CONTENTS

CONTENTS (continued)

TABLES

FIGURES

APPENDIX

CLEANUP ACTION PLAN
MOUNTAIN VIEW BROWNFIELD
ELLENSBURG, WASHINGTON

1.0 INTRODUCTION

This Cleanup Action Plan (CAP) describes the implementation of a physical removal remedy coupled *in situ* chemical and biological treatment for the Mountain View Brownfield site in Ellensburg, Washington (Site). The Site is currently being evaluated for beneficial reuse and redevelopment under the Washington Department of Ecology's (Ecology) Integrated Planning Grant #G120098.

This remedy is designed to physically remove the most severely impacted soil and destroy remaining petroleum hydrocarbons that impact both soil and groundwater. This coupled approach seeks to minimize removal and subsequent disposal requirements during the cleanup. This CAP was prepared on behalf of the Kittitas County Fire District #2, doing business as Kittitas Valley Fire and Rescue (KVFR).

2.0 BACKGROUND

This section briefly describes the Site, previous investigation findings, geology, and hydrogeology. This information is detailed in the Remedial Site Investigation & Characterization Report (Fulcrum, 2012). This Site falls under the jurisdiction of Ecology and applicable Model Toxics Model Act (MTCA) Cleanup Levels (CULs) for various petroleum-related constituents.

2.1 Site Description and Historical Use

The Mountain View Brownfield site is located at 400 East Mountain View Avenue in Ellensburg, Washington (Figure 1). The property was previously occupied by Mackner's Transport and currently serves for hay storage and a diesel repair shop. The Site consists of five tax parcels with Wilson Creek bordering to the east and mixed residential and commercial properties to the west. Undeveloped property, zoned for commercial use, is present along the south property boundary. Present on the property are an unused scale house with an attached residence that is vacant.

The Site was first developed in the 1950s as an agricultural business associated with local hay production. Expansion in the last 1960's resulted in the current

Mountain View Brownfield site. One groundwater well is shared between the Site and at least one adjacent residential parcel. Construction details for this well are not currently understood.

2.2 Summary of Environmental Conditions and Previous Investigations

Fueling services were historically offered on the site, provided by one gasoline and two diesel fuel underground storage tanks (USTs). These tanks were located directly southeast of the scale house/residence and were removed in the last 1990s to early 2000s. No site assessment services or investigation were completed at that time. In 2005, a previously unknown UST was identified adjacent to the diesel repair shop. A partial investigation reported the presence of petroleum impacted soil and groundwater.

A remedial investigation (RI) was conducted during 2012. During the investigation, the fourth UST was discovered directly north of the Mechanic Shop and removed. This investigation identified gasoline-, diesel-, and heavy oil-range hydrocarbons impacting both soil and groundwater at the site (Figure 2). Heavily stained surface soils were also noted around areas of deeper soil and groundwater contamination.

2.3 Geology and Hydrogeology

2.3.1 Site Geology

Based on the RI, the site is generally flat with a maximum topographic relief of 5 feet from north to south. Shallow soils at the Site predominantly consist of sandy clay to sandy loam extending from the surface to depths of approximately 5 to 7 feet below ground surface (bgs). Underlying this layer is clayey sandy gravel to sandy gravel extending to a maximum depth of RI borings at 15 feet bgs.

2.3.2 Site Hydrogeology

The Site's groundwater levels are influenced by the presence of Wilson Creek. Wilson Creek in turn is influenced by channel confinement, water diversions, and brush maintenance activities. Water elevations within the creek have been noted as greater than groundwater elevations. Groundwater was present within the gravelly soil horizons at depths of approximately 5 to 7 feet bgs during the RI activities. The seven new groundwater monitoring wells indicate a depth to groundwater raging from 0.89 foot (MW-7, June 2012) to 8.10 feet (MW-1, March 2012). During these events, gradients were relatively flat at 0.010 foot/foot toward the southwest (March 2012) to 0.017 foot/foot toward the west-southwest (June 2013).

2.4 Nature and Extent of Impacts to Site Soil and Groundwater

Based on soil and groundwater sample results from the RI, the primary contaminants of concern (COCs) include gasoline-, diesel-, and oil-range hydrocarbons and their related constituents. It is worth noting that the typical petroleum risk driver, benzene, was not present in any soil or groundwater sample collected during the RI.

Soil Results. Three trenches and six test pits were completed in the former diesel and gasoline UST area near the Scale House/Residence. Petroleum-type sheen was observed on groundwater within portions of the excavated trenches. Samples from this area contained the highest concentrations of gasoline-range organics, diesel, and diesel-related polyaromatic hydrocarbons found during the RI, up to 156 milligrams per kilogram (mg/kg), 5,990 mg/kg, and 1.8 mg/kg naphthalene, respectively.

North of the mechanic shop, confirmation soil samples following UST removal indicated that the highest remaining levels of gasoline (5.05 mg/kg), kerosene (35.7 mg/kg), and heavy oil (164 mg/kg) range hydrocarbons were all well below MTCA Method A CULs.

East of the mechanic shop, this highest concentrations of heavy oil were detected, at 3,370 mg/kg at ground surface. Nearby samples, collected at depths between 1 to 6 feet, only detected heavy oil up to 118 mg/kg and no field observation of “staining” was noted along the east side of the shop. This suggests that the asphalt present in the northern portion of the site provided a reasonable barrier against downward migration of surface releases. This area did also have trace detections of diesel at concentrations well below MTCA Method A CUL.

Groundwater Results. The RI identifies numerous areas of “visually impacted soils”, including staining and discolored soils. This suggests prior historical petroleum impacts resulted in the biological reduction of iron and sulfate into ferrous sulfide, a grayish to black mineral. Persistence of this mineral in the soil matrix is not indicative of current contamination, but instead indicates that natural oxidative flux (e.g., dissolved oxygen in groundwater flowing under the site) has not been able to re-oxidize the mineral back to a more brownish mineral form. Monitoring well installation logs provided in the RI do not reiterate the test pit change in geochemistry with depth, even in MW-2. As groundwater oxidative-reductive potential (ORP) is not provided in the sampling forms, further assessment of electron donor (e.g., petroleum) influence across the site is not possible.

The only petroleum detected in groundwater was from MW-2. During March, April, and June 2012, groundwater samples contained diesel-range hydrocarbons ranging between 189 micrograms per liter (µg/L) and 697 µg/L. The MTCA Method A CUL for diesel is 500 µg/L. As the laboratory narrative does not mention whether silica gel cleanup was performed, it is unclear whether detections are related to natural or petroleum organics in the diesel range. No gasoline, lead, or volatile organic compound (VOC) constituents were detected from any of the seven groundwater monitoring wells.

2.5 Exposure Pathways

The overall objective of remediation is to reduce potential risk to human health and the environment. Potential exposure pathways for soil, groundwater, and air are discussed below, along with the resulting remedial action objectives (RAOs).

2.5.1 Soil Direct Contact

Appreciable areas of the Site contain petroleum staining of the asphalt-paved areas. Petroleum was noted to have migrated to soil in only a few areas and was noted as confined to within 1 foot of the ground surface. Petroleum concentrations are present at concentrations above applicable MTCA Method A limits within six feet of ground level.

2.5.2 Soil to Groundwater

The soil to groundwater exposure pathway is complete based on groundwater samples collected from monitoring well MW-2. Elevated petroleum detections were also noted within the groundwater smear zone during the RI.

2.5.3 Groundwater to Surface Water

Groundwater to surface water exposure pathways could be of potential concern. However, available site data have not demonstrated a groundwater direction reversal toward the creek. Based on the lack of historical data at the Site, this is considered a potentially complete pathway.

2.5.4 Groundwater to Drinking Water

It is difficult to directly evaluate this pathway. Construction of the on-site domestic supply well is unknown and only one round of sampling has been completed. Without knowing the construction of the domestic well present on the site and with only limited analytical data available, it is difficult to directly evaluate this pathway.

2.5.5 Soil Vapors to Air

With no benzene detected in either soil or groundwater, it is unlikely that the low levels of other volatile constituents would pose a volatilization and inhalation risk. RI samples did not find any volatile constituents (e.g., toluene, xylene) above MTCA Method A CULs. However, a vapor intrusion assessment was not completed and risk may still be present under existing structures where the petroleum-degrading influences of precipitation and barometric pumping are minimized.

3.0 CLEANUP STANDARDS

This section discusses identified COCs, RAOs, and cleanup criteria for the site.

3.1 Constituents of Concern

The COCs identified for each medium at the property are as follows:

- **Soil**. MTCA Method A clean-up thresholds were exceeded for gasoline-, diesel-, and heavy oil range constituents. Related compounds, including toluene, ethylbenzene, xylene, and naphthalene, were also detected but below MTCA Method A CULs. Slightly elevated levels of lead were detected in confirmation samples collected around the removed heavy oil tank north of the Machine Shop, but at levels below MTCA Method A CULs.

- **Groundwater.** MTCA Method A CULs were exceeded for diesel-range hydrocarbons only. No other constituents were detected in groundwater. However, due to discrepencies between test pit and monitoring well log geochemical descriptions, the small set of groundwater data may not reflect site-wide water quality. As a result, COCs in groundwater are assumed to be the same as those for soil.

- **Air.** Gasoline-range TPH and BTEX constituents are considered COCs due to the on-going presence of surface staining and the lack of more direct soil gas or sub-slab vapor data.

3.2 Remedial Action Objectives (RAOs)

Risks to human health and the environment via the exposure pathways discussed above appear to be low.

The cleanup action to be implemented at the Site is designed to address the following RAOs:

- **Prevent Direct Contact with Impacted Soil.** Physically removed heavily impacted surface soils down to 1.0 foot bgs to prevent direct contact with petroleum-impacted soils exhibiting elevated concentrations of petroleum-related constituents and/or obvious odors.

- **Protect Groundwater.** Chemically and biologically treat the petroleum-impacted soil to reduce the potential of COCs in groundwater increasing to concentrations above MTCA CULs.

- **Prevent Potential Air Impacts.** Physically remove impacted surface soils and chemically and biologically treat petroleum-impacted groundwater in vicinity of the planned KVFR fire house.

- **Complete Cleanup to Permit Near-Term Redevelopment**. The final remedy needs to achieve target CULs within a 6 to 12 month timeframe to permits anticipated property redevelopment.

- **Achieve Protections using a More Sustainable Remedy Approach**. Develop and implement a remedial approach which achieves protective goals while minimizing the environmental footprint of the cleanup. This includes reductions in use of landfill space, traffic, and remedial chemicals.

3.3 Cleanup Criteria

3.3.1 Soil and Groundwater Cleanup Levels

Cleanup levels for the COCs at the property were developed based on unrestricted land use. The highest beneficial use of Site groundwater is as drinking water; however, there is no indication that the current on-site domestic well is screened within the same water-bearing zone.

Proposed cleanup levels for groundwater are Method A unrestricted use cleanup levels (when available and applicable).

3.3.2 Points of Compliance

The achievement of cleanup levels shall be measured at points of compliance around the gasoline UST source and at the downgradient edge of the property. As presented on Figure 3, the three key monitoring wells used to assess CAP performance will be MW-2, MW-3, and MW-4. The domestic well will also be considered a point of human drinking water compliance until it is demonstrated that the construction is such that exposure risk is *de minimus*. All wells on the Site will be sampled for comprehensive bioremediation parameters prior to beginning remediation activities.

3.3.3 Applicable or Relevant and Appropriate Requirements (ARARs)

The selected cleanup action will comply with federal, state, and local ARARs. Applicable requirements are federal and state laws or regulations that legally apply to a hazardous substance, cleanup action, location, or other circumstance at the property. Relevant and appropriate requirements are those federal and state regulations that do not legally apply but address situations sufficiently similar that they may warrant application to the cleanup action.

The following ARARs have been identified for the property:

- **Model Toxics Control Act (MTCA 70.105D RCW, Chapter 173-340 WAC).** MTCA contains detailed requirements and Washington State's expectations for cleanup of contaminated sites.
- **State Environmental Policy Act (SEPA – 43.21 RCW, Chapter 197-11 WAC).** An environmental checklist is necessary as part of any permitting activity pursuant to MTCA.
- **Minimum Standards for Construction and Maintenance of Wells (Chapter 173-160 WAC).** This regulation contains requirements for abandonment and construction of resource protection wells.
- **Underground Injection Control Program (Chapter 173-218).** Rules and requirements for conducting *in situ* remediation using the injection of amendments into the subsurface.

4.0 CLEANUP ACTION ALTERNATIVE EVALUATION

Accelerated remediation of petroleum-contaminated in soil and groundwater is commonly accomplished through physical removal, chemical oxidation, and/or biological oxidation. Each approach offers different strengths in terms of cost, reliability, protectiveness, time to cleanup, and sustainability. All these approaches are considered permanent.

4.1 Physical Removal

Physical removal of contamination could include excavation, vapor extraction, or groundwater extraction. Because of the large impacted area, the weathered and heavy nature of residual petroleum, and very low dissolved concentrations, soil vapor extraction, air sparging, and groundwater pump-and-treat were eliminated as viable treatment options. Anticipated costs (e.g., installation, maintenance, and additional system sampling) typical of treating relatively low concentrations over a large area eliminated these technologies.

Because surface capping with asphalt appears to have limited surface release impacts to the top 1.0 foot in relatively small areas, physical removal of this soil is appropriate. Sustainability of the removal process could be enhanced by treating the soil during the removal process with oxidants and beneficially re-using the soils on-site by securing a no-longer contains determination from Ecology. Contaminated asphalt will still require disposal. The top 1.0 foot of soils identified as “stained soil” equates to XXX cubic yards.

Other potential treatment technologies were then evaluated for a potential IRAP, including chemical and biological means.

4.2 Chemical Oxidants

To address residual contamination in soils with in the vadose and saturated zones, both chemical and biological processes are regarded as potentially effective. Chemical oxidation treatments typically rely on the formation of unstable radicals, which then react with organics and convert petroleum to carbon dioxide, water, and volatile fatty acid (VFA) end products. Biological oxidation is a process of respiration whereby microbes (e.g., bacteria and fungi) gain energy for growth and cellular repair by moving electrons from VFAs and petroleum (electron donor) to an electron acceptor. In many chemical oxidation approaches, the by-product of the reaction yields a low mass of electron acceptors that stimulate secondary oxidative bioremediation. Both chemical and biological oxidation were considered potential candidates to achieve cleanup goals for the site.

There are several commercially available chemical products that are designed to directly degrade petroleum hydrocarbons through chemical reactions. For discussion purposes, chemicals are grouped by their mechanism of oxidation in this evaluation. Mechanisms include Fenton’s, modified Fenton’s, permanganate, persulfate, and ion-exchange. Product selection is discussed in Section 5.1.

4.2.1 Hydrogen Peroxide Technologies

Fenton's-type reactions rely on hydroxyl radicals derived from hydrogen peroxide to chemically react and oxidize electron-rich organics, including petroleum hydrocarbons. To generate these hydroxyl radicals, extreme chemistry (e.g., shifting aquifer pH to 2) or activators (e.g., chelated iron) are required. These changes can significantly impact broader shallow water quality and require additional work to bring the aquifer back to normal conditions. Fenton's-type reactions are active for approximately one day, making initial application contact very important. The molecular oxygen byproduct from the Fenton's reagent acts as an electron acceptor for subsequent oxidative bioremediation. The production of gasses from the subsurface reaction can guide application in the field. However, application will be limited based on controlling the reaction process to maintain appropriate health and safety conditions.

4.2.2 Highly Oxidized Metal Technologies

Permanganate is a highly oxidized manganese metal salt that chemically reacts with carbon double and triple bonds to create VFAs. In addition to chemical reactions, permanganate can also act as an electron acceptor for oxidative bioremediation until the manganese reaches the reduced +2 oxidation state. Oxidized manganese can migrate with groundwater over time and persists in an oxidized state if electron donors are not readily available. The +2 state is highly mobile and can sharply increase dissolved concentrations of manganese, potentially resulting in exceedance of Washington surface water standards for Goose Creek.

4.2.3 Persulfate Technologies

Persulfate is comprised of two covalently bonded sulfate compounds. Upon activation, two sulfate radicals are generated for oxidation reaction, and the byproduct (sulfate) supports subsequent oxidative bioremediation. Activation is accomplished through strong aquifer pH shifts (e.g., greater than a pH of 10) or various activation mechanisms, including hydrogen peroxide. Chemical reactivity can persist for days to a month, depending on activation and other conditions. The byproduct of activation is sulfuric acid, which can cause significant decreases in aquifer pH. The byproduct of this reaction (sulfate) can then act as an electron acceptor for subsequent oxidative bioremediation.

4.2.4 Ion-Exchange Technologies

Ion-exchange polymers use proton radicals to destabilize petroleum hydrocarbons, resulting in the subsequent reaction of petroleum with water to generate VFAs and carbon dioxide. The milder process of reacting with petroleum continues until the ion-exchanger is quenched, typically occurring 7 to 30 days after introduction. Once quenched, the ion-exchange oxidant is then biodegraded along with the petroleum. Incomplete oxidation (i.e., to anything less than carbon dioxide and water) by any of these chemical oxidants will result in VFA formation. These VFAs are more soluble and readily degradable by a variety of microbes. And similar to Fenton's-type organics reactions, highly contaminated soils will generate foam and bubbles to guide field application and improve initial treatment success. Unlike hydrogen peroxide though, additional the milder reaction kinetics permit greater treatment of areas displaying substantial reaction foaming and bubbles.

4.3 Biological Oxidants

There are several commercially available biological oxidants that are designed to enhance the natural attenuation of petroleum. The mechanism of biological oxidation determines which microbes can degrade the contaminant and through which pathways. Most broadly, these mechanisms are divided into aerobic and anaerobic. Aerobic mechanisms ultimately place electrons on to molecular oxygen to make carbon dioxide. Anaerobic mechanisms ultimately place electrons on to other oxidants except for molecular oxygen. Detailed discussion is provided below.

4.3.1 Aerobic Amendments

There are many products available on the market which provide electron acceptors in the form of molecular oxygen. These include the Regenesis products Oxygen Release Compound™ (ORC™) and ORC Advanced; the FMC product EHC-O™, and EOS Remediation product EOx™. This molecular oxygen is released over time as a result of peroxide chemical reactions with water.

A major limitation of molecular oxygen-based amendments is that they release oxygen regardless of microbial activity or the presence of hydrocarbons. They also require contact with water to release oxygen. Therefore, the effectiveness and efficiency of these products can be limited due to variations in contaminant mass, groundwater elevations, and groundwater flow. Of these products, only EHC-O provides a nutrient (nitrogen) to assist in developing a biomass that can fully take advantage of oxygen released during the chemical reaction.

As molecular oxygen is the highest order natural electron acceptor, microbes will also use molecular oxygen to re-oxidize Site geochemistry. This includes converting reduced metals into oxidized forms (e.g., ferrous to ferric iron) and sulfide into sulfate. The net result is commonly a less efficient, less targeted destruction of petroleum mass. Since there is no method for reliably predicting this geochemical demand (e.g., ORP), the is significant risk in either under-dosing or over-dosing the site.

4.3.2 Anaerobic Amendments

In addition to molecular oxygen, other types of electron acceptor compounds were evaluated for injection use. These include oxidized metals, humic compounds, nitrates, and sulfates. As discussed above, these naturally occurring electron acceptors are major contributors to the natural attenuation of petroleum hydrocarbon groundwater plumes. Groundwater sampling conducted since 2004 indicates that nitrate and sulfate are already significant players in the natural attenuation currently underway.

Oxidized metals, such as ferric iron, were dismissed for remedial use due to high cost and impacts on groundwater quality. Commercially available humic compounds, such as X-19, can be effective in treating hydrocarbons but have limited large-scale success in *in situ* applications. Due to these concerns, application of nitrate and sulfate anaerobic oxidation compounds were considered along with molecular oxygen releasing compounds.

There are several commercially available products that supply nitrate and/or sulfate. The advantage of using sulfate and/or nitrate-based electron acceptors for remediating petroleum sites is their ability to provide a much higher density of electron acceptor concentrations versus dissolved oxygen. Dissolved oxygen is limited to approximately 9 milligrams per liter (mg/L) before effervescing into vadose zone soils. Dissolved sulfate and nitrate can reach 33,800 mg/L and 67,200 mg/L, respectively. Combining multiple electron acceptors also allows for greater microbial diversity participating in petroleum hydrocarbon oxidation. Relying on ammonium nitrate alone to treat a dissolved plume can result in significant nitrate, nitrite, or ammonium plumes escaping from a site if not applied properly.

EOS Remediation provides a sulfate-only product called Electron Acceptor Solution™ (EAS). EAS does not provide nutrients. ETEC, LLC provides a nitrate-only product called Custom Blended Nutrients™ (CBN) that, in addition to containing nitrate, also contains microbial micro- and macro-nutrients to support hydrocarbon-degrading bacteria. However, CBN was not designed to be a stand-alone oxidative amendment. CBN is a nutrient source to support a continuous dissolved oxygen injection approach and reliance as a primary oxidant can result in the accumulation and persistence of nitrogen in an aquifer. Bioremediation Specialists, L.L.C. provides AnoxEA-aq®, which provides a blend of both nitrate and sulfate electron acceptors plus significant microbial micro- and macro-nutrients. Due to its blend of electron acceptors, AnoxEA-aq is less likely to result in exceedances of the U.S. Environmental Protection Agency (EPA) Primary Drinking Water Maximum Contaminant Limits (MCLs) for high nitrogen amendments such as ammonium nitrate or CBN.

As discussed above, one of the metabolic byproducts of sulfate reduction (provided in EAS and AnoxEA-aq) is the formation of dissolved sulfide. Upon contact with heavy metals, such as arsenic, chromium, or lead, sulfide will react to form insoluble precipitates which readily adhere to iron-containing soil matrices, reducing secondary metals plumes. Unlike EAS, AnoxEA-aq contains multiple tiers of pH buffering, maintaining pH to values between 7.0 and 8.0 during the bioremediation process. At these pH values, biologically produced sulfide is likely to persist as hydrosulfide (HS^{1-}) or sulfide (S^{2-}) ions after release from sulfate-reducing bacteria instead of toxic dihydrogen sulfide (H_2S). These ions are highly reactive with heavy metals and iron.

4.3.3 Nutrient Loading

The addition of nutrients improves microbial development, acclimation to new subsurface conditions, and rapid petroleum oxidation. In order to metabolize the introduced electron acceptors rapidly and completely within the treatment area, additional microbial growth and enzyme production typically must occur. This microbial growth requires various micro- and macro-nutrients, including nitrogen, phosphorous, and potassium. Not addressing this additional nutrient demand can limit biological stimulation and remedial performance. This is especially true of nitrate- and sulfate-based amendments, although nitrate reducing microbes and sulfate reducing microbes tend to be more active in saturated, petroleum-impacted soils compared to strict aerobic microbes.

5.0 SELECTED CLEANUP ACTION PLAN

The selected CAP alternative (chemical and biological oxidation) includes *in situ* injection of chemical oxidants for the direct destruction of petroleum hydrocarbons and subsequent enhanced biological oxidation polishing. The rationale for this approach is presented below.

5.1 Chemical Oxidant Amendment Selection

Ion-exchange oxidants were selected as the chemical to be used at the Site, and NovIOX™ has been selected as the preferred ion-exchange oxidant based on our experience with the product. Ion-exchange was selected based on implementability, cost, and proximity of Wilson Creek.

Among alternatives rejected, Fenton's/Modified Fenton's rely on strong groundwater geochemistry changes or the introduction of metal activators and generate substantial heat and potentially explosive gasses. Since the reactions are short-lived, repeated application is commonly required. Permanganate was also eliminated since the fully reduced form (Mn^{+2}) is highly mobile and could easily exceed Washington surface water quality standards in Wilson Creek if groundwater flow directions reverse, unless it is re-oxidized to a low-solubility mineral form. Similarly, persulfate also relies on strong activation chemistry (e.g., shifting groundwater pH to 10, peroxide, etc.). Additionally, because these chemical oxidation technologies are most effective in the saturated zone, their performance in preventing vapor intrusion is marginal. As a result, additional sampling or excavation could be required to meet RAOs.

In contrast, ion-exchange oxidant chemistry is fairly mild and leaves better water quality follow consumption without additional intervention compared to other alternatives considered. This class of oxidants also tends to be more chemically compatible with bioremediation amendments. This can reduce the need for multiple mobilizations to complete the chemical oxidation treatment.

Our experience with NovIOX has shown that reactions persist for approximately 7 to 30 days after introduction, is effective in treating petroleum in vadose zone soils, and substantially improves petroleum bioavailability for subsequent biological oxidation. Of the chemical oxidants evaluated, ion-exchange resins are least likely to damage underground utilities or result in long-term impacts to groundwater and surface water. Due to the milder reactivity associated with ion-exchange, there are also fewer health and safety concerns during application and waste disposal.

5.2 Biological Oxidant Amendment Selection

AnoxEA-aq bioremediation oxidant was selected to support *in situ* oxidative bioremediation at this Site. Selection was based on the existing natural attenuation pathways typically underway at petroleum-impacted sites; cost per pound of petroleum degraded; the ability to load a sufficient mass of biological oxidant with only periodic application; diverse nutrient availability to aggressively develop and maintain petroleum-degrading microbes; reduced risk to down-gradient groundwater beneficial uses; and chemical compatibility with the selected chemical oxidant, NovIOX.

The cost of biological oxidant (electron acceptor) amendments can vary considerably. In addition to its cost per pound, the oxidative power of an amendment should be considered since active ingredient concentrations can vary considerably. There are various ways to calculate this oxidative power, including stoichiometry, chemical oxidant demand, and biological oxidant demand. These calculations are approximate, because other factors, including metabolic efficiency and oxidant delivery efficiency, can also impact actual performance. Greater microbial nutrient availability results in greater microbial growth, so each pound of amendment converts more petroleum mass into biomass instead of oxidized byproducts. As mentioned above, oxygen release without sufficient microbial activity or hydrocarbon mass lowers efficiency. Table 1 presents biological oxidant amendment costs and stoichiometric degradation rate estimates based on available information.

Biological oxidation is a relatively predictable process and is generally based on the stoichiometric ratios of electron donor, electron acceptor, and byproducts. For example, approximately 3.5 pounds of molecular oxygen or 4.3 pounds of nitrate are required to degrade on pound of heptane. Assuming no other limitations (e.g., contact time, microbial activity, petroleum bio-availability), then amendment application is proportional to estimated contaminant mass. Table 2 presents the estimated mass of petroleum at the Site and the estimated mass of AnoxEA-aq required to degrade that petroleum mass.

5.3 Bioremediation Performance Enhancement

To further address the CAP goals of improving weathered petroleum bioavailability and enhancing microbial activity, Bioremediation Specialists also recommends the application of ReleaSE-Dx™ and AM3™ along with the AnoxEA-aq. RelaSE-Dx is a highly concentrated, custom blend of non-ionic and natural rhamnolipid surfactants. ReleaSE-Dx is biodegradable and specially formulated to improve bioavailability of heavily weathered gasoline- and diesel-range hydrocarbons. AM3 is a specially formulated blend of non-pathogenic, petroleum-degrading microbes selected for their ability to use AnoxEA-aq as an electron acceptor for petroleum destruction.

6.0 CLEANUP ACTION PLAN IMPLEMENATION

The selected treatment approach couples targeted physical removal of heavily impacted (i.e., stained) surface soils coupled with a chemical and biological oxidation *in situ* treatment. The combination of NovIOX colloidal ion-exchange oxidant and anaerobic oxidative bioremediation amendment (AnoxEA-aq) will promote the *in situ* degradation of residual petroleum hydrocarbons in both soil and groundwater. Unlike other combination, this approach is very effective for soils containing clays, heavily weathered, and heavy-range hydrocarbons in both vadose and saturated soils. Performance will be further enhanced with the application of ReleaSE-Dx surfactants and AM3 microbes. The patent-pending process of sequential application of these amendments is termed Advanced Multi-Oxidative Remediation, or AMOR™.

Table 2 presents the estimated mass of petroleum within the proposed treatment area at the Site based on RI soil data and the estimated mass of AnoxEA-aq to degrade that petroleum mass. To be conservative, we assumed that NovIOX would simply convert petroleum to VFAs for subsequent biological oxidation. However, some petroleum will react down to carbon dioxide and water.

This CAP outlines one round of *in situ* injections to deliver the calculated biological oxidant loading. Approximate injection areas are presented on Figure 3. Final locations will be determined in the field based on utility locates, other possible physical obstacles, and field observations of aggressive petroleum degradation by NovIOX. As discussed below, the ion-exchange chemical oxidant and biological oxidants will be injected with a pattern, based on site-specific conditions and estimates of petroleum mass distribution.

6.1 Site Preparation and Permitting

Site preparation for injection of selected amendments will include:

- Preparing a Sampling and Analysis Plan (SAP);
- Performing a survey of underground utilities on the Site (including fueling lines);
- Preparing a Site-Specific Health and Safety Plan; and
- Completing underground injection control (UIC) registration.

6.2 Excavation, Segregation, and Disposal of Surface Materials

As part of the redevelopment process, all structures on the Site will be demolished and removed. Following building demolition, areas exhibiting stained asphalt and soil will be excavated down to 1.0 foot bgs. Asphalt will be segregated to the extent practicable and disposed of or recycled, as appropriate. The underlying stained soil will be mixed in-place with AnoxEA™ and AM3 at a rate of 10 pounds and 0.25 pound per cubic yard, respectively. The amended soil will then be transferred to a lined holding cell toward the back of the site for subsequent biological polishing of the residual petroleum. AnoxEA is comparable to AnoxEA-aq except that it is more suited for land-farming applications instead of injection.

Soil moisture shall be maintained at greater than 18 percent while in the cell to ensure optimal conditions for the microbes. If additional moisture is required, the cell will be watered with a 1% solution of ReleaSE-Dx dissolved in tap water. The cell may be covered to either maintain moisture or heat (during winter). Periodic monthly sampling will be conducted to verify treatment progress. If treatment progress has stalled, then additional AnoxEA-aq may be applied along with a 1% ReleaSE-Dx solution. AnoxEA-aq and ReleaSE-Dx is indicated if nitrate and sulfate concentration are low to non-detect. Application of ReleaSE-Dx alone is indicated if composite samples still show detectable nitrate and sulfate, as a means to redistribute both petroleum and oxidant to contact each other.

Within 4 to 16 weeks, we anticipate petroleum levels in the treated soil will be low enough to qualify for beneficial re-use on the Site. Ecology will have to grant a No Longer Contains Determination for the soil, and it can be spread out over the ground. If the soil does not meet criteria, then it should meet non-hazardous standards and qualify for reduced off-site disposal costs.

The RI estimates approximately 13,500 square feet of stained soil is present south of the former scale house and 4,500 square feet east of the Mechanic Shop. This equates to almost 670 yards of potentially contaminated soil. However, we assume that only approximately half of this soil volume will require *ex situ* treatment once the overlaying asphalt is removed. As such, the CAP assumes 3,350 pounds of AnoxEA and 84 pounds of AM3 may be needed to achieve NLCD status for beneficial re-use. Treated soil will be rich in nutrients and should readily grow vegetation once spread out.

6.2 Amendment Injections

AMOR amendment solutions will be introduced following completion of the stained soil removal. The proposed amendment injection totals discussed below are estimates based on worst-case scenario estimates assuming highly reduced geochemistry and appreciable residual organics, based on test pit visual observations. Reduced amendment application may be sufficient as justified based on:

- Groundwater ORP readings across the plume as an indicator of geochemical conditions and biological activity;
- Natural nitrate and sulfate groundwater concentrations across the site; and
- Groundwater total organic carbon (TOC), which is a more direct measure of oxidant demand than residual petroleum values.

Barring any reductions based on additional groundwater data or field screening information, chemical oxidant solution will be introduced into an estimated total of 275 injection points to cover petroleum-impacted areas. A smaller subset of points (130) will include biological oxidants based on estimated mass loading.

Injection areas are divided into three main areas – the former scale house tank area, north of the mechanic shop, and east of the mechanic shop (Table 3). Injection locations will be approximately 8 to 10 feet apart and at least 6 feet from any groundwater monitoring well. Final locations and number of points will be designated in the field based on physical restrictions (e.g., utilities) and visual evidence of chemical reaction foaming.

6.2.1 Amendment Solutions

Two distinct amendment solutions will be prepared. A chemical oxidant solution will be comprised of NovIOX concentrate diluted with tap water to a working solution of 1:150 in tap water, based on manufacturer's recommendation. A biological oxidant solution will be comprised of AnoxEA-aq, AM3, and ReleaSE-Dx. The biological oxidant solution will be prepared in 50-gallon batches comprised of up to 50 pounds of AnoxEA-aq, 25 grams of AM3, and 0.5 liter of ReleaSE-Dx in tap water.

6.2.2 Injection Methodology

Using a roto-hammer drill, a small pilot will be cored through the surface soil material approximately 6 to 12 inches. The chemical oxidant will then be injected from the top of soil to a total depth of 8 feet bgs using a high-pressure lance injection technique. The lance will be advanced by hand to protect any unidentified utility or subsurface features. The chemical oxidant solution will be introduced at a rate of approximately 2.0 gallons per vertical foot, or approximately 16 gallons per location, based on manufacturer's recommendation. A total of up to 30 gallons of oxidant concentrate and 4,400 gallons of chemical oxidant solution will be injected into the boreholes.

The borehole will then be sealed at the surface with bentonite granules and the injection rod placed at approximately 7.5 feet bgs. The biological oxidant solution, comprised of AnoxEA-aq, AM3, and ReleaSE-Dx, will be injected into the sealed borehole using a pump. Injections at each point will be discontinued if excessive short-circuiting is noted. Up to 50 gallons of solution will be injected into each location. If necessary, additional boreholes may be completed if any individual borehole is not able to receive the full amendment amount. A total of up to 6,000 pounds of AnoxEA-aq, 9 pounds of AM3, 60 liters of ReleaSE will be introduced in solution with 6,500 gallons of tap water into the boreholes during each event.

Once subsurface pressures have equilibrated, the injection tooling will be withdrawn. Each borehole will then be filled with concrete or bentonite and the surface finished with like materials. To maximize injection labor efficiency, we recommend tapping into a high-pressure municipal water line (e.g., fire hydrant) to improve water delivery to the mixing and injection locations.

6.3 Rational for Selecting the Cleanup Action

Section 173-340-360(10) of the MTCA regulation states that the Cleanup Action Plan should include a preliminary determination that the cleanup action complies with subsections (2) and (3) of WAC 173-340-360. As specified in subsections (2) and (3), the selected cleanup action is designed to accomplish the following.

6.3.1 Protection of Human Health and the Environment

Implementation of the preferred remedial alternative will minimize potential exposures from each of the pathways identified as being of potential concern. Chemical oxidation treatment from ground surface to a depth between 8 and 10 feet will reduce direct contact exposures and prevent potential air impacts from petroleum-impacted groundwater. It is the most effective alternative for minimizing direct contact. Further enhancing the established natural attenuation mechanisms is the most effective approach to protect groundwater quality.

Additionally, sulfide formed during the petroleum oxidation process will assist in maintaining immobilization of heavy metals and reducing any potential risk to the adjacent lake. By introducing the proscribed amount of oxidants, microbes, and surfactant during injection events, there is reduced risk of amendment migration out of the treatment areas, further reducing risk to the adjacent lake.

6.3.2 Comply with Cleanup Standards per Chapter 173-340 through 173-760 WAC

One goal of this cleanup action is to protect groundwater and surface water quality. The cleanup action is intended to meet cleanup standards for both soil and groundwater.

6.3.3 Use of Permanent Solutions to the Maximum Extent Practicable per WAC 173-340-360 (4), (5), (7), and (8)

Physical removal coupled with chemical and biological oxidation is a preferred technology because it permanently eliminates risk from the highest concentration source soils, converts petroleum to carbon dioxide and water end-products, and precipitates heavy metals to insoluble sulfides to reduce dissolved lead and arsenic concentrations. The preferred remedy is protective of human health and the environment, can be effectively implemented, and is cost-effective. It is the most practicable alternative for addressing the primary exposure pathways of concern.

6.3.4 Compliance with Applicable State and Federal Laws per WAC 173-340-710

The cleanup action will comply with all relevant laws and requirements, as required in WAC 173-340-710. A detailed analysis of federal, state, and local laws and regulations that pertain to this project is provided in Section 3.3.3.

6.3.5 Provide Compliance Monitoring per WAC 173-340-410

During implementation of remedial actions, performance monitoring will be conducted to confirm that treatment compounds remain within the plume boundary (UIC requirement) and that cleanup actions have attained cleanup levels and treatment goals. After remedial actions are completed and amendments have been consumed, confirmation soil and groundwater monitoring will be conducted to ensure that cleanup actions have attained cleanup levels and performance standards.

6.3.6 Provide for a Reasonable Restoration Time Frame per WAC 173-340-360

The proposed cleanup action provides for a reasonable restoration time frame. Once cleanup activities at the property are completed, the potential exposure pathways for groundwater will be substantially reduced or eliminated.

7.0 CLEANUP ACTION PLAN SCHEDULE

To facilitate excavation and ex situ treatment progress, earthwork and land-farming activities would ideally occur after the final snow, as average daily temperatures are rising. Timeframe to achieve soil re-use is 4 to 16 weeks. The *in situ* injections can occur during any time of the year. However, periods of higher groundwater elevation provide enhanced biological amendment contact. Baseline groundwater sampling should occur prior to completing the injections, and initial performance sampling could be completed in as little as 1 to 2 months following injections. Thereafter, quarterly compliance groundwater monitoring should be conducted until oxidant levels return to background levels.

8.0 PERFORMANCE MONITORING

Groundwater monitoring will primarily be used to assess on-going CAP treatment progress. Groundwater monitoring will include collection of samples from all wells (MW-1 through MW-11). The nitrate present in AnoxEA-aq and ReleaSE surfactant are likely to result in a temporary and localized increase in dissolved petroleum concentrations. As the oxidants are consumed and surfactant degraded, dissolved concentrations of petroleum will return to more normal two-phase equilibrium ratios.

Samples from all groundwater wells will be analyzed for gasoline-range hydrocarbons (NWTPH-Gx), diesel- and residual-range hydrocarbons with silica gel cleanup (NWTPH-Dx), full-list VOCs (EPA 8260), total organic carbon (EPA 415.1 or equivalent), total lead (EPA 6020), and nitrate and sulfate (EPA 300.0). Field parameters (dissolved oxygen [DO] by optical methods, ORP, pH, specific conductivity, and temperature) will be monitored and recorded during the low-flow sampling procedures to ensure stabilization has been achieved. Groundwater monitoring procedures are detailed in the Sampling and Analysis Plan.

9.0 REFERENCES

Fulcrum 2012. *Remedial Site Investigation & Characterization Report, IPG #G120098, 400 East Mountain View Avenue, Ellensburg, Washington*. August 14, 2012.