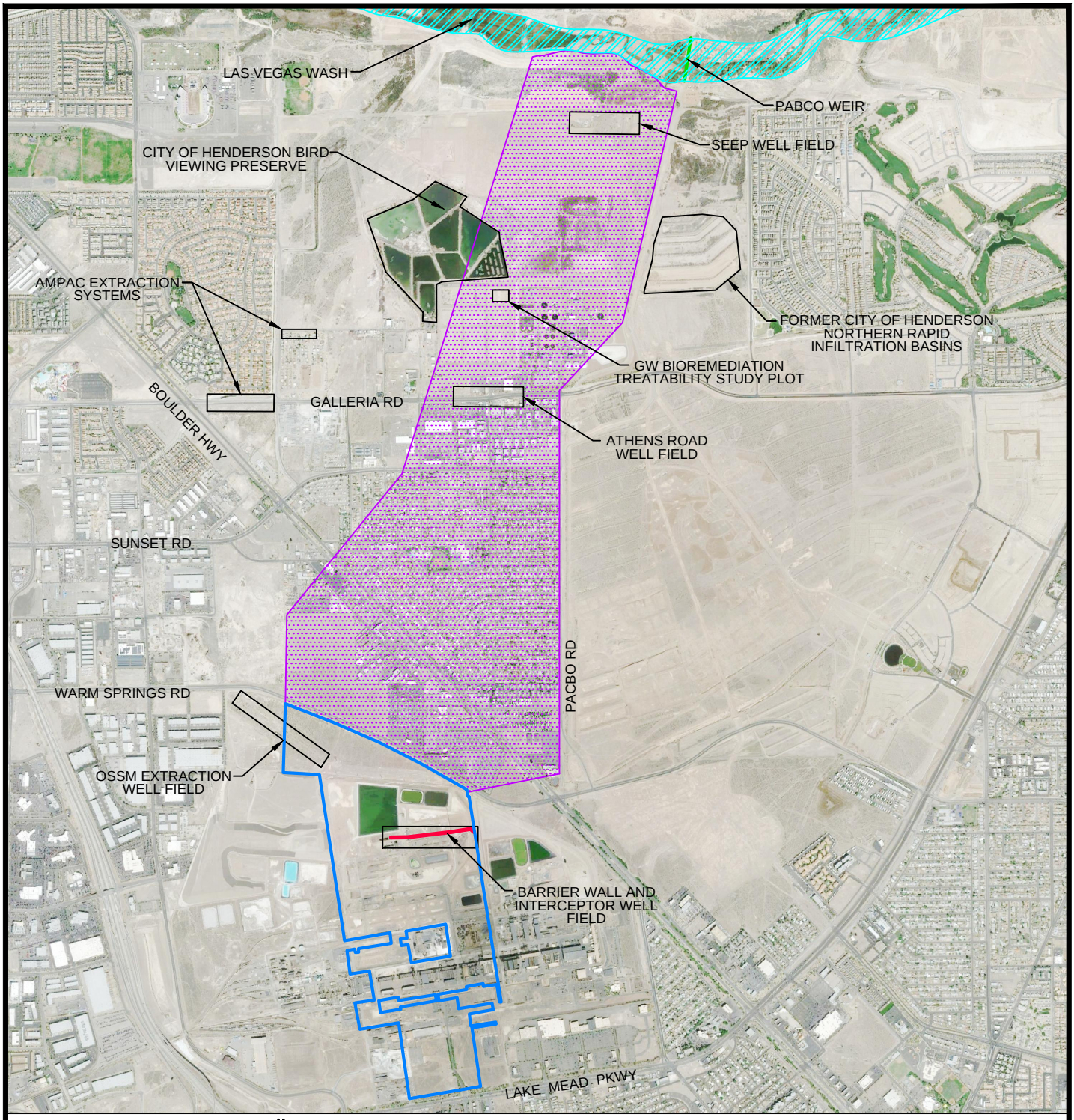
Figures



N

APPROXIMATE SCALE IN FEET

0 2,500 5,000

LEGEND

NERT SITE BOUNDARY

DOWN GRADIENT PLUME AREA

NOTES:

1. "LAS VEGAS, NV." MAP. GOOGLE EARTH PRO. GOOGLE, 22 MAR. 2015.
2. ALL LOCATIONS ARE APPROXIMATE.

SITE LOCATION MAP

NEVADA ENVIRONMENTAL RESPONSE TRUST HENDERSON, NV

PREPARED BY:

TETRA TECH, INC.

1489 WEST WARM SPRINGS ROAD, SUITE 110
HENDERSON, NEVADA 89014
Phone (702) 966-8340

PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
87600001	CL	WRI	MAY 2016	1

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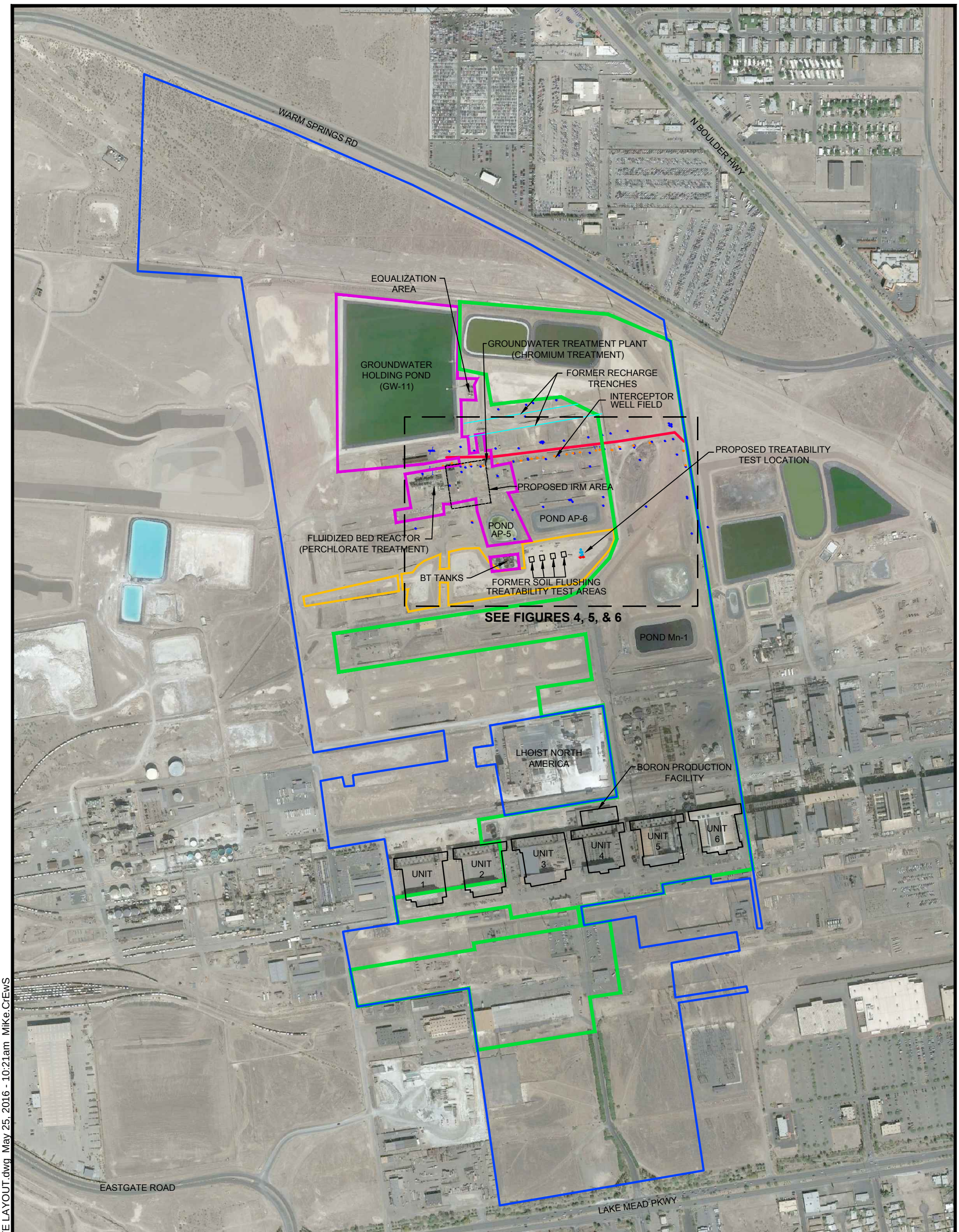

P:\87600001-NERT - L07\CAD\FIGURE 2 - SITE LAYOUT.dwg May 25, 2016 - 10:21am MiKe.CrEwS

LEGEND

- NERT SITE BOUNDARY
- TRONOX OPERATIONAL AREA
- GWETS OPERATIONAL AREA
- CENTRAL RETENTION BASIN
- GROUNDWATER BARRIER WALL
- M-14A MONITORING WELL
- I-G EXTRACTION WELL
- PROPOSED MONITORING WELL
- PROPOSED INJECTION WELL

N

APPROXIMATE SCALE IN FEET

0 600 1,200

NOTES:

1. "LAS VEGAS, NV." MAP. GOOGLE EARTH PRO. GOOGLE, 22 MAR. 2015.
2. ALL LOCATIONS ARE APPROXIMATE.

SITE LAYOUT

NEVADA ENVIRONMENTAL RESPONSE TRUST — HENDERSON, NEVADA

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PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
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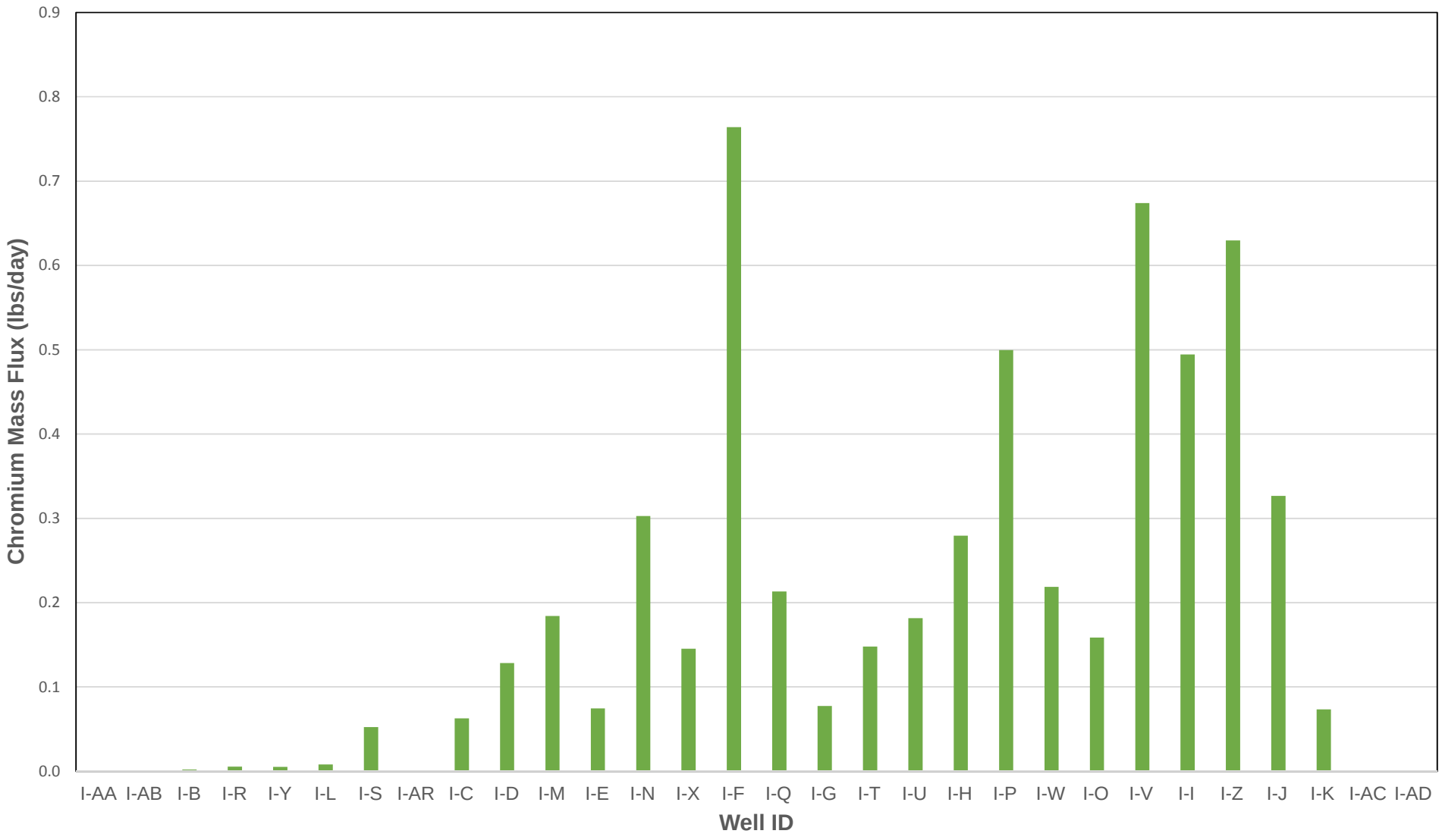

CHROMIUM MASS FLUX AT INTERCEPTOR WELL FIELD
NEVADA ENVIRONMENTAL RESPONSE TRUST
HENDERSON, NV

SOURCE: 2014-2015 ANNUAL PERFORMANCE REPORT (RAMBOLL ENVIRON, 2015)

PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
87600001	CL	JRL	MAY 2016	3

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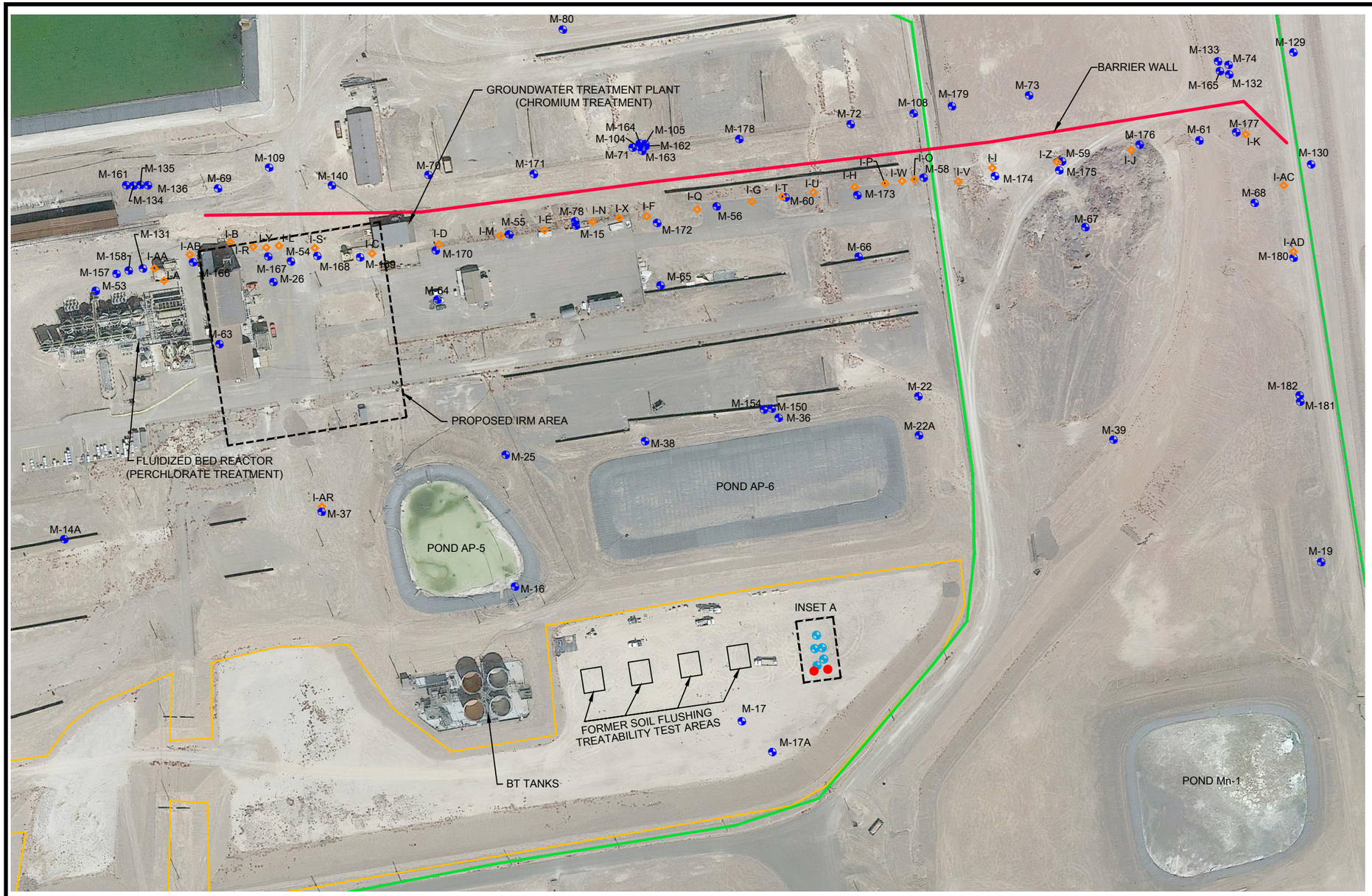

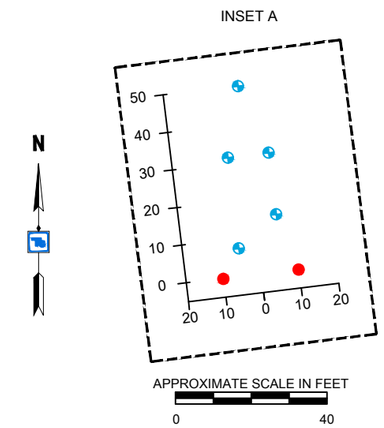

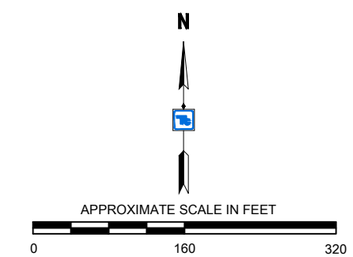

NOTES:
1. "LAS VEGAS, NV." MAP. GOOGLE EARTH PRO. GOOGLE, 22 MAR. 2015.
2. ALL LOCATIONS ARE APPROXIMATE.

REFERENCE:
1. 2014-2015 ANNUAL PERFORMANCE REPORT (RAMBOLL ENVIRON, 2015)

LEGEND

- TRONOX OPERATIONAL AREA
- CENTRAL RETENTION BASIN
- GROUNDWATER BARRIER WALL
- M-14A MONITORING WELL
- I-G EXTRACTION WELL
- PROPOSED MONITORING WELL
- PROPOSED INJECTION WELL

PROPOSED TREATABILITY TEST LOCATION

NEVADA ENVIRONMENTAL RESPONSE TRUST — HENDERSON, NEVADA

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PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
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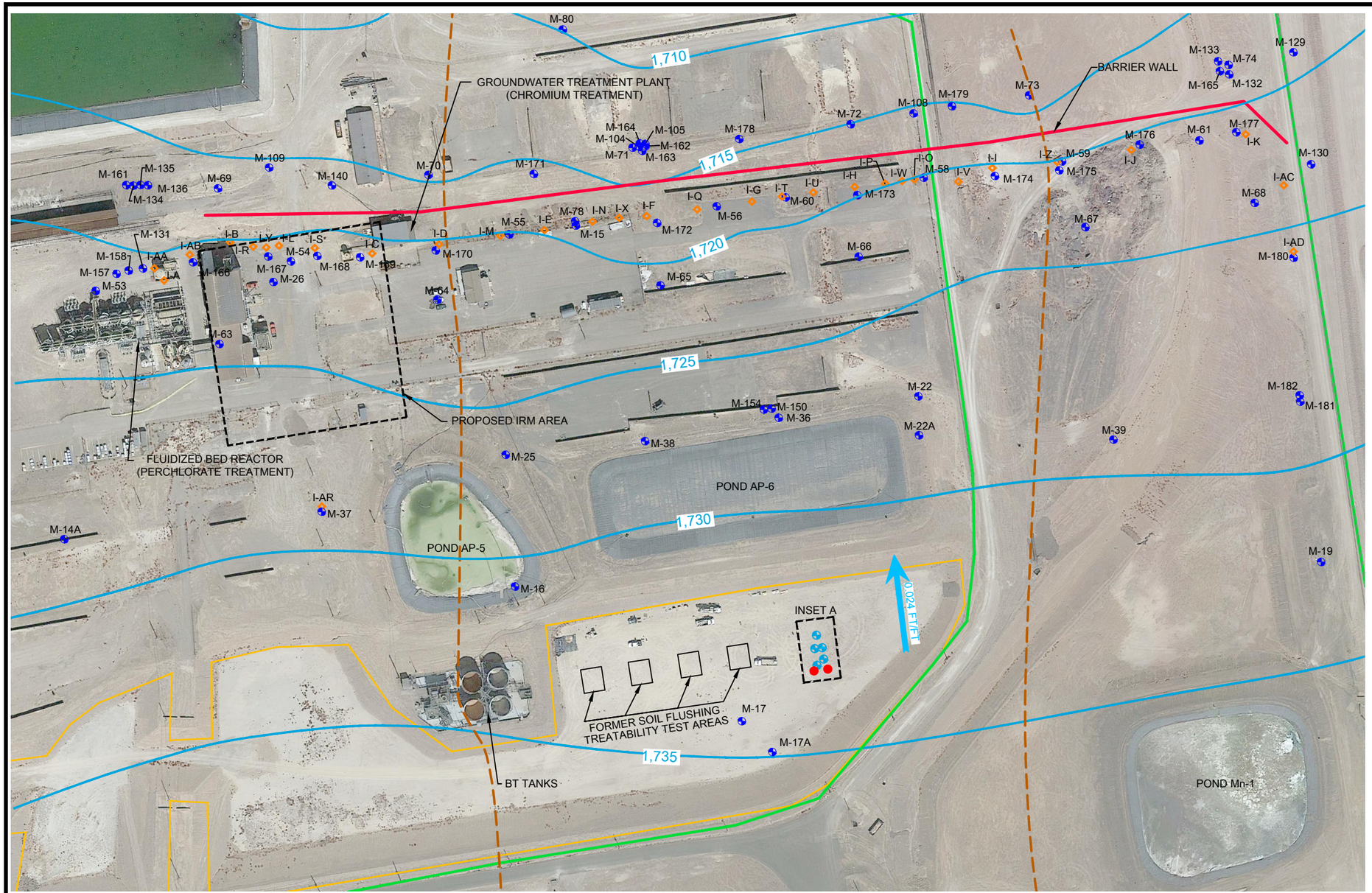

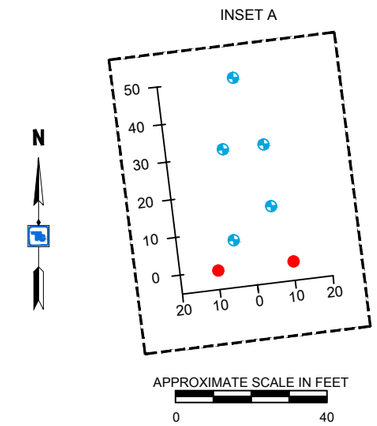

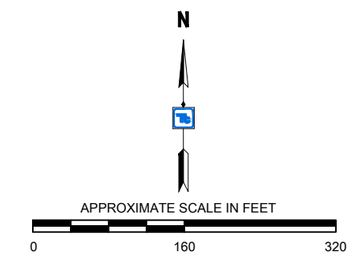

NOTES:

1. "LAS VEGAS, NV." MAP. GOOGLE EARTH PRO. GOOGLE, 22 MAR. 2015.
2. ALL LOCATIONS ARE APPROXIMATE.
3. ONLY SHALLOW WATER BEARING ZONE MONITORING AND EXTRACTION WELLS USED IN CONTOURING.

REFERENCE:

1. 2014-2015 ANNUAL PERFORMANCE REPORT (RAMBOLL ENVIRON, 2015)

LEGEND

- TRONOX OPERATIONAL AREA
- CENTRAL RETENTION BASIN
- GROUNDWATER BARRIER WALL
- M-14A MONITORING WELL
- I-G EXTRACTION WELL
- PROPOSED MONITORING WELL
- PROPOSED INJECTION WELL
- 1720 APPROXIMATE POTENTIOMETRIC SURFACE CONTOUR (FEET ABOVE MEAN SEA LEVEL)
- 0.024 FT/FT APPROXIMATE GROUNDWATER DIRECTION GROUNDWATER GRADIENT
- APPROXIMATE LOCATION OF PALEOCHANNELS (RAMBOLL ENVIRON, 2015)

POTENTIOMETRIC SURFACE MAP WITH PROPOSED TREATABILITY TEST LOCATION

NEVADA ENVIRONMENTAL RESPONSE TRUST — HENDERSON, NEVADA

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PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
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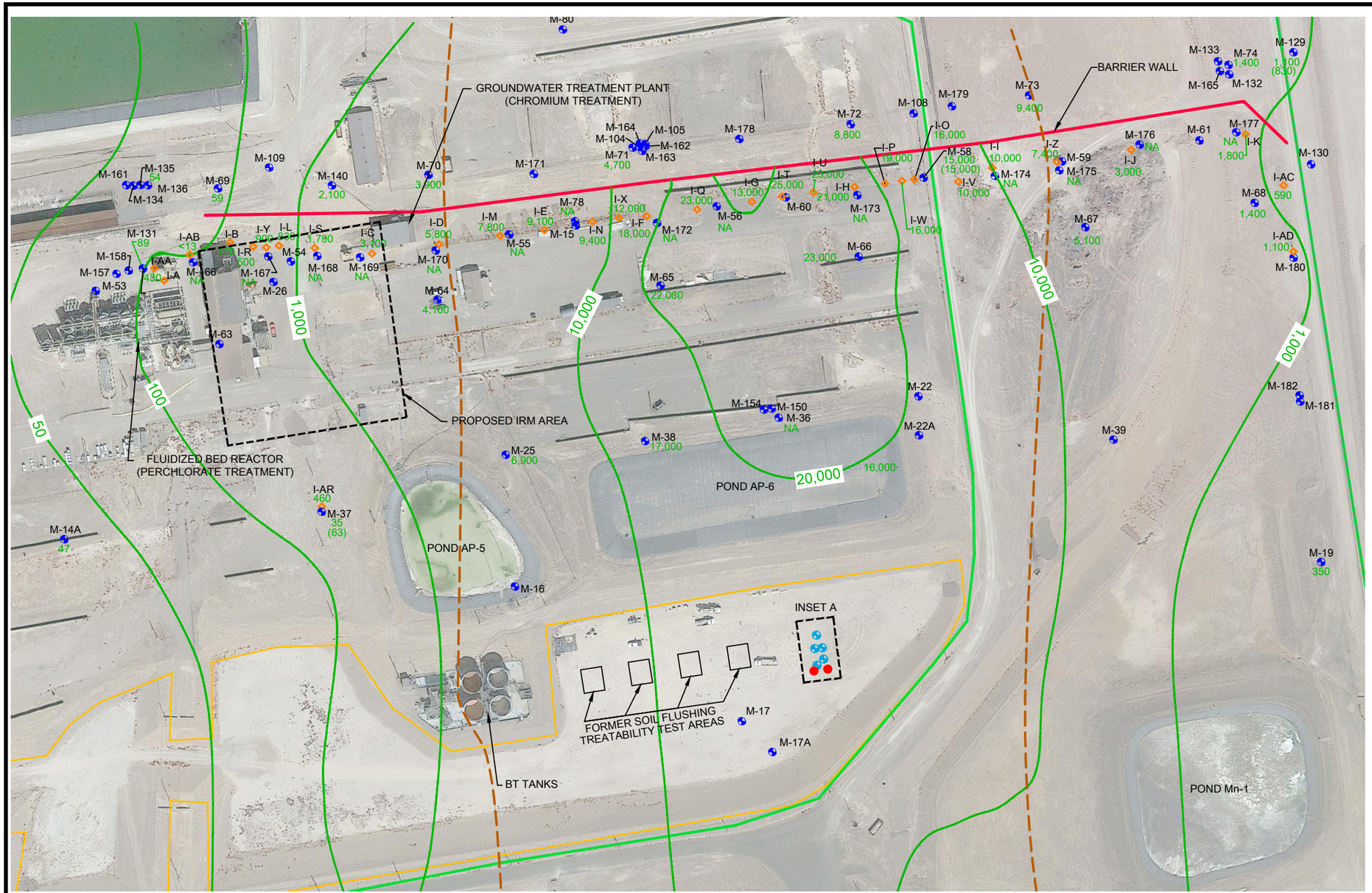

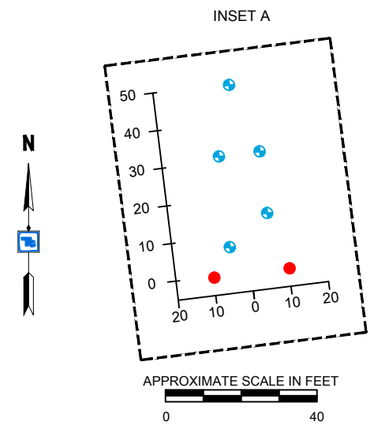

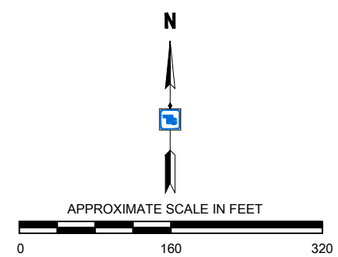

NOTES:

1. "LAS VEGAS, NV." MAP. GOOGLE EARTH PRO. GOOGLE, 22 MAR. 2015.
2. ALL LOCATIONS ARE APPROXIMATE.
3. ALL CHROMIUM CONCENTRATIONS IN MICROGRAMS PER LITER (µg/L).
4. ONLY SHALLOW WATER BEARING ZONE MONITORING AND EXTRACTION WELLS USED IN CONTOURING.

REFERENCE:

1. 2014-2015 ANNUAL PERFORMANCE REPORT (RAMBOLL ENVIRON, 2015)

LEGEND

	TRONOX OPERATIONAL AREA	100	APPROXIMATE TOTAL CHROMIUM CONTOUR (µg/L)
	CENTRAL RETENTION BASIN	23,000	TOTAL CHROMIUM CONCENTRATION (µg/L)
	GROUNDWATER BARRIER WALL	(15,000)	HEXAVALENT CHROMIUM CONCENTRATION (µg/L)
M-14A	MONITORING WELL	µg/L	MICROGRAMS PER LITER
I-G	EXTRACTION WELL	NA	NOT ANALYZED
	PROPOSED MONITORING WELL		APPROXIMATE LOCATION OF PALEOCHANNELS (RAMBOLL ENVIRON, 2015)
	PROPOSED INJECTION WELL		

TOTAL CHROMIUM MAP WITH PROPOSED TREATABILITY TEST LOCATION

NEVADA ENVIRONMENTAL RESPONSE TRUST — HENDERSON, NEVADA

PREPARED BY:
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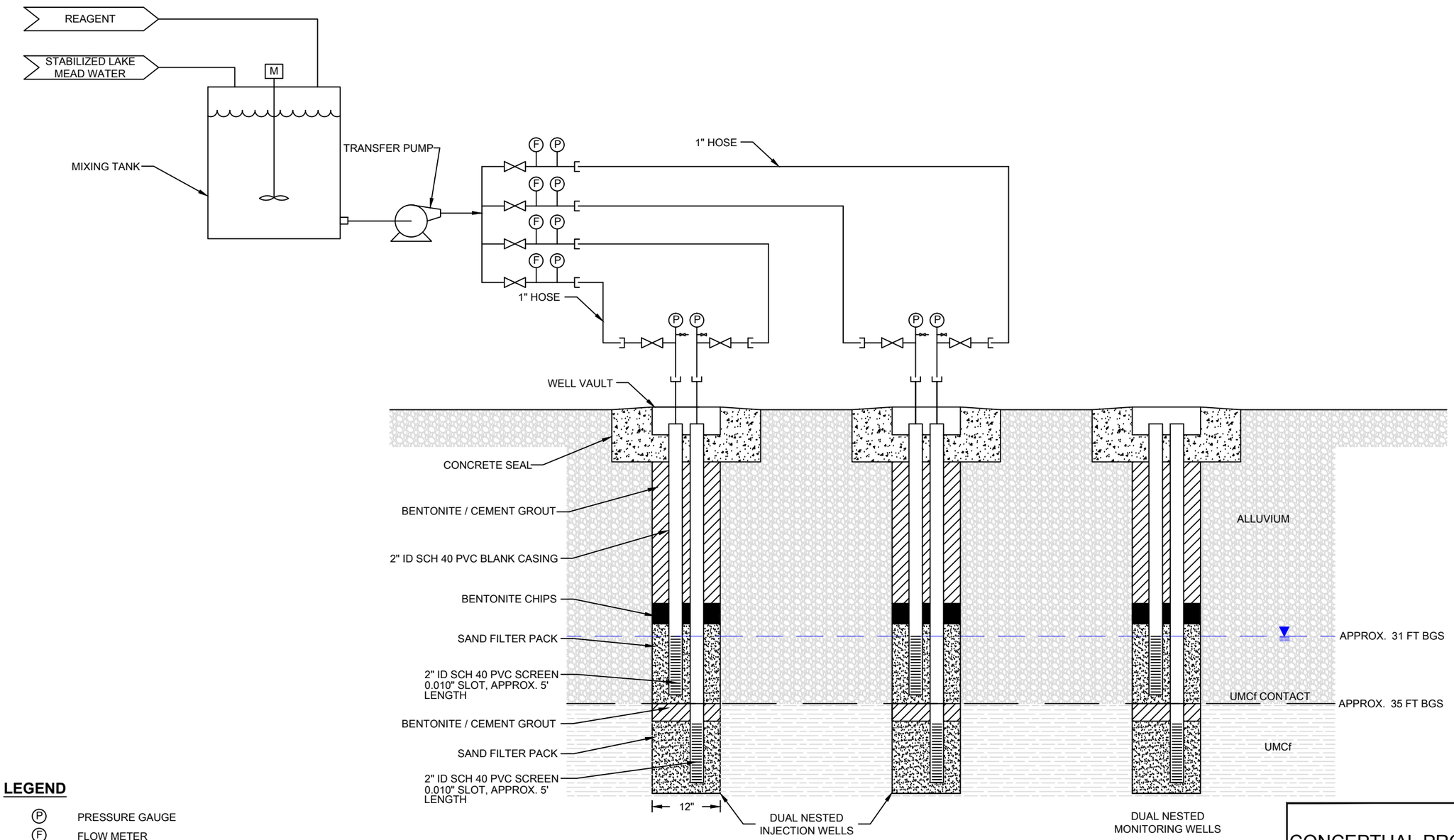
HENDERSON, NEVADA 89014
Phone (702) 966-8340

PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
87600001	CL	WRI	MAY 2016	6

P:\87600001-NERT - L07\CAD\FIG 6 CHROMIUM.dwg May 25, 2016 - 10:25am Mike.CrEwS



LEGEND

Ⓟ	PRESSURE GAUGE
Ⓕ	FLOW METER
	VALVE - GATE
	QUICK-CONNECT UNION
	AIR BLEED VALVE
	GROUNDWATER LEVEL
UMCf	UPPER MUDDY CREEK FORMATION
FT BGS	FEET BELOW GROUND SURFACE

NOTE: ACTUAL WELL CASING DEPTH AND SLOT SIZE TO BE DETERMINED BASED ON FIELD DATA.

DRAWING NOT TO SCALE

CONCEPTUAL PROCESS FLOW DIAGRAM

NEVADA ENVIRONMENTAL RESPONSE TRUST — HENDERSON, NEVADA

PREPARED BY:
TETRA TECH, INC.
1489 WEST WARM SPRINGS ROAD, SUITE 110
HENDERSON, NEVADA 89014
Phone (702) 966-8340

PROJECT NUMBER	APPROVED BY	DRAWN BY	DATE	FIGURE
87600001	CL	WRI	MAY 2016	7

P:\87600001-NERT - L07\CAD\FIGURE 7 - CONCEPTUAL PROCESS FLOW DIAGRAM_dual nested.dwg May 20, 2016 - 1:24pm joel.lagade

Appendix A
Relevant Boring Logs

BORING LOG Tt-TP4-B1

Project	: NERT-Soil Flushing Pilot	Borehole Depth	: 27 ft.	Sampling Method	: Split Spoon
Location	: Henderson, NV	Borehole Diameter	: 8 in.	Northing Coord. (ft)	: TBA
Project No.	: 100-SBO-T35000.M05	Drilling Contractor	: Gregg Drilling	Easting Coord. (ft)	: TBA
Logged By	: D. Manriquez	Drilling Method	: HSA	Surface Elev. (ft MSL)	: TBA
Date Boring Started	: 3/19/2015	Date Completed	: 3/19/2015	TOC Elev. (ft MSL)	: TBA

Well:
Elev.:

Depth (feet bgs)	Sample Interval	Blow Count	Recovery (%)	Time	Lab No.	USCS	GRAPHIC	DESCRIPTION	PID (ppm)
0								SILTY SAND: About 5% fine gravel (~1/4 to 1/2"); 60% sand, mostly fine grained with little medium and some coarse grained; about 35% silt. Brown (7.5 YR 5/3), poorly graded, dense, moist. (ALLUVIUM) Sample collected using a hand auger.	
2	☒	--	100	1435	Tt-TP4-B1-2				0.0
4									
6	☒	14 50	100	1443	Tt-TP4-B1-6			Very dense	0.0
8									
10	☒	27 50	100	1446	Tt-TP4-B1-10	SM			0.6
12									
14	☒	37 50	100	1452	Tt-TP4-B1-14			About 5% fine gravel; 70% sand, some fine to coarse grained; about 25% silt. Brown (7.5 YR 4/4).	0.0
16									
18	☒	24 33 50	100	1500	Tt-TP4-B1-18			About 10% fine gravel; 60% sand, some fine and coarse grained with little medium grained; about 30% silt.	0.1
20									

BORING LOG Tt-TP4-B1

Project	: NERT-Soil Flushing Pilot	Borehole Depth	: 27 ft.	Sampling Method	: Split Spoon
Location	: Henderson, NV	Borehole Diameter	: 8 in.	Northing Coord. (ft)	: TBA
Project No.	: 100-SBO-T35000.M05	Drilling Contractor	: Gregg Drilling	Easting Coord. (ft)	: TBA
Logged By	: D. Manriquez	Drilling Method	: HSA	Surface Elev. (ft MSL)	: TBA
Date Boring Started	: 3/19/2015	Date Completed	: 3/19/2015	TOC Elev. (ft MSL)	: TBA

Well:
Elev.:

Depth (feet bgs)	Sample Interval	Blow Count	Recovery (%)	Time	Lab No.	USCS	GRAPHIC	DESCRIPTION	PID (ppm)
20									
22	X	31 50	100	1504	Tt-TP4-B1-22	SM		About 80% sand, mostly coarse grained with some medium and few coarse grained; about 20% silt. Brown (7.5 YR 5/3), poorly graded, very dense, wet. Brown (7.5 YR 4/4) at 22.5 feet.	0.0
24									
26	X	37 50	100	1509	Tt-TP4-B1-26	ML		About 55% sand, mostly fine grained with some medium and few coarse grained; about 45% silt. Brown (7.5 YR 5/4).	0.0
28								SILT: About 70% silt and 30% clay. Brown (7.5 YR 5/4), high to medium plasticity, hard, wet. (UPPER MUDDY CREEK FORMATION) Total Depth: 27 ft.	
30									
32									
34									
36									
38									
40									

BORING LOG Tt-TP4-B2

Project	: NERT-Soil Flushing Pilot	Borehole Depth	: 27.5 ft.	Sampling Method	: Split Spoon
Location	: Henderson, NV	Borehole Diameter	: 8 in.	Northing Coord. (ft)	: TBA
Project No.	: 100-SBO-T35000.M05	Drilling Contractor	: Gregg Drilling	Easting Coord. (ft)	: TBA
Logged By	: D. Manriquez	Drilling Method	: HSA	Surface Elev. (ft MSL)	: TBA
Date Boring Started	: 3/20/2015	Date Completed	: 3/20/2015	TOC Elev. (ft MSL)	: TBA

Well:
Elev.:

Depth (feet bgs)	Sample Interval	Blow Count	Recovery (%)	Time	Lab No.	USCS	GRAPHIC	DESCRIPTION	PID (ppm)
0						SM		SILTY SAND: About 10% fine gravel (~1/4 t. 3/4"); 55% sand, mostly fine grained with little medium and coarse grained; about 35% silt. Brown (7.5 YR 5/4), poorly graded, very dense, moist. (ALLUVIUM)	
2	X	--	100	0802	Tt-TP4-B2-2			Sample collected using a hand auger.	0.0
4									
6	X	28 50	100	0808	Tt-TP4-B2-6			Fine gravel (~1/4")	0.0
8									
10	X	18 50	90	0817	Tt-TP4-B2-10			Trace coarse gravel (~2")	0.0
12									
14	X	32 50	90	0821	Tt-TP4-B2-14			About 10% fine gravel; 65% sand, some fine and coarse grained with little medium grained; about 25% silt.	0.0
16									
18	X	13 18 29	100	0825	Tt-TP4-B2-18	SM		SILTY SAND WITH GRAVEL: About 15% fine gravel (~1/4 t. 1/2"); 65% sand, mostly coarse grained with little medium and some coarse grained; about 20% silt. Brown (7.5 YR 4/3), poorly graded, dense, moist.	0.0
20									

BORING LOG Tt-TP4-B2

Project	: NERT-Soil Flushing Pilot	Borehole Depth	: 27.5 ft.	Sampling Method	: Split Spoon
Location	: Henderson, NV	Borehole Diameter	: 8 in.	Northing Coord. (ft)	: TBA
Project No.	: 100-SBO-T35000.M05	Drilling Contractor	: Gregg Drilling	Easting Coord. (ft)	: TBA
Logged By	: D. Manriquez	Drilling Method	: HSA	Surface Elev. (ft MSL)	: TBA
Date Boring Started	: 3/20/2015	Date Completed	: 3/20/2015	TOC Elev. (ft MSL)	: TBA

Well:
Elev.:

Depth (feet bgs)	Sample Interval	Blow Count	Recovery (%)	Time	Lab No.	USCS	GRAPHIC	DESCRIPTION	PID (ppm)
20									
22	X	27 50	100	0831	Tt-TP4-B2-22	SM		About 20% fine gravel (~1/4 t. 3/4"); 60% sand, mostly coarse grained with little fine and some medium grained; about 20% silt. Brown (7.5 YR 5/3), poorly graded, very dense, moist.	0.0
24									
26	X	18 27 32	100	0837	Tt-TP4-B2-26	ML		SILT: About 5% sand; 75% silt and 20% clay. Brown (7.5 YR 5/4), low plasticity, hard, wet. (UPPER MUDDY CREEK FORMATION)	0.0
28									
30									
32									
34									
36									
38									
40									

Total Depth: 27.5 ft.

05-26-2015 P:\GIS\QuickLog\BoringLogs\Nevada\Tt-TP4-B2.bor

Appendix B
Chemical Fact Sheets and Safety Data Sheets

Material Safety Data Sheet

Calcium polysulfide solution

MSDS Number 6100 (Revised: 4/29/02) 6 Pages

Section 1: CHEMICAL PRODUCT and COMPANY IDENTIFICATION

1.1 Product Name ..... **Calcium polysulfide solution**
Chemical Family ..... Inorganic salt solution
Synonyms ..... Calcium polysulfide, CaPS, calcium sulfide, lime sulphur
Formula ..... CaS_x

1.2 Manufacturer ..... Tessenderlo Kerley Inc.
2255 N. 44th Street, Suite 300
Phoenix, Arizona 85008-3279
Information ..... (602) 889-8300

1.3 Emergency Contact ..... (800) 877-1737 (Tessenderlo Kerley)
(800) 424-9300 (CHEMTREC)

Section 2: COMPOSITION, INFORMATION ON INGREDIENTS

2.1 Chemical Ingredients (% by wt.)

Calcium polysulfide	CAS #:1344-81-6	29%
Water	CAS #:7732-18-5	71%

(See Section 8 for exposure guidelines)

Section 3: HAZARDS IDENTIFICATION

NFPA: Health - 3 Flammability - 0 Reactivity - 1

EMERGENCY OVERVIEW

Warning:
Avoid inhalation of product fumes (hydrogen sulfide) near openings on storage container. Release of the product to the environment may cause the evolution of highly toxic hydrogen sulfide vapors. Product solution is very alkaline and corrosive to the skin. Eye contact will cause severe eye irritation and possible corneal damage. Ingestion will result in corrosion of tissues and the release of hydrogen sulfide in the gastrointestinal tract.

Section 3: HAZARDS IDENTIFICATION (Cont.)

3.1 POTENTIAL HEALTH EFFECTS

EYE: Contact with the eyes by product mist or solution will cause irritation and a burning sensation. Eye contact may result in severe corneal injury.

SKIN CONTACT: Contact with product mist or solution will cause skin irritation and may result in corrosion of the skin.

SKIN ABSORPTION: Absorption is unlikely to occur.

INGESTION: Ingestion of product solution will cause irritation and corrosion of the gastrointestinal tract to include nausea, vomiting and diarrhea. Contact with stomach acid will cause highly toxic hydrogen sulfide to evolve.

INHALATION: Inhalation of product vapors (hydrogen sulfide) may cause dizziness and unconsciousness possibly resulting in serious falls from elevated positions..

CHRONIC EFFECTS/CARCINOGENICITY: Not listed as a carcinogen by NTP, IARC or OSHA.

Section 4: FIRST AID MEASURES

4.1 EYES: Immediately flush with large quantities of water for 15 minutes. Hold eyelids apart during irrigation to insure thorough flushing of the entire area of the eye and lids. Obtain immediate medical attention.

4.2 SKIN: Immediately flush with large quantities of water. Remove contaminated clothing under a safety shower. Obtain immediate medical attention.

4.3 INGESTION: DO NOT INDUCE VOMITING. If victim is conscious, immediately give large quantities of water. If vomiting does occur, continue to give fluids. Obtain immediate medical attention.

4.4 INHALATION: Remove victim from contaminated atmosphere. If breathing is labored, administer oxygen. If breathing has ceased, clear airway and start mouth to mouth resuscitation. If heart has stopped beating, external heart massage should be applied. Obtain immediate medical attention.

Section 5: FIRE FIGHTING MEASURES

5.1 FLAMMABLE PROPERTIES

FLASH POINT: Not flammable (See Section 5.4) **METHOD USED:** NA

5.2 FLAMMABLE LIMITS **H_2S** **LFL**: 4% **UFL**: 44%

5.3 EXTINGUISHING MEDIA: Water spray or foam or as appropriate for combustibles involved in fire.

Section 5: FIRE FIGHTING MEASURES (Cont.)

5.4 FIRE & EXPLOSIVE HAZARDS: When heated or diluted, hydrogen sulfide vapors will evolve. This gas may form explosive mixtures with air. (See Section 5.2) Keep containers/storage vessels in fire area cooled with water spray.

5.5 FIRE FIGHTING EQUIPMENT: Because of the possible presence of toxic gases and the corrosive nature of the product, wear self-contained breathing apparatus, positive pressure, (MSHA/NIOSH approved or equivalent) and full protective gear.

Section 6: ACCIDENTAL RELEASE MEASURES

6.1 Small releases: Confine and absorb small releases on sand, earth or other inert absorbent. Released material may contain residual sulfides. Spray with weak (~5%) hydrogen peroxide to oxidize sulfides.

6.2 Large releases: Confine area to qualified personnel. Wear proper protective equipment. Shut off release if safe to do so. Dike spill area to prevent runoff into sewers, drains (possible toxic or explosive mixtures) or surface waterways (potential aquatic toxicity). Spray product vapors with fine water spray or mist. Recover as much of the solution as possible. Treat remaining material as a small release (above).

Section 7: HANDLING and STORAGE

7.1 Handling: Handle in enclosed containers to avoid breathing product. Avoid contact with skin and eyes. Dilute only in enclosed containers. Use in a well ventilated area. Wash thoroughly after handling.

7.2 Storage: Store in well ventilated areas in enclosed containers. Do not store combustibles in the area of storage vessels. Keep away from any sources of heat or flame. Store tote, drums and small containers out of direct sunlight at moderate temperatures [<90ºF (32ºC)]. (See Section 10.4 for materials of construction)

Section 8: EXPOSURE CONTROLS, PERSONAL PROTECTION

8.1 RESPIRATORY PROTECTION: Wear self-contained breathing apparatus, positive pressure, MSHA/NIOSH (approved or equivalent).

8.2 SKIN PROTECTION: Gloves, boots, and chemical suit should be worn to prevent liquid contact. Wash contaminated clothing prior to reuse. Contaminated shoes cannot be cleaned and should be discarded

8.3 EYE PROTECTION: Chemical goggles and a full face shield.

8.4 EXPOSURE GUIDELINES:

	OSHA		ACGIH	
	TWA	STEL	TLV	STEL
Hydrogen sulfide	20 ppm (ceiling)		10 ppm (ceiling)	

8.5 ENGINEERING CONTROLS: Use adequate exhaust ventilation to prevent inhalation of product vapors. Maintain eyewash/safety shower in areas where chemical is handled.

Section 9: PHYSICAL and CHEMICAL PROPERTIES

9.1 APPEARANCE:	Deep-red-orangish brown liquid
9.2 ODOR:	Strong order of rotten eggs
9.3 BOILING POINT:	Not determined
9.4 VAPOR PRESSURE:	Not determined (Believed to be minimal)
9.5 VAPOR DENSITY:	Not determined
9.6 SOLUBILITY IN WATER:	Dissolves with precipitation of elemental sulfur.
9.7 SPECIFIC GRAVITY:	1.27 (10.6 lbs/gal)
9.8 FREEZING POINT:	Not determined
9.9 pH:	11.0 - 11.9
9.10 VOLATILE:	Not applicable

Section 10: STABILITY and REACTIVITY

10.1 STABILITY: This is a stable material

10.2 HAZARDOUS POLYMERIZATION: Will not occur.

10.3 HAZARDOUS DECOMPOSITION PRODUCTS: Heating this product will evolve hydrogen sulfide vapors. Continued heating will also cause oxides of sulfur to be released.

10.4 INCOMPATIBILITY: Strong oxidizers such as nitrates, nitrites or chlorates can cause explosive mixtures if heated to dryness. Acids, acidic materials or dilution with water will cause the release of hydrogen sulfide, a highly toxic gas.

Section 11: TOXICOLOGICAL INFORMATION

11.1 ORAL: Data not available

11.2 DERMAL: Data not available

11.3 INHALATION: Data not available

11.4 CHRONIC/CARCINOGENICITY: No evidence available

11.5 TERATOLOGY: Data not available

11.6 REPRODUCTION: Data not available

11.7 MUTAGENICITY: Data not available

Section 12: ECOLOGICAL INFORMATION

No data available.

Section 13: DISPOSAL CONSIDERATIONS

If released to the environment for other than its intended purpose, this product should be checked to see it meets the criteria of a D002, Corrosive waste. In addition the product contains some reactive sulfides but not a sufficient quantity to meet the definition of a D003, Reactive waste.

Section 14: TRANSPORT INFORMATION

14.1 DOT Shipping Name:	Corrosive liquid, toxic, n.o.s.
14.2 DOT Hazard Class:	8
14.3 UN/NA Number:	2922
14.4 Packing Group:	II
14.5 DOT Placard:	Corrosive
14.6 DOT Label(s):	Corrosive
14.7 IMO Shipping Name:	Corrosive liquid, toxic, n.o.s.
14.8 RQ (Reportable Quantity):	Not applicable
14.9 RR STCC Number:	

Section 15: REGULATORY INFORMATION

15.1 OSHA: This product is listed as a hazardous material under criteria of the Federal OSHA Hazard Communication Standard, 29 CFR 1910.1200.

15.2 SARA TITLE III:

a. **EHS** (Extremely Hazardous Substance) List: No

b. Section 311/312, (Tier I,II) Categories:

Immediate (acute)	Yes
Fire	No
Sudden release	No
Reactivity	Yes
Delayed (chronic)	No

c. Section 313 (Toxic Release Reporting-Form R): No

Chemical Name	CAS Number	Concentration

15.2 SARA TITLE III: (Cont.)

d. **TPQ** (Threshold Planning Quantity): No

15.3 CERCLA/SUPERFUND: RQ (Reportable Quantity) No

Section 15: REGULATORY INFORMATION (Cont.)

15.4 TSCA (Toxic Substance Control Act) Inventory List:	Yes	
15.5 RCRA (Resource Conservation and Recovery Act) Status:		Possible D002 (See Section 13)
15.6 WHMIS (Canada) Hazard Classification:		E, D2B
15.7 DOT Hazardous Material: (See Section 14)	Yes	
15.8 CAA Hazardous Air Pollutant (HAP)		No

Section 16: OTHER INFORMATION

REVISIONS: The entire MSDS was reformatted to comply to ANSI Standard Z400.1-1993, by Technical Services-Tessenderlo Kerley, Inc.

Address updated, 4/30/99
Section 8.3, Eye Protection revised and logo revised, 4/29/02

THE INFORMATION PUBLISHED IN THIS MATERIAL SAFETY DATA SHEET HAS BEEN COMPILED FROM OUR EXPERIENCE AND OSHA, ANSI, NFPA, DOT, ERG, AND CHRIS. IT IS THE USER'S RESPONSIBILITY TO DETERMINE THE SUITABILITY OF THIS INFORMATION FOR THE ADOPTION OF NECESSARY SAFETY PRECAUTIONS. WE RESERVE THE RIGHT TO REVISE MATERIAL SAFETY DATA SHEETS PERIODICALLY AS NEW INFORMATION BECOMES AVAILABLE.

MATERIAL SAFETY DATA SHEET
Ferrous Sulfate (5% Fe^{2+})

SECTION 1: CHEMICAL PRODUCT AND COMPANY INFORMATION

Manufacturer's Name and Address:

ALTIVIA Chemicals, LLC
1100 Louisiana, Ste. 4800
Houston, TX 77002
USA • (713) 658-9000

Product Name:	**Ferrous Sulfate 5%**		
Synonyms:	Iron (II) Sulfate	**Molecular Formula:**	$FeSO_4 \bullet 7H_20$
CAS #:	7720-78-7	**Preparation Date (M/D/Y):**	10/16/2012
Control #:	A 2904	**Revision Date (M/D/Y):**	01/06/2014
Product Use:	Water and wastewater treatment		

EMERGENCY CONTACTS (24 HR)

TRANSPORTATION EMERGENCIES – CHEMTREC: (800) 424-9300

SECTION 2: COMPOSITION / INFORMATION ON INGREDIENTS

		Exposure Limits			
Hazardous Ingredient(s)	**% (w/w)**	**OSHA (PEL)**	**ACGIH (TLV)**	**Carcinogen**	**CAS NO.**
Ferrous Sulfate	25 +/- 5	1 mg/m^3 Fe (TWA)	1 mg/m^3 Fe (TWA)		7720-78-7
Sulfuric Acid	< 0.25	1 mg/m^3 (TWA)	0.2 mg/m3 thoracic fraction (TWA)	IARC 1 ACGIH A2	7664-93-9

SECTION 3: HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

APPEARANCE AND ODOR:

Color: greenish-blue
Appearance: liquid
Odor: slightly acidic

STATEMENTS OF HAZARD:

WARNING! IRRITATING TO EYES, SKIN, RESPIRATORY AND DIGESTIVE TRACTS

POTENTIAL HEALTH EFFECTS

EFFECTS OF EXPOSURE:
Oral LD50 (Mouse) 1520 mg/kg

Refer to TOXICOLOGICAL INFORMATION (Section 11) for additional information.

SECTION 4: FIRST AID MEASURES

Ingestion: Never give anything by mouth to an unconscious person. Obtain medical attention. Do not induce vomiting. Administer 250 – 300 ml water to dilute material in the stomach.

Skin Contact: In case of skin contact, wash affected areas of skin with soap and water. If skin irritation persists, call a physician.

Eye Contact: Rinse immediately with plenty of water for at least 15 minutes. Obtain medical advice if there are persistent symptoms.

Inhalation: If breathing has stopped, trained personnel should administer artificial respiration. If the heart has stopped, trained personnel should administer CPR. Remove to fresh air. If breathing is difficult, give oxygen. Obtain medical advice if there are persistent symptoms.

SECTION 5: FIRE FIGHTING MEASURES

Suitable Extinguishing Media: Use extinguishing media appropriate for the surrounding fire. This material will not burn easily.

Protective Equipment: Wear full firefighting protective clothing. See MSDS Section 8 (Exposure Controls/Personal Protection). Firefighters and others exposed, wear self-contained breathing apparatus.

Special Hazards: Sulfur oxides and/or toxic and flammable hydrogen sulfide may be formed under fire conditions. Keep unnecessary people away.

Mechanical/Static Sensitivity Statements: None

NOTE: Also see “Section 10 – Stability and Reactivity”

SECTION 6: ACCIDENTAL RELEASE MEASURES

Personal precautions: Where exposure level is not known, wear approved, positive pressure, self-contained respirator. Where exposure level is known, wear approved respirator suitable for level of exposure. Refer to Section 8 (Exposure Controls/Personal Protection) for appropriate personal protective equipment.

Methods for Cleaning Up:
Cover spills with some inert absorbent. Sweep up into containers for disposal.

Environmental Precautions:
Use appropriate containment to avoid environmental contamination. Prevent water contaminated with this product from entering drains, sewers or streams, growing crops/keeping animal areas, and site of native flora and fauna.

SECTION 7: HANDLING AND STORAGE

HANDLING
Precautionary Measures: Do not get in eyes. Handle with caution. Wash thoroughly after handling. See MSDS for details.

Special Handling Statements: Review the label, this MSDS and any other applicable information before use. Keep separated from incompatible substances. Use appropriate Personal Protective Equipment per Section 8. Handle only with equipment, materials and supplies specified by their manufacturer as being compatible and appropriate for use with this product.

STORAGE
Prevent material from coming in contact with common metals. Ensure that all storage vessels are labeled. Avoid skin and eye contact. Wear appropriate protective clothing. Store only in dry rubber-lined, plastic, FRP or stainless steel (304,316). Keep storage temperatures between 10° and 30°C. Store away from incompatible materials such as alkalis. Keep smaller containers (drums and totes) tightly closed when not in use or when empty. Product should be used within one year. Storage facilities should have secondary containment as required by law or regulation. Storage tanks, piping and offloading points should be labeled with appropriate signage to avoid accidents.
Containers of this material may be hazardous when empty since they retain product residues (vapors, liquid); observe all warnings and precautions listed for the product.

SECTION 8: EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Measures: A ventilation system of local/general exhaust is recommended to keep employee exposure below the Airborne Exposure Limits. Ensure that eyewash station and safety showers are proximal to the workstation location.

Respiratory Protection: Where exposures are below the established exposure limit, no respiratory protection is required. Where exposures exceed the established exposure limit, use respiratory protection recommended for the material and level of exposure.

Eye Protection: Provide eye wash fountain and safety shower in close proximity to points of potential exposure. Wear eye/face protection such as chemical splash proof goggles or face shield. Prevent eye and skin contact.

Skin Protection: Prevent contamination of skin or clothing when removing protective equipment. Wear impermeable gloves and suitable protective clothing.

Additional Advice: Before eating, drinking, or smoking wash face and hands thoroughly with soap and water. Food, beverages, and tobacco products should not be carried, stored, or consumed where this material is in use.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Color	Greenish – blue
Appearance	Liquid
Odor	Slightly Acidic
Boiling Point	105-110°C (220-230°F)
Melting Point	Not Available
Vapor Pressure	Not Available
Specific Gravity	1.12 – 1.18 @ 25°C
Percent Volatile (% by wt.)	~50
pH	>2.0
Saturation by Air (% by Vol.)	Not Available
Evaporation Rate	Similar to water
Solubility in Water	Soluble
Volatile Organic Content	Not Applicable
Flash Point	Not Applicable
Flammable Limits (% by Vol.)	Not Applicable
Autoignition Temperature	Not Applicable
Decomposition Temperature	Not Applicable
Partition coefficient (n-octanol/water)	Not Applicable
Odor Threshold	Not Available

SECTION 10: STABILITY AND REACTIVITY

Stability: Stable.

Conditions to Avoid: Avoid contact with mineral acids, excessive heat and bases/alkalis.

Polymerization: Will not occur.

Conditions to Avoid: None known.

Materials to Avoid: Carbon steel, brasses, and nylon.

Hazardous Decomposition Products: Thermal decomposition; after completely dry and heated to decomposition will produce oxides and sulfur.

SECTION 11: TOXICOLOGICAL INFORMATION

For additional toxicological information, refer to Section 3. Toxicological information on the regulated components of this product is as follows:

Ferrous sulfate has oral (rat) LD50 value of 237 mg/kg. Direct contact may cause severe eye and moderate skin irritation. Inhalation overexposure may cause irritation of the respiratory tract.

The acute oral (rat) LD50 and acute 1-hour inhalation (rat) for sulfuric acid are 2,140 mg/kg and 347 ppm (0.348 mg/L/4hr), respectively. Sulfuric acid is corrosive to the skin and eyes. Concentrated sulfuric acid can also be corrosive to the nose, mucous membranes, respiratory tract and gastrointestinal tract. Inhalation of the vapors or mist can cause pulmonary edema, emphysema or permanent changes in pulmonary function. Chronic exposure has been reported to be associated with dermatitis, chronic bronchitis, gastritis, erosion of dental enamel, conjunctivitis, increased frequency of respiratory tract infections and cancer of the larynx, lungs and upper respiratory tract.

SECTION 12: ECOLOGICAL INFORMATION

No aquatic LC50, BOD, or COD data available.

SECTION 13: DISPOSAL CONSIDERATIONS

The information on RCRA waste classification and disposal methodology provided below applies only to the product, as supplied. If the material has been altered or contaminated, or it has exceeded its recommended shelf life, the guidance may be inapplicable. Hazardous waste classification under federal regulations (40 CFR Part 261 et seq) is dependent upon whether a material is RCRA 'listed hazardous waste' or has any of the four RCRA 'hazardous waste characteristics.' Refer to 40 CFR Part 261.33 to determine if a given material to be disposed of is a RCRA 'listed hazardous waste'; information contained in Section 15 of this MSDS is not intended to indicate if the product is a 'listed hazardous waste.' RCRA Hazardous Waste Characteristics: There are four characteristics defined in 40 CFR Section 261.21-61.24: Ignitability, Corrosivity, Reactivity, and Toxicity. To determine Ignitability, see Section 9 of this MSDS (flash point). For Corrosivity, see Sections 9 and 14 (pH and DOT corrosivity). For Reactivity, see Section 10 (incompatible materials). For Toxicity, see Section 2 (composition). Federal regulations are subject to change. State and local requirements, which may differ from or be more stringent than the federal regulations, may also apply to the classification of the material if it is to be disposed. ALTIVIA Chemicals, LLC encourages the recycle, recovery and reuse of materials, where permitted, as an alternate to disposal as a waste. ALTIVIA Chemicals, LLC recommends that organic materials classified as RCRA hazardous wastes be disposed of by thermal treatment or incineration at EPA approved facilities. ALTIVIA Chemicals, LLC has provided the foregoing for information only; the person generating the waste is responsible for determining the waste classification and disposal method.

SECTION 14: TRANSPORT INFORMATION

This section provides basic shipping classification information. Refer to appropriate transportation regulations for specific requirements.

US DOT

Proper Shipping Name: Corrosive liquid, acidic, inorganic, n.o.s.
Hazard Class: 8
Packing Group: III
UN/ID Number: UN3264
Transport Label Required: Corrosive
Technical Name (N.O.S.): Contains ferrous sulfate
Hazardous Substances:

Component/CAS No.	Reportable Quantity of Product (lbs)
Ferrous sulfate	~4000 lbs. (Ferrous Sulfate RQ=1000 lbs)

SECTION 15: REGULATORY INFORMATION

INVENTORY INFORMATION

United States (USA): This product is manufactured in compliance with all provisions of the Toxic Substances Control Act, 15 U.S.C. 2601 et. seq.

OTHER ENVIRONMENTAL INFORMATION
The following components of this product may be subject to reporting requirements pursuant to Section 313 of CERCLA (40 CFR 372), Section 12(b) of TSCA, or may be subject to release reporting requirements (40 CFR 307, 40 CFR 311, etc.) See Section 13 for information on waste classification and waste disposal of this product.

Component / CAS No.	%	TPQ (lbs)	RQ (lbs)	S313	TSCA 12B
Ferrous Sulfate 7720-78-7	~ 25 +/- 5	None	1000	No	No
Sulfuric Acid	< 0.25	1000	1000	Yes	No

PRODUCT HAZARD CLASSIFICATION UNDER SECTION 311 OF SARA

- Acute

SECTION 16: OTHER INFORMATION

The information provided in this Material Safety Data Sheet has been obtained from sources believed to be reliable. ALTIVIA Chemicals, LLC provides no warranties either expressed or implied and assumes no responsibility for the accuracy or completeness of the data contained herein. This information is offered for your information, consideration, and investigation. You should satisfy yourself that you have all current data relevant to your particular use. ALTIVIA Chemicals, LLC knows of no medical condition, other than those noted on this material safety data sheet, which are generally recognized as being aggravated by exposure to this product.

National Fire Protection Association (NFPA) Rating
Hazardous Materials Identification System (HMIS) Rating

	NFPA	HMIS
HEALTH	2	2
FIRE	0	0
REACTIVITY / INSTABILITY	0	0
SPECIAL HAZARDS	N/Ap	N/Ap

4 = Extreme/Severe
3 = High/Serious
2 = Moderate
1 = Slight
0 = Minimum
W = Water Reactive
OX = Oxidizer
* = Chronic Health Hazard

Emergency Information:

Call toll free 24 hours a day: 800-424-9300

For Any Other Information Contact:

ALTIVIA Chemicals, LLC, Technical Marketing, 1100 Louisiana, Suite 4800, Houston, TX 77002.

Phone: 713-658-9000

8 AM – 5 PM CST, Monday through Friday

EOS Remediation, LLC

Experience you can rely on, Products you can trust™

EOS 100

PRODUCT INFORMATION SHEET

Emulsified Oils Family

Description

EOS 100 is a water-mixable vegetable oil based organic substrate which provides a long-lasting source of carbon for enhanced *in situ* anaerobic bioremediation. EOS 100 is shipped as a concentrate; simply mix with water to instantly create an injection-ready oil solution.

EOS 100 benefits:

- 100% fermentable
- Contains no water to reduce freight costs
- Employs the proven EOS® technology
- Longer shelf-life than competing emulsion products
- Greater oil retention – excellent for barrier applications or high velocity aquifers

Domestic supply *made in the USA* with US farmed soybeans.

USDA CERTIFIED BIOBASED PRODUCT PRODUCT 96%

Chemical & Physical Properties

Oil Concentrate: EOS 100	Typical
Organic Carbon (% by wt.)	100
Refined and Bleached US Soybean Oil (% by wt.)	85
Slow Release Organics (% by wt.)	15
Specific Gravity	0.92 - 0.93
Mass of Hydrogen Produced (lbs. H_2 per lb. EOS 100)	0.40

Packaging

Shipped in 55-gallon drums, 275-gallon IBC totes or bulk tankers (40,000 lbs.)

Handling & Storage

EOS 100 is shipped as concentrated oil that is diluted with water in the field to prepare a solution for easy injection. EOS 100 has a low viscosity and can be distributed with commonly available pumps or by continuous metering with a diluter (e.g., Dosatron™). Dilution ratios for EOS 100 typically range from 4:1 to 20:1 (water: EOS 100) depending on site conditions. EOS 100 injections should be followed with additional chase water to maximize distribution of EOS 100 into the formation.

EOS 100 has a shelf-life of ≥ 2 years depending on storage conditions.

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EOS 100

SAFETY DATA SHEET

Section 1: Identification	
Product Name:	EOS 100
Chemical Description:	Mixture; vegetable oil-based
Manufacturer:	EOS Remediation 1101 Nowell Road Raleigh, NC 27607 (P): 919-873-2204
Recommended Use:	Groundwater Bioremediation (environmental applications)
Restricted Use:	Not for human consumption
24-Hour Emergency Contact:	ChemTel: United States (P): 800-255-3924 ChemTel: International (P): 813-248-0585

Section 2: Hazard(s) Identification	
Hazard Classification:	Irritant (eye and skin)
Signal Word:	Warning
Hazard Statement(s):	Potential eye and skin irritant.
Pictograms:	
Precautionary Statement(s):	Not for human consumption. Protect from freezing. Do not store near excessive heat or oxidizers. Avoid contact with eyes and skin. Wear protective gloves and eye protection.

Section 3: Composition/Information on Ingredients		
Common Name(s)	**CAS NO.**	**% by Weight**
Soybean Oil	8001-22-7	85
Emulsifiers Trade Secret[1,2]	Proprietary	15

1 – The precise composition of this product is proprietary information. A more complete disclosure will be provided to a physician in the event of a medical emergency.
2 – The soluble substrates and emulsifiers are generally recognized as safe for food contact.

Section 4: First-Aid Measures	
Routes of Exposure	**Emergency First-Aid Procedures**
Inhalation	Remove to fresh air.
Eye Contact	Flush with water for 15 minutes; if irritation persists see a physician.
Dermal	Wash with mild soap and water.
Ingestion	Product is non-toxic. If nausea occurs, induce vomiting and seek medical attention.

Section 5: Fire-Fighting Measures	
Extinguishing Media:	CO_2, foam, dry chemical Note: Water, fog and foam may cause frothing and spattering.
Special Fire Fighting Procedures:	Wear self-contained breathing apparatus and chemical resistant clothing. Use water spray to cool fire exposed containers.
Fire Hazard(s):	Burning will cause oxides of carbon.

Section 6: Accidental Release Measures	
Personal Precautions:	Avoid contact with eyes and skin. Do not consume.
Emergency Procedures:	N/A
Methods & Materials used for Containment:	Compatible granular absorbent
Cleanup Procedures:	Spread compatible granular absorbent over spill area and sweep using broom and pan; dispose in appropriate receptacle. Clean area with water.

Section 7: Handling and Storage	
Safe Handing & Storage:	Do not store near excessive heat or oxidizers.
Other Precautions:	Consumption of food and beverages should be prevented in work area where product is being used. After handling product, always wash hands and face thoroughly with soap and water before eating, drinking, or smoking.

Section 8: Exposure Controls/Personal Protection		
Exposure Limits		
OSHA PEL:	Vegetable Oil Mist	15 mg/m^3 (total) 5 mg/m^3 (respirable)
ACGIH TLV:	NE	NE
NIOSH REL:	Vegetable Oil Mist	10 mg/m^3 (total) 5 mg/m^3 (respirable)
Personal Protective Measures		
Respiratory Protection:	Not normally required. P95 respirator if aerosols might be generated.	
Hand Protection:	Protective gloves are recommended	
Eye Protection:	Recommended	
Engineering Measures:	Local exhaust ventilation if aerosols are generated	
Hygiene Measures:	Wash promptly with soap & water if skin becomes irritated from contact.	
Other Protection:	Wear appropriate clothing to prevent skin contact.	

NE – Not Established

Section 9: Physical and Chemical Properties			
Appearance:	Pale Yellow	Explosive Limits:	NE
Odor:	Vegetable Oil	Vapor Pressure:	NE
Odor Threshold:	NE	Vapor Density:	Heavier than air
pH:	NE	Relative Density:	0.92-0.93
Melting Point/Freezing Point:	Liquid at room temperature	Solubility:	Easily soluble & dispersible
Boiling Point:	N/A	Partition coefficient:	NE
Flash Point:	>600°F (316°C)	Auto-ignition Temperature:	NE
Evaporation Rate:	NE	Decomposition Temperature:	N/A
Flammability (solid, gas):	NE	Viscosity:	50 cP

NE – Not Established
N/A – Non-Applicable

Section 10: Stability and Reactivity	
Stability:	Stable
Incompatibility:	Strong acids and oxidizers
Hazardous Decomposition Products:	Thermal decomposition may produce oxides of carbon
Hazardous Reactions/Polymerization:	Will not occur
Conditions to Avoid:	None known

Section 11: Toxicological Information		
Likely Routes of Exposure:		Ingestion, dermal and eye contact
Signs and Symptoms of Exposure:		None known
Health Hazards		
	Acute:	Potential eye and skin irritant
	Chronic:	None known
Carcinogenicity		
	NTP:	No
	IARC:	No
	OSHA:	No

Section 12: Ecological Information (non-mandatory)
There is no data on the ecotoxicity of this product.

Section 13: Disposal Considerations (non-mandatory)	
Waste Disposal Methods:	Dispose of according to Federal and local regulations for non-hazardous waste.

Section 14: Transport Information (non-mandatory)
The product is not covered by international regulation on the transport of dangerous goods.
No transport warning required.

Section 15: Regulatory Information (non-mandatory)
N/A

Section 16: Other Information	
Date of Preparation:	29 May 2014
Last Modified Date:	5 September 2014
The information contained herein is based on available data and is believed to be correct. However, EOS Remediation, LLC makes no warranty, expressed or implied, regarding the accuracy of this data or the results to be obtained thereof. This information and product are furnished on the condition that the person receiving them shall make his/her own determination as to the suitability of the product for his/her particular purpose.	

MATERIAL SAFETY DATA SHEET **Blackstrap Molasses**

SECTION 1: CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

1.1 Product Name:	**Blackstrap Molasses**
Common Name:	**Molasses**
Chemical Description:	**Inverted syrup from the juice of sugar cane**

1.2 Manufactured For:	Plant Food Company, Inc.	***Emergency Telephone Number***	609-448-0935
	38 Hightstown-Cranbury Station Road	***Telephone Number for Information***	609-448-0935
	Cranbury, NJ 08512	**Date Prepared** 11/1/2011	

SECTION 2: COMPOSITION/INFORMATION ON INGREDIENTS

Hazardous Components (Specific Chemical)

Identity: Common Name	(CAS #)	OSHA PEL	ACGIH TLV	Other Limits Recommended
This product is a mixture--no specific CAS number	#REF!	N/A	N/A	N/A

SECTION 3: HAZARDS IDENTIFICATION

Black/brown liquid with typical odor.

NEPA: Health:0 Reactivity:0 Flammability:1 Environment:0 (0=Insignificant=1 Slight 2=Moderate 3=High 4=Extreme)

EMERGENCY OVERVIEW

This material is not a 'health hazard' or a "physical hazard" as determined when reviewed according to the requirements of the Occupational Safety and Health Administration Hazard Communication Standard, 20 CFR 1910.1200

SECTION 4: FIRST AID MEASURES

4.1 EYES: Flush immediately with plenty of water for at least 15 minutes while holding eyelids apart to ensure complete irrigation of all eye and lid tissue. If irritation occurs, seek medical attention.

4.2 SKIN: Wash with plenty of soap and water. Remove contaminated clothing and shoes. Get medical attention if irritation persists.

4.3 INGESTION: If conscious and alert, administer water or milk to dilute, then induce vomiting. Call Poison Control Center or physician immediately. Do not give anything by mouth to an unconscious person.

4.4 INHALATION: Remove victim to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth and get medical attention.

SECTION 5: FIREFIGHTING MEASURES

5.1 FLAMMABLE PROPERTIES
FLASHPOINT: Not flammable METHOD USED: Closed Cup/NONCOMBUSTIBLE

5.2 FLAMMABLE LIMITS: LFL: NA UFL: NA

5.3 EXTINGUISHING MEDIA: Foam, carbon dioxide, dry chemical, or water fog.

5.4 FIRE & EXPLOSIVE HAZARDS: Not Combustible

5.5 FIRE FIGHTING EQUIPMENT: As in any fire, wear self-contained breathing apparatus, pressure demand, MSHA/NIOSH (approved or equivalent) and full protective gear. Avoid smoke inhalation. Contain any liquid runoff.

SECTION 6: ACCIDENTAL RELEASE MEASURES

6.1 SMALL RELEASES: Confine and absorb small releases on sand earth or other inert absorbent. Use water spray to dilute .

6.2 LARGE RELEASES: Shut off release if safe to do so. Dike spill area to prevent runoff into sewers, rains or surface waterways. Recover as much of the solution as possible. Treat remaining material as a small release (above).

SECTION 7: HANDLING AND STORAGE

7.1 HANDLING: Avoid contact with eyes. Use only in a well ventilated area. Wash thoroughly after handling. Avoid prolonged or repeated breathing of vapors. Avoid prolonged or repeated contact with the skin.

7.2 STORAGE: Store in original container only in a cool, well-ventilated, dry place at temperatures between 40° and 95°F. Do not store near food or feeds.

7.3 TRANSER EQUIPMENT: Transfer product using chemical-resistant plastic or stainless steel tanks, pumps, valves, etc.

SECTION 8: EXPOSURE CONTROLS, PERSONAL PROTECTION

8.1 RESPIRATORY PROTECTION: Not normally needed. If use generates an aerosol mist or respiratory irritation, use NIOSH-approved dust/moist respirator (such as 3M#8710).Ventilation: Where air contaminants can exceed acceptable criteria, use NIOSH/MSHA approved respiratory protection equipment. Respirators should be selected based on the form and concentration of contaminate.

8.2 SKIN PROTECTION: Neoprene rubber groves and apron should be worn to prevent repeated or prolonged contact with the liquid. Wash contaminated clothing prior to reuse.

8.3 EYE PROTECTION: Chemical goggles and a full face shield. DO NOT WEAR CONTACT LENSES.

8.4 EXPOSURE GUIDELINES:	**TWA**	**STEL**
OSHA	N/A	N/A
ACGIH	N/A	N/A

8.5 ENGINEERING CONTROLS: Use adequate exhaust ventilation to prevent inhalation of product vapors.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

9.1 APPEARANCE	**Black/brown, clear viscous liquid**
9.2 ODOR:	**Fruity sweet**
9.3 VAPOR PRESSURE:	**None**
9.4 VAPOR DENSITY:	**Not available**
9.5 SOLUBILITY IN WATER:	**Highly soluble**
9.6 SPECIFIC GRAVITY (H_20 = 1):	**1.4**
9.7 MELTING POINT:	**N/A**
9.8 pH:	**5.1**
9.9 VOLATILE:	**Not available**
9.10 COLOR:	**Black/brown, clear viscous liquid**
9.11 WEIGHT PER GALLON:	**11.7 lbs (5.3 kg)**
9.12 STORAGE LIFE AT 70° F:	**> 1 Year**
9.13 PH-21C:	**N/A**
9.15 VISCOSITY:	**Not available**
9.16 FREEZING POINT:	**< 32° F**
9.17 EVAPORATION RATE:	**Not determined**
9.18 BOILING POINT:	**224°F**

SECTION 10: STABILITY AND REACTIVITY

10.1 STABILITY: Stable

10.2 HAZARDOUS POLYMERIZATION: Will not occur.

10.3 HAZARDOUS DECOMPOSITION PRODUCTS: None Known

10.4 INCOMPATIBILITY: None. Avoid heat over 140°F. Keep container vented to allow release of CO_2 produced by natural yeast in product

SECTION 11: TOXICOLOGICAL INFORMATION

11.1 ORAL: May cause stomach cramps and/or nausea.

11.2 DERMAL: May cause slight irritation, especially from prolonged exposure. May cause redness.

11.3 INHALATION: None expected but inhalation may cause mild irritation of nasal mucous membranes.

11.4 CHORNIC/CARCINOGENICTY: Data not available

11.5 TERATOLOGY: Data not available

11.6 REPRODUCTION: Data not available

11.7 MUTAGENICITY: Data not available

11.8 EYES: May cause temporary eye irritation.

SECTION 12: ECOLOGICAL INFORMATION

12.1 Alga/Lemna Growth Inhibition: Not known.

12.2 Toxicity to Fish and Invertebrates: Not known

12.3 Toxicity to Plants: Not known

12.4 Toxicity in Birds: Not known

SECTION 13: DISPOSAL CONSIDERATIONS

Do not contaminate lakes, streams, ponds, estuaries, oceans or other waters by discharge of waste effluents or equipment washwaters. Dispose of waste effluents in accordance with state and local waste disposal regulations. Also, chemical additions or other alterations of this product may invalidate any disposal information in this MSDS. Therefore, consult local waste regulators for proper disposal.

SECTION 14: TRANSPORTATION INFORMATION

D.O.T.	Not D.O.T. Regulated
Other Shipping Description:	Fertilizing Compounds (Manufactured), Liquid. NMFC Item 6810 Sub 6, LTL Class 70

SECTION 15: REGULATORY INFORMATION

15.1 CERCLA: None

15.2 SARA TITLE III, Section 313 Toxic Chemicals: None

SECTION 16: OTHER INFORMATION

This information was developed from information on the constituent materials. No warranty is expressed or implied regarding the completeness or continuing accuracy of the information contained herein, and Plant Food Company, Inc. disclaims all liability for reliance thereon. The user should satisfy himself that he has all current data relevant to his particular use.