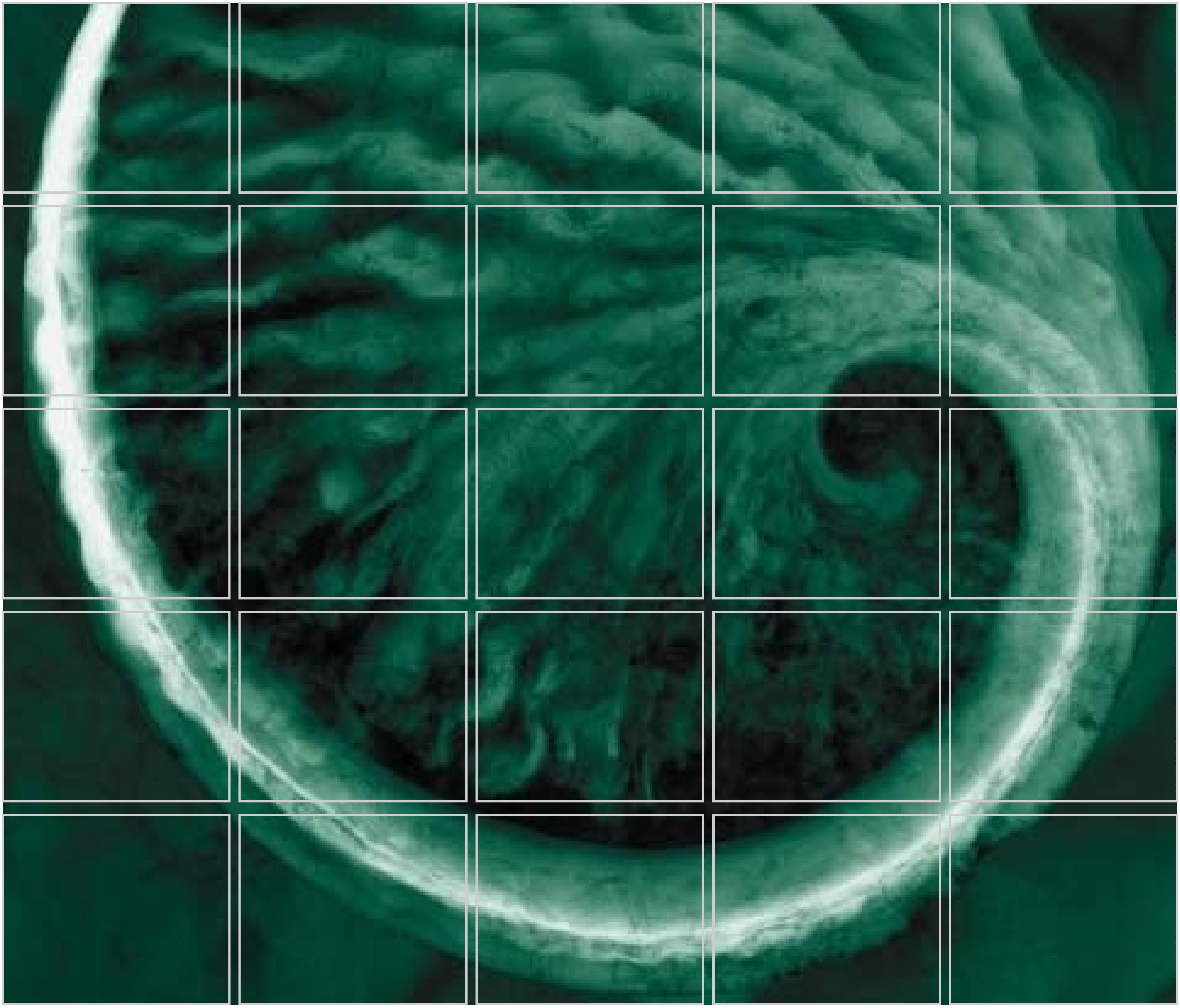

In-Situ Persulfate Oxidation Interim Remedial Measure Work Plan

Arkema, Inc. Facility
Portland, Oregon

7 July 2005

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Arkema, Inc.

In-Situ Persulfate Oxidation Interim Remedial Measure Work Plan

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Portland, Oregon

7 July 2005

Project No. 0020602

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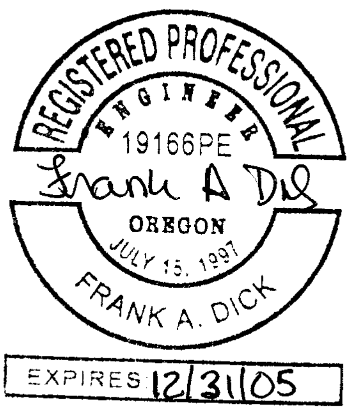
PROFESSIONAL ENGINEER'S CERTIFICATION

I, Frank A. Dick, do certify that to the best of my knowledge the data and information utilized for the design of this In Situ Persulfate Oxidation Interim Remedial Measure for the Arkema, Inc. Portland, Oregon facility is accurate and complete. In addition, I have reviewed and verified the authenticity of the information presented in this In Situ Persulfate Oxidation Interim Remedial Measure Work Plan.

Frank A. Dick, Environmental Engineer
ERM-West, Inc.
Oregon P.E. #19166PE

6-July-2005
Date

Stamp:



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LIST OF ACRONYMS

bgs	below ground surface
CO_2	Carbon dioxide
DDT	Dichlorodiphenyltrichloroethane
DNAPL	Dense non-aqueous phase liquid
ERM	ERM-West, Inc.
HASP	Health and Safety Plan
IRM	Interim remedial measure
IAS	In-situ air sparging
mg/L	Milligrams per liter
MCB	Monochlorobenzene
MPR	Manufacturing process residue
ODEQ	Oregon Department of Environmental Quality
ORP	Oxidation reduction potential
pH	Acidity/alkalinity
SVE	Soil vapor extraction
μg/L	Micrograms per liter
UIC	Underground Injection Control
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

1.0 INTRODUCTION

This *In-Situ Persulfate Oxidation Interim Remedial Measure Work Plan* (Work Plan) has been prepared by ERM-West, Inc. (ERM), on behalf of Arkema, Inc. (Arkema) (formerly ATOFINA Chemicals, Inc.), for the Arkema facility (the "facility" or "Site") in Portland, Oregon. The purpose of this Work Plan is to provide details of the proposed environmental remediation work that will be conducted. The work described in this Work Plan is an expansion upon the work performed during the sodium persulfate oxidation pilot study conducted in the Acid Plant area. This proposed Interim Remedial Measure (IRM) consists of injecting a solution of the oxidant sodium persulfate into the shallow, shallow-intermediate, and intermediate water-bearing zones to remediate dissolved monochlorobenzene (MCB or chlorobenzene) and DDT in groundwater downgradient of the Acid Plant area.

The remainder of this section includes:

- Background;
- IRM objectives;
- General approach; and
- Work Plan organization.

1.1 BACKGROUND

The Arkema facility is located at 6400 N.W. Front Avenue in the northwest industrial area of Portland, Oregon (Figure 1). The facility is bounded by Front Avenue on the north and west, the Willamette River on the east, and an asphalt roofing manufacturer on the south. The plant operated as a chemical manufacturing facility for over 50 years until 2001. Manufacturing activities at the facility were terminated at that time and the plant is currently being decommissioned.

1.1.1 Historical Operations

The facility was constructed in 1941 and was used to manufacture DDT between approximately 1947 and 1954. MCB was used as a raw material in the DDT manufacturing process. The DDT manufacturing facility consisted of a DDT process building, MCB recovery unit, various aboveground storage tanks, warehouse buildings, and a manufacturing process residue (MPR) pond and trench. In subsequent years, a hydrochloric acid plant was constructed in the area and it became known as the Acid Plant area. The MPR pond and trench received residue (including DDT and MCB) from the former DDT process building.

Historical photographs and site investigation data indicate the pond was rectangular and approximately 55 by 60 feet in dimension. The MPR trench, which was constructed to increase the capacity of the pond, was approximately 8 feet wide and extended approximately 285 feet north from the pond (Exponent 1998). After 1954, when DDT manufacturing operations ceased, the MPR pond and trench no longer received process residues. Portions of the MPR pond and trench were excavated as part of a soil removal IRM in Fall 2000. Soils containing DDT and MCB were removed from these two historical features and disposed at an approved off-site disposal facility. This IRM was documented in the *Interim Remedial Measures Implementation Report*, dated 26 February 2001 (ERM 2001a).

1.1.2 Local Geology

The Site is situated on fill and alluvial deposits of the Willamette River. The fill material consists of river dredge spoils, silty sands to sandy gravelly silts, asphalt, concrete, metal piping, and other miscellaneous materials. The fill thickness ranges from a few feet near the Acid Plant area to approximately 25 feet along the river bank. The upper alluvial soils underlying the fill and near the surface in the center and western portions of the Site are predominantly dark gray-brown, poorly sorted fine to medium grained silty sands with occasional silt lenses. The location of cross-sections constructed through the Acid Plant area are shown on Figure 2. Cross-section diagrams are provided on Figures 3 and 4.

A 0.5- to 2-foot thick silt horizon occurs within a depth range of 30 to 38 feet below ground surface (bgs) and separates the upper alluvial sand from an intermediate-depth black fine to medium grained sand unit (5 to 10 feet thick). Below a depth of 35 to 40 feet, the intermediate sand unit grades into an underlying horizon of low permeability bedded silt, clay, and silty/clayey fine sand. Underlying the unconsolidated alluvium is bedrock consisting of Columbia River Basalt (Exponent 1999).

A more thorough discussion of regional geology is provided in the *Draft Upland Remedial Investigation Report, Lots 3 & 4 and Tract A* (Draft RI Report; ERM 2004a).

1.1.3 Local Hydrogeology

Groundwater occurs within several zones beneath the Site: a shallow unconfined zone, a thin semi-confined area (shallow-intermediate zone), two confined to semi-confined lower zones (intermediate and deep zones), and a deeper zone in the basalt bedrock. The shallow unconfined groundwater surface is present in the fill and upper sand alluvium from approximately 10 to 20 feet bgs. The intermediate groundwater zone occurs between depths of approximately 36 to 46 feet bgs in the Acid Plant area. The intermediate groundwater zone has a saturated thickness of approximately 5 to 10 feet. Downgradient of the former MPR pond, the shallow and intermediate groundwater zones are separated by a thin interstitial water-bearing zone identified as the shallow-intermediate zone. This 5-foot thick zone is isolated from the shallow and intermediate zones by thin silt horizons. This shallow-intermediate zone is present only in this area of the Site (in the vicinity of monitoring well MWA-17si). The presence of dissolved-phase MCB and DDT (and it's metabolites DDD and DDE) in the shallow, shallow-intermediate, and intermediate groundwater zones is the focus of this IRM.

A more thorough discussion of regional and site-specific hydrogeology is provided in the Draft RI Report (ERM 2004a).

1.1.4 Chemical Occurrence

Groundwater and soil in the Acid Plant area contain MCB and DDT. The process residue from manufacturing operations was historically disposed in the MPR pond and trench, located northeast of the DDT process building. Based on previous soil and groundwater investigations (ERM 2004a), the source of MCB and DDT in soil and groundwater in the Acid Plant area is the historical MPR pond and the former MCB recovery unit. MCB and DDT concentrations observed in groundwater during a groundwater sampling event conducted in June 2003 are presented on Figure 2. Figures 3 and 4 present chlorobenzene concentrations within the various water-bearing zones along cross-sections through the Acid Plant area.

Remedial investigations performed at the Site in 1999 indicated the presence of residual MCB dense non-aqueous phase liquid (DNAPL) in soil in the shallow zone beneath the former MPR pond and in a thin zone downgradient of the Acid Plant area. The observed residual DNAPL was found primarily near the upper sand unit/silt layer interface (i.e., the bottom of the shallow groundwater zone). The presence of elevated MCB concentrations in groundwater samples obtained from MWA-15r suggested that residual DNAPL within the Acid Plant area may be a continuing source of MCB to groundwater.

A two-phase DNAPL investigation was initiated in early 2002 in accordance with the *Work Plan for Dense Non-Aqueous Phase Liquid Investigation, Acid Plant Area* (DNAPL Investigation Work Plan; ERM 2002a). The objective of the DNAPL investigation was to delineate the extent of residual MCB DNAPL in the shallow and intermediate zones and to provide sufficient basis for evaluating remedial alternatives. The results of the DNAPL investigation indicated that nearly all residual MCB DNAPL occurred in the shallow zone, within a roughly circular area approximately 120 feet in diameter, centered near the northeastern corner of the former MPR pond. Furthermore, the results of the investigation indicated that MCB DNAPL is distributed in the form of ganglia or microglobules coating soil particles rather than as a continuous, pore-filling phase.

DDT and its metabolites, DDD and DDE, have been detected in shallow- and intermediate zone groundwater downgradient of the Acid Plant area. DDT has extremely low solubility in water and, therefore, is not typically observed in groundwater at concentrations greater than 1 microgram per liter (μg/L). However, due to cosolvency with chlorobenzene, DDT has been observed in groundwater at concentrations up to 450 μg/L (shallow zone monitoring well MWA-15r, 30 March 2001). DDD has a higher aqueous solubility than DDT. DDD has been observed in groundwater in the Acid Plant area at concentrations up to 37 μg/L (shallow zone monitoring well MWA-15r, 30 March 2001). DDE has an aqueous solubility similar to that of DDT (i.e., extremely low) and has been observed in groundwater in the Acid Plant area at concentrations up to 0.4 μg/L (shallow zone monitoring well MWA-4, 25 August 1999).

1.1.5 *Bench-Scale Demonstration of Persulfate Oxidation*

Prior to performing a field-scale pilot study to evaluate the potential for oxidation of MCB, a bench-scale treatability study was performed at ERM's Remediation Technology Center in West Chester, Pennsylvania, on groundwater samples collected from the Site. The treatability study was performed in order to determine the ability and extent of several chemical oxidants (including sodium persulfate) to oxidize MCB in the Site groundwater. The complete treatability study report is provided in the *Final MCB Oxidation Pilot Study Work Plan* (ERM 2001b).

The results from the treatability study demonstrated that persulfate can effectively and completely oxidize the MCB present in the Site groundwater. At 15 degrees Celsius, MCB concentrations were reduced from 45,000 μg/L to below detection (< 10 μg/L) in 84 days following the addition of 5,000 milligrams per liter (mg/L) of sodium persulfate.

1.1.6 Previous Remediation Pilot Studies

In-Situ Sodium Persulfate Pilot Study

In 2001, ERM implemented a pilot study to investigate the effectiveness of persulfate as a chemical oxidant for the remediation of dissolved-phase MCB in the vicinity of the MPR pond, based on the results of the bench-scale demonstration. The pilot study was conducted in accordance with the *Final MCB Oxidation Pilot Study Work Plan* (ERM 2001b). Water quality samples collected within the pilot study area had concentrations of MCB ranging from 25,000 to 270,000 μg/L (MCB aqueous solubility is 470,000 μg/L at 20 degrees Celsius), indicating that MCB DNAPL may be present. DNAPL was observed during the pilot study in one pilot study monitoring well (NMP-4D). The pilot study was not initially designed to address the presence of DNAPL. Therefore, the study was suspended to evaluate the extent of residual MCB DNAPL (i.e., the two-phase DNAPL investigation described above [ERM 2002b and 2002c]). Although the pilot study was never fully carried out, early results indicated that sodium persulfate was an effective oxidant for remediation of MCB at lower initial dissolved-phase MCB concentrations (e.g., 10 to 25 mg/L). In addition, significant reduction in DDT, DDD, and DDE concentrations was observed during the initial monitoring with no observed rebound, indicating the effectiveness of sodium persulfate at remediating DDT.

Dense Non-Aqueous Phase Liquid Remediation Pilot Study

Upon conclusion of the DNAPL investigation in 2002, a pilot study was conducted in the area where the majority of residual-phase DNAPL was observed during the investigation. The DNAPL pilot study was conducted in accordance with the *Dense Non-Aqueous Phase Liquid Remediation Pilot Study Work Plan* (DNAPL Pilot Study Work Plan; ERM 2003). The pilot study involved the installation, operation, and monitoring of a pilot-scale remediation system consisting of traditional in-situ air sparging (IAS) and soil vapor extraction (SVE) technologies. The system consisted of two air sparging and two SVE wells and ancillary monitoring wells and equipment.

The DNAPL pilot study systems were operated for 2 months, shut down, and monitored for an additional 3 months. MCB concentrations were monitored in 10 groundwater monitoring wells both during and after system operation. At the end of the pilot study, an average reduction in dissolved-phase MCB concentration of approximately 64 percent was achieved. A detailed summary of the implementation and results of the DNAPL pilot study is provided in the *Dense Non-Aqueous Phase Liquid Remediation Pilot Study Completion Report* (DNAPL Pilot Study Report; ERM 2004b). An expanded IAS/SVE system has been installed to remediate MCB DNAPL surrounding the former MPR pond. The IAS/SVE IRM is likely to be operating during performance of this IRM. The details of the IAS/SVE IRM are presented in the *Air Sparging/Soil Vapor Extraction Interim Remedial Measure Work Plan* (ERM 2004c).

1.2 INTERIM REMEDIAL MEASURE OBJECTIVES

The primary objective of the in-situ persulfate oxidation IRM described in this Work Plan is to reduce the mass of dissolved MCB and DDT (and its co-metabolites DDD and DDE, collectively referred to as DDT) in the shallow, shallow-intermediate, and intermediate groundwater downgradient from the Acid Plant area before potential discharge to the Willamette River. This IRM has been designed to remediate MCB in Site groundwater to achieve the Portland Harbor Joint Source Control Strategy screening level (i.e., Oregon Department of Environmental Quality's [ODEQ's] Ecological Risk Assessment Level II Screening Limit Value) of 50 μg/L for MCB at monitoring wells adjacent to the river. This IRM has also been designed to reduce the mobility of DDT in Site groundwater by direct oxidation of DDT and reduction of the potential for transport due to cosolvency with MCB.

1.3 GENERAL APPROACH

The IRM will consist of injecting sodium persulfate solution into groundwater in the vicinity of the Acid Plant area to provide source control for groundwater containing dissolved MCB and DDT. Shallow, shallow-intermediate, and intermediate zone groundwater will be treated by injecting sodium persulfate through temporary direct-push boreholes.

Groundwater in the treatment zones will be monitored prior to, during, and following five phases of injections.

Phase I will consist of injection of sodium persulfate in the shallow and shallow-intermediate zones over an area downgradient of the Acid Plant Area and north of the footprint of the Hexavalent Chromium Reduction IRM treatment area. This phase will include post-injection sampling to monitor parameters indicative of oxidation, confirm the effectiveness of the sodium persulfate dosage design, evaluate the spacing of injection points, monitor for potential impact to the Willamette River, and monitor for increases in metals concentrations resulting from the sodium persulfate injections. Results of performance monitoring during this phase will be used to refine the implementation of subsequent injection phases, to assess the need for follow-up (or maintenance) injections, and to design the maintenance injection program for the Phase I footprint.

Phase II will consist of injection of persulfate in the intermediate zone downgradient of the Acid Plant area (i.e., beneath the previous Phase I footprint). The injection program calls for injecting in the shallow zone (Phase I) prior to the intermediate zone (Phase II) to remediate shallow zone groundwater prior to conducting direct-push borings into the intermediate zone, thereby minimizing the potential for cross-contamination. Data from performance monitoring conducted during this phase will be used to determine the need for maintenance injections and to design the maintenance injection program for the Phase II footprint.

Phase III will consist of injection of persulfate in the shallow and intermediate zones within the footprint of the Hexavalent Chromium Reduction IRM. This allows for the completion of the Hexavalent Chromium Reduction IRM and complete reaction of the calcium polysulfide prior to persulfate injection. It is important that the Hexavalent Chromium Reduction IRM be completed prior to initiating the Phase III injections because the injection of persulfate will oxidize any residual calcium polysulfide, thereby ending any further reduction of hexavalent chromium. Moreover, residual calcium polysulfide in groundwater will increase the oxidant demand, thereby increasing the mass of persulfate required to treat the area. Therefore, the second round of calcium polysulfide injection in the Hexavalent Chromium Reduction IRM will be designed to achieve the goals of that IRM without yielding a significant mass of residual calcium polysulfide in groundwater. An assessment of calcium polysulfide content in the groundwater will be performed prior to this phase to ensure that there is little or no excessive oxidant demand in the area. Previous testing has shown that the persulfate injections will not reverse the hexavalent chromium treatment (i.e., causing chromium to revert back to a hexavalent state from its trivalent state). The Phase III injections will be conducted in the shallow and intermediate zones at the same time because the silt layer between these two zones is discontinuous in this area and the two zones are already interconnected. Performance monitoring will be conducted during this phase, and data from the performance monitoring will be used to determine the need for maintenance injections and to design the maintenance injection program for the Phase II footprint.

Phase IV injections will be conducted in the shallow and intermediate zones within the footprint of the IAS/SVE IRM system. A majority of the injections will be conducted in the shallow zone only. These injections will be conducted prior to the direct-push borings which will extend into the intermediate zone. Performance monitoring results will be used to determine the effectiveness of the remedy and determine the need and implementation plan for maintenance injections in this area.

Phase V includes all of the maintenance injections conducted as part of this IRM, and the phase has been divided into four rounds of injections, each of which correlates to a round of maintenance injections for the areas covered by Phases I through IV. Each round of maintenance injections will be performed immediately following evaluation of the performance monitoring data from the corresponding phase of injections. For example, if the performance monitoring data from the Phase I injections show that maintenance injections are required to complete the treatment in that area (i.e., the shallow/shallow-intermediate zone downgradient of the Acid Plant Area), the maintenance injections would be Round I of Phase V and would be implemented concurrent with the next regularly scheduled phase of injections (i.e., the Phase II injections).

Approximately 2 months after completion of all persulfate injections, a final performance monitoring event will be conducted to evaluate overall effectiveness of the IRM.

1.4 WORK PLAN ORGANIZATION

This Work Plan consists of six sections and four appendices. The contents of the sections are as follows:

- Section 1.0 – Introduction;
- Section 2.0 – Remedial Technology Background. A discussion of oxidation reactions with persulfate;

- Section 3.0 – IRM Implementation. A description of the specific activities involved with construction, performance, monitoring, and reporting of the IRM;
- Section 4.0 – Health and Safety. This section emphasizes the importance of adhering to established health and safety practices at the Arkema facility and outlines the purpose of the Site-specific Health and Safety Plan;
- Section 5.0 – Project Schedule and Reporting. The schedule for implementation of IRM field activities and reporting are presented; and
- Section 6.0 – References.

The appendices consist of the following:

- Appendix A – Persulfate IRM Implementation Schedule;
- Appendix B – the ODEQ Underground Injection Control (UIC) registration form;
- Appendix C – Design calculations for persulfate injections in this IRM; and
- Appendix D – Material safety data sheet for sodium persulfate.

2.0 REMEDIAL TECHNOLOGY BACKGROUND

Persulfates are strong oxidants. They exist as salts and are available as sodium, potassium, or ammonium persulfate. Persulfates are used as oxidizing agents for industrial purposes such as chemical etching in the electronics industry or as a pulp and paper processing chemical. Persulfates are also widely used as primary components of consumer products such as hair coloring and swimming pool treatment products. The use of persulfates in groundwater treatment applications is a relatively new technology, developed for use with contaminants that are not amenable to oxidation using other, more traditional oxidants such as ozone or permanganates. The common persulfate form used in groundwater treatment is sodium persulfate ($Na_2S_2O_8$). Dissolution of sodium persulfate results in the formation of the persulfate ion ($S_2O_8^{2-}$) and two sodium ions (Na^+).

Persulfate can be applied with minimal risk to the environment or human health and safety. The sections below describe the reactions and reaction products anticipated when persulfate is applied to the subsurface.

2.1 OXIDATION REACTIONS OF PERSULFATE

There are two alternative mechanisms for sodium persulfate oxidation treatment: direct oxidation and free radical formation. Direct oxidation involves utilizing the oxidation capacity of the persulfate ion itself, converting to the sulfate ion (SO_4^-) upon reaction. This oxidation method is capable of oxidizing some volatile organic compounds (VOCs), including benzene-based compounds such as MCB. The second method of sodium persulfate oxidation involves catalyzing the production of sulfate free radicals through the addition of heat or transitional metals such as iron. Use of this method can expand the capabilities of sodium persulfate oxidation, but field implementation is not as simple as the direct oxidation method. The direct oxidation method will be applied in this IRM. This application method was used during the in-situ sodium persulfate pilot study, where effectiveness was observed on both MCB and DDT.

The injection of persulfate will result in two types of oxidation reactions: (1) the oxidation of the target compounds (MCB and DDT); and (2) to a lesser degree, oxidation of the soil matrix, particularly humates or other soil organics. Both reactions will produce carbon dioxide (CO_2), sulfate, and hydrochloric and sulfuric (H_2SO_4) acids.

The chemical equation for the persulfate oxidation of MCB (C_6H_5Cl) is:

$$C_6H_5Cl + 12H_2O + 14Na_2S_2O_8 \rightarrow 6CO_2 + HCl + 14H_2SO_4 + 28\ Na^+ + 14SO_4^{-2}$$

The chemical equation for the complete oxidation of DDT ($C_{14}H_9Cl_5$) is:

$$C_{14}H_9Cl_5 + 28H_2O + 30Na_2S_2O_8 \rightarrow 14CO_2 + 5Cl^- + 65\ H^+ + 60\ Na^+ + 60SO_4^{-2}$$

In these reactions, several byproducts, including CO_2, sulfate, and chloride and hydrogen ions, are generated and released to the groundwater. The byproducts of this reaction are not expected to pose water quality problems because most of the byproducts are either innocuous or will readily react with aquifer material and subsequently stabilize. The only foreseeable negative impacts resulting from the persulfate injections are short-term impacts and include:

- Increased sulfate concentration in groundwater; and
- Generation of acid, which may increase dissolved metals concentrations.

No significant increases in sulfate or dissolved metals concentrations were observed during the pilot study, and significant, long-term increases in these constituents are not expected as a result of this IRM.

The secondary chemical reaction for the persulfate oxidation of humates (soil matrix) is:

$$C_{20}H_{18}O_8\ \text{(humate)} + 32H_2O + 41S_2O_8^{2-} \rightarrow 20CO_2 + 41H_2SO_4 + 41SO_4^{-2}$$

Reactions between the soil matrix and persulfate will also produce sulfate and generate acid. The soil demand is generally very low when using persulfate so the production of sulfate and acid will generally be due to the reaction of persulfate with VOCs.

The potential impacts to groundwater chemistry include an increase in sulfate and a decrease in acidity/alkalinity (pH). One strategy for reducing the effects of increased acidity/decreased pH is to amend the injected sodium persulfate to stabilize the pH of the injected solution. This not only has the effect of preventing acidic conditions following injection, but has been shown to stabilize the natural reactivity of the persulfate ion. Buffered sodium persulfate is available and has been shown to effectively reduce the effects of decreased pH while allowing the persulfate solution to readily oxidize contaminants. Buffered sodium persulfate will be used in this IRM.

As shown in the chemical equations above, sulfate ion will be generated from the reaction of persulfate with contaminants and native soil material. Depending on the contaminant concentration and the rate of reaction of persulfate, the concentration of sulfate ion may temporarily exceed groundwater quality guidelines, such as the United States Environmental Protection Agency (USEPA) secondary standard of 250 mg/L for sulfate as a nuisance chemical. However, it is expected that the sulfate ion will be generated slowly and will attenuate naturally. No statistically significant increase in sulfate concentration was observed during the in-situ sodium persulfate pilot study, based on the comparison of the mean sulfate concentrations in the 12 pilot study wells, before and 2 months after persulfate injections. During implementation of this IRM, groundwater will be monitored to evaluate pH and sulfate concentrations across the treatment area. No significant changes in pH were observed during the pilot study.

The amount of oxidant needed to completely and effectively remediate the contaminants is a function of the following:

- The stoichiometric demand of the contaminants; and
- The natural decomposition of the oxidant.

The stoichiometric demand is the amount of oxidant that needs to be added to achieve complete oxidation of the contaminants. This amount is determined from the balanced chemical equation. The stoichiometric demand of sodium persulfate with MCB (based on mass $Na_2S_2O_8$:mass C_6H_5Cl) is 30:1. Therefore, 30 pounds of sodium persulfate is needed for every pound of MCB oxidized. In addition, the stoichiometric demand of sodium persulfate by DDT is 20:1, on a mass basis. However, since the concentration of DDT is generally three to four orders of magnitude less than that of MCB at any particular location, the amount of persulfate required to oxidize the DDT is insignificant relative to that required for MCB.

Persulfate consumption has been shown to be a function of decomposition in laboratory tests (Brown and Robinson, 2003). Therefore, the remediation design must account for the decomposition of the persulfate to ensure adequate oxidant mass and contact time for the required treatment. A degradation rate of 1.1 percent per day was used in the calculations for this IRM.

Soil matrix demand is another factor that affects the mass of oxidant required to completely and effectively remediate the contaminant. However, the soil matrix demand for persulfate is very low relative to its degradation rate and the stoichiometric demand of the contaminants (Brown and Robinson 2003). Therefore, soil matrix demand is considered negligible for the purposes of this IRM.

3.0 INTERIM REMEDIAL MEASURE IMPLEMENTATION

Specific tasks for implementation of the IRM are described in this section and include:

- Obtaining regulatory approval;
- Site preparation activities;
- Installing monitoring wells;
- Performing baseline groundwater monitoring;
- Implementing Phase I injections in the shallow/shallow-intermediate zone downgradient of the Acid Plant area and conducting Phase I performance monitoring and data evaluation;
- Implementing Phase II injections in the intermediate zone downgradient of the Acid Plant area, any maintenance injections in the Phase I area, if required (Phase V – Round 1), and conducting Phase II performance monitoring and data evaluation;
- Implementing Phase III injections over the shallow and intermediate zones in the footprint of the Hexavalent Chromium Reduction IRM treatment area, any maintenance injections in the Phase II area, if required (Phase V – Round 2), and conducting Phase III performance monitoring and data evaluation;
- Implementing Phase IV injections in the IAS/SVE IRM treatment area in the shallow and intermediate zones, any maintenance injections in the Phase III treatment area, if required (Phase V – Round 3), and conducting the Phase IV performance monitoring and data evaluation;
- Conducting the maintenance injections in the Phase IV area, if required (Phase V - Round 4) and conducting the Phase V performance monitoring and data evaluation;
- Conducting the final performance monitoring event approximately 2 months after the final injection event and evaluating the data; and
- Handling of wastes generated during implementation.

The proposed injection approach is designed to:

- Minimize or eliminate the potential for cross-contamination between aquifers by addressing shallow and shallow-intermediate groundwater impacts prior to conducing injections in the intermediate zone;

- Minimize discharge of harmful chemicals to the Willamette River;
- Allow for evaluation and refinement of the injection program as the IRM proceeds;
- Complete the Hexavalent Chromium Reduction and the IAS/SVE IRMs prior to persulfate treatment in those areas to avoid incomplete treatment of the hexavalent chromium and an inefficient use persulfate;
- Allow targeted maintenance injections in areas where additional treatment is needed; and
- Attain compliance with the MCB and DDT clean-up criteria at the monitoring wells adjacent to the Willamette River by 1 July 2007.

A schedule for implementation of the IRM is provided in Appendix A.

3.1 REGULATORY APPROVAL

Prior to implementation of this IRM, Arkema will obtain written approval of the proposed work from ODEQ. This will involve receiving written approval of this Work Plan and obtaining applicable permits for the installation of the proposed injection and groundwater monitoring wells. The persulfate injection boreholes are considered Class V injection wells for aquifer remediation and require registration with the ODEQ UIC program. The required UIC registration form is included in Appendix B.

3.2 SITE PREPARATION

Prior to any drilling or injection activities, the proposed locations will be marked using white spray paint. A Site meeting will be arranged to identify applicable utilities needing clearance. A meeting with the facility's environmental manager will be scheduled to review and clear the injection locations.

3.3 WELL INSTALLATION

During the design of this IRM, data gaps were identified where MCB and/or DDT concentrations are not well understood. In the shallow zone, additional data are needed to determine the northern extent of the injection area (i.e., the area north of MWA-5) and whether injections are needed between Warehouse No. 3 and MWA-20 (Figure 5). Moreover, several additional shallow zone and shallow-intermediate zone monitoring wells are needed to track the performance of the persulfate treatment (Figure 5). In the intermediate zone, additional data are needed to determine the northern and western extent of the southern injection area (i.e., the area north and west of MWA-34i), and additional intermediate zone monitoring wells are needed to track the performance of the persulfate treatment in the northern injection area (Figure 6).

A total of nine additional shallow zone, two additional shallow-intermediate zone, and six additional intermediate zone monitoring wells will be installed and sampled to assess the baseline contaminant distribution and concentrations and to track the performance of the persulfate treatment. Four of the additional shallow zone and three of the additional intermediate zone monitoring wells will be installed as part of the Hexavalent Chromium Reduction IRM. The additional monitoring wells are shown on Figures 5 and 6 and listed in Table 1. The baseline sampling results will be used to refine the layout of persulfate injection points (i.e., possibly increasing or decreasing the number of injection points in areas that are currently uncertain).

The procedures used to install the groundwater monitoring wells are described below. The procedures and specifications for installing these wells and monitoring points are based on the *Elf Atochem Acid Plant Area Remedial Investigation/ Feasibility Study Work Plan* (RI/FS Work Plan; Exponent 1998).

All wells will be installed by an Oregon-licensed well driller in accordance with Oregon monitoring well construction requirements (Oregon Administrative Rule 690-240), ODEQ guidance, and the RI/FS Work Plan. The monitoring well boreholes will be drilled using a hollow-stem auger or a sonic drilling rig. Soil samples will be collected using a split spoon sampler every 5 feet for lithologic logging. When the boring has been advanced to within 5 feet of the final depth, continuous sampling will be conducted to ensure well placement in the correct hydrogeologic zone. An experienced ERM field geologist will log the soil samples, monitor the drilling operations, record the well installation procedures, and prepare boring logs and well construction diagrams.

All performance monitoring wells installed as part of this IRM will be abandoned upon completion of the IRM in accordance with Oregon monitoring well abandonment requirements.

3.3.1 Shallow Zone Performance Monitoring Wells

Five shallow zone performance monitoring wells (MWA-60, -61, -62, -63, and -69) will be installed as part of the IRM. These five new shallow zone performance monitoring wells, the four new shallow zone monitoring wells (MWA-42, -44, -45 and -46) installed as part of the Hexavalent Chromium Reduction IRM, and the existing shallow zone monitoring wells will be used during the IRM to monitor the shallow zone groundwater quality and gauge effectiveness of the persulfate injections. The locations of the proposed shallow zone performance monitoring wells are shown on Figure 5. A typical performance monitoring well construction diagram is presented on Figure 8. A discussion of the monitoring program is presented in Section 3.5.

The performance monitoring wells will be constructed inside the hollow-stem auger after completion of the shallow zone monitoring well boreholes to a target depth of between 30 and 34 feet bgs. Construction will consist of Schedule 40 polyvinyl chloride casing and screen. Well materials will include 10 feet of 0.010-inch slotted, flush-threaded screen and 2-inch Schedule 40 polyvinyl chloride casing to ground surface. This construction is chemically compatible with sodium persulfate.

The well screens will include centralizers at the top and bottom of the screened interval. The wells will be packed to 2 feet above the screened interval with washed silica sand (Colorado Silica Sand 10-20 or equivalent). The sand filter pack will be surged repeatedly with a surge block to promote settling. The seal will be set using a 3-foot thick layer of bentonite pellets. The well will then be sealed to ground surface with a high solids bentonite grout pumped from the bottom up via tremie pipe. The wells will be completed with flush-mount traffic-rated well boxes.

3.3.2 Shallow-Intermediate Zone Performance Monitoring Wells

Two proposed shallow-intermediate zone monitoring wells (MWA-67si and –68si) will be installed by an Oregon-licensed well driller. These two proposed shallow-intermediate zone monitoring wells and the existing shallow-intermediate zone monitoring wells will be used during the IRM to monitor the shallow-intermediate zone groundwater quality and gauge effectiveness of the persulfate injections. The proposed shallow-intermediate zone wells will be installed to an anticipated depth of approximately 35 feet bgs with approximately 1.5 feet of screen. This target depth is based on the anticipated depth of the silt zone at the base of the shallow-intermediate zone aquifer and will be dependent upon the observations of the field geologist overseeing the well installation. Proposed shallow-intermediate zone monitoring well locations are shown on Figure 5. Well construction and completion will be the same as for the shallow zone performance monitoring wells.

3.3.3 *Intermediate Zone Performance Monitoring Wells*

Three proposed intermediate zone monitoring wells (MWA-64i, -65i and -66i) will be installed by an Oregon-licensed well driller. These three proposed intermediate zone monitoring wells, the three new intermediate zone monitoring wells (MWA-49i, -51i, and –55i) to be installed as part of the Hexavalent Chromium Reduction IRM, and the existing intermediate zone monitoring wells will be used during the IRM to monitor the intermediate zone groundwater quality and gauge effectiveness of the persulfate injections. The proposed intermediate zone wells will be installed to an anticipated depth of 44 to 46 feet bgs with 5 to 10 feet of screen to maximize the screened interval in the intermediate zone aquifer. This target depth is based on the anticipated depth of the silt zone at the base of the intermediate zone aquifer and will be dependent upon the observations of the field geologist overseeing the well installation. Proposed intermediate zone monitoring well locations are shown on Figure 6.

The boreholes will be drilled using an auger/casing of sufficient size such that a casing reduction can be performed to seal off the shallow zone/shallow-intermediate zone aquifers, if needed. A step down in auger size will only be implemented if the silt layer between the shallow/shallow-intermediate and intermediate zones is encountered. Well construction and completion will be the same as for the shallow zone performance monitoring wells.

3.4 *BASELINE GROUNDWATER SAMPLING*

Prior to performing any injections, samples will be collected from select monitoring wells to evaluate baseline dissolved-phase MCB, DDT, DDD, and DDE concentrations in groundwater. Samples will be collected from existing monitoring wells, monitoring wells to be installed as part of the Hexavalent Chromium Reduction IRM, and wells to be installed as part of this IRM. Baseline groundwater samples will be collected from monitoring wells screened within each of the three zones (shallow, shallow-intermediate and intermediate) being treated. These wells are listed in Table 1. Samples will be collected in accordance with the Field Sampling Plan in the RI/FS Work Plan. The following field parameters will be measured during sample collection:

- Dissolved oxygen concentration;
- Oxidation/reduction potential (ORP);
- Specific conductance;
- Turbidity;
- Temperature; and
- pH.

Groundwater samples will be analyzed by an Oregon-certified laboratory. The laboratory will analyze all groundwater samples for MCB by USEPA Method 8260 , organochlorine pesticides by USEPA Method 8081A, dissolved priority pollutant metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc) by USEPA Method 6000/7470A, and sulfate by USEPA Method 300.0. Table 2 is a baseline and performance sampling matrix for groundwater for this IRM.

The results of the baseline sampling will be tabulated and plotted on site maps and used to verify and finalize the layout of the persulfate injection points for Phases I through III. In the event that the groundwater concentrations have changed significantly since the June 2003 data, upon which this Work Plan is based, the layout of the persulfate injections will be revised to address the baseline areas of contamination.

3.5 OXIDANT MIXING AND DELIVERY SYSTEM

Sodium persulfate will be delivered to the Site as a dry powder in 225-pound drums. The product to be used is an FMC brand buffered sodium persulfate with a trade name of OPS-300. The sodium persulfate will be stored at the Arkema Portland facility, covered to protect the material from the elements prior to use. The sodium persulfate will only be handled by personnel who have had persulfate safety training.

Field personnel will set up a temporary mixing system to produce a solution of sodium persulfate by mixing the sodium persulfate powder with water. As discussed in Sections 3.6 through 3.10, the concentration of the buffered sodium persulfate solution to be injected will be mixed based on the concentration of MCB in groundwater treatment zone. The temporary mixing system will consist of a holding tank for water and one or more holding tanks for the sodium persulfate solution.

Personnel will then use a temporary delivery system that will take the persulfate solution from the holding tank and deliver it to the appropriate injection point(s). The delivery system will consist of a transfer pump, distribution hoses, and fittings to connect to each injection point. All equipment surfaces that come into contact with the sodium persulfate solution will be constructed of materials compatible with the sodium persulfate solution, as the solution is highly corrosive and will damage common materials like carbon steel.

3.6 PHASE I SODIUM PERSULFATE INJECTIONS

The purpose of this phase is to deliver the sodium persulfate into shallow and shallow-intermediate groundwater downgradient of the Acid Plant area (Figure 5). As in all injection phases, injection points will be spaced at 20-foot intervals in a hexagonal array. As a protective measure against release of sodium persulfate to the Willamette River, injections will not be conducted within 30 feet of the top of the riverbank. This is approximately two times the expected distance of distribution of persulfate from each injection point. A conceptual cross-sectional view of the location and depth of the proposed injection points is shown on Figure 7.

Two concentrations of injectant will be used during Phase I. In areas where MCB concentrations are greater than 500 μg/L, a 15 percent (by weight) solution will be injected. In areas where MCB concentrations are less than 500 μg/L, a 2 percent (by weight) solution will be used. Injection design rationale and calculations are provided in Appendix C. Each Phase I injection boring will be advanced to a depth of approximately 36 feet bgs (the depth of the bottom of the shallow-intermediate zone).

To limit contaminant migration resulting from injection of the oxidant, the sodium persulfate will be injected at the downgradient and cross-gradient locations first, thereby establishing a curtain of oxidant around the treatment area. The upgradient injections will then be conducted. This method will be employed during each phase of injections.

The sodium persulfate will be injected at multiple depths to treat groundwater throughout the water column at each injection point. The injection depth intervals and injection volumes for Phase I injections are summarized in Table 3. The direct-push rods will be driven to the target depth and then partially extracted to release the expendable drive tip. The prescribed volume of sodium persulfate solution will be injected at that interval. The drive rod will then be withdrawn upward approximately 4 feet, at which point the volume of solution planned for that interval will be injected. This process will be repeated until injection is completed at each target depth at each injection point.

In the event that the subsurface soils do not accept the persulfate solution at the planned injection rate (due to limited permeability), the injection will be temporarily suspended for 10 to 15 minutes and then restarted. If difficulties with injection continue, the injection location will be backfilled with grout and the location will be adjusted in the field. The total injection volume for each boring will be noted in the field notebook.

During injection activities, groundwater monitoring will be conducted in nearby monitoring wells (MWA-2, MWA-3, -4, -5, -4, -17si, -60, -61, -64i, -66i, -67si, -68si, and -69). A field water quality meter will be used to measure each of the following parameters:

- Temperature;
- Dissolved oxygen concentration;
- Conductivity;
- ORP; and
- pH.

An increase in ORP will be used to identify the presence of oxidant solution at each monitoring well. Groundwater will be actively pumped from the monitoring wells using dedicated whale pumps, thereby allowing real-time measurement of the water quality parameters. Additionally, the riverbank and near-shore water line downgradient of the Phase I treatment area will be visually monitored for the presence of oxidant solution (i.e., seeps). The oxidant solution is clear, therefore, if seeps are observed on the bank, a sample of water from the seep will be collected and measured for ORP. It is not anticipated that any oxidant solution will be detectable at the near-shore water line.

The injection borings will be abandoned by filling the boreholes with a cement/bentonite grout from the bottom of the boring to approximately 6 inches below the surface. The borings will be sealed at the surface with asphalt or concrete. This boring abandonment procedure will be used in all phases of injections.

3.6.1 Post-Injection Monitoring

Following Phase I injections, field parameters will be monitored in selected monitoring wells using the same procedures used during injections. The wells will be monitored bi-weekly for the first month and monthly for the following 2 months.

At the end of the first month following Phase I injections, groundwater samples will be collected from selected wells and analyzed for VOCs using USEPA Method 8260, organochlorine pesticides using USEPA Method 8081A, sulfate by USEPA Method 300.0, and priority pollutant metals by USEPA Method 6000/7470A. The wells to be monitored following Phase I injections are identified in Table 2. In the event that significant persulfate is present in a monitoring well, during this or any performance monitoring event, groundwater quality parameters will not be collected due to possible damage to the field meter sensors. Monthly monitoring will continue for 3 months.

3.6.2 Data Analysis

The objective of the Phase I data analysis is to evaluate the effectiveness of the sodium persulfate injections to reduce MCB, DDT, DDD, and DDE concentrations in groundwater and to provide a basis for refining subsequent injection phases. The data will be evaluated to determine the distribution of oxidant in the groundwater, the area of influence of each injection point, changes in contaminant concentrations, other changes in groundwater chemistry, and the potential for impact to the Willamette River from the injections. If appropriate, the results of the data analysis will be used to adjust the implementation plans for the subsequent phases of injection. For example, the injection point spacing, injection intervals, oxidant dosing, and/or the performance monitoring plan may be revised based on the Phase I injection data. Proposed revisions will be transmitted to the ODEQ for approval prior to initiating the next phase of injections.

3.7 *PHASE II SODIUM PERSULFATE INJECTIONS*

Phase II consists of injections in the intermediate groundwater zone, directly beneath the shallow and shallow-intermediate zones treated in Phase I (Figure 6). In addition to the intermediate zone injections, maintenance injections in the Phase I area (i.e., Phase V – Round 1) may be conducted concurrently with Phase II if performance monitoring results indicate additional treatment in the shallow and shallow-intermediate zones is necessary. The Phase II injection program is summarized in Table 3.

During this and subsequent injection phases, the most proximal well to the individual injection point will be monitored for the field parameters listed in Section 3.6.

3.7.1 *Post-Injection Monitoring*

Following Phase II injections, groundwater samples will be collected from the monitoring wells and analyzed for the analytes indicated in Table 2. Samples will be collected 1 and 2 months following the completion of the Phase II injections.

3.7.2 *Data Analysis*

The objective of the Phase II data analysis is to further evaluate the effectiveness of the sodium persulfate injections and to determine the need for maintenance injections in the Phase II area (Phase V – Round 2).

3.8 *PHASE III SODIUM PERSULFATE INJECTIONS*

Phase III of the IRM consists of injecting sodium persulfate solution in the shallow and intermediate zones in the southern portion of the IRM treatment area (i.e., within the footprint of the Hexavalent Chromium Reduction IRM treatment area) as shown on Figures 5 and 6. The Phase III injection program is summarized in Table 3. If required, based on data obtained from Phase II performance monitoring, maintenance injections will be conducted in the Phase I and II areas concurrently with Phase III injections.

3.8.1 *Post-Injection Monitoring*

Following Phase III injections, groundwater samples will be collected and analyzed as indicated in Table 2.

3.8.2 *Data Analysis*

The objective of the Phase III data analysis is to evaluate the effectiveness of persulfate in the Phase III area. Phase III monitoring data will be used to determine whether maintenance injections will be required in this area (Phase V – Round 3).

3.9 *PHASE IV SODIUM PERSULFATE INJECTIONS*

Phase IV injections will be conducted in the shallow and intermediate groundwater zones in the area of the IAS/SVE IRM footprint (Figures 5 and 7). Injections will not be conducted in this area until completion of the operational phase of the IAS/SVE IRM. The Phase IV injection program is summarized in Table 3. Additionally, maintenance injections in the Phase III area may be conducted concurrently with Phase IV injections if Phase III performance monitoring indicates that additional injections are needed.

3.9.1 *Post-Injection Monitoring*

Following Phase IV injections, groundwater samples will be collected and analyzed as indicated in Table 2.

3.9.2 *Data Analysis*

The objective of the Phase IV data analysis is to evaluate the effectiveness of persulfate in the Phase IV area. Phase IV monitoring data will be used to determine whether maintenance injections will be required in the IAS/SVE IRM system footprint (Phase V – Round 4).

3.10 *PHASE V SODIUM PERSULFATE INJECTIONS*

As indicated in the preceding sections, a fifth phase is included in this IRM as an ongoing maintenance phase. The intent of this phase is to efficiently address any required additional work by conducting follow-up maintenance injections concurrently with each subsequent phase of field work. Phase V includes four rounds of maintenance injections for each of the four previously conducted injection phases. Injection locations, dosages, and volumes may all be modified based on performance monitoring results conducting following each phase of work. It is expected that approximately 33 percent of all areas will require some degree of additional treatment, based on experience implementing prior chemical oxidation remediation projects.

Performance monitoring will be conducted in areas that have been retreated concurrently with the performance monitoring for the subsequent injection phase. Monitoring wells to be sampled will be determined based on the size and location of the retreated area (Table 2).

3.11 FINAL PERFORMANCE MONITORING

Two months after the last round of injections, whether that is the Phase IV injections or the last round of Phase V maintenance injections in the Phase IV treatment area, a final performance monitoring event will be conducted. Groundwater samples from all IRM performance monitoring wells will be analyzed, as listed in Table 2.

3.12 WASTE GENERATION, TRANSPORTATION, AND DISPOSAL

Waste generated during the IRM will be handled according to type. Soil, groundwater, and decontamination water will be temporarily stored on site, tested, and disposed of as discussed below.

Waste soil generated from monitoring well installation will be stored in 55-gallon drums in a secured area of the Site. Each drum will be labeled to indicate its contents and source (individual sample locations). The waste soil in each drum will be profiled. Although all waste soils will be disposed at a Subtitle C facility, the specific disposal method will be based on the profiling results.

Wastewater generated from drilling, sampling, or other activities (e.g., well development or purging) will be temporarily stored on site in 55-gallon drums. Each drum will be labeled to indicate its contents and source. Although all liquids will be disposed at a Subtitle C facility, the specific disposal method will be based on the baseline and performance monitoring analytical results.

4.0 HEALTH AND SAFETY

Prior to initiating any Site work, all field personnel, including subcontractors, will receive training on proper persulfate handling, storage, and injection procedures. Site-specific health and safety procedures will be presented during daily safety tailgate meetings.

A revised Health and Safety Plan (HASP) has been developed for work anticipated at the Site. The procedures described in the HASP will be implemented and enforced by a health and safety representative during Site work. The purpose of the HASP will be to:

- Assign Site personnel with health and safety responsibilities;
- Establish process safety requirements for all equipment, including hazards associated with the operation of motorized equipment;
- Prescribe mandatory operating procedures;
- Establish personal protective equipment requirements for work activities;
- Establish chemical handling and disposal procedures; and
- Establish emergency response procedures.

The HASP complies with all applicable Federal Occupational Safety and Health Administration regulations, as they may be applicable and appropriate. A material safety data sheet for sodium persulfate is included in this Work Plan in Appendix D.

5.0 PROJECT SCHEDULE AND REPORTING

The schedule and reporting methods to be followed during implementation of this IRM are discussed in this section.

5.1 PROJECT SCHEDULE

Arkema and ERM are prepared to initiate the scope of work outlined in this Work Plan within 1 month following its approval by ODEQ. It is anticipated that well installation will require approximately 4 weeks. Individual injection phases are expected to take approximately 3 to 5 months. A project schedule has been included in Appendix A.

5.2 REPORTING

Periodic observations and performance monitoring results will be reported in the Quarterly Progress Reports, required as part of the Voluntary Agreement for the Site (ODEQ No. ECVC-WMCVC-NWR-97-14, dated 26 August 1998).

A detailed completion report will be prepared at the conclusion of the IRM to document the results. The report will include a description of the procedures employed during the IRM, the results of the data analysis, conclusions from the work, and recommendations for future remedial work, if necessary. The report will also include figures presenting the pilot study findings, investigation-derived waste sample results, discussion of waste management including waste manifests, and logs from the field activities.

6.0 REFERENCES

Brown, Richard A., and David Robinson. 2003. *Response to Naturally Occurring Organic Material: Permanganate vs. Persulfate.* Presented at the 8th International Conference on Soil-Water Systems, 12-16 May 2003, Gent, Belgium.

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Exponent. 1998. *Elf Atochem Acid Plant Area Remedial Investigation/ Feasibility Study Work Plan*. September 1998.

Exponent. 1999. *Elf Atochem Acid Plant Area Remedial Investigation Interim Data Report*. June 1999.

Figures

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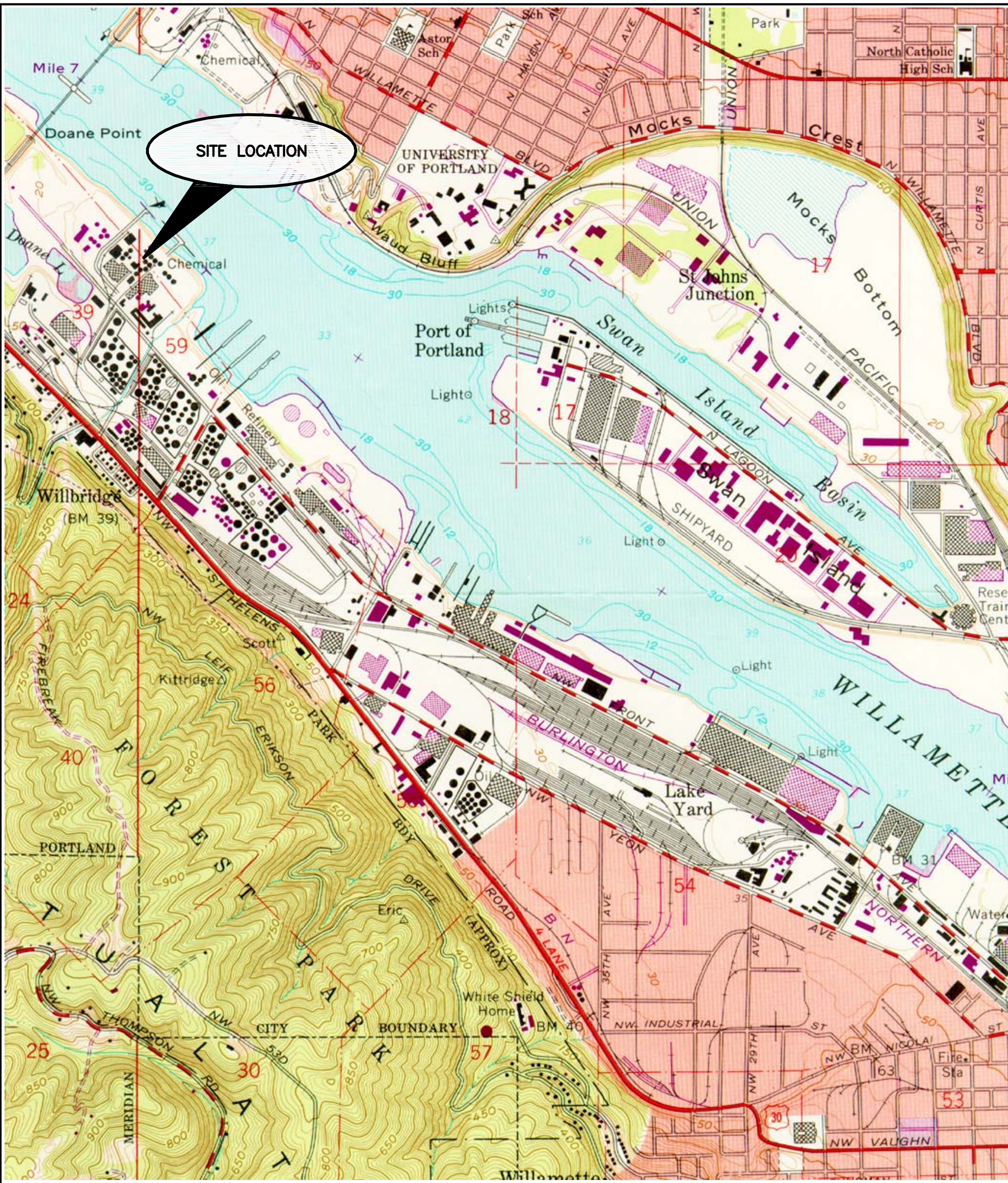
Drawn By: J. Estrada

Date: 01/13/05

Project No. 0020423.30



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1 — 1/2 — 0 — 1 MILE

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1 — .5 — 0 — 1 KILOMETER

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References:
U.S.G.S. 7.5 Minute Series (Topographic Portland, Oregon–Washington)
Dated: 1961; Photorevised 1970 and 1977

Figure 1
Site Location Map
Arkema, Inc.
Portland, Oregon

ERM 01/05

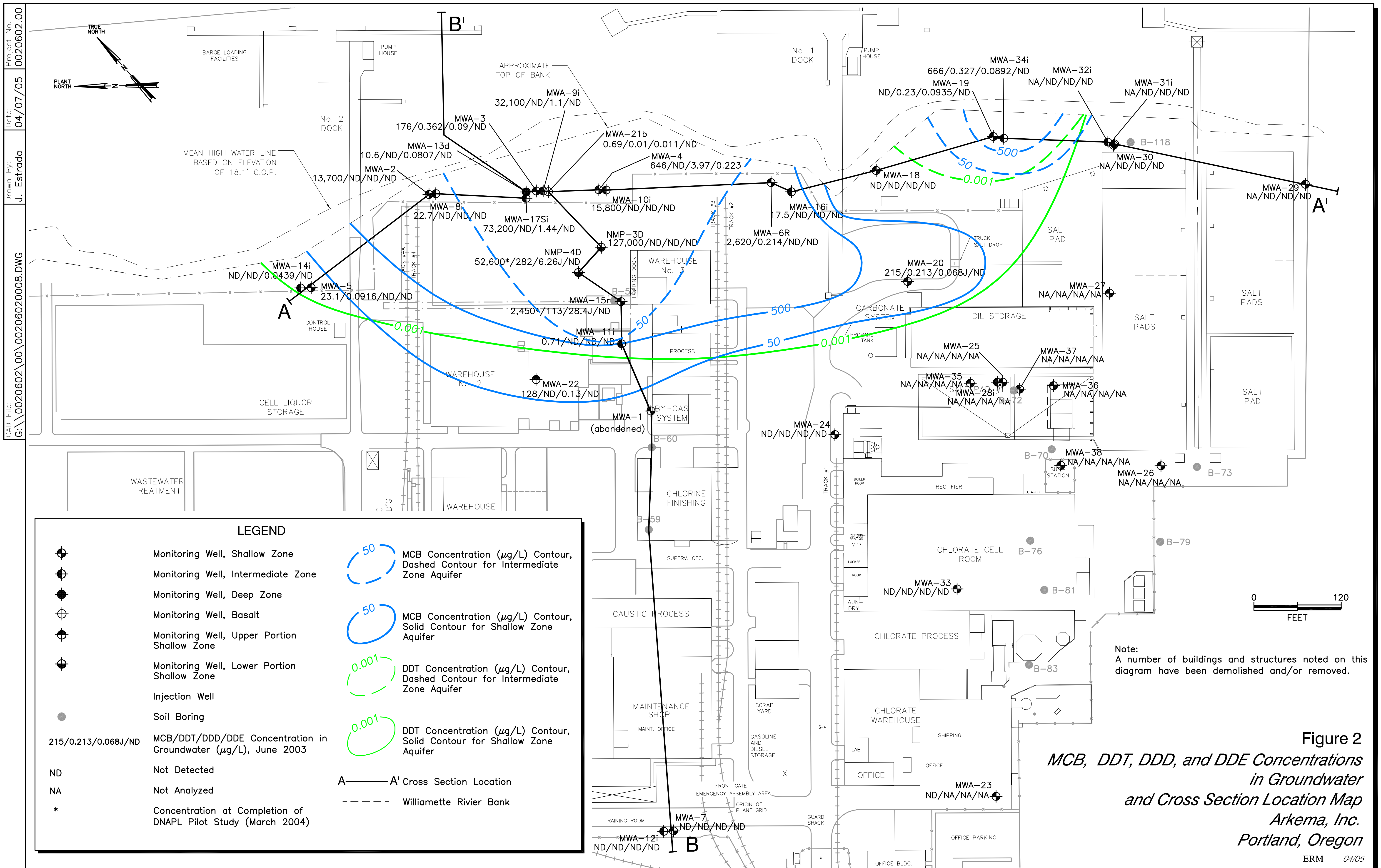

Figure 2

MCB, DDT, DDD, and DDE Concentrations in Groundwater and Cross Section Location Map Arkema, Inc. Portland, Oregon

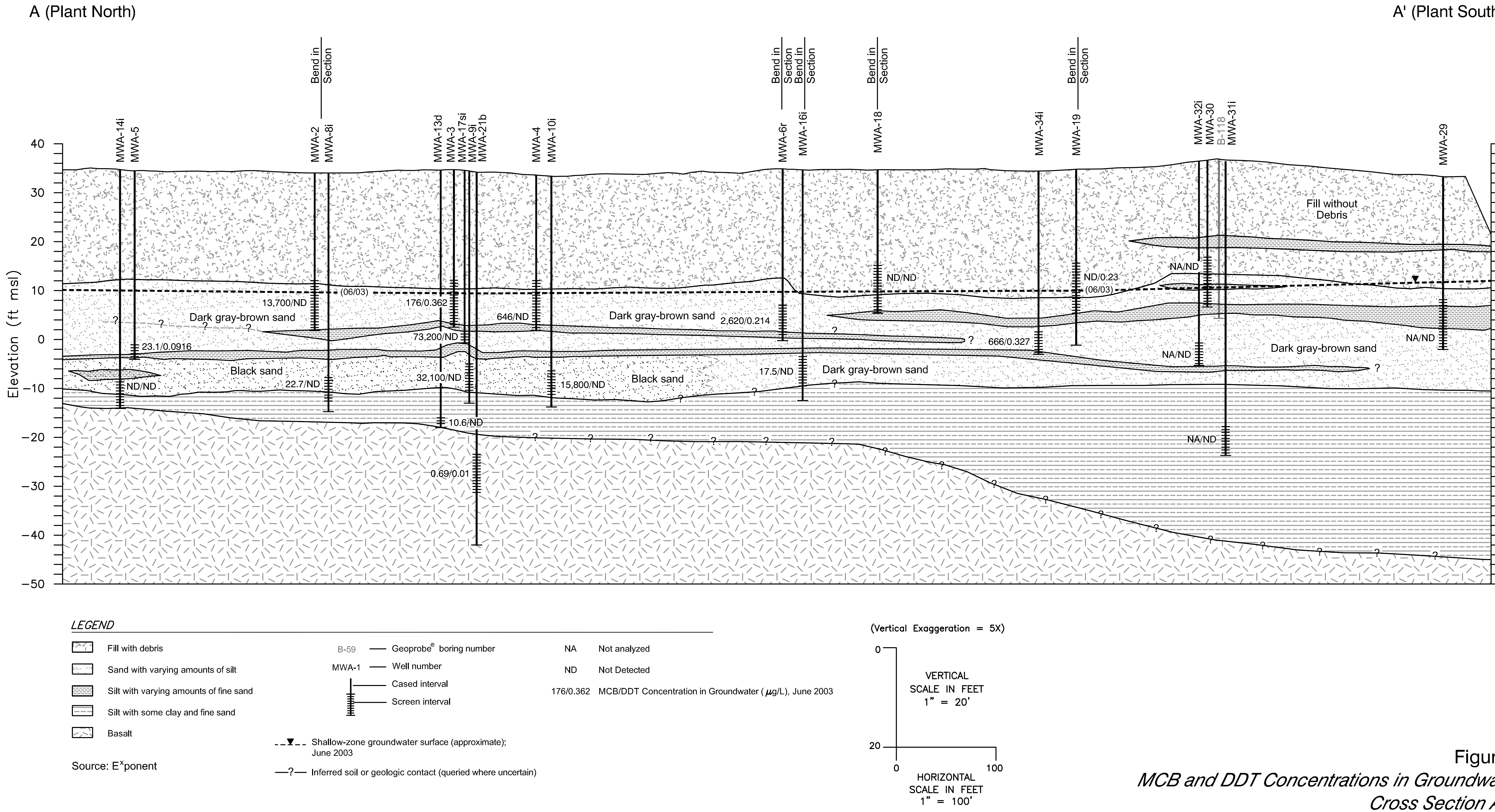

Figure 3

MCB and DDT Concentrations in Groundwater
Cross Section A-A'
Arkema, Inc.
Portland, Oregon

ERM 09/04

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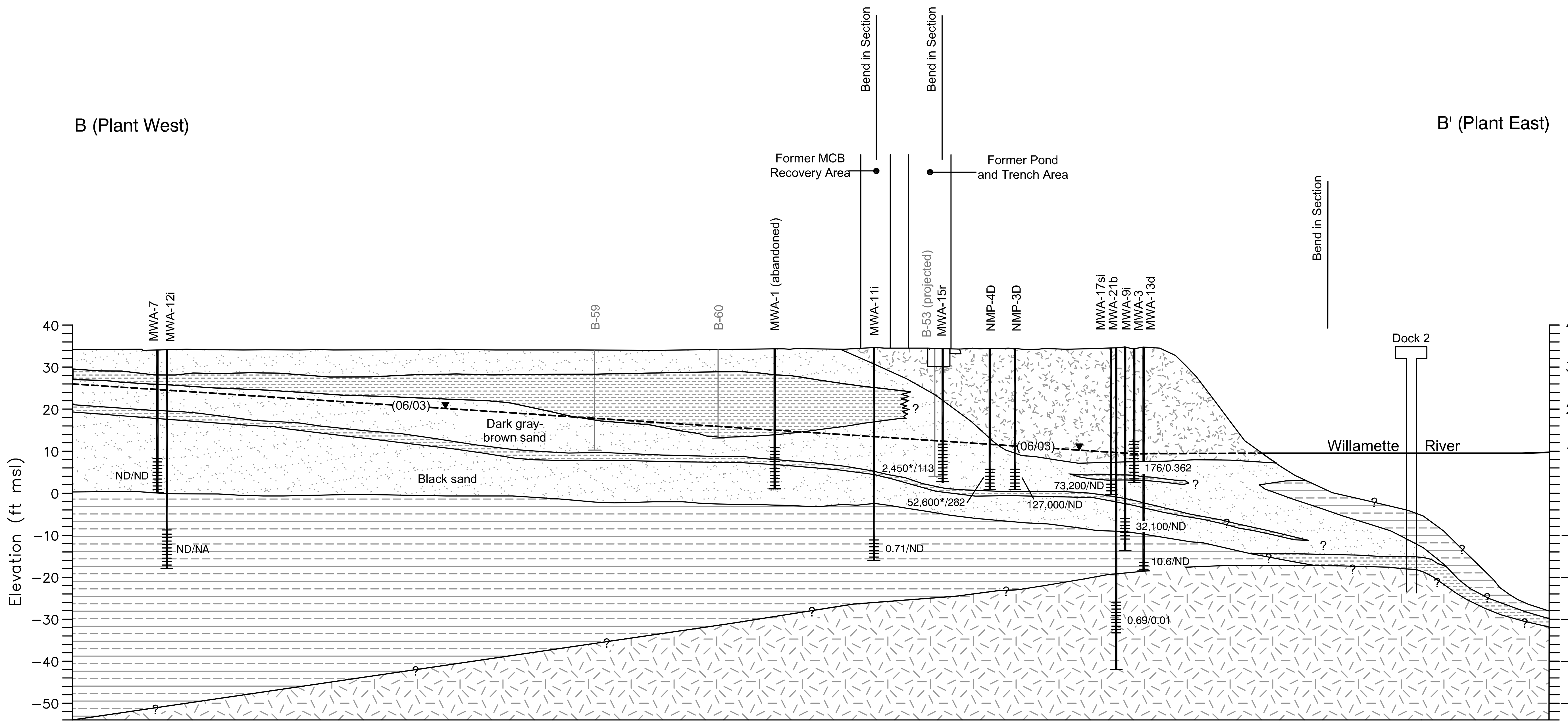
Date: 09/16/04
Project No. 0020602.00



LEGEND

Fill with debris	B-59	Geoprobe® boring number	ND	Not detected above reporting limits
Sand with varying amounts of silt	MWA-1	Well number	NS	Not sampled
Silt with varying amounts of fine sand		Cased interval	*	Concentrations at Completion of DNAPL Pilot Study (March 2004)
Silt with some clay and fine sand		Screen interval	176/0.362	MCB/DDT Concentration in Groundwater (μg/L), June 2003
Basalt		Shallow-zone groundwater surface (approximate); June 2003		
		—?— Inferred soil or geologic contact (queried where uncertain)		

Source: E[x]ponent

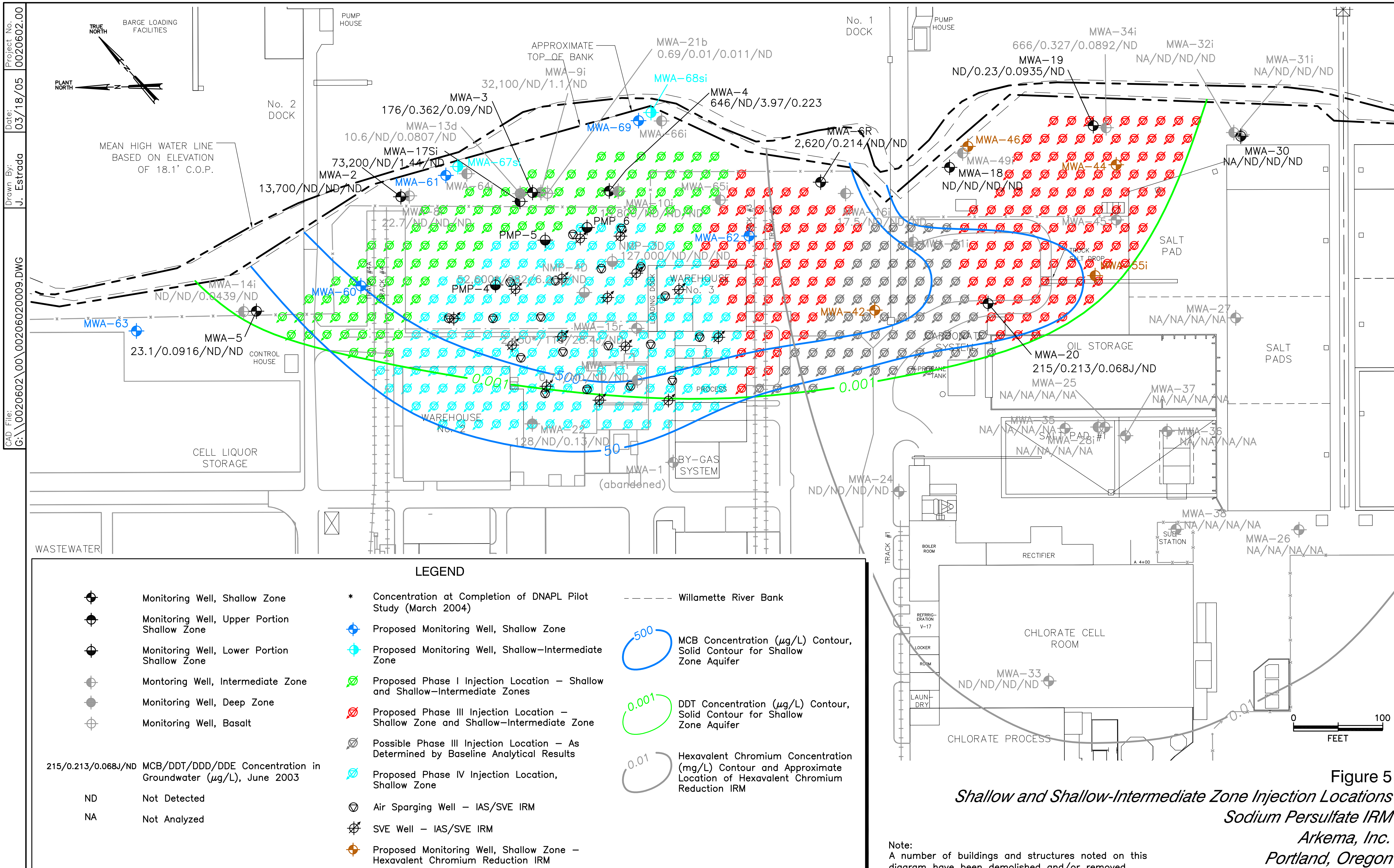
(Vertical Exaggeration = 4X)

0
APPROX. VERTICAL SCALE IN FEET
1" = 25'
25

0 100
APPROX. HORIZONTAL SCALE IN FEET
1" = 100'

Figure 4
MCB and DDT Concentrations in Groundwater
Cross Section B-B'
Arkema, Inc.
Portland, Oregon

ERM 09/04



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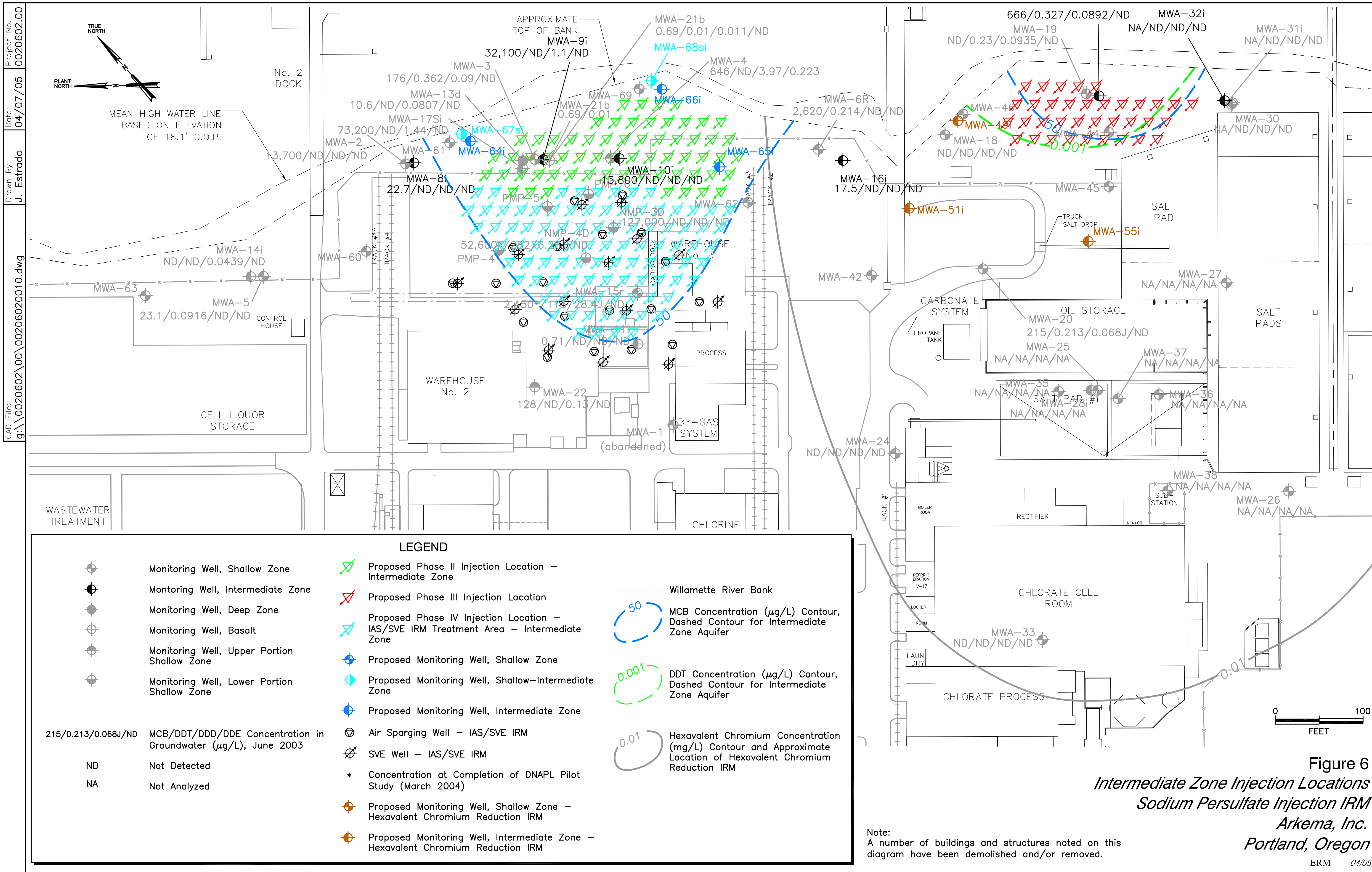
Note:
A number of buildings and structures noted on this diagram have been demolished and/or removed.

Figure 5

Shallow and Shallow-Intermediate Zone Injection Locations
Sodium Persulfate IRM
Arkema, Inc.
Portland, Oregon

ERM 03/05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TRUE NORTH
PLANT NORTH
MEAN HIGH WATER LINE BASED ON ELEVATION OF 18.1' C.O.P.
No. 2 DOCK
APPROXIMATE TOP OF BANK
MWA-9i 32,100/ND/1.1/ND
MWA-3 176/0.362/0.09/ND
MWA-13d 10.6/ND/0.0807/ND
MWA-17Si 73,200/ND/1.44/ND
MWA-2 13,700/ND/ND/ND
MWA-21b 0.69/0.01/0.011/ND
MWA-68si
MWA-4 646/ND/3.97/0.223
MWA-69
MWA-66i
MWA-67si
MWA-64i
MWA-61
MWA-65i
MWA-6R 2,620/0.214/ND/ND
MWA-8i 22.7/ND/ND/ND
MWA-10i 15,800/ND/ND/ND
MWA-16i 17.5/ND/ND/ND
PMP-5
PMP-3D 127,000/ND/ND/ND
MWA-62
PMP-4D
52,600/ND/76.2J/ND
PMP-4
WAREHOUSE No. 3
LOADING DOCK
MWA-15i
2,460/ND/128.4J/ND
0.71/ND/ND/ND
MWA-14i ND/ND/0.0439/ND
MWA-60
MWA-63
MWA-5 23.1/0.0916/ND/ND
CONTROL HOUSE
CELL LIQUOR STORAGE
WAREHOUSE No. 2
MWA-22 128/ND/0.13/ND
PROCESS
MWA-1 (abandoned)
BY-GAS SYSTEM
WASTEWATER TREATMENT
CHLORINE
TRACK #4A
TRACK #4
TRACK #3
TRACK #2
TRACK #1
666/0.327/0.0892/ND
MWA-32i NA/ND/ND/ND
MWA-19 ND/0.23/0.0935/ND
MWA-31i NA/ND/ND/ND
MWA-48
MWA-49i
MWA-44
MWA-18 ND/ND/ND/ND
MWA-30 NA/ND/ND/ND
0.001
50
MWA-45
MWA-51i
TRUCK SALT DROP
MWA-55i
SALT PAD
MWA-42
MWA-27 NA/NA/NA/NA
CARBONATE SYSTEM
OIL STORAGE
MWA-20 215/0.213/0.068J/ND
MWA-25 NA/NA/NA/NA
MWA-37 NA/NA/NA/NA
PROPANE TANK
SALT PADS
MWA-35 NA/NA/NA/NA
SALT PAD #1
MWA-28i NA/NA/NA/NA
MWA-36 NA/NA/NA/NA
MWA-24 ND/ND/ND/ND
MWA-38 NA/NA/NA/NA
SUB STATION
MWA-26 NA/NA/NA/NA
BOILER ROOM
RECTIFIER
REFRIGERATION V-17
LOCKER ROOM
LAUNDRY
CHLORATE CELL ROOM
MWA-33 ND/ND/ND/ND
CHLORATE PROCESS
0.01
0 100 FEET
LEGEND
Monitoring Well, Shallow Zone
Montoring Well, Intermediate Zone
Monitoring Well, Deep Zone
Monitoring Well, Basalt
Monitoring Well, Upper Portion Shallow Zone
Monitoring Well, Lower Portion Shallow Zone
215/0.213/0.068J/ND MCB/DDT/DDD/DDE Concentration in Groundwater (µg/L), June 2003
ND Not Detected
NA Not Analyzed
Proposed Phase II Injection Location – Intermediate Zone
Proposed Phase III Injection Location
Proposed Phase IV Injection Location – IAS/SVE IRM Treatment Area – Intermediate Zone
Proposed Monitoring Well, Shallow Zone
Proposed Monitoring Well, Shallow-Intermediate Zone
Proposed Monitoring Well, Intermediate Zone
Air Sparging Well – IAS/SVE IRM
SVE Well – IAS/SVE IRM
* Concentration at Completion of DNAPL Pilot Study (March 2004)
Proposed Monitoring Well, Shallow Zone – Hexavalent Chromium Reduction IRM
Proposed Monitoring Well, Intermediate Zone – Hexavalent Chromium Reduction IRM
Willamette River Bank
50 MCB Concentration (µg/L) Contour, Dashed Contour for Intermediate Zone Aquifer
0.001 DDT Concentration (µg/L) Contour, Dashed Contour for Intermediate Zone Aquifer
0.01 Hexavalent Chromium Concentration (mg/L) Contour and Approximate Location of Hexavalent Chromium Reduction IRM
Note:
A number of buildings and structures noted on this diagram have been demolished and/or removed.
Figure 6
Intermediate Zone Injection Locations
Sodium Persulfate Injection IRM
Arkema, Inc.
Portland, Oregon
ERM 04/05

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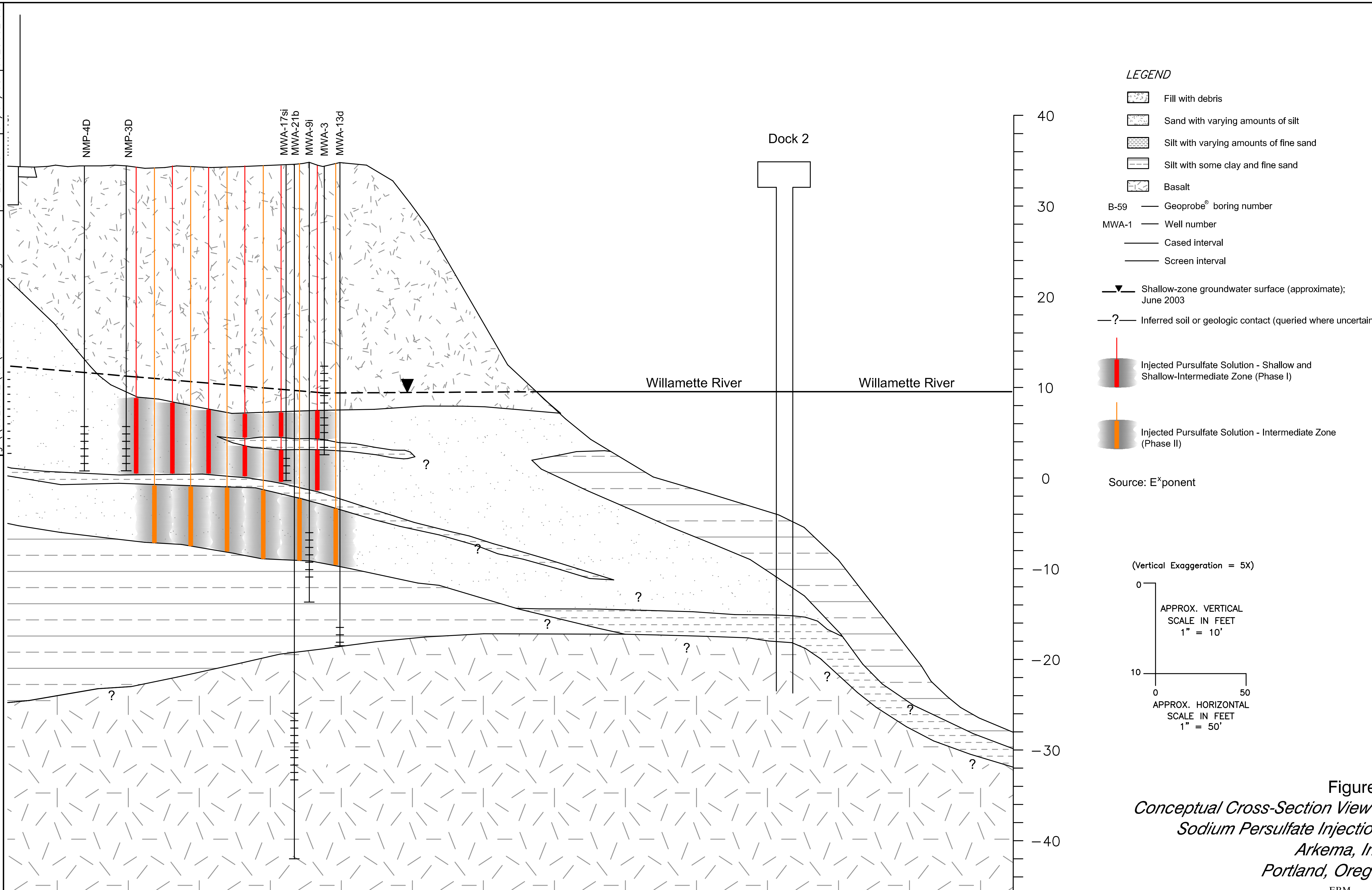

Figure 7
Conceptual Cross-Section View of Sodium Persulfate Injections
Arkema, Inc.
Portland, Oregon

ERM 04/05

Project No. 0020602.00
Date: 08/19/04
Drawn By: J. Estrada
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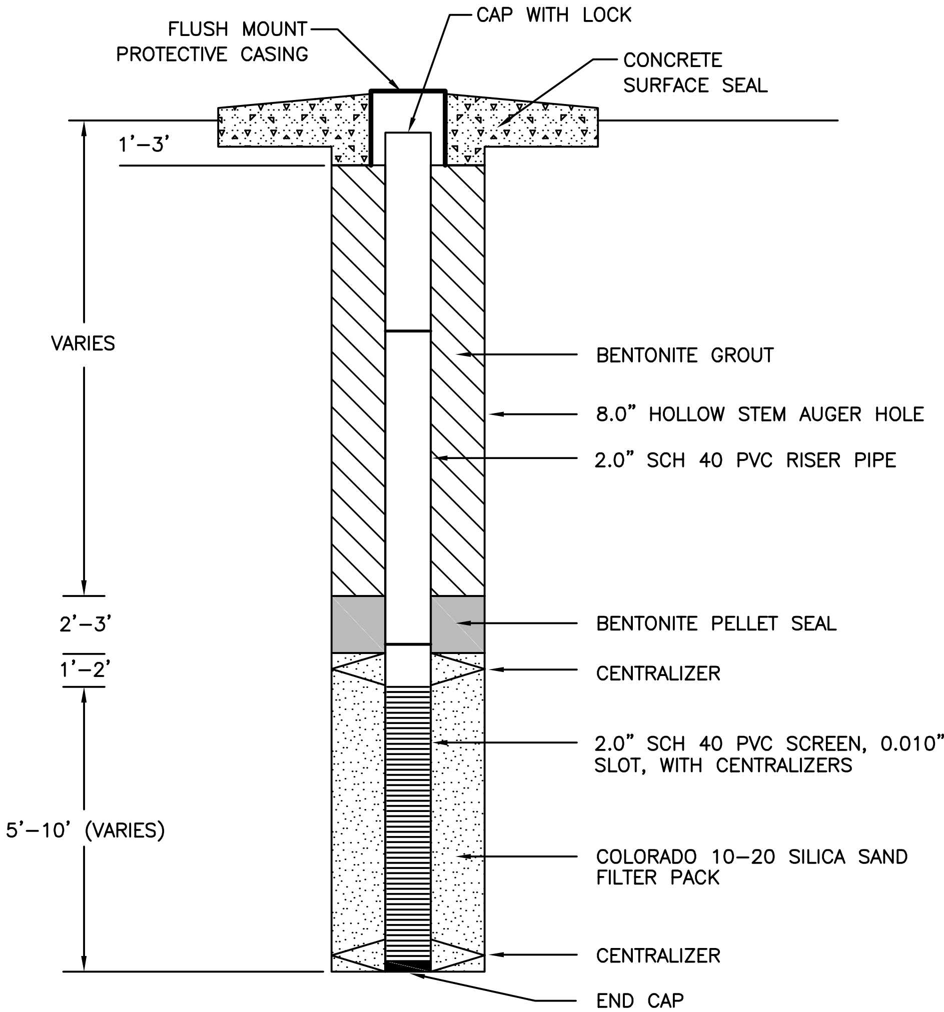


GROUNDWATER MONITORING WELL

NOT TO SCALE

Figure 8
Typical Groundwater Monitoring Well Construction Diagram
Arkema, Inc.
Portland, Oregon

ERM *08/04*

Tables

Table 1
Performance Monitoring Well Summary
Persulfate Oxidation Interim Remedial Measure
Arkema, Inc. Portland, Oregon

Location ID	Groundwater Zone	Total Depth (feet)	Screened Interval (feet bgs)	Material of Construction
MWA-2	Shallow	32.3	21.5-31.5	Stainless Steel & PVC
MWA-3	Shallow	32.1	20.7-30.7	Stainless Steel & PVC
MWA-4	Shallow	30.5	19.5-29.5	Stainless Steel & PVC
MWA-5	Shallow	38.2	35.7-38.2	Stainless Steel & PVC
MWA-6R	Shallow	33.2	28.2-33.2	Stainless Steel & PVC
MWA-15R	Shallow	32.5	23.4-32.4	Stainless Steel & PVC
MWA-18	Shallow	29.2	19.2-29.2	Stainless Steel & PVC
MWA-19	Shallow	29.2	19.2-29.2	Stainless Steel & PVC
MWA-20	Shallow	34.7	24.7-34.7	Stainless Steel & PVC
MWA-22	Shallow	36.0	24.7-34.7	Stainless Steel & PVC
MWA-30	Shallow	29.5	19.1-29.1	Stainless Steel & PVC
MWA-42(1)	Shallow	35	25-35	PVC
MWA-44(1)	Shallow	35	25-35	PVC
MWA-45(1)	Shallow	35	25-35	PVC
MWA-46(1)	Shallow	35	25-35	PVC
MWA-60(2)	Shallow	35	25-35	PVC
MWA-61(2)	Shallow	35	25-35	PVC
MWA-62(2)	Shallow	35	25-35	PVC
MWA-63(2)	Shallow	35	25-35	PVC
MWA-69(2)	Shallow	35	35-35	PVC
NMP-3D	Shallow	37.0	30-35	Stainless Steel & PVC
NMP-4D	Shallow	36.0	30-35	Stainless Steel & PVC
PMP-4	Shallow	32.5	21.6-31.0	PVC
PMP-5	Shallow	33.0	22.2-31.6	PVC
PMP-6	Shallow	36.0	25.9-34.9	PVC
MWA-17si	Shallow-Intermediate	35.3	33.6-35.1	Stainless Steel & PVC
MWA-67si(2)	Shallow-Intermediate	~35	~33.5-35	PVC
MWA-68si(2)	Shallow-Intermediate	~35	~33.5-35	PVC
MWA-8i	Intermediate	47.3	42-47	Stainless Steel & PVC
MWA-9i	Intermediate	46.5	40-45	Stainless Steel & PVC
MWA-10i	Intermediate	45.6	40.3-45.3	Stainless Steel & PVC
MWA-11i	Intermediate	51.3	46-51	Stainless Steel & PVC
MWA-14i	Intermediate	49.1	44.1-49.1	Stainless Steel & PVC
MWA-16i	Intermediate	44.2	39.2-44.2	Stainless Steel & PVC
MWA-32i	Intermediate	44	37-42	Stainless Steel & PVC
MWA-34i	Intermediate	37	32-37	Stainless Steel & PVC
MWA-49i(1)	Intermediate	45	40-45	PVC
MWA-51i(1)	Intermediate	45	40-45	PVC
MWA-55i(1)	Intermediate	45	40-45	PVC
MWA-64i(2)	Intermediate	48	(3)	PVC
MWA-65i(2)	Intermediate	48	(3)	PVC
MWA-66i(2)	Intermediate	48	(3)	PVC

Notes:
1. These wells are proposed for installation as part of the Hexavalent Chromium Reduction IRM.
2. These wells are proposed for installation as part this IRM.
3. The proposed intermediate zone wells will be screened over the entire intermediate zone aquifer.

Table 2
Performance Monitoring Program
Persulfate Oxidation Interim Remedial Measure
Arkema, Inc. Portland, Oregon

Location ID	Groundwater Zone	Baseline Sampling				Phase I - Shallow Zone Injections, North						Phase II - Intermediate Zone Injections, North					Phase III - Shallow and Intermediate Zone Injections, South					Phase IV - IAS/SVE Treatment Area Injections					Phase V - Maintenance Injections					Final				
						2 Weeks	1, 2 and 3 Months After Injections					1 and 2 Months After Injections					1 and 2 Months After Injections					1 and 2 Months After Injections					1 and 2 Months After Injections					2 Months After Last Injections[2]				
		VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}	VOCs (8260B)	Pesticides (8081A)	Sulfate (300.0)	Metals (6000/7470A)[1]	Field SO_4^{-2}
MWA-2	Shallow	(5)	(5)	X	X	X	X	X	X	X	X																TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-3	Shallow	(5)	(5)	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-4	Shallow	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-5	Shallow	X	X	X	X	X	X	X	X	X	X																TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-6R	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-15R	Shallow	(5)	(5)	X	X																	X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-18	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-19	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-20	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-22	Shallow	X	X	X	X																	X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-30	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-42[3]	Shallow	X	X	X	X												X[6]	X[6]	X[6]	X[6]	X[6]						TBD	TBD	TBD	TBD	TBD	X[6]	X[6]	X[6]	X[6]	X[6]
MWA-44[3]	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-45[3]	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-46[3]	Shallow	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-60[4]	Shallow	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-61[4]	Shallow	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-62[4]	Shallow	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-63[4]	Shallow	X	X	X	X	X	X	X	X	X	X																TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-69[4]	Shallow	X	X	X	X	X	X	X	X	X	X																TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
NMP-3D	Shallow	(5)	(5)	X	X																	X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
NMP-4D	Shallow	(5)	(5)	X	X																	X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
PMP-4	Shallow	(5)	(5)	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
PMP-5	Shallow	(5)	(5)	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
PMP-6	Shallow	(5)	(5)	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-17si	Shallow-Intermediate	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-67si[4]	Shallow-Intermediate	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-68si[4]	Shallow-Intermediate	X	X	X	X	X	X	X	X	X	X											X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-8i	Intermediate	(5)	(5)	X	X	X	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-9i	Intermediate	(5)	(5)	X	X	X	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-10i	Intermediate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-11i	Intermediate	X	X	X	X							X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-14i	Intermediate	X	X	X	X	X	X	X	X	X	X																TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-16i	Intermediate	X	X	X	X																						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-32i	Intermediate	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-34i	Intermediate	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-49i[3]	Intermediate	X	X	X	X												X	X	X	X	X						TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-51i[3]	Intermediate	X	X	X	X												X[6]	X[6]	X[6]	X[6]	X[6]						TBD	TBD	TBD	TBD	TBD	X[6]	X[6]	X[6]	X[6]	X[6]
MWA-55i[3]	Intermediate	X	X	X	X												X[6]	X[6]	X[6]	X[6]	X[6]						TBD	TBD	TBD	TBD	TBD	X[6]	X[6]	X[6]	X[6]	X[6]
MWA-64i[4]	Intermediate	X	X	X	X							X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-65i[4]	Intermediate	X	X	X	X							X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X
MWA-66i[4]	Intermediate	X	X	X	X							X	X	X	X	X						X	X	X	X	X	TBD	TBD	TBD	TBD	TBD	X	X	X	X	X

Notes:
1. Metals analyses are for priority pollutant metals: Antimony (Sb), Arsenic (As), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), and Zinc (Zn).
2. Final performance monitoring will be conducted after the second Phase IV performance monitoring event and after all maintenance injections have been completed.
3. These wells are proposed for installation as part of the Hexavalent Chromium Reduction IRM.
4. These wells are proposed for installation as part this IRM.
5. The baseline values for these wells will be determined during the In Situ Air Sparging/Soil Vapor Extraction IRM.
6. MWA-42, MWA-51i, and MWA-55i will only be sampled in performance monitoring events if injections are conducted in the vicinity of these wells, based on baseline monitoring events.
TBD = To be determined.
Field quality control samples (rinsate blanks and field duplicates) will be collected at the rate specified in the Elf Atochem Acid Plant Area Remedial Investigation and Feasibility Study Work Plan (Exponent, September 1998).

Table 3

Injection Program Summary

Persulfate Oxidation Interim Remedial Measure

Arkema, Inc. Portland, Oregon

Injection Phase	Targeted Groundwater Zone	Injection Point Spacing (feet)	Concentration of Oxidant Solution (% by weight)	Number of Injection Points	Depth Interval of Injections (feet bgs)	Total Injection Thickness (feet)	Number of Injection Intevals	Volume of Solution per Interval (gallons)	Volume of Solution per Injection Point (gallons)	Mass of Oxidant per Injection Point (lbs)	Total Volume of Solution per Treatment Area (gal)	Total Mass of Oxidant per Treatment Area (lbs)
Phase I	Shallow/Shallow-Intermediate (<500 μg/L MCB)	20	2	23	20-35	15	3	80	250	40	5,750	920
	Shallow/Shallow-Intermediate (>500 μg/L MCB)	20	15	83	20-35	15	3	290	875	1,120	72,630	92,960
Phase II	Intermediate	20	15	62	40-50	10	2	130	250	320	15,500	19,840
Phase III	Shallow (<500 μg/L MCB)	20	2	169	20-35	15	3	80	250	40	42,250	6,760
	Shallow (>500 mg/L MCB)	20	15	88	20-35	15	3	290	875	1,120	77,000	98,560
	Intermediate	20	15	35	40-50	10	2	130	250	320	8,750	11,200
Phase IV	Shallow/Shallow-Intermediate (<500 mg/L MCB)	20	2	66	20-35	15	3	80	250	40	16,500	2,640
	Shallow/Shallow-Intermediate (>500 mg/L MCB)	20	15	113	20-35	15	3	290	875	1,120	98,880	126,560
	Intermediate	20	15	94	40-50	10	2	130	250	320	23,500	30,080
Phase V[1]	Shallow/Shallow-Intermediate (<500 mg/L MCB)	20	2	TBD(2) (~85)	20-35	15	3	80	250	40	TBD(1) (~21,300)	TBD(1) (~3,400)
	Shallow/Shallow-Intermediate (>500 mg/L MCB)	20	15	TBD(2) (~94)	20-35	15	3	290	875	1,120	TBD(1) (~82,250)	TBD(1) (~105,280)
	Intermediate	20	15	TBD(2) (~58)	40-50	10	2	130	250	320	TBD(1) (~14,500)	TBD(1) (~18,560)

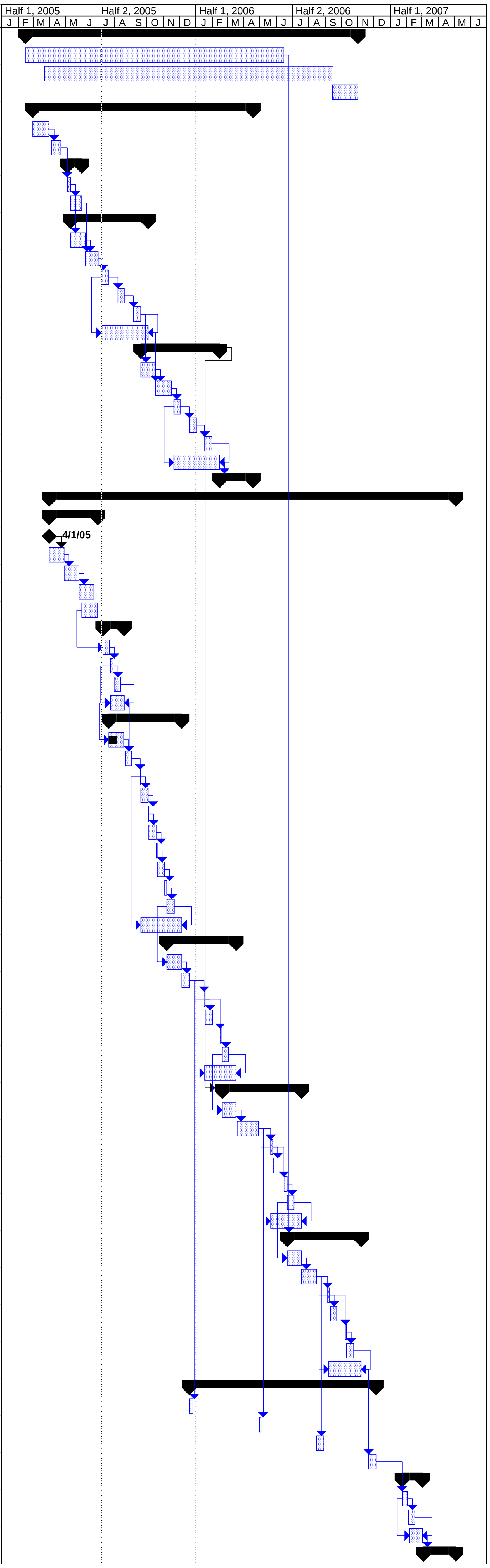
Notes:

1. Phase V is a maintenance injection phase. For estimating purposes, it is assumed that approximately 1/3 (33%) of the injection areas will be retreated.

Appendix A
Persulfate Oxidation IRM
Implementation Schedule

Injection Program Schedule
Persulfate Oxidation Interim Remedial Measure
Arkema, Inc. Portland, Oregon

ID	Task Name	Duration	Start	Finish
1	**IAS/SVE IRM**	**89.6 wks**	**Tue 2/15/05**	**Wed 11/1/06**
2	Operation and Maintenance	69.6 wks	Tue 2/15/05	Thu 6/15/06
3	Performance Monitoring	77.8 wks	Wed 3/23/05	Fri 9/15/06
4	Reporting	6.8 wks	Fri 9/15/06	Wed 11/1/06
5	**Hexavalent Chromium IRM**	**59.2 wks**	**Tue 3/1/05**	**Tue 4/18/06**
6	Work Plan Approval	4.6 wks	Tue 3/1/05	Thu 3/31/05
7	Monitoring Well Installation	14 days	Tue 4/5/05	Fri 4/22/05
8	Baseline Work	**3.8 wks**	**Thu 5/5/05**	**Tue 5/31/05**
9	Baseline Groundwater Sample Collection	4 days	Thu 5/5/05	Tue 5/10/05
10	Data Evaluation	15 days	Wed 5/11/05	Tue 5/31/05
11	Round 1 Injections	**20.8 wks**	**Wed 5/11/05**	**Mon 10/3/05**
12	Subcontracting and Mobilization	20 days	Wed 5/11/05	Tue 6/7/05
13	Injections	18 days	Wed 6/8/05	Fri 7/1/05
14	One Month Monitoring Event	10 days	Fri 7/8/05	Thu 7/21/05
15	Two Month Monitoring Event	10 days	Mon 8/8/05	Fri 8/19/05
16	Three Month Monitoring Event	10 days	Tue 9/6/05	Mon 9/19/05
17	Data Evaluation	62 days	Fri 7/8/05	Mon 10/3/05
18	Round 2 Injections	**21.2 wks**	**Tue 9/20/05**	**Tue 2/14/06**
19	Subcontracting and Mobilization	20 days	Tue 9/20/05	Mon 10/17/05
20	Injections	22 days	Tue 10/18/05	Wed 11/16/05
21	One Month Monitoring Event	10 days	Mon 11/21/05	Fri 12/2/05
22	Two Month Monitoring Event	10 days	Tue 12/20/05	Mon 1/2/06
23	Three Month Monitoring Event	10 days	Wed 1/18/06	Tue 1/31/06
24	Data Evaluation	62 days	Mon 11/21/05	Tue 2/14/06
25	Reporting	**9 wks**	**Wed 2/15/06**	**Tue 4/18/06**
27	**Persulfate Oxidation IRM**	**109.4 wks**	**Fri 4/1/05**	**Fri 5/4/07**
28	**Work Plan Approval**	**13 wks**	**Fri 4/1/05**	**Thu 6/30/05**
29	Work Plan Submittal	0 days	Fri 4/1/05	Fri 4/1/05
30	ODEQ Review and Comment	20 days	Fri 4/1/05	Thu 4/28/05
31	ERM/Arkema Response to Comments	20 days	Fri 4/29/05	Thu 5/26/05
32	ODEQ Response Review and Prep for Public Notice	20 days	Fri 5/27/05	Thu 6/23/05
33	Public Comment	22 days	Wed 6/1/05	Thu 6/30/05
34	Baseline Work	**6 wks**	**Mon 7/11/05**	**Fri 8/19/05**
35	Monitoring Well Installation	10 days	Mon 7/11/05	Fri 7/22/05
36	Baseline Groundwater Sample Collection	5 days	Mon 7/25/05	Fri 7/29/05
37	Sample Analysis	10 days	Mon 8/1/05	Fri 8/12/05
38	Data Evaluation	20 days	Mon 7/25/05	Fri 8/19/05
39	Phase I - Shallow Zone, North	**19.4 wks**	**Fri 7/22/05**	**Mon 12/5/05**
40	Subcontracting and Mobilization	20 days	Fri 7/22/05	Thu 8/18/05
41	Injections - 2 weeks	10 days	Mon 8/22/05	Fri 9/2/05
42	Two Week Monitoring Event	1 day	Mon 9/19/05	Mon 9/19/05
43	Sample Analysis	10 days	Tue 9/20/05	Mon 10/3/05
44	One Month Monitoring Event	1 day	Tue 10/4/05	Tue 10/4/05
45	Sample Analysis	10 days	Wed 10/5/05	Tue 10/18/05
46	Two Month Monitoring Event	2 days	Wed 10/19/05	Thu 10/20/05
47	Sample Analysis	10 days	Fri 10/21/05	Thu 11/3/05
48	Three Month Monitoring Event	2 days	Fri 11/4/05	Mon 11/7/05
49	Sample Analysis	10 days	Tue 11/8/05	Mon 11/21/05
50	Data Evaluation	55 days	Tue 9/20/05	Mon 12/5/05
51	Phase II - Intermediate Zone, North	**18.8 wks**	**Tue 11/8/05**	**Fri 3/17/06**
52	Subcontracting and Mobilization	20 days	Tue 11/8/05	Mon 12/5/05
53	Injections	10 days	Tue 12/6/05	Mon 12/19/05
54	One Month Monitoring Event	2 days	Tue 1/17/06	Wed 1/18/06
55	Sample Analysis	10 days	Thu 1/19/06	Wed 2/1/06
56	Two Month Monitoring Event	2 days	Thu 2/16/06	Fri 2/17/06
57	Sample Analysis	10 days	Mon 2/20/06	Fri 3/3/06
58	Data Evaluation	43 days	Wed 1/18/06	Fri 3/17/06
59	Phase III - Shallow and Intermediate Zones, South	**21.6 wks**	**Mon 2/20/06**	**Tue 7/18/06**
60	Subcontracting and Mobilization	20 days	Mon 2/20/06	Fri 3/17/06
61	Injections	30 days	Mon 3/20/06	Fri 4/28/06
62	One Month Monitoring Event	4 days	Mon 5/22/06	Thu 5/25/06
63	Sample Analysis	0.2 wks	Fri 5/26/06	Fri 5/26/06
64	Two Month Monitoring Event	4 days	Fri 6/16/06	Wed 6/21/06
65	Sample Analysis	10 days	Thu 6/22/06	Tue 7/4/06
66	Data Evaluation	43 days	Mon 5/22/06	Tue 7/18/06
67	Phase IV - IAS/SVE Area	**20 wks**	**Thu 6/22/06**	**Tue 11/7/06**
68	Subcontracting and Mobilization	20 days	Thu 6/22/06	Tue 7/18/06
69	Injections	20 days	Wed 7/19/06	Tue 8/15/06
70	One Month Monitoring Event	3 days	Wed 9/6/06	Fri 9/8/06
71	Sample Analysis	10 days	Mon 9/11/06	Fri 9/22/06
72	Two Month Monitoring Event	2 days	Mon 10/9/06	Tue 10/10/06
73	Sample Analysis	10 days	Wed 10/11/06	Tue 10/24/06
74	Data Evaluation	43 days	Fri 9/8/06	Tue 11/7/06
75	Phase V - Maintenance Injections	**50.4 wks**	**Tue 12/20/05**	**Tue 12/5/06**
76	Shallow Zone, North	5 days	Tue 12/20/05	Mon 12/26/05
77	Intermediate Zone, North	3 days	Mon 5/1/06	Wed 5/3/06
78	Shallow and Intermediate, South	10 days	Wed 8/16/06	Tue 8/29/06
79	IAS/SVE Area	10 days	Wed 11/22/06	Tue 12/5/06
80	Final Performance Monitoring	**5.6 wks**	**Wed 1/24/07**	**Fri 3/2/07**
81	Final Performance Monitoring Sample Collection	8 days	Wed 1/24/07	Fri 2/2/07
82	Sample Analysis	10 days	Mon 2/5/07	Fri 2/16/07
83	Data Evaluation	18 days	Wed 2/7/07	Fri 3/2/07
84	Reporting	**9 wks**	**Mon 3/5/07**	**Fri 5/4/07**



Appendix B
ODEQ UIC Registration Form

DEQ USE ONLY
Registration #:__________
File #:__________
Mail ID #2/#9:__________
DOC Conf.:__________
Notes:__________

UNDERGROUND INJECTION CONTROL REGISTRATION

Aquifer Remediation

Oregon Department of Environmental Quality

(see pp. 3 - 4 for detailed instructions)

DEQ USE ONLY
Received:__________
☐ IND ☐ DOM ☐ UIC: ________
Notes:__________

A. FACILITY NAME, LOCATION & CONTACT

1. Legal Name:	2. Common Name:
3. Facility Physical Address: City, State, Zip Code:	4. Facility Mailing Address: City, State, Zip Code:
5. Latitude: _____ degrees _____ minutes _____ seconds	Longitude: _____ degrees _____ minutes _____ seconds
6. Facility Contact Name: Contact Telephone #: Fax #:	7. Responsible Official Name: Address: City, State, Zip Code:
8. DEQ Contact Name: Region:	Telephone #:

B. FACILITY DESCRIPTION (ATTACH DOCUMENTS AS NEEDED)

1. SIC code: or NAICS code: Secondary SIC/NAICS code:
2. Is this a RCRA/CERCLA site? ☐ Yes ☐ No or **Do you have an ECSI number?** ____________________
3. Briefly describe the nature of business at this facility: ____________________
4. Briefly describe the types of materials, products, and wastes handled at the facility: ____________________
5. Describe the contamination characteristics (Attach analytical results, if available): ____________________
6. Land use zoning of facility: ☐ Industrial ☐ Commercial ☐ Residential ☐ Other: __________
7. Describe the proposed remediation or provide a remedial action plan: ____________________
8. Drinking water source: ☐ Public water ☐ Private Well Distance to nearest domestic water well: __________
9. Depth to winter high water table: _____ feet or Average depth to groundwater: _____
10. Attach documentation illustrating the UIC spill prevention or containment facilities at the site. ☐ Attached
11. List any other DEQ or public agency permits applied for or issued to this facility: ____________________
12. Are stormwater drywells in use at this site? ☐ Yes ☐ No

C. UNDERGROUND INJECTION CONTROL INFORMATION – Go to page 2 of this form.

To expedite the registration of your facility, please fill out this form in its entirety.

D. SIGNATURE OF LEGALLY AUTHORIZED REPRESENTATIVE

I hereby certify that the information contained in this registration is true and correct to the best of my knowledge and belief.

____________________ ____________________

Name of Legally Authorized Representative (Type or Print) **Title**

____________________ ____________________

Signature of Legally Authorized Representative **Date**

UIC REGISTRATION FOR AQUIFER REMEDIATION SYSTEMS

Oregon Department of Environmental Quality

(See pp. 3-4 for detailed instructions)

LEGAL NAME:

C. UNDERGROUND INJECTION CONTROL INFORMATION

Complete the information requested below for each UIC system that is used for aquifer remediation at the facility. Attach additional copies of this sheet if necessary. In addition, attach a facility map that clearly identifies the location of each UIC by name or number.

UIC SYSTEM # or NAME: ____________________ **INSTALLATION DATE:** ____________________

1. Latitude: _____ degrees _____ minutes _____ seconds
   Longitude: _____ degrees _____ minutes _____ seconds
2. Distance to nearest: Domestic/public water well: __________
   Wetland: _____ Other surface water(s): __________
   Attach well log of nearest water well. ☐ Attached
3. Bioremediation fluids discharged: ____________________
4. Discharge rate: ____________________
   Discharge volume: ____________________
5. Status: (see instructions for status definition)
   ☐ Planning stage ☐ Under construction ☐ Active
   ☐ Not in use ☐ Temporarily Abandoned
   ☐ Permanently Abandoned/Decomissioned (date & method): ____________________
6. Characteristics:
   Depth: _____ ft Diameter: _____ ft
   Injection depth of remediation fluids: _____ft
   Type of treatment prior to discharge: ____________________

UIC SYSTEM # or NAME: ____________________ **INSTALLATION DATE:** ____________________

1. Latitude: _____ degrees _____ minutes _____ seconds
   Longitude: _____ degrees _____ minutes _____ seconds
2. Distance to nearest: Domestic/public water well: __________
   Wetland: _____ Other surface water(s): __________
   Attach well log of nearest water well. ☐ Attached
3. Bioremediation fluids discharged: ____________________
4. Discharge rate: ____________________
   Discharge volume: ____________________
5. Status: (see instructions for status definition)
   ☐ Planning stage ☐ Under construction ☐ Active
   ☐ Not in use ☐ Temporarily Abandoned
   ☐ Permanently Abandoned/Decomissioned (date & method): ____________________
6. Characteristics:
   Depth: _____ ft Diameter: _____ ft
   Injection depth of remediation fluids: _____ft
   Type of treatment prior to discharge: ____________________

UIC SYSTEM # or NAME: ____________________ **INSTALLATION DATE:** ____________________

1. Latitude: _____ degrees _____ minutes _____ seconds
   Longitude: _____ degrees _____ minutes _____ seconds
2. Distance to nearest: Domestic/public water well: __________
   Wetland: _____ Other surface water(s): __________
   Attach well log of nearest water well. ☐ Attached
3. Bioremediation fluids discharged: ____________________
4. Discharge rate: ____________________
   Discharge volume: ____________________
5. Status: (see instructions for status definition)
   ☐ Planning stage ☐ Under construction ☐ Active
   ☐ Not in use ☐ Temporarily Abandoned
   ☐ Permanently Abandoned/Decomissioned (date & method): ____________________
6. Characteristics:
   Depth: _____ ft Diameter: _____ ft
   Injection depth of remediation fluids: _____ft
   Type of treatment prior to discharge: ____________________

Use this form to register underground injection control (UIC) systems used for aquifer remediation.

A. FACILITY NAME, LOCATION & CONTACT

1. Enter the legal name of the applicant. This name must be the **legal** Oregon corporate name (i.e., Acme Products, Inc.) or the **legal** representative of the company if the company operates under an assumed business name (i.e., John Smith, dba Acme Products). The name must be a legal, active name registered with the Oregon Department of Commerce, Corporation Division (503) 378-4752, unless otherwise exempted by the Department of Commerce regulations.
2. Enter the common name of this facility if different than the legal name.
3. Enter the physical location of the facility (not mailing address), including city, state, and zip code.
4. Enter the mailing address of the facility if different from the physical location.
5. Enter the latitude and longitude of the approximate center of the facility or site in degrees/minutes/seconds. Latitude and longitude can be obtained from United States Geological Survey (USGS) quadrangle or topographic maps by calling 1-888 ASK-USGS, or by accessing MapBlast's web site at http://www.mapblast.com/mblast/mAdr.mb. DEQ also has instructions for obtaining latitude and longitude from maps at http://waterquality.deq.state.or.us/wq/wqpermit/LatLongInstr.pdf or by calling the number at the end of these instructions.
6. Enter the name, telephone and fax number of the facility contact; this would be the person to call in case there are any questions about this registration.
7. Enter the name and mailing address of the responsible official or organization for this facility, if different from #4.
8. Enter the DEQ representative who is assigned to your site and indicate their region and work telephone number.

B. FACILITY DESCRIPTION

1. Enter the Standard Industrial Classification (SIC) four-digit code **or** North American Industry Classification System five or six-digit code (NAICS) for the facility. These codes are used to describe the primary activity at the facility that generates the most money and may be found on fire marshal reports, insurance papers, or tax forms. The NAICS codes replaced the SIC system in 1997, however, it is usually easy to convert between the two systems so either code is acceptable. SIC or NAICS information is also available from the U.S. Census Bureau at 1-888-756-2427 or at http://www.naics.com/search.htm. Include a secondary code if applicable.
2. Note if this site is part of an EPA-designated RCRA/CERCLA action or part of a state cleanup effort.
3. Briefly describe the nature of business at the facility. For example, "retail clothing store," "gasoline service station with repair shop," "retail and wholesale cabinet store with cabinet manufacturing," or "rental service store for home, yard, and contractor equipment with in-house maintenance shop."
4. Briefly describe the types of materials, products, and wastes handled at the facility. For example, from a service station one might expect "new and used gasoline, diesel, transmission oil, brake fluid, antifreeze, solvents and tires; general cleaners (409, Simple Green, etc.); office wastes; and general garbage."
5. Briefly describe the contamination characteristics of this site, and attach analytical results if available.
6. Indicate if the facility is located on property that is zoned for industrial, commercial, residential, or some other use.
7. Estimate the monthly average usage of drinking water in gallons per day and indicate the source.
8. Estimate the monthly average usage of water for processing or manufacturing purposes and indicate the source.
9. Provide the depth in feet to the winter high water table. If that information is unavailable or unknown, provide the average depth to groundwater in feet from your well log. If you do not have your well log, you may be able to access it through the Oregon Water Resources Department (WRD) web site at http://www.wrd.state.or.us/groundwater/index.shtml, or by calling (503) 378-8455. The Natural Resource Conservation Service in your area may also have this information.
10. Attach documentation illustrating the UIC spill prevention or contamination facilities at the site.
11. In order for DEQ to coordinate with other DEQ offices and public agencies, list all permits applied for or issued to this facility.
12. Stormwater drywells include french drains, drill holes, subsurface trenches, perforated pipes, sumps, etc.

C. UNDERGROUND INJECTION CONTROL (UIC) INFORMATION

Please submit a facility map that clearly identifies the location of each UIC system (specific point of discharge or injection).

For each UIC system, provide the number or name and its installation date. The installation date will be on your well log or permit. Also, for **each** UIC system provide the following:

1. Latitude and longitude. If available, use a Global Positioning System (GPS) unit to determine the latitude and longitude of each system. Otherwise, please provide enough detail in your facility map to clearly identify where your system(s) is located. Use as many reference points on the map as necessary to clearly describe the site.
2. Estimated distance in feet of the UIC system to the nearest domestic or public water supply well, wetland, and other surface water. This information is used by DEQ to evaluate the risk to sensitive sites that could be impacted by accidental spills or contaminated storm water drainage. Attach a well log for the nearest water well.
3. Describe any bioremediation fluids that are being discharged.
4. State the average discharge rate and volume.
5. Whether the UIC system is being planned, under construction, active, inactive, temporarily abandoned, or permanently abandoned (decommissioned). A UIC system is considered "temporarily abandoned" when it is taken out of service but still exists. Owners of temporarily abandoned UICs intend to bring them back into service at a future date. A watertight cap or seal that prevents any materials from entering the UIC must cover temporarily abandoned UICs. A UIC is considered "permanently abandoned" when it is completely filled so that movement of water within the UIC is permanently stopped. With the exception of hand-dug UIC systems, a licensed water well constructor, or the landowner under a Landowner's Water Well Permit, must perform a permanent abandonment. Please see Oregon Administrative Rule (OAR) 690-220-0005 or visit WRD's web page for the rule at http://arcweb.sos.state.or.us/rules/OARS_600/OAR_690/690_220.html for more information. WRD has also developed a well guide that may be of use: *A Consumer's Guide to Water Well Construction, Maintenance and Abandonment* available at http://www.wrd.state.or.us/publication/wellcon99/index.shtml#abandoning. You may also contact WRD at (503) 378-8455. If the UIC system has been permanently abandoned/decommissioned, provide the date and method of closure.
6. The following design characteristics:
   - Depth and diameter in feet
   - The injection depth of the remediation fluids
   - Type of treatment prior to subsurface discharge

D. SIGNATURE OF LEGALLY AUTHORIZED REPRESENTATIVE

The signature of a legally authorized representative must be provided in order to process this registration.

Definition of Legally Authorized Representative:
Please also provide the information requested in brackets *[ ]*

- **Corporation** — president, secretary, treasurer, vice-president, or any person who performs principal business functions; or a manager of one or more facilities that is authorized in accordance to corporate procedure to sign such documents
- **Partnership** — General partner *[list of general partners, their addresses and telephone numbers]*
- **Sole Proprietorship** — Owner(s) *[each owner must sign the application]*
- **City, County, State, Federal, or other Public Facility** — Principal executive officer or ranking elected official
- **Limited Liability Company** — Member *[articles of organization]*
- **Trusts** — Acting trustee *[list of trustees, their addresses and telephone numbers]*

REGISTRATION SUBMITTAL AND QUESTIONS

Send the registration form to the DEQ Water Quality Division:

DEQ Water Quality Division, 811 SW 6th Avenue, Portland, OR 97204
For questions, contact Barbara Priest at (503) 229-5945, or Janice Leber at (503) 229-5189 or at 1-800-452-4011 (toll-free, inside Oregon), TTY (503) 229-6993; Fax: (503) 229-6037.
Or visit the UIC Net Site: http://www.deq.state.or.us/wq/groundwa/uichome.htm

Appendix C
Sodium Persulfate Injection Design Calculations

Environmental Resources Management
915-118th Avenue S.E., Suite 130 – Bellevue, WA 98005
(425) 462-8591 – Fax (425) 455-3573

Purpose: **Calculate volume and mass of sodium persulfate to be injected during IRM.**

Assumptions:

- The MCB and DDT plume is composed of three groundwater zones:
    - Zone 1: Shallow/Shallow-Intermediate zone having MCB concentrations less than 500 ug/L
    - Zone 2: Shallow/Shallow Intermediate zone having MCB concentrations greater than 500 ug/L and up to 73,200 ug/L
    - Zone 3: Intermediate zone having MCB concentrations up to 32,100 ug/L
- The maximum MCB concentration in each zone is used as the design MCB concentration to ensure treatment of the hot spots. This may be a conservative assumption.
- Concentration of DDT and metabolites are insignificant relative to MCB concentration for calculation of oxidant mass required for remediation.
- Saturation thickness = ~15 feet for shallow and shallow-intermediate zone and 10 feet for intermediate zone.
- Treatment area for each injection point = 400 square feet (20′ spacing between points).
- Soil Porosity (n) = 0.25 (typical).
- Soil organic fraction = 0.001
- Soil Density (ρ) = 110 pound/cubic foot / 1760 kg/m^3
- Chlorobenzene Koc = 220 ml/g (EPA 2002)

Calculation Basis:

The volume and mass of sodium persulfate to be injected into groundwater to treat MCB are calculated by evaluating several treatment factors. The calculations are performed in the following order:

1. Calculate total mass of MCB in the treatment areas. Soil/water partition data is used to estimate mass of MCB adsorbed on soil.

2. Calculate mass of persulfate required to oxidize mass of MCB in each zone. Persulfate decomposition rate, the expected time to oxidize MCB, and the total mass of MCB in the treatment zone are used for this calculation.

3. Calculate design treatment volume of persulfate required to achieve the radius of influence at each injection point.

4. Calculate the design concentrations of the persulfate solution required for each treatment zone based on the design treatment volume and the mass of persulfate required to treat each zone.

5. Apply a safety factor to account for site uncertainties.

6. Evaluate results based on past field experience to ensure calculated injection volumes and concentrations are in line with past successful injection programs.

1. MASS OF MCB PER VOLUME UNIT OF AQUIFER MATERIAL IN EACH TREATMENT ZONE:

Zone 1 – Shallow/Shallow- Intermediate Zone with MCB concentrations below 500 ug/L. Use 500 ug/L as design MCB concentration in groundwater.

Dissolved MCB mass/bulk volume = 500 ug/L x 2.205E-09 lb/ug x 28.32 L/ft^3 x 0.25 (porosity)

= 7.8 E-06 pounds dissolved-phase MCB/cubic feet (bulk)

Use partition equation to determine mass of MCB adsorbed on soil.

Kd = (mass MCB sorbed/mass soil)/ (mass MCB in water/volume water) = Koc x foc

Kd = 220 ml/g x 0.001 = 0.22 ml/g

Adsorbed mass of MCB/unit mass of soil = dissolved MCB concentration x Kd

= 500 ug/L x 0.22 ml/g x 1 L/1000 ml x 1 ug/1000 g x 1000 g/kg = 0.11 mg/kg

Adsorbed mass of MCB/unit volume = adsorbed MCB concentration (mg/kg) x ρ

= 0.11 mg/kg x 1760 kg/m^3 x 2.205E-06 lb/mg x 1 m^3/1000 L x 28.32 L/ft^3

= 1.2 E-5 pounds MCB adsorbed per cubic feet (bulk)

Total MCB Mass within Zone 1 per cubic feet of aquifer material

= 7.8 E-06 pounds (diss.) + 1.2 E-5 pounds (ads) = **2.0 E-05 pounds total/cubic feet (bulk)**

Zone 2 – Shallow/Shallow-Intermediate Zone with MCB concentrations above 500 ug/L. Use high concentration of 73,200 ug/L as design MCB concentration in groundwater.

Dissolved MCB mass/bulk volume = 73,200 ug/L x 2.205E-09 lb/ug x 28.32 L/ft^3 x 0.25 (porosity)

= 1.1E-03 pounds dissolved-phase MCB/cubic feet (bulk)

Use partition equation to determine mass of MCB adsorbed on soil.

Kd same as for Zone 1 = 0.22 ml/g

Adsorbed mass of MCB/unit mass of soil = dissolved MCB concentration x Kd

= 73,200 ug/L x 0.22 ml/g x 1 L/1000 ml x 1 ug/1000 g x 1000 g/kg = 16.1 mg/kg

Adsorbed mass of MCB/unit volume = adsorbed MCB concentration (mg/kg) x ρ

= 16.1 mg/kg x 1760 kg/m^3 x 2.205E-06 lb/mg x 1 m^3/1000 L x 28.32 L/ft^3

= 1.8 E-3 pounds MCB adsorbed per cubic feet (bulk)

Total MCB Mass within Zone 2 per cubic feet of aquifer material

= 1.1E-03 pounds (diss.) + 1.8 E-3 pounds (ads) = **2.9 E-03 pounds total/cubic feet (bulk)**

Zone 3 – Intermediate Zone treatment area. Use high concentration of 32,100 ug/L as design MCB concentration in groundwater.

Dissolved MCB mass/bulk volume = 32,100 ug/L x 2.205E-09 lb/ug x 28.32 L/ft^3 x 0.25 (porosity)

= 5.0E-04 pounds dissolved-phase MCB/cubic feet (bulk)

Use partition equation to determine mass of MCB adsorbed on soil.

Kd same as for Zone 1 = 0.22 ml/g

Adsorbed mass of MCB/unit mass of soil = dissolved MCB concentration x Kd

= 32,100 ug/L x 0.22 ml/g x 1 L/1000 ml x 1 ug/1000 g x 1000 g/kg = 7.06 mg/kg

Adsorbed mass of MCB/unit volume = adsorbed MCB concentration (mg/kg) x ρ

= 7.06 mg/kg x 1760 kg/m^3 x 2.205E-06 lb/mg x 1 m^3/1000 L x 28.32 L/ft^3

= 7.8E-04 pounds MCB adsorbed per cubic feet (bulk)

Total MCB Mass within Zone 3 per cubic feet of aquifer material

= 5.0E-04 pounds (diss.) + 7.8E-04 pounds (ads) = **1.3E-03 pounds total/cubic feet (bulk)**

2a. MCB MASS RATIO PER UNIT AREA CALCULATIONS

The equation:

$C_6H_5Cl + 12H_2O + 14Na_2S_2O_8 \rightarrow 6CO_2 + HCl + 14H_2SO_4 + 28\ Na^+ + 14SO_4^{-2}$

gives a molar ratio of sodium persulfate to MCB of 14:1.

Using the molecular weights of 238.2 pounds per pound-mole for sodium persulfate and 112.5 pounds per pound-mole for MCB, the mass ratio of sodium persulfate to MCB = 30:1

Using the mass ratio of 30:1, calculate mass required to oxidize MCB in soil and groundwater based on mass of MCB calculated above. This is calculated for each of the treatment zones:

Zone 1 – Shallow/Shallow-Intermediate zone below 500 ug/L

Oxidant requirement = 2.0E-05 lb total MCB/ft^3 x 30 = 6.0E-04 lbs sodium persulfate/ft^3

Zone 2 – Shallow/Shallow-Intermediate zone above 500 ug/L

Oxidant requirement = 2.9E-03 lb total MCB/ft^3 x 30 = 8.9E-02 lbs sodium persulfate/ft^3

Zone 3 –Intermediate zone

Oxidant requirement = 1.3E-03 lb total MCB/ft^3 x 30 = 3.9E-02 lbs sodium persulfate/ft^3

2b. DECOMPOSITION OF PERSULFATE CALCULATIONS

To account for the natural decomposition of sodium persulfate, the mass required to react with the MCB is scaled up by a factor based on the expected reaction period of the MCB of 60 days and the expected degradation rate of sodium persulfate of 1.1 percent per day. The 60 day reaction period is based on the results of the bench scale testing which showed that little persulfate remained after 60 days. As a conservative estimate, this decomposition is calculated as a true daily rate of 1.1 percent, rather than as a compounded reduction. The following calculation represents the scaling of persulfate dose:

Scaled Persulfate Dose = mass required x (1 + (60 days x 1.1%/day)/100%)

Zone 1 – Shallow/Shallow-Intermediate zone below 500 ug/L

Scaled oxidant requirement = 6.0 E-04 lbs /ft^3 x (1 + (60 days x 1.1%/day)/100%)

= 1.0 E-03 lbs sodium persulfate/ft^3

Zone 2 – Shallow/Shallow-Intermediate zone above 500 ug/L

Scaled oxidant requirement = 8.9E-02 lbs /ft^3 x (1 + (60 days x 1.1%/day)/100%)

=0.148 lbs sodium persulfate/ft^3

Zone 3 –Intermediate zone

Scaled oxidant requirement = 3.9E-02 lbs /ft^3 x (1 + (60 days x 1.1%/day)/100%)

= 0.065 lbs sodium persulfate/ft^3

2c. PERSULFATE MASS PER INJECTION LOCATION CALCULATIONS

Zones 1 & 2 - Shallow and Intermediate Zone:

Using a shallow zone thickness of 15 feet and treatment area of 400 square feet (20 foot grid injection spacing), and the persulfate mass requirements per unit volume calculated above, the mass of sodium persulfate required at each shallow and shallow-intermediate injection location is:

Zone 1: 400 ft^2 x 15 ft x 1.0E-03 pounds persulfate/cubic feet

= 6.0 pounds sodium persulfate per location

Zone 2: 400 ft^2 x 15 ft x 0.148 pounds persulfate/cubic feet

= 886 pounds sodium persulfate per location

Zone 3 - Intermediate Zone

Using an intermediate zone thickness of 10 feet and treatment area of 400 square feet, the mass of sodium persulfate required at each intermediate zone injection location is:

Environmental Resources Management
915-118th Avenue S.E., Suite 130 – Bellevue, WA 98005
(425) 462-8591 – Fax (425) 455-3573

400 ft^2 x 10 ft x 0.065 pounds persulfate/cubic feet

= 260 pounds sodium persulfate per location

3. MINIMUM VOLUME OF PERSULFATE SOLUTION CALCULATIONS

A persulfate pilot test was conducted in 2001 to determine design criteria for the IRM. The pilot test indicated a radius of influence in excess of 40 feet per injection point based an injection volume of approximately 2,500 gallons (4% solution). Based on these results, a minimum volume of 0.5 gallons/ft^2 (2,500 gallons/[3.24 x 40 feet x 40 feet]) is assumed for calculating the minimum radius of influence.

For the well spacing of 20 feet proposed for this IRM (400 ft^2), a minimum volume of 200 gallons of solution would be required to correspond to the result obtained from the pilot test.

4. DESIGN PERSULFATE SOLUTION CONCENTRATION CALCULATIONS

Zone 1 – Shallow/Shallow Intermediate zone below 500 ug/L

Oxidant requirement = 6.0 pounds sodium persulfate per location

Solution % = 6.0 lb_{pers} /(8.5 lb_{pers}/gal_{sol} x 200 gal_{sol})

= **0.35% solution (200 gallons)**

Zone 2 – Shallow/Shallow Intermediate zone above 500 ug/L

Oxidant requirement = 886 pounds sodium persulfate per location

Solution % = 886 lb_{pers}/(8.5 lb_{pers}/gal_{sol} x 200 gal_{sol})

= **52.1% solution (200 gallons)**

Zone 3 –Intermediate zone

Oxidant requirement = 260 pounds sodium persulfate per location

Solution % = 260 lb_{pers} /(8.5 lb_{pers}/gal_{sol} x 200 gal_{sol})

= **15.3% solution (200 gallons)**

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(425) 462-8591 – Fax (425) 455-3573

5. SAFETY FACTOR CALCULATIONS

To account for uncertainties related in site heterogeneities, possible localized MCB hot spots, and other unaccounted for persulfate demands, a safety factor of 25% will be added to the calculated persulfate mass. Based on the application of this safety factor, the minimum injection will be increased to 250 gallons.

6. COMPARISION TO PAST SUCCESSFUL INJECTION PROGRAMS

Zone 1: Past injection programs have used minimum persulfate solution concentrations of 2%. This ensures that an adequate concentration of persulfate is available in the subsurface to treat the contaminats. As a result, a minimum of a 2% solution is recommended for this zone.

Zone 3: For ease of mixing, documentation, and injection tracking, persulfate concentrations are typically mixed to rounded concentrations. As a result, it is recommended that the calculated concentration of the Zone 2 injections be adjusted from 15.3 % to 15% and the volume adjusted accordingly (i.e., 250 gallons x 15.3%/15% = 255 gallons) for this zone.

Zone 2: Since the injection in Zone 2 and Zone 3 will be occurring through the same borehole, the concentration of the solution must be the same for the two Zones. As a result, the concentration should be adjusted from 52.1% to 15% and the volume adjusted accordingly (i.e., 250 gallons x 52.1%/15% = 868 gallons) for this zone.

7. RECOMMENDED INJECTION VOLUMES PER INJECTION POINT

The recommended volume and concentration of persulfate solutions (rounded to nearest 25 gallons) to be injected are as follows:

Zone 1 – 250 gallons of 2% solution

Zone 2 – 875 gallons of 15% solution

Zone 3 – 250 gallons of 15% solution

Note: *As part of the Hex. Chrome IRM, a comparison of injection volumes to the seasonal groundwater fluctuations was conducted to verify that the injections would not adversely effect groundwater flows at the site. The evaluation for the Hex. Chrome IRM indicated that groundwater would not be adversely effected (i.e., mounding, flow reversals, excessive displacement) by the injections. The volumes per injection point for the persulfate IRM are significantly lower (~5 times) than the Hex. Chrome IRM. As a result, hydrogeologic conditions are not expected to be affected by the persulfate injection program.*

Appendix D
Material Safety Data Sheets for Sodium Persulfate

MATERIAL SAFETY DATA SHEET

Sodium Persulfate

MSDS Ref. No.: 7775-27-1
Date Approved: 04/28/2004
Revision No.: 8

This document has been prepared to meet the requirements of the U.S. OSHA Hazard Communication Standard, 29 CFR 1910.1200; the Canada's Workplace Hazardous Materials Information System (WHMIS) and, the EC Directive, 2001/58/EC.

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:	Sodium Persulfate
SYNONYMS:	Sodium Peroxydisulfate; Disodium Peroxydisulfate
ALTERNATE PRODUCT NAME(S):	RemedOx™
GENERAL USE:	Polymerization initiator. Etchant and cleaner in manufacture of printed circuit boards. Booster in hair bleaching formulations in cosmetics. Secondary oil recovery systems as a polymerization initiator and a gel breaker.

MANUFACTURER

FMC CORPORATION
Active Oxidants Division
1735 Market Street
Philadelphia, PA 19103
(215) 299-6000 (General Information)

EMERGENCY TELEPHONE NUMBERS

(800) 424-9300 (CHEMTREC - U.S.)
(303) 595-9048 (Medical - Call Collect)

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW:

- White, odorless, crystals
- Oxidizer: Decomposes in storage under conditions of moisture (water/water vapor) and/or excessive heat causing release of oxides of sulfur, nitrogen and oxygen that supports combustion. Decomposition could form a high temperature melt.

POTENTIAL HEALTH EFFECTS: Airborne persulfate dust may be irritating to eyes, nose, lungs, throat and skin upon contact. Exposure to high levels of persulfate dust may cause difficulty in breathing in sensitive persons.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name	CAS#	Wt.%	EC No.	EC Class
Sodium Persulfate	7775-27-1	>99	231-892-1	Not classified as hazardous

4. FIRST AID MEASURES

EYES: Flush with plenty of water. Get medical attention if irritation occurs and persists.

SKIN: Wash with plenty of soap and water. Get medical attention if irritation occurs and persists.

INGESTION: Rinse mouth with water. Dilute by giving 1 or 2 glasses of water. Do not induce vomiting. Never give anything by mouth to an unconscious person. See a medical doctor immediately.

INHALATION: Remove to fresh air. If breathing difficulty or discomfort occurs and persists, contact a medical doctor.

NOTES TO MEDICAL DOCTOR: This product has low oral toxicity and is not irritating to the eyes and skin. Flooding of exposed areas with water is suggested, but gastric lavage or emesis induction for ingestions must consider possible aggravation of esophageal injury and the expected absence of system effects. Treatment is controlled removal of exposure followed by symptomatic and supportive care.

5. FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA: Deluge with water.

FIRE / EXPLOSION HAZARDS: Product is non-combustible. On decomposition releases oxygen which may intensify fire. Presence of water accelerates decomposition.

FIRE FIGHTING PROCEDURES: Do not use carbon dioxide or other gas filled fire extinguishers; they will have no effect on decomposing persulfates. Wear full protective clothing and self-contained breathing apparatus.

FLAMMABLE LIMITS: Non-combustible

SENSITIVITY TO IMPACT: No data available

SENSITIVITY TO STATIC DISCHARGE: No data available

6. ACCIDENTAL RELEASE MEASURES

RELEASE NOTES: Spilled material should be collected and put in approved DOT container and isolated for disposal. Isolated material should be monitored for signs of decomposition (fuming/smoking). If spilled material is wet, dissolve with large quantity of water and dispose as a hazardous waste. All disposals should be carried out according to regulatory agencies procedures.

7. HANDLING AND STORAGE

HANDLING: Use adequate ventilation when transferring product from bags or drums. Wear respiratory protection if ventilation is inadequate or not available. Use eye and skin protection. Use clean plastic or stainless steel scoops only.

STORAGE: Store (unopened) in a cool, clean, dry place away from point sources of heat, e.g. radiant heaters or steam pipes. Use first in, first out storage system. Avoid contamination of opened product. In case of fire or decomposition (fuming/smoking) deluge with plenty of water to control decomposition. For storage, refer to NFPA Bulletin 430 on storage of liquid and solid oxidizing materials.

COMMENTS: VENTILATION: Provide mechanical general and/or local exhaust ventilation to prevent release of dust into work environment. Spills should be collected into suitable containers to prevent dispersion into the air.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

EXPOSURE LIMITS

Chemical Name	ACGIH	OSHA	Supplier
Sodium Persulfate	0.1 mg/m^3 (TWA)		

ENGINEERING CONTROLS: Provide mechanical local general room ventilation to prevent release of dust into the work environment. Remove contaminated clothing immediately and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT

EYES AND FACE: Use cup type chemical goggles. Full face shield may be used.

RESPIRATORY: Use approved dust respirator when airborne dust is expected.

PROTECTIVE CLOTHING: Normal work clothes. Rubber or neoprene footwear.

GLOVES: Rubber or neoprene gloves. Thoroughly wash the outside of gloves with soap and water prior to removal. Inspect regularly for leaks.

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9. PHYSICAL AND CHEMICAL PROPERTIES

ODOR:	None
APPEARANCE:	White crystals
AUTOIGNITION TEMPERATURE:	Not applicable. No evidence of combustion up to 800°C. Decomposition will occur upon heating.
BOILING POINT:	Not applicable
COEFFICIENT OF OIL / WATER:	Not applicable
DENSITY / WEIGHT PER VOLUME:	Not available
EVAPORATION RATE:	Not applicable (Butyl Acetate = 1)
FLASH POINT:	Non-combustible
MELTING POINT:	Decomposes
ODOR THRESHOLD:	Not applicable
OXIDIZING PROPERTIES:	Oxidizer
PERCENT VOLATILE:	Not applicable
pH:	typically 5.0 - 7.0 @ 25 °C (1% solution)
SOLUBILITY IN WATER:	73 % @ 25 °C (by wt.)
SPECIFIC GRAVITY:	2.6 (H_2O=1)
VAPOR DENSITY:	Not applicable (Air = 1)
VAPOR PRESSURE:	Not applicable

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10. STABILITY AND REACTIVITY

CONDITIONS TO AVOID:	Heat and moisture.
STABILITY:	Stable (becomes unstable in presence of heat, moisture and contamination).
POLYMERIZATION:	Will not occur
INCOMPATIBLE MATERIALS:	Acids, alkalis, halides (fluorides, chlorides, bromides), combustible materials, heavy metals, oxidizable materials, reducing agents and organic compounds.

HAZARDOUS DECOMPOSITION PRODUCTS: Oxygen that supports combustion and oxides of sulfur and nitrogen.

11. TOXICOLOGICAL INFORMATION

EYE EFFECTS: Non-irritating (rabbit) [FMC Study Number: ICG/T-79.029]

SKIN EFFECTS: Non-irritating (rabbit) [FMC Study Number: ICG/T-79.029]

DERMAL LD_{50}: > 10 g/kg [FMC Study Number: ICG/T-79.029]

ORAL LD_{50}: 895 mg/kg (rat) [FMC Study Number: ICG/T-79.029]

INHALATION LC_{50}: 5.1 mg/l (rat) [FMC I95-2017]

SENSITIZATION: May be sensitizing to allergic persons. [FMC Study Number: ICG/T-79.029]

TARGET ORGANS: Eyes, skin, respiratory passages

ACUTE EFFECTS FROM OVEREXPOSURE: Dust may be harmful and irritating. May be harmful if swallowed.

CHRONIC EFFECTS FROM OVEREXPOSURE: Sensitive persons may develop dermatitis and asthma [Respiration 38:144, 1979]. Groups of male and female rats were fed 0, 300 or 3000 ppm sodium persulfate in the diet for 13 weeks, followed by 5000 ppm for 5 weeks. Microscopic examination of tissues revealed some injury to the gastrointestinal tract at the high dose (3000 ppm) only. This effect is not unexpected for an oxidizer at high concentrations. [Ref. FMC I90-1151, Toxicologist 1:149, 1981].

CARCINOGENICITY:

NTP:	Not listed
IARC:	Not listed
OSHA:	Not listed
OTHER:	ACGIH: Not listed

12. ECOLOGICAL INFORMATION

ECOTOXICOLOGICAL INFORMATION:

Bluegill sunfish, 96-hour LC_{50} = 771 mg/L [FMC Study I92-1250]
Rainbow trout, 96-hour LC_{50} = 163 mg/L [FMC Study I92-1251]
Daphnia, 48-hour LC_{50} = 133 mg/L [FMC Study I92-1252]

Grass shrimp, 96-hour LC_{50} = 519 mg/L [FMC Study I92-1253]

CHEMICAL FATE INFORMATION: Biodegradability does not apply to inorganic substances.

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD: Dispose as a hazardous waste in accordance with local, state and federal regulatory agencies.

14. TRANSPORT INFORMATION

U.S. DEPARTMENT OF TRANSPORTATION (DOT)

PROPER SHIPPING NAME:	Sodium Persulfate
PRIMARY HAZARD CLASS / DIVISION:	5.1 (Oxidizer)
UN/NA NUMBER:	UN 1505
PACKING GROUP:	III
LABEL(S):	5.1 (Oxidizer)
PLACARD(S):	5.1 (Oxidizer)
MARKING(S):	Sodium Persulfate, UN 1505
ADDITIONAL INFORMATION:	Hazardous Substance/RQ: Not applicable 49 STCC Number: 4918733 This material is shipped in 225 lb. fiber drums, 55 lb. poly bags and 1000 - 2200 lb. IBC's (supersacks).

INTERNATIONAL MARITIME DANGEROUS GOODS (IMDG)

PROPER SHIPPING NAME:	Sodium Persulfate

INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO) / INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA)

PROPER SHIPPING NAME:	Sodium Persulfate

OTHER INFORMATION:

Protect from physical damage. Do not store near acids, moisture or heat.

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15. REGULATORY INFORMATION

UNITED STATES

SARA TITLE III (SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT)

SECTION 302 EXTREMELY HAZARDOUS SUBSTANCES (40 CFR 355, APPENDIX A):
Not applicable

SECTION 311 HAZARD CATEGORIES (40 CFR 370):
Fire Hazard, Immediate (Acute) Health Hazard

SECTION 312 THRESHOLD PLANNING QUANTITY (40 CFR 370):
The Threshold Planning Quantity (TPQ) for this product, if treated as a mixture, is 10,000 lbs; however, this product contains the following ingredients with a TPQ of less than 10,000 lbs.: None

SECTION 313 REPORTABLE INGREDIENTS (40 CFR 372):
Not listed

CERCLA (COMPREHENSIVE ENVIRONMENTAL RESPONSE COMPENSATION AND LIABILITY ACT)

CERCLA DESIGNATION & REPORTABLE QUANTITIES (RQ) (40 CFR 302.4):
Unlisted, RQ = 100 lbs., Ignitability

TSCA (TOXIC SUBSTANCE CONTROL ACT)

TSCA INVENTORY STATUS (40 CFR 710):
Listed

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)
RCRA IDENTIFICATION OF HAZARDOUS WASTE (40 CFR 261):
Waste Number: D001

CANADA

WHMIS (WORKPLACE HAZARDOUS MATERIALS INFORMATION SYSTEM):

Product Identification Number:	1505
Hazard Classification / Division:	Class C (Oxidizer), Class D, Div. 2, Subdiv. B. (Toxic)
Ingredient Disclosure List:	Listed

INTERNATIONAL LISTINGS

Sodium persulfate:
Australia (AICS): Listed
China: Listed
Japan (ENCS): (1)-1131

Korea: KE-12369
Philippines (PICCS): Listed

16. OTHER INFORMATION

HMIS

Health	1
Flammability	0
Physical Hazard	1
Personal Protection (PPE)	J

Protection = J (Safety goggles, gloves, apron & combination dust & vapor respirator)

HMIS = Hazardous Materials Identification System

Degree of Hazard Code:
4 = Severe
3 = Serious
2 = Moderate
1 = Slight
0 = Minimal

NFPA

Health	1
Flammability	0
Reactivity	1
Special	OX

SPECIAL = OX (Oxidizer)

NFPA = National Fire Protection Association

Degree of Hazard Code:
4 = Extreme
3 = High
2 = Moderate
1 = Slight
0 = Insignificant

REVISION SUMMARY:
This MSDS replaces Revision #7, dated March 10, 2004.
Changes in information are as follows:
Section 1 (Product and Company Identification)
Section 16 (Other Information)

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