Work Plan to Conduct In-Situ Permeable Reactive Barrier Pilot Test For Perchlorate-Impacted Groundwater

Tronox, LLC
Henderson, Nevada

~~August 27~~October 25, 2010

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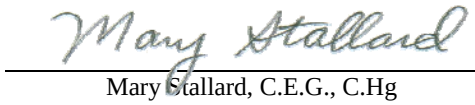

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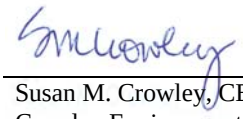
Responsible CEM for this Project:

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



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1.0 INTRODUCTION

Northgate Environmental Management, Inc. (Northgate) has prepared this work plan on behalf of Tronox LLC for the Tronox facility located in Henderson, Nevada (the Site; Figure 1). This document describes work to be performed to evaluate the technical feasibility and effectiveness of an in-situ permeable reactive barrier (PRB) to reduce concentrations of perchlorate in groundwater between the Athens Road Well Field and the Seep Area Well Field north and downgradient of the Site (Figure 2). In-situ permeable reactive barriers using edible oil-based electron donor substrates have been shown to be effective in remediating perchlorate impacted groundwater (ESTCP 2006, 2008, 2009 and 2010; ITRC 2007).

The Tronox Site has been undergoing active remediation for groundwater contamination since 1986 (hexavalent chromium) and 1998 (perchlorate) under the oversight of the Nevada Division of Environmental Protection (NDEP). As part of the remediation program, Tronox has implemented a series of well fields, both on- and off-Site, for the capture and treatment of perchlorate-impacted groundwater associated with historical Site operations. While substantial perchlorate control and reduction have been achieved to date, elevated concentrations of perchlorate (>10 milligrams per liter [mg/L]) continue to be observed in groundwater monitoring wells located downgradient from the off-site hydraulic containment wells at Athens Road. [Although the current name is now Galleria Road, the historical name of Athens Road will be used throughout this document to agree with the 'Athens Road Well Field' moniker given to the set of extraction wells in this area.]

Groundwater from this area continues to flow north and intersects the Las Vegas Wash, located approximately 6,000 feet further downgradient from Athens Road. Just before the wash is a row of 10 extraction wells (Seep Area Well Field) that capture and pump impacted groundwater back to the Site groundwater treatment system. A surface water collection system, known as the Seep Surface Collection System, is located ~~within~~ nearer the Wash to capture intermittent surface flows downgradient of the Seep Area extraction wells, though no surface flows have occurred in several years.

Currently, the groundwater flow rates ~~extracted~~ from the Seep Area Well Field represent up to about 60% of the total water ~~throughput~~volume treated in the on-Site water treatment plant. Tronox is interested in evaluating alternatives for the enhanced control/treatment of perchlorate migrating in groundwater downgradient from the Athens Road Well Field to not only reduce the need for extraction in Seep Area Well Field, but also minimize the chance for perchlorate to migrate into the Las Vegas Wash.

The proposed PRB pilot test consists of laboratory-scale column and batch testing and a pilot-scale demonstration to further assess this technology for use at the Site.

2.0 OBJECTIVES

The overall objective of the proposed pilot test is to examine the feasibility of an in-situ ~~edible~~emulsified-oil PRB as a remedial approach to significantly reduce perchlorate concentrations in groundwater near the line of Tronox monitoring wells known as the City of Henderson (COH) transect, approximately midway between the Athens Road Well Field and the Seep Area Well Field~~.~~ (Figure 1). In-situ permeable reactive barriers using edible oil-based electron donor substrates have been shown to be effective in remediating perchlorate impacted groundwater (ESTCP 2006, 2008, 2009 and 2010; ITRC 2007).

Analyses of water from COH transect wells in November 2009 showed perchlorate concentrations of 15-20 mg/L for wells PC-103, PC-98R, and MW-K5 (Figure 20A, Semi-Annual Remedial Performance Report; Northgate, 2010a). The proposed PRB test area incorporates well PC-98R.

While the effectiveness of the PRB has yet to be determined, reduction of perchlorate along the COH transect would reduce the perchlorate to be captured by the Seep Area Well Field. Nevada has set a Provisional Standard for perchlorate of 18 micrograms per liter (µg/L). If the pilot test demonstrates that substantial perchlorate reduction can be effectively achieved using this method, the PRB could be expanded to cover the entire COH transect width. PRB perchlorate destruction would minimize perchlorate requiring capture at Seep Area wells. Seep well flows could then be reduced to free up capacity of the on-Site biological treatment plant for treating more of the higher-concentration groundwater beneath the Site.

Specific objectives of the pilot test are as follows:

- Determine the retention of EOS® 598 B42 and lecithin-modified EOS® 598B42 emulsions on site-specific aquifer material using laboratory column testing.
- Determine the optimum electron donor substrate mixture and injection volume given the site-specific groundwater flow velocities and groundwater chemistry that includes desired contaminant removal and competing electron acceptor loading.
- Complete laboratory batch tests to examine the effect of in-situ bioremediation of perchlorate on metals mobilization and ~~metals~~subsequent attenuation on downgradient aquifer material.
- Determine the optimum well spacing for both substrate injection and performance monitoring.
- Measure the reduction of perchlorate concentrations in groundwater attainable with an in-situ ~~edible~~ emulsified oil-based PRB.

- Measure groundwater quality parameters to determine whether the ~~edible~~ bacteria in the emulsified oil-based PRB ~~is degrading~~are metabolizing competing electron acceptors such as sulfate, ~~iron,~~Fe(II), and ~~manganese.~~Mn(IV).

3.0 PILOT TEST METHODOLOGY AND PROCEDURES

The proposed in-situ biological remediation of perchlorate involves a similar process as the above-ground fluidized bed reactor in the on-Site water treatment plant, relying on anaerobic biodegradation of the perchlorate. Natural indigenous perchlorate-degrading bacteria found in the subsurface can, under anoxic conditions, reduce perchlorate to chloride ions and water. To achieve these conditions, an appropriate food source (electron donor) must be provided to promote growth of the bacteria that will consume dissolved oxygen, nitrate and chlorate, and lower the oxidation reduction potential (ORP) to the point at which perchlorate will be consumed.

Several strategies are available to determine the ~~best food source~~optimal electron donor and nutrient mixture for ~~the~~ site-specific conditions, and to determine the best application method for introducing and distributing the mixture into the zone of interest.

Based on a review of lithologic and aquifer flow characteristics, perchlorate plume concentrations and distribution, and limited access issues in the test area, the proposed substrate mixture for this pilot test will be composed of EOS Remediation's EOS® Concentrate ~~598B-42 edible~~598 B42 emulsified oil substrate injected into the test area via fixed-point wells. Laboratory-scale retention testing will be accomplished prior to substrate injection to determine if the ~~edible~~emulsified oil substrate needs to be amended with lecithin to enhance substrate retention onto aquifer materials.

The proposed pilot test will be conducted in two stages: laboratory bench-scale column and batch testing followed by a pilot-scale demonstration at the Site. Each of these stages is described below.

3.1 Laboratory Bench-scale Tests

Bench-scale tests are proposed to obtain the necessary design parameters to optimize PRB performance and to examine if reductive conditions created by in-situ bioremediation could lead to metals mobilization. If arsenic is mobilized then additional bench-scale tests will be conducted to determine its ability to attenuate onto downgradient aquifer soils.

3.1.1 Oil Retention Testing

The first laboratory scale test will consist of an oil loading test to determine the capacity of the Site-specific aquifer soils using samples collected during the drilling of one of the proposed injection wells; samples are expected to be classified as gravelly sands or sandy gravels. ~~A laboratory experienced in the setup and conduct of treatability tests for environmental~~

~~remediation will perform t~~The tests~~.~~ will be performed by the Environmental Engineering Laboratory in the Department of Civil, Construction, and Environmental Engineering Department at North Carolina State University using methods described in (SERDP, 2006). Experimental design, testing, and analysis will be performed under the supervision of Professor Robert C. Borden, the inventor of the EOS electron-donor substrate.

The proposed testing will measure the retention of two different emulsions in this aquifer soil: (1) the standard EOS® 598 B42 formulation; and (2) a lecithin-based emulsion with a larger droplet size intended to exhibit higher retention.

The proposed scope of work is presented below:

1) Two 5-gallon pails of aquifer soils will be provided by Northgate ~~or others~~. This soil shall be collected from the saturated zone ~~within~~during the ~~formation where~~drilling of the first injection well for the PRB ~~will be formed~~. On receipt, the soil will be passed through a #4 or similar size sieve. The fractions retained by and passing through the sieve will be weighed to determine the % passing by weight. Only the fraction passing through the #4 sieve will be used for the oil retention column tests. The particle size distribution of the fraction passing through the #4 sieve will ~~then~~ be determined by ~~standard sieve analyses to 200 mesh and by laser diffraction~~ASTM D422, *Standard Test Method for* ~~finer particles.~~*Particle Size Analysis of Soils.*
2) The aquifer soils that passed through the #4 sieve will be used to pack two 2-ft long x 1-inch diameter clear polyvinyl chloride (PVC) columns. The columns will be packed wet and flushed with several pore volumes (PV) of de-aired water to reduce the amount of entrained air. If a substantial percentage of the material falls within the ¾" to #4 sieve size range, this material may be incorporated into the sample and a 2-inch diameter column would be used to accommodate these coarser particles.
3) The oil retention tests will then be conducted as follows for each of the two emulsions (EOS598B42 and lecithin-based emulsion):

    a. Set up pumping system to maintain a constant flow rate of approximately 2 milliliters per minute (~~ml~~mL/min). This should result in an effective transport velocity through the column of approximately 48 feet per day (ft/d).
    b. Pump 0.6 liters (L) (~5 PV) of de-aired water through column (5 hr).
    c. Pump 0.6 L (~5 PV) diluted emulsion through column (5 hr).
    d. Pump 0.6 L (~5 PV) de-aired water through column (5 hr).

e. In the event a 2-inch column is required, the feed flow rate and volumes listed above will be adjusted accordingly to achieve the target transport velocity of approximately 45 ft/d and 5 PVs.

4) Following completion of the flushing, extrude or cut the column into 0.25-ft sections and measure the volatile solids (VS) concentration on each segment. Dry each sample at 104 degrees Celsius (˚C) and weigh. Measure VS by weight loss on ignition at 550˚C. The VS of untreated sediment will also be determined by drying a sample at 104˚C, followed by weight loss on ignition at 550˚ C and the oil retention (OR) will be calculated by the equation:

   OR = VS treated sediment – VS untreated sediment

   A correction factor will be applied to the OR result assuming that no oil will be retained by the coarse fraction (particles retained on the #4 sieve or the ¾" sieve if ¾" minus particles are incorporated into the columns) to determine the maximum oil retention within the target PRB zone.

Upon completion of the proposed testing, a short letter report documenting the results of the oil retention tests will be prepared and the results will be used to determine an appropriate oil loading rate for the field pilot PRB testing program.

3.1.2 Metals Mobilization Testing

The second laboratory scale test will consist of batch tests to gain preliminary knowledge of the behavior of arsenic in Site-specific saturated soil and groundwater exposed to an ~~edible~~emulsified oil-based organic electron-donor substrate in the presence of perchlorate and competing electron acceptors. If needed, additional tests, included column tests, may be designed and conducted to better simulate field conditions. The metals mobilization testing will be conducted by Prima Environmental, Inc., under the direction of Dr. Cindy Schrier.

The goals of this study are to:

- Establish the change in ORP by adding an organic electron-donor substrate in the presence of indigenous bacteria, perchlorate, and competing electron acceptors.
- Estimate the effective removal rate of perchlorate reduction in the test reactors.
- Determine the effect of ORP on ~~metal~~the stability of metals in representative aquifer material.

- If dissolved metal concentrations decrease due to the formation of sulfides, assess the stability of the sulfides as conditions ~~approach~~return to the ~~more~~ aerobic pre-treatment condition.
- If dissolved metals concentrations increase, assess whether attenuation ~~may occur~~occurs as treated groundwater moves downgradient.

The proposed scope of work is presented below:

Task 1. Soil and Groundwater Preparation and Characterization

Prior to testing, 10 kg of ~~soil~~saturated soil from the proposed PRB Site will be homogenized and large rocks greater than about 3/16-inch (4 mesh) will be removed. If the soil contains primarily large rocks, the contracted laboratory PRIMA will contact Northgate to discuss options. Homogenized soil will be analyzed for:

- ~~total metals (arsenic[As], iron [Fe])~~
- ~~leachable metals (DI WET test, As)~~
- total metals testing for Iron (Fe), Manganese (Mn), Uranium (U), and the 13 EPA Priority Pollutant Metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), and Zinc(Zn)).
- leachable metals using SPLP test (extraction fluid 3) for Iron (Fe), Manganese (Mn), Uranium (U), and the 13 EPA Priority Pollutant Metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), and Zinc(Zn))
- pH.

Prior to testing, 18 L of unpreserved groundwater, if received in multiple containers, will be composited, then analyzed for:

- dissolved ~~metals~~arsenic (As(III), As(V~~),~~))
- dissolved Iron (Fe~~)~~), Manganese (Mn), Uranium (U), and the 13 EPA Priority Pollutant Metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), and Zinc(Zn))
- dissolved organic carbon (DOC)
- ORP
- pH
- dissolved oxygen (DO)
- ~~ferrous iron~~
- nitrate
- ~~ORP~~
- perchlorate
- , chlorate
- , and chloride
- ~~pH~~
- sulfate
- and sulfide.

Task 2. Evaluation of Perchlorate Removal/Mobilization of Metals

Up to 13 reactors each containing approximately 200 g of soil and one L of groundwater with minimal headspace will be prepared. Five of these reactors will be capped and serve as the Time 0 and Control reactors. The Control reactors will be run under non-sterile conditions. The remaining eight reactors will be treated with an emulsified oil-based electron donor substrate. Periodically, the groundwater from two reactors will be destructively sampled and analyzed for:

- dissolved ~~metals~~arsenic (As(III), As(V~~),~~))
- dissolved Iron (Fe~~)~~), Manganese (Mn), Uranium (U), and the 13 EPA Priority Pollutant Metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), and Zinc(Zn))
- ~~DOC~~
- ~~DO~~
- ~~ferrous iron~~
- dissolved organic carbon (DOC)
- ORP
- pH
- dissolved oxygen (DO)
- nitrate
- ~~ORP~~
- ~~perchlorate~~
- ~~, chlorate~~
- , and chloride
- ~~pH~~
- ~~sulfate~~
- and sulfide.

Note that ORP and DO will be measured by inserting a probe directly into the reactor – this will minimize exposure to air and ensure more accurate measurements. The estimated sampling times are 0 hrs, 48 hrs, 5 days, 14 days, and 6 weeks. However, a series of smaller reactors containing Resazurin or other visual redox indicator will be prepared. The sample times may be adjusted based on the changes in the redox indicator as well as results of previous samplings. The tests are summarized below:

Summary of Perchlorate Removal/Metals Mobilization Tests

Test	# Reps	Treatment	Est. Sample Times
Time 0	1	None	0
Control	4	None	48h, 5d, 14d, 6 wk
Emulsified Oil	8*	Substrate added	48h, 5d, 14d, 6 wk

* Duplicate samples are proposed since control of ORP may be relatively difficult.

Task 3. Stability of Precipitated/Sorbed Metals

If dissolved arsenic concentrations decrease ~~in~~during Task 2, then soil will be analyzed to assess the stability of the precipitated and/or sorbed species under aerobic conditions, which will likely be re-established once treatment at the Site is complete. The proposed leach test is the ~~DI WET test.~~SPLP test using extraction fluid #3 (reagent water). This test will be conducted for all conditions in which dissolved metal concentrations have decreased since the stability under aerobic conditions may depend upon the ORP at which it was removed from solution.

Task 4. Attenuation of Mobilized Metals

If arsenic and iron concentrations increase in Task 2, then the treated groundwater will be mixed with fresh, untreated soil from the saturated zone to evaluate whether these mobilized metals will likely attenuate once they come into contact with soil that has not been exposed to reducing conditions. In this test, treated water will be mixed with untreated soil in a 2:1 liquid to soil ratio for about 10 minutes. The aqueous phase will then be analyzed for dissolved arsenic and ferrous iron, as appropriate. This test will be conducted for all samples that mobilized metals in Task 2 since the speciation of the metal (and hence its ability to attenuate) may depend upon the ORP at which it was liberated.

Task 5. Reporting

A report describing procedures, observations, results and discussion will be prepared. ~~If requested, recommendations for further study (if needed) will be included.~~A reassessment of the proposed volume of injected edible oil substrate will be made in this report, including a recommendation to relocate or cancel the proposed PRB pilot test if the oil retention fails to meet the level required to conduct a successful pilot test. If results are supportive of moving forward with the PRB pilot test, this report will also include a description of how the slug and step-injection test results will be used to determine if the proposed injection rate should be adjusted. This report will be submitted to NDEP prior to implementation of the field pilot test.

Analytical Methods

The method for each analysis and the laboratory to perform the analysis for samples collected under Task 3.1.2 are provided below:

Analytical Methods

Analyte	Method	Lab performing test*
DOC	EPA 9060	Alpha
Dissolved oxygen	Probe	PRIMA
~~DI WET~~SPLP leaching	~~DI WET~~EPA 1312 (fluid 3)	K PRIME
Ferrous iron	Colorimetric/Hach**	PRIMA
Metals (other than Hg)	EPA 6020	K PRIME
Mercury (Hg)	EPA 245.1	K PRIME
Arsenic speciation	IC-ICP-DRC-MS***	Applied Speciation or Alpha Analytical
Nitrate	EPA 300	Alpha Analytical
ORP	Probe	PRIMA
Perchlorate	EPA 314	Alpha Analytical
~~Ph~~pH	Probe	PRIMA
Sulfate	Hach	PRIMA
Sulfide	Hach	PRIMA

* Alpha Analytical (Sparks, NV); K PRIME (Santa Rosa, CA)
** Hach DR 2800 Spectrophotometer and appropriate Hach kit reagents
*** Ion chromatography - inductively coupled plasma - dynamic reaction cell - mass spectrometry

A technical memorandum summarizing the laboratory scale test results will be prepared, and any resulting changes made to the pilot test design will be discussed with NDEP prior to conducting the pilot test. The following section describes the proposed approach to the pilot-scale field test.

3.2 Pilot-Scale Field Test

Following review of laboratory column test and batch study results, a pilot-scale PRB will be demonstrated approximately 2,000 feet downgradient (north) of the Athens Road Well Field, approximately midway between the Athens Road Well Field and the Seep Area Well Field, as shown on Figure 3.

In order to create the PRB, the ~~edible~~emulsified oil-based substrate will be injected into the saturated alluvium overlying the Muddy Creek ~~Bedrock formation~~Formation in the pilot test area. The substrate mixture, concentration, and volume will be determined based on the results of the bench-scale tests.

The proposed pilot study demonstration area is shown on Figure 3. This area was selected because: (1) it is far enough from the extraction well fields that the injected substrate will not be affected by pumping gradients; (2) it is located within the alluvial channel that appears to serve as the primary perchlorate transport mechanism from the Site to the Las Vegas Wash; (3) perchlorate concentrations are elevated (>10 mg/L), making observation of reductions easier and effecting a greater mass removal of perchlorate; and (4) there is sufficient distance downgradient of the test area prior to the Wash to monitor for degradation byproducts, dissolution/release of compounds that may adversely affect water quality, and unconsumed substrate.

It should be noted that the pilot test is designed to evaluate the PRB concept and will not cover the entire width of the alluvial channel at the COH transect. If the test is successful, additional injection wells may be added to complete the full barrier.

3.2.1 Health and Safety

As required under Occupational Safety and Health Administration Standards Code of Federal Regulations Title 29, Labor, Part 1910.120, a Site-specific health and safety plan (HASP) was prepared by Northgate (Northgate, 2010b). All Northgate personnel and its subcontractors will be required to review and sign the HASP prior to commencement of field work.

3.2.2 Permitting

Prior to conducting drilling activities, the location of each proposed well will be staked in the field, and a minimum 48-hour notice will be provided to Underground Service Alert (USA) to allow for the identification of any subsurface utilities or piping that may be in the area of drilling. All wells will be drilled in accordance with Nevada Division of Water Resources (DWR) requirements outlined in Nevada Administrative Code (NAC) Chapter 534, and notices of intent

to drill will be submitted to the DWR for each of the eight new wells. Land access to the test area will be obtained from the City of Henderson.

Discussions with NDEP Bureau of Corrective Action group (NDEP-BCA) and the NDEP Underground Injection Control (UIC) group have led to agreement to utilize the State general UIC permit for the in-situ test. Copies of the required application forms to use the State long-term permit are attached in Appendix B. If pilot testing procedures and/or well specifications are modified from what is presented in this Work Plan, the Work Plan will be revised and resubmitted for NDEP BCA and UIC approval before making the proposed changes.

The appropriate permit/approval will be obtained depending on the source of water to be used during the injection.

3.2.3 Well Drilling and Installation

Fixed-point wells are proposed for injecting the substrate into the aquifer due to the difficulties that lower-cost alternatives such as direct push would have penetrating the gravelly nature of the alluvium. Also, wells are preferred in the event that subsequent injections are required to maintain proper subsurface conditions for the in-situ biological reduction of perchlorate and for minimizing unwanted secondary reactions such as sulfate reduction, methanogenesis, and/or mobilization of certain metals such as arsenic.

It is expected that in the highly permeable alluvial soil (groundwater flow velocities of 30-45 feet per day [Errol Montgomery & Associates 2000]), the injection wells will have a radius of influence of 30 feet or greater. Based on this estimate, three injection wells and five observation/monitoring wells are proposed for the pilot test. The injection wells will be used to create an in-situ PRB up to approximately 150 feet wide by 100 feet long (parallel to the groundwater flow) and the monitoring wells will be used to confirm ~~edible~~emulsified oil coverage, measure reductions in perchlorate concentrations, and monitor for secondary byproducts of the in-situ remediation of perchlorate. For ease of reference, the wells have been labeled I-1, I-2, and I-3 (injection wells); and O-1 through O-5 (observation/monitoring wells) in this Work Plan.

The wells will be located as shown on Figure 4 and will be drilled and completed as follows:

- All wells will be drilled with a hollow stem auger rig using 8-inch-diameter auger flights to a depth of 40 feet below ground surface (ft bgs). However, drilling will be stopped if the top of the Muddy Creek formation is encountered, and the well will be completed at that depth instead.

- Soil samples will be collected every 5 feet during drilling for lithologic description.
- Injection wells I-1 through I-3 will be spaced 50 feet apart, perpendicular to the groundwater flow direction, and located approximately 120-140 feet downgradient of existing well PC-98R, as shown on Figure 4.
- The observation/monitoring wells will be spaced as follows:
  - O-1 is approximately 15 feet downgradient and midway between I-2 and I-3 to verify the expected cross-gradient radius of influence~~;~~.
  - O-2 and O-3 are 30 and 60 feet, respectively, downgradient of I-2 to measure the performance within the anticipated PRB zone~~;~~.
  - O-4 is approximately 90 feet downgradient of I-1 and I-2 to measure the performance (and potential formation of byproducts) near the expected downgradient edge of the PRB zone~~; and~~.
  - O-5 is 120 feet downgradient of I-1 and I-2 to measure potential formation of byproducts downgradient of the expected PRB zone.
  - O-6 is approximately 75 feet east of O-1, and placed to measure the eastern extent of the potential PRB zone given the uncertainty in groundwater flow direction.
  - O-7 is approximately 60 feet east of O-3 and placed to measure performance at near the expected downgradient edge of the PRB zone..
  - O-8 is 75 feet east of O-5, and placed to monitor the potential formation of byproducts downgradient of the expected PRB zone.
- In addition, existing well PC-98R will be used to supplement the monitoring program as follows:
  - PC-98R is approximately 120-140 feet upgradient of the injection wells and will serve as a pretreatment baseline.
- Well screen intervals will be approximately 20-40 feet bgs for the injection wells and 15-40 feet bgs (or starting approximately 5 feet above static groundwater level) for the monitoring wells. The screen interval for existing well PC-98R is 20-35 feet bgs.
- All wells will be constructed of 2-inch diameter Schedule 40 PVC blank and slotted well casing. Slotted well casing will contain slot openings of 0.020-inch and will extend from the bottom of the well up to the depths mentioned above.
- Lonestar #3 sand, or equivalent, will be used as the annular filter pack material and will be placed from the bottom of the annulus up to at least 1 foot above the top of the well slots. After proper well surging, additional filter pack material will be placed as needed to

bring the filter pack back up to 1 foot above the well slots. This will be repeated as necessary to ensure no voids in the filter pack.

- A minimum 2-foot thick hydrated bentonite seal will then be place above the filter pack, followed by a bentonite/cement slurry to ground surface.
- To limit well access and protect the wells from damage during the test period, each new well will be installed within a locking stovepipe enclosure.

Following well installation, the location and elevation of each new well will be surveyed to the nearest 0.01-foot by a Nevada-licensed surveyor.

Following well completion activities, all wells to be used in the pilot test will be allowed to set for a minimum of 48 hours prior to development using a combination of bailing, surging, and pumping. During development, turbidity, temperature, pH, and conductivity will be measured and recorded. Development procedures are discussed in more detail in Section 3.3.

3.2.4 Substrate Injection

Prior to starting injection activities and at least 24 hours after well development, baseline groundwater samples will be collected from each newly installed well plus existing well PC-98R. Sampling will be conducted using a low-flow method involving a downhole pump connected to a flow-through cell. Field parameters such as ORP, DO, pH, and specific conductance will be measured and recorded at each well, and a sample from each well will be for perchlorate, chlorate, nitrate, sulfate, total organic carbon, and volatile fatty acids. The ~~five~~ eight new observation/monitoring wells will also be analyzed for total and speciated arsenic, total and dissolved manganese and iron, and hexavalent chromium. ~~Some~~These eight observation/monitoring wells will be sampled and analyzed for additional compounds, such as bromide, chloride, and/or dissolved methane. All proposed sampling and analyses are summarized in Table 1. In addition to baseline sampling, slug tests will be conducted in several of the new wells to estimate aquifer conductivities, and a short (2- to 4-hour) step-rate injection test will be conducted to help establish well injection rates and pressures.

To accomplish the injection activities, a holding tank will be temporarily placed near the injection wells. Water will be obtained from a City of Henderson fire hydrant (under a hydrant tap permit) and used for the step-injection test and for mixing with the ~~edible~~emulsified oil-based substrate solution to form an emulsion that will be injected to create the PRB zone. The emulsion will then be concurrently pumped into the three injection wells at approximately 15 gpm per well, depending on the results of the step-injection test.

The injected emulsion at each injection well will consist of a mixture of 550 gallons of EOS® 598 B42 or lecithin-modified EOS® ~~598B 42 edible~~598 B42 emulsified oil-based substrate and approximately 60,000 gallons of push water, along with bromide tracer. The total injected quantity (1,650 gallons) of substrate is expected to provide enough electron donor agent to degrade perchlorate passing through the PRB zone for a period of between 6 ~~and~~to 9 months.

At the proposed 15 gpm injection rate, the application should take approximately 3 days. During this injection period, monitoring will be conducted on several of the observation/monitoring wells. In addition, water levels will be measured in all wells including the injection wells, if practicable. Monitoring and sampling frequencies, parameters, and analytes for each well are summarized in Table 1.

After the completion of injection activities, all equipment will be flushed and removed from the location, and well caps/covers will be re-installed and locked.

3.2.5 Post-Injection Monitoring and Reporting

Groundwater conditions will continue to be monitored for a minimum 6-month period following completion of injection activities. Periodically during this timeframe, field parameters will be measured and groundwater samples will be collected. Vertical variability in ORP, DO and pH will be monitored at three discrete intervals within the screened interval (one foot below the water table, midpoint depth between the water table and well bottom, and one foot above the well bottom) using a flow-through cell and low flow purging methods. Monitoring and sampling frequencies, parameters, and analytes for each well are identified in Table 1.

Although most measurements/analyses will be performed to delineate the extent of the PRB zone and to measure the reduction of perchlorate within the PRB, several groundwater samples will also be analyzed for byproducts of the in-situ bioremediation such as metals precipitation. As the naturally occurring bacteria utilize the injected edible oils as a food source, they will begin to reduce, in sequence: dissolved oxygen, nitrate, chlorate, perchlorate, and possibly manganese, iron, and sulfate. Whereas the on-Site biological treatment plant and the AMPAC in-situ systems closely control electron donor concentrations to minimize sulfate reduction, the PRB may provide an excess of electrons that could allow the bacteria to reduce manganese and iron as well as potentially generate some sulfides from reduction of sulfate. As a result, it is anticipated that a portion of the iron, arsenic, manganese, and possibly other constituents present in groundwater may mobilize and then may precipitate out of solution as sulfides or possibly co-precipitate as arsenic-laden ferrihydrite as they move downgradient out of the PRB zone.

Groundwater baseline samples from both upgradient and downgradient monitoring wells will be analyzed to estimate potential impact. In addition, wells O-1 through O-~~5~~8 will be analyzed for

arsenic, iron, manganese, and hexavalent chromium. Monitoring and sampling frequencies, parameters, and analytes for each well are included in Table 1. As noted on this table, analysis of additional metals may be recommended in the bench-scale testing report (see Section 3.1.2 above) based on the metals mobilization test results.

In addition to monitoring groundwater conditions, the baseline slug tests conducted prior to initiating injection (as described in Section 3.2.4) will be repeated at the 3-month mark following injection to determine if any loss of aquifer porosity and/or hydraulic conductivity occurs within or downgradient of the PRB zone as a result of the emulsion injection or resulting biologiocial/geochemical processes.

At the conclusion of the pilot test, all analytical and operational data collected during the demonstration will be evaluated. A report summarizing testing procedures and results will be prepared and submitted to NDEP.

3.3 Standard Operating Procedures

All well installation, development, and sampling, and analysis work will be conducted in accordance with the following Basic Remediation Company (BRC) Standard Operating Procedures (SOPs; ERM-West, Inc and MWH 2009).):

- SOP-0 Quality Assurance and Quality Control for Submittals to the Nevada Division of Environmental Protection
- SOP-1 Drilling Methods
- SOP-2 Groundwater Monitoring Well Design
- SOP-3 Groundwater Monitoring Well Development
- SOP-4 Aquifer Testing Methods
- SOP-5 Water Sampling and Field Measurements
- SOP-6 Sample Management and Shipping
- SOP-7 Soil Sampling

- SOP-10 Surveying
- SOP-13 Operating and Calibration Procedures - Field Equipment
- SOP-14 Field Documentation
- SOP-15 Field Logbook
- SOP-17 Soil Logging
- SOP-20 Filter Pack and Well Screen Slot Size Determination
- SOP-30 Field Analytical Procedure
- SOP-31 Drilling Equipment Decontamination
- SOP-34 Investigative Derived Waste (IDW) Management
- SOP-35 Waste Sampling
- SOP-40 Data Review/Validation

Chemical analyses will be performed by a Nevada-certified laboratory using the same methods approved by NDEP for use in the compliance monitoring and Phase B Investigation groundwater sampling at the Site. ~~Sample containers will be sealed, labeled, placed on ice inside an ice chest, and provided to the laboratory under chain-of-custody protocol~~

~~All drilling equipment will be decontaminated after each well location.~~ Soil cuttings (including unused soil cores) will be temporarily stored in a roll-off bin pending laboratory analysis and profiling for disposal. Purge water associated with the installation and sampling of groundwater monitoring wells will be disposed of using the on-Site groundwater treatment system.

4.0 PROPOSED SCHEDULE

The proposed schedule for the work described in this work plan is as follows:

Task No.	Task Description	Timeline from Work Plan Approval
1	- Collection of Aquifer Material for Laboratory Studies	~~*~~2 weeks
	- Complete Maximum Oil Retention Testing	~~*~~4 weeks
	- ~~Geochemical and~~ Complete Microcosm Testing for Contaminant Reduction ~~Microcosms~~and Metals Mobilization	~~*~~8 weeks
	- Submit Laboratory Testing Report to NDEP	~~2 wks~~10 weeks
2	- Drilling, Well Installation, Well Development	~~6 wks~~16 weeks*
3	- Baseline Sampling, Slug testing	~~8 wks~~18 weeks
4	- EOS Emulsion Injection~~**~~	~~9 wks~~19 weeks
5	- Performance Monitoring (6-month period)	~~33 wks~~45 weeks
6	- Submit Final PRB Pilot ~~Testing~~Test Report to NDEP	~~44 wks~~52 weeks

* ~~It is anticipated that the collection of soil samples~~ Assuming no significant changes to ~~be used for conducting the~~ plan based on laboratory ~~tests, as well as the bench-scale~~ testing~~, will be conducted prior to~~ report

** Injection of EOS Emulsion is contingent on NDEP ~~review~~ BCA and UIC approval ~~of this work plan.~~

5.0 REFERENCES

ERM-West, Inc. and MWH 2009. *BRC Field Sampling and Standard Operating Procedures*. December 2009.

Errol Montgomery & Associates 2000. *Analysis of Rate of Groundwater Movement Based on Results of Tracer and Hydraulic Tests Conducted Between Pittman Lateral and Seep Area*. 2000.

Environmental Security Technology Certification Program (ESTCP) ~~2010. *Comparative Demonstration of Active and Semi-Passive In-Situ Bioremediation Approaches for Perchlorate-Impacted Groundwater at Longhorn Army Ammunitions Plant: Cost and Performance Report*. ER-0219. Arlington, VA. 2010.~~

2006. *Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil*. Arlington, VA. 2006.

ESTCP ~~ESTCP 2009. *In Situ Bioremediation of Perchlorate in Groundwater: Final Report*. ER-0224. Arlington, VA. 2009.~~

~~ESTCP 2009. *Comparative Demonstration of Active and Semi-Passive In-Situ Bioremediation Approaches for Perchlorate-Impacted Groundwater at Longhorn Army Ammunitions Plant: Final Report*. ER-0219. Arlington, VA. 2009.~~

~~ESTCP~~ 2008. *Edible Oil Barriers for Treatment of Perchlorate-Contaminated Groundwater*. ER-0221. Arlington, VA. 2008.

~~ESTCP 2007a. *Field Comparison of Biofouling Control Measures for In Situ Bioremediation of Groundwater*. ER-0429. Arlington, VA. 2007.~~

~~ESTCP 2007b. *Field and Laboratory Evaluation of the Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Final Technical Report*. ER-0428. Arlington, VA. 2007.~~

~~ESTCP 2006.~~ESTCP 2009. *In Situ Bioremediation of Perchlorate in Groundwater: Final Report*. ER-0224. Arlington, VA. 2009.

ESTCP ~~*Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil*. Arlington, VA. 2006.~~

~~ESTCP~~ 2010. *Loading Rates and Impacts of Substrate Delivery for Enhanced Anaerobic Degradation*. ER-0627. Arlington, VA. 2010.

~~Interstate Technology & Regulatory Council (ITRC)~~ITRC 2007. *Remediation Technologies for Perchlorate Contamination in Water and Soil*. PERC-2. Washington, DC. 2007.

~~ITRC 2002. *A Systematic Approach to In Situ Bioremediation in Groundwater Including Decision Trees on In Situ Bioremediation for Nitrates, Carbon Tetrachloride, and Perchlorate*. Washington, DC. 2002.~~

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Northgate Environmental Management, Inc. (Northgate) 2010a. *Semi-annual Remedial Performance Report for Chromium and Perchlorate*, July 2009 – December 2010. February 26, 2010.

Northgate 2010b. *Health & Safety Plan for Well Installation and Subsurface Investigation and Remediation of Soils and Groundwater*, Tronox LLC, Henderson, Nevada. April 16, 2010.

Strategic Environmental Research and Development Program ~~2008. Environmental Fate and Exposure Assessment for Arsenic in Groundwater. ER-1374. 2008~~(SERDP) 2006. *Development of Permeable Reactive Barriers (PRB) Using Edible Oils*. ER-1205. 2006.

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FIGURES

TABLE

APPENDICES