AOC A Source Control Evaluation
Grenada Manufacturing, LLC Facility
Grenada, Mississippi

Prepared for

Grenada Manufacturing, LLC

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Section 1

Introduction

This report compares remedial technologies for source control at AOC A at the Grenada Manufacturing, LLC facility (facility) in Grenada, Mississippi. Its purpose is to provide a framework under which a preferred alternative may be selected. This introduction provides a brief facility history and information about, and a conceptual model for, AOC A.

1.1 Facility History

The Grenada Manufacturing facility was constructed by Lyon in 1961 and sold to Rockwell International Corporation (Rockwell) in 1965. Rockwell manufactured wheel covers at the facility from 1965 to 1985, when the plant and property were sold to Randall Wheel Trim, Inc., a wholly-owned subsidiary of Textron Inc. (Textron). In 1999, Textron sold the operations and property to Grenada Manufacturing, Inc. (Grenada Manufacturing), which continued to operate the wheel cover plant until 2008, when ICE Industries, Inc. (ICE) leased a portion of the facility. ICE has operated the facility to the present, providing stamp-formed parts to various industries.

1.2 Environmental History

On January 20, 1989, the United States Environmental Protection Agency, Region IV (EPA) advised Textron “that there may be a release or threat of a release of hazardous substances from the site into the surrounding environment” and that EPA would be inspecting the facility pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In addition, by letter dated February 16, 1989, the Mississippi Department of Natural Resources, now known as the Mississippi Department of Environmental Quality (MDEQ), advised Textron that the facility had been included on EPA’s Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) list of potential hazardous waste sites.

On August 22, 1990, MDEQ issued an administrative order to Textron and Rockwell requiring the companies to “develop and execute a work plan to delineate and characterize the extent of any contaminant releases or potential releases” from an on-site landfill located west of the wastewater treatment plant, which is between the treatment plant and Riverdale Creek. Non-hazardous waste materials identified within the former on-site landfill area were excavated subsequently and disposed in an off-site facility, and a fence was constructed around the former on-site landfill.

On March 19, 1991, Textron and the MDEQ entered into an “Agreed Order” (Order Number 1859-90) pursuant to which Textron consented to undertake the measures necessary to bring a wastewater impoundment containing regulated hazardous wastes (the EQ Lagoon) into compliance with the applicable RCRA regulations.

The site remedial investigation (RI) began in 1991 and continued through 1993. In August 1993, MDEQ shifted authority for project oversight from the Uncontrolled Sites Branch to the Hazardous Waste Branch. A Baseline Risk Assessment (BRA) was conducted for soil and shallow groundwater (i.e., Shallow and Deep Zones of the Upper Aquifer) as part of the Supplemental RI Report prepared by Eckenfelder in March 1994. A Draft Remedial Investigation Report, Randall Textron Plant Site, Grenada, Mississippi (Eckenfelder, 1994) was submitted to MDEQ reflecting the results of a comprehensive site investigation and BRA. The remedial investigation identified several source areas that contained contaminants of concern (COCs) in addition to the former on-site landfill area. The areas of concern identified in the RI were: former on-site landfill, EQ Lagoon, former Sludge Lagoon, Chromium Reduction Unit, Raw Waste Station/Wet Well, Process Sewers, Outfall Ditch, former Toluene Storage Area, former trichloroethene (TCE) Storage Area and former Burn Area.

The RI identified the presence of trichloroethylene (TCE) and its degradation products, as well as toluene and chromium, in the soil and groundwater at the site. Based on the BRA, the primary concern with respect to impacted groundwater was the migration of chlorinated volatile organic compounds (CVOCs) to Riverdale Creek on the western side of the site. The BRA identified as COCs eight volatile organic compounds (VOCs) (1,2-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethene [total], tetrachloroethene [PCE], toluene, 1,1,2-trichloroethane, trichloroethylene, and vinyl chloride), one semi-volatile organic compound [bis(2-ethylhexyl) phthalate], and two metals (chromium VI and arsenic).

In 1995 EPA assumed authority for the project oversight, and determined that the investigation and cleanup of the site would proceed as a corrective action under the terms of the RCRA permit issued to the facility. In 1996 and 1997, a RCRA Facility Assessment (RFA) was performed by the EPA and its contractor (A.T. Kearney, Inc.) as part of the Federal Hazardous and Solid Waste Amendments (HSWA) permit process for the facility. The RFA report was sent to the facility in November 1997.

As a result of the Preliminary Review (PR) and Visual Site Inspection (VSI), 26 solid waste management units (SWMUs) and 3 areas of concern (AOCs) were identified. Of the 26 SWMUs identified, 18 SWMUs (1, 5, 6, 8, 9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26) were investigated, no evidence of a release was found, and no further action required. Prior to the date that the facility became regulated under RCRA, remedial actions had been completed at SWMU 2 (former EQ Lagoon) and SWMU 3 (former on-site landfill). A RCRA Facility Investigation (RFI) was required for the remaining SWMUs (2, 3, 4, 7, 12, 13, 14, 15 and 27) and for AOCs A, B, and C.

As a condition of the facility's HSWA Permit, EPA required preparation of an Interim Measures Work Plan (IM Work Plan) to address the Chromium Destruct Pit (SWMU 14), former TCE Storage Area (AOC A), former Toluene Storage Area (AOC B), Wet Well (SWMU 12), plant process sewers (SWMU 15), and facility-wide groundwater. In July 1998, EPA issued a HSWA permit to the facility.

In March 1999, EPA issued a combined RFI/Confirmatory Sampling (CS) Work Plan call letter. EPA requested summaries of data obtained subsequent to issuance of the RI Report be prepared and that the available data be organized by SWMU or AOC. A Summary of Investigative Work (SOIW) document was prepared by Brown and Caldwell and transmitted to EPA and MDEQ in July 1999. Comments on the SOIW were received from the EPA, which required that it be revised and resubmitted as the RFI Report. Additional groundwater sampling was performed to update the groundwater database and to incorporate the updated information in the RFI Report (revised SOIW).

An Interim Measures (IM) Work Plan was submitted to EPA in June 2000 and approved in July 2000. The IM Work Plan addressed additional data collection and the evaluation of interim measures for both source control and facility-wide groundwater. The additional data collected and reported in the RFI Report were used in evaluating interim measures. The RFI Report, including responses to EPA comments on the Draft SOIW and the results of the additional sampling, was issued in final form in October 2001. (Brown and Caldwell, 2001).

In 2003, a report entitled "Corrective Measures Study, Grenada Manufacturing, LLC" (CMS) (Brown and Caldwell, 2003) recommended eight site-specific components as the final corrective measures for the facility (in addition to the measures that already had been undertaken):

- Additional dense non-aqueous-phase liquid (DNAPL) recovery at AOC A;
- Additional light non-aqueous-phase liquid (LNAPL) recovery at AOC B;
- Additional non-aqueous-phase liquid (NAPL) recovery at the former Sludge Lagoon;
- Construction of a high vacuum multi-phase extraction system at AOC B;
- Installation of a sheet pile barrier upgradient of AOC A for groundwater migration control;

- Closure of the former Sludge Lagoon (SWMU 4);
- Installation of a permeable reactive barrier (PRB) for facility-wide groundwater migration control; and
- Implementation of select institutional controls for the facility.

The CMS was approved by EPA in September 2003, and in December 2005, the plant's HSWA permit was modified to require implementation of the corrective measures.

On July 18, 2006, a Corrective Measures Pre-Design Activities Work Plan ("Pre-Design Work Plan", Brown and Caldwell, 2006) was submitted to EPA identifying work to be completed prior to implementing the approved CMS. The Work Plan was approved by EPA, and the activities outlined therein were completed. The performance of the work provided information for design of the measures and/or evaluation of the expected effectiveness of certain of the measures proposed in the CMS. The Corrective Measures Pre-Design Investigation Results for the facility ("Pre-Design Investigation Report") was submitted to EPA on July 18, 2008. This report included design information concerning the former Sludge Lagoon Closure and further recommendations regarding whether other of the corrective measures should be implemented. (Brown and Caldwell, 2008).

1.3 Summary of Corrective Measures at AOC A

DNAPL was identified in a monitoring well near the former TCE Above-Ground Storage Tank within AOC A. The tank was placed in service in 1973 and removed from service in the 1980s following a reported release from underground piping associated with the tank. A new above-ground tank was installed at that time and placed within a containment berm with above-ground piping. TCE use at the facility was discontinued in 1992 ("Draft Remedial Investigation Report, Randall Textron Plant Site, Grenada, Mississippi", Eckenfelder, 1994).

An automated DNAPL recovery system was installed in October 1993 within AOC A. The DNAPL recovery well was located between the plant building and the plant warehouse to the east in the vicinity of the Former TCE Storage Tank. The automated DNAPL recovery system was operated for a period of approximately three years to recover free-phase TCE. As a result of this interim action, over 200 gallons of TCE were removed before product thickness decreased to the point that additional recovery using the automated system was no longer beneficial. Automated recovery ceased in 1996, but recovery of DNAPL continued through periodic manual bailing from 1996 through 2003, when it was determined that no additional free-phase TCE could be removed. Approximately 39 additional gallons of DNAPL was recovered through manual bailing, bringing the total documented DNAPL recovery to at least 239 gallons. Additional monitoring has indicated that DNAPL no longer accumulates in the recovery well.

The CMS called for additional DNAPL recovery in AOC A. In preparation for installing additional DNAPL recovery wells in this area, the Pre-Design Work Plan included an evaluation of the potential for additional DNAPL recovery in AOC A. This work plan was approved by EPA on April 8, 2007. The Work Plan called for installing a grid of temporary wells in the vicinity of the former DNAPL recovery well to determine if additional recoverable zones of DNAPL were present in AOC A. The wells were screened at the interface of the aquifer with the Shaley Clay Aquitard and were equipped with a sump that extended into the Aquitard to allow accumulation of DNAPL if recoverable quantities were present. A total of 31 temporary wells were installed and measurements were obtained from the wells for a period of four months following installation. DNAPL was not detected in any of the temporary wells. The methods and results of this investigation are described in detail in the Pre-Design Investigation Report. Based on the results of these activities, the Pre-Design Report recommended no further action be taken for DNAPL removal in AOC A.

The Pre-Design Work Plan also recommended the further evaluation of a sheet pile barrier to be placed upgradient of the DNAPL source area as a means of source area control. Due to the location of the DNAPL source area and surrounding buildings and utilities, a full barrier around the source area would not be practical, so a partial barrier upgradient of the source area was envisioned. The Pre-Design Work Plan described groundwater fate and transport modeling that would be completed to evaluate the effects of this type of partial barrier on the source area control for AOC A.

Groundwater fate and transport modeling was completed as a pre-design study for the sheet pile barrier concept. A regional MODFLOW/MT3D model was used to complete this analysis, and the methods and results of the evaluation were included in the Pre-Design Investigation Report. The fate and transport modeling results indicated that the barrier would create a minor reduction in the total flux of TCE to the PRB; however, the reduction was small enough to be within the margin of error for the modeling effort. In addition, the model predicted that the TCE flux to the PRB would continue for a longer period of time with the barrier in place, negating any potential benefit of a reduced total quantity of TCE reaching the PRB. In light of the foregoing, the report recommended eliminating the sheet pile barrier as a viable source area control measure for AOC A and AOC B.

EPA approved the Pre-Design Investigation Report, accepting the recommendations that the sheet pile barrier be eliminated as a corrective measure for AOC A.

1.4 AOC A Conceptual Model

A detailed conceptual site model (CSM) for the facility was included as a Supplement to the 2012 Annual Report (Attachment E to the 2012 Annual Report). Additional facility and regional geologic and hydrogeologic data have been obtained since the CSM was updated for the 2012 Annual Report. The additional information was incorporated in the study area conceptual model presented in the *Moose Lodge Area Additional Investigation Report – Comprehensive Study Area Groundwater Investigation* (MLRA Additional Investigation Report, T&M, 2015). Information from this investigation also will be incorporated in an update to the Supplemental Report (from the 2012 Annual Report) to be provided with the 2016 Annual Report, which also will include the results of the facility quadrennial sampling event.

The stratigraphy at AOC A is comprised of approximately 10 feet of clayey silt or silty clay soil overlying approximately 45 feet of saturated, fine- to medium-grained sands that contain varying amounts of silt. The saturated sand is referred to as the Upper Aquifer. East of AOC A, the Upper Aquifer is bisected by a discontinuous clay (Intermediate Clay) unit at a depth between 20 and 30 feet below ground surface (bgs). This Intermediate Clay was not observed at AOC A or in most areas of the facility to the west of AOC A. The sands present above and below the Intermediate Clay (IC), where it is present, are referred to as the Shallow Zone and Deep Zone of the Upper Aquifer. At the base of the Upper Aquifer is a thinly-bedded, slightly-sandy, clayey-silt aquitard, which is encountered at a depth of approximately 55 feet bgs at AOC A. This unit, referred to as the Shaley Clay Aquitard (SCA), separates the Upper and Lower Aquifers. It is approximately 16 feet thick at well MW-9 and historically identified as marl. The SCA typically is comprised of dense soils, exhibiting much higher blow counts than the overlying soils of the Upper Aquifer. Below this unit is another sand layer that comprises the Lower Aquifer. Well MW-9 is screened in the Lower Aquifer.

The Upper Aquifer is the primary horizontal transport pathway for the facility. The groundwater in this aquifer is generally under semi-confined conditions, flows to the west/northwest, and discharges into Riverdale Creek. Riverdale Creek is in direct communication with the Upper Aquifer. The Upper Aquifer is semi-confined above by the surficial confining unit and below by the SCA. A significant upward gradient exists between the Upper and Lower Aquifers, where measured, thereby precluding advective transport of COCs to the Lower Aquifer. No contamination impact has been identified in the Lower Aquifer. The Upper Aquifer is confined at AOC A by the Surficial Soils except during very low water table conditions.

The aerial extent of the TCE DNAPL source area within AOC A is not known. Borings and wells were installed at AOC A during the RI including MW-25, MW-27, MW-28, MW-29, and MW-30. DNAPL was encountered at MW-27 and was recovered from this well during the 1990's as described in Section 1.3.

The other wells installed within AOC A did not accumulate DNAPL. A grid consisting of 30 wells was installed in 2007 as a part of the CMS Pre-Design Investigation to determine if recoverable DNAPL was present at any other location within AOC A. All of the wells installed in 2007 were screened across the interface between the Upper Aquifer and the SCA. None of the wells indicated the presence of DNAPL after a four-month period of observation, and the wells were abandoned.

Additional investigation would be required to identify the zone where residual DNAPL exists within the sand of the Upper Aquifer and along base of the SCA.

1.5 Report Organization

The remainder of this report describes potential alternatives for source control for AOC A and a preliminary screening of the available technologies (Section 2.1); presents selection criteria to be used in a more detailed screening of alternatives (Section 2.2); provides a more detailed description of the viable alternatives (Section 2.3); provides screening of the viable alternatives based on the selection criteria (Section 2.4); and identifies additional investigation required to complete the comparative analysis of the two technologies considered for source control at AOC A (Section 3).

Section 2

Source Control Technology Screening

2.1 Potential Alternatives

Several technologies have historically been applied in DNAPL source areas that may be applicable for source area control at AOC A. Some technologies have long track records and multiple applications in conditions similar to those in AOC A, while others have a limited track record and/or have not been applied in similar settings. This section briefly describes the primary technologies previously applied to DNAPL source areas and screens them based primarily on technical feasibility and performance for possible use at AOC A. Technologies that screen favorably in this section are evaluated in greater detail in Section 2.3.

The following technologies have been applied in DNAPL source areas to contain and/or remediate the source:

1. Hydraulic control;
2. Excavation and disposal;
3. Physical containment;
4. Air sparging and soil vapor extraction;
5. In situ chemical oxidation (ISCO);
6. In situ chemical reduction (ISCR);
7. Surfactant and cosolvent flushing;
8. Enhanced reductive dechlorination (ERD); and
9. In situ thermal treatment (ISTT).

Each of these alternative technologies is described below and screened for technical feasibility, performance and other factors that may impact its suitable application at AOC A.

2.1.1 Hydraulic Control

Hydraulic control arguably has the longest track record of all technologies used to contain DNAPL source areas. The track record of hydraulic control for accomplishing containment is unmatched. However, since the first hydraulic control systems were installed in the 1970s and 1980s, it has been demonstrated that this technology works well for containment, but is not as well suited for treatment. Hydraulic control systems can be designed to ensure that no contaminants leave a source area, but the mass treated by these systems tends to be relatively small and long-term operation is needed to ensure containment. Thus, they are not a good treatment choice, particularly when DNAPL source material is present.

AOC A contains unrecoverable DNAPL TCE. Presently, the quantity and distribution of residual DNAPL are not well defined, but the plume generated from AOC A suggests that the "footprint" of the residual

DNAPL may be relatively large (i.e., greater than 10,000 square feet) and that an unknown mass of TCE remains. The ability of a hydraulic control system to contain the source at AOC A is nearly certain, but the time period that hydraulic control would need to remain in place and effective is long. Because a hydraulic control system would need to remain in place for a lengthy duration, this technology is not retained for further consideration.

2.1.2 Excavation and Disposal

When a source area is limited to relatively shallow soils and is of limited overall extent, excavation and disposal of the source area soils can be a viable option. This option also generally requires that the source area is located away from structures such that the excavation work can be completed without damage to or demolition of adjacent buildings.

AOC A has TCE source material deep within the Upper Aquifer (>55 feet bgs), and the source area is located adjacent to, and likely under, surrounding structures. For these reasons, excavation and disposal is not considered further.

2.1.3 Physical Containment

It is sometimes possible to physically contain a DNAPL source area and prevent the continued generation of a groundwater plume. Containment materials can include sealed sheet pile to prevent groundwater movement and slurry walls constructed with low-permeability materials that restrict groundwater flow in and out of the contained zone. Some level of hydraulic control typically is needed with the physical control to maintain an inward gradient through the barrier and prevent source material from leaking from potential weak spots in the containment. Containment walls are limited by depth and the cost for containment increases with depth from the surface. The presence of buildings on and around the area to be contained is typically problematic as well.

A sheet pile barrier was considered for AOC A during the CMS and the CMS Pre-Design Investigation. It was determined at that time that complete containment of AOC A was not feasible due to the presence of buildings and utilities. A partial containment barrier was proposed, but later rejected due to the ineffectiveness of this technology when complete containment is not possible. Given that complete containment of AOC A is not possible, this approach will not be considered further.

2.1.4 Air Sparging and Soil Vapor Extraction

Historically, this technology is used to only a limited extent in treatment of DNAPL source areas. To be effective, the sparge zone must be developed beneath the DNAPL source such that air stripping can occur throughout the source zone. Also, a soil vapor extraction system is needed above the sparge zone to collect and treat the sparge air and VOCs. Considerable difficulty has been encountered when trying to access the full volume of the treatment zone with air sparging. Sparge air tends to flow through soil channels of least resistance within the subsurface and does not disperse widely through the aquifer. As a result, some zones are preferentially treated with little or no treatment in other zones. Air sparging has been effective in treatment of LNAPL petroleum source zones in part due to the introduction of oxygen for biodegradation of the dissolved phase released from the source.

In AOC A, a portion of the source is present on the surface of the SCA. Air sparging could not access this DNAPL volume and potential effectiveness would be largely limited to residual source in the more permeable Upper Aquifer. The more permeable Upper Aquifer in AOC A is overlain by a silty-clay surficial soil, and groundwater generally is under confining conditions. Such conditions would not provide an appropriate zone for soil vapor extraction to collect and treat the sparge air. For these reasons, air sparging and soil vapor extraction are not considered further.

2.1.5 In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) has been applied successfully in some DNAPL source areas. Chemical oxidants such as Fenton's-type reagents, potassium and sodium permanganates, ozone and persulfate can be used to oxidize TCE and its daughter products. Delivering sufficient oxidant to locations where DNAPL is in contact with groundwater and maintaining the oxidant in these zones is challenging. Also, most oxidants used for ISCO also can cause oxidation of trivalent chromium to hexavalent chromium.

Some chromium may have been released to the aquifer at the facility. Hexavalent chromium is periodically detected in groundwater, although at lower concentrations than historically detected. The aquifer currently is under reducing conditions, and hexavalent chromium appears to travel limited distances before it is reduced to trivalent chromium and precipitated onto aquifer soils. However, trivalent chromium from natural sources in the aquifer and from precipitation of reduced hexavalent chromium potentially would be subject to oxidation during ISCO, which could mobilize chromium present in the aquifer into the more toxic and mobile hexavalent form. With the need for large quantities of oxidant to treat AOC A, the Upper Aquifer downgradient of AOC A likely would be converted to aerobic conditions over time, preventing the natural reduction of hexavalent chromium and its precipitation onto aquifer soils in the trivalent form. The conversion of the aquifer to aerobic and/or more oxidizing conditions also would have a detrimental effect on the PRB by allowing additional oxidized groundwater components to reach the PRB, increasing the corrosion rate of the zero valent iron (ZVI). The PRB must continue to treat the downgradient portion of the plume to minimize the introduction of TCE and its daughter products to Riverdale Creek and results that are detrimental to the PRB are not preferred.

Given the likely challenges of oxidant distribution and reapplication within AOC A, the concern that hexavalent chromium would be for generated and mobilized, and the likely detrimental effects on the facility's PRB, this technology is not considered further in this evaluation.

2.1.6 In Situ Chemical Reduction

In situ chemical reduction was first introduced in the environmental field with the use of ZVI PRBs. The technology has been expanded in recent years to include the injectable forms of chemical reductants, including micro and nano-scale ZVI, ZVI incorporated into emulsified vegetable oil (EVO) droplets and ZVI incorporated with activated carbon and other metals that act in a reducing capacity similar to ZVI. Methods of introducing ZVI into a source zone through soil mixing also have been implemented to a limited extent in source areas.

However, the only successful implementation of this technology for source area control has occurred with ERD. One exception is the use of soil mixing where ZVI is added to the soil as it is mixed and treated in a variety of ways. This approach to the use of this technology has not been considered for AOC A due to access issues. Thus, ISCR likely will not be considered further, except possibly in conjunction with ERD.

2.1.7 Surfactant and Co-solvent Flushing

This technology first was explored in the petroleum industry as a means to enhance product recovery. Co-solvents and surfactants are used to enhance the dissolution of DNAPL and LNAPL and allow much improved recovery as groundwater is passed through a source area. A variety of co-solvents and surfactants has been developed for use in source zone remediation, although the research has focused more on LNAPL recovery. When groundwater is flushed through the source area, the water preferentially flows through higher conductivity pathways and bypasses less permeable zones. Work in this field has focused on methods to restrict flow in the high permeability pathways and force flow through less permeable zones. Better recovery is achieved with this approach, but significant limitations remain in the ability of the fluids to access low permeability zones.

Given the likely presence of DNAPL in lower permeability zones within AOC A, including the SCA, and the lack of successful implementation of this technology in settings similar to AOC A, this technology will not be considered further.

2.1.8 Enhanced Reductive Dechlorination

Enhanced reductive dechlorination (ERD) began as a technology for treatment within dissolved-phase plumes and as a means to enhance natural attenuation processes within a chlorinated solvent plume. Over time, it has been recognized that the consortium of microorganisms responsible for reductive dechlorination, and in particular *Dehalococcoides mccartyi*, can survive and even thrive in source areas and in close contact with DNAPL. When ERD is implemented in a source area, enhanced dissolution of the DNAPL can be expected based on both (1) the concentration gradient that results when higher chlorinated species, such as TCE, are degraded to daughter products, cis-1,2-DCE (cDCE) and VC, and (2) amendments acting as co-solvents and microbial production of biosurfactants. DNAPL dissolution enhancement of two to five times over the background dissolution rate have been reported.

ERD is also a process that can be sustained for long periods of time in source zones. With proper design and monitoring, containment of source can be maintained. Factors such as the type of amendment, the rate of groundwater flow and the rate of ERD and side reactions govern the frequency of amendment injections. In recent years, bioaugmentation has been considered in many ERD applications to ensure that *D. mccartyi* is present and to aid in a quick start for the process. ERD can be effective in difficult, low permeability zones. Processes such as back-diffusion allow some amendment to enter less permeable zones and potentially stimulate ERD.

Problems associated with ERD include a sensitivity to low pH, the production of byproducts such as methane and sulfide, and the mobilization of iron and arsenic. *D. mccartyi* is sensitive to low pH and has been shown to become less effective at dechlorination below pH 5.5 and to stop dechlorinating altogether below a pH of 5.0. Metals mobilization typically is localized to the treatment zone, and the metals generally become oxidized downgradient of the treatment zone and re-precipitate on aquifer materials. Although the ERD treatment process in source zones is slow in comparison to ISCO, ISCR and ISTT, the process often can be maintained for long periods of time at a reasonable cost in comparison to these competing technologies.

ERD will be retained for further evaluation for source control in AOC A.

2.1.9 In Situ Thermal Treatment

As with many other technologies used for DNAPL source zone remediation, in situ thermal treatment (ISTT) was first used in the petroleum industry to aid in recovery from production wells and wellfields. Several forms of ISTT are commercially available, including three primary approaches: thermal conductive heating (TCH), electric resistance heating (ERH) and steam enhanced extraction (SEE). Positive aspects of ISTT include the rapid removal of DNAPL mass from a source zone, relatively complete removal of a high percentage of DNAPL mass, and the ability to remove DNAPL from soils with low permeability and low permeability zones within more permeable aquifers (e.g., clay lenses). The primary drawbacks for ISTT are the cost and energy consumption. The cost per cubic yard of treated DNAPL zone is typically higher with ISTT than most other technologies that have been applied successfully in source areas. A mounting body of successful cases with ISTT is developing, as are lessons learned from many applications completed to date.

ISTT will be retained for further consideration for source control at AOC A.

2.2 Alternatives Screening Criteria

The following screening criteria will be used to compare the remaining potential technologies:

1. Protective of human health and the environment;
2. Implementability;
3. Long-term reliability and effectiveness;
4. Time frame within which to reach end point/Short-term effectiveness;
5. Cost and value;

These criteria are briefly described in the sections below and are used in comparing the remedial alternatives in Section 2.3.

2.2.1 Protection of Human Health and the Environment

Technologies/approaches considered must be protective of human health and the environment. The evaluation may include consideration of measures that are needed to be protective, but that may not be directly related to media cleanup, source control or management of wastes. An example would be a requirement to provide alternative drinking water supplies to prevent exposure to releases from an aquifer used for drinking water purposes. A discussion/comparison is provided for any short-term measures necessary to meet this standard.

2.2.2 Implementability

Information to be considered when assessing implementability includes:

i. The administrative activities needed to implement the corrective measure alternative (e.g. permits, rights of way, etc.), and the length of time these activities will take;
ii. The constructability, time for implementation and time for beneficial results;
iii. The availability of adequate off-site treatment, storage capacity, disposal services, needed technical services and materials; and
iv. The availability of prospective technologies for each alternative.

2.2.3 Long-Term Reliability and Effectiveness

The following should be evaluated when considering the long-term reliability and effectiveness of a particular technology:

i. Whether the technology, or combination of technologies, has been used effectively under analogous conditions;
ii. Whether failure of any alternative would have immediate impact on receptors; and
iii. Whether the alternative would have the flexibility to deal with uncontrollable changes at the facility.

Operation and maintenance requirements include consideration of factors such as frequency and complexity. Each corrective measure alternative also should be evaluated in terms of the projected useful life of the alternative and of its component technologies. Useful life is defined as the time duration the level of effectiveness can be maintained.

2.2.4 Time to Reach Endpoint/Short-Term Effectiveness

The time to reach the endpoint is defined both as the time until contaminant flux is no longer occurring from AOC A and the time at which the source control action no longer needs to be maintained at AOC A due to achievement of containment. Each alternative also is evaluated for short-term effectiveness. Possible factors to consider are fire, explosion, exposure to hazardous constituents during implementation and potential threats associated with the treatment, excavation, transportation and disposal or containment of waste material during corrective measure implementation.

2.2.5 Cost

An estimated cost for each alternative (and for each phase or segment of the alternative) is developed and compared. The cost estimate includes both capital and operation and maintenance costs. The capital costs include costs for: engineering, site preparation, construction, materials, labor, sampling/analysis, waste management/disposal, permitting, health and safety measures, etc. The operation and maintenance costs include labor, training, sampling and analysis, maintenance materials, utilities, waste disposal and/or treatment. Costs are calculated as the net present value of the capital and operation and maintenance costs.

2.3 Description of Remedial Alternatives

Based on the screening completed in Section 2.1, two remedial alternatives remain as viable candidates for potential source control in AOC A, ISTT and ERD. These technologies are described in greater detail in Sections 2.3.1 and 2.3.2. These alternatives are then compared in Section 2.4 on the basis of the comparison criteria described in Section 2.2.

2.3.1 In Situ Thermal Technologies (ISTT)

In Situ Thermal Treatment (ISTT) involves the application of heat to a zone impacted with DNAPL TCE and the use of physical methods for recovering VOCs and semi-volatile organic compounds (SVOCs) that are driven from the subsurface as a result of heating. ISTT can be highly effective for depleting DNAPL source zone mass, with mass removal effectiveness as high as 99% possible. ISTT is particularly effective in DNAPL source zones that include low-permeability media that can be difficult to treat using other technologies.

ISTT typically includes one of three methods for heating the subsurface: thermal conductive heating (TCH), electric resistance heating (ERH) and steam-enhanced extraction (SEE). Other heating methods, such as radio frequency heating (RFH), also have been explored, but insufficient field application data are available to include them in this evaluation. The three primary ISTT technologies differ in the method used to transfer heat to the soil and groundwater, the rate of aquifer heating, the spacing of heating and vapor extraction points and the ability to treat NAPL sources in various geologic settings.

TCH utilizes a heating element placed in a recovery well to heat the soil around the well. It relies on the thermal conductance of the soil and groundwater to transfer heat away from the heating and vapor recovery well. As the aquifer around the well is heated to the co-boiling point of the DNAPL and water and vapors are released in the subsurface, a vacuum applied to the heating well collects the vapors for treatment. TCH is capable of heating the aquifer to higher temperatures than the other thermal technologies. It can heat to temperatures above 100 degrees Celsius (C) and can fully boil/evaporate water from soils above the water table and/or in lower permeability zones below the water table.

ERH includes the application of electrical current to the aquifer through electrodes distributed throughout the source area. The electrical resistance of the aquifer releases heat as current is passed through the aquifer, heating the soil and groundwater. The electrical resistance of tighter soils, such as silt and clay, is higher than more permeable soils, allowing this technology to heat the tighter soils at a slight preference to more permeable soils. This is a good feature of the technology, as DNAPL present in tighter soils tends to be more difficult to remove. The maximum temperature that ERH can heat the soils to is approximately 100 degrees C.

SEE was used as early as the 1930s in the petroleum industry to improve the recovery of oil fields with reduced production capacity. It has been applied successfully in this capacity to the present day with periodic improvements in methods of steam application in the subsurface. The use of SEE for ISTT involves injection of pressurized steam into wells completed within the DNAPL source area. Steam entering the aquifer travels through more permeable zones in much the way groundwater or sparged air would travel. Thus, SEE does not tend to heat less permeable zones of the aquifer as quickly as ERH, but these zones will typically be heated through thermal conduction from more permeable areas. Overall, SEE is less suited for fine grained source areas in comparison to either TCH or ERH. However, the rate of delivery of heat to the subsurface can be more rapid with steam injection, due largely to the high thermal capacity of steam.

Thermal technologies require that the temperature of the aquifer be raised above the co-boiling point of the DNAPL and water at the highest pressure present in the treatment zone (generally the deepest location to be treated). Co-boiling is a phenomenon in which vaporization of both the DNAPL and water can occur at a temperature lower than the boiling point of either constituent alone at locations where the two constituents are in contact. The boiling point is determined by the additive partial pressure of the two constituents. Water and TCE have a co-boiling point of approximately 74 degrees C at atmospheric pressure, significantly below the individual boiling points of either constituent (100 degrees C and approximately 88 degrees C, respectively). Raising the temperature of the aquifer above 74 degrees C at the water table, or a higher temperature depending on the pressure at a given depth in the aquifer, results in co-boiling of water and DNAPL. The expansion of the resulting vapor creates fractures in the aquifer that result in pathways for the water vapor and DNAPL to move to extraction wells and be removed from the aquifer through vacuum extraction wells, sometimes co-located with the heating points.

Other factors contribute to the rapid removal of DNAPL in a source area during heating, including: (1) increased solubility of the DNAPL and thus more rapid dissolution, (2) decreased density, and thus expansion, of the DNAPL, (3) decreased viscosity of the DNAPL and water, allowing greater mobility and access to the DNAPL, and (4) increased volatilization of the DNAPL due to an increase in the Henry's Law constant at higher temperature. However, the most important and effective factor for DNAPL removal with thermal methods is the co-boiling effect and the creation of water and TCE vapors. Each of the ISTT approaches involves the capture of vapors produced through subsurface heating and treatment of the vapors.

Significant limitations of thermal technologies include: (1) higher unit cost in comparison to other available technologies, (2) high energy consumption; (3) mass removal may be incomplete in low permeability portions of a treatment zone, and (4) limitations related to heat flux out of a source zone in an aquifer with a rapid groundwater flow rate. Moreover, source zone definition is of particular importance for ISTT because effective treatment will only occur in those zones where the aquifer has reached a sufficient temperature for vaporization of DNAPL.

Key advantages of ISTT include: (1) rapid clean-up of DNAPL source areas – typically in one year or less, (2) improved ability to access tighter soils and extract DNAPL, (3) the potential to remove a large fraction of the DNAPL present in a source area, and (4) the potential to reduce the flux of TCE from the source area by one to three orders of magnitude.

2.3.2 Enhanced Reductive Dechlorination (ERD)

Enhanced reductive dechlorination (ERD) takes advantage of naturally-occurring or bioaugmented microbes that carry out halorespiration utilizing chlorinated solvents as the terminal electron acceptor in an anaerobic respiration process. Multiple organisms are known to dechlorinate TCE to cDCE, but only one microorganism is known to carry out the remaining two dechlorination steps from cDCE to VC and ultimately to ethene, *Dehalococcoides mccartyi*. Although this is the only organism capable of utilizing cDCE and VC as terminal electron acceptors in halorespiration, several strains of this organism have been identified and these organisms are fairly widespread in aquifers.

ERD is carried out by adding amendments to the aquifer to feed microbial populations that use up all electron acceptors in the aquifer. Oxygen (if present in the groundwater) is the first electron acceptor to be used by micro-organisms that feed on the added amendments until all oxygen is used up. When oxygen is no longer present, two large groups of microbes gain energy from the added food source. The first group gains its energy from fermentation, producing dissolved hydrogen gas and acetate. The second group uses these byproducts to carry out anaerobic respiration using alternate terminal electron acceptors such as ferric iron, nitrate, sulfate, carbon dioxide and chlorinated solvents.

D. mccartyi competes in anaerobic respiration with these organisms for available hydrogen and acetate; in most cases it does not thrive until most other electron acceptors become scarce or are fully depleted. At that point the remaining competition for hydrogen and acetate comes from methanogens that utilize dissolved carbon dioxide as their terminal electron acceptor, with a byproduct of methane gas. In many cases, *D. mccartyi* can compete effectively with methanogens and can carry out the full reductive dechlorination of cDCE to ethene. As remaining amendments to the aquifer continue to be fermented, *D. mccartyi* produces ethene from dissolved chlorinated solvents, and methanogens generate methane.

ERD has been applied effectively for decades in dissolved-phase chlorinated solvent plumes to reduce the concentration of chlorinated solvents and produce the harmless byproduct ethene. In the past ten to fifteen years, this process has been applied to DNAPL chlorinated solvent source areas. It now is widely accepted that *D. mccartyi* can survive in DNAPL source zones and can be used to effectively dechlorinate chlorinated solvents as they dissolve from the DNAPL surface, such as TCE dissolving from the DNAPL surface in AOC A. Application of ERD in AOC A would involve addition of an electron donor across the full extent of the DNAPL zone for this source area, and most likely bioaugmentation of the source area with a microbial consortium, including *D. mccartyi*, capable of carrying out all the functions needed to fully dechlorinate the TCE. As the dissolved TCE is dechlorinated to cDCE, VC and ethene, the TCE concentration in solution adjacent to the DNAPL declines, and a concentration gradient is formed that results in additional dissolution of TCE from the DNAPL state. In most cases, the ERD process carried out in a DNAPL source area will result in increased rates of dissolution of the DNAPL and effective dechlorination of the dissolved TCE.

While ERD is widely accepted as a means to treat TCE DNAPL source areas, several challenges have been documented where this approach has been implemented. One challenge is to provide adequate distribution of the donor amendments to zones near the DNAPL where it is needed for reductive dechlorination, and to continue to supply adequate donor to these zones over time. Another challenge in some aquifer systems is to maintain the pH of the treatment zone at or above a pH of 5.5. Below this pH, *D. mccartyi* generally becomes less active and less effective in the dechlorination process. Below a pH of 5.0, most strains of *D. mccartyi* will no longer carry out dechlorination to ethene.

Groundwater throughout the study area surrounding AOC A has a naturally low pH, which in places can be at or below 5.5 even without active ERD. When ERD is applied to the aquifer, the fermentation process and the dechlorination processes result in the generation of some acid and a corresponding decrease in pH. The extent of pH drop that would occur at AOC A or in other parts of this aquifer has not yet been tested. Some buffering capacity is expected in the groundwater system, but it is not known at this time if the buffering capacity will be sufficient to prevent a drop in pH to 5.0 or lower. Researchers at Clemson University have developed a bioaugmentation consortium shown to be effective at lower pH in comparison to standard consortia that are commercially available for use in bioaugmentation. A pilot test using the Clemson bioaugmentation culture is scheduled to be completed on the south end of the PRB at the Grenada Manufacturing facility. Information gained from that pilot test will be useful to better understand the potential to use ERD in the AOC A source area as the primary means of source control.

2.4 Comparison of Alternatives

The alternatives that have passed initial screening, ISTT and ERD, are compared in this section based on the criteria described in Section 2.2.

2.4.1 Protection of Human Health and the Environment – Comparative Analysis

Riverdale Creek remains the single pathway for the AOC A plume to reach potential receptors (human or environmental), and the PRB is the primary means for blocking this pathway. However, recent performance of the PRB may be insufficient to fully block this pathway; rejuvenation work will be undertaken that will enhance the PRB and enable it to provide full control of this pathway to potential receptors. The primary effect source control at AOC A will have on protection of human health and the environment will be long-term; a reduction may occur in the duration the PRB must remain effective through the application of source control at AOC A.

Both alternatives can provide source control at AOC A within a reasonably short period of time. Once source control is in place, the time expected to reach MCLs at the PRB will be relatively long with either alternative. The short duration to reach a remedial end point possible with ISTT does not provide a measurable benefit to human health and the environment when compared to ERD, as long as source control is maintained by ERD during the time that remediation of source material is occurring. The difference in time needed to reach remedial goals in AOC A for the two alternatives does not affect the overall protection of human health and the environment at the facility, as long as both alternatives would attain source control within a similarly short period of time and maintain this control.

Both ISTT and ERD would be protective of human health and the environment in the short term, and both have the potential to be protective of human health and the environment in the long term, although ISTT appears to have some advantage in the long term.

2.4.2 Implementability – Comparative Analysis

ISTT is implementable in AOC A. The technology has proven effective in similar settings for removal of most DNAPL mass and for attainment of relatively low flux rates of TCE (or other source DNAPL compounds) from source areas. Minor obstacles to implementation exist, such as the likely need to work within areas that are in use by the facility and the need to capture all vapors produced by subsurface heating. Neither of these obstacles is considered to be insurmountable, though, and this technology likely can be implemented in AOC A.

ERD is likely to be implementable at AOC A, but additional testing is needed to confirm that a low pH strain of *D. mccartyi* is capable of full and rapid dechlorination of TCE in this setting. A pilot test is needed to confirm this, and one is currently planned for the south end of the PRB, where similarly low pH groundwater conditions are present. If this pilot test is successful, it is likely that ERD can be successfully applied in groundwater in AOC A.

Access to the areas above the DNAPL zone at AOC A will need to be provided by the current facility tenant, Ice Industries, Inc. (ICE). Both technologies will require that some facility space be taken out of service while work is occurring. ISTT will have a greater footprint and will involve a more complete use of facility space in comparison to ERD. However, the time period for which space is occupied and access is needed would be longer with ERD. It is unlikely that either technology will provide insurmountable issues in terms of access.

The time required to implement control of the CVOC plume sourced in AOC A will be similar for the two technologies. ISTT is often accompanied by a short-term increase in groundwater CVOC concentrations while the aquifer is heated, before reaching the temperature where significant boiling occurs at the DNAPL/water interface. ERD typically exhibits an initial period of incomplete dechlorination to ethene/ethane. The small effects of these start-up periods are not considered significant for either technology within the overall scope of source control at AOC A.

The primary materials and infrastructure needed to implement either technology likely are readily available. Substrate amendments for ERD are commercially available in quantities that are more than adequate to meet the needs for application of the technology in AOC A. If the low pH strain of *D. mccartyi* is needed for successful ERD, some efforts will be needed to grow sufficient quantities of bioaugmentation culture. This need can be met with a few months of advance notice. Microbes also can be harvested, to a limited extent, in groundwater from the south end of the PRB if the above-referenced pilot test in that area is successful.

The power infrastructure needed to implement ISTT is likely already present at the facility. However, the facility is active and may be using a large portion of the currently available power. Additional power or gas lines may be needed to meet the requirements of both the facility and ISTT, but it is expected this can be supplied with some premium in cost to obtain the needed power.

The useful life of the components needed to implement the three primary versions of ISTT is more than sufficient to complete the source control corrective measures at AOC A. In general, the infrastructure needed for ISTT remains usable at the end of the technology's application. However, the in-ground components of the system are not recovered due to the high cost of removal compared to the value of the in-ground components.

Issues that can affect the usable life of an ERD installation include aquifer clogging due to biomass and gas buildup. This can be overcome with effective scheduling of ERD amendment injections and by installing additional injection and recirculation wells. Long-term application of ERD within a source area can lead to a groundwater pH that is lower than during the initial stages of application. This can be overcome with amendments to buffer the aquifer at an increased expense. Overall, lifespan issues for ERD in AOC A are considered manageable.

Both technologies are considered implementable in AOC A, although more is known at this time about the implementability of ISTT in AOC A at this time.

2.4.3 Time to Reach Endpoint/Short Term Effectiveness

The time required to reach an endpoint when significant source material (DNAPL) is no longer present in AOC A is clearly shorter with ISTT compared to ERD. The time required to reach source control in AOC A is similar with the two technologies.

ERD will require that source control be actively maintained for a much longer duration than ISTT, thus there is a greater risk that impacted groundwater could be released from AOC A while source control measures still are being actively applied. If back-up systems are in place to handle short term releases of impacted groundwater from the NAPL zone, the risk is relatively low, and the time to reach the endpoint when the PRB is no longer needed is similar with the two technologies.

Short term effectiveness, when defined as the time needed to achieve control of the plume from AOC A, is similar between the technologies. An increase in the flux of CVOCs from the source area is expected in the early phase of ISTT as the aquifer is being heated. Increased flux of partially dechlorinated CVOCs from AOC A is expected in the early stages of ERD implementation. Both effects should only occur for a short period of time, and neither technology has a significant advantage in this category.

A short term issue that could occur for ISTT is the potential for remobilization of DNAPL if present in pooled form within the SCA. It will be important to estimate the thickness of the SCA in the source area and to characterize the upper portion of the SCA to determine: (1) the depth that DNAPL has penetrated into the SCA, (2) if the DNAPL may be capable of movement when the forces holding it in place are diminished, and (3) how much protective SCA is present beneath the DNAPL penetration. Potential for remobilization of DNAPL is an important issue for the short-term effectiveness of ISTT and requires investigation.

2.4.4 Cost

Feasibility-level cost estimates for capital expenditures and long-term O&M for the two alternatives are provided in Appendix A. The capital costs are estimated in terms of major categories such as design, amendment injections and infrastructure, and major capital categories are broken down into general cost elements. Operation and maintenance and monitoring (O&M) costs are provided for a single year and the overall O&M costs are estimated as the net present value of single year costs applied to the duration of the O&M activities. A discount rate of 5 percent is used in all cases for future years.

The expected range of capital and O&M costs for implementing ERD in AOC A is $350,000–$2,000,000. The expected range of capital and O&M costs for implementing ISTT in AOC A is $1,450,000–$4,200,000. The wide range in cost estimates for these alternatives results from uncertainties regarding (1) the size of the DNAPL-impacted area within AOC A, (2) the mass of DNAPL present within AOC A, (3) the ease of implementing ERD within this lower pH aquifer with the selected bioaugmentation culture, (4) the depth of penetration of DNAPL into the SCA, and (5) the required duration of source control activities for both alternatives.

The range of costs will be reduced significantly following the investigation of AOC A to determine the area and volume of the DNAPL-impacted aquifer and the assessment of DNAPL presence and mass within the SCA and other low permeability zones in AOC A. The overall area requiring thermal treatment is the most important factor associated with cost determination for ISTT. The area, volume and mass of DNAPL present in AOC A will have a significant effect on the cost for implementing ERD. Determination of the effectiveness and sustainability of ERD at the ambient aquifer pH following completion of the pilot test at the south end of the PRB will be a major factor in narrowing the range of costs for ERD.

Section 3

Additional Investigation

A total of nine alternatives were screened for source control at AOC A at the facility. Of these, two were selected for more detailed analysis, ISTT and ERD. The alternatives and screening process are provided in Section 2 of this report. Both ERD and ISTT are candidate technologies for application at AOC A.

However, a recommendation presently cannot be made because additional investigation would be needed to determine the total area and volume of the aquifer affected by DNAPL within AOC A to estimate the mass of DNAPL present. This information would be needed to better define the cost of implementing ISTT and to better estimate the time to completion and overall feasibility of implementing ERD. A pilot test of ERD would be needed in this lower pH aquifer with a bioaugmentation culture selected for lower pH that has been acclimated to low pH conditions. A work plan for this pilot test, to be conducted at the south end of the PRB, has been submitted to, and approved by, the USEPA

Upon completion of these additional activities, the selection criteria discussed in Section 2 could be reconsidered and the evaluation updated.

Appendix A

IN SITU THERMAL TREATMENT (ISTT)

DIRECT CAPITAL COST	Low	High
ISTT Design		
Design	12,000	18,000
Permitting	1,500	1,500
Procurement	9,000	14,000
Reporting	8,500	12,000
Subtotal Design	**31,000**	**45,500**
ISTT Implementation		
Mob/Demob	185,000	400,000
Install Infrastructure and apply	1,100,000	2,600,000
Off-gas treatment	100,000	400,000
Subtotal ISTT Implementation	**1,385,000**	**3,400,000**
SUBTOTAL CAPITAL COSTS	**1,416,000**	**3,445,500**
OPERATIONS COSTS		
Follow-Up Monitoring (3) Annual Cost		
Equipment and Materials	3,000	5,000
Waste Disposal	1,500	4,000
Groundwater Monitoring (additional)	5,000	9,000
Reporting and Management (additional)	2,500	4,000
Subtotal Monitoring	**12,000**	**22,000**
OPERATIONS COSTS, 30 yr. Net Present Value	**33,943**	**62,229**
TOTAL NET PRESENT VALUE COST	**1,449,943**	3,507,729
ISTT WITH 99% REMOVAL AND PERFORMANCE GUARANTEE	1,819,943	**4,197,729**

Enhanced Reductive Dechlorination (ERD) - Fesasibility Level Cost Estimate

DIRECT CAPITAL COST	**Low**	**High**
ERD Design		
Design	12,000	30,000
Permitting	1,500	5,000
Procurement	7,500	12,500
Reporting	8,500	10,000
Subtotal Design	**29,500**	**57,500**
Phase I EVO Placement and Bioaugmentation (Aquifer)		
Mob/Demob	12,500	15,000
Install Wells	35,000	50,000
EVO Injections	150,000	270,000
Bioaugmentation	35,000	50,000
Waste Management and Dsiposal	10,000	15,000
Subtotal Phase I EVO Placement and Bioaugmentation (Aquifer)	**242,500**	**400,000**
Phsae I EVO Placement and Bioaugmentation (SCA)		
Mob/Demob	0	15,000
Well Placement	0	65,000
Amendments and Bioaugmentation Materials	0	160,000
Waste Management and Disposal	0	8,000
Subtotal Phsae I EVO Placement and Bioaugmentation (SCA)	**0**	**248,000**
Phase II EVO Placement (Aquifer)		
Mob/Demob	0	47,500
EVO Injections	0	250,000
Waste Management and Dsiposal	0	1,500
Subtotal Phase II ERD Substrate Placement (Aquifer)	**0**	**299,000**
Phsae II EVO Placement (SCA)		
Mob/Demob	0	15,000
Well Placement	0	65,000
Amendments and Bioaugmentation Materials	0	125,000
Waste Management and Disposal	0	8,000
Subtotal Phsae II EVO Placement (SCA)	**0**	**213,000**
Phase III EVO Placement (Aquifer)		
Mob/Demob	0	47,500
EVO Injections	0	162,000
Waste Management and Dsiposal	0	1,500
Subtotal Phase III ERD Substrate Placement (Aquifer)	**0**	**211,000**
SUBTOTAL CAPITAL COSTS	**272,000**	**1,428,500**

Enhanced Reductive Dechlorination (ERD) - Fesasibility Level Cost Estimate

OPERATIONS COSTS			
Follow-Up Monitoring (10 years) Annual Cost			
	Equipment and Materials	4,000	14,000
	Waste Disposal	0	6,000
	Groundwater Monitoring (additional)	3,500	40,000
	Reporting and Management (additional)	1,500	7,000
Subtotal Monitoring		**9,000**	**67,000**
OPERATIONS COSTS, 30 yr. Net Present Value		**76,772**	**571,524**
TOTAL NET PRESENT VALUE COST		**348,772**	**2,000,024**