INITIAL SOURCE CONTROL TECHNOLOGIES EVALUATION
SILTRONIC CORPORATION SITE
7200 NW FRONT AVENUE
PORTLAND, OREGON

Prepared for

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ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
COC	chemical of concern
DAF	dissolved air flotation
DCE	dichloroethene
DNAPL	dense nonaqueous-phase liquid
ERH	electrical resistive heating
ET-DSP™	electro thermal dynamic stripping process
GAC	granular activated carbon
GCW	groundwater circulation well
gpm	gallons per minute
ISOTEC	In-Situ Oxidative Technologies, Inc.
MC2	McMillan-McGee
MFA	Maul Foster & Alongi, Inc.
mg/L	milligrams per liter
MGP	manufactured gas plant
NAPL	nonaqueous-phase liquid
PAH	polycyclic aromatic hydrocarbon
PCE	perchloroethylene
PDS	power delivery system
PRB	permeable reactive barrier
SCE	source control evaluation
SCM	source control measures
SER	steam-enhanced remediation
Siltronic	Siltronic Corporation
TCE	trichloroethene
USEPA	U.S. Environmental Protection Agency
VC	vinyl chloride
VOC	volatile organic compound
ZOI	zone of influence

1 INTRODUCTION AND EXECUTIVE SUMMARY

The goal of the source control measures (SCM) treatment at the Siltronic site is to reduce concentrations of trichloroethene (TCE) and its breakdown products (cis-1,2-dichloroethene [DCE]; trans-1,2-DCE; and vinyl chloride [VC]) entering the Willamette River to below acceptable risk levels. With respect to Area 1, this can be achieved by reducing or eliminating the TCE source south of the FAB1 building and/or addressing the plume downgradient of the source. At Area 2, this can be accomplished by removal or treatment at the source. (Note: Figure 1 in the body of the work plan delineates the site features as defined for purposes of this SCE.)

For the purposes of this evaluation, it was assumed that no treatment would be feasible under the FAB1 building. The upland source area treatment dimensions south of FAB1 have been assumed to be 100 feet (north-south) by 300 feet (east-west) and to extend from 20 to 100 feet below ground surface (bgs). The treatment area for the downgradient plume located north of FAB1 between the building and the Willamette River is assumed to be 80 feet (north-south) by 300 feet (east-west) and to extend from 70 to 130 feet bgs. The following treatment technologies were initially considered:

Upland Source Area

- Thermal treatment
- Chemical oxidation
- Bioremediation
- Groundwater circulation wells (GCWs) with treatment
- Pump and treat
- Air sparging

Downgradient Plume

- Permeable reactive barriers (PRBs)
- Sheet-pile wall
- Thermal treatment
- Chemical oxidation
- Bioremediation
- Bioremediation through GCW nutrient delivery
- GCWs with treatment

- Pump and treat
- Air Sparging

As part of an initial screening step, GCWs and air sparging were eliminated from the upland source area technologies to be evaluated in detail because they are not compatible with fine-grained geology present at the site. In addition, air sparging was not evaluated because the technology would inhibit existing anaerobic biodegradation processes that are occurring at the site.

PRBs, sheet-pile walls, thermal treatment, and air sparging were eliminated from the downgradient plume technologies to be evaluated in detail. PRBs were eliminated due to issues with MGP waste mobilization through and blockage of the PRB. Sheet-pile walls may be a component of a long-term remedy for the site, but were not evaluated as a stand-alone SCM, based on the length of wall required, the depth to competent bedrock, and the need for hydraulic control. Thermal treatment was eliminated because of the extremely high cost associated with downgradient treatment over many years, due to continued influx of contaminants from the upland source area. Similar to the source area, air sparging was eliminated form consideration in the downgradient plume due to its negative impact on ongoing anaerobic degradation.

Further evaluation of retained technologies as summarized in this attachment was completed based on applicability, short-term effectiveness, long-term effectiveness, implementability, scalability, impacts of MGP waste, operational impacts to Siltronic, limitations, cost, and cost certainty. Cost estimates were prepared assuming operation and maintenance for five years and a 20-percent contingency.

The most promising technologies for treatment of the upland source area contamination include thermal treatment, in-situ chemical oxidation, and bioremediation. Thermal treatment has the highest certainty of working within the area accessible and would remove the most TCE (concentrations reduced to nondetect), but is also the most expensive technology (approximately $7.9 million). Chemical oxidation and bioremediation technologies are less expensive ($3.0 million and $1.3 million, respectively), and could achieve significant mass removal (up to 90 percent), but are limited by the geology (lenses of fine-grained materials), and in the case of chemical oxidation, the presence of MGP waste. The downgradient treatment technologies that are the most promising include standard bioremediation and bioremediation using GCWs ($1.7 million and $2.4 million, respectively).

Given the relatively small size and discrete nature of Area 2, enhanced bioremediation and source removal were considered potentially applicable SCM technologies. The remaining technologies listed previously are not applicable for in-water source areas. However, other technologies (e.g., reactive barriers) may be applicable as a final remedy if an SCM is not implemented at Area 2, or as an enhancement to an SCM. The need for and applicability of these technologies will be assessed in the feasibility study.

The conclusion of the initial screening is that a bench-scale bioremediation test is warranted. It is now underway and has been designed to produce information necessary for reaching a conclusive determination on the viability of bioremediation applied at both Areas 1 and 2. This determination is based on the initial indication that bioremediation of the downgradient plume will likely best meet Siltronic's overall goals. The benefits of this technology include: no need for ex-situ treatment and disposal (thus reducing environmental risks during implementation), the ability to leverage bioremediation activity currently occurring in the subsurface environment at the site, and relative cost. The reasons for focusing on treatment of the downgradient plume area during the SCM stage of the cleanup include the following:

- Accessing the upland source area is problematic due to its location relative to facility infrastructure. Given that disruption of facility operations and/or reconfiguring the facility layout in the vicinity of the source (e.g., pipe rerouting) is to be avoided, full access likely cannot be reasonably attained.

- Treatment of the downgradient plume will have more immediate effects at the receptor point (Willamette River) as compared to focusing treatment in the source area.

- If properly structured, it is probable that a successful treatment system for the downgradient plume associated with Area 1 could be incorporated as part of the final remedy.

- Once downgradient treatment is achieved, additional treatment in the upland source area, which would have the effect of shortening the amount of time over which the downgradient controls would need to operate, may be warranted as a remedial action. This would be determined through the pending feasibility study.

Based on the outcome of the bench test, it may be necessary to revisit previously assessed factors. That is, if bioremediation is found to have limited applicability for either Area 1 or Area 2, other technologies and resources (e.g., existing wastewater treatment plant) will be reassessed. Conversely, if bioremediation is confirmed to be viable, SCM design can be initiated, as outlined elsewhere in this document.

As previously noted, five treatment technologies (pump and treat, thermal remediation, groundwater circulation, chemical oxidation, and bioremediation) were retained and evaluated in detail. An overview of each technology is provided in the following sections, along with factors of evaluation, cost and cost certainty, and limitations. Recommendations on each technology are given at the end of each section. Next steps and overall SCM recommendations are given in the final section.

2 PUMP AND TREAT TECHNOLOGY

2.1 Process Overview

Conventional pump and treat technologies are among the most widely used systems for the remediation of contaminated groundwater. Pump and treat systems typically include one or more extraction wells and an aboveground treatment system. Air strippers and granular activated carbon (GAC) are common treatment system components for volatile organic compounds (VOCs), but there are many other potential treatment trains. The treated water may be reinjected into the ground, discharged to a sanitary or storm sewer system, or discharged to a surface water body.

2.2 Evaluation Factors

2.2.1 Applicability

In general, pump and treat systems are much more effective at hydraulic containment than treatment. They generally require protracted periods of time to make significant reductions in contaminant mass, particularly if highly concentrated source areas are present. Nonetheless, within the constraints summarized below, pump and treat technologies may be applicable at this site. For the purpose of this evaluation, it was assumed that one pump and treat system would be installed to treat both the upland source area and the downgradient plume area.

2.2.2 Short-Term Effectiveness

The short-term effectiveness of a pump and treat system depends on the site-specific soil and groundwater conditions and the type of contaminant being treated. The effectiveness in reducing contaminant concentrations to site cleanup levels is moderately low due to slow contaminant transport and interphase transfer. Hydraulic containment and a moderate reduction in contaminant concentrations can be achieved much more rapidly.

Due to the variability in hydrogeologic parameters (e.g., hydraulic conductivity) and uncertainty regarding optimal well placement and pumping rates, a phased installation approach can be more cost-effective than grossly overdesigning groundwater pump and treat systems. Pumping could be initiated at several locations to obtain monitoring data that would then be used to determine system expansion requirements (i.e., optimal well locations and pumping rates). While the phased implementation approach may be more cost-effective overall, it should be noted that it would also reduce the short-term effectiveness.

2.2.3 Long-Term Effectiveness

The long-term effectiveness of a pump and treat system depends on the mass of contaminants, characteristics of site soil and groundwater, and cleanup goals. The long-term effectiveness to reduce contaminant concentrations to cleanup levels is moderately low. As discussed above, it is not uncommon for a pump and treat system to require design modifications after initial startup. Modifications may be required in the extraction and/or treatment systems.

In general, a pump and treat cleanup is a relatively slow process. It will usually require at least five to ten years, but can last for decades. As long as the system is operating properly, it will continue to be effective at hydraulic containment and maintaining lower contaminant concentrations. In some conditions, well screens can become clogged by mineral precipitates or biogrowth, as can the aquifer formation. This will decrease the capture zone of the extraction well and decrease the long-term effectiveness of the system.

2.2.4 Implementability

Pump and treat systems in general have a relatively high implementability. Extraction wells and treatment system components are based on well-established and readily available technologies. There are many vendors and contractors experienced with the components of pump and treat systems. Pump and treat systems have been installed at many chlorinated solvent sites. However, the extraction wells for pump and treat systems are more difficult to implement than smaller-diameter wells used for injection of treatment agents.

Access is one issue that affects implementability of any technology at the Siltronic site. The upland source area is in an active operational area and there is little room for installation of extraction wells or a new treatment system. Consequently, for the purpose of this evaluation, one well was assumed in the source area and discharge, following treatment, was assumed to be accomplished using the existing FAB1 wastewater treatment system. Based on these assumptions, the implementability of a pump and treatment system at the Siltronic site is high.

2.2.5 Scalability

The pump and treat system could be scalable, but would require additional drilling for well installations, pipe trenching, and power access. It would also require additional treatment-system capacity.

2.2.6 Impact of MGP Waste

The location of the MGP waste may in part dictate the depth of the extraction well screens. MGP waste will be present in extracted water, regardless of well placement and depth. Water treatment to reduce MGP waste constituent concentration to allowable discharge levels would likely be necessary. The presence of MGP waste may dictate the design of the treatment system. If TCE products were the only contaminants present in the groundwater, an air stripper system would likely be used for treatment. However, due to the presence of MGP waste at the Siltronic site, groundwater treatment would likely require dissolved air flotation (DAF) or GAC adsorption unit. For the purposes of this evaluation, DAF was assumed to be the primary treatment mechanism.

2.2.7 Impacts to Operations

It is highly likely that modification of Siltronic operations or infrastructure would be necessary in order to implement a pump and treat system. The extraction wells, piping, and aboveground treatment system would take up otherwise useable space. Siltronic's existing wastewater treatment system might be used for treatment of groundwater (as noted above, given the TCE/MGP mixture, this is considered unlikely without pretreatment). If the existing treatment system could not be used, it would be necessary to construct an additional treatment system pad, possibly near the west side of FAB1. Regardless of the location of the treatment system, some trenching and related pavement repair work would be required.

2.3 Requirements

2.3.1 Design Requirements

Aquifer testing would be conducted to acquire field-scale measurement of hydrogeologic properties such as the formation transmissivity and storage coefficient, which are critical to extraction system design. It may be advisable to extend aquifer tests to days or weeks to evaluate capture zones, boundary conditions, and groundwater treatability issues. Slug tests could also be used to augment aquifer test results. However, short-term aquifer and slug tests generally are not as reliable as system performance indicators when compared to long-term aquifer tests. Multiple aquifer tests are warranted at large and heterogeneous sites, such as Siltronic. The impact of tidal influence would also need to be considered in completing aquifer testing.

Screening-level characterizations and design tools would result in significant uncertainty. Consequently, if this technology is pursued, a capture zone analysis should be completed using a model that is appropriate for the level of complexity present at the Siltronic site.

The resulting data from the aquifer testing and capture zone analysis would be used to determine well pumping rates and drawdowns and to help determine well locations. Well locations would also largely be dictated by what locations are available (not occupied by Siltronic buildings, equipment, piping, etc.). Extraction well design parameters include drilling/installation method, well diameter, screen and casing specifications, completion depth interval, and pump specifications. The location and depth of MGP waste NAPL would also be considered during design.

Typically, the time required to pump one pore volume (the volume of groundwater within a contamination plume) is calculated, as are estimates of the number of pore volumes needed for cleanup. Theoretically, this would provide an estimate of the time required to operate the pump and treat system. However, such analyses generally oversimplify highly complex site conditions, and it may be impracticable to characterize the site in sufficient detail to reduce uncertainty in these estimates.

Design of the treatment system would be based on the need to reduce TCE and its breakdown products to concentrations low enough to discharge. However, it would also be necessary to treat MGP waste. Part of the design of the treatment system would be an evaluation of treatment technologies to determine the most efficient method for treating both TCE and MGP waste. For the purpose of this evaluation, a DAF and GAC treatment system is assumed. The selection of this technology would need to be assessed further during the design phase. As previously indicated, the possibility of using existing treatment equipment at Siltronic's wastewater treatment plant should be further assessed if this technology is pursued.

Generally, treatability data needed for design would be acquired by conducting chemical analyses and treatability studies on contaminated groundwater extracted during aquifer tests. Analysis of water samples obtained at different times during an aquifer test often will provide data regarding the initial range of contaminant concentrations in influent water to the treatment plant. Bench- and pilot-scale treatability studies are valuable means for determining the feasibility of candidate processes for treating contaminated groundwater. Laboratory bench-scale tests use small quantities of extracted groundwater to provide preliminary data on various treatment processes, pretreatment requirements, and potential costs. During pilot-scale tests, skid-mounted or mobile pilot equipment is operated to study the effect of varying system parameters (e.g., flow rate) on treatment results and to identify potential problems, such as chemical precipitation of dissolved iron and manganese in an air stripper.

Construction of portions of the treatment system may be avoided if the extracted groundwater can be integrated into Siltronic's unused FAB1 wastewater treatment system. Siltronic has indicated that unused treatment system components include old TCE storage tanks, sand filters, two inclined plate lamella clarifiers, a filter press, and a thermal oxidizer. Again, the presence of MGP waste may limit or preclude this option.

2.3.2 Operation and Maintenance Requirements

Operation and maintenance requirements for a pump and treat system are relatively high. Depending on treatment system configuration and complexity, a full-time operator may be required. Operation and maintenance will include well rehabilitation and treatment media change-out. Maintenance schedules and plans typically are developed during design.

2.4 Cost and Cost Certainty

As compared to the other technologies evaluated, pump and treat system costs are moderate. Capital costs account for a lower percentage of total system cost, with operation and maintenance costs accounting for the remainder. Cost certainty for pump and treat systems is moderate for capital costs and low for operation and maintenance costs. The initial capital costs are dependent primarily on the number of extraction wells and type of treatment system components designed. Due to inherent uncertainty, operational costs are less amenable to precise estimation.

For the purpose of this evaluation, it was assumed that the pump and treat system would treat the entire TCE plume area, and separate cost estimates for the source area and the downgradient plume area were not completed. It is assumed that some components of Siltronic's FAB1 wastewater treatment system can be used. Using a planning timeline of five years, the total costs were estimated to be $3.6 million (approximately $265,000 for remedial design; $266,000 for installation of source control and downgradient containment; $719,000 for installation of and/or modifications to the treatment system; $1,403,000 for operation and maintenance for five years; $266,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $601,000 for a 20-percent contingency). The costs associated with relocating Siltronic equipment or disruptions to Siltronic operations were not evaluated or included in the preliminary cost estimate.

2.5 Limitations

As stated above, pump and treat systems are generally more effective for hydraulic containment than for remediation of the groundwater. The ability of a pump and treat system to adequately treat significant accumulations of NAPL is limited. Additionally, maintaining an adequate plume capture zone may be hindered due to proximity to the river and its hydraulic influence.

Monitoring contaminant concentrations in groundwater with time at pump and treat sites often reveals “tailing,” which refers to the progressively slower rate of dissolved contaminant concentration decline observed with continued operation of the system. The tailing contaminant concentration may exceed cleanup standards. The time required for tailing concentrations to decrease below the target cleanup levels is a great uncertainty. Reasonable estimates of cleanup times under these conditions require an understanding of the physical and chemical processes that can cause tailing. At many sites, much of the contaminant mass is not dissolved in groundwater, but is present as NAPL, adsorbed species, and solids. Slow mass transfer of contaminants from these phases to groundwater during pump and treat will cause tailing and prolong the cleanup effort. Physical causes of tailing include groundwater velocity and flowpath variations, and the slow diffusion of contaminants from low-permeability zones during pump and treat operation.

Another common problem is dissolved contaminant concentrations “rebounding” when pumping is discontinued after temporarily attaining a cleanup standard. This requires restarting the systems and continuing treatment.

2.6 Additional Data Needs

As mentioned in the design requirements section above, data needs include estimates of hydraulic conductivity, storage coefficient, porosity distribution, contaminant mass, seasonal trends in contaminant concentration, and sorption data. Contaminant transformation processes and migration rates as well as NAPL properties and treatability data are required to complete a pump and treat system design. Also, a value engineering analysis should be performed to determine whether costs to further refine Siltronic’s understanding of the treatment zone dimensions are warranted.

Utilizing some components of the existing wastewater treatment systems requires further evaluation. More information on treatment system components, average and maximum operating flows, influent and effluent concentrations, and available additional capacity is also needed.

As discussed above, access in the source area will be an issue, regardless of what technology is selected. An understanding is needed of whether certain operational areas, equipment, process lines, and utilities can be moved, and if so, at what cost.

2.7 Recommendations

The pump and treat technology would not likely clean up the source area for many years. Since the SCM goal is to remove TCE contamination from the upland source area and decrease concentrations to below target levels in a relatively short time, other technologies should be considered first. The pump and treat technology may be considered during the feasibility study for hydraulic containment, if there is an opportunity to use the existing wastewater treatment system for groundwater treatment, and/or if there is an opportunity to use pump and treat with another technology.

3 THERMAL REMEDIATION TECHNOLOGY

3.1 Process Overview

Thermal technologies for the in-situ treatment of TCE and its associated breakdown products considered for use at the Siltronic site include:

- Steam-Enhanced Remediation (SER)—Thermal treatment in which steam is injected into the source zone to volatilize, mobilize, or degrade contaminants.

- Electrical Resistive Heating (ERH)—Thermal treatment in which electrical current is passed through the contaminated zone, increasing the subsurface temperature based on the electrical resistance of the soil and groundwater to volatilize, mobilize, or degrade contaminants.

- Thermal Conductive Heating—Thermal treatment in which surface or subsurface conductive heating elements are used to create high-temperature zones to volatilize, mobilize, or degrade contaminants.

SER and thermal conductive heating were screened out because of the geology and extent of contamination at the Siltronic site. SER is more appropriate in coarse-grained soils. Siltronic's geology is fine-grained and lends itself more to ERH or thermal conductive heating. Thermal conductive heating is more appropriate if temperatures in excess of 100°C are required, which is not the case with TCE, or if the contamination is shallow and localized (thermal conductive heating requires installations that are very close together).

For the reasons mentioned above, ERH was the technology considered for use at the Siltronic site. Multiple vendors provide ERH technologies, and one of these, McMillan-McGee (MC2) of Alberta, Canada, was used as a resource for this evaluation. MC2 has a patented technology called the electro thermal dynamic stripping process (ET-DSP™). ET-DSP differs from other ERH technologies in the way the current is controlled and the fact that MC2 injects water into the electrode to enhance electrical conductivity and create steam. Literature from MC2 about its technology and a TCE remediation project is included in Appendix B2.

3.2 Evaluation Factors

3.2.1 Applicability

ERH is an aggressive remediation technology. It has to be actively managed and maintained. It typically is used to remediate heavily contaminated source areas, and because of cost and infrastructure, it is not a good technology for light to moderate groundwater contamination. For these reasons it was considered only for use within the upland source area and was not considered for the downgradient plume at the Siltronic site.

Unlike other in-situ technologies, ERH does not rely on groundwater transport and geology to distribute an injected solution, and therefore, is not as restricted by these factors. Current can be varied between electrodes to overcome geologic restrictions, and heat transfer does not rely on groundwater transport.

The technology is effective at removing volatile compounds such as TCE and benzene, and semivolatile compounds such as naphthalene. It has been used with some success at sites with MGP-like wastes (e.g., creosote).

ERH and other thermal technologies rely predominantly on increased mass recovery, not in-place destruction. This recovery is accomplished predominately as vapor and to a lesser degree in the liquid phase. This requires an aboveground treatment system to treat extracted liquids and vapors.

Success or failure at thermal remediation sites has less to do with the thermal technology being applied and more to do with the aboveground treatment system treating the recovered liquid and vapor. The treatment system must have the capability of handling spikes of contaminant mass loading. In addition, materials must be specified that are compatible with high temperature and chemical attack.

3.2.2 Short-Term Effectiveness

The short-term effectiveness of ERH within the treatment area is high. A typical treatment time is six to nine months. Actual treatment time is dependent on how long it takes to heat the target volume. For TCE the target temperature would be between 80 and 100°C. The mass recovery is very dramatic during the treating period. Complete remediation of contamination, especially for a contaminant such as TCE, is not uncommon. It is reasonable to pursue nondetect concentrations in the source area treatment zone within a six- to nine-month treatment time.

Short-term effectiveness at the point of potential exposure (Area 1) would be negligible, since treatment is confined to the accessible portion of the upland source area only.

3.2.3 Long-Term Effectiveness

Long-term effectiveness in the treatment area is expected to be high, because little to no residual contamination would remain in the accessible portion of the upland source area following application of ERH. Since ERH is being considered only for the accessible portion of the upland source area, at this point, it would be expected that TCE contamination would not migrate upgradient into this area. Downgradient reduction in plume concentrations due to continued natural attenuation would also be expected.

3.2.4 Implementability

ERH has moderate implementability. The most significant factors are associated with drilling the ERH borings and extraction wells, installing the recovery piping, and constructing the treatment system. However, the biggest restriction to implementability is access, since a portion of the source areas is under the FAB1 building. Additionally, installation and operation of ERH would require aboveground piping, wires, controls, and treatment equipment in active areas of the facility.

3.2.5 Scalability

ERH is a scalable technology. MC2's ERH system has been designed to be a modular system to facilitate expansion. A module consists of a specific number of electrodes per power delivery system (PDS) and a specific number of electrodes for a given volume of soil. Treatment system scalability is a bigger issue. Notwithstanding access constraints, it is easy to add electrodes and PDSs to new areas, but the capacity of the resulting treatment system is likely not as readily scalable. Because of the temporary nature of the ERH treatment process, it is preferred to have small treatment systems that can be moved in and out quickly.

3.2.6 Impacts of MGP Waste

The presence of MGP in the source area is not expected to hinder the removal of TCE using ERH, although the treatment system would have to be configured to handle MGP-associated contamination. The TCE and its degradation products would be stripped from soil and groundwater more quickly and at lower temperatures than many of the MGP constituents. The MGP NAPL within the treatment area will become more mobile at higher temperatures and would likely be recovered by a liquid extraction system.

3.2.7 Impacts to Operations

Installing an ERH system within the source area would cause a large impact to Siltronic's operations south of the FAB1 building. Existing Siltronic infrastructure in this area would likely need to be completely relocated to facilitate the installation of ERH wells, piping, wires, controls, and treatment equipment.

3.3 Requirements

3.3.1 Design Requirements

As part of design, samples of soil would be submitted to one or more potential vendors to measure conductivity and possibly complete bench testing. Extraction and treatment systems would be developed during design, using well-proven and readily available equipment.

3.3.2 Operation and Maintenance Requirements

MC2 typically operates these systems remotely, but they will require some site visits and monitoring. A daily inspection of the system by Siltronic staff or their representative would likely be necessary to ensure a correctly operating treatment system. Routine system checks and system monitoring would likely be conducted on a weekly basis during operation. MC2 would monitor temperature and make adjustments to the below-ground system remotely.

As discussed previously, the size of the aboveground treatment system may be reduced or the construction of a new treatment system may be avoided altogether if the liquid and vapor waste streams can be integrated into one of Siltronic's existing wastewater treatment or air treatment systems. Further analysis is necessary to determine if this is viable.

3.4 Cost and Cost Certainty

The relative cost of ERH is high. Using a planning timeline of five years,[1] the total costs were estimated to be $7.9 million (approximately $135,000 for remedial design; $4,991,000 for installation of ERH, extraction, and treatment systems; $1,257,000 for operation and maintenance; $133,000 for groundwater monitoring and system evaluation; $50,000 for a final report; and $1,313,000 for a 20-percent contingency). The cost estimate was based in part on a cost estimate from MC2 that is included in Appendix B2.

[1] The system would run only for one year. A five-year basis is chosen to compare all technologies.

The costs associated with relocating Siltronic equipment or with disruptions to Siltronic operations were not evaluated or included in the preliminary cost estimate.

3.5 Limitations

Aside from the implementation limitations discussed in Section 3.2.4, limitations of thermal treatment technologies include: very large power demands during active remediation that may require additional infrastructure; treatment will occur only between electrodes, so effects will not be seen outside of the treatment area; and no residual treatment effects. Contamination remaining in the groundwater in the downgradient plume area will require further remedial measures to fully address discharges to the river at Area 1.

3.6 Additional Data Needs

Because the vertical and horizontal distribution of TCE and MGP waste significantly impacts the treatment cost, a value engineering analysis should be performed to determine whether costs to further refine Siltronic's understanding of the treatment zone dimensions are warranted.

Utilizing some components of the existing wastewater treatment systems requires further evaluation, including treatment system components, average and maximum operating flows, influent and effluent concentrations, and available additional capacity.

Access in the source area will be an issue, regardless of what technology is selected. An understanding is needed of whether existing operational areas, equipment, process lines, and utilities practicably can be moved and at what cost.

3.7 Recommendations

Due to access constraints and the corresponding reduction in effectiveness, complications associated with managing MGP waste, and cost, ERH is not recommended as an SCM. It may be appropriate as a component of the remedial action and will therefore be revisited in the feasibility study.

4 GROUNDWATER CIRCULATION WELL TECHNOLOGY

4.1 Process Overview

Groundwater circulation wells (GCWs) are an in-situ treatment technology that generally induces a three-dimensional groundwater circulation cell within a single aquifer. This is accomplished by drawing water from an aquifer through one screen section of a dual-screened well (extraction) and discharging it through the other screen section (injection), as shown in the Figure, Part a. Circulation of water in this manner is accomplished in both the horizontal and vertical axes. Vertical groundwater circulation in the saturated zone is established by creating a pressure differential across two screens in the treatment well. The circulation pattern is generally from top to bottom through the formation, referred to as “standard circulation,” but can also be from bottom to top, which is referred to as “reverse circulation.” Treatment of the groundwater occurs between the extraction and injection steps and typically consists of air stripping or activated carbon adsorption, although bioreactors have also been used. In both circulation modes, water is not removed from the aquifer, but rather is circulated in the aquifer around the central GCW.

Natural groundwater flow can distort the ideal circulation pattern that is shown in the Figure, Part a. The circulation pattern becomes skewed in the direction of groundwater flow as shown in the Figure, Part b and Part c. A portion of the groundwater entering the GCW at any time is untreated groundwater captured upgradient. To balance this, an equal portion of treated groundwater leaves the circulation cell through a downgradient release zone. The remaining portion of water entering the well is recirculated within the circulation cell around the remediation well.

During the initial stage of circulation around the well, the bulk of the contaminant mass that is drawn into the well is in the dissolved phase within the aquifer. As the treated water is reinjected into the aquifer and is drawn back into the extraction screen, it passes through soil containing sorbed contaminants. This process increases the contaminant concentration gradient between the soil surface and the groundwater, which causes sorbed mass to transfer into groundwater. As the system operates over time, the concentrations of contaminants in groundwater may fluctuate initially due to soil flushing and mobilization, but should typically decrease to an asymptotic level.

Water is moved in the well through one of two mechanisms: air lift or mechanical pumping. An air lift system can be used in the standard circulation mode and causes water movement by pumping air to a point below the upper screen and diffusing it into the water column in the well. An air lift system also oxygenates the groundwater, which is not desired at the Siltronic site since anaerobic conditions exist and are enhancing biodegradation; therefore, air lift is not considered further. A mechanical groundwater pump can be used in the standard or reverse circulation modes and can develop a high rate of circulation (>25 gpm). In order to use a pump, a packer must be installed to separate the screens intervals. The pump is then installed in one screened section of the well and pumps the water through the treatment unit and into the other screen section. Water moving out of one screen section, through the soil formation, and into the second screen section creates the circulation cell.

Several treatment mechanisms are currently used with GCW systems. Air stripping is a commonly used treatment technique. Counter-current air strippers are able to achieve stripping efficiencies between 95 and 99.9 percent, but these systems are typically large and may require an aboveground system or an in-ground vault. For treatment technologies that rely on air (i.e., air stripping), the air vapors also require treatment prior to discharging the air into the atmosphere. Vapor treatment can utilize vapor phase activated carbon/permanganate, zeolite, catalytic oxidizer, or flame oxidizer, depending on concentrations. The air stripper can be operated in a closed-loop fashion to eliminate the introduction of oxygen to the groundwater during the stripping process. Under closed-loop operation, the outlet of the vapor treatment system is piped back to the inlet of the air stripper, resulting in no air emissions from the system. Closed-loop operation is also helpful in reducing fouling caused by metals precipitation and provides some noise reduction of the system.

Another water treatment technology is the use of liquid-phase GAC in an aboveground installation, which reduces concentrations of chemicals of concern (COCs) to nondetectable levels, as long as the system is maintained. Vinyl chloride (VC), a breakdown product of TCE, generally can pass through activated carbon more quickly than TCE, and can increase the carbon change-out frequency. Activated carbon would require periodic replacement, but this method of water treatment does not generate vapors requiring treatment. Large vessels would be required for liquid-phase activated carbon systems, which precludes in-well or below-ground vault treatment.

GCWs can be used effectively as nutrient delivery systems for enhanced bioremediation. Since biodegradation through reductive dechlorination appears to be occurring at the site, the process can be enhanced by adding a mix of nutrients to the reinjected groundwater. These systems do not typically contain a water treatment train in the circulation process, since the contaminant concentrations are low. Instead, the extracted groundwater is pumped directly to the reinjection screen of the well where it is amended with the nutrient mix. The GCW system will then distribute the nutrient through the various soil layers and enhance the biodegradation process.

Other modifications that have been made to GCW systems include air sparging, soil vapor extraction, and bioventing.

4.2 Evaluation Factors

4.2.1 Applicability

Typically, GCWs are used for source removal and treatment of highly contaminated plumes and for the prevention of off-site migration. When placed in a source area, the GCW can effectively remove contaminants dissolved in groundwater and then continue to wash sorbed contaminants from soil, providing additional benefit in mass removal. Since the soils in the immediate vicinity of the suspected upland source at the Siltronic site consist mainly of silts and clays, the likelihood of establishing a circulation cell is small, so the use of GCWs as an upland source removal option at Siltronic was not considered further.

GCWs may be well suited for use at the Siltronic site as a treatment option for the downgradient plume. The likelihood of establishing circulation cells in this area is better since there are fewer substantial silt/clay layers. The vertical extent of a single circulation cell can be up to about 60 feet, and cells can be stacked, providing a vertical treatment zone of about 120 feet, using a well with three screened sections. The rate at which the GCW can treat water within the plume is limited to the velocity of groundwater flow through the soils, and the amount of time it will take for water at the upper end of the plume to travel to the GCW under natural conditions. So treatment time would depend on the ability to locate wells as close to the upland source as possible, but could be on the order of four to six years from the time the upland source was removed (based on a groundwater flow rate of 0.2 to 0.3 feet per day and the distance under FAB1).

The use of GCWs to establish a treatment wall may also be well suited to the downgradient plume area to stop or reduce the concentration of contaminants migrating to Area 1. In this type of installation, a series of GCWs is installed in a line with overlapping treatment zones, ensuring that all water passing through the treatment wall is treated by the GCWs before being discharged. The considerations for establishing a treatment wall are similar to those discussed for treating the plume. The treatment wall may be operated using a standard air stripping setup as discussed in the technology description, but may also be effective when implemented as a nutrient-delivery system to enhance natural bioremediation already occurring at the site. In this situation, the GCW typically does not have an air stripping component, instead having only a nutrient-delivery system. The nutrients are then circulated through a smaller circulation zone, which is based on the ability to distribute the nutrients through the entire zone before being consumed. The aboveground equipment for such a system would be limited to a shed and tank containing the nutrient solution, with a small dosing pump.

4.2.2 Short-Term Effectiveness

In general, GCWs tend to be effective in source locations where soils are permeable and the contaminant mass is mostly present in dissolved and sorbed phases. Source areas with NAPL are more challenging conditions for application of GCW. Due to the low-permeability soil present in the upland source area, GCWs are not likely to be effective. Sufficiently sized circulation cells will be difficult to establish under these conditions. Therefore, as a source removal option and as previously noted, GCWs should not be considered.

If installed as a plume-treatment technology in the more permeable downgradient areas, GCWs may be effective at treating the water and soil within the zone of influence (ZOI) and from the upgradient capture zone. Groundwater leaving the treatment zone should be below target levels, so continuation of the plume past the GCW should not occur.

GCWs are also very effective when installed as a treatment wall at the leading edge of the plume to prevent off-site migration. If the GCW treatment wall is designed with sufficient overlap, all groundwater passing through the wall will receive treatment, which can be as effective as a dewatered zone or sheet-pile wall in preventing contaminants from migrating past the wall, without impacting the overall aquifer flow regime.

4.2.3 Long-Term Effectiveness

The long-term effectiveness of GCW depends greatly on the understanding of the aquifer characteristics and contaminant properties. Water chemistry can have a significant impact on the long-term effectiveness, since scaling and biofouling can adversely impact the ability to extract water from or inject water to the aquifer, and reduce the efficiency of the circulation well. These water characteristics can be accounted for through design by reducing the amount of oxygenation of the water or heat transfer to the water during treatment, or by addition of a weak biocide to the reinjected water to prevent biofouling of the screen.

The main potential for system redesign is to accommodate effects from water chemistry or biological growth. This could lead to piping redesign or the addition of biological inhibitors. If actual groundwater contaminant concentrations are higher than those assumed during design, redesign might incorporate capacity increases for the treatment equipment.

The design capacity of the treatment system typically is based on the startup period and during the first year while the circulation cell is being established and the first flush of pore water is occurring. The treatment portion of the system is typically designed to accommodate twice the ambient concentrations to account for mobilization of COCs that may have sorbed to soil from the plume. After the initial flush of the cell, the COC concentrations are expected to decrease, since the circulation zone will have been treated at least once, and most of the incoming COCs are from the upgradient capture zone instead of pore water within the treatment zone.

If the incoming concentrations were to increase beyond the capabilities of the treatment system, modifications to the treatment system would be needed to achieve the desired target levels. In the case of a stripping system, modifications would require increasing the contact time, such as adding more trays or increasing the volume of the aeration chamber. For an activated carbon/permanganate zeolite treatment system, modifications could simply require increased change-out frequency or additional contact chambers.

4.2.4 Implementability

GCW technology has moderate implementability. The GCWs would likely be double- or triple-screened wells 6 to 12 inches in diameter. Site access constraints associated with a drill rig can affect the implementability of GCW. The GCW wellhead is usually installed in an underground vault for protection and access for piping installation. Excavation would be required during installation. The vault can also be used to contain water-treatment equipment if in-well equipment is not used. Pumps, well packers, and/or piping are installed in the well and typically require assembly above ground before lowering into the GCW, requiring adequate overhead clearance over the well.

Aboveground equipment for the GCW generally requires a covered location to prevent freezing of water and protect equipment from rain. In an air stripping GCW system, the vapor treatment portion requires a vacuum blower and vapor treatment components, such as activated carbon and permanganate zeolite canisters. In a liquid-phase activated carbon treatment system, storage is required for the activated carbon canisters to protect them from freezing. Typically the aboveground equipment can be combined for several GCWs that are located close to each other, as long as accommodation can be made for underground piping or piping at the surface. In an air-stripping-based treatment system, a single set of vapor equipment can be used to run several air strippers. Carbon-based water-treatment systems generally require the water from individual wells to remain segregated, so separate treatment canisters are required for each well.

The GCW does not dewater the surrounding soils, so they can be placed relatively safely adjacent to or inside of buildings without increasing the risk of soil consolidation and settling of the structure.

Other items affecting implementability include:

- The vacuum blower and pump control equipment generally requires three-phase power.

- Depending on well layout, piping of vapor treatment lines may be aboveground or underground.
- Depending on treatment method, water treatment equipment may be in-well, in-ground, or aboveground.
- Carbon-based vapor treatment equipment requires vehicle access for servicing by carbon truck.
- A closed-loop vapor treatment system may require a heat exchanger to minimize heat transfer to treated water.
- A large wellhead vault may be needed to accommodate stripping equipment.

4.2.5 Scalability

Since each GCW can be a stand-alone treatment unit, additional GCWs can be added as needed to address untreated portions of the plume, but there is little or no opportunity to increase the treatment zone of an individual GCW. If more GCWs are added, there might be some opportunity to make use of available capacity of existing aboveground equipment for other GCWs, depending on the design capacity.

4.2.6 Impacts of MGP Waste

Dissolved contaminants from the MGP waste should not interfere with the normal operation of the GCW system. BTEX and naphthalene are reliably removed using air strippers and activated carbon. PAHs might not be removed by an air stripper, but are readily absorbed by activated carbon. Therefore, the MGP waste would increase the activated carbon consumption rate. The selection of a proper treatment technology for recirculated water is necessary, since the GCW has the potential to introduce contaminants to areas of the aquifer where they are not currently found.

The presence of NAPL can affect the operation of in-well pumps, depending on its viscosity; additionally, the NAPL can clog air strippers and activated carbon. It is essential to design safeguards to keep MGP DNAPL segregated within the extraction portion of the well, such as by incorporating a sump at the bottom of the intake screen to accumulate DNAPL with a means for removal from the sump. If the DNAPL is compatible with the in-well pump equipment, separation basins to remove the DNAPL can be incorporated before water treatment. Removal of the DNAPL prior to reinjection is essential so that the material is not introduced into new portions of the aquifer.

4.2.7 Impacts to Operations

In general (and depending on site access conditions), a cluster of four GCWs can be operated with a single vapor treatment system and control unit. The space required to house this equipment is 10 feet by 12 feet minimum, with clear access on one side for use by a forklift (for servicing equipment). Piping for the system is generally high-density polyethylene, which can be above ground, but below ground is preferred.

Each GCW generally requires a subsurface vault to house the wellhead and piping connections, as well as any subsurface water stripping chambers.

4.3 Requirements

4.3.1 Design Requirements

Design requirements require field testing to estimate values for:

- Vertical hydraulic conductivity
- Horizontal hydraulic conductivity
- Contaminants present in groundwater and chemical properties
- Groundwater characteristics, including Ryznar's and Langelier's Indices (to indicate scaling potential)
- Enhanced bioremediation parameters, if desired

Additional pilot testing is recommended to provide more accurate estimates of the following:

- Ability to establish a circulation cell
- Range of groundwater circulation flow rates that can be sustained under equilibrium conditions
- GCW ZOI and capture zone width (top and bottom) to determine well spacing

4.3.2 Operation and Maintenance Requirements

Operation and maintenance requirements for a GCW system are relatively high and comparable to the requirements for a pump and treat system. Operational needs of the

GCW depend on the type of system that is installed, but are typically minimal once the circulation cell is established. During startup, it is necessary to establish an equilibrium pumping rate that maximizes the extraction and injection rate. This requires monitoring of the water level in the extraction screen interval and head pressure in the injection screen, combined with manipulation of the pump rates to achieve a maximum steady state rate. After starting the system, operational requirements of the GCW systems include periodically recording pump rates and pressures, checking blower operation, and maintaining treatment equipment. Control equipment may also require occasional troubleshooting if anomalies in groundwater flow begin to appear. Sampling of the air discharge may be required, depending on permit requirements or type of system installed (open or closed loop). Weekly inspections of the treatment systems to record operating parameters and check equipment should be planned. Changing of activated carbon is typically designed to occur on a two- to six-month basis.

Maintenance items typically include servicing of water or vapor treatment equipment and monitoring of well screens. Pumps and blowers associated with treatment equipment can require periodic lubrication or replacement of parts. The equipment must be selected properly to ensure that it is compatible with the contaminants expected, since some types of plastics can become brittle in the presence of certain materials. If activated carbon and permanganate zeolite are used in the treatment process, monitoring and replacement of the materials will be required on a periodic basis. Stripping equipment requires periodic cleaning of sediment and buildup to ensure proper air flow.

4.4 Cost and Cost Certainty

As compared to the other technologies evaluated, GCW costs are relatively high. The cost depends on the site-specific soil and groundwater conditions, the type of contaminant being treated, and the method of treatment used. Cost certainty is moderate.

Using a planning timeline of five years, the total cost for installation and operation of a GCW system as a treatment wall in the downgradient plume area is estimated to be $4.1 million (approximately $221,000 for remedial design; $115,000 for drilling costs; $237,000 for installation of treatment system; $2,454,000 for operation and maintenance for five years; $266,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $676,000 for a 20-percent contingency). The costs associated with relocating Siltronic equipment or with disruptions to Siltronic operations were not evaluated or included in the preliminary cost estimate. However, since there is little or no significant Siltronic equipment or infrastructure north of FAB1, facility modifications are not considered to be necessary and will not impact costs significantly.

4.5 Limitations

The ability of GCWs to treat dissolved-phase plumes is limited by the rate of groundwater flow. The amount of time that the system will be required to operate would depend on the mass of contaminants remaining in the upland source area.

Since the installation of GCWs would likely require large diameter boreholes, access for a large drill rig will probably be required, but given the probable location on the north side of FAB1, this should not be an issue.

As noted previously, it is possible that transport and mixing of MGP materials from areas of relatively high concentrations to areas with lower concentrations could occur. Site characterization and specific analyses during design would be necessary to avoid this.

4.6 Additional Data Needs

A pilot test designed to evaluate the ability to establish a circulation cell is necessary. Since there are many layers of low-permeability materials interbedded with the sand layers at Siltronic, the pilot test is necessary to provide the design information needed to properly space the treatment wells. The pilot test would require that a GCW be installed along with three crossgradient piezometer pairs (shallow and deep) at 25, 50, and 75 percent of the expected radius of influence.[2] The pilot test would provide information relating to radius of influence (capture zone) and hydraulic conductivity (vertical and horizontal). Assuming satisfactory results, the pilot test well can be converted into an operating GCW with the addition of treatment equipment. The piezometers would also become part of the SCM system.

4.7 Recommendations

For the Siltronic site, GCWs are best implemented in series as a treatment wall in the downgradient plume area north of the FAB1 building, where the subsurface soils are generally more permeable. The treatment wall would act to eliminate or reduce the concentration of contaminants migrating from the site to Area 1. Given the variations seen in the boring logs at the site, a pilot test is strongly recommended if GCWs are considered for the site. Deep treatment zones would require stacked circulation cells, which can be accomplished with an additional screened section.

Consideration should also be given to the use of a GCW as a delivery system for a "bio-barrier" treatment wall. This would reduce implementation costs when compared with the system described above and would enhance the existing biological degradation processes

[2] A typical hydraulic radius of influence for a GCW ranges between 120 and 200 feet.

occurring at the site. The GCW/enhanced bioremediation system would require the installation of a groundwater pump, a packer, and nutrient-dosing pump.

5 CHEMICAL OXIDATION TECHNOLOGY

5.1 Process Overview

In-situ chemical oxidation has become a well-recognized technology for remediating contaminated soils and groundwater. Oxidants can be mixed with soil, placed as an oxidation wall, or injected into soil and/or groundwater.

Vendors of chemical oxidants claim that a wide range of contaminants in soils and groundwater can be treated effectively in a short time frame. Their lists of treatable contaminants include petroleum hydrocarbons, BTEX, chlorinated alkenes (tetrachloroethene [perchloroethylene or PCE], TCE, dichloroethene [DCE], VC), chlorinated alkanes (e.g., 1,1,1-trichloroethane, 1,1-dichloroethane), PAHs, pesticides (e.g., lindane, chlordane), methyl-tert-butylether, and pentachlorophenol.

Oxidants used for chlorinated solvent treatment include Fenton's reagent (a mixture of hydrogen peroxide and dissolved ferrous iron in a low pH [acidic] solution), modified Fenton's reagent (a patented mixture consisting of moderate [12 to 15 percent] hydrogen peroxide concentrations and chelated iron catalysts under neutral pH conditions), potassium permanganate, sodium permanganate, persulfates, and ozone.

5.1.1 Fenton's Reagent

When Fenton's reagent is used, hydrogen peroxide reacts with iron to generate hydroxyl radicals. Hydroxyl radicals are very strong oxidizers that quickly react with most contaminants to convert them into water, carbon dioxide, and salt. A typical oxidation reaction of TCE with a Fenton's reagent hydroxyl radical is:

$$H_2O_2 + Fe^{+2} \rightarrow OH + OH^- + Fe^{+3}$$

$$C_2HCl_3 + 2OH + O_2 \rightarrow 2CO_2 + 3H^+ + 3Cl^-$$

A low pH must be maintained to keep the iron in the ferrous state to initiate the generation of hydroxyl radicals. The reaction can be performed successfully at a pH range between five and seven standard units, but optimal conditions are observed between three and five standard units. Unless there is low pH, the iron can precipitate within inches from the point of injection, which makes the hydroxyl radical generation much slower. Acidified iron solution will remain in solution longer than regular iron solution; however, the low pH can be buffered by the native soil to its natural circum-neutral pH, resulting in iron precipitation. Elevated concentrations of calcium carbonate require large amounts of acid to reduce and maintain the pH of the treatment area. Furthermore, acidification of the entire contaminated aquifer may not be practical.

The reaction of most contaminants with Fenton's reagent is typically complete in a matter of one to three hours.

5.1.2 Modified Fenton's Reagents

Modified Fenton's reagents are patented. In-Situ Oxidative Technologies, Inc. (ISOTEC), a vendor of modified Fenton's reagent, claims that it produces reductants such as superoxide radical anion and hydroperoxide anion in addition to the strong oxidant hydroxyl radical. It claims that its modified Fenton's Reagent is formulated to avoid issues with iron precipitation and maintaining a low pH (ISOTEC, 2005a).

5.1.3 Potassium Permanganate

Potassium permanganate is an oxidizing agent with a unique affinity for organic compounds containing carbon-carbon double bonds (including TCE), aldehyde groups, or hydroxyl groups. Potassium permanganate is capable of providing rapid destruction of chlorinated alkenes such as PCE, TCE, DCE, and VC. The permanganate oxidation reaction creates inert and nontoxic by-products (carbon dioxide, chloride salt, and manganese dioxide). Manganese dioxide is an insoluble mineral (pyrolusite) commonly found in soils in many parts of the United States. If the precipitation of manganese dioxide in the soils is excessive, it can reduce the permeability of the soil, thus limiting injection of the aqueous oxidant. Potassium permanganate is often used in the treatment of drinking water at surface water treatment plants. A typical oxidation reaction of TCE with potassium permanganate is:

$$C_2HCl_3 + 2KMnO_4 \rightarrow 2CO_2 + 2MnO_2 + 2KCl + HCl$$

The reaction of these compounds with potassium permanganate is typically completed in a matter of minutes to hours. It is assumed that sodium permanganate and persulfates would perform similarly to potassium permanganate.

5.1.4 Ozone

Ozone is one of the strongest oxidants available for chemical oxidation. Ozone oxidizes organic contaminants in two ways, either through direct oxidation by ozone molecules or by free radicals that are generated as intermediates by other ozone interactions. The hydroxyl radicals are nonselective oxidizers, which rapidly attack organic contaminants (typically in less than ten seconds) and break down their carbon-to-carbon bonds. Ozone can oxidize chlorinated alkenes (such as TCE), but oxidation by hydroxyl radicals is faster than oxidation by the ozone itself. Typical application ratios range from 1 to 10 pounds of ozone per pound of contaminant. Generally, moderate ozone gas saturation in the subsurface achieves optimum treatment effectiveness.

5.2 Evaluation Factors

5.2.1 Applicability

In general, chemical oxidation is very effective where the treatment chemical comes in contact with the contaminants and poor where there are interferences from other soil constituents, other contaminants, or where the oxidant cannot reach the contaminants. The effectiveness depends upon the site-specific soil and groundwater conditions, the type of contaminant being treated, and the method used to apply the treatment chemical.

Based on the boring log for WS-13, the site geology in the upland source area at Siltronic consists of clays and silts from 24 to 42 feet and interbedded silts and sands from 42 to 100 feet bgs. Any technology that involves injection will have difficulties achieving even distribution throughout the geologic layers within this area. It seems unlikely that chemical oxidation would reduce concentrations in the upland source area down to target levels, but it could remove up to 90 percent of the mass of TCE in the source area. It may be able to decrease concentrations enough that natural attenuation or other treatment technologies could be used outside the upland source area.

There is less fine-grained material in the downgradient plume area, and distribution of an oxidant through the soil and groundwater may be achieved more readily. Chemical oxidation could be used in the downgradient plume area, but unless the mass of TCE in the upland source area was removed, repeated applications would be necessary. Based on information provided by ISOTEC (2005b), and a hydraulic conductivity of 0.2 to 0.3 feet per day, injections may be required every six to nine months.

5.2.2 Short-Term Effectiveness

Given the difficulties expected in achieving even distribution, short-term effectiveness in reducing concentrations of TCE below cleanup levels in the upland source area would be low. In fact, dissolved-phase concentrations may actually increase shortly after the first injection because the reactants are pushing the contaminants into solution. However, this phenomenon is not permanent, and additional injections would reduce the concentrations. The short-term effectiveness in removing up to 90 percent of the contaminant mass in the upland source area would be moderately high. A 90 percent mass removal would decrease average TCE concentrations to approximately 7 mg/L, but will not reduce TCE to target levels (which could be two to three orders of magnitude lower).

Short-term effectiveness in the downgradient plume area would likely be moderately high. It is possible that concentrations in the downgradient area would be reduced to target levels.

5.2.3 Long-Term Effectiveness

The oxidants are short-lived and will not stay in the soil for extended periods of time. In general, the long-term effectiveness is very similar to short-term effectiveness: it is effective where the treatment chemical comes in contact with the contaminants. Multiple injections would be required in the upland source area to reduce the mass of TCE. Multiple injections would also be required in the downgradient plume area, to address the ongoing migration of TCE to Area 1.

5.2.4 Implementability

In general, the implementability of in-situ chemical oxidation is high. Knowledgeable vendors are available to assist in the selection of oxidant and design of the injection system. A source of on-site water would be required along with a method for water disposal.

For the Siltronic site, an estimated 43 injection wells (approximately 20- to 25-foot spacing) would be required in the upland source area and an estimated 27 wells would be required in the downgradient area. Additional monitoring wells would also be necessary. Currently, there is not adequate access for the installation of the injection wells in the upland source area. Given the space limitations and site geology, the implementability of in-situ chemical oxidation at the upland source area is expected to be moderately low, without substantial modifications to operations and infrastructure south of FAB1. Injection wells could easily be installed in the downgradient plume area, and thus the implementability of in-situ chemical oxidation in the downgradient area is moderately high.

5.2.5 Scalability

Bench- and/or pilot-scale testing would be necessary before implementation of chemical oxidation. The results of bench-scale testing may not be directly (linearly) applied to the design of a corresponding pilot-scale study. The same may be said for pilot studies as they relate to full-scale design; however, pilot studies are often conducted at a scale that is essentially the same as the full system under consideration. Bench-scale tests are based on small volumes of disturbed soil and/or groundwater, and the test apparatus may not adequately recreate the geometric nature or flow characteristics of the physical system observed in the field. Also, bench-scale tests often are based on well-mixed static systems, while the field implementation involves dynamic plug flow. Notwithstanding these constraints, chemical oxidation could be applied in a limited area, and if successful, could be expanded. Therefore, this technology is scalable.

5.2.6 Impacts of MGP Waste

The oxidants used to treat the groundwater are not selective and will essentially oxidize any organic material. Therefore, the MGP waste is a potential sink for the oxidants and would likely increase the volume of chemical required for treatment.

5.2.7 Impacts to Operations

As discussed above, the injection well spacing required for chemical oxidation in the upland source area would require that Siltronic move some of its operations and infrastructure south of FAB1. Using chemical oxidation in the downgradient plume area would cause minimal impacts to Siltronic operations.

5.3 Requirements

5.3.1 Design Requirements

Before design of an in-situ treatment system, limited additional site characterization (see additional data needs below) would be needed. Much of the design process would then involve working with vendors to select the proper oxidant and determine the proper chemical addition ratios. The proper selection of an oxidant is important because reaction effectiveness varies with contaminant type. Siltronic would supply soil and/or groundwater samples to the vendors to allow for selection and optimization of the oxidant through bench testing. Specific concentrations and volumes of the reagents to be injected in the field would be determined based on bench testing with different catalyst and oxidizer amendments.

An understanding of reaction times and the life span for reactants is also necessary to ensure adequate contact time. This involves both testing at the bench-scale level and field monitoring during pilot- or full-scale oxidant application to evaluate reaction progress. Potential reaction interferences must be identified. It would be necessary to calculate the mass of chemical required for treatment.

Siltronic and the vendor would also need to design the injection system layout to ensure adequate chemical contact times. Chemical delivery to the contaminated region is the key for successful in-situ remediation of contaminants. Siltronic would need to determine whether to inject using a Geoprobe™ rig or whether to install injection well points. Additional monitoring wells would need to be designed and installed. For each depth of injection, a monitoring well screened at the same depth would be required.

5.3.2 Operation and Maintenance Requirements

There is virtually no operation and maintenance involved with in-situ chemical oxidation. Possibly, there would be limited maintenance associated with the injection wells and monitoring wells. Groundwater monitoring would be necessary after injection to monitor the effectiveness of the treatment.

5.4 Cost and Cost Certainty

Compared to other treatment technologies evaluated, the cost of chemical oxidation is moderate. The cost of chemical oxidation depends on the site-specific soil and groundwater conditions, the type of contaminant being treated, and the method used to apply the treatment chemical. The vertical and horizontal distribution of MGP NAPL would significantly impact the treatment cost. The cost of the chemical itself can be provided through vendor quotes. The more difficult question is how much chemical would be required for treatment. As discussed above, the soil properties and interferences from other organics would greatly affect this. For these reasons, the cost certainty is low.

Based on a planning timeline of five years, the total cost for chemical oxidation in the upland source area is estimated to be $3.0 million ($152,000 for remedial design; $2,210,000 for installation of source control and downgradient containment; $89,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $508,000 for a 20-percent contingency). The costs are based in part on a budgetary cost estimate prepared by ISOTEC for 90-percent mass removal in the upland source area (see attached estimate in Appendix B2). The estimate assumes 43 injection wells with injection at two to three depths.

Based on the same planning timeline of five years, the total cost for chemical oxidation in the downgradient plume area is estimated to be $2.4 million ($152,000 for remedial design; $607,000 for installation of source control and downgradient containment; $914,000 for operation and maintenance for five years [repeated injections]; $266,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $406,000 for a 20-percent contingency). The costs are based in part on a budgetary cost estimate prepared by ISOTEC for treatment to cleanup levels in the downgradient plume area (ISOTEC, 2005b). The estimate assumes 27 injection wells.

The costs associated with relocating Siltronic equipment or disruptions to Siltronic operations were not evaluated or included in the preliminary cost estimate. These costs are expected to be much higher in the upland source area than in the downgradient plume area.

5.5 Limitations

For sites with low permeability or heterogeneous soils, effective injection of chemicals to the contaminated region may be difficult due to preferential flow paths and diffusion limitations. Site-specific soil and groundwater conditions can also affect the performance of chemical oxidation through direct competition with contaminants for the oxidant. Soils with elevated natural or anthropogenic organic material react with the oxidants, thus increasing the overall chemical demand. As discussed above in the overview section, there are other potential interferences, depending on the type of oxidant used.

Using chemical oxidation on a site that is benefiting from natural attenuation may temporarily upset the geochemistry that facilitates the process. Without knowing the specific mechanisms causing the current natural attenuation at the site, it is not clear what effect chemical oxidation would have on natural attenuation at the site.

Aquifer clogging may be another limitation for some oxidants. The formation of insoluble manganese dioxide when using potassium or sodium permanganate can reduce the permeability of the soil and limit the injection of the aqueous oxidant.

Another concern is the hazards related to the chemicals and the potential for vigorous, uncontrolled reactions in the subsurface that may occur with Fenton's reagent. Volatile compounds may be released by even moderate changes in temperature. There could be a significant change in both the concentration and distribution of flammable vapors and/or toxic vapors when using an in-situ chemical oxidation method. This dynamic environment is less predictable than most other cleanup situations.

5.6 Additional Data Needs

As mentioned above, the vertical and horizontal distribution of MGP NAPL significantly impacts the treatment cost. Therefore, a value engineering analysis should be performed to determine whether costs to further refine Siltronic's understanding of the treatment zone dimensions are warranted.

Information on hydraulic conductivity, porosity, vadose zone permeability, organic carbon content, chemical oxidation demand, pH, oxidation reduction potential, dissolved oxygen, and conductivity/resistivity is required to complete a chemical oxidation system design. Depending on what oxidant is used, additional information such as calcium carbonate content; iron content and iron oxidation state; alkalinity; soluble manganese concentrations; permanganate impurities; lower explosive limit; carbon dioxide; oxygen; and moisture content of vadose zone may be required.

Bench and pilot tests should be completed prior to full-scale design, as discussed in the design requirements section above.

5.7 Recommendations

The site access and site geology present major barriers for consideration of in-situ chemical oxidation at Siltronic. It is unlikely that chemical oxidation would reduce the TCE concentrations to target levels because contaminants within the silt lenses would not come in contact with the oxidants. Therefore, it is not considered a preferred technology for the upland source area at this time.

Chemical oxidation could be used in the downgradient plume area, but frequent injections (approximately every six to nine months) would be necessary due to ongoing releases from the upland source area. For this reason, chemical oxidation is not considered a preferred technology for the downgradient plume area at this time.

6 BIOREMEDIATION TECHNOLOGY

6.1 Process Overview

Bioremediation technologies rely on engineered systems to enhance or stimulate the degradation of chlorinated solvents. Some microscopic organisms (primarily bacteria) are capable of transforming relatively toxic VOCs into nontoxic organic chemicals, through a process is referred to as intrinsic biodegradation. Bioremediation technologies attempt to enhance these degradation processes to reduce the mass of a contaminant at an increased rate.

There are several pathways by which biodegradation of VOCs may occur at a site. Through aerobic and anaerobic oxidation, microbes directly oxidize VOCs to derive energy. In some situations, cometabolism results in the beneficial breakdown of VOCs as microbes metabolize other constituents. Reductive dechlorination of VOCs occurs when microbes directly reduce VOCs in order to derive energy from other organic compounds. Highly chlorinated VOCs (e.g., TCE) are often most efficiently degraded under reducing conditions, whereas less chlorinated VOCs (e.g., VC) are often most efficiently degraded under oxidizing conditions. An important early objective is to identify effective and efficient biodegradation mechanisms at a site, the rate-limiting steps in the preferred biodegradation processes, and factors that can be manipulated to enhance biodegradation.

Numerous factors such as the types, concentrations, and distribution of chlorinated VOCs; redox conditions; natural microbial community composition; and hydrogeological conditions can affect biodegradation processes (Remediation Technologies Development Forum. 2005). Identification of the key factors that can be manipulated to bolster a particular biodegradation process is complicated. Below is a description of the general process for evaluating and implementing a bioremediation program.

1) Evaluate the conditions at a site that will affect bioremediation options.
   a) Geology and Hydrogeology
      i) Characterize conductivity, infiltration, well yields, anisotropy, heterogeneity, vadose zone thickness, effective porosity, and preferential flow paths.
      ii) Data are used to identify potential monitoring/injection locations, residence times of amendments (e.g., electron donors/acceptors, bacteria), amendment application mass and rates, and groundwater flow directions and rates.

b) Geochemistry
   i) Characterize TCE (and degradation products) concentrations and distributions, electron donor/receptor concentrations and distributions, monitored natural attenuation parameters.
   ii) Data used to identify target treatment areas, amendment loading requirements, current transport and degradation processes, rate limiting processes and how degradation can be augmented, secondary water quality impacts, and potential biofouling.
c) Microbiology
   i) Determine the presence and concentrations of key microorganisms. Look for certain bacteria (*Dehalococcoides*) that are important for reductive dechlorination of VOCs. Reductive dechlorination is often the most efficient biodegradation process for complete degradation of highly chlorinated VOCs such as TCE.
   ii) Data used to determine if complete dechlorination will occur, what amendments may be needed to enhance degradation processes, and where bioaugmentation (addition of microbes) may be needed.

2) Set remedial objectives.
   a) Identify goals of remediation. Remediation goals may include:
      i) Restoration—mass reduction in source area or in plume
      ii) Containment—no chemical flux beyond a treatment zone
      iii) Polishing—restoration of plume after source is treated with another technology
   b) Determine factors that constrain design/objectives.
      i) Hydrogeological setting (design/operation)—treatment zone size, heterogeneity, groundwater gradients and velocity
      ii) Mass transfer (cleanup times/feasibility)—DNAPL mass and distribution, sorbed phase, dissolved phase
      iii) Target chemicals (design/feasibility)—chemical properties, distribution, and concentrations
      iv) Geochemistry (design/feasibility/operation)—solid and dissolved electron donors/acceptors, concentrations, distributions
      v) Microbiology (design/feasibility/operation)—microbial community composition and response to amendments
      vi) Site setting (design)—obstructions such as buildings, etc.
      vii) Nutrients (design/operation)—types, persistence, delivery, distribution
3) Lab and/or pilot studies to test and optimize system.
   a) Confirm degradation processes and rates.
   b) Identify challenges (fouling, operations).
   c) Optimize performance.
   d) Evaluate design and cost of system.

4) Bioremediation design.
   a) Design calculations
      i) Stoichiometry—amount of electron donor/acceptor required
      ii) Decay rates—concentration vs. distance estimates
   b) Delivery design
      i) Direct injection versus well injection/circulation
      ii) How to mix nutrients
      iii) Well placement or injection locations
   c) Modeling
      i) Amendment transport and consumption
      ii) Monitoring system/schedule
   d) Cost
5) Implementation.
   a) Well system
      i) Installation and instrumentation
      ii) Startup and calibration
      iii) Operation, maintenance, troubleshooting
      iv) Performance monitoring
      v) Safety and QA/QC
   b) Direct injection
      i) Site preparation
      ii) Injection
      iii) Monitoring
      iv) Reinjection (as needed)
6) Operation and maintenance (well system only).
   a) Routine maintenance
   b) Biofouling control
   c) Troubleshooting
7) Performance monitoring.
   a) Sampling programs—parameters and frequency
   b) Sampling techniques
   c) Verification—statistical evaluation

6.2 Evaluation Factors

6.2.1 Applicability

Available evidence indicates that intrinsic biodegradation processes are likely contributing to the observed breakdown of TCE in the contaminated aquifer. Bioremediation through enhancement of existing biodegradation processes or by augmenting the existing microbial community is an applicable technology for the upland source area and for the downgradient plume.

Access limitations and low-permeability soils may limit the use of wells for the delivery of amendments in the upland source area, so applications of amendments through direct injection should be considered. In the downgradient plume area north of FAB1, the soils are more coarse-grained, allowing for better dispersion of amendments, and general access for equipment is better, so application of amendments using wells or direct injection may be appropriate.

6.2.2 Short-Term Effectiveness

In general, the short-term effectiveness of bioremediation is moderate to high. Bioremediation is capable of fairly rapid mass reduction of dissolved-phase VOCs if the desired organisms and nutrients are available or can be delivered effectively. Based on the results for other sites with similar contamination, substantial contaminant mass reduction can be achieved in less than one year.

Given the difficulties expected in achieving distribution of nutrients to the fine-grained soils in the upland source area, short-term effectiveness in reducing concentrations of TCE below target levels in the area will be low. However, some mass reduction would be expected. Inadequate access to the aquifer under FAB1 may be a limiting factor in the rapid reduction of contaminants within the dissolved-phase plume immediately downgradient of the upland source.

Short-term effectiveness in the downgradient plume north of FAB1 area will likely be moderately high. It is possible that concentrations in the downgradient area will be reduced to target levels. Remediation of the entire dissolved-phase plume would likely rely on natural groundwater flow under FAB1 to the downgradient treatment zone, and would depend on the mass of contaminants remaining in the upland source area.

6.2.3 Long-Term Effectiveness

Bioremediation results in irreversible chemical transformation. As a result, it can be a highly effective long-term remedy. However, given the difficulties expected in achieving even distribution of nutrients through fine-grained soils in the upland source area, long-term effectiveness in reducing concentrations of TCE below target levels in the upland source area is expected to be moderately low. Long-term effectiveness in the downgradient plume area will likely be moderately high because soils are more permeable and because the existing contaminant concentrations are lower. It is possible that concentrations in the downgradient area will be reduced to target levels if properly designed.

Long-term effectiveness is dependent on changing microbial communities. These communities of living organisms are dynamic. Long-term maintenance of effective biodegradation processes may require regular monitoring and periodic adjustments as microbial communities change over time.

Bioaugmentation involves adding desired bacteria to change the composition of a microbial community. When properly designed, it is generally a single-application technology. The presence of the contaminants and proper nutrients ensures the viability of the microbial community. As the contaminant concentrations change, the microbial population will naturally expand or contract in a lagging fashion. Increases in contaminant concentration will generally cause the population to grow, so sudden slugs of increased concentration may not be effectively treated if the community has been allowed to decrease, which could require subsequent applications. Additionally, if the design process fails to identify competing microbes, establishing the desired microbial community can be difficult.

Long-term effectiveness is also dependent on the method of nutrients or substrates delivery. A slow-release compound is typically administered through a direct-push process and remains effective until the material is completely dissolved or is consumed (typically six to 60 months, depending on the product used). A more permanent delivery system, such as an injection well or circulation system, can remain effective as long as the system is operated or maintained. Downgradient applications of the enhanced bioremediation technology would require the use of methods that would remain effective in the long term, in order to treat groundwater moving under FAB1, as discussed above. Multiple applications or continuous circulation of substrates should be included in the downgradient design.

In general, system design will be determined by amendment-delivery considerations and constraints. For example, hydrogeological conditions would affect the spacing and density of amendment-delivery points. The design would also need to consider obstructions that constrain well placement, such as existing buildings and the river.

6.2.4 Implementability

In general, the implementability of enhanced bioremediation is high. Knowledgeable vendors are available to assist in the design. Implementation of a bioremediation program would require completing soil borings or installing wells for delivering amendments and monitoring biodegradation processes. Application of materials using direct-push requires access for a Geoprobe truck or a smaller, track-mounted unit. Monitoring wells or delivery wells will require access for a drill rig requiring more space.

Within the upland source area, application technologies would be limited because of the tight soils, so direct-push methods with a very tight grid might be appropriate. Other application methods, such as hydrofracturing and GCWs (see Section 4), may also be applicable.

Downgradient application of amendments using either direct injection or well delivery (diffusion or circulation) is more easily accomplished. If a circulation well delivery system is considered, the additional circulation well issues would need to be addressed as discussed for GCW systems.

6.2.5 Scalability

Enhanced bioremediation is very le, as long as access is available. Direct injection can be reapplied as needed in the same or new locations, since there are no permanent equipment requirements for this technique. Groundwater circulation systems are also very scalable, since, when used as a nutrient-delivery system, the GCW consists of a double-screened well, a packer, a groundwater pump, a nutrient tank, and a dosing pump.

6.2.6 Impacts of MGP Waste

The presence of the MGP waste may not be detrimental to the bioremediation process. The degradation of MGP constituents at the site is most likely occurring under anaerobic conditions, given the low dissolved-oxygen content of the groundwater. Anaerobic degradation is generally a slow process when compared to aerobic degradation, so it is important to understand the process that is occurring to assess the impacts of altering the existing system.

The goal of the substrate amendment for enhanced bioremediation at this site would be to provide an organic carbon source with the proper nutrients to support biological growth and to drive the general environment to be within a much lower reducing range (i.e., the reductive dechlorination range). The reductive dechlorination environment favors microbes that degrade TCE and its daughter products, which may reduce the rate at which dissolved MGP constituents are biologically degraded. The addition of the manufactured substrate will also provide an alternate organic carbon source to the MGP waste, and may be preferred. This would have the effect of slowing the degradation of dissolved MGP-waste constituents in the treatment area and for an unknown distance downgradient.

6.2.7 Impacts to Operations

There are very few anticipated impacts to Siltronic’s operation in using enhanced bioremediation. The largest impacts would require restricting access to specific areas during direct injection or well installation. As discussed in the previous technology evaluations, the impacts to Siltronic operations are expected to be much higher in the upland source area than in the downgradient plume area. The installation of a circulation well nutrient delivery system in the downgradient area would have the same impacts as those discussed for the GCW systems.

6.3 Requirements

6.3.1 Design Requirements

Bioremediation design requirements vary depending on the type of program desired (e.g., source treatment, barrier, polishing). In all cases, a thorough understanding of the subsurface conditions (such as the types, concentrations, and distribution of chlorinated VOCs; redox conditions; natural microbial community composition; and hydrogeological conditions) are required for an effective design. It is very important to know if preferred substrates or unfavorable redox conditions exist, and if amendments can be delivered within the aquifer to the desired location. A thorough understanding of the subsurface layers is necessary to select an efficient design for a delivery system.

6.3.2 Operation and Maintenance Requirements

Direct injection of amendments has no long-term operation requirements. However, reapplication of amendments may be required on a six to 18-month frequency. Quarterly groundwater monitoring within the treatment area is usually necessary to judge performance.

A circulation well delivery system would require weekly checking of the pumps and nutrient tank, as well as reinjection pressure. Biofouling of the reinjection screen is possible and would require rehabilitation of the well, which is labor-intensive.

6.4 Cost and Cost Certainty

Compared to other treatment technologies evaluated, the cost of bioremediation is low. The cost and effectiveness depend on numerous factors that have yet to be fully characterized. Site-specific soil and groundwater conditions, the type and distribution of contaminants being treated, the composition of the microbial community, redox conditions, and the method used to apply treatments can all affect cost and effectiveness. For these reasons, the cost certainty is moderate.

Using a planning timeline of five years, the total cost for treatment within the upland source area is estimated to be $1.3 million ($144,000 for remedial design; $456,000 for first application of biodegradation materials; $343,000 for operation and maintenance via three reapplications; $90,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $220,000 for a 20-percent contingency).

For a five-year planning timeline, the total costs for treatment of the downgradient plume area were estimated to be $1.7 million ($143,000 for remedial design; $579,000 for first application of biodegradation materials; $393,000 for operation and maintenance via three reapplications; $266,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $294,000 for a 20-percent contingency).

Using GCW with bioremediation, the total costs for treatment of the downgradient plume area and a five-year time frame are estimated to be $2.4 million ($259,000 for remedial design; $238,000 for treatment system and well installation; $1,187,000 for operation and maintenance for five years; $266,000 for groundwater monitoring and system evaluation; $89,000 for semiannual reporting for five years; and $408,000 for a 20-percent contingency). The costs associated with relocating Siltronic equipment or with disruptions to Siltronic operations were not evaluated or included in the preliminary cost estimate.

6.5 Limitations

The tight soils in the upland source area may present a challenge to distributing the soil amendments, but this can be overcome by decreasing the injection grid interval or by researching innovative techniques, such as hydrofracturing. Additionally, if a viable community of the proper microbes is not currently in place in the soil, establishing a community through bioaugmentation may require some amount of time before the microbes are able to attach themselves to the soil particles and begin to be effective. It is also possible that the groundwater conditions do not exist that would promote the success of the community, so significant modification may be required through the introduction of additional amendments.

Another limitation of this technology is the potential for slowing the natural degradation of dissolved MGP compounds (BTEX, naphthalene, and PAHs), if it is occurring.

6.6 Additional Data Needs

A bench-test evaluation can provide detailed information regarding the rates at which degradation of TCE, DCE, VC, and MGP compounds is currently occurring, as well as the impacts of adding different manufactured amendment compounds or microorganisms. This information would be sufficient to optimize the design of the treatment wall and the amount of amendment that will be needed. Due to the potential impacts to MGP degradation, the bench test should be designed to include an analysis of the MGP compounds. This would be necessary to determine if biodegradation of the MGP constituents is already occurring at the site, under what conditions, and at what rate.

Push-Pull tests might also provide substantial information about the ability of the existing microbial community to degrade TCE with the addition of specific nutrients. This analysis would require the development of a well in which materials could be injected into the formation, allowed to be acted upon within the aquifer, and then monitored. Test solutions generally consist of water containing nonreactive tracers such as bromide, the substrate of interest, and reactive solutes that are designed to permit the estimation of the in-situ transformation rates of the VOCs of interest. Since the test is conducted in-situ, normal groundwater flow can carry the materials being studied beyond the reach of the original groundwater well. This limits the duration over which the test can be conducted.

6.7 Recommendations

The enhancement of biodegradation is an applicable technology at the Siltronic site. It appears that the biodegradation process is currently being aided by the presence of the MGP waste, and enhancement efforts might be found to be minimal. More research would be necessary to determine the methods and success rates for application of materials within the upland source area. The amount of time required to treat the upland source area may be impeded by the tight soils in the area. Additionally, considerable time may be required to treat the dissolved-phase plume in the upland source area because the plume is present under the FAB1 building and treatment would rely on groundwater transport to the treatment zone, which could take five to ten years, based on flow estimates.

Given the amount of time required for contaminated groundwater to reach treatment areas, efforts should be made to locate commercial products with a high persistence to limit the number of applications. Thought should also be given to the implementation of a GCW-enhanced bioremediation treatment zone to treat the downgradient plume and prevent off-site migration. The GCW-based system may be hindered by the amount of silt in the soils, so bench testing is recommended.

It is recommended that continued sampling of monitored natural attenuation parameters occur. These data would be incorporated into the existing site data set and the pending bench test results.

7 CONCLUSIONS

The technologies that were evaluated for the SCM at the Siltronic site have been summarized in Tables B-1 and B-2. Cost estimates for application of the technologies in the upland source area and in the downgradient plume area have been prepared by MFA as part of this analysis and are contained in Appendix B3.

Table B-1 evaluates technologies that can be used to remove TCE in the upland source area south of the FAB1 building. Based on the current understanding of the site, the most promising technologies for treatment of the upland source area contamination include thermal treatment, in-situ chemical oxidation, and bioremediation. Thermal treatment has the highest certainty of working and would remove the most TCE (concentrations reduced to nondetect), but is also the most expensive technology (approximately $7.9 million). Chemical oxidation and bioremediation technologies are less expensive ($3.0 million and $1.3 million, respectively), and could achieve significant mass removal (up to 90 percent), but are limited by the geology (lenses of fine-grained materials), and in the case of chemical oxidation, the presence of MGP waste.

Table B-2 evaluates technologies that can be used in the downgradient plume area to reduce or eliminate TCE migration to Area 1. Based on the current understanding of the site, the downgradient treatment technologies that are the most promising include standard bioremediation and bioremediation using GCWs ($1.7 million and $2.4 million, respectively). Any technology installed downgradient of the upland source area would likely require longer-term operation and/or maintenance, since the upland source could continue to release COCs for some period of time.

The conclusion of this evaluation is that a bench-scale bioremediation test is warranted. As previously noted, it is now underway and has been designed to produce information necessary for reaching a conclusive determination on the viability of bioremediation applied at this site. This determination is based on the initial indication that bioremediation of the downgradient plume will likely best meet Siltronic's overall goals. The benefits of this technology include: no need for ex-situ treatment, the ability to leverage bioremediation activity currently occurring in the subsurface environment at the site, and relatively low cost. The reasons for focusing on treatment of the downgradient plume area include the following:

- Accessing the upland source area is problematic due to its location relative to facility infrastructure. Given that disruption of facility operations and/or reconfiguring the facility layout in the vicinity of the upland source (e.g., pipe rerouting) is to be avoided, full access likely cannot be attained.

- Treatment of the downgradient plume will have result in a much shorter amount of time required to reduce the concentration of contaminants migrating to Area 1 as compared to focusing treatment in the upland source area.

- If properly structured, it is probable that a successful treatment system for the downgradient plume could be incorporated as part of the final remedy.

- Once a downgradient treatment zone is established and verified, an evaluation of additional treatment of the upland source area could be performed to estimate the amount of time over which the downgradient controls would need to operate.

The bench test has been designed to also provide information on enhanced bioremediation applicability for Area 2.

Based on the outcome of the bench test, it may be necessary to revisit previously assessed factors. That is, if bioremediation is found to have limited applicability, other technologies and resources (e.g., existing wastewater treatment plant) will be reassessed. Conversely, if bioremediation is confirmed to be viable, SCM design can be initiated.

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TABLES

Table B-1
Source Control Measure Technology Screen for Upland Source Area
Siltronic Corporation
Portland, Oregon

Technology	Overview	Expected Results	Total Cost[1]	Pros	Cons
Thermal Treatment: Electrical Resistive Heating	Pass electrical current through contaminated zone to increase temperature through soil resistance and mobilize contaminants. Extract groundwater and vapors and treat vapors and water above ground. Discharge treated water and vapor.	Non-detect concentrations within six- to nine-month treatment time.	$7.9 million	Complete removal of both dissolved and NAPL phase TCE within one year. MGP waste will not hinder the treatment process. Potential to use Siltronic treatment system. No ongoing operation and maintenance after first year.	High capital costs. Treatment system must be able to handle MGP waste stream. Existing infrastructure in source area may need to be removed.
Chemical Oxidation	Inject oxidant into soil and groundwater to react with contaminants and convert them to relatively inert end products.	Up to 90 percent mass removal, with some TCE remaining in silt and clay layers at concentrations above target levels. Multiple applications required. Silts and clays will require very tight injection grid (approximately 43 wells).	$3.0 million	Cost is less than thermal, while still reducing mass of source area.	Access for 43 wells is an issue. MGP waste will act as a "sink" for reactive compounds requiring application of additional material. Limited impact on DNAPL. Residual life of oxidants is very short, so there would be no ongoing treatment.
Bioremediation	Inject nutrients and/or microorganisms into soil and groundwater to transform contaminants into nontoxic organic chemicals.	Significant degradation of dissolved-phase TCE where microbes are established and nutrients can be delivered. Some TCE may remain in silt and clay layers at concentrations above target levels. Silts and clays will require very tight injection grid.	$1.3 million	Low cost. Enhances existing biodegradation processes at the site. MGP waste provides carbon source for biological activity and does not hinder processes.	Injection methods other than direct push may be required, such as hydrofracturing. Application may be inconsistent due to low conductivity of soils. Unclear whether bioremediation would work in areas with highest concentrations of TCE and MGP waste.

Table B-1
Source Control Measure Technology Screen for Upland Source Area
Siltronic Corporation
Portland, Oregon

Technology	Overview	Expected Results	Total Cost[1]	Pros	Cons
Groundwater Circulating Wells with Treatment	Extract and re-inject groundwater in same well with treatment in well or vault or above ground.	Unlikely to be able to develop circulation cell in continuous silt and clay layers.	Cost not estimated because technology not effective with geology in source area.	Low capital costs likely. Increased desorption of contaminants in areas within circulation cell.	Unlikely to be able to develop circulation cell in continuous silt and clay layers. Potential to distribute DNAPL or contaminants to injection screen and surrounding formation. Operation and maintenance costs are relatively high.
Pump and Treat	Pump water out of extraction wells, treat above ground, discharge treated water. Pump and treat system would include both source area and downgradient plume area.	Possible hydraulic containment, but the impact from the river would need to be evaluated. Limited mass removal. Ongoing treatment for many years.	$3.6 million*	Lower capital costs. Potential to use Siltronic treatment system.	Long-term operation required. Extraction wells close to river may complicate containment. Operation and maintenance costs are relatively high. Doesn't significantly reduce contaminant mass. Requires treatment of extracted MGP waste.
Air Sparging	Inject air into the subsurface soil below and within zone of contamination to strip contaminants from groundwater. Extraction system recovers most vapors and treats prior to exhausting to atmosphere.	Limited effectiveness due to occurrence of fine-grained materials. Disruption of existing anaerobic degradation.	Cost not estimated because technology not effective with geology in source area.	Recovery and destruction of contaminants in treatment zone.	Generates aerobic environment, disrupting existing anaerobic degradation processes. Unrecovered vapors may migrate to nearby buildings.

NOTES:
DNAPL = dense nonaqueous-phase liquid.
MGP = manufactured gas plant.
NAPL = nonaqueous-phase liquid.
TCE = trichloroethene.
[1]All costs are approximate and for comparison purposes only. Costs are based on a five-year horizon, though some technologies may not require five years of operation and other technologies may continue to be operated
*Costs for pump and treat system assume that capture zone includes both source area and downgradient plume.

Table B-2
Source Control Measure Technology Screen for Downgradient Area
Siltronic Corporation
Portland, Oregon

Technology	Overview	Expected Results	Total Cost[1]	Pros	Cons
PRBs	Permeable treatment area oriented to intercept and remediate a contaminant plume in a passive manner by physical, chemical, or biological processes.	TCE concentrations would initially be reduced below cleanup levels. MGP waste may cause blockages of the PRB.	Cost not estimated due to issues with MGP waste mobilization and blockage of PRB.	No ex-situ treatment and disposal required.	Potential vertical migration of MGP. Potential blockage of PRB by MGP NAPL.
Sheet-Pile Wall	Drive sheet pile to stop contaminants from migrating to river.	Plume containment would be achieved, but not necessarily cost-effectively. No treatment of contaminants would occur. Depth of contaminants would require large wall.	$3.6 million	Containment of downgradient plume. No ex-situ treatment and disposal required (unless used in conjunction with hydraulic control).	No treatment of contaminants. Hanging wall design would be required due to depth of bedrock. Special production of long sheet piles and delivery to site will increase cost.
Thermal Treatment: Electrical Resistive Heating	Pass electrical current through contaminated zone to increase temperature through soil resistance and mobilize contaminants. Extract groundwater and vapors and treat vapors and water above ground. Discharge treated water and vapor.	Cost of treating a large downgradient area makes the use of this technology impractical.	Cost not estimated due to high cost for ongoing treatment of downgradient plume.	Not evaluated, technology not practical.	Not evaluated, technology not practical.
Chemical Oxidation	Inject oxidant into soil and groundwater to react with contaminants and convert them to relatively inert end products.	Approximately 27 injection wells, each with two 20-foot long screens. Initially, two injections would be required within two months to treat contaminants sorbed to soil, then periodic applications would be required to treat migrating contaminants in groundwater (approximately every six to nine months).	$2.4 million	No ex-situ treatment and disposal required.	MGP waste will act as a "sink" for reactive compounds requiring application of additional material. Residual life of oxidants is very short, so there would be no ongoing treatment

Table B-2
Source Control Measure Technology Screen for Downgradient Area
Siltronic Corporation
Portland, Oregon

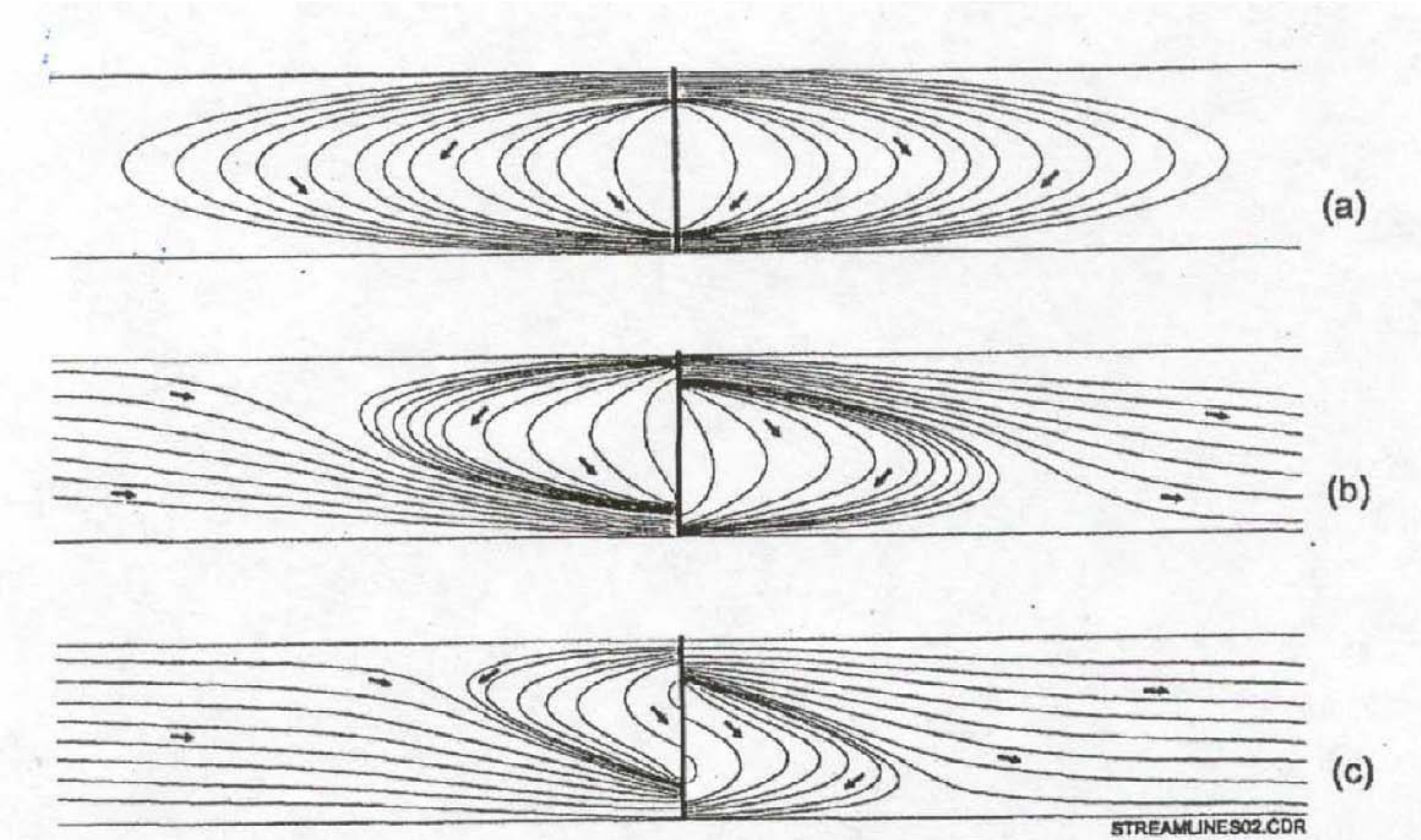
Technology	Overview	Expected Results	Total Cost[1]	Pros	Cons
Bioremediation	Inject nutrients and/or microorganisms into soil and groundwater to transform contaminants into nontoxic organic chemicals.	Significant degradation of dissolved-phase TCE where microbes are established and nutrients can be delivered. Periodic injections would be required (assumed to be every three years).	$1.8 million	No ex-situ treatment and disposal required. Enhances existing biodegradation processes at the site. MGP waste provides carbon source for biological activity and does not hinder processes. The number of applications would be less than chemical oxidation because the microbes and nutrients have a longer life than the oxidants.	Performance uncertain.
Bioremediation through GCW Nutrient Delivery	Extract and re-inject groundwater in same well with no treatment, but inject nutrients.	Biodegradation of TCE to ethane. Design would require the use of an oil/water separator to remove DNAPL prior to reinjection.	$2.4 million	Lower capital costs. No ex-situ treatment and disposal required, except for separated DNAPL (if seen).	May not develop adequate circulation cell. Potential to distribute MGP wastes to injection screen and surrounding formation.
GCW with Treatment	Extract and re-inject groundwater in same well with treatment in well or vault or above ground.	Assume four wells as a treatment wall to prevent contaminants from reaching river, and two wells immediately north of Fab1 for plume contaminant mass reduction. If good circulation is established, treatment may occur in four to six years (depending on mass of TCE in the source area and hydraulic transport rate).	$4.1 million	Lower capital costs. No disposal of treated water required. Increased desorption of contaminants in areas within circulation cell.	May not develop adequate circulation cell. Potential to distribute MGP wastes to injection screen and surrounding formation, unless proper design controls are implemented. Operation and maintenance costs are relatively high.

Table B-2
Source Control Measure Technology Screen for Downgradient Area
Siltronic Corporation
Portland, Oregon

Technology	Overview	Expected Results	Total Cost[1]	Pros	Cons
Pump and Treat	Pump water out of extraction wells, treat aboveground, discharge treated water. Pump and treat system would include both source area and downgradient plume area.	Possible hydraulic containment, but the impact from the river would need to be evaluated. Limited mass removal. Ongoing treatment for many years.	$3.6 million*	Lower capital costs. Potential to use Siltronic treatment system.	Long-term operation required. Extraction wells close to river may complicate containment. Operation and maintenance costs are relatively high. Doesn't significantly reduce contaminant mass. Requires treatment of extracted MGP waste.
Air Sparging	Inject air into the subsurface soil and groundwater to strip contaminants from groundwater. Extract vapors and treat prior to exhausting to atmosphere.	Limited effectiveness due to occurrence of fine-grained materials.	Cost not calculated because technology has limited effectiveness with geology in downgradient area. Disruption of existing anaerobic degradation.	Recovery and destruction of contaminants in treatment zone.	Generates aerobic environment, disrupting existing anaerobic degradation processes. Unrecovered vapors may migrate to nearby buildings.

NOTES:
DNAPL = dense nonaqueous-phase liquid.
GCW = groundwater circulation well.
NAPL = nonaqueous-phase liquid.
MGP = manufactured gas plant.
PRB = permeable reactive barrier.
TCE = trichloroethene.
[1]All costs are approximate and for comparison purposes only. Costs are based on a 5 year time horizon, though some technologies may not require 5 years of operation and other technologies may continue to be operated for a longer period.
*Costs for pump and treat system assumes capture zone includes both source area and downgradient plume.

FIGURE



Not To Scale

Note:
Idealized Circulation Pattern Around a GCW System with Horizontal Groundwater Velocities of a (a) 0.0 m/day, (b) 0.3 m/day, and (c) 1.0 m/day (reprinted from Herrling et al., 1991).

Figure B-1
GCW Flow Patterns

Siltronic Corporation
Portland, Oregon
Draft

MAUL FOSTER ALONGI INC.
ENVIRONMENTAL & ENGINEERING CONSULTANTS
Vancouver, WA | Portland, OR | www.MFAinc.org

File: G:\8128.01 SILTRONIC CORPORATION\10_SOURCE CONTROL\FIGB-1_GCW PATTERN.DWG Last edited: DEC. 22, 2005 @ 11:12 a.m. by: cadduser Xrefs: none black/white

Layout: 1 Project: 8128.01.10 Drawn By: D. Glaus Approved By:

APPENDIX B1

PRELIMINARY COST PROPOSAL—ET-DSP THERMAL REMEDIATION

ET-DSP™

Electro-Thermal Dynamic Stripping Process

Prepared for:

MAUL FOSTER ALONGI INC.

Preliminary Cost Proposal

ET-DSP™ Thermal Remediation

Siltronics Site
Portland, Oregon

Prepared By:

McMillan-McGee Corp.

Prepared For:

Maul Foster Alongi Inc.

Preliminary Cost Proposal

ET-DSP™ Thermal Remediation

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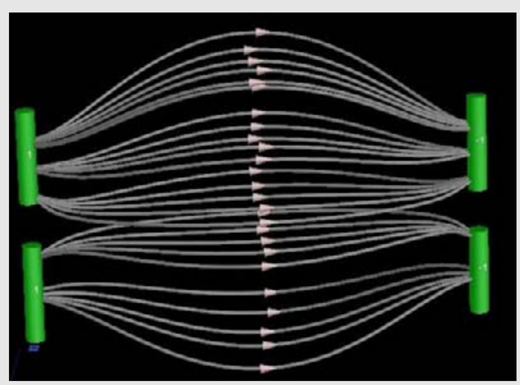
June 30, 2005



Computer simulation showing current distribution between two layers of ET-DSP™ electrodes

McMillan-McGee Corp.

Electromagnetic Systems and Services for the Energy and Environmental Industries

1. Summary

McMillan-McGee Corp. (Mc^2) is pleased to provide Maul, Foster, & Alongi (MFA) with this budgetary cost proposal to install and operate an ET-DSP™ system at the Siltronics site (Site) in Portland, Oregon.

This estimate has been based on preliminary Site information provided to Mc^2 along with experience on similar remediation projects. At this time, the following objectives have been identified for Mc^2:

1. develop a preliminary well-field layout for ET-DSP™ electrodes, extraction, and sensor well locations;
2. develop a preliminary cost estimate to install and operate the ET-DSP™ system at the site and operate until such time as criteria is met;
3. support MFA in determining a full-scale cost estimate; and
4. support MFA in developing a technical and cost proposal for the site.

Mc^2's technical points of contact will be Dacre Bush. The administrative point of contact will be Brent Winder.

This proposal includes a project summary table that was used to develop the cost estimate and an ET-DSP™ budget for the remediation of the Site. A scope of work will be developed at a later date that delineates tasks between the prime contractor (MFA) and the major subcontractors, of which Mc^2 would be one.

Please note that this proposal should be construed as budgetary until such time as a detailed numerical simulation can be performed.

2. Project Summary

The following Table presents the major parameters used to develop the cost estimate for the Siltronics site.

Table 1 Project summary for Scenario 1

Item	Description	Comments
	Site Characteristics	
Treatment Area	30,000 ft^2	Approximately
Volume Treated	89,000 yd^3	Approximately
Deep Extent of Treatment	~100 ft. BGS	Based on supplied information
Shallow Extent of Treatment	~20 ft. BGS	Based on supplied information
Depth to Groundwater	N/A	Based on supplied information
Contaminants of Concern	TCE	DNAPL suspected
Soil Resistivity (Static)	5-50 Ω·m	Expected range of resistivity
	Remedial Approach	
ET-DSP™ Electrodes	324	ET-DSP™ patent for heat transfer
Electrode Boreholes	81	Minimum 10” diameter, single stack
Power Delivery Systems	14 x 660 KVA	Complete with internet power control
DigiTAM Temp. Sensors	500	25 strings c/w 20 sensors at 5’ intervals
Total Sensor Boreholes	25	2” drop tube required
Electrode Spacing (Horizontal)	~22 feet	Tight spacing due to drilling confines
Depth to Bottom of Electrodes	~97 feet BGS	Heat transfer 3-4 feet below electrode
Depth to Top of Electrodes	~25 feet BGS	Heat transfer 3-4 feet above electrode
Target Temperature	~90° C (198° F)	Uniform average
Vapor Extraction Wells	~21	Determined with numerical modeling
Vapor Recovery Air Flow Rate	~1,000 scfm	Determined with numerical modeling
Vapor Treatment Method	TBD	To be determined
Liquid Treatment Method	TBD	To be determined
	Summary Information	
Electrical Power Input	~4,000 kW	Electrical supply to be designed
Cumulative Power Input	~16,000,000 kW·hr	Determined with numerical modeling
Water Demand	~60 gpm	Re-circulation is possible
Time to Reach Target Temp	35-45 days	Approximately
Project Duration	~150 days	More information will be determined in modeling process.

Figure 1 depicts an initial well-field layout for the site.

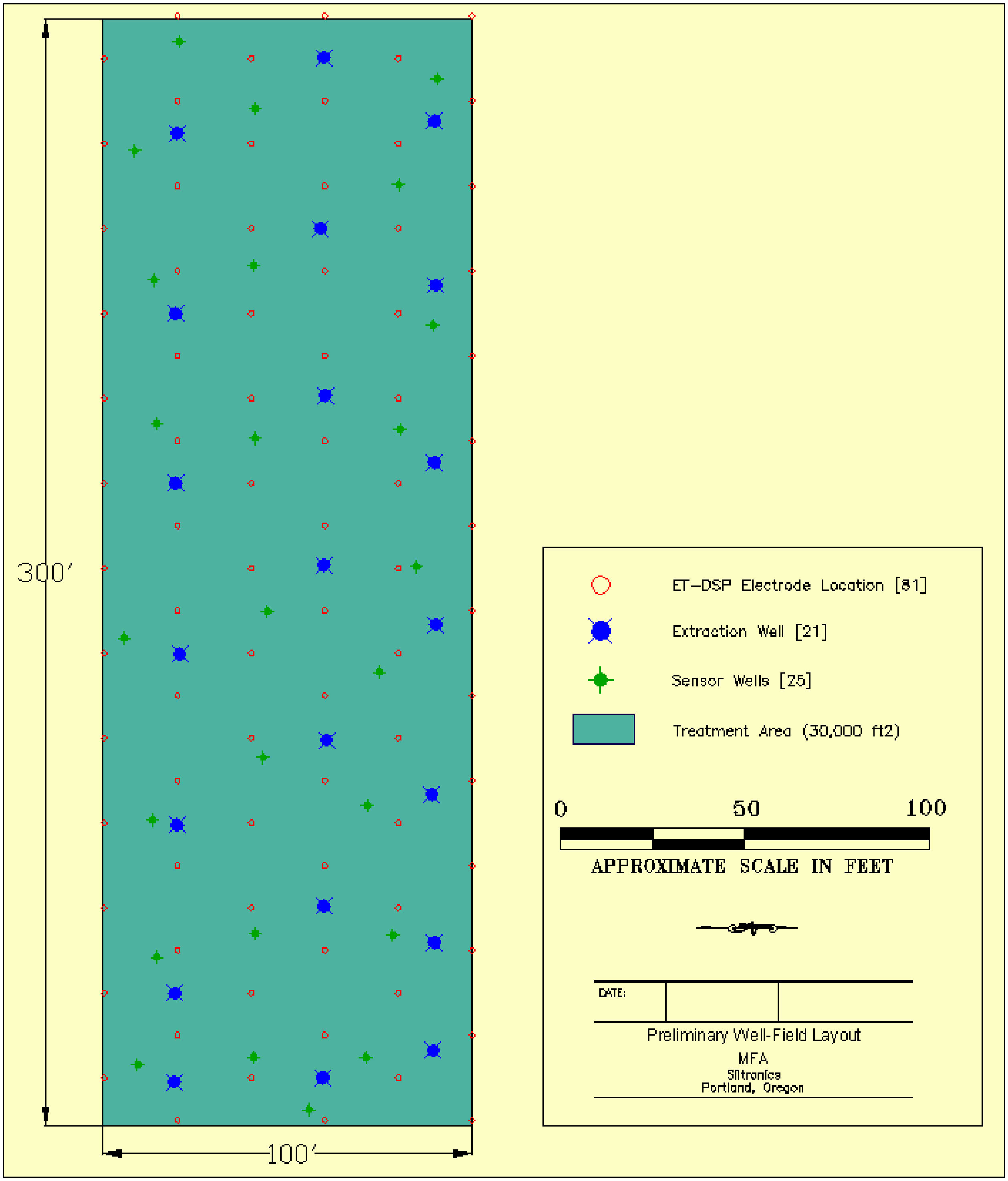


Figure 1 Preliminary well field layout

3. Schedule of Work

A detailed schedule for project completion is unavailable at this time. The goal for this stage is to present a 5-10% design to MFA to aid in the development of the full scale cost estimate. Mc^2 will perform a numerical simulation to validate the preliminary design criteria during the next stage of the project.

4. Budget Information

The following table presents a preliminary cost estimate to install and operate the ET-DSP™ system at the Siltronics site. This estimate is based on the Mc^2 scope of work to provide the ET-DSP™ equipment and services. A conservative estimate for energy costs (based on $0.065/kWHr) has also been included.

The following list presents the major cost items that have not been included in this estimate:

1. Permitting;
2. Drilling program (electrode, extraction, sensor wells);
3. Extraction and treatment system (MPE system recommended);
4. General site operations and maintenance;
5. Confirmatory sampling; and
6. Reporting.

It should be noted that a **performance guarantee** can also be made available once additional site information has been examined.

Table 2 ET-DSP™ cost estimate for Siltronics

Item	Units	Mc2	Drilling	Const.	Extraction & Other Subs	Item Subtotal
1 Electrical Profiling						**2,827**
1.1 Labour	LS	946	-	-	-	
1.2 Services		1,881	-	-	-	
1.3 Other			-	-	-	
2 Modeling & Remedial Design						**32,637**
2.1 Labour	LS	32,637	-	-	-	
2.2 Travel	LS	-	-	-	-	
2.3 Other	LS	-	-	-	-	
3 System Installation						**2,773,436**
3.1 Shipping	LS	77,863	-	-	-	
3.2 Labour	LS	86,000	-	-	-	
3.3 Equipment	LS	2,057,787	-	-	-	
3.4 Electrical Supply	LS	338,912	-	-	-	
3.5 Water Supply	LS	113,914	-	-	-	
3.6 Electronics	LS	65,565	-	-	-	
3.7 Travel	LS	33,395	-	-	-	
3.8 Other	LS		-	-	-	
4 Acceptance Testing						**18,539**
4.1 Labour	LS	11,395	-	-	-	
4.2 Travel	LS	7,144	-	-	-	
4.3 Other	LS		-	-	-	
5 Operation & Maintenance						**1,173,850**
5.1 Labour - Project Ops	LS	40,442	-	-	-	
5.2 Services - Electronics	LS	9,408	-	-	-	
5.3 Travel	LS	32,250	-	-	-	
5.4 Other	LS	-	-	-	-	
5.5 Energy ($0.065/KwHr)	16,796,160				1,091,750	
5.6 Waste Mgmt.	LS		-	-	-	
5.7 Conf. Sampling	LS		-	-	-	
5.8 Other	LS		-	-	-	
6 Demobilization						**81,690**
6.1 Labour	LS	17,566	-	-	-	
6.2 Shipping	LS	54,926	-	-	-	
6.3 Travel	LS	9,198	-	-	-	
6.4 Other	LS		-	-	-	
7 Final Report						**-**
7.1 Labour	LS	-	-	-	-	
7.2 Services	LS	-	-	-	-	
7.3 Travel	LS	-	-	-	-	
Subtotal		**2,991,228**	**-**	**-**	**1,091,750**	**4,082,979**
Total						**4,082,979**

5. Supervisory Personnel

The following table lists relevant and supervisory personnel for the design, construction and operation of the thermal remediation system.

Name	Role	Relevant Experience
Dr. Bruce McGee, Ph.D, P.Eng (Mc^2)	Senior Technical Advisor	• Inventor of ET-DSP™ • 25 years of applied electromagnetics • 15 years thermal remediation
Dacre Bush, P. Geo (Mc^2)	Project Manager	• 25 years remediation experience • 5 years thermal remediation experience
Brent Winder, MBA (Mc^2)	Mc^2 Operations Manager	• 10 years project management experience • 6 years ET-DSP™ experience
Wayne Robella (Mc^2)	Mc^2 Site Supervisor	• 15 years certified electrical mechanical experience • 3 years ET-DSP™ experience

APPENDIX B2

ISOTEC BUDGETARY ESTIMATE

In-Situ Oxidative Technologies, Inc.
ISOTEC

ISOTEC Budgetary Estimate
#900763

July 6, 2005

- Proposal requested by: Alistaire Clary; Maul, Foster, Alongi, Inc.
- Site name: Confidential
- Site location: Portland, Oregon
- Budgetary estimate:
  - Full-Scale Remediation: $750,000 - $1,500,000
  - Most likely three to five injection events will be needed
  - Estimate is for an approximate 90% mass removal.

Additional assessment information and a pilot scale injection program are needed to refine the estimate. Modified Fenton's reagent is a non-selective oxidant, however it will address the dissolved phase first and preferentially address contaminants with higher solubility before less soluble compounds. Critical data that impacts the cost is the vertical and horizontal distribution of contaminant mass, particularly DNAPL.

Project Assumptions	
Treatment area	30,000 sq-ft
Depth to water	20-30 feet bgs
Treatment zone	Upper 40 feet of saturated zone
Geology	Interbedded Sand, Silt and Clay
Hydraulic Conductivity	Varies
Contaminants	Primarily TCE
Sampling and analysis	Responsibility of MFA
Monitoring well installation	Responsibility of MFA
Injection well installation	Responsibility of MFA
ISOTEC's Field Injection Assumptions	
Reagent	Modified Fenton's Reagent
Number of Injection well locations	43
Number of injection depths	Two or three
Number of injection events	Three to five
Time on site per injection event	20 days
Mobe/Demobe per injection event	2 Days
Injection schedule	Negotiated with MFA

For further information, please contact:

Stan Haskins, P.G.
Technical Director

shaskins@insituoxidation.com

ISOTEC
5600 S. Quebec Street, Suite 320D
Greenwood Village, CO 80111
303-843-9079 (office)
303-843-9094 (fax)
303-931-4257 (cell)

ISOTEC Process Overview (More detail can be found at (www.insituoxidation.com):

ISOTEC uses a modified Fenton's Reagent in-situ chemical oxidation approach to remediation of contaminated soil and groundwater. However, if you are familiar with how conventional Fenton's is most often applied, using strong acids and high reagent concentrations under pressure, then you are familiar with its shortcomings, often including incomplete treatment, explosive reactions, organic vapor generation and contaminant migration. ISOTEC's modified Fenton's Reagent process was specifically designed to overcome these problems. ISOTEC's patented catalysts allow reagents at background pH conditions to be effectively distributed within the aquifer, destroying contaminants in saturated soil and groundwater without generating organic vapors or high temperatures.

Modified Fenton's Reagent is comprised of injecting 12% - 17% hydrogen peroxide and a chelated iron catalyst, at background pH conditions to produce oxidizing and reducing species that react with the organic contaminants within the subsurface producing innocuous by-products such as carbon dioxide and water (and chloride ions if chlorinated compounds are being treated).

With ISOTEC's Process, as the contaminants in the soil mass are desorbed into the dissolved phase, increases in dissolved phase concentrations are expected and are treated during the initial and subsequent injection events. With desorption of the contaminant mass in the saturated soil and treatment of these desorbed contaminants in the dissolved phase, groundwater treatment concentrations will be maintained and not rebound. Once equilibrium is achieved, dissolved phase concentrations can be expected to further decrease due to natural attenuation and other physical processes occurring within the aquifer.

Field Injections:

ISOTEC injects our reagents at low pressure through 2" PVC injections wells or direct push points. Injection well installation is the responsibility of the consultant; however ISOTEC will provide oversight to ensure injection wells are constructed according to ISOTEC's specifications.

ISOTEC prepares a work plan and health and safety plan prior to initiation on injections. These plans are often submitted to regulatory agencies to support any approval requirements. It is during this workplan development that detailed analysis of site information is evaluated to finalize the full scale injection design as well as identify any additional sampling and analysis requirements.

ISOTEC recommends soil and groundwater samples be collected prior to ISOTEC's treatment and within two weeks following the completion of each injection event.

Samples should be analyzed for contaminants of concern and other parameters of interest including TOC and pH.

A bound report is submitted with 30 days of receipt of sampling and analytical data. Sampling and analysis is the responsibility of the consultant. This report outlines details of the ISOTEC process, field activities, and field analyses.

Professional Arrangements:

- ISOTEC will require a source of on-site water supply to perform treatment program activities. Access and costs associated with this request will be provided/incurred by the Consultant.
- Treatment program cost includes all labor, equipment, reagents, materials, travel, and shipping.
- Work quoted is based on level D personal protection equipment (PPE) and daytime working hours. Additional costs for higher level PPE will be quoted as necessary.
- A decontamination area, water disposal and secondary containment for reagents will be provided by the Consultant, if required.
- The Consultant will be responsible for workplan approval, permits, groundwater/soil sampling, utility locates, and waste disposal.
- ISOTEC will provide oversight on groundwater sampling protocols.
- ISOTEC typically begins work within 30 days of authorization to proceed and all regulatory approvals are in place.
- Circumstances encountered during the performance of these services could warrant additional time or expense (e.g. unexpected geological or hydrogeological conditions, regulatory delays). We will notify you of any such circumstances that could affect completion of the engagement.

APPENDIX B3

COST ESTIMATES

Table B3-1
Upland Source Area Technology Cost Summary
Siltronic Corporation
Portland, Oregon

Cost Component	Thermal	Chemical Oxidation	Bioremediation	Pump & Treat*
Remedial Design	$ 135,000	$ 152,250	$ 143,750	$ 264,500
Capital Costs	$ 4,990,900	$ 2,210,200	$ 456,000	$ 985,100
Operation & Maintenance	$ 1,257,000	$ -	$ 342,913	$ 1,402,822
GW Monitoring & System Performance Evaluation	$ 133,000	$ 89,819	$ 89,819	$ 265,612
Reporting	$ 50,000	$ 89,009	$ 89,009	$ 89,009
Contingency (20%)	$ 1,313,180	$ 508,256	$ 224,298	$ 601,409
Total	**$ 7,879,080**	**$ 3,049,534**	**$ 1,345,790**	**$ 3,608,452**

Note:
1) All costs are based on a 5 year time horizon, though some technologies may continue to be operated for a longer period
*Pump & Treat system captures downgradient plume and upland source

Table B3-2
Downgradient Technology Cost Summary
Siltronic Corporation
Portland, Oregon

Cost Component	Chemical Oxidation	Bioremediation	Groundwater Circulation Wells with Treatment	Groundwater Circulation Wells with Bioremediation	Pump & Treat*
Remedial Design	$ 152,250	$ 143,750	$ 221,250	$ 258,750	$ 264,500
Capital Costs	$ 606,700	$ 579,200	$ 351,582	$ 237,772	$ 985,100
Operation & Maintenance	$ 914,370	$ 392,821	$ 2,454,719	$ 1,187,063	$ 1,402,822
GW Monitoring & System Performance Evaluation	$ 265,612	$ 265,612	$ 265,612	$ 265,612	$ 265,612
Reporting	$ 89,009	$ 89,009	$ 89,009	$ 89,009	$ 89,009
Contingency (20%)	$ 405,588	$ 294,079	$ 676,435	$ 407,641	$ 601,409
Total	**$ 2,433,530**	**$ 1,764,471**	**$ 4,058,607**	**$ 2,445,847**	**$ 3,608,452**

Note:
1) All costs are based on a 5 year time horizon, though some technologies may continue to be operated for a longer period
*Pump & Treat system captures downgradient plume and upland source

Table B3-3
Estimated Cost for Pump and Treat System at Upland Source Area and Downgradient
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$264,500**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design Site Characterization (additional hydrogeologic characterization)	$20,000	LS	1	$20,000
Remedial Design (Engineering and Permitting)				
Construction Plans and Specification/Permitting	$140,000	LS	1	$140,000
Plans (HASP, Construction QA Plan, Sampling and Analysis Plan)	$40,000	LS	1	$40,000
RA Procurement	$10,000	LS	1	$10,000
DEQ Oversight of Remedial Design (15% of design and permitting)	$230,000	percent	15%	$34,500
Total Remedial Design/Permitting Cost				*$264,500*
Capital Costs - Extraction Well Install				**$266,000**
Field Materials During Drilling	$20,250	LS	1	$20,250
Drilling Oversight	$61,500	LS	1	$61,500
Drilling (Extraction wells)	$116,250	LS	1	$116,250
Utility Locate	$750	LS	1	$750
Drop Box Rental	$9,750	LS	1	$9,750
Poly Tank Rental	$6,750	LS	1	$6,750
Extraction pumps	$1,000	EA	9	$9,000
Pump Installation	$20,000	LS	1	$20,000
Soil Disposal Fee	$14,250	LS	1	$14,250
Transportation of Soil	$7,500	LS	1	$7,500
Installation of Source Control and Downgradient Containment				*$266,000*
Capital Costs - Treatment System Installation				**$719,100**
Equipment Costs				
Mobilize Equipment	$50,000	LS	1	$20,000
4-in Carbon Steel Double-Wall Piping to Treatment System	$111.53	LF	1,700	$189,601
Diffused Air Flotation	$48,000	EA	1	$48,000
Multi-Media Filter	$33,000	EA	1	$33,000
Filter Press	$40,000	LS	1	$40,000
Granular Activated Carbon Filter	$28,132.40	EA	2	$56,265
Chemical Feed System	$2,498.10	EA	2	$7,495
pH Controllers and Coax Cables	$2,551.44	EA	2	$5,102
15 GPM Centrifugal Transfer Pump	$1,617.06	EA	2	$3,232
Controls	$50,000	LS	1	$50,000
150 GPM Centrifugal Transfer Pump	$7,754.61	EA	3	$23,264
3-in. Carbon Steel Piping Within Treatment System	$14.14	LF	600	$8,484
Permit Fees	$25,000	LS	1	$25,000
Trenching	$1.17	CY	630	$737
Vault in trench for visual inspection	$1,337.45	EA	2	$2,675
Backfill Trench	$1.48	CY	630	$932
Compaction of Trench	$4.78	CY	630	$3,011
Repave Trenched Area	$36.59	SY	570	$20,856
4-in Carbon Steel DW Piping to Wastewater Treatment Plant	$111.53	LF	200	$22,306
Consumables during construction	$50	DAY	60	$3,000
otal Equipment				*$562,960*
Labor Costs				
Engineering Oversight	$54,000	LS	1	$54,000
Mechanical Contractors	$2,251.27	DAY	40	$60,034
Electrical Contractors	$1,578.95	DAY	40	$42,105
Subtotal Labor				*$156,139*
Total Treatment System Installation				*$719,100*

Table B3-3
Estimated Cost for Pump and Treat System at Upland Source Area and Downgradient
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Operation and Maintenance Costs (5 Years)				**$1,402,822**
Pump and Motor Maintenance	$2,824.85	YR	1	$2,825
Granular activated carbon	$0.60	LB	72,000	$43,200
Granular activated carbon disposal	$1.54	LB	72,000	$110,880
Other Consumables	$24,000	LS	1	$24,000
Electrical Charge	$0.08	KWh	650,000	$52,000
Sludge Disposal as Hazardous Waste	$175	ton	120	$21,000
Part Time Treatment Plant Operator	$75	HR	416	$31,200
Sampling Equipment	$50	event	12	$600
Laboratory Costs—VOC	$175	sample	60	$10,500
Sulfuric Acid Solution, 220 lb. Drummed Liquid	$47.20	EA	6	$283
Bulk Powdered Hydrated Lime	$119.99	ton	2	$240
Annual System Shut Down and Cleanout	$50,000	LS	1	$50,000
	Annual Operation and Maintenance Costs			*$346,728*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Operation and Maintenance			*$1,402,822*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$265,612**
Labor to Collect Samples and Analyze Data	$20,750	LS	1	$20,750
Equipment and Consumables	$5,300	LS	1	$5,300
Analytical Services	$39,600	LS	1	$39,600
	Monitoring and Performance Evaluation Costs			*$65,650*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Monitoring and Performance Evaluation			*$265,612*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
			Reporting Costs	*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
			Present Value of Reporting	*$89,009*
SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS				**$3,007,043**
Contingency		percent	20%	$601,409
TOTAL ESTIMATED PRESENT VALUE COSTS				**$3,608,452**

Table B3-4
Estimated Cost for Thermal Treatment of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$135,000**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating and electrical profiling]	$25,000	LS	1	$25,000
Remedial Design (engineering and permitting)				
Modeling, construction plans, and specification/permitting	$52,500	LS	1	$52,500
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$5,000	LS	1	$2,500
DEQ oversight of remedial design (15% of design and permitting)	$100,000	percent	15%	$15,000
Total Design Costs				***$135,000***
Capital Costs - Equipment				**$4,990,900**
Drilling	$925,000	LS	1	$925,000
Thermal Equipment and setup	$2,775,000	LS	1	$2,775,000
Treatment System	$1,300,000	LS	1	$719,100
Heat Exchanger/Cooling Tower	$500,000	LS	1	$500,000
Surveying	$5,000	LS	1	$5,000
Construction QA	$90	HR	400	$36,000
Acceptance Testing	$19,000	LS	1	$19,000
As-built report labor	$90	HR	40	$3,600
As-built report direct costs	$1,000	LS	1	$1,000
DEQ oversight of remedial action	$90	HR	80	$7,200
Installation of Source Control and Downgradient Containment				***$4,990,900***
Operation and Maintenance Costs (1 Year)				**$1,257,000**
Operation & Maintenance (including electrical)	$1,175,000	LS	1	$1,175,000
Demobilization	$82,000	LS	1	$82,000
Annual Operation and Maintenance Costs				***$1,257,000***
Groundwater Monitoring and System Performance Evaluation (1 Years)				**$133,000**
Labor to Collect Samples and Analyze Data	$42,000	LS	1	$42,000
Equipment and Consumables	$11,000	LS	1	$11,000
Analytical Services	$80,000	LS	1	$80,000
Monitoring and Performance Evaluation Costs				*$133,000*
Total Years of Operation		YR	1	
Discount Rate		percent	7.5%	
Present Value of Monitoring and Performance Evaluation				*$133,000*
Reporting				**$50,000**
Prepare Final Report	$50,000	LS	1	$50,000
Reporting Costs				*$50,000*
SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS				**$6,565,900**
Contingency		percent	20%	$1,313,180
TOTAL ESTIMATED PRESENT VALUE COSTS				**$7,879,080**

Table B3-5
Estimated Cost for Groundwater Circulation Wells with Treatment Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$221,250**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
Pilot Test	$75,000	LS	1	$75,000
Construction plans, and specification/permitting	$60,000	LS	1	$60,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$10,000	LS	1	$10,000
DEQ oversight of remedial design (15% of design and permitting)	$175,000	percent	15%	$26,250
			Total Design Costs	*$221,250*
Capital Costs - Circulation Well Install				**$114,500**
Field Materials During Drilling	$5,000	LS	1	$5,000
Drilling Oversight	$35,000	LS	1	$35,000
Drilling (Extraction wells)	$55,000	LS	1	$55,000
Utility Locate	$1,000	LS	1	$1,000
Drop Box Rental	$2,500	LS	1	$2,500
Poly Tank Rental	$1,000	LS	1	$1,000
Soil Disposal Fee Including Transport	$15,000	LS	1	$15,000
			Drilling Costs	*$114,500*
Capital Costs - Treatment System Installation				**$237,082**
Equipment Costs				
Packer	$1,000	EA	8	$20,000
GW Pump	$5,000	EA	8	$40,000
Vault	$1,500	EA	4	$6,000
Stripping Chamber	$7,000	EA	4	$28,000
Piping	$41.81	LF	1,000	$41,810
Treatment Shed	$5,000	EA	1	$5,000
Flow Meter	$500	EA	8	$4,000
Sump Pump	$500	EA	4	$2,000
Control Panel	$5,000	EA	1	$5,000
Blower	$7,000	EA	2	$14,000
Carbon Canisters	$2,500	EA	6	$15,000
Carbon/Zeolite	$4,000	LS	1	$4,000
Heat Exchanger	$2,000	EA	2	$4,000
Knockout Tank	$500	EA	2	$1,000
Permit Fees	$5,000	LS	1	$5,000
Trenching	$1.17	CY	50	$59
Backfill Trench	$1.48	CY	50	$74
Compaction of Trench	$4.78	CY	50	$239
Consumables during construction	$50	DAY	60	$3,000
			Subtotal Equipment	*$198,182*
Labor Costs				
Engineering Oversight	$7,000	LS	1	$7,000
Labor	$12,000	LS	1	$12,000
Surveying	$3,000	LS	1	$3,000
As-built report labor	$90	HR	80	$7,200
As-built report direct costs	$2,500	LS	1	$2,500
DEQ oversight of remedial action	$90	HR	80	$7,200
			Subtotal Labor	*$38,900*
			Total Treatment System Installation	*$237,082*

Table B3-5
Estimated Cost for Groundwater Circulation Wells with Treatment Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Operation and Maintenance Costs (5 Years)				**$2,454,719**
Pump and Motor Maintenance	$2,000.00	LS	1	$2,000
Granular activated carbon	$0.60	LB	96,000	$57,600
Zeolite	$1.25	LB	72,000	$90,000
Carbon and Zeolite disposal	$1.54	LB	168,000	$258,720
Other Consumables	$24,000	LS	1	$24,000
Electrical Charge	$0.08	KWh	650,000	$52,000
Part Time Treatment Plant Operator	$75	HR	1,000	$75,000
Sampling Equipment	$50	event	12	$600
Laboratory Costs—VOC	$175	sample	96	$16,800
Annual System Shut Down and Cleanout	$30,000	LS	1	$30,000
Annual Operation and Maintenance Costs				*$606,720*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
'resent Value of Operation and Maintenance				*$2,454,719*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$265,612**
Labor to Collect Samples and Analyze Data	$20,750	LS	1	$20,750
Equipment and Consumables	$5,300	LS	1	$5,300
Analytical Services	$39,600	LS	1	$39,600
Monitoring and Performance Evaluation Costs				*$65,650*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
Present Value of Monitoring and Performance Evaluation				*$265,612*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
Reporting Costs				*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
Present Value of Reporting				*$89,009*
SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS				**$3,382,173**
Contingency		percent	20%	$676,435
TOTAL ESTIMATED PRESENT VALUE COSTS				**$4,058,607**

Table B3-6
Estimated Cost for Chemical Oxidation of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$152,250**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
Benchtesting, modeling, construction plans, and specification/permitting	$80,000	LS	1	$80,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$5,000	LS	1	$5,000
DEQ oversight of remedial design (15% of design and permitting)	$115,000	percent	15%	$17,250
			Total Design Costs	***$152,250***
Capital Costs - Injection Well Installation and 5 injections				**$2,210,200**
Drilling (43 Injection wells) including oversight	$559,000	LS	1	$559,000
Chemical Cost and Vendor Oversight	$1,500,000	LS	1	$1,500,000
Injection Oversight and planning (20 days per injection x 5 inj x 10 hr/day)	$100	HR	1000	$100,000
Utility Locate	$1,000	LS	1	$1,000
Drop Box Rental	$5,000	LS	1	$5,000
Poly Tank Rental	$2,000	LS	1	$2,000
Soil Transport and Disposal	$30,000	LS	1	$30,000
Surveying	$5,000	LS	1	$5,000
As-built report labor	$90	HR	40	$3,600
As-built report direct costs	$1,000	LS	1	$1,000
DEQ oversight of remedial action	$90	HR	40	$3,600
	Installation of Source Control and Downgradient Containment			*$2,210,200*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$89,819**
Labor to Collect Samples and Analyze Data	$7,000	LS	1	$7,000
Equipment and Consumables	$2,000	LS	1	$2,000
Analytical Services	$13,000	LS	1	$13,200
	Monitoring and Performance Evaluation Costs			*$22,200*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Monitoring and Performance Evaluation			*$89,819*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
			Reporting Costs	*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
		Present Value of Reporting		*$89,009*
	SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS			**$2,541,278**
Contingency		percent	20%	$508,256
	TOTAL ESTIMATED PRESENT VALUE COSTS			**$3,049,534**

Table B3-7
Estimated Cost for Chemical Oxidation Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$152,250**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
Benchtesting, modeling, construction plans, and specification/permitting	$80,000	LS	1	$80,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$5,000	LS	1	$5,000
DEQ oversight of remedial design (15% of design and permitting)	$115,000	percent	15%	$17,250
		Total Design Costs		***$152,250***
Capital Costs - Injection Well Installation and first 2 injections				**$606,700**
Drilling (27 Injection wells) including oversight	$350,000	LS	1	$350,000
Chemical Cost and Vendor Oversight	$210,000	LS	1	$210,000
Injection Oversight and planning (8 days per injection x 2 inj x 10 hr/day)	$100	HR	160	$16,000
Utility Locate	$1,000	LS	1	$1,000
Drop Box Rental	$2,500	LS	1	$2,500
Poly Tank Rental	$1,000	LS	1	$1,000
Soil Transport and Disposal	$15,000	LS	1	$15,000
Surveying	$3,000	LS	1	$3,000
As-built report labor	$90	HR	40	$3,600
As-built report direct costs	$1,000	LS	1	$1,000
DEQ oversight of remedial action	$90	HR	40	$3,600
Installation of Source Control and Downgradient Containment				*$606,700*
Operation and Maintenance Costs (5 Years)				**$914,370**
Material Cost and Vendor Oversight	$210,000	YR	1	$210,000
Injection Oversight and planning (8 days per injection x 2 inj x 10 hr/day)	$100	HR	160	$16,000
	Annual Operation and Maintenance Costs			*$226,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Operation and Maintenance			*$914,370*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$265,612**
Labor to Collect Samples and Analyze Data	$20,750	LS	1	$20,750
Equipment and Consumables	$5,300	LS	1	$5,300
Analytical Services	$39,600	LS	1	$39,600
	Monitoring and Performance Evaluation Costs			*$65,650*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
Present Value of Monitoring and Performance Evaluation				*$265,612*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
		Reporting Costs		*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
		Present Value of Reporting		*$89,009*
SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS				**$2,027,942**
Contingency		percent	20%	$405,588
TOTAL ESTIMATED PRESENT VALUE COSTS				**$2,433,530**

Table B3-8
Estimated Cost for Bioremediation of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$143,750**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
Bio bench testing, modeling	$70,000	LS	1	$70,000
Construction plans, and specification/permitting	$20,000	LS	1	$20,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$5,000	LS	1	$5,000
DEQ oversight of remedial design (15% of design and permitting)	$125,000	percent	15%	$18,750
			Total Design Costs	***$143,750***
First Application				**$456,000**
Direct Push Rig	$2,500	Day	30	$75,000
Injection Oversight	$90	HR	300	$27,000
Bioaugmentation	$30,000	LS	1	$30,000
Nutrient Material Cost	$2	LB	162000	$324,000
Surveying	$5,000	LS	1	$5,000
As-built report labor	$90	HR	40	$3,600
As-built report direct costs	$1,000	LS	1	$1,000
DEQ oversight of remedial action	$90	HR	40	$3,600
			Cost for First Application of Biodegradation Materials for Source Reduction	*$456,000*
Reapplication (3rd year)				**$342,913**
Direct Push Rig	$2,500	Day	30	$75,000
Injection Oversight	$90	HR	300	$27,000
Nutrient Material Cost	$2	LB	162000	$324,000
			Annual Operation and Maintenance Costs	*$426,000*
Reapplication (3 yr)		YR	3	
Discount Rate		percent	7.5%	
			Present Value of Reapplication	*$342,913*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$89,819**
Labor to Collect Samples and Analyze Data	$7,000	LS	1	$7,000
Equipment and Consumables	$2,000	LS	1	$2,000
Analytical Services	$13,000	LS	1	$13,200
			Monitoring and Performance Evaluation Costs	*$22,200*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
			Present Value of Monitoring and Performance Evaluation	*$89,819*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
			Reporting Costs	*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
			Present Value of Reporting	*$89,009*
			SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS	**$1,121,491**
Contingency		percent	20%	$224,298
			TOTAL ESTIMATED PRESENT VALUE COSTS	**$1,345,790**

Table B3-9
Estimated Cost for Bioremediation Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$143,750**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
Bio bench testing, modeling	$70,000	LS	1	$70,000
Construction plans, and specification/permitting	$20,000	LS	1	$20,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$5,000	LS	1	$5,000
DEQ oversight of remedial design (15% of design and permitting)	$125,000	percent	15%	$18,750
Total Design Costs				***$143,750***
Capital Cost - First Application				**$579,200**
Direct Push Rig	$2,500	Day	30	$75,000
Injection Oversight	$90	HR	300	$27,000
Bioaugmentation	$80,000	LS	1	$80,000
Nutrient Material Cost	$2	LB	193000	$386,000
Surveying	$3,000	LS	1	$3,000
As-built report labor	$90	HR	40	$3,600
As-built report direct costs	$1,000	LS	1	$1,000
DEQ oversight of remedial action	$90	HR	40	$3,600
Cost for First Application of Biodegradation Materials for Downgradient Containment				*$579,200*
O&M - Reapplication (3rd year)				**$392,821**
Direct Push Rig	$2,500	Day	30	$75,000
Injection Oversight	$90	HR	300	$27,000
Nutrient Material Cost	$2	LB	193000	$386,000
Annual Operation and Maintenance Costs				*$488,000*
Reapplication (3 yr)		YR	3	
Discount Rate		percent	7.5%	
Present Value of Reapplication				*$392,821*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$265,612**
Labor to Collect Samples and Analyze Data	$20,750	LS	1	$20,750
Equipment and Consumables	$5,300	LS	1	$5,300
Analytical Services	$39,600	LS	1	$39,600
Monitoring and Performance Evaluation Costs				*$65,650*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
Present Value of Monitoring and Performance Evaluation				*$265,612*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
Reporting Costs				*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
Present Value of Reporting				*$89,009*
SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS				**$1,470,393**
Contingency		percent	20%	$294,079
TOTAL ESTIMATED PRESENT VALUE COSTS				**$1,764,471**

Table B3-10
Estimated Cost for Groundwater Circulation Wells with Biodegradation Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Remedial Design				**$258,750**
RD/RA Work Plan and Negotiations	$20,000	LS	1	$20,000
Design site characterization [including utility locating]	$10,000	LS	1	$10,000
Remedial Design (engineering and permitting)				
GCW Pilot Test	$75,000	LS	1	$75,000
Bio bench testing, modeling	$70,000	LS	1	$70,000
Construction plans, and specification/permitting	$40,000	LS	1	$40,000
Plans (HASP, Construction QA Plan)	$20,000	LS	1	$20,000
RA procurement	$10,000	LS	1	$10,000
DEQ oversight of remedial design (15% of design and permitting)	$225,000	percent	15%	$33,750
			Total Design Costs	***$258,750***
Capital Costs - Circulation Well Install				**$114,500**
Field Materials During Drilling	$5,000	LS	1	$5,000
Drilling Oversight	$35,000	LS	1	$35,000
Drilling (Extraction wells)	$55,000	LS	1	$55,000
Utility Locate	$1,000	LS	1	$1,000
Drop Box Rental	$2,500	LS	1	$2,500
Poly Tank Rental	$1,000	LS	1	$1,000
Soil Disposal Fee Including Transport	$15,000	LS	1	$15,000
			Drilling Costs	*$114,500*
Capital Costs - Treatment System Installation				**$123,272**
Equipment Costs				
Packer	$1,000	EA	8	$20,000
GW Pump	$5,000	EA	8	$40,000
Wellhead	$1,500	EA	4	$6,000
Nutrient Storage Shed	$3,000	EA	1	$3,000
Dosing Pump	$2,500	EA	4	$10,000
Permit Fees	$5,000	LS	1	$5,000
Trenching	$1.17	CY	50	$59
Backfill Trench	$1.48	CY	50	$74
Compaction of Trench	$4.78	CY	50	$239
Consumables during construction	$50	DAY	60	$3,000
			Subtotal Equipment	*$87,372*
Labor Costs				
Engineering Oversight	$4,000	LS	1	$4,000
Labor	$12,000	LS	1	$12,000
Surveying	$3,000	LS	1	$3,000
As-built report labor	$90	HR	80	$7,200
As-built report direct costs	$2,500	LS	1	$2,500
DEQ oversight of remedial action	$90	HR	80	$7,200
			Subtotal Labor	*$35,900*
			Total Treatment System Installation	*$123,272*

Table B3-10
Estimated Cost for Groundwater Circulation Wells with Biodegradation Downgradient of Upland Source Area
Siltronic Corporation
Portland, Oregon

Item	Unit Cost	Units	Quantity	Total Cost
Operation and Maintenance Costs (5 Years)				**$539,721**
Pump and Motor Maintenance	$2,000.00	LS	1	$2,000
Other Consumables	$5,000	LS	1	$5,000
Electrical Charge	$0.08	KWh	50,000	$4,000
Part Time Treatment Plant Operator	$75	HR	1,000	$75,000
Sampling Equipment	$50	event	12	$600
Laboratory Costs—VOC	$175	sample	96	$16,800
Annual System Shut Down and Cleanout	$30,000	LS	1	$30,000
	Annual Operation and Maintenance Costs			*$133,400*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	resent Value of Operation and Maintenance			*$539,721*
Nutrient Application (5 years)				**$647,342**
Nutrient Material Cost	$2	LB	80000	$160,000
	Annual Operation and Maintenance Costs			*$160,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Reapplication			*$647,342*
Groundwater Monitoring and System Performance Evaluation (5 Years)				**$265,612**
Labor to Collect Samples and Analyze Data	$20,750	LS	1	$20,750
Equipment and Consumables	$5,300	LS	1	$5,300
Analytical Services	$39,600	LS	1	$39,600
	Monitoring and Performance Evaluation Costs			*$65,650*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Monitoring and Performance Evaluation			*$265,612*
Reporting				**$89,009**
Prepare Semi-Annual Reports	$11,000	LS	2	$22,000
	Reporting Costs			*$22,000*
Total Years of Operation		YR	5	
Discount Rate		percent	7.5%	
	Present Value of Reporting			*$89,009*
	SUBTOTAL ESTIMATED REMEDIAL ACTION COSTS			**$2,038,206**
Contingency		percent	20%	$407,641
	TOTAL ESTIMATED PRESENT VALUE COSTS			**$2,445,847**

Table Notes
Siltronic Corporation
Portland, Oregon

NOTES:

CY = Cubic Yard
EA = Each
ECHOS = Environmental Cost Handling Options and Solutions
gpm = Gallons per minute
HR = Hour
HP = Horse power
KWh = Kilowatt-hour
LB = Pound
LF = Linear foot
LS = Lump sum
mA = Milliampere
SF = Square foot
SY = Square Yard
YR = Year