1,4-DIOXANE REMEDIATION APPROACH FOCUSED FEASIBILITY STUDY

Stericycle Georgetown Site

Seattle, Washington

Prepared for:

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A wholly owned subsidiary of PSC Environmental Services, LLC,
which is a wholly owned subsidiary of Stericycle Environmental Solutions, Inc.
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1.0 INTRODUCTION

AMEC Environment & Infrastructure, Inc. (AMEC), has prepared this Focused Feasibility Study (FFS) on behalf of Burlington Environmental LLC, a wholly owned subsidiary of PSC Environmental Services, LLC (PSC), which is a wholly owned subsidiary of Stericycle Environmental Solutions, Inc. (Stericycle), for the Stericycle Georgetown site located in Seattle, Washington (the site) (Figure 1). Over the last year, Stericycle has had multiple discussions with the Washington State Department of Ecology (Ecology) regarding 1,4-dioxane. This FFS fulfills Stericycle's obligations regarding the proposed approach for the implementation of a contingent remedy for 1,4-dioxane for the area east of 4th Avenue South and downgradient from the former PSC Georgetown facility (the Outside Area), as outlined in Ecology's letter dated June 19, 2014 (Ecology, 2014), Ecology's comments regarding the 1,4-Dioxane Remediation Approach Technical Memorandum (AMEC, 2014), and as discussed in phone conferences held in August and September 2014. Figures 2 and 3 show the Outside Area downgradient of the site. As requested by Ecology, this FFS clarifies Stericycle's proposed action to reduce 1,4-dioxane mass in the area(s) of highest 1,4-dioxane mass that may be effectively treated in the Outside Area.

This FFS also outlines Stericycle's approach to fulfill the preliminary requirements for a contingent remedy as outlined in Agreed Order #DE 7347 and the 2010 Cleanup Action Plan (CAP) (Ecology, 2010) to implement a contingent remedy for the sections of the Outside Area that have the highest mass of 1,4-dioxane.

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2.0 BACKGROUND

In accordance with the Agreed Order and appended CAP, and based on discussions with Ecology, the evaluations performed to date indicate that natural attenuation of 1,4-dioxane will not achieve cleanup levels by 2015, as originally projected (Ecology, 2010). Thus, based on the CAP requirements, a contingent remedy is now required. Under Section 6.3.2 of the CAP, Stericycle is to *"propose actions, such as implementation of the contingent remedy, which should result in expeditious cleanup level attainment."* As discussed in recent documents and conference calls with Ecology, monitoring data indicate that, contrary to what was assumed in the 2010 CAP, more mechanisms than dispersion and diffusion are contributing to the fate and transport of 1,4-dioxane in the shallow and intermediate groundwater zones (DOF, 2013). It appears as though a secondary source, either from an as-yet-unidentified source or from mass flux from low permeability units containing residual concentrations held in the fine grained units within the heterogeneities of the aquifer, is contributing to higher 1,4-dioxane concentrations in the existing plume of the Outside Area groundwater. Thus, 1,4-dioxane concentrations in the Outside Area remain elevated at concentrations above cleanup levels in areas adjacent to and downgradient of well CG-122, which is downgradient of the site and east of 4th Avenue South.

Recent monitoring data indicate that the areas with the highest concentrations of 1,4-dioxane now include wells CG-127 and CG-161, which are located downgradient of well CG-122, as well as CG-122 itself (Figure 3). Concentrations from the first and third quarter of 2014 are shown on Figure 2. The highest concentrations are observed in wells screened in the intermediate groundwater zone from approximately 50 to 80 feet below ground surface (bgs). Concentrations at shallower depths are generally lower, though still greater than 190 micrograms per liter (µg/L) as measured in the first and third quarter of 2014 in wells CG-165, CG-127, CG-128, and CG-131 in the shallow groundwater zone from approximately 30 to 50 feet bgs. The area around well CG-127 has the highest concentrations measured during the first and third quarters of 2014 in the shallow and intermediate groundwater zone (410 and 580 µg/L, respectively), while CG-122-60 (approximately two blocks upgradient) also remains high (450 µg/L).

In order to address Ecology's requirements, at a minimum this FFS will cover the following items:

- A screening summary of remedial technologies and approaches evaluated (Sections 4 and 5);
- An evaluation of remedial alternatives that are capable of meeting the remedial action objectives (Section 6);
- A description of the proposed preferred alternative (Section 6.4) ;
- The preferred alternative's performance objectives (Section 6.4); and

- A schedule for future deliverables and meetings related to developing and submitting a remedial design of the proposed action (Section 7).

3.0 REMEDIAL ACTION OBJECTIVES

The objective of the cleanup action as outlined in the Agreed Order, the CAP (Ecology, 2010), and the Ecology letter (Ecology, 2014) is to reduce 1,4-dioxane mass in the plume area(s) with the highest 1,4-dioxane mass. Mass removal could hasten the attainment of 1,4-dioxane cleanup levels throughout the Outside Area. This FFS presents a brief screening of technologies and develops alternatives designed to achieve this objective and select a preferred alternative that cost-effectively meets the objective. The primary cleanup action objectives relevant to 1,4-dioxane in groundwater as outlined in the CAP were:

- Protect human and ecological receptors by reducing constituent of concern (COC) concentrations in Outside Area groundwater to cleanup levels based on protection of surface water.
- Attain, or otherwise comply with, the cleanup standards.
- Reduce COC concentrations to achieve groundwater cleanup levels at the conditional point of compliance and downgradient locations in a reasonable timeframe. Specifically, this objective will require reduction of mass within the area of the 1,4-dioxane plume containing the highest mass density. This area has been shown to be the area adjacent to well CG-127, which is slightly downgradient from the head of the 1,4-dioxane plume.

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4.0 TECHNOLOGY AND ALTERNATIVE CONSIDERATIONS

The contingent remedy in the CAP (Ecology, 2010) was developed with the objective of reducing 1,4-dioxane mass in the area(s) with the highest 1,4-dioxane mass and consisted of installing an extraction well in the vicinity of well CG-122 to remove two pore volumes of groundwater from the surrounding area. The extracted water was to be treated and discharged to the sanitary sewer or to the storm sewer with an appropriate permit. The extraction well and treatment system would need to operate for approximately 1.3 years of continuous pumping to remove two pore volumes of groundwater.

However, recent monitoring data show concentrations have not declined as fast as expected at CG-122-60. Combined with concentration trends in Outside Area wells, this indicates that a secondary source may be present. If the secondary source is due to mass flux from less permeable zones such as in silt and/or clay lenses, pumping two pore volumes would be unlikely to result in a significant removal of 1,4-dioxane mass from the aquifer that would obtain cleanup levels in CG-122-60 or in the other areas that need to be addressed. Groundwater extraction by pumping water from wells completed across the vertical lithology of the heterogeneous aquifer would remove a considerable volume of water. However, groundwater extraction would result in preferential groundwater flow paths from the higher permeability zones of the aquifer and not from the lower permeability portions, where much of the remaining contaminant mass could reside. Typically this will result in some mass being removed from the permeable section of the aquifer during the first few hours or days of pumping, after which time continued pumping will be pulling in lower-contaminant mass in the groundwater from outside the area of high 1,4-dioxane concentrations. In order to use groundwater pumping to remove significant mass, a complex approach to groundwater extraction wells, well screen design, and low or intermittent pumping schemes would be required, which would result in much higher well installation and water pumping and treatment costs. As a result, other remedial action options were also considered, as summarized in Sections 5 and 6.

Several considerations must be addressed in the development of a remedial action for the Outside Area for 1,4-dioxane. The extent of the highest contamination for 1,4-dioxane primarily lies within the intermediate and shallow groundwater zones downgradient of the site and around well CG-122 (Figure 2) at depths ranging from 35 to 75 feet bgs. The recent highest concentrations have been observed in CG-127 from 65 to 75 feet bgs and CG-122 from 50 to 60 feet bgs (Figure 3). Concentrations over 400 micrograms per liter (µg/L) also have been observed in CG-161 (screened partially in a silty layer near the upper portion of the intermediate zone). To comply with the CAP (Ecology 2010), the Agreed Order, and letters to Stericycle from Ecology; Stericycle's proposed action/actions must be able to quickly reduce 1,4-dioxane mass in the areas of the plume having the highest 1,4-dioxane mass. Reducing contaminant mass in these areas could shorten the overall groundwater remediation timeframe.

In order to determine which areas of the plume contain the most mass, a detailed analysis of the mass distribution throughout the subsurface was performed using the Thiessen Polygon method, as outlined in Appendix A. The Thiessen Polygon method is an acceptable approach used in the determination of total mass used in natural attenuation modeling and mass estimates (NJDEP, 2012). The detailed evaluation outlined in Appendix A indicates that of the 1,4-dioxane mass in the aquifer and 1,4-dioxane plume, the density of 1,4-dioxane mass per square foot in the vicinity of CG-127 is 60 percent higher than the next highest area (near CG-161). As a result, the highest amount of total 1,4-dioxane mass is clearly defined as the area adjacent to CG-127. As such, the remedial action objectives (RAOs) outlined in Section 3 and developed and evaluated in Section 6 of this FFS will address the area around CG-127. The treatment alternatives presented were developed to address the most problematic area within the shallow and intermediate groundwater zones. The remedial action response selected will also consider risk to human and ecological receptors for both the remedial approach and the existing extent and migration of the 1,4-dioxane plume. Given that the contaminated groundwater is primarily at 35 feet bgs or deeper, and that the nearest well with detections of 1,4-dioxane over the cleanup level (CI-9-70) is over 1,500 feet from the Duwamish Waterway (the potential exposure pathway), the concentrations of 1,4-dioxane at current levels are not reaching a human or ecological receptor and thus there are no current or projected risks to human or ecological health. The aquifer affected by 1,4-dioxane is not currently considered a beneficial aquifer by Ecology; therefore, the point at which a receptor could be exposed to the contaminant is the Duwamish Waterway.

Under the Model Toxics Control Act (MTCA), the conditional point of compliance (CPOC) for 1,4-dioxane for the site is defined as the Stericycle property boundary, although there is no receptor at that location. The low risk to receptors lessens the imperativeness of the restoration timeframe; however, although there is no risk to human or ecological receptors, MTCA still requires that cleanup must meet the cleanup levels at the CPOC within *“a reasonable restoration timeframe.”*

In summary; the RAOs for the Outside Area 1,4-dioxane plume are to:

- Reduce mass in the area(s) with the highest mass density of 1,4-dioxane, adjacent to CG-127; and
- Meet the cleanup levels at the CPOC within a reasonable restoration timeframe.

The Outside Area is located in a dense, built-up, mixed urban area. Several of the streets running through the Outside Area are primary arterials for traffic in the Georgetown area. The properties located within the Outside Area are residential, industrial, and commercial. As a result, the remedial action selected must be able to address the objectives discussed above while minimizing impacts to residents and businesses. Any work completed on private property will require access agreements and permitting through the Seattle Department of Planning and Development (DPD). Work taking place on City of Seattle property and in the public right of way will require permitting through the Seattle Department of Transportation (SDOT).

Permitting across multiple parcels of private property will result in longer remedy timeframes and additional costs for permitting, thus affecting Stericycle's ability to provide a timely remedy implementation. As a result, minimizing permitting is an important factor in the evaluation of the treatment technologies and the remedial alternatives. Table 1 summarizes the permitting required for the remedial technologies considered in Section 5. Working exclusively in the public right of way and permitting solely with SDOT will reduce cleanup time by at least three to four months over working on private property and permitting through DPD. In addition, this option would decrease costs associated with permitting. To expedite the cleanup of the 1,4-dioxane plume, technologies and alternatives that entail working entirely in the public right of way were considered first. It is assumed that all work will be conducted outside of the privately-owned property boundaries for the Outside Area shown in Figure 3.

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5.0 TECHNOLOGY SCREENING

This section describes the criteria used to screen potential treatment technologies and the technologies that will be retained to develop a comprehensive contingent remedy for the Outside Area.

5.1 SCREENING CRITERIA

Remedial actions for 1,4-dioxane feasible for the site were identified using a two-step screening process, consistent with U.S. Environmental Protection Agency guidance (EPA, 1994a). The first step, as outlined in this section, was to identify potentially applicable remedial technologies appropriate for 1,4-dioxane that have been proven in full-scale applications or that have been used in pilot-scale programs and appear to be potentially feasible for use at the site. The potentially applicable remedial technologies were subsequently screened using appropriate criteria to prepare a short list of potentially applicable remedial technologies, which were then used to develop appropriate remedial action alternatives to address 1,4-dioxane in the Outside Area for areas adjacent to CG-127. The criteria used to screen the selected technologies were as follows:

- **Technology Development Status:** This criterion refers to the level of development for the technology (bench, pilot, or full-scale). Technologies with full-scale implementation were favored over less developed technologies. Technologies successfully implemented in a variety of environmental and geologic settings were favored over technologies with a more restricted application record.
- **Performance Record:** This criterion refers to the technology's record of successfully attaining the remediation objectives established for the technology in prior implementations. Technologies with a more successful performance record were favored over technologies with fewer successes or more failures.
- **Implementability within the Constraints of the Site:** This criterion refers to the expected ability to successfully implement the technology within the Outside Area in a reasonable timeframe. Technologies requiring minimal access and simpler permitting were favored over technologies requiring extensive permitting or access to numerous locations. Technologies requiring significant infrastructure (permanent wells, extensive piping runs, public and private easements, and access agreements) might be difficult to implement due to the associated logistical and administrative challenges. It is possible that in some cases certain technologies might not be implementable. Non-invasive technologies were favored over highly invasive technologies, due to the extensive development in the Outside Area and the complications involved in gaining property access for conducting remediation.

5.2 TREATMENT TECHNOLOGIES CONSIDERED

As part of the preliminary screening process, potentially applicable remedial technologies were identified based on professional experience, professional literature, and other technical resources such as the Federal Remediation Technologies Roundtable and Contaminated Site Clean-Up

Information website. All the remedial technologies considered for screening are discussed in this section. The technologies that have been proven in field applications or where pilot/bench scale testing indicated a high potential of successful application for 1,4-dioxane were retained for further consideration. The remediation technologies considered potentially applicable for the Outside Area for 1,4-dioxane are summarized in Sections 5.2.1 through 5.2.4 and described in detail in Table 2. Technologies retained for further consideration were used to build remedial action alternatives to address 1,4-dioxane in the Outside Area.

5.2.1 In Situ Biological Treatment

Four in situ biological treatment technologies were considered, three of which were retained for further consideration.

5.2.1.1 Enhanced Bioremediation

In situ bioremediation (ISB) may be used to degrade 1,4-dioxane with the enhancement of existing or introduced microbes that can degrade 1,4-dioxane. Recently, 1,4-dioxane has been shown in biotraps and in bench scale studies to be biologically degraded using in situ co-metabolic processes. 1,4-dioxane was shown to be degraded at concentrations similar to those observed at the site (500 parts per billion) in microcosms prepared with groundwater taken from a contaminated site. 1-butanol was added as a substrate for the microorganisms to degrade the 1,4-dioxane (Li et al., 2010). Co-metabolic degradation can be accomplished by injecting a fuel or alcohol substrate such as tetrahydrofuran, propane, methane, 1-butanol, or 1-propanol into the groundwater (Li et al., 2013). 1-Butanol occurs naturally in the environment and is a biological degradation intermediate. 1-Butanol has been shown to have low toxicity and its fate in the environment is primarily biological degradation (EPA, 1994b). The biodegradation of 1,4-dioxane through co-metabolic processes is a relatively new development in the environmental remediation field. Drawbacks of the technology include the potential for indigenous microorganisms to outcompete 1,4-dioxane degraders for substrate. Depending on the substrate used, potentially explosive or hazardous conditions can be created, as propane or methane may create an explosive environment and substrates such as tetrahydrofuran or toluene may be considered hazardous to the environment. This technology has not been implemented within fully developed urban areas and has not been applied in source areas.

This technology could be used to assist in expedited cleanup of the 1,4-dioxane plume in the Outside Area and, more specifically, to address source areas located in low-permeability units. The EPA's guidance document, How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, mentions that bioremediation can be effective in less permeable silty or clayey media (EPA, 2014). Depending on the substrate used, potential for environmental releases, explosion hazards, or migration off-site in groundwater may be encountered; therefore, no fuels or toxic compounds will be considered. Based on previous studies performed with co-mingled plumes of

1,4-dioxane and chlorinated solvents, it is expected that biostimulation and bioaugmentation for 1,4-dioxane (and the associated byproducts) will not impede degradation of volatile organic compounds and may be beneficial, as shown by the ability of some microorganisms that use 1,4-dioxane to assist in degradation of toluene (Mahendra and Alvarez-Cohen, 2006). Bench studies by The Sentinel Environmental Group (a subsidiary of Rice University) will provide additional information on potential changes to groundwater chemistry and byproducts. Stericycle will only propose bioaugmentation and biostimulation if bench studies show that these technologies can be successful and can be applied without significant negative impact to the biodegradation of the chlorinated solvent plume. Although this technology has been shown to be successful in a lab setting, this technology has not been successfully implemented at any locations that are similar to the site based on available research. In order to evaluate this technology for the site's specific groundwater, Stericycle is working with The Sentinel Environmental Group to set up treatability studies for Outside Area groundwater using various substrates. Based on its suitability for treating source areas and more specifically diffuse areas throughout the 1,4-dioxane plume, enhanced bioremediation is retained for further consideration.

5.2.1.2 Bioaugmentation

Bioaugmentation is an in situ remedial technology in which microorganisms specifically adapted for degradation of the COC are introduced to the affected groundwater. Bioaugmentation could be conducted using anaerobic or aerobic biological microorganisms. Under aerobic conditions, the microorganisms *Mycobacterium vaccae* JOB5 and *Pseudonocardia* K1 have been observed degrading 1,4-dioxane in industrial sludge. Both bacterial strains *Pseudonocardia dioxanivorans* CB1190 and *Rhodococcus* strain 219 have been shown to be capable of using 1,4-dioxane as a sole carbon source or to co-metabolically degrade 1,4-dioxane with another substrate (Mahendra and Alvarez-Cohen, 2006). Any microorganisms that may degrade 1,4-dioxane would need to be evaluated prior to the introduction of the microorganism. Injection wells or push probes are typically used for injecting the microorganisms. The microbial culture added to the subsurface would then need to be capable of competing with indigenous organisms for nutrients and substrate. In some bioaugmentation applications, the added organisms do not compete successfully with indigenous organisms and require the addition of substrate to favor the target microorganisms.

Although this technology has been shown to be successful in a lab setting, this technology has not been successfully implemented at any locations that are similar to the site based on research. In order to evaluate this technology for the site's specific groundwater, Stericycle is working with The Sentinel Environmental Group to evaluate the options for bioaugmentation for Outside Area groundwater. Bioaugmentation has been retained for further consideration for the Outside Area due to its potential to address diffuse locations over the long term. This technology could be implemented in the event that existing microbial colonies are insufficient to fully degrade 1,4-dioxane or if no known colonies are present at the site.

5.2.1.3 Monitored Natural Attenuation

Monitored natural attenuation (MNA) is a proven technology that has been effective in reducing contaminant concentrations in groundwater when appropriate conditions are present. This process relies on the attenuation of groundwater COCs by natural processes including biodegradation, abiotic degradation, adsorption, and dilution. Due to the passive nature of this remedial technology, it can be readily implemented with a minimum amount of institutional issues such as permitting or arranging for access permissions, and also has minimal potential for implementation problems such as well fouling or the use of hazardous materials or heavy machinery. One potential drawback of sole reliance on this technology is potentially longer remediation periods compared to active groundwater remediation technologies.

MNA was the remedial technology selected in the CAP and appears to be working for the Outside Area, but at a rate slower than projected in the CAP (Ecology, 2010). Given the low permeability lenses throughout the shallow and intermediate zones in the Outside Area, any remedial design must consider the possible mass flux of 1,4-dioxane from low permeability lenses as a potential long term source. MNA will be retained for further consideration for lower-concentration parts of the Outside Area and combined with other more aggressive treatment technologies to remove 1,4-dioxane from the areas subject to the selected remedy outlined in Section 6.

5.2.1.4 Phytoremediation

Phytoremediation is a set of processes that uses plants to destroy or remove contamination in groundwater. Plants use several mechanisms in phytoremediation, including enhanced rhizosphere biodegradation, phyto-degradation, and phyto-volatilization. Enhanced rhizosphere biodegradation utilizes natural substances released by plant roots to supply nutrients to microorganisms, which enhances their ability to biodegrade organic contaminants. Phyto-degradation is the metabolism of contaminants within plant tissues, and phyto-volatilization occurs as plants take up water containing organic contaminants and release the contaminants into the air through their leaves. Phytoremediation through the use of plants such as poplars has been shown to be effective to remediate 1,4-dioxane in soil and groundwater (Aitchison et al., 2000).

The potential for application of phytoremediation in the Outside Area is extremely limited by the depth of groundwater contamination, the current land use, and the expected future land use. The heavy urban development would prevent application of the technology within the entire Outside Area. This technology would not be effective for groundwater below the water table depth interval. Therefore, this technology has been rejected for the Outside Area.

5.2.2 In Situ Chemical Oxidation Treatment

In situ chemical oxidation (ISCO) has been successfully used for treatment of 1,4-dioxane. A few different oxidants have been shown to have successfully degraded/destroyed 1,4-dioxane, but the oxidant primarily used to address 1,4-dioxane in situ has been persulfate (Regenesis, no date). Persulfate is a reactive, hazardous chemical that requires proper design and management to be used safely. This technology is based on injecting the chemical oxidant into the affected groundwater. Persulfate is typically injected into the ground using a direct push technology and may be injected with an activator such as high pH compounds or reduced iron, or in high temperature solutions to promote the formation of the sulfate radical, a stronger oxidant than persulfate alone (Wilson et al., 2013). The activator reacts with the persulfate, forming the sulfate radical, which is one of the strongest oxidants used in environmental remediation. Persulfate without an activator was shown to be successful at destroying 1,4-dioxane with 50 percent mineralization (Evans et al., 2014). Activated persulfate has also been used successfully at several sites to address 1,4-dioxane. Common methods of persulfate activation include the injection of a basic compound such as sodium hydroxide, which was injected at a 2:1 mass ratio (Klozur FMC sodium persulfate to sodium hydroxide) with good results (MACTEC, 2009). Third-party companies provide mixtures of persulfate with an activator, such as the proprietary blend provided by Regenesis called PersulfOx®, which uses alkaline conditions created by dissolving silicates during injection (Wilson et al., 2013). PersulfOx® has been used successfully in both full scale and bench scale studies for 1,4-dioxane (Regenesis, no date b). Injection of the chemicals can be accomplished using direct-push techniques, injection wells, or recirculation wells. This technology is typically only considered for treatment of highly affected source areas; the technology is not well suited for use in dilute groundwater plumes because oxidation of the target COC depends on direct contact with 1,4-dioxane and the persulfate will be consumed rapidly by other oxidant-demanding sources. High reactant chemical doses and low utilization efficiencies would be required for dilute plumes, which would result in high remediation costs.

Persulfate could be used to target the area of the highest 1,4-dioxane mass, which is located adjacent to CG-127 in the Outside Area, over the required depths. The depths of the chemical impacts, the complex geology and geochemistry (including the presence of metals in a highly reductive environment), the dispersed 1,4-dioxane, and the difficulties of delivery of the oxidant within interbedded soils could limit the potential use of this technology. Heavy metals may potentially be mobilized during injection of persulfate, as has been observed during full scale studies (MACTEC, 2009). In addition, excess sulfate is released as a byproduct of the injection of persulfate. As a result, sulfate migration must be evaluated during treatability studies if there is a concern regarding downgradient receptors. Additionally, the technology would not effectively remediate 1,4-dioxane that has diffused/dispersed into the interbedded silt layers. Due to the generally diluted nature of the Outside Area, chemical oxidation would not be cost-effective for the majority of the area. Chemical oxidation would remove 1,4-dioxane mass from the area of highest concentration of the contaminant, although the amount of mass destroyed will not be predictable. A treatability study may be required to provide valuable information for the oxidant mass requirements, potential metals mobilization, pH effects, and sulfate releases from the injection areas. This technology was retained for potential application to target the area adjacent to CG-127 for immediate mass reduction.

5.2.3 Groundwater Extraction and Treatment (Pump and Treat)

Groundwater extraction and treatment was originally selected as the contingent remedy in the CAP for the area adjacent to CG-122. Groundwater extraction will require ex situ treatment of the water to remove 1,4-dioxane prior to discharge. Extracted groundwater would need to be run through an advanced oxidation system or an absorbent media such as AmberSorb® with the treated water discharged either to the King County publicly owned treatment works (POTW) or to the Duwamish Waterway via a National Pollutant Discharge Elimination System (NPDES) permit. Discharge to the King County POTW would be the preferred option for the Outside Area due to the time and expense required to obtain an NPDES permit and also to treat the extracted groundwater to the more stringent NDPES discharge limits. In addition, a more complicated treatment system could require additional property resulting in further delays and additional costs.

Based on current groundwater sampling data and the discussion in Appendix A and Section 4.0, the area with the most mass is located adjacent to well CG-127 in both the shallow and intermediate groundwater zones. As a result, extraction wells would be installed in the public right of way in the area near CG-127. Groundwater extraction for 1,4-dioxane mass removal would be costly within the Outside Area due to the dilute 1,4-dioxane concentrations and the areal extent of affected groundwater. In addition, long-term pumping could be required to remove sufficient mass due to the potential presence of a secondary source for the 1,4-dioxane. To prevent pumping of excess clean groundwater and to maximize the ex situ remediation system performance, a number of wells would be required to allow low flow pumping from several locations within the area adjacent to CG-127. This would result in a long-term cleanup timeframe and significant operation and maintenance (O&M) costs. The use of a groundwater pump and treatment system along the public right of way could require long-term storage of potentially hazardous materials to treat the extracted groundwater to levels required for discharge. Technologies such as bioreactors that use propane injection for co-metabolic degradation and ex situ chemical oxidation with activated persulfate, hydrogen peroxide, and ozone require the long-term storage of hazardous materials. Permitting for these options has several unknowns. While SDOT has stated they would find a way to permit these options, additional spill requirements, fire prevention devices, and security would likely be required. Although the changes in knowledge of the 1,4-dioxane plume adds considerable complexity to implementing this technology, groundwater pump and treatment is a proven technology and will be retained as a potential option to be considered in the alternatives assessment.

5.2.4 Subsurface Injection Technologies

Three methods of injecting chemicals to the subsurface were screened: push probe injection, recirculation wells, and hydraulic fracturing. Recirculation wells and hydraulic fracturing are not ideal for the soil types and geochemistry in the target injection zones. Recirculation wells will cover permeable areas but will result in incomplete distribution in less permeable areas, and iron fouling problems are likely. Fracturing uses high pressures to create large flow channels in the aquifer. The large flow channels could result in transport of the injected substance outside of the target area resulting in incomplete coverage. As such, both were rejected from further consideration. Push probes were retained to be used in conjunction with ISCO and ISB, as push probes can be used to target specific areas and depth intervals more effectively.

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6.0 REMEDIAL ALTERNATIVES

This section presents the criteria used to formulate and evaluate the potential remedial alternatives identified for the Outside Area in conjunction with MTCA cleanup regulations under Washington Administrative Code (WAC) 173-340-360. The alternatives will be evaluated and a preferred alternative will be selected to address 1,4-dioxane in the shallow and intermediate aquifer within the area of well CG-127. The potential remedial alternatives were developed from the initial screening of potentially applicable remediation technologies and were designed to attain the remediation objectives presented in Section 3.0.

During conference calls with Ecology in August and September 2014, general outlines for remedial alternatives were developed. The remedial alternatives are designed to meet RAOs in the shallow and intermediate groundwater zones by reducing 1,4-dioxane mass in the areas with the highest mass of 1,4-dioxane per square foot. This will maximize treatment efficiency and destruction for the Outside Area, specifically in the area adjacent to well CG-127. Due to the additional time and cost of permitting necessary for working on both private property and in the City of Seattle right of way, conducting groundwater cleanup at locations within the public right of way is appropriate.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

In order to select the preferred alternative, each of the remedial alternatives presented in Section 6.2 were evaluated relative to the criteria specified in WAC 173-340-360. The evaluation criteria for the Outside Area are.

- ***Protectiveness:*** Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.
- ***Permanence:*** The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.
- ***Relative Cost:*** The relative costs to implement the alternative, including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost-recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. The alternatives with the lowest relative cost when compared to the other alternatives will be ranked higher.

- ***Long Term Effectiveness:*** Includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or off-site disposal in an engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring. Alternatives that actively degrade or destroy 1,4-dioxane would be ranked higher for this criterion than alternatives that utilize slower methods.

- ***Management of Short Term Risks:*** The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.

- ***Technical and Administrative Implementability:*** Ability of the alternative to be implemented, including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions. Factors considered for evaluation of this criterion include:

- The size and complexity of the remedial alternative;

- The degree to which the remedial alternative can be integrated with existing operations and activities within affected areas;

- Regulatory requirements, including permitting; and

- Present and future land use for the area above and adjacent to the project area, including any specific constraints land use may have on the alternative.

- ***Consideration of Public Concerns:*** Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns of individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site. Remedial alternatives likely to be readily accepted by the public would rank higher than alternatives that may create issues that must be addressed. Potential public concerns include factors such as increased truck traffic, adverse traffic impacts, noise, dust, odors, release of vapors, use of hazardous materials, safety, and effects on property values. The heavy industrial, commercial, and residential land uses in an urban environment create significant potential for public concern related to site remediation.

The remedial alternatives considered in this technical memorandum were designed to attain the remediation objectives outlined above to the extent practicable. Table 3 summarizes the alternatives, the screening criteria, and the alternative evaluation for the site. Alternative descriptions are provided below.

6.2 REMEDIAL ALTERNATIVES CONSIDERED

Each of the remedial alternatives discussed in this section would meet the objectives outlined in Section 3. Given that there is no current risk to human or ecological receptors, alternatives will be designed and evaluated based on each alternative's ability to reduce 1,4-dioxane mass in the area adjacent to CG-127, which has the highest mass density of 1,4-dioxane in the Outside Area. Common problems shared by all alternatives outlined below are:

- Subsurface heterogeneities, preferential flow paths, and poor mixing in the subsurface may result in incomplete treatment;
- Difficulty in targeting lower permeability zones that may be acting like secondary sources; and
- Inability to reliably predict cleanup time frames due to the complexity of the aquifer and contaminant distribution combined with the possible presence of a secondary source of 1,4-dioxane.

For the purpose of conceptual alternative design, as discussed in Section 3.0 and in Appendix A, the alternatives will address the area adjacent to CG-127 at aquifer depths from 35 to 45 feet bgs and 65 to 75 feet bgs, as this plume area and these depth intervals have the largest 1,4-dioxane mass density (more than 60 percent higher than the next largest area, well CG-122).

All alternatives will require a long term monitoring plan to evaluate the effectiveness of the alternative and to ensure that the cleanup action objectives are met. The monitoring wells will be used to monitor the important parameters for each alternative. The monitoring plan will be developed as part of the remedial design work plan for the selected alternative.

The three alternatives considered for the remediation of the Outside Area are:

- Alternative 1: A targeted injection of ISCO within the area adjacent to well CG-127,
- Alternative 2: A targeted injection of ISCO consistent with Alternative 1 followed by enhanced ISB and possibly bioaugmentation, and
- Alternative 3: Mass removal through groundwater extraction and the treatment of the extracted groundwater.

Sections 6.2.1 through 6.2.3 outline the details of the three proposed cleanup alternatives.

6.2.1 Alternative 1: In Situ Chemical Oxidation Targeted Approach

Alternative 1 incorporates the use of a push probe injection network that addresses the areas adjacent to CG-127 with the highest mass density of 1,4-dioxane. All injections will be conducted in the public right of way. A bench scale and treatability study would be required to evaluate injection techniques, oxidant dose, potential for metals migration, sulfate migration, and pH effects prior to full scale injection adjacent to CG-127. The bench scale study would evaluate the oxidant used (e.g., activated or unactivated persulfate), the oxidant dose, and the effectiveness. The treatability study would evaluate the injection of persulfate (either activated or unactivated, depending on bench scale testing) and the potential issues associated with the injection of persulfate into the aquifer (e.g., metals mobilization, sulfate migration, and pH). Based on the results of the treatability testing; injections would be conducted in an effort to reduce mass in the area of the plume with the highest contaminant mass density, which is located adjacent to well CG-127, downgradient from the head of the plume near CG-122. Alternative 1 would include the following elements:

- A bench scale study to evaluate persulfate effectiveness;
- Treatability study injections adjacent to CG-122 to determine oxidant dosing design for CG-127 and to evaluate metals mobilization, sulfate migration, and pH decreases;
- Injection of persulfate adjacent to CG-127;
- ISCO performance monitoring program; and
- Long term MNA.

The components of Alternative 1 would be implemented in phases. Phase I would involve implementing a bench scale study using soil and groundwater samples collected adjacent to CG-127 for ISCO. In addition, samples will be collected adjacent to CG-127, CG-122, and upgradient to be sent to The Sentinel Environmental Group to verify biodegradation is occurring. Phase II will consist of performing a treatability study with persulfate adjacent to CG-122 in the public right of way, based on results from the bench scale study. The treatability test at CG-122 will be conducted using four injection points placed adjacent to CG-122. The injections adjacent to CG-122 will cover a 10-foot interval in the intermediate zone around 50-60 feet bgs. Phase II will include a three month monitoring period to monitor the potential for metals mobilization, pH reduction in groundwater, and the potential for sulfate migration.

Phase III will consist of the injection of persulfate adjacent to CG-127 in the public right of way. Approximately 30 injection points would be required to effectively distribute the oxidant in the targeted treatment zones adjacent to CG-127.

The advantages of Alternative 1 are:

- Chemical oxidation is a proven technology for addressing 1,4-dioxane, and is particularly cost-effective in the areas of highest mass density source areas;
- This alternative would remove mass from the targeted area that could result in a reduced restoration time frame to meet remediation levels in the shallow and intermediate zones;
- This alternative meets the objective of effective mass reduction immediately; and
- This alternative would be less costly than Alternatives 2 and 3 and quickest to implement.

The disadvantages of Alternative 1 are:

- The geochemistry within the shallow and intermediate zones in the Outside Area is complex, and iron and manganese concentrations are very high. These metals, as well as organic carbon and soil oxidant demand, could consume a considerable amount of chemical oxidant. However, the presence of metals may alleviate any need for an activator for the persulfate.
- This alternative would be unlikely to address interbedded silt layers, which may be contaminated.
- Although the objective of this alternative would be to remove mass in the areas with the highest mass density, it is not likely that cleanup levels in any of the aquifer zones would be quickly met by this alternative, due to recontamination that would be expected to occur from the secondary source(s).
- This alternative would only address sections of the plume with the highest mass density of 1,4-dioxane within the public right of way.

6.2.2 Alternative 2: In Situ Chemical Oxidation Followed By In Situ Biological Degradation Targeted Approach

Alternative 2 incorporates the ISCO targeted mass removal approach of Alternative 1 followed by targeted ISB to address the more diffuse concentrations of 1,4-dioxane in the plume. The ISB would occur six months after the ISCO injections to allow ISCO to diffuse. The ISB would use a push probe injection network to implement the remedy, relying on diffusion and dispersion to transport the substrate and injected microorganisms throughout the plume. Target injection areas would need to be located in the public right of way. Using ISCO and ISB in tandem would provide initial mass removal of 1,4-dioxane from the highest mass density areas and the follow-up with ISB would serve as a mechanism to speed up biodegradation and reduce remediation time frames. Alternative 2 would include the following elements:

- A bench scale study to evaluate persulfate effectiveness;

- Treatability study injections adjacent to CG-122 to determine oxidant dosing design for CG-127 and to evaluate metals mobilization, sulfate migration, and pH decreases;
- The Sentinel Environmental Group bench-scale studies for substrate selection and bioaugmentation requirements;
- Injection of persulfate adjacent to CG-127;
- An ISCO performance monitoring program (approximately six months);
- Injection of substrate and microorganisms (as determined by the bench study performed by The Sentinel Environmental Group) adjacent to CG-122 (upgradient of plume area) and adjacent to CG-161 in the middle of the plume area ;
- An ISB performance monitoring program; and
- Long-term MNA for diffuse concentration locations.

The components of Alternative 2 would be implemented in four phases. Phase I would involve implementing a bench scale study using soil and groundwater samples collected adjacent to CG-127 for ISCO. In addition, samples will be collected adjacent to CG-127, CG-122, and upgradient to be sent to The Sentinel Environmental Group to evaluate enhancement and/or bioaugmentation to promote biological degradation of the 1,4-dioxane. Phase II will consist of performing a treatability study with persulfate adjacent to CG-122 in the public right of way, based on results from the bench scale study. The treatability test at CG-122 will be conducted using four injection points placed adjacent to CG-122. The injections adjacent to CG-122 will cover a 10-foot interval in the intermediate zone around 50-60 feet bgs. Phase II will include a three month monitoring period to monitor the potential for metals mobilization, pH reduction in groundwater, and the potential for sulfate migration. During the treatability study and monitoring period of Phase II, The Sentinel Environmental Group will conduct bench scale studies and provide recommendations to Stericycle and Ecology.

Phase III will consist of the injection of persulfate adjacent to CG-127 in the public right of way. Approximately 30 injection points would be required to effectively distribute the oxidant in the targeted treatment zones adjacent to CG-127. Phase III will last for six months to allow for ISCO to dissipate from the area.

For Phase IIII, approximately 36 injection points would be required to effectively distribute the substrate and/or microorganisms in the targeted treatment zones. Depending on recommendations from The Sentinel Environmental Group, Phase IIII could include the injection of substrate and microorganisms (if required) in the public right of way adjacent to CG-122 and CG-161. MNA will be implemented for other diffuse areas outside of the main plume area using the monitoring well network currently in place (Figure 2).

The advantages of Alternative 2 are:

- Chemical oxidation is a proven technology for addressing 1,4-dioxane and is particularly cost-effective in source areas;
- Targeted ISB may spread throughout the plume area and bacteria would be better able to provide long-lasting treatment for 1,4-dioxane in the interbedded silt layers, as discussed in the treatment technology evaluation;
- The alternative could attain cleanup levels in the shallow and intermediate zones in a reduced time frame when compared to MNA;
- The alternative would use both ISCO and ISB in ways that play to each technology's strengths, providing a better chance at both an initial quick mass removal action in the highest concentration areas while providing a remedial measure to accelerate biodegradation rates in the long term;
- This alternative meets the objective of effective mass reduction immediately and could reduce mass over an extended period of time; and
- This alternative would be less costly than Alternative 3.

The disadvantages of Alternative 2 are:

- The geochemistry within the shallow and intermediate zones in the Outside Area is complex, and iron and manganese concentrations are very high. These metals as well as other organic carbon and soil oxidant demand could consume a considerable amount of chemical oxidant.
- Implementing this alternative would take longer than ISCO alone and would require bench scale testing for ISB.
- There is uncertainty as to whether indigenous biota may outcompete targeted biota or planted microorganisms for selected substrate.
- The Sentinel Environmental Group study may indicate that ISB is not an effective solution for the Outside Area.
- Although the objective of this alternative would be to remove mass in the areas with the highest mass density, it is not likely that cleanup levels in any of the aquifer zones would be quickly met by this alternative, due to recontamination that would be expected to occur from the secondary source(s).
- This alternative would be more costly to implement than Alternative 1.

6.2.3 Alternative 3: Groundwater Extraction Targeted Approach

Alternative 3 relies on mass removal by a groundwater extraction well network located adjacent to CG-127. As outlined in the CAP (Ecology, 2010); two pore volumes need to be removed to sufficiently flush groundwater through the areas with the highest mass density of 1,4-dioxane to remove the mass in the permeable areas. In order to cover the area adjacent to CG-127 for both groundwater zones, we are assuming that a total of three wells drilled in each zone will be required for a total of six groundwater extraction wells to extract sufficient pore volumes and to maintain low pumping rates to maximize contaminant removal. We also assume a total pumping rate of 40 gallons per minute (gpm); however, with six extraction wells, individual wells would have average pumping rates of 6 gpm. The detailed design phase of the project could potentially determine that more wells would be needed to further reduce individual well pumping rates.

The extracted groundwater will be treated by an adsorption treatment system consisting of AmberSorb® media to minimize iron fouling of the groundwater remediation equipment. The remediation system will be located in the public right of way and will need to be in operation for approximately 1.3 years as outlined in the CAP (Ecology, 2010). The primary components of the mass extraction alternative are:

- Installation of six new groundwater extraction wells in the public right of way;
- Installation of a new adsorption-based groundwater remediation system in the public right of way to be operated for 1.3 years;
- Regulated discharge to the King County sewer with required monitoring.

The advantages of Alternative 3 are:

- The groundwater extraction network would be designed to primarily target permeable areas with the highest 1,4-dioxane mass density;
- Groundwater pump and treat is a proven technology for mass removal; and
- This alternative could result in a reduced time frame to meet cleanup levels in the shallow and intermediate zones, assuming a secondary source is not present.

The disadvantages of Alternative 3 are:

- Implementing this alternative would take significantly longer than either Alternative 1 or 2 due to permitting requirements for installation of piping, the need for groundwater treatment, and involvement of multiple agencies for permitting. Alternative 3 only addresses permeable units and may preferentially pull groundwater from areas of the Outside Area with little 1,4-dioxane mass.
- Groundwater pump and treatment is proven for plume containment but has not been successful for groundwater cleanup.
- Although the objective of this alternative would be to remove mass in the areas with the highest mass density, it is unlikely that cleanup levels in any of the aquifer zones would be quickly met by this alternative, due to recontamination that would be expected to occur from the secondary source(s).

- The alternative would be much more costly to implement than Alternatives 1 and 2.

6.3 ALTERNATIVES ANALYSIS

All alternatives evaluated in this FFS have been evaluated in accordance with WAC 173-340-350, 360 and 370. Table 3 compares the three alternatives to each other using the selection criteria. Ecology typically prefers that alternatives be compared to the most permanent remedy. In accordance with the definition of permanent solution in MTCA, ISCO would be the most permanent solution given it is the only alternative that results in complete destruction of 1,4-dioxane within the high density mass areas. Groundwater extraction may remove mass from the high mass density area but it would likely take a long time (1.3 years) and could pull the majority of water from cleaner areas of the site. The combination of ISCO and ISB Alternative 2) is considered as permanent as the ISCO alternative (Alternative 1), as it implements the same ISCO program but adds the potential to use an enhanced bioaugmentation, although bioaugmentation is not proven for the site. As a result, Alternatives 1 and 2 are considered the most permanent alternatives and Alternative 3 is the least permanent. All three alternatives will result in reduction of total 1,4-dioxane mass that could reduce the restoration timeframe; however, none of the alternatives will result in immediate cleanup of the plume. All three alternatives rely on MNA to reach cleanup levels. In addition, there is uncertainty as to whether any of the three alternatives would reduce the restoration timeframe due to the potential presence of a secondary source of contamination. All three alternatives are evaluated in Table 3 to develop a semi-quantitative score to determine the preferred alternative. As shown on Table 3, Alternative 1 had the highest score of 16 using the evaluation criteria defined in MTCA. The next highest score was 13 for Alternative 2 and the lowest score was 10 for Alternative 3.

Appendix B summarizes the costs associated with each alternative for implementation and O&M. Given that all three alternatives will include similar long term performance monitoring after implementation (i.e., after the first couple of years), only the capital costs, O&M, and short term performance monitoring were considered in the comparison of the three selected alternatives. All three alternatives include the costs associated with performing a study with The Sentinel Environmental Group to evaluate biodegradation, enhanced biodegradation, and bioaugmentation. Pursuant to WAC 173-400 (3)(e)(ii)(A-C), the alternatives were ranked as least to most permanent, with Alternatives 1 and 2 the most permanent and Alternative 3 the least permanent. The costs for each of the three alternatives are summarized in Table 4. According to Table 4; Alternative 3 costs nearly four times more than Alternative 1 and 2.7 times more than Alternative 2. In addition, as shown on Table 3, Alternative 1 is the highest scoring alternative of the three based on the screening criteria outlined in MTCA and is more than four times less costly than the least permanent alternative, Alternative 3. Alternative 1 is also the quickest and easiest alternative to implement and as a result has the least impact on the public community. Alternative 1 also scored highest for permanence of the remedy, tied with Alternative 2. The most permanent of the three alternatives would have been

Alternative 2; however, the fact that ISB for 1,4-dioxane has not been proven in the field lowered the score for Alternative 2. Alternative 2 is also 1.5 times more than Alternative 1. Pump and treat (Alternative 3) had the least permanence partly since contaminant mass would not be destroyed but only transferred to another medium and it would take longer to remove contaminant mass from the groundwater.

Because the benefits of Alternative 3 are assumed to be less than those of Alternative 1 compared to the RAOS and to the MTCA criteria outlined in Section 6; Alternative 3 has a disproportionately high cost to benefit ratio compared to Alternative 1. In addition, Alternative 3 was ranked lower than Alternative 1 for most of the MTCA criteria, which further highlights the disproportionate cost of Alternative 3. Alternative 2 also has a higher cost than Alternative 1; but the primary factor against Alternative 2 was the unproven ISB technology. As a result, Alternative 1, In Situ Chemical Oxidation Targeted Approach, is clearly the preferred alternative to be implemented as the contingent remedy for the Outside Area.

6.4 PREFERRED ALTERNATIVE

Alternative 1 is the preferred alternative to implement as a contingent remedy in place of the existing groundwater extraction contingent remedy presented in the CAP as outlined in Section 6.3. The assumed risk for exposure to 1,4-dioxane for ecological or human receptors is negligible, so the primary objective for the selected alternative is to aggressively remove mass in the highest 1,4-dioxane mass density areas to expedite cleanup of the Outside Area. Alternative 1 addresses these objectives equally as well as the other technologies, and can be implemented the quickest at the lowest cost.

Alternative 1 will address the 1,4-dioxane contamination in three phases as outlined in Section 6.2.1. All necessary permits to implement each phase will be in hand prior to implementing either phase of the selected remedy (see Push Probe Injections on Table 1).

Prior to the implementation of Phase I, a bench scale work plan will be developed to provide the final design of the bench scale program. The bench scale's objectives are to:

- Evaluate the use of persulfate and activated persulfate on the site's groundwater and soil; and
- Evaluate the oxidant dose.

Samples for the bench scale study will be collected adjacent to CG-127 in the intermediate zone. In addition, samples will be collected to perform The Sentinel Environmental Group study to evaluate ISB even though Alternative 2 was not selected as the preferred alternative.

Phase II will consist of performing a treatability study based on the results from Phase I. The treatability study's objectives are to:

- Evaluate the potential for pH depression in the aquifer;
- Evaluate the potential for sulfate migration downgradient of the injection areas; and
- Evaluate the potential for metals mobilization.

Phase II will target high concentration areas in the intermediate zone near CG-122. Persulfate will be used to oxidize the 1,4-dioxane. Figure 4 shows the approximate injection locations for the treatability study with the potential radius of influence of 5–6 feet for each injection point, which is estimated based on information from Regenesis for geologic units similar to those encountered during monitoring well installations in the area planned for injection (primarily silty sands). It is assumed that approximately four injection locations will be sufficient to evaluate the efficacy of using persulfate.

Treatability study results will be evaluated and a final ISCO injection work plan will be developed prior to beginning Phase III of the contingent remedy. Persulfate will be injected in the approximate locations shown on Figure 4, although injection locations may change slightly to avoid conflicting utilities or surface structures. It is assumed that approximately 30 injection locations will be sufficient to target the highest 1,4-dioxane mass density locations adjacent to CG-127.

A monitoring plan will be developed and presented in the remediation design work plan. The monitoring network will be used to track 1,4-dioxane concentrations and to project the cleanup time frame during annual reporting to Ecology.

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7.0 SCHEDULE

This FFS acts as an alternatives evaluation for the Outside Area to address 1,4-dioxane and a conceptual design to implement Alternative 1. Upon approval of the 1,4-dioxane Final Draft FFS by Ecology, a draft amendment to the CAP under AO DE7347 will be prepared, as an attachment to the Agreed Order. Since the Agreed Order acknowledges Stericycle may produce plans for approval by Ecology after the Engineering Design Report is approved, a remedial design and remedial action (RD RA) work plan would fall under that description. A draft of the RD RA will outline the design for the ISCO bench scale study, the treatability study, and the ISCO injection system as outlined as part of the preferred alternative in this FFS. Assuming that Ecology wishes to consider this a *“substantial change to the work to be performed”* as defined under Section VIII of the Agreed Order, the work plan would go through 30-day public comment prior to approval and implementation.

Stericycle will collect samples for the The Sentinel Environmental Group study in the beginning of 2015. Phase I of the preferred alternative will be completed by the end of the first quarter of 2015 and the treatability study (phase II) will be completed by the end of the first quarter of 2016. It is anticipated that minor edits may need to be made to the RD RA submitted to Ecology based on the bench scale study results to clarify the exact oxidant and dose to be used in the full scale injection of ISCO. Phase III will consist of full scale injections adjacent to CG-127 as outlined in Section 6.0. It is anticipated that ISCO will be completed in the second quarter of 2016 and will be followed by a long term monitoring period. Progress reports would be provided as part of the currently prepared quarterly progress reports and summarized as part of the final implementation report for the cleanup east of 4th Avenue South. The preliminary schedule for the implementation of the preferred alternative is shown in Figure 5.

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TABLES

TABLE 1

SUMMARY OF PERMIT REQUIREMENTS FOR POTENTIAL REMEDIAL ACTION TECHNOLOGIES

Stericycle Georgetown Site
Seattle, Washington

Potential Remediation Technology	Work Location	Permanent Equipment (Minimum 1–2 years)	DPD Permits Required	DPD Time	SDOT Permits Required	SDOT Time	KC Permits Required	KC Time	Ecology Permits Required	Ecology Time	Maximum Potential Permitting Time (Weeks)
Mass Removal through Groundwater Extraction and Treatment (Pump and Treat)[1]	Public Right of Way	- Extraction well vault - Trenching for piping to sewer - Electrical connection to system - Treatment system temporary bldg	Over-the-counter electrical and side sewer permits	1 day	51A- Well Installation Permit "Utility Major Permit" requiring an annual permit	10–20 weeks	Discharge Authorization	4–6 weeks	Well Start Card	1 day	27
Mass Removal through Groundwater Extraction and Treatment (Pump and Treat)[2]	Private Property	- Extraction well vault - Trenching for piping to sewer - Electrical connection to system - Treatment system temporary bldg	Over-the-counter electrical and side sewer permits and a full permit review	3–4 months	51A- Well Installation Permit "Utility Major Permit" requiring an annual permit	10–20 weeks	Discharge Authorization	4–6 weeks	Well Start Card	1 day	43
Subsurface Injection Technologies (Recirculation Wells)[1]	Public Right of Way	- Extraction and injection well vault - Electrical connection to system - Treatment system temporary bldg	Over-the-counter electrical permits	1 day	51A- Well Installation Permit "Utility Major Permit" requiring an annual permit	10–20 weeks	None	None	Well Start Card UIC permit	2 weeks	23
Subsurface Injection Technologies (Recirculation Wells)[2]	Private Property	- Extraction and injection well vault - Electrical connection to system - Treatment system temporary bldg	Over-the-counter electrical permit and a full permit review	3–4 months	51A- Well Installation Permit "Utility Major Permit" requiring an annual permit	10–20 weeks	None	None	Well Start Card UIC permit	2 weeks	38
Subsurface Injection Technologies (Push Probe Injections)	Public Right of Way	Temporary injection points	None	None	51A- Well installation permit Utility Major Permit	8–12 weeks	None	None	Well Start Card UIC permit	2 weeks	14
Subsurface Injection Technologies (Push Probe Injections)[2]	Private Property	Temporary injection points	Full permit review	3–4 months	51A- Well installation permit Utility Major Permit	8–12 weeks	None	None	Well Start Card UIC permit	2 weeks	30

Notes:

1. Technology does not include time to negotiate terms for long-term storage of hazardous chemicals and/or an indemnity agreement for long-term equipment in SDOT right of way. SDOT said they could not provide time until application was submitted.
2. Technology does not include time for negotiations with individual property owners. Time and associated costs may be prohibitive.

Abbreviations:

DPD = Seattle Department of Planning and Development
Ecology = Washington State Department of Ecology
KC = King County
SDOT = Seattle Department of Transportation
UIC = underground injection Control

TABLE 2

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
Stericycle Georgetown Site
Seattle, Washington

General Response Actions	Remediation Technologies	Technology Description	Technology Characteristics			Rationale for Retention or Rejection	Screening Result
			Technology Development Status	General Performance Record	Site-Specific Issues Affecting Technology or Implementation		
In Situ Biological Treatment	Enhanced Bioremediation	Injection of substrate to promote in situ biological degradation. Injection of limiting nutrients for the indigenous or planted microorganisms to allow for the target species to out-compete other indigenous microbes in the groundwater.	Pilot-Scale	Has been effective for biodegradation of 1,4-dioxane on small-scale studies. Requires application of specific substrate such as fuels (i.e., propane and THF) or alcohols such as 1-butanol.	Target organisms may not compete successfully with indigenous organisms. 1,4-Dioxane appears to be currently degrading at the site, based on historic trend data. Most cost-effective if injected on the upgradient edge or the middle of the plume, allowing groundwater flow to distribute across a large area. Has not been implemented full scale at a site similar to the site.	Enhanced biodegradation is retained as a potential technology to supplement and speed up existing biodegradation or to use in conjunction with bioaugmentation if the results from The Sentinel Environmental Group study suggest that this technology can be implemented safely and successfully.	Retain
	Bioaugmentation	Injection of specialty microbes (may be non-indigenous or currently present) to enhance biodegradation. Microorganisms are commercially available for degradation of 1,4-dioxane.	Pilot-Scale	Has been effective for biodegradation of 1,4-dioxane on small-scale studies. Requires application of specific microorganisms. May require repeated application.	Non-indigenous organisms may not compete successfully with indigenous organisms. 1,4-Dioxane appears to be currently degrading at the site, based on historic trend data. May be especially cost-effective on upgradient edge or the middle of the plume. Best chance to add a long-lasting treatment that would continue to degrade 1,4-dioxane releases from low permeability lenses.	Bioaugmentation is retained as a potential technology to supplement and speed up existing biodegradation. In addition, it is the most likely to provide long lasting treatment for 1,4-dioxane from low permeability lenses if the results from The Sentinel Environmental Group study suggest that this technology can be implemented safely and successfully.	Retain
	Monitored Natural Attenuation	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation (aerobic and/or anaerobic), adsorption, and dilution. This passive technology relies on natural conditions within affected groundwater.	Full-Scale	Traditionally believed to be primarily based on dilution, biodegradation has been shown to occur in situ at sites with appropriate conditions.	Natural biodegradation of 1,4-dioxane is likely active in area groundwater, resulting in declining trends in most monitoring wells. Technology has potentially longer remediation times than more active technologies.	This technology would result in longer restoration timeframes for 1,4-dioxane but may be feasible for lower concentrations, given that monitoring data indicate no threat to surface waters.	Retain
	Phytoremediation	Works by absorption into the roots of the plant. 1,4-Dioxane is typically absorbed into the plant's biomass or transpired. Poplars have shown the ability to remediate 1,4-dioxane in groundwater and soil.	Small-Scale	Has been proven in mostly small-scale applications.	The extent of contamination for 1,4-dioxane is primarily in the intermediate and shallow aquifer; too deep to target with phytoremediation. In addition, remediation would need to take place in dense urban locations, making it difficult to plant appropriate plants. A large number of plants would be required and likely a lot of maintenance would be required to maintain plants.	The depth of contamination prohibits the use of this treatment technology.	Reject
In Situ Chemical Oxidation Treatment	In Situ Chemical Oxidation	An oxidizing chemical (persulfate, hydrogen peroxide, Fenton's Reagent) is added to the groundwater to chemically oxidize 1,4-dioxane. Usually applied through injection wells or via direct push technology.	Full-Scale	Usually applied to source areas or higher concentration areas. Mixed performance record. Some applications have been effective, while others have been unsuccessful in attaining cleanup objectives. Technology depends on contact with 1,4-dioxane and oxidant demand of the soil, organic carbon and inorganics in the subsurface. Persulfate both activated and unactivated have shown good performance records.	High iron concentrations at the site will exert a large oxidant demand, reducing efficiency of treatment and reducing the longevity of treatment in situ. Variability in oxidant demand from other sources such as soil oxidant demand, total organic carbon, and other organics and inorganics may result in very high oxidant demands to have sufficient contact with 1,4-dioxane to fully oxidize it. Penetration of low permeability lenses is unlikely, even with many injections. Technology not cost-effective for treatment of diffuse groundwater concentrations. May be combined with enhanced biodegradation or bioaugmentation if planned correctly. Requires handling of hazardous chemicals.	High oxidant demand and diffuse groundwater concentrations make treatment of the entire area costly. This technology is retained for areas in which it will be most cost-effective for mass removal areas with the highest mass density of 1,4-dioxane.	Retain

TABLE 2

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

Stericycle Georgetown Site
Seattle, Washington

General Response Actions	Remediation Technologies	Technology Description	Technology Characteristics			Rationale for Retention or Rejection	Screening Result
			Technology Development Status	General Performance Record	Site-Specific Issues Affecting Technology or Implementation		
Groundwater Extraction and Treatment (Pump and Treat)	Mass Reduction	Groundwater extraction wells are installed to remove contaminated groundwater, thereby reducing contaminant mass. Extracted water is then treated and discharged.	Full-Scale	Has been used to remove contaminants in source areas. Requires ongoing operation and maintenance. Is a long-duration technology. Not effective to expeditiously attain cleanup levels or to treat diffuse plumes.	Limited ability to target highest 1,4-dioxane concentrations. Not cost-effective for diffuse plumes. Pumping from the 1,4-dioxane plume will pull primarily from the most permeable zones, while the majority of the 1,4-dioxane mass could likely be trapped in less permeable geology. 1,4-dioxane could likely continue to slowly back diffuse from the less permeable silt and clay layers. Long-term pumping would be required to attain cleanup levels. Long-term O&M facilities would trigger additional permitting requirements, delaying implementation and adding cost. Long-term property access would be needed to install, operate, and maintain the extraction and treatment components. Volume of discharge water would be limited by King County publicly owned treatment works, or National Pollutant Discharge Elimination System permitting would be necessary. Would require substantial permitting time prior to implementation.	Implementation of a multi-well extraction and treatment system across many different properties is logistically complex, and would not likely attain cleanup levels in an expedient time frame. Ancillary treatment technologies for 1,4-dioxane could likely result in long-term storage of hazardous contaminants in the public right of way. Permitting would delay response action significantly and be costly. Given this technology's proven performance at removing mass in areas adjacent to the extraction wells from permeable zones, groundwater mass removal is retained.	Retain
	Biological Reactors	This technology is used in conjunction with pump and treat systems. Extracted groundwater is passed into a bioreactor where substrate is added to assist in the bioremediation of 1,4-dioxane. Initial microorganisms would be required in the bioreactor and likely a fuel such as propane or THF would need to be added.	Full-Scale	Has been used to remove contaminants in source areas. Requires ongoing operation and maintenance. Requires fuels that may be considered hazardous chemicals to be stored on site.	Long-term property access would be needed to install, operate, and maintain the extraction and treatment components in areas not owned by Stericycle. Significant long-term O&M costs make active in situ technologies preferable. Would require substantial permitting time prior to implementation. Technology would result in significant waste generation and would require long-term storage of hazardous chemicals in the public right-of-way. Biological reactors are sensitive to environmental changes (temperature, system shutdown.)	Technology requires storage of large bioreactors in public right of way. Technology's success is highly dependent on maintaining consistent influent conditions for the bioreactors and maintaining temperatures and oxygen levels to promote sufficient degradation rates of 1,4-dioxane. Given that the technology requires significant solids handling and disposal along with the other issues discussed above; this technology is rejected from further consideration.	Reject
	Adsorption	This technology is used in conjunction with pump and treat systems. Extracted groundwater is passed through vessels containing adsorptive media that preferentially absorbs 1,4-dioxane and certain volatile organic compounds. The media is reclaimed by using a steam method to strip and concentrate the 1,4-dioxane into a waste stream that is then pumped through activated carbon and recirculated into the process stream.	Full-Scale	Has been effectively used to remove 1,4-dioxane and chlorinated volatile organic compounds from the aqueous phase at several sites on the east coast. Pre-packaged treatment and media regeneration systems are now available for sale.	Long-term property access would be needed to install, operate, and maintain the extraction and treatment components in areas not owned by Stericycle. Significant long-term O&M costs make active in situ technologies preferable. Would require substantial permitting time prior to implementation. Technology could result in significant waste generation (primarily activated carbon, in addition to sanitary sewer discharge).	Technology does not require the storage or handling of hazardous chemicals along the public right of way. The technology may also be configured as a small and compact system. Due to the reasons discussed above, this ancillary technology is retained in conjunction with mass removal.	Retain
	Advanced Oxidation	This technology is used to support pump and treat remediation. Extracted groundwater is passed through a specially designed advanced oxidation unit. Advanced oxidation processes typically use ultraviolet light, hydrogen peroxide and ozone, or other aggressive advanced oxidation technologies to aggressively oxidize organics. Treatment products are typically carbon dioxide, water, and hydrochloric acid (if chlorinated compounds are present).	Full-Scale	Has been effectively used to treat groundwater, including 1,4-dioxane. Requires ongoing operation and maintenance. Requires hazardous chemicals to be stored on site.	Long-term property access would be needed to install, operate, and maintain the extraction and treatment components in areas not owned by Stericycle. Significant long-term O&M costs make active in situ technologies preferable. Would require substantial permitting time prior to implementation. Technology would result in significant waste generation and would require long-term storage of hazardous chemicals in the public right of way. High concentrations of inorganics such as iron will add to cost of O&M.	Technology requires the storage and handling of hazardous chemicals along the public right of way. The technology will result in significant waste generation and will require regular cleaning from iron fouling resulting in elevated O&M costs. Due to the reasons discussed above, this ancillary technology is rejected from further consideration.	Reject

TABLE 2

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

Stericycle Georgetown Site
Seattle, Washington

General Response Actions	Remediation Technologies	Technology Description	Technology Characteristics			Rationale for Retention or Rejection	Screening Result
			Technology Development Status	General Performance Record	Site-Specific Issues Affecting Technology or Implementation		
Subsurface Injection Technologies	Push Probes	This technology is commonly used for temporary well installation for subsurface investigation and chemical treatment of the subsurface. A drill rig pushes steel rod into the ground. Minimal waste is created.	Full-Scale	Good for sandy and silty soils, unable to reach deeper units in formations with gravel or cobbles. Spacing is determined by porosity and permeability of site soils.	A higher number of injection points ensure better distribution than recirculation wells. No permanent equipment or subsurface installations are left behind.	Retained for use with in situ bioremediation or in situ chemical oxidation technologies.	Retain
	Recirculation Wells	Recirculation wells are permanent wells typically installed by hollow stem auger drill rigs. A drill rig augers soil out of the ground and a permanent well casing is installed. More drill cuttings are created, depending heavily on the size of boring.	Full-Scale	Best for projects where repeat injections are likely for the long term and where site soils are uniform.	Recirculation wells require either permanent or portable equipment, electrical, and pumping systems. Not ideal for heterogeneous soils due to the likelihood of short circuiting. Most cost effective when many rounds of repeat injections are necessary.	Rejected due to poor control of where in situ bioremediation or in situ chemical oxidation would go in the subsurface.	Reject
	Hydraulic Fracturing	A high-pressure injection technique that is useful for injections into low permeability material.	Full-Scale	Most useful for injecting into bedrock or other very low permeability geologic units.	Chemicals may daylight for shallower injections. Adds cost and health and safety concerns (high pressure) with minimal benefit to distribution. May create flow channels that transport injected chemicals outside of treatment area.	Rejected, not appropriate for site geology.	Reject

Abbreviations:
O&M = operation and maintenance
Stericycle = Stericycle Environmental Solutions, Inc.
THF = tetrahydrofuran

TABLE 3

1,4-DIOXANE TREATMENT ALTERNATIVES EVALUATION

Stericycle Georgetown Site
Seattle, Washington

Alternative[1]	Implementation Method	Protectiveness	Permanence	Cost[2]
Preferred Alternative Alternative 1: In Situ Chemical Oxidation Targeted Approach	Upon Ecology approval, perform bench scale study for ISCO with groundwater and soil samples collected from area adjacent to CG-127. Also send soil and groundwater samples to The Sentinel Environmental Group for bench scale studies for ISB. Assumes ISB bench scale results are poor. Based on ISCO bench scale results, perform treatability study adjacent to CG-122 along the west side of Maynard Street, starting at the northwest corner of Lucile and Maynard Streets in the intermediate zone. Full scale injection of persulfate based on treatability study results by push probe adjacent to CG-127 along the east side of 6th Ave South between South Findlay and South Orcas Streets in both the shallow and intermediate zones.	- Should immediately reduce 1,4-dioxane mass in target areas. - Should reduce remedial time frame assuming no secondary source. Alternative 1 scores 3 for protectiveness as a result of the immediate reduction in 1,4-dioxane and because there is no risk to downgradient receptors.	- Permanently destroys 1,4-dioxane. - Minimal wastes created. - mobilization of metals, sulfate, and other contaminants possible but distance of mobilization small. Alternative 1 scores 2 for permanence because it results in the destruction of 1,4-dioxane in areas where there is adequate contact between the oxidant and contaminant, and does not generate excess wastes. Does not get a 3 rating due to fact ISCO likely will not treat low permeability silts.	- Alternative costs $520k. - Alternative has the lowest cost of the three alternatives. Alternative 1 is the least costly of the alternatives and thus scores 3 for cost.
Alternative 1 Score:	--	3	2	3
Alternative 2: In Situ Chemical Oxidation Followed By In Situ Biological Degradation Targeted Approach	Use a combination of ISCO and ISB delivered by push probe to target different areas of the plume. Upon Ecology approval, perform bench scale study for ISCO with groundwater and soil samples collected from area adjacent to CG-127. Also send soil and groundwater samples to The Sentinel Environmental Group for bench scale studies for ISB. Based on bench scale results from ISCO studies, perform treatability study adjacent to CG-122 along the west side of Maynard Street, starting at the northwest corner of Lucile and Maynard Streets in the intermediate zone. Full scale injection of persulfate based on treatability study results by push probe adjacent to CG-127 along the east side of 6th Ave South between South Findlay and South Orcas Streets in both the shallow and intermediate zones, followed approximately six months to one year later by injection of microorganisms and substrate along the upgradient edge of the plume adjacent to CG-122 based on The Sentinel Environmental Group bench scale results. This assumes that bench scale testing indicates ISB should work.	- ISCO should immediately reduce concentrations of 1,4-dioxane in target areas. - Could increase degradation rate of 1,4-dioxane in target areas. - Should reduce remedial time frame assuming no secondary source. - ISB Substrate and microorganisms anticipated to spread to entire plume area over time. - Microorganisms should penetrate low permeability lenses. - Could provide a long-lasting treatment for slow release of 1,4-dioxane from low permeability units if The Sentinel Environmental Group study implies that ISB can be effective for site. Alternative 2 scores 3 for protectiveness as a result of the immediate reduction in 1,4-dioxane and because there is no risk to downgradient receptors.	- Both ISCO and ISB would permanently destroys 1,4-dioxane under conditions similar to those in groundwater on site. - Minimal wastes created. - Some risk of mobilization of metals, sulfate, and other contaminants but mobilization will be only for short distance. Alternative 2 scores 2 for permanence because it results in destruction of 1,4-dioxane in areas where there is adequate contact between the oxidant and contaminant, does not generate excess wastes; ISB effectiveness not proven at this point.	- Alternative costs $770k. - Second lowest cost alternative; 1.5 times higher than Alternative 1. Alternative 2 is the second least costly of the alternatives and thus scores 2 for cost.
Alternative 2 Score:	--	3	2	2
Alternative 3: Groundwater Extraction Targeted Approach	Send soil and groundwater samples to The Sentinel Environmental Group for bench scale studies for ISB. Assumes ISB bench scale results are poor. Use a combination of groundwater extraction for mass removal and a remediation system to treat the extracted groundwater prior to discharge to the sanitary sewer. Six groundwater extraction wells installed adjacent to CG-127. Three wells screened in the intermediate zone from approximately 65 to 75 feet bgs and three wells screened in the shallow zone from approximately 35 to 45 feet bgs. A groundwater remediation system consisting of adsorbers containing AmberSorb® with a steam stripping system and activated carbon used to regenerate the AmberSorb® media would be located in the public right of way on the east side of 6th Avenue South between South Findlay and South Orcas Streets.	- May slowly reduce concentrations of 1,4-dioxane in target areas over two years. - Should reduce remedial time frame assuming no secondary source. Alternative 3 scores 3 for protectiveness as a result of the slow removal of mass of 1,4-dioxane and because there is no risk to downgradient receptors.	- 1,4-Dioxane is extracted from groundwater and adsorbed to media. - Wastes generated in the form of spent activated carbon, 1,4-D concentrate, and treated groundwater. - Pumping will pull from the highest permeability zones, not necessarily the zones with the highest 1,4-D mass. Very little control on targeting the highest 1,4-D zones and still extracting sufficient volumes of water for flushing of low permeability lenses. -Depending on the amount of mass in low permeability zones vs. high permeability zones, once the pumping is turned off 1,4-D concentrations could rebound significantly. Alternative 3 scores 1 for permanence because it has the least targeting of 1,4-D mass and generates wastes that require further disposal/recycling.	- Alternative costs $2.1 million. - Most expensive alternative; four times more expensive than Alternative 1 and 2.7 times more than Alternative 2. Alternative 3 is the most costly of the alternatives and thus scores 1 for cost.
Alternative 3 Score:	--	3	1	1

TABLE 3

1,4-DIOXANE TREATMENT ALTERNATIVES EVALUATION

Stericycle Georgetown Site
Seattle, Washington

Alternative [1]	Long Term Effectiveness	Management of Short Term Risks	Technical and Administrative Implementability	Consideration of Public Concerns	Final Score
Preferred Alternative Alternative 1: In Situ Chemical Oxidation Targeted Approach	- ISCO will destroy any 1,4-dioxane that it comes into direct contact with. - ISCO is unlikely to penetrate deeply into silt and clay layers, so 1,4-dioxane could possibly continue to be released through slow release diffusion/dispersion from the silts. - Persulfate will be scavenged by total organic carbon and inorganic chemicals in soil in groundwater. Alternative 1 scores 1 for long term effectiveness because it results in immediate destruction only.	- Short-term risk to human health during injection (from construction equipment and potential chemical exposure). All workers will wear appropriate PPE. Chemical handling and injection will be performed a safe distance from members of the public, who will be barred from entry into the work zone. - Small risk from daylighting of chemicals during injection, which can be mitigated using engineering controls. - Small risk to underground utilities. All utility companies with nearby buried lines will be consulted prior to injection of chemicals and a utility locate will be performed prior to subsurface disturbance. All alternatives have short term risks associated with their implementation. ISCO requires the injection of potentially hazardous oxidants but can be controlled with PPE and proper spill prevention and control planning. As a result Alternative 1 scores 2 for the management of short term risks.	- Oxidant should remove a significant amount of 1,4-dioxane mass in the areas injected. - The injection locations are on side streets and in the right of way, where significant room is available, thus limiting disturbance to traffic and pedestrians. - Locations where injections could be completed would not cover the entire plume and some residual concentrations would remain in low permeability silt layers. - Minimal permitting required as all work would be completed in the City of Seattle right of way. Alternative 1 has no long term O&M, minimal scheduling requirements, and very straightforward on-site activities, and thus scores 3 for technical and administrative implementability.	- A traffic control plan will be set up to ensure minimal disruption to vehicle and pedestrian traffic. - The injection locations are on side streets and in the right of way, where significant room is available, thus limiting disturbance to traffic and pedestrians. - Surface streets and pavement with residual chemicals will be pressure washed and waste water will be managed appropriately. - Work can be completed during normal business hours and equipment will be muffled if necessary. Alternative 1 involves the injection of a potentially hazardous substance in the public right of way that could result in sulfate migration downgradient and potentially metals migration; impacts to public have low potential and work will be very short term, and thus scores 2 for consideration of public concerns.	
Alternative 1 Score:	1	2	3	2	16
Alternative 2: In Situ Chemical Oxidation Followed By In Situ Biological Degradation Targeted Approach	- ISCO will destroy any 1,4-dioxane that it comes into direct contact with. - ISB effectiveness depends on ability of injected microorganisms to out-compete local organisms. - ISB has shown effectiveness at 1,4-dioxane degradation in bench scale studies through co-metabolic processes. - ISB has the best chance for long-lasting remediation of 1,4-dioxane diffusing/dispersing from less permeable units if site-specific studies prove it is an effective treatment alternative. Alternative 2 scores 1 for long term effectiveness because it may result in immediate destruction only and more likely to reduce the restoration timeframe; however, ISB has not proven effectiveness for 1,4-dioxane.	- Short-term risk to human health during injection (from construction equipment and potential chemical exposure). All workers will wear appropriate PPE. Chemical handling and injection will be performed a safe distance from members of the public, who will be barred from entry into the work zone. - Small risk from daylighting of chemicals during injection, which can be mitigated using engineering controls. - Since use of ISCO is replaced by the likely less dangerous ISB substrates, less risk than ISCO use alone. - Small risk to underground utilities. All utility companies with nearby buried lines will be consulted prior to injection of chemicals and a utility locate will be performed prior to subsurface disturbance. All alternatives have short term risks associated with their implementation. ISCO requires the injection of potentially hazardous oxidants but can be controlled with PPE and proper spill prevention and control planning. As a result Alternative 2 scores 2 for the management of short term risks.	- In order to distribute oxidant, substrate, and microorganisms throughout the targeted plume, a large number of injection points would be required. However, injection points could be located on side streets to minimize traffic impacts. - Locations where injections could be completed would not cover the entire plume and some residual concentrations would remain in impermeable zones. - Precipitation of iron in the ISCO area may make follow-up injections difficult due to increasing injection pressures required. - Minimal permitting required as all work would be completed in the City of Seattle right of way. Alternative 2 has no long term O&M, minimal scheduling requirements (though more than Alternative 1) with follow up ISB injections, and very straight-forward on-site activities, and thus scores 2 for technical and administrative implementability.	- A traffic control plan will be set up to ensure minimal disruption to vehicle and pedestrian traffic. - The injection locations are on side streets and in the right of way, where significant room is available, thus limiting disturbance to traffic and pedestrians. - Surface streets and pavement with residual chemicals will be pressure washed and waste water will be managed appropriately. - Work can be completed during normal business hours and equipment will be muffled if necessary. Alternative 2 involves the injection of a potentially hazardous substance in the public right of way that could result in sulfate migration downgradient and potentially metals migration. In addition, ISB work will increase time in city streets and increase traffic nuisance compared to Alt 1, and thus scores 1 for consideration of public concerns.	
Alternative 2 Score:	1	2	2	1	13
Alternative 3: Groundwater Extraction Targeted Approach	- Groundwater extraction will initially remove high 1,4-dioxane concentration groundwater. - Groundwater extraction will pull from high permeability zones and reduce mass of 1,4-D extracted from the ground after prolonged pumping periods or under high pumping rates. Alternative 3 scores 1 for long term effectiveness because groundwater pumping has not been very successful at removing mass in heterogeneous aquifers that result in preferential pathways even with low pumping rates and many wells.	- Short-term risk to human health during well installation (from construction equipment). All workers will wear appropriate PPE. All construction work will be performed a safe distance from members of the public, who will be barred from entry into the work zone. - Small risk from spills. A spill control plan will be developed and best management practices will be used in the prevention and handling of spills. - Risk to underground utilities. All utility companies with nearby buried lines will be consulted prior to any construction and a utility locate will be performed prior to subsurface disturbance. All alternatives have short term risks associated with their implementation. The installation of new wells and a treatment system requires working with heavy equipment in the public right of way. Risks can be minimized with appropriate health and safety plans and work zone isolation from the public. As a result Alternative 3 scores 2 for the management of short term risks.	- In order to cover the area adjacent to CG-127, 6 wells will need to be installed throughout the targeted area. However, well points could be located on side streets to minimize traffic impacts. - Locations where recovery wells could be completed would not cover the entire plume and some residual concentrations would remain in impermeable zones. - Trenching and piping and conduit installation would be required in the public right of way requiring a traffic control plan. - Remediation system would need to be installed in the public right of way adjacent to CG-127. The remediation system would need to be enclosed and locked, with secondary containment. - much more permitting required than the other alternatives due to sewer discharge requirements, installation of pipe trenching on public streets, and long term need for a treatment system. Alternative 3 has several complexities associated with its implementation due to trenching in the public right of way and installation of a large treatment system and six wells in the public right of way. In addition, Alternative 3 requires O&M for approximately two years. Thus, Alternative 3 scores 1 for technical and administrative implementability.	- A traffic control plan will be set up to ensure minimal disruption to vehicle and pedestrian traffic. - The well locations are on side streets and in the right of way, where significant room is available, thus limiting disturbance to traffic and pedestrians. - Work can be completed during normal business hours and equipment will be muffled if necessary. -Portion of the City ROW will be occupied by a treatment system for over 2 years resulting in traffic/parking nuisance. Alternative 3 requires trenching adjacent to businesses and residential areas and the use of heavy equipment to implement. Alternative 3 does not have any hazardous materials associated with it, but may have hazardous waste from spent media. Thus, Alternative 3 scores 1 for consideration of public concerns.	
Alternative 3 Score:	1	2	1	1	10

Notes:

1. All alternatives assumes all work will take place in the public right of way to reduce cost and time for permitting.
2. A summary of the costs for each alternative are provided in Table 4. Appendix B provides a more thorough breakdown of costs.

Abbreviations:

bgs = below ground surface
Ecology = Washington State Department of Ecology
ISB = in situ bioremediation
ISCO = in situ chemical oxidation
O&M = operation and maintenance
PPE = personal protective equipment

TABLE 4

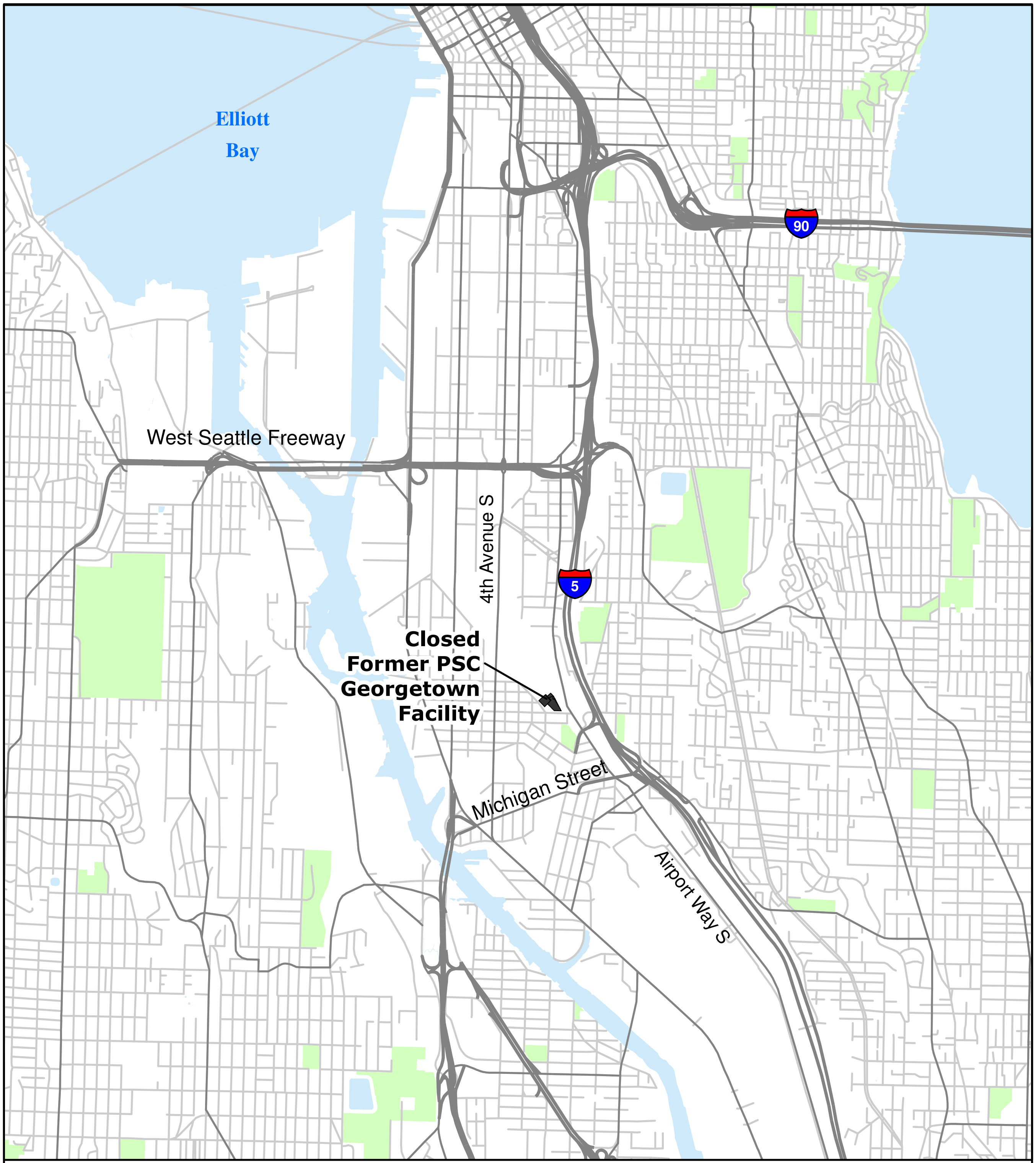
1,4-DIOXANE TREATMENT ALTERNATIVES COST SUMMARY
Stericycle Georgetown Site
Seattle, Washington

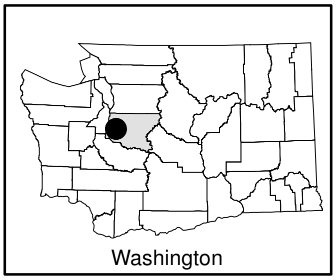
Cost Details	**Preferred Alternative Alternative 1: In Situ Chemical Oxidation Targeted Approach**	**Alternative 2: In Situ Chemical Oxidation Followed By In Situ Biological Degradation Targeted Approach**	**Alternative 3: Groundwater Extraction Targeted Approach**
Reporting/Correspondance[1]	$86,385	$174,355	$94,440
Permitting	$20,790	$41,580	$51,440
Locates	$1,200	$2,400	$3,620
Startup Costs[2]	$108,394	$187,963	$1,164,210
Maintenance/Monitoring[3]	$20,000	$30,000	$196,723
The Sentinel Environmental Group Costs[4]	$200,000	$200,000	$200,000
Total Costs	**$520,000**	**$770,000**	**$2,100,000**

Notes:

1. Includes the development of work plans and correspondence with Washington State Department of Ecology.
2. Startup costs include pilot studies and all rounds of injections for in situ technologies and treatment system installation for Alternative 3.
3. Maintenance and monitoring costs include samples collected after in situ technologies are implemented and maintenance costs to operate treatment system for Alternative 3.
4. The Sentinel Environmental Group costs include study to be performed at the site to evaluate biological degradation, bioenhancement, and bioaugmentation.

FIGURES





SITE LOCATION
Stericycle Georgetown Site
Seattle, Washington

By: APS	Date: 01/14/15	Project No. 8770
		Figure 1

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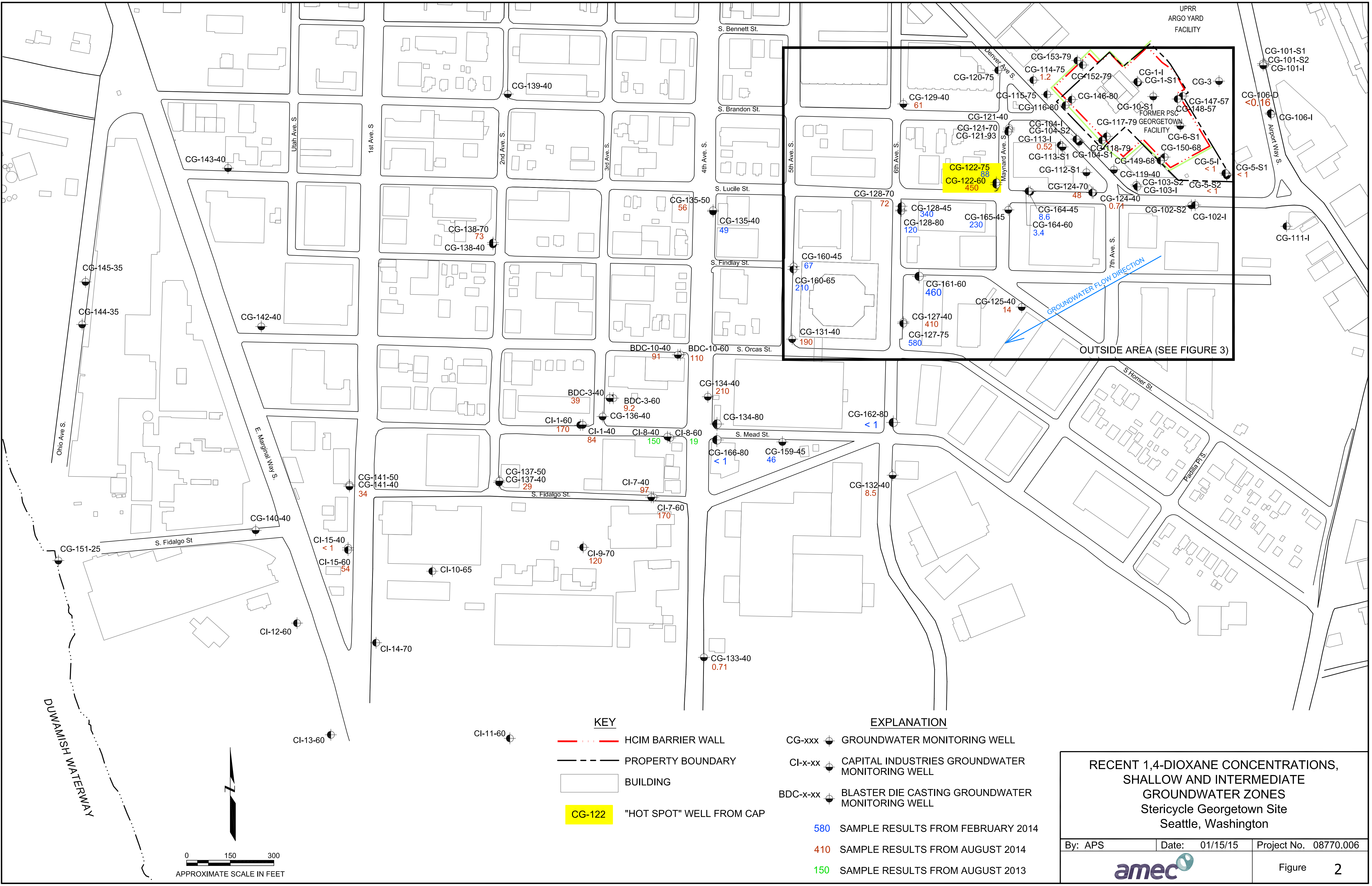

RECENT 1,4-DIOXANE CONCENTRATIONS,
SHALLOW AND INTERMEDIATE
GROUNDWATER ZONES
Stericycle Georgetown Site
Seattle, Washington

By: APS	Date: 01/15/15	Project No. 08770.006
amec		Figure 2

Plot Date: 01/15/15 - 9:40am, Plotted by: adam.stenberg
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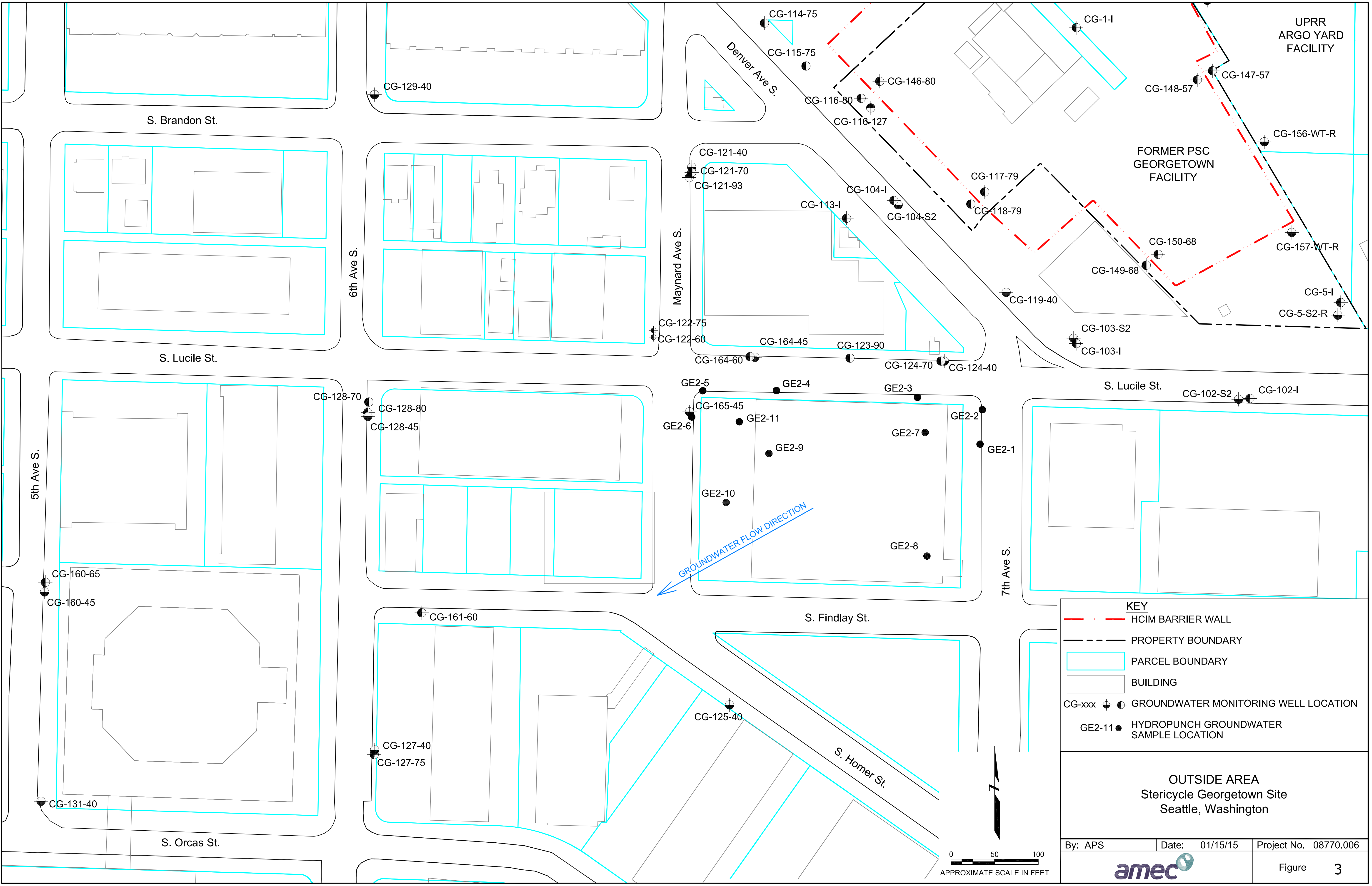

OUTSIDE AREA
Stericycle Georgetown Site
Seattle, Washington

By: APS
Date: 01/15/15
Project No. 08770.006

amec

Figure 3

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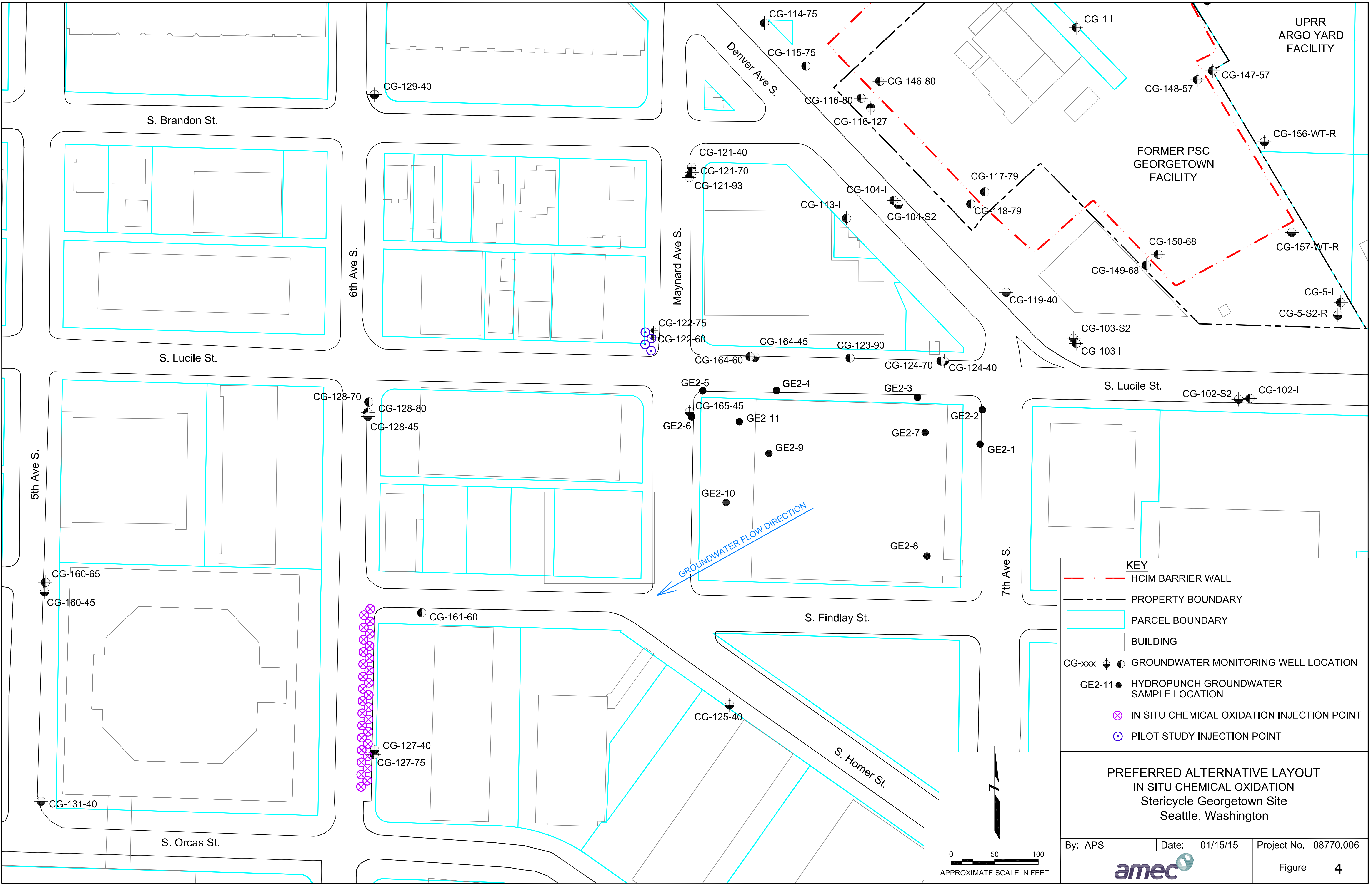

PREFERRED ALTERNATIVE LAYOUT
IN SITU CHEMICAL OXIDATION
Stericycle Georgetown Site
Seattle, Washington

By: APS | Date: 01/15/15 | Project No. 08770.006

amec

Figure 4

Plot Date: 01/15/15 - 9:55am, Plotted by: adam.stenberg
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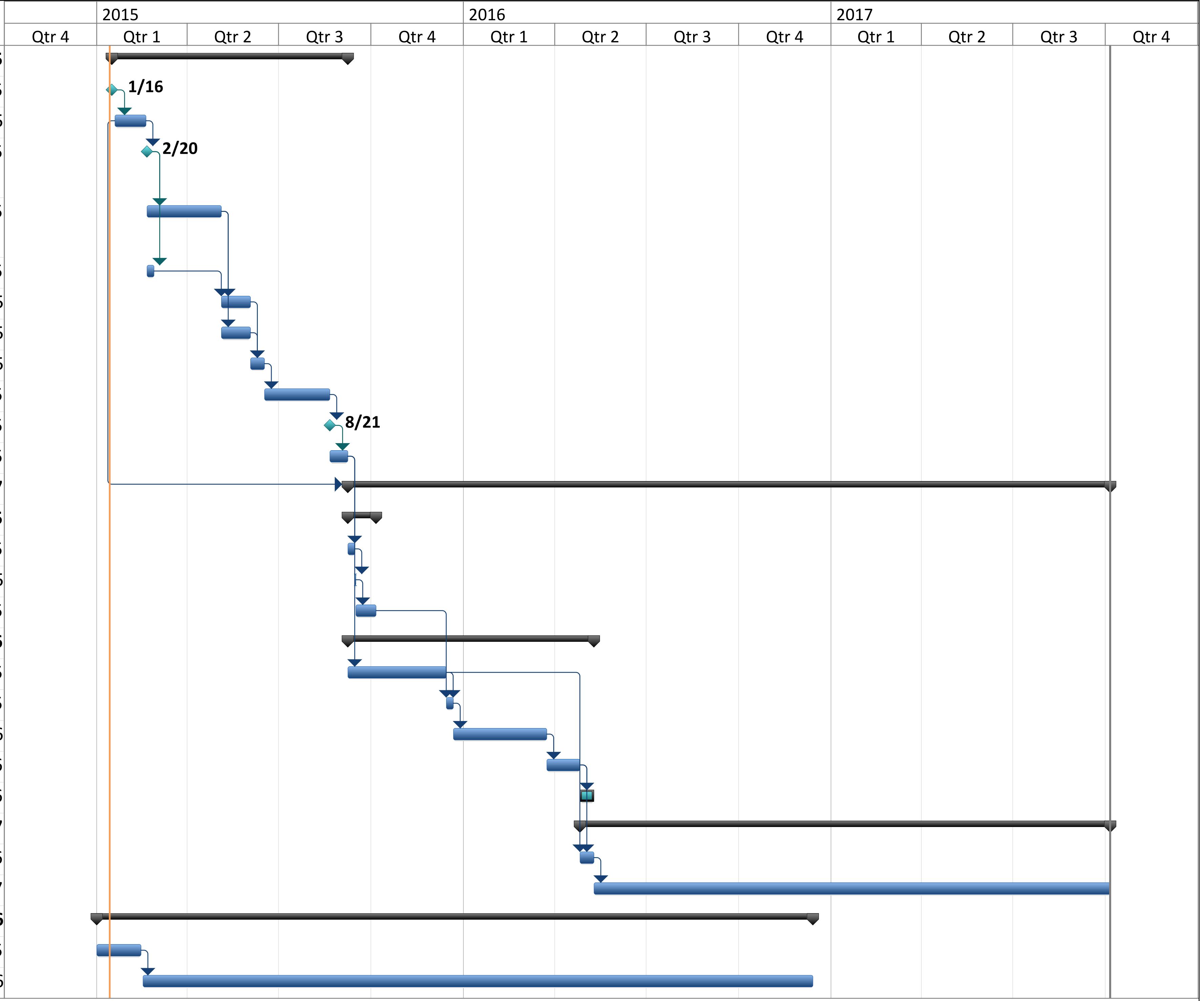
FIGURE 5

1,4-Dioxane Remediation Approach Proposed Schedule

Stericycle Georgetown Site
Seattle, WA

ID	Task Name	Duration	Start	Finish
1	**1,4-Dioxane Remediation Approach**	**167 days**	**Fri 1/16/15**	**Mon 9/7/15**
2	1,4-Dioxane Final Draft of FFS Submitted	0 days	Fri 1/16/15	Fri 1/16/15
3	Ecology Review and Response Period	23 days	Mon 1/19/15	Wed 2/18/15
4	1,4-Dioxane Finalization and Approval of FFS - Preferred Alternative Selection	0 days	Fri 2/20/15	Fri 2/20/15
5	Stericycle and Ecology Develop Draft Cleanup Action Plan Amendment to AO DE7347	52 days	Fri 2/20/15	Mon 5/4/15
6	Preparation of SEPA Checklist	5 days	Fri 2/20/15	Thu 2/26/15
7	EPA Region 10 Reviews Draft Order Ammendment	21 days	Tue 5/5/15	Tue 6/2/15
8	Public Comment and Response Period	21 days	Tue 5/5/15	Tue 6/2/15
9	Ecology Selects Final Cleanup Action and Finalizes Amended AO	10 days	Wed 6/3/15	Tue 6/16/15
10	Stericycle Drafts RD RA Work Plan	47 days	Wed 6/17/15	Thu 8/20/15
11	Stericycle Submits Draft RD and RA Work Plan	0 days	Fri 8/21/15	Fri 8/21/15
12	Ecology Approves Final RD RA Work Plan	12 days	Fri 8/21/15	Mon 9/7/15
13	**Alternative 1 : In Situ Chemical Oxidation Implementation**	**543 days**	**Tue 9/8/15**	**Thu 10/5/17**
14	**Phase I: Bench Scale Studies**	**20 days**	**Tue 9/8/15**	**Mon 10/5/15**
15	Collect Samples for Bench Scale Study	5 days	Tue 9/8/15	Mon 9/14/15
16	Submit Samples to Lab for Testing	1 day	Tue 9/15/15	Tue 9/15/15
17	Sample Analysis and Reporting	14 days	Wed 9/16/15	Mon 10/5/15
18	**Phase II: Treatability Study**	**175 days**	**Tue 9/8/15**	**Mon 5/9/16**
19	Permitting Process with Seattle DOT	70 days	Tue 9/8/15	Mon 12/14/15
20	Treatability Study Injections	5 days	Tue 12/15/15	Mon 12/21/15
21	Treatability Study Monitoring	67 days	Tue 12/22/15	Wed 3/23/16
22	Edit RD RA Work Plan	23 days	Thu 3/24/16	Mon 4/25/16
23	Ecology Approval of Edited RD RA Work Plan	10 days	Tue 4/26/16	Mon 5/9/16
24	**Phase III: Full Scale ISCO Injection**	**378 days**	**Tue 4/26/16**	**Thu 10/5/17**
25	In Situ Chemical Oxidation Injections	10 days	Tue 4/26/16	Mon 5/9/16
26	Additional 1,4-Dioxane Monitoring	368 days	Tue 5/10/16	Thu 10/5/17
27	**In Situ Bioremediation Evaluation**	**509 days**	**Thu 1/1/15**	**Tue 12/13/16**
28	First Sample Collection for Rice University Study	32 days	Thu 1/1/15	Fri 2/13/15
29	The Sentinal Environmental Group 1,4-Dioxane Study	477 days	Mon 2/16/15	Tue 12/13/16



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

Estimate of 1,4-Dioxane Mass in Outside Area Plume

APPENDIX A
ESTIMATE OF 1,4-DIOXANE MASS IN OUTSIDE AREA PLUME

This appendix provides an analysis of the estimated mass of 1,4-dioxane within the groundwater plume downgradient of the former Philip Services Corporation (PSC) Georgetown facility. The analysis of 1,4-dioxane mass in the plume was conducted in order to evaluate the feasibility of implementing a remedy for 1,4-dioxane in the Outside Area (the area downgradient of the former PSC Georgetown facility outside the barrier wall and east of 4th Ave South), as required per the contingent remedy outlined in Agreed Order #DE 7347 and the Final Cleanup Action Plan (Ecology, 2010).

Ecology has determined that the risk to downgradient receptors from the 1,4-dioxane plume is low; therefore, the goal for additional 1,4-dioxane cleanup is to reduce total 1,4-dioxane mass. Because the groundwater in the vicinity of the former PSC Georgetown facility is not currently used as drinking water, the nearest receptor for the contaminated groundwater is the Duwamish Waterway, which is more than 1,500 feet downgradient. Since mass removal of 1,4-dioxane is the primary goal for this focused feasibility study, the analysis of the mass distribution of 1,4-dioxane will be used to determine the areas of the plume that contain the highest amount of mass of 1,4-dioxane and thus should be addressed as part of the contingent remedy.

In order to estimate the mass of 1,4-dioxane distributed throughout the Outside Area, the Thiessen Polygon method was used to calculate contributing areas for each monitoring point in the shallow groundwater zone (30–50 feet below ground surface [bgs]) and the intermediate groundwater zone (50–80 feet bgs). The use of Thiessen Polygons has been used historically to estimate the mass of contaminants in the subsurface for petroleum cleanup sites (Wisconsin Department of Natural Resources, 2014). Figures A1 and A2 show the Thiessen polygons (which represent the contributing areas for each monitoring location) and sampling results for the Outside Area monitoring locations in the shallow and intermediate zone groundwater, respectively.

The average concentrations, as calculated from 1,4-dioxane concentrations from 2010 through the third quarter of 2014, were used to calculate the mass of 1,4-dioxane contained within each Thiessen Polygon by assuming a 10-foot contaminated thickness (well screen length) and an assumed effective porosity of 30 percent. Given that 1,4-dioxane is miscible in water, the mass will primarily be dissolved within the groundwater observed in each well. Table A1 summarizes the mass calculated for each area that corresponds to a sample location as well as the mass density of 1,4-dioxane in each area, defined as the mass of 1,4-dioxane per square foot of surface area. The mass density can then be used to directly compare areas to determine which areas have the highest mass density. Treatment of the areas with the highest mass density would be most effective at reducing total mass within the aquifer and also would be most cost effective.

As shown in Table A1, the area with the highest mass density is the area located adjacent to well CG-127, with a mass density of 99 milligrams per square foot (mg/ft^2) of 1,4-dioxane. The next closest mass density corresponds to CG-122 but is only 65 mg/ft^2, 66 percent of that for CG-127. The next largest mass density is located adjacent to CG-128, which is 49.5 mg/ft^2 or 50 percent of the mass density adjacent to CG-127. All other areas have a mass density that is 37 percent of CG-127 or less.

REFERENCES

Washington State Department of Ecology (Ecology), 2010, Final Cleanup Action Plan, PSC Georgetown Facility, Seattle, Washington, April 28.

Wisconsin Department of Natural Resources, 2014, Guidance on Natural Attenuation for Petroleum Releases, RR-614, January.

TABLE A1

1,4-DIOXANE MASS ESTIMATES

Stericycle Georgetown Site
Seattle, Washington

	Shallow					Intermediate					
Sample ID	Well Depth[1] (feet)	Avgerage Result[2] (µg/L)	Contributing Area[3] (ft^2)	Mass (pounds)	Mass Density[4] (mg/ft^2)	Well Depth[1] (feet)	Avgerage Result[2] (µg/L)	Contributing Area[3] (ft^2)	Mass (pounds)	Mass Density[4] (mg/ft^2)	Total Mass Density (mg/ft^2)
BDC-3	40	41.7	278,132	2.2	3.5	60	11.7	101,359	0.2	1.0	4.5
BDC-10	40	123.7	148,495	3.4	10.5	60	130.0	223,293	5.4	11.0	21.5
CG-113	--	--	--	--	--	75	1.8	93,965	0.0	0.2	0.2
CG-114	--	--	--	--	--	75	1.0	227,441	0.0	0.1	0.1
CG-122	**--**	--	--	--	--	60	654.1	104,502	12.8	55.5	**65.0**
						75	111.5		2.2	9.5	
CG-124	40	0.7	271,046	0.0	0.1	70	41.0	372,174	2.9	3.5	3.5
CG-125	40	22.3	807,091	3.4	1.9	--	--	--	--	--	1.9
CG-127	40	434.3	179,796	14.6	36.9	75	732.0	182,420	25.0	62.1	**99.0**
CG-128	45	386.0	157,435	11.4	32.8	70	60.3	332,639	3.8	5.1	49.5
						80	137.1		8.5	11.6	
CG-129	40	56.3	281,769	3.0	4.8	--	--	--	--	--	4.8
CG-131	40	224.3	116,195	4.9	19.0	--	--	--	--	--	19.0
CG-132	40	8.9	1,185,752	2.0	0.8	--	--	--	--	--	0.8
CG-133	40	0.6	541,351	0.1	0.1	--	--	--	--	--	0.1
CG-134	40	180.0	62,120	2.1	15.3	--	--	--	--	--	15.3
CG-135	40	97	928,596	16.9	8.3	--	--	--	--	--	13.9
	50	67		11.6	5.7						
CG-137	40	29.8	409,642	2.3	2.5	--	--	--	--	--	2.5
CG-138	--	--	--	--	--	70	77.5	1,405,898	20.4	6.6	6.6
CG-141	40	34.0	768,339	4.9	2.9	--	--	--	--	--	2.9
CG-159	45	52.4	189,131	1.9	4.4	--	--	--	--	--	4.4
CG-160	45	84.6	134,620	2.1	7.2	65	250.0	493,033	23.1	21.2	28.4
CG-161	--	--	--	--	--	60	436.0	126,223	10.3	37.0	37.0
CG-162	--	--	--	--	--	80	0.1	987,523	0.0	0.0	0.0
CG-164	45	11.9	126,049	0.3	1.0	60	5.5	89,583	0.1	0.5	1.5
CG-165	45	276.0	87,920	4.5	23.4	--	--	--	--	--	23.4
CG-166	--	--	--	--	--	80	0.4	226,008	0.0	0.0	0.0
CI-1	40	81.7	184,589	2.8	6.9	60	155.0	245,726	7.1	13.2	20.1
CI-7	40	105.7	221,051	4.4	9.0	60	160.0	179,106	5.4	13.6	22.6
CI-8	40	185.0	62,312	2.2	15.7	60	23.0	49,108	0.2	2.0	17.7
CI-9	--	--	--	--	--	70	104.5	216,679	4.2	8.9	8.9
CI-15	40	0.1	476,725	0.0	0.0	60	53.0	530,864	5.3	4.5	4.5
Total Mass:				100.8					136.9		

Notes:

1. Well depth is the depth to the bottom of the well screen below ground surface.
2. Average results taken from 2010 up through third quarter 2014.
3. Contributing area calculated from Thiessen Polygons.
4. Mass density is the average mass of dioxane per square foot in the contributing area for each monitoring point.

Bolded values indicate wells with highest mass denisty of 1,4-dioxane.

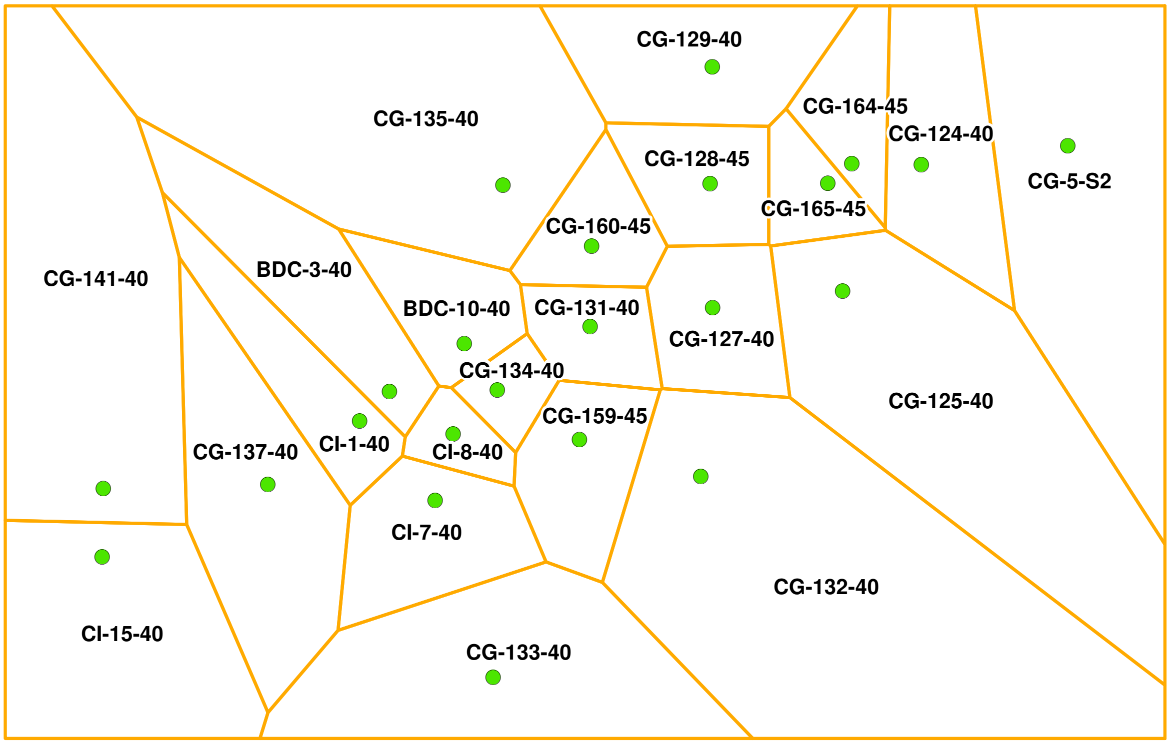
Assumptions:

The effecitve porosity for the contaminant zone is: 30% .

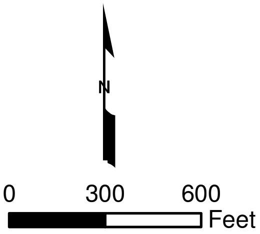
Thickness in feet of contaminant zones for shallow and intermediate aquifers is: 10

Abbreviations:

µg/L = micrograms per liter
ft^2 = square feet
mg/ft^2 = milligrams per square foot



Sample ID	Result (µg/L)[1]	Area (sq ft)
BDC-3-40	41.7	278,132
BDC-10-40	123.7	148,495
CG-124-40	0.7	271,046
CG-125-40	22.3	807,091
CG-127-40	434.3	179,796
CG-128-45	386.0	157,435
CG-129-40	56.3	281,769
CG-131-40	224.3	116,195
CG-132-40	8.9	1,185,752
CG-133-40	0.6	541,351
CG-134-40	180.0	62,120
CG-135-40	97	928,596
CG-135-50	67	928,596
CG-137-40	29.8	409,642
CG-141-40	34.0	768,339
CG-159-45	52.4	189,131
CG-160-45	84.6	134,620
CG-164-45	11.9	126,049
CG-165-45	276.0	87,920
CI-1-40	81.7	184,589
CI-7-40	105.7	221,051
CI-8-40	185.0	62,312
CI-15-40	0.1	476,725



Legend

● Shallow Zone Sample Well

☐ Shallow Zone Thiessen Polygon

[1] Results are average concentrations measured from first quarter 2010 through third quarter 2014.

THIESSEN POLYGONS AND SAMPLING RESULTS
FOR SHALLOW ZONE 1,4-DIOXANE
MONITORING WELLS
Stericycle Georgetown Site
Seattle, Washington

By: PM	Date: 12/17/14	Project No. 8770
amec		Figure A1

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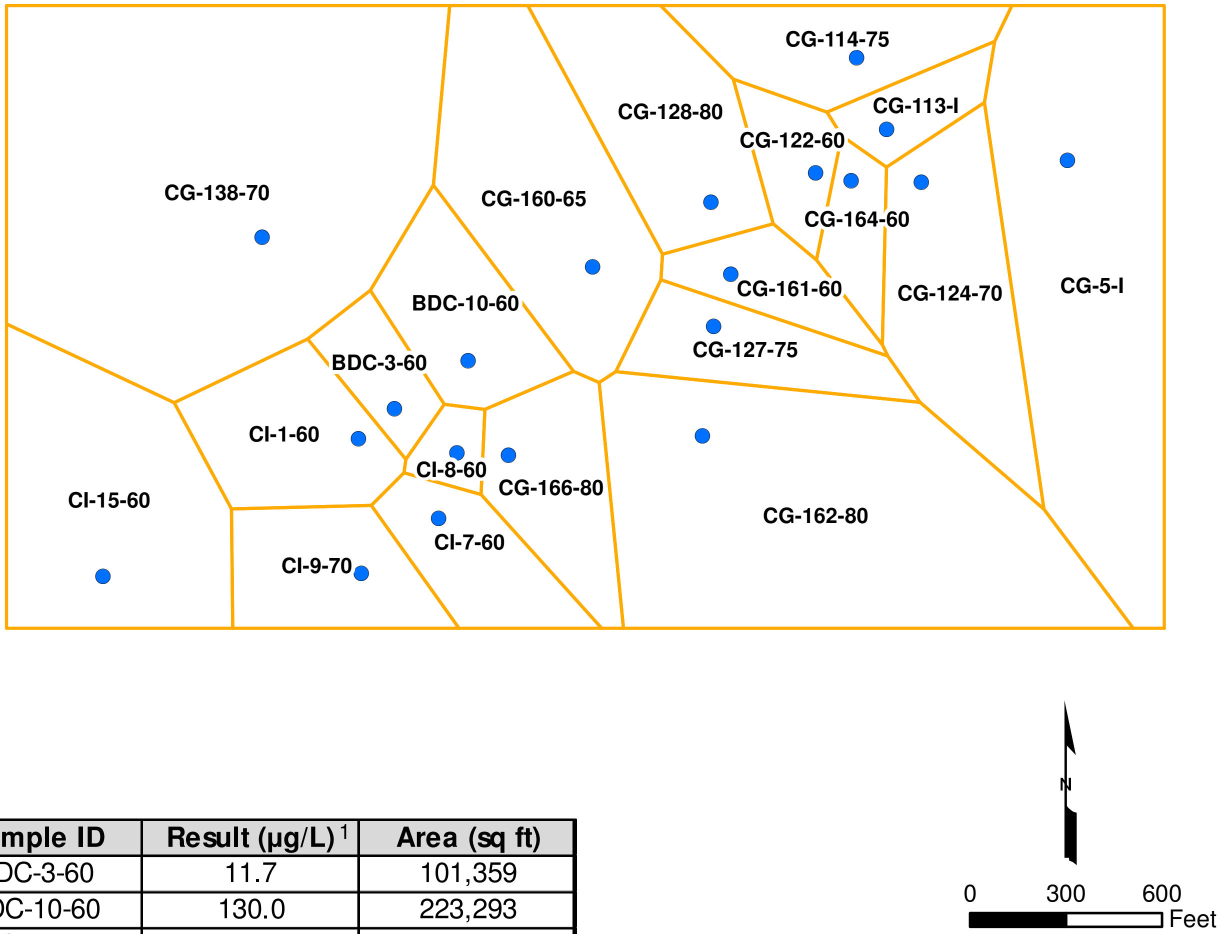

Sample ID	Result (µg/L)[1]	Area (sq ft)
BDC-3-60	11.7	101,359
BDC-10-60	130.0	223,293
CG-113-I	1.8	93,965
CG-114-75	1.0	227,441
CG-122-60	654.1	104,502
CG-122-75	111.5	104,502
CG-124-70	41.0	372,174
CG-127-75	732.0	182,420
CG-128-70	60.3	332,639
CG-128-80	137.1	332,639
CG-138-70	77.5	1,405,898
CG-160-65	250.0	493,033
CG-161-60	436.0	126,223
CG-162-80	0.1	987,523
CG-164-60	5.5	89,583
CG-166-80	0.4	226,008
CI-1-60	155.0	245,726
CI-7-60	160.0	179,106
CI-8-60	23.0	49,108
CI-9-70	104.5	216,679
CI-15-60	53.0	530,864

Legend

● Intermediate Zone Sample Well

▭ Intermediate Zone Thiessen Polygon

[1] Results are average concentrations measured from first quarter 2010 through third quarter 2014.

THIESSEN POLYGONS AND SAMPLING RESULTS
FOR INTERMEDIATE ZONE 1,4-DIOXANE
MONITORING WELLS
Stericycle Georgetown Site
Seattle, Washington

By: PM	Date: 12/17/14	Project No. 8770
amec		Figure A2

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APPENDIX B

Alternatives Cost Analysis

TABLE B1

ALTERNATIVE 1 ISCO COSTS

Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum 1	AMEC Engineer II Hours at $90	AMEC Sr Engineer Hours at $155	CAD Drafter Hours at $90	Admin Staff Hours at $65	Total Cost per Subtask
Reports											
	Bench Scale WP:						40	5		1	$4,440
	Treatability Study WP:						60	10	4	1	$7,375
	Final Injection SOP:						120	80	6	1	$23,805
	Health and Safety Plan:						32	8	2	1	$4,365
	Completion Report						120	80			$23,200
	Correspondence with Ecology:						120	80			$23,200
Total Reports Cost:											**$86,385**
Permitting											
	SDOT Major Utility Permit:										
		Utility Major Transmittal Form				$2,500	16	1			$4,095
		Permit Application					16	1			$1,595
		Pavement Restoration Plan Checklist					16	1			$1,595
		Plans					16	2	8		$2,470
		Profile									$0
		Restoration Plan					16	1	2		$1,775
		Traffic Control Plan					40	20	2	1	$6,945
		Total Cost:									**$18,475**
	Well Start Permit[1]										
	Underground Injection Permit						24	1	0	0	$2,315
Total Permitting Cost											**$20,790**
Locates											
	Public						2				$180
	Private					$300	8				$1,020
Total Locates Cost											**$1,200**
Phase I: ISCO Bench Scale Study											
	Lab Study					$3,000					$3,000
	Results Analysis/Communication						16	2			$1,750
	Final Reporting						24	8			$3,400
	Sample Collection										
		AMEC Oversight					14	2			$1,570
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
	Total Bench Scale Cost:										**$12,220**
Phase II: ISCO Treatability Study											
	AMEC Oversight[2]						34	5			$3,835
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
		Utility Truck[3]	per day	$450	1						$450
		WA Start Cards[4]	each point	$65	4						$260
		WA Decommission Cards[4]	each point	$35	4						$140
	PersulfOx+Regenesis[4,5]					$8,000					$8,000
	Forklift		per day	$650	1						$650
	GPS Survey Equipment					$2,000					$2,000
	Monitoring (Monthly Sampling)					$5,000					$5,000
	Total Treatability Study Cost										**$22,835**

TABLE B1

ALTERNATIVE 1 ISCO COSTS
Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II Hours at	AMEC Sr Engineer Hours at	CAD Drafter Hours at	Admin Staff Hours at	Total Cost per Subtask
						1	**$90**	**$155**	**$90**	**$65**	
Phase III: ISCO Injections											
	AMEC Oversight[2]						84	10			$9,110
	Push Probes										
		Probe Rig[3, 5]	per day	$2,500	6						$15,000
		Utility Truck[3]	per day	$450	6						$2,700
		WA Start Cards[5]	each point	$65	30						$1,950
		WA Decommission Cards[5]	each point	$35	30						$1,050
	PersulfOx+Regenesis[5,6]					$32,000					$32,000
	Water Truck[7]		per month	$4,029	1						$4,029
	Forklift		per month	$2,000	1						$2,000
	GPS Survey Equipment					$2,000					$2,000
	Waste Disposal and Profiling					$3,500					$3,500
	Total ISCO Injection Cost										**$73,339**
Total ISCO Cost:											**$108,394**
Monitoring (Quarterly and Semi-annual for First 2 Years)											**$20,000**
Evaluation of Enhanced Biodegradation/Bioaugmentation											
	Sentinel Environmental Group Lab Study Cost					$110,000					$110,000
	AMEC Oversight						140	80			$25,000
	Sample Collection										
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
		Waste Profiling/Disposal				$3,000					$3,000
	Results Analysis/Communication						40	20			$6,700
	Pilot Study Costs										
		Substrate Costs				$5,000					$5,000
		Permitting Costs				$5,000					$5,000
		AMEC Field Costs					80	20			$10,300
	Final Reporting						80	20			$10,300
	Results Analysis/Communication						40	120			$22,200
	Total Sentinel Environmental Group Study Cost:										**$200,000**
Total Cost											**$436,769**
Contingency (10%)											$43,677
Tax											$41,493
Total Cost											**$520,000**

Notes:
1. WA Start Cards costs included in Cascade Drilling Cost Proposal.
2. Assumes ISCO injections will take approximately one day for the pilot study and an additional 20 hours of preparation. To complete all injections will require six days at fourteen hours per day.
3. Assumes one push probe rig completing four injections per day. And assumes only one utility truck is required for the probe rig.
4. Four total injection points for ISCO treatability study.
5. Regenesis costs includes chemicals and equipment for injections.
6. Thirty total ISCO injection points.
7. Water truck rental cost assumes a 2,000 gallon capacity truck.
8. The Sentinel Environmental Group study will be performed independent of alternative selected to evaluate biodegradation, enhanced biodegradation, and bioaugmentation.

Abbreviations:
Ecology = Washington State Department of Ecology
ISB = in situ bioremediation
ISCO = in situ chemical oxidation
SDOT = Seattle Department of Transportation
SOP = standard operating procedure

TABLE B2

ALTERNATIVE 2 ISCO + ISB COSTS

Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum 1	AMEC Engineer II hours at $90	AMEC Sr Engineer hours at $155	CAD Drafter hours at $90	Admin Staff hours at $65	Total Cost per Subtask
Phase I											
Reports											
	Bench Scale WP:						40	5		1	$4,440
	Treatability Study WP:						60	10	4	1	$7,375
	Final Injection SOP:						120	80	6	1	$23,805
	Health and Safety Plan:						32	8	2	1	$4,365
	Completion Report						120	80			$23,200
	Correspondence with Ecology:						120	80			$23,200
Total Reports Cost:											**$86,385**
Permitting											
	SDOT Major Utility Permit:										
		Utility Major Transmittal Form				$2,500	16	1	0	0	$4,095
		Permit Application					16	1	0	0	$1,595
		Pavement Restoration Plan Checklist					16	1	0	0	$1,595
		Plans					16	2	8	0	$2,470
		Profile					0	0	0	0	$0
		Restoration Plan					16	1	2	0	$1,775
		Traffic Control Plan					40	20	2	1	$6,945
		Total Cost:									**$18,475**
	Well Start Permit[1]										
	Underground Injection Permit						24	1	0	0	$2,315
Total Permitting Cost											**$20,790**
Locates											
	Public						2				$180
	Private					$300	8				$1,020
Total Locates Cost											**$1,200**
ISCO Bench Scale Study											
	Lab Study					$3,000					$3,000
	Results Analysis/Communication						16	2			$1,750
	Final Reporting						24	8			$3,400
	Sample Collection										
		AMEC Oversight					14	2			$1,570
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
	Total Bench Scale Cost:										**$12,220**

TABLE B2

ALTERNATIVE 2 ISCO + ISB COSTS
Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II hours at	AMEC Sr Engineer hours at	CAD Drafter hours at	Admin Staff hours at	Total Cost per Subtask
						1	$90	$155	$90	$65	
ISCO Treatability Study											
	AMEC Oversight[2]						34	5			$3,835
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
		Utility Truck[3]	per day	$450	1						$450
		WA Start Cards[4]	each point	$65	4						$260
		WA Decommission Cards[4]	each point	$35	4						$140
	PersulfOx+Regenesis[4,5]					$8,000					$8,000
	Forklift		per day	$650	1						$650
	GPS Survey Equipment					$2,000					$2,000
	Monitoring (Monthly Sampling)					$5,000					$5,000
	Total Treatability Study Cost										**$22,835**
ISCO Injections											
	AMEC Oversight[2]						84	10			$9,110
	Push Probes										
		Probe Rig[3, 6]	per day	$2,500	6						$15,000
		Utility Truck[3]	per day	$450	6						$2,700
		WA Start Cards[6]	each point	$65	30						$1,950
		WA Decommission Cards[6]	each point	$35	30						$1,050
	PersulfOx+Regenesis[5,6]					$32,000					$32,000
	Water Truck[6]		per month	$4,029	1						$4,029
	Forklift		per month	$2,000	1						$2,000
	GPS Survey Equipment					$2,000					$2,000
	Waste Disposal and Profiling					$3,500					$3,500
	Total ISCO Injection Cost										**$73,339**
Monitoring (Quarterly and Semi-annual up to ISB Implementation)											**$20,000**
Total ISCO Cost:											**$128,394**
Total Phase I Cost											**$236,769**

TABLE B2

ALTERNATIVE 2 ISCO + ISB COSTS

Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II hours at	AMEC Sr Engineer hours at	CAD Drafter hours at	Admin Staff hours at	Total Cost per Subtask
						1	$90	$155	$90	$65	
Phase II											
Reports											
	Final Injection SOP:						120	80	6	1	$23,805
	Review Sentinel Environmental Group Report:						32	8	2	1	$4,365
	Completion Report						120	80			$23,200
	Completion Report						80	40			$13,400
	Correspondences with Ecology:						120	80			$23,200
Total Reports Cost:											**$87,970**
Permitting											
	SDOT Major Utility Permit:										
		Utility Major Transmittal Form				$2,500	16	1			$4,095
		Permit Application					16	1			$1,595
		Pavement Restoration Plan Checklist					16	1			$1,595
		Plans					16	2	8		$2,470
		Profile									$0
		Restoration Plan					16	1	2		$1,775
		Traffic Control Plan					40	20	2	1	$6,945
		Total Cost:									**$18,475**
	Underground Injection Permit						24	1			$2,315
Total Permitting Cost											**$20,790**
Locates											
	Public					$0	2				$180
	Private					$300	8				$1,020
Total Locates Cost											**$1,200**
ISB Injections											
	AMEC Oversight[9]						126	10			$12,890
	Substrate/Bioaugmentation					$25,000					$25,000
	Push Probes										
		Probe Rig[9,10]	per day	$2,500	9						$22,500
		Utility Truck[9]	per day	$450	9						$4,050
		WA Start Cards[11]	each	$65	36						$2,340
		WA Decommission Cards[11]	each	$35	36						$1,260
	Water Truck/Fire Hydrant[8]					$4,029					$4,029
	GPS Survey Equipment					$2,000					$2,000
	Forklift		per month	$2,000	1						$2,000
	Waste Disposal and Profiling					$3,500					$3,500
Total Injection Cost											**$79,569**
Monitoring (Semi-annual)											**$10,000**
Total Phase II Cost											**$199,529**

TABLE B2

ALTERNATIVE 2 ISCO + ISB COSTS
Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II hours at	AMEC Sr Engineer hours at	CAD Drafter hours at	Admin Staff hours at	Total Cost per Subtask
						1	$90	$155	$90	$65	
Evaluation of Enhanced Biodegradation/Bioaugmentation											
	Sentinel Environmental Group Lab Study Cost					$110,000					$110,000
	AMEC Oversight						140	80			$25,000
	Sample Collection										
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
		Waste Profiling/Disposal				$3,000					$3,000
	Results Analysis/Communication						40	20			$6,700
	Pilot Study Costs										
		Substrate Costs				$5,000					$5,000
		Permitting Costs				$5,000					$5,000
		AMEC Field Costs					80	20			$10,300
	Final Reporting						80	20			$10,300
	Results Analysis/Communication						40	120			$22,200
	Total Sentinel Environmental Group Study Cost:										**$200,000**
Total Cost											**$636,298**
Contingency (10%)											$63,630
Tax											$60,448
Total Cost											**$770,000**

Notes:
1. WA Start Cards costs included in Cascade Drilling Cost Proposal.
2. Assumes ISCO injections will take approximately one day for the pilot study and an additional 20 hours of preparation. To complete all injections will require six days at fourteen hours per day.
3. Assumes one push probe rig completing four injections per day. And assumes only one utility truck is required for the probe rig.
4. Four total injection points for ISCO treatability study.
5. Regenesis costs includes chemicals and equipment for injections.
6. Thirty total ISCO injection points.
7. Regenesis costs includes chemicals and equipment for injections.
8. Water truck rental cost assumes a 2,000 gallon capacity truck.
9. Assumes ISB injections will take approximately nine days for all injections at approximately fourteen hours per day
10. Assumes one push probe rig completing four injections per day per rig. Assumes one utility truck is required for a push probe rig.
11. Thirty-six total ISB injection points.
12. The Sentinel Environmental Group study will be performed independent of alternative selected to evaluate biodegradation, enhanced biodegradation, and bioaugmentation.

Abbreviations:
Ecology = Washington State Department of Ecology
ISB = in situ bioremediation
ISCO = in situ chemical oxidation
SDOT = Seattle Department of Transportation
SOP = standard operating procedure
WP = Work Plan

TABLE B3

ALTERNATIVE 3 GROUNDWATER EXTRACTION AND TREATMENT COSTS
Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II	AMEC Senior Engineer	CAD	Admin	Total Cost per Subtask
				$/unit		1	$90	$155	$90	$65	
Groundwater Extraction Capital Costs											
Reports											
	Final SOP:						160	80	6	1	$27,405
	Health and Safety Plan:						32	8	2	1	$4,365
	King County Monthly and Annual Reporting[1]:						110	34	5	10	$16,270
	Completion Report						120	80			$23,200
	Correspondence with Ecology:						120	80			$23,200
Total Reports Cost:											**$94,440**
Permitting											
	SDOT Major Utility Permit:										
		Utility Major Transmittal Form				$2,500	40	10			$7,650
		Permit Application					80	20			$10,300
		Pavement Restoration Plan Checklist					16	1			$1,595
		Plans					16	2	8		$2,470
		Profile									$0
		Restoration Plan					16	1	2		$1,775
		Traffic Control Plan					80	20	2	1	$10,545
		Total Cost:									**$34,335**
	Side Sewer Permit										
		Side Sewer Connection				$5,000					$5,000
		Permit Application					10	5		2	$1,805
		Plans					10	2	10		$2,110
		Total Cost:									**$8,915**
	King County Discharge Permit:						20	5		2	$2,705
		Permit Application					10	2	10		$2,110
		Plans					10	5	2	2	$1,985
		Spill Control Plans					10	2	2		$1,390
		Total Cost:									**$8,190**
Total Permitting Cost											**$51,440**
Locates											
	Public					$0	2				$180
	Private					$2,000	16				$3,440
Total Locates Cost											**$3,620**
P&T System Installation											
	AMEC Oversight[2]						84	10			$9,110
	Mob/Demob[3]		each		2	$10,000					$20,000
	Conduit and Piping[3]		LS		1	$45,000					$45,000
	Phone and Electric[4]		month	$200	18						$3,600
	ECT$_2$ Remediation System[5]		LS		1	$1,000,000					$1,000,000
	Treatment System Storage Fee[5]		$/sq ft/year	$10	600						$6,000
	Water Storage Tank		LS			$5,000					$5,000
	Well Installation[2]										
		6" Well 75' Deep	each	$11,000	3						$33,000
		6" Well 40' Deep	each	$9,000	3						$27,000
	Waste Disposal					$3,500					$3,500
	Survey Well Monuments					$2,000					$2,000
	Well Abandonment and Restoration		LS			$5,000					$5,000
	System Decommissioning		LS			$5,000					$5,000
Total GW Extraction Capital Cost											**$1,164,210**

TABLE B3

ALTERNATIVE 3 GROUNDWATER EXTRACTION AND TREATMENT COSTS

Stericycle Georgetown Site
Seattle, Washington

Phase/ Task	Subtasks	Line Items	Unit	Unit Cost	# of Units	Contractor/Agency Lump Sum	AMEC Engineer II	AMEC Senior Engineer	CAD	Admin	Total Cost per Subtask
				$/unit		1	$90	$155	$90	$65	
Pump and Treat System Maintenance											
	AMEC O&M[6]										
		Monthly Site Visits					576				$51,840
	Water Disposal[7]		gallon	$0.00396	3.2E+07						$124,883
	Carbon Changeouts		LS	$10,000	1						$10,000
	Groundwater Treatment Sampling (Quarterly for Permit)		LS	$10,000	1						$10,000
Total O&M Cost											**$196,723**
Evaluation of Enhanced Biodegradation/Bioaugmentation											
	Sentinel Environmental Group Lab Study Cost					$110,000					$110,000
	AMEC Oversight						140	80			$25,000
	Sample Collection										
		Probe Rig[3, 4]	per day	$2,500	1						$2,500
		Waste Profiling/Disposal				$3,000					$3,000
	Results Analysis/Communication						40	20			$6,700
	Pilot Study Costs										
		Substrate Costs				$5,000					$5,000
		Permitting Costs				$5,000					$5,000
		AMEC Field Costs					80	20			$10,300
	Final Reporting						80	20			$10,300
	Results Analysis/Communication						40	120			$22,200
	Total Sentinel Environmental Group Study Cost:										**$200,000**
Total Cost											**$1,710,433**
Contingency (10%)											$171,043
Tax											$162,491
Total Cost											**$2,100,000**

Notes:

1. Assume King County monthly and quarterly reporting will require five hours per month for a junior engineer and two hours per month for a senior engineer. Annual discharge reporting will require fifty hours for a junior engineer and ten hours for a senior engineer.
2. Assumes installation of wells will take six days for all wells at approximately fourteen hours per day.
3. Based on engineering judgment. Conduit and piping include pulling power to remediation system.
4. Phone line for autodialer.
5. Approximate cost provided by ECT$_2$ vendor for conceptual level design. Cost includes conex box and fire suppression system for remediation system. Remediation system has a footprint of 400 square feet.
6. Assume system will run for one and a half years with thirty-two hours a month of maintenance required.
7. Treatment system will treat forty gallons per minute and the sewer discharge cost per gallon is $0.00396
8. The Sentinel Environmental Group study will be performed independent of alternative selected to evaluate biodegradation, enhanced biodegradation, and bioaugmentation.

Abbreviations:

Ecology = Washington State Department of Ecology
LS = lump sum
O&M = operation and maintenance
SDOT = Seattle Department of Transportation
SOP = standard operating procedure
sq ft = square feet