

FINAL

**ENHANCED BIOREMEDIATION PILOT STUDY
WORK PLAN**

SILTRONIC CORPORATION

Prepared for
Siltronic Corporation
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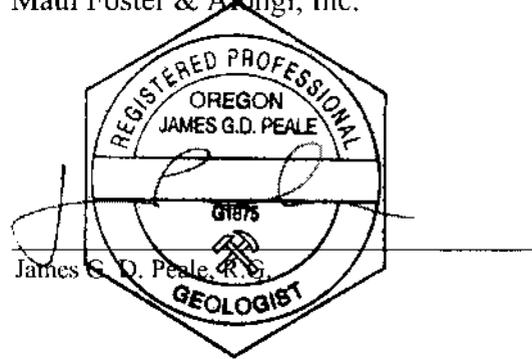
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Siltronic Corporation**

The material and data in this report were prepared under the supervision and direction of the undersigned.

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ACRONYMS AND ABBREVIATIONS

AAI	Adventus Americas, Inc.
BAZ	biologically active zone
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cVOC	chlorinated volatile organic compound
DCE	dichloroethene
DEQ	Oregon Department of Environmental Quality
DP	direct-push
FS	Feasibility Study
JSCS	Joint Source Control Strategy
MFA	Maul Foster & Alongi, Inc.
MGP	manufactured gas plant
µg/L	micrograms per liter
ppm	parts per million
PAH	polycyclic aromatic hydrocarbon
OAR	Oregon Administrative Rules
the Order	<i>Order Requiring Remedial Investigation and Source Control Measures</i>
ORS	Oregon Revised Statutes
OWRD	Oregon Water Resources Department
RI	remedial investigation
Siltronic	Siltronic Corporation
TCE	trichloroethene
TOC	total organic carbon
UIC	underground injection control
USEPA	U.S. Environmental Protection Agency
UST	underground storage tank
VFA	volatile fatty acid
VOC	volatile organic compound
ZVI	zero-valent iron

1 INTRODUCTION

Maul Foster & Alongi, Inc. (MFA) has prepared this work plan (the Work Plan) for conducting an enhanced bioremediation pilot study for the Siltronic Corporation (Siltronic) facility located at 7200 NW Front Avenue, Portland, Oregon. Siltronic is in the process of completing a remedial investigation (RI) per the *Order Requiring Remedial Investigation and Source Control Measures* (the Order), Oregon Department of Environmental Quality (DEQ) No. VC-NWR-03-16, issued to Siltronic on February 9, 2004. Section 5.B of the Order states that Siltronic shall identify and evaluate source control measures, and that the DEQ will review and approve these measures pursuant to Oregon Administrative Rules (OAR) 340-122-0070 and through consultation with the United States Environmental Protection Agency (USEPA). The pilot study will be completed consistent with OAR 340-122-0070 and related regulations OAR 340-122-0040(1), (5), and (6).

This pilot study is occurring within upland areas adjacent to the Portland Harbor National Priorities List (NPL, or Superfund) site. As such, it is within the jurisdiction of DEQ, consistent with the 2001 Memorandum of Understanding between DEQ, USEPA and partners, and consistent with the Joint Source Control Strategy for the Portland Harbor (JSCS) (DEQ and USEPA, 2005).

The results of the pilot study are expected to inform the Feasibility Study (FS) with respect to the selection of a site-wide remedy. The results will be applicable to areas of the site under both DEQ's and USEPA's jurisdiction. The results will also be directly applicable in developing a source control measure, should that approach be pursued. The pilot study work plan is based on treatability study guidance from USEPA and is therefore consistent with the National Contingency Plan, as required for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions.

1.1 Site Documentation

Several documents have been prepared or are in progress that present site conditions and/or test results. These include the Supplemental Investigation Report (MFA, 2005), Draft Source Control Evaluation Work Plan (MFA, 2006), RI Report (in progress), and Enhanced Bioremediation Bench Test Report (Appendix A).

The results of the RI indicate that an evaluation of source control measures is warranted. Trichloroethene (TCE) and its degradation products (specifically, cis-1,2-dichloroethene (DCE), trans-1,2-DCE, and vinyl chloride) were detected in deep upland groundwater, and in two separate and distinct areas of transition-zone water (and limited areas of surface water) in the Willamette River. The concentrations of TCE and its degradation products exceeded screening levels identified in the JSCS, suggesting potential risk to human health and the environment.

The draft Source Control Evaluation Work Plan included a technology alternatives screening that was completed consistent with USEPA Engineering Evaluation/Cost Analysis guidance under CERCLA. The screening is included in this work plan as Appendix B. The technology screen indicated that enhanced bioremediation warranted a site-specific evaluation. As a result, MFA conducted a bench scale test of several enhanced bioremediation technologies.

The bench test results indicate that a combination of a naturally occurring microbial inoculum (KB-1^{TM1} by SiREM Laboratory) and a slow release carbon source with zero-valent iron (ZVI) (EHC^{TM2} by Adventus Americas, Inc. [AAI]) provided the best evidence of complete degradation of TCE to ethene given the site conditions. Based on the bench test results and known subsurface conditions, an in-situ pilot study of the KB-1 and EHC products is warranted. The bench test report is included as Appendix A.

Implementation of the Pilot Study work was approved by DEQ based on the draft Work Plan (dated April 10, 2006), a draft Addendum (dated April 14, 2006), and subsequent meetings and communications between Siltronic and DEQ. DEQ provided comments on the draft Work Plan and Addendum on June 15, 2006; MFA provided a response to the comments on June 30, 2006. The comments and response are included as Appendix C. Where appropriate, this Work Plan has been revised consistent with DEQ's comments.

1.2 Site Conditions

Figure 1-1 shows the site location. The Supplemental Investigation Report and the RI Report conclude that the concentrations of TCE and its degradation products in deep upland groundwater are the result of a release from a former underground storage tank (UST) area where TCE and TCE wastewater were collected between 1980 and 1983. The USTs were disconnected in 1983; TCE use at the plant was discontinued in 1989.³

¹ KB-1TM is a trademark of SiREM Laboratory

² EHCTM is a trademark of Adventus Intellectual Property Inc.

³ The 2002 MFA *TCE Use and Management Report* provides more information regarding the TCE use history.

In the Willamette River, TCE and its degradation products were detected below the mudline in transition-zone water samples above JSCS screening levels in two separate and distinct areas. Area 1 is generally located offshore of upland monitoring well WS-12-125/161. Area 2 is located downstream of Area 1 and offshore of upland monitoring well WS-11-125 (Figure 1-2). Area 2 is also offshore of Siltronic's National Pollutant Discharge Elimination System permitted outfall.

Area 1 represents the in-river expression of the upland groundwater plume of degradation products originating from the former UST area. Area 2 represents a separate, shallow localized source of TCE and its degradation products unrelated to the upland TCE plume or another upland source of groundwater contamination. There are no known on-going releases related to Area 2.

1.2.1 Ongoing Reduction of Risk

Groundwater monitoring data indicate that a natural process (i.e., biodegradation) is dechlorinating TCE and its degradation products in the upland plume and Area 1, and to a lesser extent in Area 2. Complete dechlorination to ethene results in a reduction of risk to human health and the environment. Enhanced bioremediation is an appropriate technology to accelerate dechlorination and further reduce the limited potential risk to human health and the environment.

It is important to note that throughout the site, the concentrations of TCE and its degradation products are found within a much larger area of documented impacts to soil, groundwater and sediment from manufactured gas plant (MGP) waste. The TCE-related impacts are distinguishable from the MGP waste impacts and source control measures involving enhanced bioremediation can be developed independent of the implementation of remedial measures for the MGP wastes. The investigation and remediation of the MGP impacts are the ongoing responsibility of NW Natural. The presence of the MGP waste (and its potential to impact TCE-related source control) was considered during the technology screening and bench test, as discussed in the bench test report.

In their comments regarding the draft PSWP, DEQ inquired about the ability of the approach (outlined below) to "treat TCE that has partitioned into [MGP] DNAPL." DEQ's concerns were addressed in MFA's response to comments (see Appendix C) and in Section 2 (Treatment Technology Description).

1.3 Supplemental Soil and Groundwater Characterization

DEQ required additional soil and groundwater characterization in the source zone pilot study area (SZPSA, see Figure 1-3) and riverbank pilot study area (RPSA, see Figure 1-4) prior to implementation of the work.

Two soil borings were initially completed in the SZPSA and were located upgradient of WS-13 (GP86), and downgradient of WS-13 and adjacent to GP02-02 (GP87). Based on the analytical data from GP87, an additional boring was later completed farther downgradient (GP89). The borings are shown on Figure 1-3.

Soil borings were completed using a truck mounted GeoProbe drilling unit advancing a 2-inch macrocore soil sampler. The soil cores were logged by a MFA field geologist under the oversight of an Oregon-Registered Geologist. Water samples were collected from intervals of sandy material consistent with the criteria agreed upon by MFA and DEQ during meetings prior to implementation. Water samples were analyzed for volatile organic compounds (VOCs) by USEPA Method 8260 and total organic carbon (TOC) by USEPA Method 4151.

One soil boring (GP88) was completed in the RPSA (Figure 1-4). Water samples were collected from intervals of sandy material consistent with the criteria agreed upon by MFA and DEQ during meetings prior to implementation.

The results of the water sample analyses are summarized in Table 1-1. A schematic of the soil stratigraphy and corresponding groundwater TCE concentrations in the SZPSA are presented in Figure 1-5. The results were used to determine the vertical extents of the treatment zones and screen intervals for the new monitoring wells.

The soil cores were screened for evidence of NAPL using “Oil-In-Soil” kits which contain a reactive dye (Sudan IV) that changes colors in the presence of NAPL. Although significant MGP impacts (including NAPL) were observed and confirmed with the dye test kits, no TCE NAPL was conclusively identified. As required by DEQ, soil samples from the SZPSA were collected for permeability analysis by American Society of Testing Materials (ASTM) Method D5084. The permeability testing results are under review and will be included in a subsequent submittal.

1.4 Pilot Study Goals

The pilot study is designed to evaluate performance of the EHC/KB-1 product combination within the existing subsurface conditions in aggregate, which includes TCE (and its degradation products) in the dissolved (aqueous) phase, adsorbed to soil, and adsorbed in MGP DNAPL where present.

In both areas, the goal is to install a permeable reactive barrier (PRB) through which groundwater impacted by TCE and its degradation products will flow. In the SZPSA, concentrations of TCE and cis-1,2-DCE are high relative to the RPSA. In the RPSA, the concentrations of vinyl chloride and MGP constituents are high relative to the SZPSA.

In both areas, contaminant concentration data will periodically be collected upgradient, within, and downgradient of the PRBs. Comparison of changes in concentrations over time and distance will provide performance data used to evaluate the technology.

The pilot study will aid in the evaluation of source control/remedial alternatives for groundwater under Areas 1 and 2. In addition, the information from the pilot study will be used along with the bench test data to compare enhanced bioremediation against other potential technologies in the FS.

1.5 Data Collection Objectives

Data will be collected upgradient, within, and downgradient of the pilot study areas to evaluate the following:

- Changes in the concentrations of TCE and its degradation products within and downgradient of the treatment zone
- Verify the presence of chemical by-products that indicate successful treatment by EHC/KB-1
- Influence of EHC/KB-1 on dissolved phase MGP constituents
- The potential for metals to be mobilized by groundwater chemistry changes resulting from the injection of EHC.

2 TREATMENT TECHNOLOGY DESCRIPTION

Bioremediation technologies rely on engineered systems to enhance or stimulate the natural degradation of contaminants such as chlorinated solvents. Several species of naturally occurring microscopic organisms (primarily bacteria) have been identified that are capable of transforming potentially harmful chlorinated volatile organic compounds (cVOCs) into nontoxic organic chemicals, through a process referred to as intrinsic biodegradation. Bioremediation technologies attempt to enhance these degradation processes.

Biodegradation of cVOCs (aka, biodechlorination) occurs when microbes directly remove chlorine atoms from cVOCs in order to derive energy from other organic compounds, under reducing, anaerobic conditions. The enhanced bioremediation technologies identified in the technology screening and evaluated in the bench test improve in-situ conditions for reductive biodechlorination by providing an electron donor and increasing the population of dechlorinating microbial strains. The technology selected for evaluation in the pilot study includes the additional dechlorination pathways of beta-elimination using ZVI, and thermodynamic instability (see Sections 2.2 and 2.3).

2.1 Bench Test Results

MFA contracted with AAI to perform a bench test of selected enhanced bioremediation approaches. The goal of the bench test was to compare the performance of three electron donor materials (EHC, EOS^{®4}, and HRC-X^{TM5}) with and without an added microbial population (KB-1). The bench test consisted of adding the various amendments to columns packed with soil from the site. Groundwater from the site was spiked with TCE and the MGP constituents benzene and naphthalene at concentrations comparable to site conditions at the downgradient extent of the plume. The groundwater was circulated for four contact periods with periodic sampling and re-spiking. During the fifth contact period, the TCE feed concentrations was increased to 240,000 micrograms per liter (µg/L), a concentration comparable to what has been measured in WS-13-69 (i.e., the source area).

⁴ EOS[®] is a registered trademark of EOS Remediation, Inc.

⁵ HRCTM is a trademark of Regensis.

MFA's observations of the bench test data from the first four contact periods are summarized as follows:

- All three donor materials effectively degraded TCE to the primary degradation product cis-1,2-DCE without the addition of the microbial population.
- cis-1,2-DCE was not effectively degraded to vinyl chloride by the columns without the microbial populations, with the exception of the column containing EHC™.
- The columns containing EHC and EOS and the KB-1 demonstrated the best performance with respect to fully dechlorinating TCE and its degradation products as evidenced by the production of ethene.

The summary data from the first four contact periods were submitted to and reviewed by DEQ during the March 23, 2006 meeting. MFA's observations of the bench test data from the fifth contact period (i.e., with a starting TCE concentration of 240,000 µg/L) are summarized as follows:

- The columns containing EHC (with and without the KB-1) demonstrated the best performance with respect to dechlorinating TCE and its degradation products.
- The columns containing the EOS (with and without the KB-1) did not perform as well as the EHC columns, with significant accumulation of cis-1,2-DCE and vinyl chloride.
- The columns containing the HRC-X amendments (with and without the KB-1) did not perform as well as the EOS columns, with substantially greater accumulations of cis-1,2-DCE, and little production of vinyl chloride. The HRC-X columns demonstrate a pattern of "stalled" dechlorination, where TCE is dechlorinated but the primary degradation product is not.

The summary data from the fifth contact period is included as Table 2-1. Appendix A includes the bench test report for the first four contact periods. The bench test results indicated that the EHC and EOS products are capable of dechlorinating TCE and its degradation products at concentrations observed in WS-11-125. The results also indicate that the EHC product is additionally capable of dechlorinating TCE and its degradation products at significantly higher concentrations as observed in the former UST area.

MFA further evaluated the EOS and EHC products in the context of the widespread MGP impacts throughout the site. Based on MFA's understanding of the site conditions and taking into account information provided by the EOS manufacturer, as compared to EHC,

the EOS product has a higher potential to change the physio-chemical characteristics of the MGP dense nonaqueous-phase liquid, or change the distribution of MGP compounds in the dissolved phase, which are undesirable results. This is due to the fact that EOS is an oil-based material, and requires a larger flushing volume during application.

The EHC product provides an additional dechlorination pathway (beta-elimination) as a result of the inclusion of ZVI. As demonstrated during the fifth contact period, EHC is more effective at higher concentrations of TCE. Based on all the factors summarized above, EHC is the preferred technology for further evaluation in the pilot study.

2.2 Electron Donor Material—EHC

EHC has the potential to accelerate the dechlorination of TCE and its degradation products via the following three pathways:

- Initial conditioning – EHC produces strong reducing conditions that favor the low redox environment preferred by the *dehalococcoides* bacteria. The plant fiber (i.e., the carbon source) contained in EHC is first degraded by indigenous bacteria to release volatile fatty acids (VFAs). The VFAs supply hydrogen which is used by the *dehalococcoides* bacteria for dechlorination of TCE and its degradation products. During the consumption of the plant fiber, oxygen is consumed by the indigenous bacteria, reducing the redox potential within the water.
- Beta-elimination – EHC includes up to 50% by weight of ZVI particles. ZVI particles dechlorinate TCE and its degradation products via the beta-elimination pathway (Figure 2-1). Unlike biodegradation, the beta-elimination pathway is not a step-wise dechlorination, and as such intermediate degradation products (including vinyl chloride) are not produced.
- Thermodynamic instability - The combined effect of the conditioning and beta-elimination processes can increase the reducing conditions in the groundwater to a point where TCE and its degradation products are thermodynamically unstable and they degrade abiotically. Thermodynamic decomposition of TCE and its degradation products occurs in a redox range of -400 to -600 millivolts. These conditions typically take time to develop and are heavily influenced by the amount of water passing through the treatment zone, but if they can be produced it would provide a supplemental pathway for ensuring complete mineralization of TCE and its degradation products.

Initial conditioning and beta-elimination are the primary treatment processes that are expected to be observed in the pilot study. As evidenced in the bench test, the presence of

the *dehalococcoides* bacteria in favorable conditions (sufficient electron acceptor and donor levels, absence of oxygen, appropriate redox conditions) can rapidly degrade TCE at concentrations exceeding those measured at the site. The beta-elimination pathway is an abiotic, physio-chemical process that occurs as soon as the ZVI particles are injected into the plume.

The development of conditions that will favor the thermodynamic decomposition of TCE have been found to be very site specific and can depend on many other factors such as groundwater velocity and other groundwater chemistry parameters (oxidation/reduction potential, sulfate, manganese, etc). The ability to develop these conditions at the Siltronic site will be assessed during the pilot study. The inability to develop thermodynamic instability at the site will not impair the other pathways.

The EHC application is expected to actively enhance the bioremediation conditions for a period of 3 to 5 years. Since the duration of the pilot study will be shorter, reapplication of materials is not necessary.

It should be noted that the EHC and the KB-1 materials are designed to primarily treat TCE and its degradation products in the dissolved phase. The DEQ has requested that Siltronic evaluate the potential for TCE (and its degradation products) to be sorbed into MGP DNAPL at the site. The mechanics of the sorption and desorption of TCE into and out of the MGP DNAPL are not clear.

MFA is developing a proposal for a bench test to evaluate desorption of TCE from MGP DNAPL. It may be possible to correlate bench test data to the pilot study data to develop an implicit understanding of the desorption phenomenon. It is important to note that assessing the potential for EHC and KB-1 to dechlorinate TCE and its degradation products partitioned into MGP DNAPL is not an explicit goal of the pilot study.

2.3 Microbial Culture—KB-1

Specific naturally-occurring microbial strains have been identified that are capable of dechlorinating TCE, DCE, and VC to the relatively non-toxic end-product ethene. The *Dehalococcoides* microbes perform this process only under anaerobic reducing conditions. The microbes have been isolated from soil samples so that they can be cultured commercially (similar to yogurt cultures) for application at various sites for groundwater remediation of chlorinated solvents. These cultures have not been genetically modified in the laboratory, and are only reproduced in the lab.

The bench test utilized a commercial culture named KB-1 Dechlorinator (KB-1), which is produced by SiREM. The KB-1 culture contains a combination of microbes of the genera *Dehalococcoides*, *Geobacter*, *Methanomethylovorans*, which are able to rapidly

dechlorinate TCE and its degradation products completely to ethene. The conversion to ethene is generally carried out by the *Dehalococcoides* bacteria, whereas degradation of TCE to DCE may be carried out by the *Geobacter*. The bench test data indicate that the presence of the KB-1 culture had the largest influence on the degradation rates of the test columns.

Bioaugmentation of the aquifer through the KB-1 application is expected to be a one time event. The microbes will continue to be active as long as there are chlorinated solvents in the groundwater.

3 PILOT STUDY OBJECTIVES

The objectives of the pilot study are to generate performance and cost data to be used in the FS for remedy selection. The pilot study will also provide additional design information if enhanced bioremediation is selected as the preferred remedy. The following criteria will be used in evaluating the pilot study:

- Performance
 1. Contaminant destruction efficiency (total mass removal and residual concentrations of TCE and degradation products)
 2. Timeframe for treatment
 3. Density of application and resultant treatment zone size

- Cost
 1. Application method
 2. Application rate
 3. Installation materials and cost
 4. Monitoring

The primary source of performance data will be the analytical results of groundwater samples collected from new and existing monitoring wells located upgradient, within, and downgradient of the biologically active zones (BAZs) developed following injection of the amendments. The following sections summarize the performance and cost criteria.

3.1 Contaminant Destruction Efficiency

The contaminant destruction efficiency will be evaluated as a measure of how well the treatment area is able to effectively remove TCE and its degradation products from the aqueous phase. The efficiency will be based on comparison of concentrations of TCE and its degradation products in samples collected upgradient, within, and downgradient of the BAZs. Concentration vs. distance plots will be developed to illustrate the efficiency of the BAZs.

3.2 Timeframe for Treatment

A timeframe for treatment will be evaluated by reviewing downgradient residual concentrations along with estimated groundwater flow velocities over the duration of the pilot study. Concentration vs time plots (combined with the concentration vs. distance plots) will help develop treatment timeframes.

This information can be used to estimate the amount of time that would be required for dechlorinated groundwater to travel from the SZPSA to the RPSA, and similarly from the RPSA to in-river.

3.3 Density of Application and Resultant Treatment Zone Size

Based in part on the bench test results, it is expected that the BAZ will be able to completely degrade incoming concentrations of TCE and degradation products with a treatment zone thickness (measured along the groundwater flow direction) of approximately 20 feet. Concentration data from the sampling points within and downgradient of the BAZs will be used to evaluate the treatment zone thickness. The evaluation of the treatment zone thickness will be carried forward to the FS for design purposes.

3.4 Application Method

The application method (high-pressure injection through direct-push equipment) chosen for the pilot study is based on known subsurface conditions and vendor recommendations. Confirmation of its effectiveness will be verified during injection and following the pilot study. Adjustments made to equipment or application methods during the field application of the EHC in the pilot study, if any, will be carried forward into the FS.

3.5 Application Rate

The application rate used in the pilot study will help establish the optimum rate for full-scale implementation. The application rate data from the bench test will be incorporated in the evaluation as well. The pilot study application rate for the source area and the downgradient area will be evaluated with regard to the treatment efficiency (remaining TCE concentration) versus the application rate and destruction efficiency from the bench test. Information regarding the ability to deliver the required amount of material to the treatment zone in each injection interval for the source area and downgradient area will

also be used in ensuring that the application rate for the EHC that is selected in the FS is reasonable.

3.6 Installation Materials and Cost

The need for miscellaneous materials and the overall cost of installation will be developed after completing the pilot study installation. Full-scale implementation will be comprised of the same equipment and unit costs applied to a larger area.

3.7 Monitoring

The monitoring data collected during the pilot study can provide insight for the selection of monitoring parameters in the full-scale implementation. Parameters that exhibit little or no impact due to the treatment technology may be considered for deletion in the full-scale phase. Conversely, if additional monitoring parameters are deemed to be necessary during the pilot study to provide additional clarity on the effectiveness of treatment, they would be included in the monitoring efforts planned for the full-scale implementation.

4 TEST PROCEDURES

The pilot study will evaluate the effectiveness of enhanced bioremediation in the SZPSA and the RPSA. The design of the riverbank pilot study is based on a site-specific proposal prepared by AAI, which is included as Appendix D. The design of the source area pilot study is similar in layout and implementation to the river bank study, and was developed based on discussions between MFA and DEQ.

The approach for each area is generally the same. The areas differ with respect to the range of TCE concentrations (higher in the SZPSA), presence or absence of MGP DNAPL (measured in WS-11-125 in the RPSA), and the vertical extent of the injection intervals (approximately 50-105 ft bgs in the SZPSA, and 90-130 ft bgs in the RPSA). The following sections describe the pilot study procedures for each area.

4.1 Source Zone Pilot Study Area (SZPSA)

The source zone is considered to be the former underground storage tank (UST) area on the south side of FAB1. The purpose of the source area pilot study is to provide in-situ field data regarding the viability of enhanced bioremediation of trichloroethene (TCE) and its degradation products (specifically, cis-1,2-dichloroethene (DCE), trans-1,2-DCE, 1,1-DCE, and vinyl chloride) within a high concentration zone (up to approximately 260,000 ug/L TCE in WS-13-69). Information from the pilot study will be used in conjunction with bench test data in the technology evaluation portion of the FS. The information will also be used to design a full scale BAZ in the source area if enhanced bioremediation is selected for the site as a source control measure, or final remedy.

The approach for the source area pilot study is similar to that for the riverbank pilot study. As shown on Figure 1-3, the source area pilot test will include the following components:

- Installation of a BAZ in the area of highest TCE concentrations (between GP87 and GP89)
- Installation of a monitoring well pair downgradient of the BAZ (WS-18-71 and WS-18-101)

- Installation of a monitoring well pair within the BAZ (WS-19-71 and WS-19-101)
- Data collection from the new and existing monitoring wells over a 6-month period.

The following sections provide more information with respect to the pilot study setup in the SZPSA.

4.1.1 BAZ Dimensions

The location and dimensions of the BAZ are based on site characterization information from the RI and the bench test data, and incorporate feedback from DEQ⁶ regarding the general approach. The injection grid is approximately 15 feet long (perpendicular to the groundwater flow direction) and 10 feet wide (parallel to groundwater flow), and will be installed within the source area at a location approximately 35 feet downgradient of WS-13. The BAZ will consist of three rows of four injection points spaced 5 feet apart and offset in the direction of groundwater flow. The layout of the BAZ is shown on Figure 1-3.

The length and width of the injection grid are estimated to provide a sufficient treatment area to optimize the potential to observe increased degradation of TCE and production of related byproducts, including ethene and chloride. The requirement to provide sufficient contact time to allow breakdown of TCE (based on the results of the high concentration test periods in the bench test) determines the appropriate treatment length through the BAZ. A treatment length of 10 feet should provide sufficient contact time for the production of the daughter products and chloride which will be used as evidence of successful TCE treatment. Due to the higher TCE concentrations and relatively high permeability of the soils, EHC will be applied at about 3% by weight of the total soil within the treatment zone.

The vertical extent of the injection interval is from 50 feet to 106 feet bgs. The vertical extent is based on the concentration data (TCE in groundwater) and the observed stratigraphy (which included substantial silt zones above 50 feet bgs and below 106 feet bgs).

⁶ Comments provided by Dana Bayuk, Tom Gainer and Heidi Blischke to Siltronic and MFA during a meeting held on March 23, 2006.

4.1.2 In-Situ Application

The BAZ will be developed by injecting an EHC slurry to provide nutrients and lower the redox potential. The KB-1 will be injected several days after the EHC material. The two-step approach will reduce the dissolved oxygen content of the water within the EHC injection interval to anaerobic levels (<1 milligrams per liter), prior to KB-1 injection.

MGP waste-related impacts have been observed in the shallow portions of the aquifer between approximately 20 to 45 feet bgs. The zone between the surface and 45 feet bgs will be isolated (to minimize MGP contaminant dragdown) by boring a large diameter hole (6 inch diameter), which will be backfilled with hydrated bentonite chips.

The DP rods will be pushed to 50 feet bgs, where the injection will commence in a top down fashion. The EHC powder will be mixed in a 20% slurry with water and injected (using a hydraulic-powered pump) through a pressure activated injection tip attached to the end of the DP rods. The injections will proceed in 4 foot intervals down to 106 feet bgs. Approximately 80 gallons of EHC slurry (150 pounds of EHC powder) will be injected at each interval. The mass of EHC injected is approximately 3% of the mass of the soil in the BAZ. Once the bottom injection interval is completed, additional EHC slurry will be injected as the DP rods are pulled out of the ground to an elevation of 50 feet. Between 50 feet bgs and 40 feet bgs, the boring will be allowed to collapse in on itself as the rods are removed. Between 40 bgs and the surface, bentonite grout will be injected to abandon the hole through the MGP zone.⁷

After injecting the EHC, approximately 84 liters of KB-1 will be injected into the BAZ using the same injection holes and intervals as for the EHC. Prior to injecting KB-1 at each location, water samples will be obtained from the bottom of each injection hole (approximately 106 feet bgs) to verify that the redox potential is less than -75 mV and that DO is less than 0.5 mg/l. After verifying the parameters, the KB-1 will be injected in a bottom-up fashion at 4 foot intervals from 106 feet to 50 feet bgs. Approximately 500 mL of KB-1 will be injected at each interval, followed by approximately 3 liters of anaerobic chase water to distribute the cultures into the soil formation. Between 50 feet bgs and 40 feet bgs, the boring will be allowed to collapse in on itself as the rods are removed. Between 40 bgs and the surface, bentonite grout will be injected to abandon the hole through the MGP zone. The design parameters of the BAZ are summarized in Table 4-1.

⁷ Bentonite grout will not be used near the injection zone because of potential changes in water chemistry (pH) that result in the presence of bentonite which could have an adverse impact on the microbiology in the treatment zone. DEQ approved this approach in the May 18th 2006 meeting and subsequent emails.

4.1.3 Monitoring Well Installation

Two pairs of 2-inch diameter monitoring wells will be installed using a mini-sonic drill rig. One pair of wells (WS-19-71/101) will be installed within the BAZ. The second pair (WS-18-71/101) will be installed approximately 15 feet downgradient of WS-19-71/101. The monitoring wells will be constructed using PVC casing and 10 foot-long stainless steel wire wrapped well screens with a 1 foot stainless steel sump at the bottom. Each pair will be screened from 60-70 feet bgs and from 90-100 feet bgs. WS-13-69 and WS-13-105 will be used as upgradient monitoring points. The location of the monitoring wells will provide data that relate changes in concentration over both time and distance.

4.2 Riverbank Pilot study Area (RPSA)

The purpose of the riverbank pilot study is to provide in-situ field data on the viability of enhanced bioremediation of TCE and its degradation products within a moderate concentration zone (up to 1,000 ug/L TCE, and up to 20,000 ug/L cis-1,2-DCE). Information from the pilot study will be used in conjunction with bench test data in the technology evaluation portion of the FS. The information will also be used to design a full scale BAZ if enhanced bioremediation is selected for the site as a source control measure, or final remedy.

At the riverbank, the plume of TCE and its degradation products occurs between WS12 and WS14, with the estimated plume centerline near WS-11-125. The pilot study will be implemented downgradient from the northern edge of the Fab 1 building, using WS-11-125 and a new monitoring well as a downgradient monitoring point. The riverbank pilot study will include the following components:

- Installing a BAZ upgradient of WS-11-125
- Installation of new monitoring wells upgradient, within and downgradient of the BAZ and WS-11-125
- Data collection from the monitoring wells over a 6-month period.

The following section provides more information with respect to the pilot study setup, based on data collected during the RI and the manufacturers' recommendations for optimizing results.

4.2.1 BAZ Dimensions

The location and dimensions of the BAZ are based on site characterization information from the RI and the bench test data, and incorporate feedback from DEQ⁸ regarding the general approach. The injection grid is approximately 30 feet long (perpendicular to groundwater flow) and approximately 21 feet wide. The injection grid will be installed approximately 10 feet upgradient of WS-11-125. The BAZ will consist of four rows of five injection points spaced 7 feet apart and offset in the direction of groundwater flow. The layout of the BAZ is shown on Figure 1-4.

The length and width of the injection grid are estimated to provide a sufficient treatment area to optimize the potential to observe increased degradation of TCE and production of related byproducts, including ethene and chloride.

The results of the bench test indicate that a contact time of 15 to 20 days is sufficient to completely mineralize TCE and its degradation products. Estimates of horizontal groundwater velocities in the downgradient plume area range from 0.3 to 1.7 foot per day, with an average value of approximately 1 foot per day. The treatment time (i.e., the contact time developed from the bench test) determines the appropriate treatment length through the BAZ. The treatment length needed (i.e., the length of the BAZ) is therefore approximately 20 feet, based on the average horizontal groundwater velocity. EHC will be applied at about 1% by weight of the total soil within the treatment zone, the same rate that was used in the bench test.

The vertical extent of the BAZ is approximately 90 feet bgs to 130 feet bgs. The vertical extent is based on the concentration data (TCE and its degradation products in groundwater).

4.2.2 In-Situ Application

The BAZ will be developed by injecting an EHC slurry to provide nutrients and lower the redox potential. The KB-1 will be injected several days after the EHC material. The two-step approach will reduce the dissolved oxygen content of the water within the EHC injection interval to anaerobic levels (<1 milligrams per liter), prior to KB-1 injection.

The EHC powder will be mixed in a 30% slurry with water injected using direct-push (DP) methods. The RPSA is known to have MGP impacts, including potential NAPL in the shallow portions of the aquifer to about 35 feet bgs (in addition to the MGP DNAPL observed in the deeper well screen). To prevent carrying this material down to deeper

⁸ Comments provided by Dana Bayuk, Tom Gainer and Heidi Blischke to Siltronic and MFA during a meeting held on March 23, 2006.

parts of the aquifer, the zone between the surface and 35 feet bgs will be isolated by installing a steel casing or boring a large diameter (6 inch diameter) which will be backfilled with hydrated bentonite chips.

The DP the rod will be advanced to 90 feet bgs, where the injection will commence in a top-down fashion. The EHC powder will be mixed in a 30% slurry with water and injected (using a hydraulic-powered pump) through a pressure activated injection tip attached to the end of the DP rods. The injections will proceed in 4 foot intervals down to 130 feet bgs. Approximately 80 gallons of EHC slurry (200 pounds of EHC powder) will be injected at each interval. The mass of EHC injected is approximately 1% of the mass of the soil in the BAZ. Once the bottom injection interval is completed, additional EHC slurry will be injected as the DP rods are pulled out of the ground to an elevation of 90 feet. Between 90 feet bgs and 40 feet bgs the bore hole will be allowed to collapse in on itself as the rods are removed. Between 40 bgs and the surface, bentonite grout will be injected to abandon the hole through the MGP zone.⁹

After injecting the EHC, 60 liters of KB-1 will be injected into the BAZ using the same injection holes and intervals as used for the EHC. Prior to injecting KB-1 at each location, water samples will be obtained from the bottom of each injection hole (approximately 130 feet bgs) to verify that the redox potential is less than -75 mV and that DO is less than 0.5 mg/l. After verifying the parameters, the KB-1 will be injected in a bottom-up fashion at 4 foot intervals from 130 to 90 feet bgs. KB-1 will be introduced to the aquifer by placing polyethylene tubing down the DP rods to a standard DP water screen that has been modified so that only 1 foot of screen will be exposed. Approximately 300 mL of KB-1 will be added to the tubing, which will then be pumped down the tubing to the screen and into the aquifer followed by approximately 3 liters of anaerobic chase water to distribute the cultures into the soil formation. Between 90 feet bgs and 40 feet bgs the bore hole will be allowed to collapse in on itself as the rods are removed. Between 40 bgs and the surface, bentonite grout will be injected to abandon the hole through the MGP zone (see previous footnote). The design parameters of the riverbank pilot study BAZ are summarized in Table 4-2.

4.2.3 Monitoring Well Installation

Three 2-inch diameter monitoring wells will be installed using a mini-sonic drill rig. A single upgradient monitoring point (WS21-112) will be installed approximately 15 feet from the upgradient edge of the BAZ. Two downgradient monitoring points will be

⁹ Bentonite grout will not be used near the injection zone because of potential changes in water chemistry (pH) that result in the presence of bentonite which could have an adverse impact on the microbiology in the treatment zone. DEQ approved this approach in the May 18th 2006 meeting and subsequent emails.

installed - one internal to the BAZ (WS-22-112) near the downgradient edge, and one approximately 20 feet downgradient of the BAZ (WS-20-112). The monitoring wells will be constructed using PVC casing and 15 foot stainless steel wire wrapped well screens with a 1 foot stainless steel sump at the bottom. The new wells will be screened from 96 to 111 feet bgs. WS-11-125 will be used as the downgradient monitoring point. The location of the monitoring wells will provide data that relate changes in concentration over both time and distance.

5 SAMPLING AND ANALYSIS

The pilot study groundwater monitoring program will be implemented prior to and following injection of the amendments. Soil samples will also be collected at the conclusion of the pilot study to evaluate subsurface conditions related to enhanced bioremediation. The following section describes the sampling and analysis program for the pilot study, including analytical scope and schedule. The source area sampling procedures will be discussed in an addendum to this work plan.

5.1 Source Area Sampling

The SZPSA monitoring program will consist of collecting groundwater samples from upgradient (WS-13-69/105), within (WS-19-71/101), and downgradient (WS-18-71/101) for up to six months following implementation.

The analytical scope for the monitoring program includes VOCs, polycyclic aromatic hydrocarbons (PAHs), TOC, alkalinity, chloride, sulfate, total metals, dissolved metals, VFAs, and fixed gases (carbon dioxide, ethene, ethane, methane), and is shown in Table 5-1. The groundwater samples will be analyzed for VOCs and fixed gases to monitor the changes in concentration of TCE and its degradation products. Samples will also be analyzed for parameters that are indicators of subsurface conditions important for and indicative of the desired microbial populations.

5.2 Riverbank Sampling

The RPSA monitoring program will consist of collecting groundwater samples from upgradient (WS-21-112), within (WS-22-112), and downgradient (WS-11-125 and WS-20-112) of the BAZ for up to six months following implementation.

The analytical scope for the monitoring program includes VOCs, polyaromatic hydrocarbons (PAHs), TOC, alkalinity, chloride, sulfate, total metals, dissolved metals, VFAs, and fixed gases (carbon dioxide, ethene, ethane, methane), and is shown in Table 5-1. The groundwater samples will be analyzed for volatile organic compounds (VOCs) and fixed gases to monitor the changes in concentration of TCE and its degradation

products. Samples will also be analyzed for parameters that are indicators of subsurface conditions important for and indicative of the desired microbial populations.

5.2.1 Soil Sampling

At least one soil sample will be taken in each of the pilot study areas at the end of the pilot study period. The soil samples will be collected from within the BAZ in the riverbank pilot study area, and adjacent to the injection point for the source area pilot study.¹⁰ The soil samples will be analyzed for total organic carbon (TOC), which will provide an estimate of the carbon consumption rate of the EHC. Carbon consumption data could be used to modify the amount of EHC to be applied, increasing or decreasing the expected life of the treatment zone. The soil core from the boring will also be inspected for evidence of EHC to help evaluate the spread of EHC from the injection points and the overlap between injection points (if any).

5.3 Schedule

Groundwater samples for both pilot study areas will be obtained after 1, 2, 3, 4, and 6 months for each study area. This sampling schedule was developed using a schedule based on the estimated travel times for groundwater and the bench test data.

In the downgradient area, the sample schedule corresponds to the travel time from the upgradient edge of the BAZ to WS-11-125, which is approximately 1 month (at an average linear velocity of 1 foot per day). This schedule also allows time for the microbial community to develop – bench testing demonstrated an increasing effectiveness over the three month test period. The schedule will also allow sufficient time for the extreme reducing conditions to be generated by the EHC, which can take several months to develop. The sampling schedule is shown in Table 5-2.

Groundwater samples for both pilot studies will be obtained after 1, 2, 3, 4, and 6 months. This sampling schedule is based on the estimated travel times for groundwater and the bench test data. Following the completion of the pilot study period, Siltronic will add WS-21-112 (upgradient of the RPSA) to the quarterly monitoring program (as a replacement for WS-11-125).

Soil samples will be obtained after the 6 month groundwater monitoring event has occurred.

¹⁰ The location of the soil boring will be contingent upon the location of subsurface utilities.

5.4 Sampling and Analysis Procedures

Sampling and analysis will be performed consistent with the methods and equipment specified in the RI Work Plan (MFA, 2004). In addition to the analytes covered by the RI Work Plan, MFA will also collect samples for analysis of VFAs.

5.4.1 Groundwater

Groundwater samples will be collected using dedicated pumps bladder pumps. Field parameters (including temperature, turbidity, conductivity, dissolved oxygen, and oxidation/reduction potential) will be recorded during purging prior to sampling; samples will be collected when the field parameters have stabilized using the criteria established for the ongoing quarterly monitoring program.

Groundwater samples will be submitted to Specialty Analytical of Tualatin, Oregon for analysis. The groundwater samples will be analyzed for VOCs, polycyclic aromatic hydrocarbons (PAHs), TOC, alkalinity, chloride, sulfate, total metals, dissolved metals, VFAs, and fixed gases (carbon dioxide, ethene, ethane, methane). Table 5-1 summarizes the analytical scope for the sampling locations. Quality assurance/quality control samples will be collected consistent with the quarterly groundwater monitoring program.

5.4.2 Soil

At the conclusion of the six-month monitoring period, soil samples will be obtained by advancing at least one soil boring adjacent to an injection point in both the RPSA and SZPSA. The soil core will be logged and inspected for evidence of EHC. Soil samples in areas where EHC is evident will be submitted to Specialty Analytical for analysis of TOC. The TOC data will be used to evaluate the amount of TOC in the soil after the EHC injections and help to project the expected life in the soil to determine reapplication timeframes.

6 PERMITTING

Actions taken pursuant to OAR 340-122-0070 do not require state or local permits, consistent with Oregon Revised Statutes (ORS) 465.315(3). The pilot study will include injection of bioremediation products to the aquifer through temporary borings that will be completed at surface grade. Injection of materials to any aquifer is regulated by the underground injection control (UIC) program within DEQ. All monitoring wells and soil borings are regulated by the Oregon Water Resources Department (OWRD).

6.1 UIC

UIC is regulated by DEQ. Injection wells for bioremediation systems typically fall under the UIC definition of Class V, which is a non-specific category for the injection of non-hazardous fluids not covered in Classes I through IV. Class V injection wells can be rule authorized, which precludes the need for a permit. Requirements for a rule authorized UIC include:

- Owner/operator submits inventory information to register the injection system
- No potential to cause groundwater contamination
- Owner/operator submits additional information as needed to determine the potential for groundwater contamination

The inventory information must be submitted prior to construction and operation of a new injection system. When the injection system is no longer in use, the system must be decommissioned or converted. DEQ must be notified 30 days prior to closure. Potentially contaminated injection systems may be required to submit a closure plan and report sampling results to DEQ. An aquifer remediation registration form is included in Appendix E.

6.2 Oregon Water Resources Department

Each injection point will be required to comply with the regulations that are managed by OWRD. As such, a registered well driller will be used for installing all wells and soil

borings associated with the pilot study. The driller will be responsible for filing the necessary paperwork for obtaining OWRD permits, start cards, and variances for the wells or soil borings.

6.3 City of Portland Development Regulations

The City of Portland Bureau of Development Services regulates development activities within city limits. Under ORS 465.315(3), the City's procedural requirements may be waived for on-site hazardous substance removal or remedial actions. However, the substantive requirements of the local regulations still must be met.

A greenway review might be required by the Bureau of Development Services in order to determine the substantive requirements that could apply to the local regulations during DP activities. The purpose of greenway review is to ensure that:

- Development will not have a detrimental impact on the use and functioning of the river and abutting lands;
- Development will conserve, enhance and maintain the scenic qualities and natural habitat of lands along the river;
- Development will conserve the water surface of the river by limiting structures and fills riverward of the greenway setback;
- Practicable alternative development options are considered, including outside the River Water Quality zone setback; and
- Mitigation and enhancement activities are considered for development within the River Water Quality zone.

It is not expected that installation of temporary piezometers or injection points at surface grade will meet the definition of "development" or "development-related definitions" listed in Chapter 33.900 of the City of Portland Zoning Code. Further, the installation appears to be consistent with an exempted situation that does not require greenway review (under 33.440.320.G.).

7 REPORTING

7.1 Health and Safety

The site health and safety plan (MFA, 2002) will be amended to address the safe handling procedures of the materials to be used for the pilot study. The current site health and safety plan addresses drilling and groundwater sampling procedures. The update of the site health and safety plan will include Material Safety Data Sheets for the EHC and KB-1 products.

7.2 Progress Updates after Sampling

MFA will issue progress reports following receipt and validation of analytical reports from the laboratory. Each progress report will include a summary of the data and a description of data trends or anomalies. MFA will prepare the progress report in conjunction with AAI and SiREM personnel to ensure that past experience can be incorporated in the analysis of the results. Progress reports will be developed within one to two weeks of receiving the final lab data.

7.3 Final Report

MFA will prepare a final report summarizing the overall results for each of the pilot study areas at the end of the pilot study period. The report will document the field activities and present the analytical data. The report will discuss overall data trends and anomalies, and present the findings regarding the overall viability of using enhanced bioremediation as a source control technology or final remedy in the source area, downgradient plume area (including Area 1), and Area 2.

8 SCHEDULE

The pilot study in both areas will run concurrently to make the most efficient use of effort. Figure 8-1 outlines milestone dates for the project in Gantt chart form.

Coordination and setup for the studies will include the approval process for DEQ, registration with the UIC program, and coordination with subcontractors. This is expected to require approximately 4 to 6 weeks. Near the beginning of this process, the material orders will be placed to ensure that sufficient quantities can be produced and delivered to the site. The drilling subcontractor will be responsible for coordinating with OWRD to obtain the necessary start cards for each of the soil borings and monitoring wells as well as any necessary variances. Well installation will proceed when the necessary permits have been obtained in conjunction with the field injections.

Baseline monitoring samples will be collected in the source area after the monitoring wells have been installed and before injecting the bioamendments. Baseline data for the downgradient area will be obtained from the previous quarterly sampling event (May, 2006).

Field implementation is estimated to require approximately three to four weeks per area. Field implementation will be scheduled to occur as soon as possible after receiving approval from the Cleanup Program and UIC Program within DEQ. Implementation will include the installation of the 20 downgradient EHC injection points, 20 downgradient KB-1 injection points, the 12 source area EHC injection points, and the 12 source area KB-1 injection points.

The monitoring period will commence immediately after the installation of the biodegradation materials, and will continue for six months. A time zero sample will be obtained from the monitoring wells upon the completion of the material injections in that area. Additional samples will be obtained after 1, 2, 3, 4, and 6 months, and progress reports will be prepared three to four weeks after each sampling event. The sampling period may be extended based on the needs of the project for additional data.

A final pilot study report will be prepared upon the conclusion of the sampling period. Preparation of the final report is expected to require approximately 4 weeks.

It should be noted that ordering, shipping, and injection of the KB-1 product are time-critical actions due to the perishable nature of the material. Once the product is ordered, it must be injected shortly after receipt.

REFERENCES

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- MFA. 2002. Health and safety plan. Prepared for Siltronic Corporation, Portland, Oregon. Maul Foster & Alongi, Inc., Portland, Oregon. September 24.
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TABLES

FIGURES

APPENDIX A
AAI BENCH TEST RESULTS

APPENDIX B
TECHNOLOGY SCREENING RESULTS

APPENDIX C
DEQ COMMENTS AND MFA RESPONSE

APPENDIX D
AAI PILOT STUDY PROPOSALS

APPENDIX E
UIC REGISTRATION