Treatability Study Work Plan
Soil Flushing Pilot Test
Revision 3
Nevada Environmental Response Trust Site
Henderson, Nevada

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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: Revised Soil Flushing Pilot Test Work Plan, Nevada Environmental Trust Site, Henderson, Nevada

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1.0 INTRODUCTION

On behalf of the Nevada Environmental Response Trust (NERT), Tetra Tech, Inc. (Tetra Tech) has prepared this Revised Soil Flushing Pilot Test Work Plan for the NERT site, located in Clark County, Nevada (Figure 1). This Revised Work Plan is being submitted as part of the Remedial Investigation/Feasibility Study for the site, pursuant to the Interim Consent Agreement effective February 14, 2011.

A work plan for performing a soil flushing pilot test was previously submitted to and approved by the Nevada Department of Environmental Protection (NDEP) on May 20, 2014 (Environ, 2014b). This Revised Work Plan presents an updated technical approach and scope of work for the pilot test. Specific differences between this and the previous work plan include the following:

- The pilot testing program has been expanded to include four individual test plots, which will be used to evaluate flushing with water only, as well as potential performance enhancements from carbon substrate addition and flushing at reduced flow rates
- Test plot size has been reduced to conserve water during testing
- The preliminary field and laboratory testing program has been rescoped to focus on the parameters most relevant for pilot system design
- Dye tracer testing has been included in the field testing program to allow the infiltrated water to be tracked as it migrates through soil and groundwater
- The pre- and post-testing soil sampling program has been expanded to provide a more robust basis for evaluating perchlorate removal efficiency
- The proposed analytical program for pore water, groundwater, and soil has been revised to focus on the parameters most relevant to evaluating technology performance

Background information on the site, including regulatory status, previous studies, physical setting, geology, hydrogeology, and contaminant distribution, is provided in the previous submittal (Environ, 2014b).

1.1 Objective

The overall objective of the soil flushing pilot test is to evaluate the feasibility of using soil flushing as a technology for remediating contaminants, primarily perchlorate, in vadose zone soils at the site.

1.2 Work Plan Organization

This Revised Work Plan is organized as follows:

- **Introduction**: This introduction section describes the objectives of the pilot test and the organization of this work plan
- **Technology Description (Section 2.0)**: Provides a brief description of soil flushing, and presents a case study for this technology at a perchlorate-impacted site in southern California
- **Pilot Test Conceptual Design (Section 3.0)**: Presents the conceptual design of the proposed soil flushing pilot test, including objectives, test location, preliminary field and

laboratory testing, system components, system operation, permitting requirements, and health and safety

- **Performance Monitoring Plan (Section 4.0)**: Presents the conceptual monitoring program for the pilot test, including monitoring of system parameters, pore water, groundwater, and soil
- **Reporting (Section 5.0)**: Summarizes reporting related to design and execution of the pilot test
- **Schedule (Section 6.0)**: Summarizes the schedule for conducting the pilot test
- **References (Section 7.0)**: Lists the documents referenced in this Work Plan

2.0 TECHNOLOGY DESCRIPTION

Perchlorate is the anionic component of ammonium perchlorate, a common component of solid rocket fuel. Perchlorate salts are very soluble in water (solubility limit is approximately 200,000 milligrams per liter [mg/L] for ammonium perchlorate; approximately 2,100,000 mg/L for sodium perchlorate), do not adsorb very strongly to most soils, and are not amenable to chemical oxidation. Perchlorate tends to be biologically stable under aerobic conditions or when there is limited source of organic carbon. However, in the presence of a continuing carbon source and after dissolved oxygen and nitrate have been depleted, perchlorate can act as an electron acceptor for anaerobic respiration, and undergoes stepwise biodegradation to chlorate, chlorite, and finally chloride and water. Aqueous perchlorate may also be treated using ion exchange resins and tailored granular activated carbon.

The following subsections briefly describe soil flushing as a technology for remediating perchlorate in the vadose zone, and provide a case study of soil flushing at another perchlorate-impacted site.

2.1 Soil Flushing Description

The high aqueous solubility of perchlorate compounds suggests that flushing the vadose zone with water could be a viable means of removing perchlorate from vadose zone soils. In concept, water infiltrated from the surface would mobilize and transport perchlorate compounds from the vadose zone to groundwater. Once in groundwater, the perchlorate would be collected by groundwater extraction and then treated. This technology was previously investigated using soil collected from the site in a series of column tests performed by Prima Environmental and reviewed in the previous work plan (Environ, 2014b). The column testing results suggested that up to 99% of the perchlorate in soil could be removed by flushing with as little as two pore volumes of water. Field conditions typically differ from those in the laboratory, and the previous work plan concluded that a minimum of four and as many as eight pore volumes of water may be necessary to achieve similar results in the field (Environ, 2014b). Tetra Tech concurs that flushing more than two pore volumes of water through the vadose zone may be necessary to achieve results comparable to the column tests.

While conceptually attractive, full-scale implementation of this technology also has some shortcomings. For example, flushing perchlorate to groundwater would increase the perchlorate load to the existing groundwater extraction and treatment system (GWETS), and would need to be carefully managed to keep the existing fluidized bed reactor (FBR) system within operational limits. Soil flushing would also mobilize other water-soluble salts from soil to groundwater, which could affect FBR operation. Effluent from the GWETS is a potential source of water for use in full-scale soil flushing. However, the additional salt loading from soil flushing, combined with recycling of treatment system effluent, could potentially result in salt buildup in the system that would also require careful management.

The additional perchlorate loading that would result from soil flushing could potentially be alleviated by adding an organic carbon substrate to the water used for flushing. The carbon substrate would be transported with the perchlorate, and could potentially stimulate biodegradation of the perchlorate in both the vadose zone and groundwater. This could potentially reduce or eliminate loading of additional perchlorate to the FBR. Residual carbon substrate would also remain in the soil pore space after flushing is completed, and biodegradation could potentially act as a polishing step to further reduce perchlorate concentrations in the vadose zone to levels below those attainable by flushing alone. Potential issues with salt loading could be addressed by using another water source, such as stabilized Lake Mead water, rather than GWETS effluent for soil flushing.

2.2 Soil Flushing Case Study

The following is a description of a pilot test performed to evaluate soil flushing for remediation of perchlorate in the vadose zone at a different but similar site.

2.2.1 Test Description

The pilot test was performed at a former rocket motor test facility located in southern California (Tetra Tech, 2013). Perchlorate was the primary contaminant of concern in the area where the pilot test was performed. Vadose zone soils consisted primarily of clayey sand and are likely significantly less permeable than soils at the site; the depth to groundwater at the test location was approximately 65 feet, about three times greater than the depth to groundwater at the site. Prior to testing, perchlorate concentrations in soils at the test area ranged from 0.0056 to 45 milligrams per kilogram (mg/kg); perchlorate concentrations in groundwater were generally above 100 mg/L.

The pilot test consisted of infiltrating a 0.3% glycerin solution into the vadose zone through a 10- by 15-foot infiltration gallery. The carbon substrate and substrate dosage were selected based on laboratory microcosm testing results. Several techniques were used to monitor subsurface conditions before, during, and after the test. Electrical resistivity tomography, a non-invasive geophysical method, was used to monitor the geometry of the moisture front as it advanced through the vadose zone. Sodium fluorescein, a water-soluble dye, was added to the infiltration gallery when it was initially filled, and was analyzed in both pore water and groundwater samples to determine the arrival of infiltrating water at the monitoring points. Three lysimeters were installed adjacent to the infiltration gallery to allow collection and analysis of pore water samples, and two groundwater monitoring wells, located approximately 5 and 30 feet from the infiltration gallery, were used to monitor changes in groundwater chemistry over the course of the pilot test.

The overall effectiveness of treatment was evaluated by analyzing perchlorate concentrations in six soil borings drilled before the test, and comparing these results with perchlorate data for seven soil borings drilled after the test. The soil data were used to develop geostatistical models of the distribution and mass of perchlorate in the vadose zone. The mass estimates were developed using Mining Visualization System, a geostatistical modeling software package (C Tech, 2014).

2.2.2 Results

Approximately two pore volumes of water were infiltrated during the pilot test. The results of the pilot test were as follows:

- **Pore water**: Pore water sampling results (Figure 2) show large perchlorate concentration reductions over the course of the pilot test. Results for the intermediate depth lysimeter (TT-LY2-2; Figure 2) show a sharp perchlorate concentration decline from 14 mg/L in the initial sample to <0.001 mg/L over a period of 8 weeks. Results for the deep lysimeter (TT-LY2-3; Figure 2) show a slow concentration decline from 210 mg/L to 12 mg/L over a period of about 9 weeks, followed by a sharp decline from 12 mg/kg to <0.001 mg/kg over the next 8 weeks. The sharp concentration declines observed in both lysimeters coincided with breakthrough of fluorescein and organic carbon. The association between the concentration declines and organic carbon breakthrough, as well as the magnitude of the concentration declines, suggest that biodegradation was induced in the vadose zone during the pilot test.

- **Groundwater**: Groundwater sampling results for the closest monitoring well (TT-MW2-44; Figure 2) show that organic carbon substrate was successfully transported to groundwater during the pilot test. Perchlorate concentrations show an initial increase from about 40 mg/L to 100 mg/L over a period of approximately 9 weeks, followed by a rapid decline from 100 mg/L to <0.001 mg/L over a period of 10 weeks. The rapid concentration reductions coincided with breakthrough of fluorescein and organic carbon, suggesting that biodegradation was induced in groundwater.
- **Soil**: Despite clear evidence for flushing and biodegradation of perchlorate in the vadose zone, soil sampling results (Figure 3) indicate the overall efficiency of perchlorate removal was approximately 50%. The difference between the large concentration declines observed in the pore water data vs. the relatively low removal efficiency observed in the soil data was attributed to flow along preferential pathways, most likely fractures in the relatively dry clayey sand soils.

2.2.3 Lessons Learned

The most important result of the pilot test was that the dominant factor affecting perchlorate removal from the vadose zone was flow along preferential pathways. These effects cannot be reproduced in laboratory studies and are difficult to observe in the field. Field testing of the soil flushing technology is critical.

After approximately 12 weeks, the average infiltration rate declined to less than 0.05 inches per hour (in/hr), approximately 20% of the average infiltration rate of 0.26 in/hr observed for the entire 29 week study. The decline in the infiltration rate was most likely due to aerobic biofouling in the infiltration gallery. Continuous addition of an oxygen scavenger to the water and modification of the infiltration gallery design to minimize water residence time were recommended to reduce biofouling.

Although field conditions at the case study site and the NERT site clearly differ with respect to vadose zone permeability and depth to groundwater, the basic framework used for evaluating technology performance is considered to be applicable. Operational improvements recommended in the case study, particularly with respect to continuous addition of an oxygen scavenger to the water used for flushing, will be implemented to reduce the effects of biofouling during the proposed pilot test.

3.0 PILOT TEST CONCEPTUAL DESIGN

This section describes the conceptual design for the proposed soil flushing pilot test. The conceptual design includes objectives, an overview of the testing program, pilot test location, preliminary field and laboratory testing, system components, system operation, potential impacts to the GWETS, permitting requirements, and health and safety requirements. The system design and performance monitoring program, which is described in Section 4 of this Revised Work Plan, may be modified or refined based on the results of additional data collection, described in Section 3.4 below. The results of the additional data collection and any changes to the pilot test conceptual design will be presented in a technical memorandum amending this Work Plan.

All field work will be conducted in accordance with the existing Site Management Plan (Environ, 2012b) and Field Sampling Plan (Environ, 2014c).

3.1 Objectives

The objectives of the proposed pilot test are to:

- Evaluate the effectiveness of soil flushing for reducing perchlorate mass in the vadose zone
- Determine optimal water infiltration and substrate amendment rates
- Assess perchlorate mobilization effects on groundwater during flushing operations
- Estimate treatment timeframes and unit costs for full-scale implementation, if the pilot test shows that soil flushing is effective. The costs will include modifications to the GWETS, if necessary

The pilot test directly addresses the Vadose Zone Source Control remedial action objective discussed in the Remedial Investigation and Feasibility Study Work Plan for the site. (Environ, 2014a).

3.2 Pilot Test Overview

The pilot testing program is designed to assess the potential for remediating perchlorate-impacted soil and groundwater by infiltrating water into the vadose zone. Infiltrating water will dissolve and transport perchlorate from the vadose zone to groundwater, where it can be collected and treated by the existing GWETS. As previously noted in Section 2.3, this process can be enhanced by amending the infiltration water with an organic carbon substrate, which would provide the following potential benefits:

- Reducing the mass of perchlorate flushed to groundwater by inducing biodegradation in the vadose zone, which could potentially increase perchlorate removal efficiency in the vadose zone and reduce perchlorate loading to groundwater and, ultimately, to the GWETS.
- Inducing biodegradation in the groundwater by transporting organic carbon to the saturated zone, which could potentially provide partial or complete treatment of groundwater in the pilot test area, thus further reducing perchlorate loading to the GWETS.

To evaluate soil flushing in detail, the pilot test will consist of constructing and operating four test plots, each of which represents a variation of the technology. The proposed testing scheme includes the following test plots:

- High flow, water only
- High flow, carbon substrate-amended water
- Reduced flow, water only
- Reduced flow, carbon substrate-amended water

Both high flow test plots will be operated so that standing water is maintained in the infiltration galleries throughout the test. These conditions can readily be achieved by using water level sensors to control the introduction of water into the infiltration galleries. Water in these test plots will infiltrate at the maximum rate allowed by local soil conditions. Both reduced flow test plots will be operated so that water is introduced continuously and uniformly into the soil at roughly one-half of the rate observed in the high flow test plots. These conditions can be achieved by several means, including the use of agricultural drip irrigation equipment with closely-spaced emitters. Results from the reduced flow test plots will be compared with results from the high flow test plots to evaluate whether efficiencies in water usage or perchlorate removal can be realized by infiltrating water at a lower rate.

Water amended with an organic carbon substrate will be used in two test plots (one high flow and one reduced flow). Water without carbon substrate will be used in the other two test plots. The results from the amended test plots will be compared with the unamended test plots to evaluate potential benefits and drawbacks from biodegradation.

Several techniques will be used to monitor the test, including the following:

- Flow readings and other system parameters will be recorded on a periodic basis to determine water infiltration and substrate addition rates.
- A tracer dye will be added to each of the test plots at system startup to allow positive detection of the flushed water as it migrates vertically through the vadose zone and then laterally in the saturated zone.
- The chemistry of the infiltrating solution will be monitored in the vadose zone by collecting pore water samples from lysimeters installed in each test plot.
- The chemistry of groundwater in the vicinity of the test plots will be monitored by collecting groundwater samples from wells installed downgradient of the test plots.

The test will be conducted until approximately 4 to 8 pore volumes of water have been flushed through the vadose zone. For the purpose of this work plan, it is assumed that the pilot test will require approximately four months to complete. However, the test may be terminated earlier or later based on actual infiltration rates observed in the field, and may be further extended in duration based on performance monitoring data.

Treatment effectiveness will be evaluated by collecting and analyzing soil samples before and after the pilot test. Soil borings will be drilled in each test plot prior to the start of the test to provide an estimate of baseline conditions. After pilot testing is completed, borings will be drilled adjacent to each of the baseline borings to evaluate changes in perchlorate, total organic carbon (TOC), water-soluble cations and anions, and moisture content in the subsurface.

3.3 Pilot Test Location

The proposed area for the pilot test is east of the BT Tank Farm, as shown in Figure 4. This area was excavated during the Soil Removal Action performed in 2010 and 2011 (Environ, 2012a), and has residual perchlorate in soil, similar to the location that was selected for testing in the previous work plan (Environ, 2014b). This area was selected for the following reasons:

- The proposed area offers the additional working space needed to accommodate four test plots in the required geometry.
- Similar to the location specified in the previous work plan (Environ, 2014b), the proposed location is within the capture zone of the interceptor well field (IWF). However, the proposed location is closer to the center of the capture zone, which will minimize potential hydraulic effects from the pilot test.
- The infrastructure needed for performing the pilot test, including water sources and electrical power, are available in the area. Existing tanks and piping present within the area could also potentially be used for water storage.
- As noted in the previous work plan, the proposed area is outside of the excavation control areas, is located outside of the current Tronox leasehold and is not near any ongoing industrial or remediation activities, and is within the central stormwater collection basin.

3.4 Preliminary Field and Laboratory Testing

The following subsections describe field and laboratory testing to be performed prior to design and construction of the pilot test systems.

3.4.1 Infiltration Tests

Four infiltration tests will be conducted using a double-ring infiltrometer apparatus, in accordance with ASTM Standard D3385-09 (Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer) (ASTM International, 2009). The tests will be performed within the four proposed test plot locations, shown in Figure 4. Briefly, the double-ring infiltrometer consists of two metal cylinders approximately 20 inches long, with diameters of 12 and 24 inches. The cylinders are arranged concentrically and driven approximately 6 inches into the soil. The inner and outer rings are then filled with water to a depth of 6 inches or less. The water is maintained at a constant level during the test using a constant-head device (float valves or a Mariotte tube). The volume of water lost through infiltration is measured at regular intervals during the test, and is used to calculate the infiltration rate in inches per hour. Tests are typically conducted for a period of approximately 6 hours, or until approximate steady-state conditions are achieved. The tests will be conducted by a subcontracted soils engineering firm, with supervision provided by Tetra Tech.

To obtain results that are representative of likely field conditions, the infiltration tests will be conducted in shallow excavations constructed by hand or with a small backhoe. Any disturbed soil at the bottom of the excavation will be removed by hand prior to emplacing the double-ring infiltrometer. Upon completion of the infiltration tests, the excavated soil will be replaced in the excavation and compacted by wheel rolling.

3.4.2 Soil Sampling

Soil borings will be drilled in each test plot to establish baseline soil conditions and to collect soil samples for the laboratory microcosm studies described in Section 3.4.3. Five soil borings will be drilled in each test plot using a hollow stem auger or rotosonic drill rig, with soil samples collected for chemical analysis at 4-foot depth intervals from approximately 2 to 22 feet below ground surface (bgs). The proposed boring layout is shown in Figure 5. The soil samples will be analyzed for perchlorate, metals (including total chromium), hexavalent chromium, TOC, moisture content, soil pH, water-soluble cations and anions, and total dissolved solids (TDS). The proposed soil analytical program is summarized in Section 4.5 of this Revised Work Plan. Drilling and soil sampling procedures are provided in the *Field Sampling Plan, Revision 1* (Environ, 2014c).

3.4.3 Laboratory Microcosm Studies

Laboratory microcosm studies will be conducted to select a carbon substrate for use in the amended test plots during the pilot test. Batch microcosms will be performed using three different substrates, and will evaluate the effects of carbon substrate dosage, nutrients (nitrogen and phosphorous), soil moisture content, and soil pH on perchlorate biodegradation. Lag time for inducing perchlorate biodegradation and biodegradation kinetics will also be addressed. Procedures, analytical methods, and a detailed scope of work will be formalized with the laboratory prior to performing the studies. The following subsections briefly outline the scope of the laboratory microcosm studies.

3.4.3.1 Soil Testing

Soil collected from the borings discussed in Section 3.4.2 and stabilized Lake Mead water obtained from the site will be used in the laboratory studies. The soil will be homogenized and analyzed for the following parameters in the laboratory to establish baseline conditions: perchlorate, chlorate, chloride, metals (including total chromium), hexavalent chromium, TOC, nitrate, sulfate, and soil pH. In addition, soil physical characteristics—including native soil moisture content, porosity, and saturated moisture content—will be analyzed.

3.4.3.2 Substrates

Three substrates will be evaluated in the microcosm studies: glycerin (a water-soluble substrate); emulsified vegetable oil (a long-lasting, slow-release substrate); and compost and wood chips (a solid substrate). The compost and wood chips will be leached in an open-bottomed screened container, and the leachate containing dissolved organic carbon will be used in the microcosm tests.

3.4.3.3 Microcosm Set-Up and Testing

The batch microcosm tests will be performed in 250-mL microcosm bottles containing a predetermined mass of amended soil. The bottle headspace will be purged with nitrogen prior to sealing the bottles with air-tight septum caps. The microcosms will then be incubated at room temperature. At designated time intervals, a set of microcosms (one per amendment, plus a control) will be opened and sacrificially sampled to evaluate perchlorate degradation. The media in the batch microcosms will be tested for perchlorate; a subset of the microcosms will also be analyzed for chloride, TOC, nitrate, sulfate, and pH. Selected samples will also be analyzed for phospholipid fatty acids (PLFAs) and the perchlorate reductase gene by polymerase chain reaction (PCR) assay.

Two different dosages will be examined for each substrate. In addition, tests will be performed at saturated moisture content and at a reduced moisture content. Based on the response observed in the saturated and reduced moisture content microcosms, additional microcosms may also be performed at other moisture contents. The need for nutrient (nitrogen and phosphorus) amendment will be evaluated in selected microcosms.

3.4.3.4 Evaluation of Results

All results will be tabulated and graphed, if necessary, and presented in a technical memorandum amending this Work Plan. Based on the conclusions of the microcosm studies, a substrate will be selected for use during the soil flushing pilot test.

3.4.3.5 Additional Soil Leaching Studies

If the results of the batch microcosm tests indicate that compost leachate is the most appropriate substrate for testing in the field, additional laboratory testing will be performed to evaluate long-term leaching characteristics. Water will be infiltrated into open-bottomed containers at different flow rates, and the effluent water will be collected periodically and analyzed for TOC. A plot showing changes in effluent TOC over time will be used to evaluate the likely response and longevity of compost leaching during field testing.

3.5 System Components

The following sections briefly describe the primary components of the proposed pilot test system.

3.5.1 Water Source

Two potential water sources are available in the vicinity of the proposed pilot test location: stabilized Lake Mead water and treated effluent from the GWETS. As previously noted in Section 2, the recycling of GWETS effluent for use in soil flushing has the potential to increase the salt content of groundwater, which could in turn affect the treatment system. Stabilized Lake Mead water is therefore preferred for the purpose of the pilot test. If the pilot test is successful and full-scale implementation is recommended, a detailed evaluation to determine the optimal water source will be conducted during full-scale design.

3.5.2 Water and Amendment Storage, Pretreatment, and Conveyance

Water will be piped to a storage tank placed in the vicinity of the pilot test location. To the extent feasible, the conveyance piping to the water storage tank will be placed above-ground. Water to be applied to the unamended test plots will be filtered, pretreated with an oxygen scavenger, and conveyed directly to the test plots via aboveground piping.

Water to be applied to the amended test plots will be filtered, and then pretreated by adding an oxygen scavenger, carbon substrate, and other amendments, such as nutrients, as recommended based on the microcosm testing results. To the extent feasible, all of the amendments will be premixed with water to form a concentrated solution, and stored in polyethylene tanks. Metering pumps will be used to inject the amendments directly into the conveyance piping, where they will be mixed with an inline mixer prior to conveyance to the test plots via aboveground piping.

3.5.3 Test Plot Construction

The proposed test plot layout is shown in Figure 5. Infiltration galleries will be constructed at the two high flow test plots within an 18-inch deep excavation measuring 30 by 30 feet in plan dimension. The bottom of the excavation will be scarified to promote infiltration. Approximately 6 inches of gravel will then be placed at the bottom of the excavation. Perforated piping will be placed on the gravel base to distribute water within the gallery. The remainder of the excavation will be backfilled with gravel to match the surrounding grade. The gallery will then be covered with approximately 1 foot of excavated soil to reduce water loss from evaporation and help maintain anaerobic conditions within the amended test plot. Geotextile filter fabric will be placed between the gravel and overlying soil to minimize migration of fines into the gravel backfill.

The reduced flow test plots will consist of 30- by 30-foot areas where the ground surface has been lightly scarified to promote infiltration. A conventional agricultural drip irrigation system will then be installed at each test plot. Testing will be performed during construction to determine the emitter flow rate and emitter spacing needed to uniformly wet the ground surface at the required total flow rate. Drip tape, dripline, or polyethylene tubing with on-line emitters may be used, depending on the required flow. After installation of the irrigation systems, the test plots will be covered with polyethylene sheeting weighted down with sandbags. Covering the test plots will reduce water loss from evaporation, while allowing for inspection, maintenance, and repair of the system, if needed.

3.5.4 Lysimeters

Two pressure-vacuum lysimeters will be installed at the center of each test plot to allow sampling of pore water in the vadose zone during the pilot test. The lysimeters will be installed concurrently with the soil sampling described in Section 3.4.2. The lysimeter locations are shown in Figure 5. Lysimeters consist of a porous ceramic cup that allows collection of pore water samples from the surrounding unsaturated soil when a vacuum is applied from the ground surface. A sample chamber in the lysimeter is then pressurized to lift the sample to the surface. The lysimeters will be set in a silica flour slurry to improve hydraulic communication with the formation.

Lysimeter installation procedures are provided in Appendix A. The proposed lysimeter sampling program is described in Section 4.3 of this Revised Work Plan.

3.5.5 Groundwater Monitoring Wells

No existing groundwater monitoring wells are located near the proposed pilot test location. Groundwater monitoring wells will be installed approximately 10 and 40 feet downgradient of each test plot to monitor groundwater chemistry and groundwater levels during the pilot test. Two additional monitoring wells will be installed approximately 40 feet cross-gradient of the test plots to evaluate potential hydraulic effects due to groundwater mounding. The monitoring wells will be installed concurrently with the soil sampling described in Section 3.4.2. The proposed well locations are shown in Figure 5. The new monitoring wells will be constructed so that the well screen extends a minimal distance above the water table, to avoid creating a preferential vertical flow pathway at depth.

Drilling, well installation, and well development procedures are provided in the *Field Sampling Plan, Revision 1* Environ, 2014c). The proposed monitoring well sampling program is described in Section 4.4 of this Revised Work Plan.

3.6 System Operation

System operation will commence with a 3- to 5-day startup period for the high flow test cells. System startup will include the following:

- Inspecting the tanks and piping for leaks
- Initiating a dye tracer test (described in Section 4.2 of this Revised Work Plan)
- Testing, troubleshooting, and adjusting of system controls
- Monitoring fluid levels in the tanks and infiltration galleries
- Monitoring and adjusting flow rates as the system approaches steady-state conditions.

The startup period will be followed by one week of site visits every two days to monitor water, substrate, and oxygen scavenger usage, and make further adjustments to the system, as needed.

Startup data for the high flow test plots will be used to estimate the maximum infiltration rate that can be achieved in the pilot test area. Once the maximum infiltration rate has been determined, the design of the drip irrigation systems for the reduced flow test plots will be finalized and the systems constructed. Reduced flow pilot testing will begin with a three- to five-day startup period, followed by one week of site visits every two days, as described above.

After the startup period, routine system operation, maintenance, and monitoring (OM&M) will be performed at weekly intervals for the duration of the pilot test, assuming a test duration of approximately four months. This frequency may be increased or decreased after system startup, based on the observed infiltration rates and the estimated time needed to infiltrate 4 to 8 pore volumes of water. Routine OM&M will include the following:

- System maintenance checks, including inspecting tanks and visible piping for leaks; testing system alarms; monitoring and recording fluid levels in the tanks and infiltration galleries; and recording flow to each test plot
- Replenishment of the substrate and oxygen scavenger storage tanks on an as-needed basis
- Checking the lysimeters for moisture, and if moisture is present, collecting pore water samples for chemical analysis as described in Section 4.3 of this Revised Work Plan. Sampling of the lysimeters will continue for the duration of the pilot test and for a 4-week period after the systems are shut down
- Collecting groundwater samples from the downgradient monitoring wells for chemical analysis, as described in Section 4.4 of this Revised Work Plan. Initially, only the wells located 10 feet downgradient from the test plots will be sampled. Once tracer arrival at the closest well has been confirmed, sampling will be initiated at the wells located 40 feet downgradient from the test plots. Sampling of the monitoring wells will continue for a 4-week period after the system is shut down

3.7 Impacts to the GWETS

Potential hydraulic impacts to the GWETS due to groundwater mounding, as well as impacts to the treatment process due to additional perchlorate loading, were evaluated by Environ in a previous submittal (Environ, 2014b). These calculations assumed that infiltration would be performed in a 100- by 100-foot covered pond, which is nearly three times larger than the combined area of the four test plots proposed in this Revised Work Plan. Environ concluded that impacts to the GWETS from the much larger treatment area would be negligible. Tetra Tech concurs with this assessment and therefore, no significant impacts to the GWETS are anticipated from the pilot test proposed in this document.

3.8 Permitting Requirements

The pilot test will require a temporary Groundwater Discharge Permit from the NDEP Bureau of Water Pollution Control, as required by the Nevada Revised Statute 445A.485. The temporary permit is valid for a maximum of 180 days. If the pilot test extends beyond 180 days, an application for a new temporary Groundwater Discharge Permit will be submitted at least 30 days prior to expiration of the initial permit.

It is unlikely that construction for the pilot test will disturb more than 0.25 acres of land. However, if this assumption changes, a Dust Control Permit will be obtained from the Clark County Division of Air Quality, as required by Clark County Air Quality Regulations Section 94.

Well permits will be obtained from the Nevada Division of Water Resources as required.

Building permits will be obtained as necessary from the Clark County Building Department.

3.9 Health and Safety

Field work will be conducted in accordance with a site-specific Health and Safety Plan, which will address potential chemical and physical hazards associated with the pilot test. It is anticipated that Level D personal protective equipment will be required for all field activities.

4.0 PERFORMANCE MONITORING PLAN

This section describes the conceptual monitoring program associated with implementation, operation, and system shut down to determine treatment effectiveness. Performance monitoring will include the following:

- System parameter monitoring
- Tracer study to track infiltrated water in the vadose zone and groundwater
- Pore water sampling and analysis
- Groundwater sampling and analysis
- Soil sampling and analysis within each test plot

4.1 System Parameters

System parameter monitoring will consist of recording flow meter readings and measuring fluid levels in tanks on a daily basis for the three to five days during system start-up, followed by measurements every other day for one additional week. Readings will be recorded on a weekly basis during regular system maintenance visits. This frequency may be increased or decreased based on the observed infiltration rates and the estimated time needed to infiltrate 4 to 8 pore volumes of water.

Infiltration rates will be determined using totalizing flow meters installed in the process lines leading to the test plots. Oxygen scavenger and substrate dosages will be estimated from the water flow and fluid level measurements.

4.2 Tracer Study

A tracer study will be conducted as part of the pilot test to track the infiltrated water as it migrates through the vadose zone and groundwater. Sodium fluorescein is a commonly used dye tracer, and was determined to be the most appropriate tracer for this study due to its high solubility, low toxicity, detectability at low concentrations, and stability (e.g., Smart and Laidlaw, 1977). This tracer is a bright yellow fluorescent dye that can be readily detected visually and quantitatively analyzed in the field at part per billion concentrations using a fluorometer. Because fluorescein is a man-made compound, it is unlikely that it would be present in the vadose zone or aquifer. However, baseline samples will be collected from the newly installed monitoring wells to verify that fluorescein is not present in groundwater.

A sufficient quantity of tracer is required to impact the study area at concentrations that would be in the detectable range. Approximately 10 pounds of fluorescein diluted in 1,200 gallons of water will be infiltrated as a slug in each test plot at the beginning of the pilot test.

Tracer concentrations will be monitored in pore water by collecting samples from the pressure-vacuum lysimeters; tracer concentrations in groundwater will be monitored in samples collected from newly-installed monitoring wells. The pore water and groundwater samples will be analyzed in the field using a hand-held fluorometer configured for fluorescein. Sampling frequencies for pore water and groundwater are discussed below in Sections 4.3 and 4.4, respectively.

4.3 Pore Water Sampling

The lysimeters installed in each test plot will be evacuated and checked for water on a weekly basis. If the moisture content of the soil is high enough to allow sampling of the lysimeters, pore water samples will be collected on a weekly basis for the duration of system operation, plus a period of 4 weeks after operation is terminated. The sampling frequency may be increased or decreased based on the observed infiltration rates and the estimated time needed to infiltrate 4 to 8 pore volumes of water.

The proposed pore water monitoring program is summarized in Table 1. Lysimeters typically yield relatively small volumes of water during sampling. The pore water analysis program proposed in the previous work plan (Environ, 2014b) would have required collection of more than three liters of water from each lysimeter to provide a sufficient sample volume to the laboratory. Recognizing the limitations of lysimeters, the pore water sampling program has therefore been reduced from the comprehensive list of constituents outlined in the previous work plan (Environ, 2014b) to a more manageable program consisting only of constituents which are key for evaluating technology performance, including perchlorate, TDS, TOC, and fluorescein. If sufficient sample volume is available, total chromium and hexavalent chromium will also be analyzed in the pore water samples.

Lysimeter sampling procedures are provided in Appendix A.

4.4 Groundwater Level Gauging

Potential hydraulic effects due to groundwater mounding during the pilot test will be evaluated by gauging groundwater levels in the ten monitoring wells on at least a daily basis during system startup, and on a weekly basis during operation of the pilot systems. The gauging frequency may be increased or decreased based on the observed infiltration rates and the estimated time needed to infiltrate 4 to 8 pore volumes of water.

Monitoring well gauging procedures are provided in the *Field Sampling Plan, Revision 1* (Environ, 2014c).

4.5 Groundwater Sampling

Groundwater samples will be collected from all new monitoring wells prior to the start of infiltration (baseline samples). The monitoring wells located 10 feet downgradient from the test plots will be sampled on a weekly basis for the duration of system operation, and for a period of four weeks after operation is terminated. The monitoring wells located 40 feet downgradient from the test plots will be sampled on a weekly basis starting one week after the initial detection of fluorescein in the wells located 10 feet from the test plots. These wells will be sampled on a weekly basis for the remainder of system operation, and for a period of four weeks after operation is terminated. The sampling frequency may be increased or decreased after system startup, based on the observed infiltration rates and the estimated time needed to infiltrate 4 to 8 pore volumes of water. Sampling will not be performed in the cross-gradient monitoring wells.

The proposed groundwater sampling program is summarized in Table 2. The groundwater sampling program includes weekly sampling for parameters considered key for evaluating technology performance, including field parameters (ph, electrical conductivity, dissolved oxygen, oxidation reduction potential, and temperature), fluorescein, perchlorate, total chromium, hexavalent chromium, TOC, and TDS. More comprehensive sampling to evaluate potential secondary effects from soil flushing, such as mobilization of salts and metals, will be performed on a monthly basis. The monthly sampling events will include the parameters listed above, plus cations and anions, dissolved metals, and hexavalent chromium.

Monitoring well sampling procedures are provided in the *Field Sampling Plan, Revision 1* (Environ, 2014c).

4.6 Soil Sampling

Soil samples will be collected before and after system operation to verify treatment effectiveness. Baseline sampling will be conducted prior to system construction to establish baseline soil conditions. The baseline borings will include the four soil borings in each test plot previously discussed in Section 3.4.2, plus one soil boring at the center of each test plot drilled for lysimeter installation. Soil samples will be collected for chemical analysis from the baseline borings at 4-foot depth intervals from approximately 2 to 22 feet bgs. The soil samples will be analyzed for perchlorate, metals (including total chromium), hexavalent chromium, TOC, moisture content, soil pH, water-soluble cations and anions, and TDS.

After pilot testing is completed, soil borings will be drilled adjacent to each of the baseline borings to evaluate changes in perchlorate, metals (including total chromium), hexavalent chromium, TOC, moisture content, soil pH, water-soluble cations and anions, and TDS in the subsurface. The post-testing borings will be sampled at the same depths as the baseline borings.

The proposed soil sampling program is summarized in Table 3. Drilling and soil sampling procedures are provided in the *Field Sampling Plan, Revision 1* (Environ, 2014c).

5.0 REPORTING

Following completion of the infiltration tests, baseline soil sampling, and microcosm studies, a technical memorandum will be prepared for NDEP review and comment. The technical memorandum will summarize the results of the preliminary field and laboratory testing previously described in Section 3.4, and will use this information to refine the conceptual design of the soil flushing pilot test, as needed.

Following completion of the pilot test, a Soil Flushing Pilot Test Report will be prepared for NDEP review and comment. The report will include the following:

- Evaluation of the effectiveness of soil flushing for reducing perchlorate mass in the vadose zone, including a comparison of the results from the high flow, reduced flow, substrate-amended and unamended test plots
- Assessment of perchlorate mobilization into groundwater during system operations
- Evaluation of the effects of the substrate-amended water in inducing biodegradation in the vadose zone and groundwater
- A preliminary cost-benefit analysis to determine the technology's feasibility and cost effectiveness for full-scale application

6.0 SCHEDULE

Figure 6 provides a schedule for completion of the preliminary field and laboratory studies; preparation and submittal of the technical memorandum; implementation, operation, and monitoring of the pilot-study; and submittal of the Soil Flushing Pilot Test Report.

7.0 REFERENCES

ASTM International, 2009. *Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer.* ASTM Standard D3385-09, 2009.

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Environ, 2012a. *Interim Soil Removal Action Completion Report, Nevada Environmental Response Trust Site, Henderson, Nevada, August 2010-November 2011*. January 2012.

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Smart, P.L and Laidlaw, I.M.S., 1977. *An Evaluation of Some Fluorescent Dyes for Water Tracing.* Water Resources Research Vol. 13, No. 1, pp. 15-33.

Tetra Tech, 2013. *Soil Treatability Study and Hydraulic Testing Report.* (Technical report submitted to California Department of Toxic Substances Control summarizing results of soil flushing pilot test). March 2013.

TABLES

Table 1
Pore Water Sampling Plan

Parameter	Method	Frequency	Purpose
Perchlorate	E314	Weekly[1]	Assess treatment effectiveness
Chromium	SW6020	Weekly[2]	Assess treatment effectiveness
Hexavalent Chromium	SW7199	Weekly[2]	Assess treatment effectiveness
TOC	E415	Weekly[1]	Assess delivery of carbon substrate
TDS	E160.1	Weekly[1]	Assess salt loading
Fluorescein	Fluorometer	Weekly[1]	Assess tracer arrival

Acronyms and Abbreviations
TOC: total organic carbon
TDS: total dissolved solids

Notes
1. Analysis will be performed weekly (or at intervals to be determined based on infiltration rate) when moisture content of soil is high enough to allow sampling.
2. Analysis will be performed weekly (or at intervals to be determined based on infiltration rate) when adequate sample volume is recovered from lysimeters.

Table 2
Groundwater Sampling Plan

Parameter	Method	Frequency[1]	Purpose
pH	Field meter	Baseline and Weekly	Assess geochemical conditions
EC	Field meter	Baseline and Weekly	Assess geochemical conditions
DO	Field meter	Baseline and Weekly	Assess geochemical conditions
ORP	Field meter	Baseline and Weekly	Assess geochemical conditions
Temperature	Field meter	Baseline and Weekly	Assess geochemical conditions
Fluorescein	Fluorometer	Baseline and Weekly	Assess tracer arrival
Perchlorate	E314	Baseline and Weekly	Assess treatment effectiveness
Chromium	SW6020	Baseline and Weekly	Assess treatment effectiveness
Hexavalent Chromium	SW7199	Baseline and Weekly	Assess treatment effectiveness
TOC	E415	Baseline and Weekly	Assess delivery of carbon substrate
TDS	E160.1	Baseline and Weekly	Assess salt loading
Cations and Anions[2]	Note 2	Baseline and Monthly	Assess salt loading and effects of treatment
Metals[3]	SW6020	Baseline and Monthly	Assess secondary impacts of treatment

Acronyms and Abbreviations
EC: electrical conductivity
DO: dissolved oxygen
ORP: oxidation-reduction potential
TOC: total organic carbon
TDS: total dissolved solids

Notes
1. Weekly sampling of wells 40 feet from test plots will start 1 week following initial detection of fluoroscein in wells 10 feet from test plots. Sampling intervals may be modified based on infiltration rate and estimated test duration.
2. Cations include sodium, potassium, calcium, and magnesium (Method SW6020). Anions include chloride, sulfate, nitrate (Method E300/SW9056), carbonate, and bicarbonate (Method E2320B).
3. Metals include silver, arsenic, boron, barium, beryllium, cadmium, cobalt, copper, iron, mercury, molybdenum, manganese, nickel, lead, antimony, selenium, titanium, and zinc.

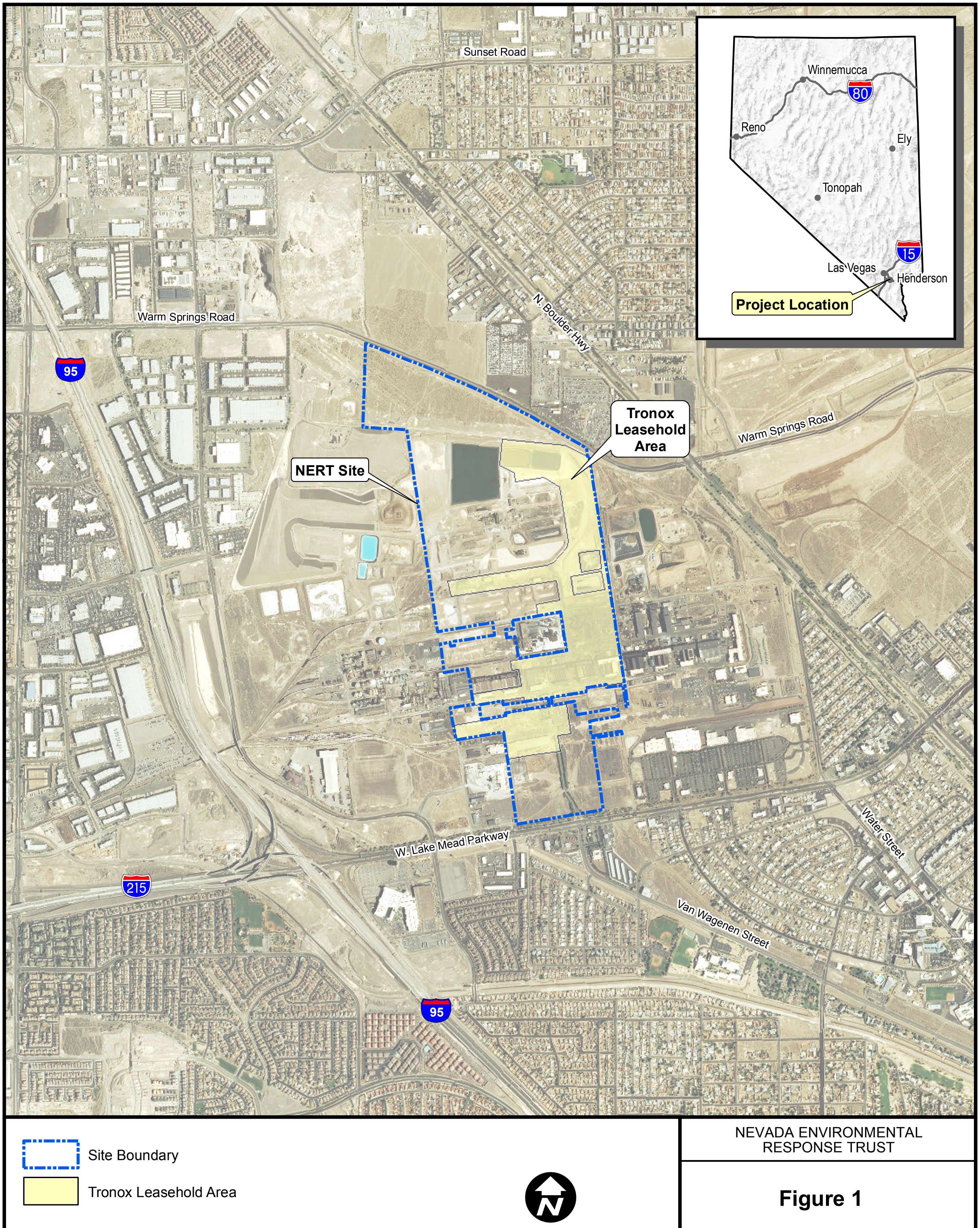
Table 3
Soil Sampling Plan

Parameter	Method	Frequency	Purpose
Perchlorate	E314	Baseline and post-treatment	Assess treatment effectiveness
Metals[1]	SW6020	Baseline and post-treatment	Assess treatment effectiveness
Hexavalent Chromium	SW7199	Baseline and post-treatment	Assess treatment effectiveness
TOC	E415	Baseline and post-treatment	Assess delivery of carbon substrate
Moisture Content	ASTM D2216	Baseline and post-treatment	Assess delivery of water
Soil pH	SW9045	Baseline and post-treatment	Assess geochemical conditions
Soluble Cations and Anions[2]	Note 2 Note 3	Baseline and post-treatment	Assess salt loading
TDS[2]	E160.1	Baseline and post-treatment	Assess salt loading

<u>Acronyms and Abbreviations</u>
TOC: total organic carbon
TDS: total dissolved solids

<u>Notes</u>
1. Metals include silver, arsenic, boron, barium, beryllium, cadmium, chromium, cobalt, copper, iron, mercury, molybdenum, manganese, nickel, lead, antimony, selenium, titanium, and zinc.
2. Cations include sodium, potassium, calcium, and magnesium (Method SW6020). Anions include chloride, sulfate, nitrate (Method E300/SW9056), carbonate, and bicarbonate (Method E2320B)
3. Analysis to be performed on water extract prepared per method SW9056.

FIGURES



Source:
NAIP 2013 aerial photograph.

NEVADA ENVIRONMENTAL RESPONSE TRUST

Figure 1

Site Location

TETRA TECH

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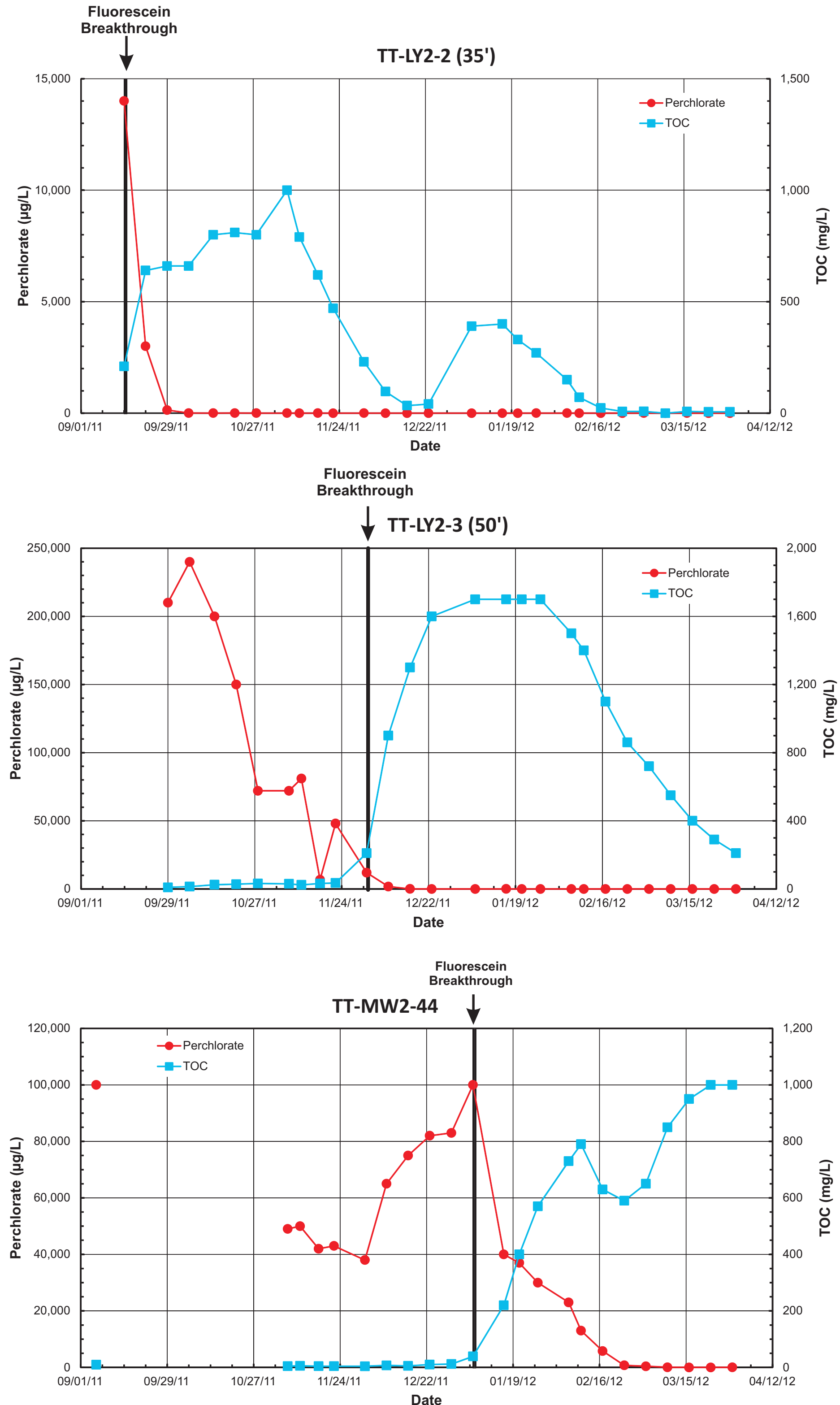

NEVADA ENVIRONMENTAL RESPONSE TRUST

Figure 2
Case Study Results Pore Water and Groundwater

TETRA TECH

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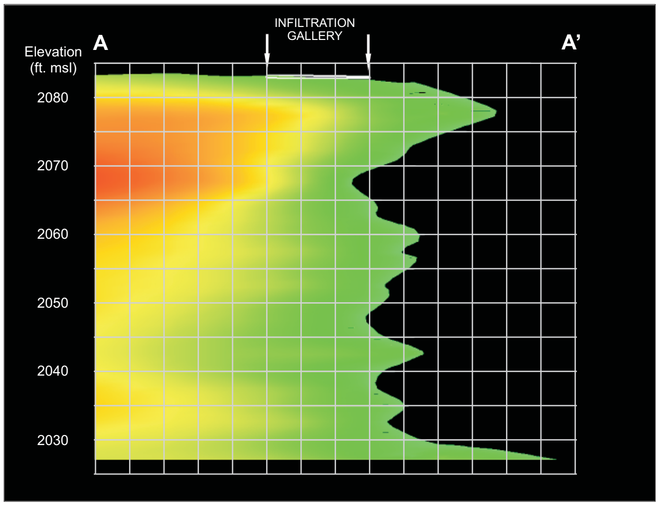

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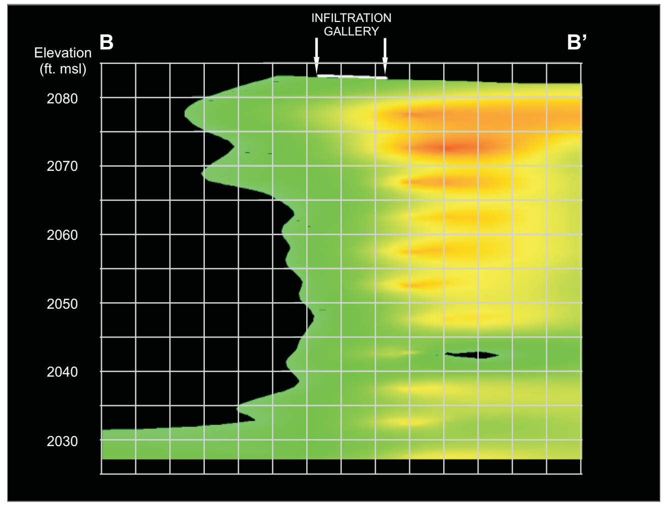

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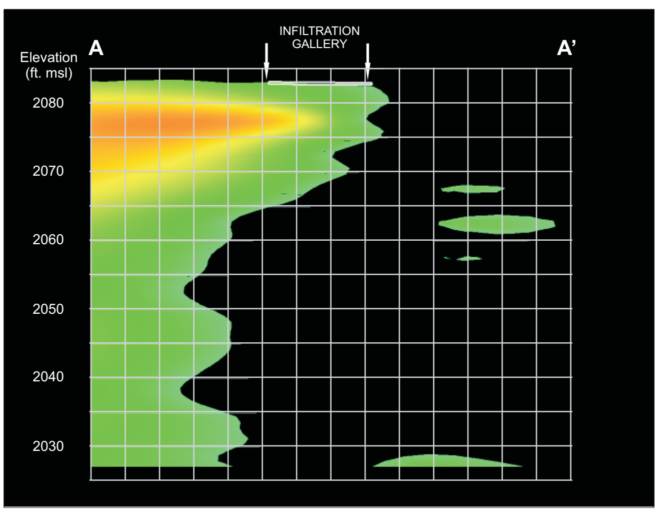
Pre-Treatment



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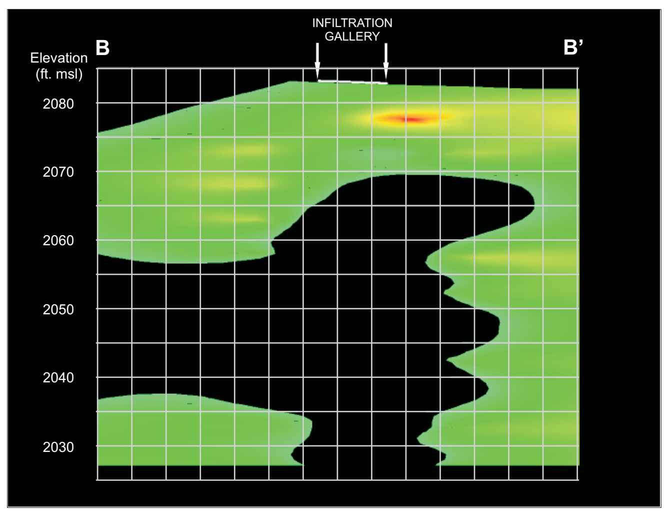

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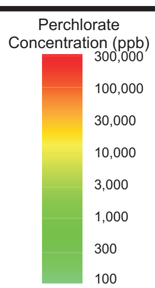

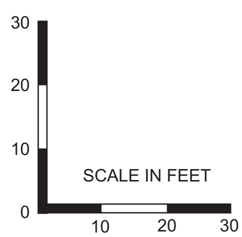

NEVADA ENVIRONMENTAL RESPONSE TRUST

Figure 3

Case Study Results
Soil Sampling

TETRA TECH

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0 100 200 Feet

Source:
Google Earth 2013 aerial photograph.

- Groundwater Barrier Wall
- Site Boundary
- Tronox Leasehold Area
- Test Plot Location

NEVADA ENVIRONMENTAL RESPONSE TRUST

Figure 4

Test Plot Locations

TETRA TECH

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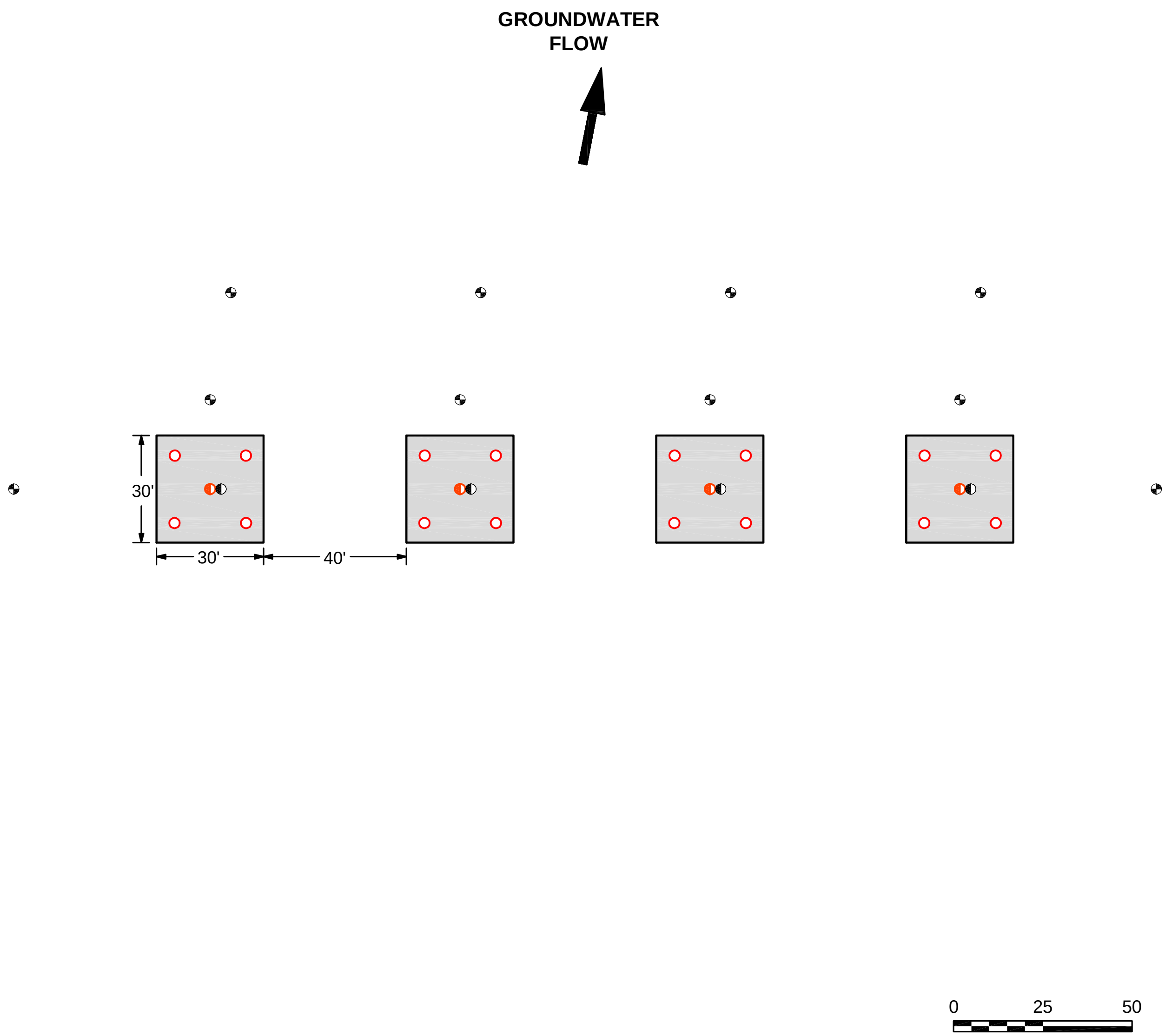


MONITORING WELL

LYSIMETER / SOIL SAMPLES

LYSIMETER

SOIL BORING

TEST PLOT

NEVADA ENVIRONMENTAL
RESPONSE TRUST

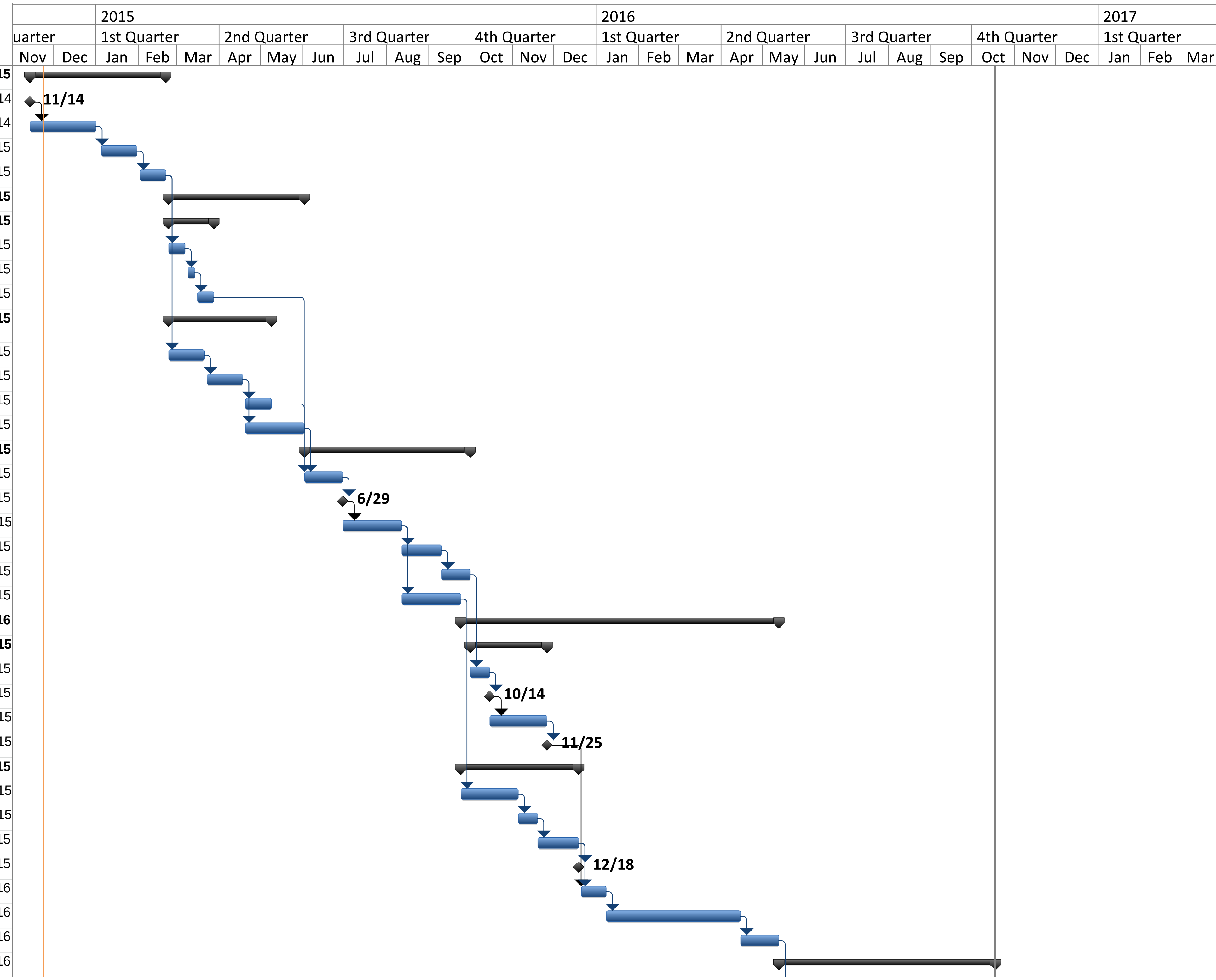
Figure 5

Test Plot Layout

TETRA TECH

Figure 6
Soil Flushing Pilot Test Project Schedule

ID	Task Name	Duration	Start	Finish
1	**Revised Work Plan**	**65 days**	**Fri 11/14/14**	**Fri 2/20/15**
2	Submit Revised Work Plan to NDEP	0 days	Fri 11/14/14	Fri 11/14/14
3	NDEP Review	30 days	Fri 11/14/14	Wed 12/31/14
4	Respond to NDEP Comments	20 days	Mon 1/5/15	Fri 1/30/15
5	NDEP Approval of Revised Work Plan	15 days	Mon 2/2/15	Fri 2/20/15
6	**Preliminary Field Testing**	**70 days**	**Mon 2/23/15**	**Mon 6/1/15**
7	**Infiltration Tests**	**25 days**	**Mon 2/23/15**	**Fri 3/27/15**
8	Field Preparation/Scheduling	10 days	Mon 2/23/15	Fri 3/6/15
9	Field Work	5 days	Mon 3/9/15	Fri 3/13/15
10	Data Analysis/Report	10 days	Mon 3/16/15	Fri 3/27/15
11	**Soil Boring, Lysimeter, and Monitoring Well Installation**	**55 days**	**Mon 2/23/15**	**Fri 5/8/15**
12	Field Preparation/Scheduling	20 days	Mon 2/23/15	Fri 3/20/15
13	Field Work	20 days	Mon 3/23/15	Fri 4/17/15
14	Laboratory Analysis	15 days	Mon 4/20/15	Fri 5/8/15
15	Microcosm Tests	30 days	Mon 4/20/15	Mon 6/1/15
16	**Technical Memorandum**	**85 days**	**Tue 6/2/15**	**Wed 9/30/15**
17	Prepare Technical Memorandum	20 days	Tue 6/2/15	Mon 6/29/15
18	Submit Technical Memorandum to NDEP	0 days	Mon 6/29/15	Mon 6/29/15
19	NDEP Review	30 days	Tue 6/30/15	Tue 8/11/15
20	Respond to NDEP Comments	20 days	Wed 8/12/15	Wed 9/9/15
21	NDEP Approval of Technical Memorandum	15 days	Thu 9/10/15	Wed 9/30/15
22	Detailed Pilot Test System Design	30 days	Wed 8/12/15	Wed 9/23/15
23	**Pilot Test Implementation**	**160 days**	**Thu 9/24/15**	**Thu 5/12/16**
24	**Groundwater Discharge Permit**	**40 days**	**Thu 10/1/15**	**Wed 11/25/15**
25	Prepare Permit Application	10 days	Thu 10/1/15	Wed 10/14/15
26	Submit Permit Application to NDEP	0 days	Wed 10/14/15	Wed 10/14/15
27	NDEP Review	30 days	Thu 10/15/15	Wed 11/25/15
28	Issue Temporary Permit	0 days	Wed 11/25/15	Wed 11/25/15
29	**System Construction**	**60 days**	**Thu 9/24/15**	**Fri 12/18/15**
30	Equipment Procurement/Scheduling	30 days	Thu 9/24/15	Wed 11/4/15
31	Mobilization	10 days	Thu 11/5/15	Wed 11/18/15
32	Construction	20 days	Thu 11/19/15	Fri 12/18/15
33	Construction Complete	0 days	Fri 12/18/15	Fri 12/18/15
34	System Startup	10 days	Mon 12/21/15	Thu 1/7/16
35	System OM&M	70 days	Fri 1/8/16	Thu 4/14/16
36	Post-Infiltration Monitoring	20 days	Fri 4/15/16	Thu 5/12/16
37	Pilot Test Reporting	110 days	Fri 5/13/16	Mon 10/17/16

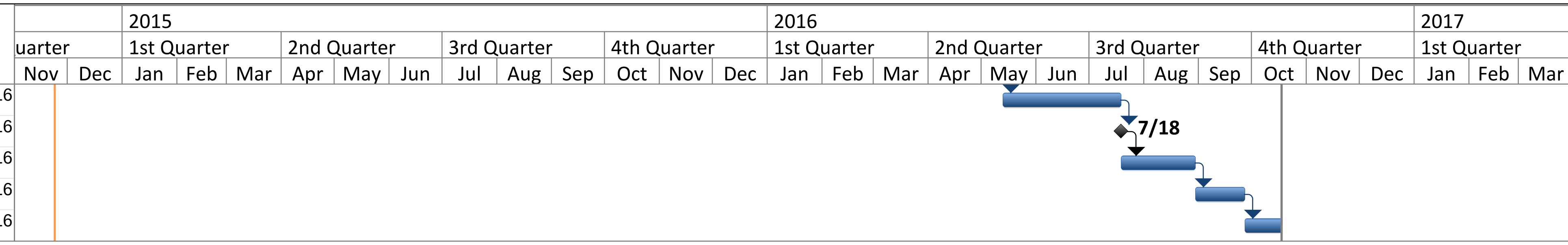


Project: NERT_Soil Flush Wkp_Pdf
Date: Mon 11/24/14

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

Figure 6
Soil Flushing Pilot Test Project Schedule

ID		Task Name	Duration	Start	Finish
38		Prepare Pilot Test Report	45 days	Fri 5/13/16	Mon 7/18/16
39		Submit Pilot Test Report to NDEP	0 days	Mon 7/18/16	Mon 7/18/16
40		NDEP Review	30 days	Tue 7/19/16	Mon 8/29/16
41		Respond to NDEP Comments	20 days	Tue 8/30/16	Mon 9/26/16
42		NDEP Approval of Pilot Test Report	15 days	Tue 9/27/16	Mon 10/17/16



Project: NERT_Soil Flush Wkp_Pdf
Date: Mon 11/24/14

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

APPENDIX A
FIELD PROCEDURES FOR LYSIMETER INSTALLATION AND SAMPLING

FIELD PROCEDURES FOR LYSIMETER INSTALLATION AND SAMPLING

1.0 Introduction

This document describes field procedures and quality assurance/quality control (QA/QC) procedures for lysimeter installation and sampling at the Nevada Environmental Response Trust (NERT) site. This document serves as a supplemental planning document to the project-specific Work Plan, and describes field and QA/QC procedures that will be used for the installation and sampling of lysimeters. The remainder of this document is organized as follows:

- **Field Sampling Plan (FSP) Addendum (Section 2.0)**: The FSP Addendum describes field operations, environmental sampling procedures, field measurements, field QA/QC, record keeping requirements, and site management.
- **Quality Assurance Project Plan (QAPP) Addendum (Section 3.0)**: The QAPP Addendum describes the project-specific analytical procedures, methods, and criteria that will be utilized for this program.
- **References (Section 4.0)**: Provides a listing of documents cited herein.

2.0 Field Sampling Plan Addendum

This document amends the FSP for the NERT site (Environ, 2014a), and describes field and QA/QC procedures for lysimeter installation and sampling. This FSP Addendum has been prepared to comply with the United States Environmental Protection Agency (EPA) document titled *Guidance for the Data Quality Objectives Process (EPA QA/G4)* (EPA, 2006).

Moisture in the unsaturated zone is held within the soil pore space by surface tension forces. These forces are referred to as soil water tension, negative pore pressure, or soil suction. Lysimeters are pore water sampling devices typically consisting of a hollow porous cup attached to a non-porous body. When the lysimeter is placed under a vacuum that exceeds the tension forces holding water in the soil pore space, a potential gradient is created that causes the pore water to move toward the lysimeter, where it can be retrieved by any of several methods. As a general rule, pore water samples can be readily collected when negative pore pressures are 0.65 bar or less. Where negative pore pressures exceed 0.85 bar, flow is negligible and samples typically cannot be retrieved. It should be noted pore pressures are positive under saturated conditions; lysimeters can also be used to collect pore water samples from the saturated zone.

2.1 Lysimeter Installation

The following subsections describe procedures to be used for the installation of lysimeters.

2.1.1 Lysimeter Types and Selection

Several types of commercially manufactured lysimeters are commonly available. This document address porous cup lysimeters, which are typically installed in soil borings.

Porous cup lysimeter types include the following:

- Vacuum lysimeters, which have a single tube used to apply vacuum to the lysimeter prior to sampling and to retrieve the sample to the surface by applying a vacuum after the sample has accumulated in the lysimeter body.
- Pressure-vacuum lysimeters, which have a pressure-vacuum tube used to apply vacuum to the lysimeter prior to sampling and to apply pressure to the lysimeter to lift the sample to the surface, and a sampling tube used for sample retrieval.
- Multiple chamber pressure-vacuum lysimeters, which have internal check valves which allow the retrieval of samples from greater depths than single-chamber pressure-vacuum lysimeters without excessive sample loss.

The lysimeter design appropriate for a particular application is determined by installation depth. Vacuum lysimeters rely on vacuum to lift retrieve the samples, and are only suitable for very shallow installations. Pressure/vacuum lysimeters are appropriate for installation depths up to 60 to 80 feet; at greater depths, a significant portion of the sample may be lost through the porous cup when the lysimeter is pressurized. Multiple chamber pressure-vacuum lysimeters are suitable for installation depths up to 300 feet.

The porous cup is typically manufactured from ceramic materials. High purity ceramics and stainless steel are also used to manufacture lysimeters suitable for a wide variety of environmental sampling.

2.1.2 Lysimeter Preparation

All lysimeters should be pressure tested before installation. Prior to pressure testing, the lysimeter (including tubing) is assembled, and the porous cup is conditioned by soaking in deionized water for approximately two hours. The sampling tube then is closed to the atmosphere. An air pump or compressed gas cylinder is then attached to the pressure-vacuum tube and used to pressurize the lysimeter to approximately 15 to 20 pounds per square inch (psi). The entire lysimeter body and all tube fittings are then placed under water. If bubbles are observed at the tube fittings, the fittings should be checked for correct assembly and retightened until no bubbles are observed. If bubbles are observed on the lysimeter body, the lysimeter may be defective. In this case, the manufacturer should be contacted to obtain a replacement.

2.1.3 Lysimeter Installation

Lysimeters may be installed in borings drilled by any technique which does not involve the use of a drilling mud. Prior to installation, the lysimeter is attached to a string of polyvinyl chloride (PVC) well casing. The casing diameter and the system used to couple the lysimeter to the casing depend on the lysimeter design; the manufacturer's specification for casing diameter and coupling type should be followed. The lysimeter tubing is placed inside the casing to prevent contact between the tubing and borehole wall, which could potentially create preferential vertical flow pathways.

Centralizers are placed on the lysimeter body, at least 2 feet above the top of the porous cup, and at 20-foot intervals on the casing string to ensure that the lysimeter and casing are not in contact with the borehole wall. Approximately one foot of <200-mesh silica flour slurry (50 pounds of silica flour to 1 gallon of water) is placed at the bottom of the borehole using a tremie pipe. The lysimeter and casing are then lowered into the borehole and gently pushed into the slurry. Additional slurry is then placed to approximately 1 to 1.5 feet above the top of the porous cup using a tremie pipe. A seal consisting of a minimum of 3 feet of bentonite is placed above the silica flour slurry and hydrated. The remainder of the borehole is then backfilled with hydrated bentonite or cement-bentonite grout.

2.1.4 Lysimeter Purging

No sooner than 24 hours after installation, newly-installed lysimeters are purged to remove fluids introduced into the silica flour slurry and surrounding formation during installation. Purging consists of sampling the lysimeter as described in Section 2.2 below. Purging is continued until approximately three borehole volumes of water have been removed from the silica slurry, or until water samples can no longer be retrieved from the lysimeter.

2.2 Lysimeter Sampling

Prior to sampling, the sampling tube is opened to the atmosphere and an air pump or compressed gas cylinder is attached to the pressure-vacuum tube. The lysimeter is then pressurized to remove any water which may have accumulated in the lysimeter between sampling events. The sampling tube is closed to the atmosphere and the pressure-vacuum line is attached to a vacuum pump. The lysimeter is then placed under a vacuum of approximately 0.65 to 0.85 bars. The pressure-vacuum line is closed and the vacuum pump is removed. The lysimeter is then left under vacuum to allow pore water to accumulate in the lysimeter body. When a sufficient volume of water has accumulated in the lysimeter, the sampling and pressure-vacuum tubes are opened to the atmosphere, and an air pump is attached to the pressure-vacuum tube to pressurize the lysimeter and retrieve a sample to the surface through the sampling tube. Samples are collected in either a decontaminated sampling jar and then transferred to containers appropriate for the analyses to be conducted, or are collected directly into the appropriate containers.

The time needed to collect a pore water sample using a lysimeter is dependent on soil type and soil moisture content, and can range from hours to days. If the time needed to accumulate a sufficient sample volume is greater than the time that a vacuum can be maintained in the lysimeter, a vacuum-tight reservoir (for example, an empty, decontaminated propane tank) may be attached to the system using a tee fitting. The use of a vacuum reservoir will allow the lysimeter to maintain vacuum for a longer period of time.

Under some circumstances, the suction pressure in the soil may exceed the bubbling pressure of the porous cup, causing the meniscus in the porous cup to break. If this occurs, the lysimeter will not hold vacuum, and the porous cup will need to be rewetted. The rewetting operation consists of introducing deionized water into the lysimeter through the sampling tube and allowing it to set for approximately 1 hour. Excess water used for rewetting is then removed through the sampling tube by pressurizing the lysimeter as described above.

3.0 Quality Assurance Project Plan Addendum

This QAPP Addendum amends the QAPP for the NERT site (Environ, 2014b), and has been prepared to comply with the *Guidance for Quality Assurance Project Plans (EPA QA/G5)* (EPA, 2002). The primary function of this QAPP Addendum is to describe QA/QC procedures to be used for collection and analysis of environmental samples at the NERT site. This QAPP Addendum describes laboratory-specific information and any QA/QC procedures for analytical testing and data management not already stated in EPA QA/G-5.

This document describes the QA/QC procedures that will be used for analytical work performed by a Nevada-certified laboratory.

3.1 Sample Volumes, Container Types, and Preservation Requirements

Pore water samples collected from lysimeters are treated in the same manner as groundwater samples collected from monitoring wells. Sample volume, container type, preservation, and laboratory QA/QC requirements are therefore the same as those described for other aqueous samples in the QAPP. It should be noted that because samples are collected under vacuum, lysimeters are not suitable for collecting pore water samples for analysis of volatile compounds.

3.2 Field Activities Quality Control

Field activities quality control sampling for soil and groundwater samples include trip blanks, equipment blanks, and duplicate/replicate samples. QC procedures associated with sample collection are an integral part of each sampling methodology. These procedures are designed to ensure the collection of representative samples that are free of external contamination. The following field QA/QC procedures will be used during pore water sample collection with lysimeters:

- **Trip Blanks**: As previously noted, lysimeters are not suitable for collecting pore water samples for analysis of volatile compounds. Trip blank samples are therefore not required.
- **Equipment Blanks**: Lysimeters are dedicated sampling devices, so equipment blank samples are not required.
- **Duplicate Samples**: Due to the nature of the sampling process, the volume of pore water that can be retrieved with a lysimeter may be quite small. The collection of duplicate samples is therefore recommended, but not required. In cases where sample volumes are adequate, duplicate pore water samples will be collected at a frequency of one for every 10 environmental samples. Duplicate water samples are two samples collected at one sampling location during the same sampling event.

4.0 References

Environ, 2014a. *Field Sampling Plan, Revision 1, Nevada Environmental Response Trust Site, Henderson, Nevada.* July 18, 2014.

Environ, 2014b. *Quality Assurance Project Plan, Revision 1, Nevada Environmental Response Trust Site, Henderson, Nevada.* July 18, 2014.

United States Environmental Protection Agency, 2002. *Guidance for Quality Assurance Plans (EPA QA/G-5)*. EPA/240/R-02/009, Office of Environmental Information, December 2002.

United States Environmental Protection Agency, 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA QA/G-4)*. EPA/240/B-06/001, Office of Environmental Information, February 2006.