Pinellas Environmental Restoration Project at the Young-Rainey STAR Center

Building 100 Area Plume Control Technology Selection Report

February 2002
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Pinellas Environmental Restoration Project
  at the
  Young-Rainey STAR Center

Building 100 Area Plume Control Technology Selection Report

February 2002

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Work Performed Under DOE Contract Number DE–AC13–96GJ87335
   Task Order Number MAC02–10
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Acronyms and Abbreviations

bls     below land surface
Center  Young-Rainey Science, Technology, and Research Center
CMIP    Corrective Measures Implementation Plan
CMS     Corrective Measures Study
COPC    contaminants of potential concern
DCE     dichloroethene
DOE     U.S. Department of Energy
DPE     dual phase extraction
EPA     U.S. Environmental Protection Agency
ETI     Environmental Technologies, Inc
FDEP    Florida Department of Environmental Protection
FRTR    Federal Remediation Technologies Roundtable
ft      feet
ft/day  feet per day
ft/ft   feet per foot
ft/year feet per year
gpm     gallons per minute
HRC®    Hydrogen Release Compound
ITRC    Interstate Technology Regulatory Cooperation
ITRD    Innovative Treatment Remediation Demonstration
kg/cm²  kilograms per square centimeter
MCL     maximum contaminant level
µg/L    micrograms per liter
O&M     operation and maintenance
ORC®    Oxygen Release Compound
PCE     tetrachloroethene
PRB     permeable reactive barrier
RCRA    Resource Conservation and Recovery Act
RFI     RCRA Facility Investigation
RFP     Request for Proposal
SWMU    Solid Waste Management Unit
TCE     trichloroethene
VC      vinyl chloride
VOCs    volatile organic compounds
yd³    cubic yard
ZVI     zero valent iron
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Executive Summary

The Building 100 Area is located at the southeast corner of the Young-Rainey Science, Technology, and Research Center (Center). A contaminant plume extends from under Building 100 downgradient to near the south and east property boundaries. Implementation of a plume control technology is necessary to ensure that contaminants do not move off the property. The objective of this document is to conduct a detailed evaluation of five potential plume control technologies, and to recommend the technology that should be implemented for plume control at the Building 100 Area. The technologies evaluated are:

1. Enhanced bioremediation,
2. Dual phase extraction,
3. Permeable reactive barrier walls,
4. Groundwater pumping with ex situ treatment, and
5. Vertical barriers.

Based on this evaluation, enhanced bioremediation is recommended to control the contaminant plume. There are a number of reasons for this choice. Most importantly, biodegradation already is occurring naturally in the subsurface at the Building 100 Area as evidenced by the presence of dichloroethene and vinyl chloride, which are products from trichloroethene degradation. Therefore, to expedite the naturally occurring biodegradation, it is recommended that an enhancement chemical be added to the subsurface to aid the existing microorganisms in completing the degradation process. Because the contaminant concentrations are only slightly above the maximum contaminant levels (MCLs) near the property boundary, it is believed that enhanced bioremediation can degrade the contaminants in that area to below the MCLs in a reasonable amount of time.

Other important advantages enhanced bioremediation has over the other technologies are its relatively low impact to Center operations, its minimal effect to the surrounding environment, and its likely acceptability to the public. Enhancement chemicals can be delivered to the subsurface by direct injection using either temporary or permanent injection points. Implementation of the technology would involve a minimal amount of equipment and would occur over a relatively short time period. Although subsequent injection events probably would be necessary, the potential use of enhancement chemicals that are “slow release” would lengthen the time interval between injection events.

Enhanced bioremediation is protective of the environment and will not adversely affect the long-term remediation strategy for the Building 100 Area. This technology also would not preclude the use of other interim measures should bioremediation prove ineffective.

Additionally, enhanced bioremediation is potentially applicable for remediation of the residual source and dissolved phase plume at the Building 100 Area, and may be applicable at other areas of the Center as well. The relatively small scale of implementation for plume control could serve to evaluate the applicability of the technology to ongoing remediation activities at the rest of the Center.
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1.0 Introduction

The Young-Rainey Science, Technology, and Research Center (Center), formerly known as the Pinellas Science, Technology, and Research Center, is a former U.S. Department of Energy (DOE) facility located in Largo, Florida. Two of the remaining four active Solid Waste Management Units (SWMUs) at the Center are PIN06, the Old Drum Storage Site, and PIN12, Industrial Drain Leaks-Building 100 Area (Figure 1). These two SWMUs are being remediated together because they are adjacent and have similar contaminants of potential concern (COPCs). Together, these two SWMUs are referred to as the Building 100 Area.

Remediation at the Building 100 Area has been divided into three tasks, arranged in order of decreasing priority.

Task 1. Plume control near the property boundary at the southeast corner of the Center.
Task 2. Treatment of potential contaminant source(s) under Building 100.
Task 3. Treatment of dissolved phase contamination in the Building 100 Area.

Plume control needs to be accomplished first because vinyl chloride (VC) has been measured above the cleanup goal in two wells located approximately 50 feet (ft) hydraulically upgradient from the property boundary, indicating that the potential exists for the plume to move off-site in the future.

The Building 100 Area Remediation Technology Screening Report (DOE 2001) conducted a screening of all available remediation technologies for their applicability to the three remediation tasks at the Building 100 Area, and recommended technologies or groups of technologies that should be retained for detailed consideration at a later time. The plume control technologies recommended in that report were:

1) Enhanced bioremediation,
2) Dual phase extraction (DPE),
3) Permeable reactive barrier (PRB) walls,
4) Groundwater pumping with ex situ treatment, and
5) Vertical barriers.

1.1 Objectives

The objective of this document is to conduct a detailed evaluation of these five plume control technologies, and to recommend the technology that should be implemented for plume control at the Building 100 Area. Guidance for this evaluation was taken from DOE’s Ground Water Evaluation and Remediation Strategy Guide for Department of Energy Sites. The chosen technology must be consistent with the long-term remediation strategy for the site.

DOE’s current objective for Building 100 Area remediation is to control the plume by either:

1. containing onsite the groundwater that contains concentrations of COPCs above their cleanup goals, or
2. treating the groundwater so that it does not contain COPCs at concentrations above the cleanup goals prior to the groundwater moving off the Center property.
Plume control (Task 1) will need to continue until the dissolved phase plume that reaches from under the building to near the property boundary is treated (Task 3). Remediation of the dissolved phase plume currently is scheduled to be completed by October 2010.

1.2 Report Organization

Section 2.0 contains background information including geology and hydrogeology, nature and extent of contamination, remediation history, utility locations, and Center information. Section 3.0 describes the technologies in detail, including case studies and cost information. The evaluation of the technologies is conducted in Section 4.0. Conclusions and recommendations are presented in Section 5.0, and references reviewed during this evaluation are listed in Section 6.0.
2.0 Background Information

This section describes the site characteristics that are relevant to choosing a plume control technology.

2.1 Geology and Hydrogeology

2.1.1 Geology

The following formations, from shallowest to deepest, are present beneath the Building 100 Area: surficial deposits, Hawthorn Group (Hawthorn), Tampa Limestone, Suwannee Limestone, Ocala Limestone, and Avon Park Formation. Currently, contamination is found only in the groundwater in the surficial deposits, and the Hawthorn is generally considered to act as an aquitard between the surficial deposits and the lower limestone units. Therefore, only these two upper units are discussed further.

The surficial deposits are unconsolidated and are variable in thickness but are approximately 35 ft deep in this area of the site. Contouring of the top of the Hawthorn indicates the depth may range from approximately 33 ft at the eastern property boundary to approximately 37 ft in the South Pond area. The Hawthorn is at least 70 ft thick as extrapolated from nearby lithologic logs.

The surficial rocks consist of well-sorted or poorly graded fine to very fine sands. According to sieve analysis of surficial sands in the Building 100 Area, silt and clay content is approximately 3% to 10% by weight, whereas gravel-sized sediment is less than 5% by weight. Measured porosity has ranged from approximately 30% to 40%.

Piezocone testing was conducted at three locations along the southeastern property boundary, ranging from 33 to 48 ft in depth. Point stress, friction ratio, pore pressure, and other results were recorded. Point stress measurements were 100 kilograms per square centimeter (kg/cm²) in the surficial sands, and some denser layers exhibited values up to approximately 200 kg/cm². Dense materials (point stress of 300 kg/cm² or more) were encountered below approximately 30 ft, marking the transition to the upper portion of the Hawthorn. The Hawthorn is composed of semi-consolidated heterogeneous silty clay with limestone fragments and phosphatic sand that becomes more consolidated with increasing depth.

During the piezocone testing, depth to the top of the Hawthorn was interpreted to range from 33 to 48 ft. It is believed that a depth of approximately 33 to 37 ft is more representative for this area based on the correlation with lithologic logs in the vicinity. The greater depth of 48 ft probably resulted from the occurrence of a softer silty clay that forms the upper portion of the Hawthorn at this location. The Hawthorn ranges from 55 to 78 ft in thickness in the area of the Center (DOE 1991).

The upper portion of the Hawthorn is relatively heterogeneous and distinguished from the surficial sand by lithologic properties more than the relative density of surficial sands or consistency of clays. The contact between the overlying surficial aquifer and the Hawthorn is sometimes indicated by the presence of a clayey gravel layer less than one ft in thickness consisting of phosphatic weathered limestone or shell before transition to a clay with variable amounts of silt and sand. Sand may be interlayered with the clay in the upper 10 to 15 ft of the Hawthorn.
2.1.2 Hydrogeology

The surficial aquifer is located in the surficial deposits, and is bounded below by the Hawthorn, which acts as an aquitard. In the Building 100 Area, depth to water ranges from about one to five ft below land surface (bls), depending on the season and recent rainfall. Based on the depth to water and the depth to Hawthorn described in Section 2.1.1, the saturated thickness of the surficial aquifer ranges from approximately 28 to 36 ft.

Currently, no municipal water supplies are derived from the surficial aquifer due to the poor quality and limited availability of the groundwater (DOE 1991). However, due to recent drought conditions, interest in the surficial aquifer as a water source has increased.

Specific-capacity tests were conducted in May 1995 on four monitoring wells located outside the northwest corner of Building 100, and additional specific-capacity tests were conducted in November 2001 at two wells located near the southeast corner of Building 100. The purpose of these tests was to estimate the horizontal hydraulic conductivity of the surficial aquifer in the immediate vicinity of the tested wells. Estimated hydraulic conductivity values are summarized in Table 1.

These hydraulic conductivity values for the surficial aquifer are in agreement with previous estimates, based on slug tests around Building 100, of 0.17 to 1.3 feet per day (ft/day) (DOE 1991). However, it should be noted that estimates of hydraulic conductivity have been as high as approximately 3 ft/day to 7 ft/day. This wide range of hydraulic conductivity values demonstrates the heterogeneous nature of the surficial deposits, resulting from local variations in silt, clay, and shell/gravel content.

Based on data from wells screened at shallow and deep intervals in the surficial aquifer, this aquifer appears to have shallow and deep zones, with the division located approximately half way between the land surface and the top of the Hawthorn. Current groundwater elevations and contours for the shallow and deep surficial aquifers in the Building 100 Area are shown on Figures 2 and 3, respectively. The ambient groundwater flow direction is to the southeast with limited influence from recovery wells located at the northwest corner of Building 100.

In the shallow surficial aquifer, the hydraulic gradient beyond the influence of pumping was approximately 0.005 feet per foot (ft/ft) in April 2001. Using Darcy’s Law, along with approximations of one ft/day for hydraulic conductivity and 0.3 for effective porosity, groundwater velocity in the shallow surficial aquifer in this area is approximately six feet per year (ft/year). In the deeper surficial aquifer beneath the southeast corner of the building, a rough hydraulic gradient of 0.002 ft/ft was estimated, leading to an estimated horizontal groundwater velocity of two to three ft/year.

A number of utility lines run along the south and east property boundary (discussed in Section 2.4). It is believed that the backfill material around these utility lines consists of native sand having a similar hydraulic conductivity to the native sediments. Therefore, utility lines at shallow depths should not provide preferred pathways for groundwater flow in the aquifer.

Underlying the surficial aquifer is the Hawthorn that forms a widespread dividing layer between the surficial aquifer and the Tampa Limestone. Aquifer tests to estimate the hydraulic properties
of this formation were conducted as part of the site-wide Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) (DOE 1991). Results indicated that the Hawthorn has an average vertical hydraulic conductivity of 0.0011 ft/day. The estimated vertical travel time for groundwater movement through the formation is 629 years (DOE 1991). Thus, in the vicinity of the Center, the Hawthorn is considered an aquitard (i.e., a semi-confining geologic unit that restricts vertical groundwater flow). Results from these aquifer tests indicate that it is unlikely that contamination in the surficial aquifer will travel through the Hawthorn and affect the underlying Floridan aquifer (DOE 1991).

Surface water levels in the South Pond (Figure 2) show limited influence of groundwater on the pond. The pond is lined with concrete on the sides, and penetrates less than approximately one-third of the saturated surficial aquifer thickness. The bottom of the pond is unlined and is hydraulically connected to the shallow surficial aquifer. Some observed changes between quarterly water levels indicate that lower fluctuations in deep surficial aquifer levels near the pond may result from recharge or loading effects of the pond. At these times, the downward vertical gradient exerted by the pond may enhance the easterly component of groundwater flow, especially when surface water runoff is directed to the pond and adjacent groundwater levels are low.

2.2 Nature and Extent of Contamination

Contamination at the Building 100 Area originates from historic waste handling practices at the Old Drum Storage Site, located at the northwest corner of Building 100, and from leaks from drain systems under the building (DOE 2001).

Currently, the list of groundwater COPCs for the Building 100 Area (Table 2) is a combination of the COPCs identified for the Old Drum Storage Site and Building 100 Industrial Drain Leaks in the RFI Report (DOE 1991). Per U.S. Environmental Protection Agency (EPA) and Florida Department of Environmental Protection (FDEP) direction, the cleanup goals for groundwater are FDEP drinking water maximum contaminant levels (MCLs), or EPA drinking water standards, whichever is more stringent (Table 2).

Currently, the Building 100 Area COPCs are being reviewed as a separate task, so the possibility exists that some of the COPCs on the current list may be dropped and others may be added at a later date. Part of this review includes the evaluation of metals as potential COPCs. The evaluation conducted in this document assumes that the contaminants that will need to be controlled by the plume control technology are volatile organic compounds (VOCs) identical to or similar to the COPCs listed in Table 2. If it is determined that metals dissolved in groundwater should be considered COPCs, and it is determined that there is a metals plume near the southeastern property boundary, the recommendation made as a result of this evaluation should be reviewed for its applicability to control the metals plume.

2.2.1 Contaminant Plume

Historically, COPCs detected above the MCLs in wells downgradient to the south and east of Building 100 are tetrachloroethene (PCE), trichloroethene (TCE), cis- and trans-1,2-dichloroethene (DCE), 1,1-DCE, VC, 1,1-dichloroethane, chloroethane, and benzene. A data summary is presented in Table 2. Table 3 lists the highest historic concentration of each COPC at each well downgradient from Building 100. This table also lists the screened intervals
for each well. It should be pointed out that several of the wells referred to in this section are actually sampling points that technically are not monitoring wells. These points are slotted steel pipe pushed into the subsurface with no filter pack or grout seal. The sampling points are 12-S61 through 12-S66 (B, C, and D designations at each location).

Currently, VC is the only contaminant detected above its MCL near the property boundary. Figure 4 shows the approximate extent of the VC plume. Plume maps for the other COPCs are not shown; however, these other COPCs plumes would likely be contained within the boundaries of the VC plume.

Wells 12–0513, –0514, –0517, –0518, –0524, and –0525 define the dissolved phase plume as it emerges from under the building (Figure 4). Wells 0517 and 0518, located near the center of the southern edge of the building, appear to be very near the westernmost extent of the plume. No VOCs have been detected in shallow well 0517, while deeper well 0518 has shown very low levels of only VC over the last three years. Wells 0524 and 0525 appear to be located within the main part of the plume, as evidenced by relatively high concentrations of cis-1,2-DCE and VC, as well as several other compounds detected at lower concentrations. Concentrations are higher in the deeper well, 0524. Wells 0513 and 0514 also appear to be located in the main part of the plume as evidenced by relatively high concentrations of several contaminants, with the deeper well containing the higher concentrations.

The boundary of the plume north of wells 0513/0514 is poorly defined as to where it emerges from under the building, but the boundary of the plume east of 0513/0514 appears to be located between wells S64 and S65. Wells S65B, S65C, and S65D have never contained detectable VOCs, while well S64C contains VC above the MCL and cis- and trans-1,2-DCE below their MCLs. Wells S64B and S64D have never contained VOCs above the reporting limit.

The plume extends east to well S66, located approximately 50 ft from the eastern property boundary. S66B contained cis- and trans-1,2-DCE below their MCLs and VC above the MCL during the well’s initial sampling events in April and July 1997, but these compounds have not been detected since that time. During every sampling event since the well’s installation, S66C has contained detectable concentrations of cis- and trans-1,2-DCE below their MCLs and VC above its MCL. VC was already present above its MCL in this well when it was first sampled in April 1997, so the location of the leading edge of the VC plume in this area is not known. VOCs have never been detected above the reporting limit in well S66D.

The extent of the plume near the southern property boundary is defined by wells 21–0502, –0503, –0504, –0505, and –0512. VOCs have never been detected in wells 0502 and 0503, located at the very southeast corner of the property, probably indicating that the VOCs plume has not yet reached this location. Additionally, VOCs have never been detected in wells 0504 and 0505. Well 0512 defines the extent of the plume nearest the southern property boundary. This well contained TCE above its MCL during its first sampling event in November 1998, followed by a TCE detection below the MCL in the following event, with TCE not detected in any subsequent event. VC (above the MCL) and cis-1,2-DCE (below the MCL) appeared in well 0512 in January 1999, and have been detected consistently at low levels in subsequent sampling events.

Wells 12–S61B, C, and D, located north of well 21–0512, appear to be in the central part of the southern extent of the plume. Well S61B has never contained VOCs. Well S61C contained
cis-1,2-DCE and VC at elevated concentrations when it was first sampled in April 1997. These concentrations have shown a decreasing trend over time, with cis-1,2-DCE now well below its MCL and VC just above its MCL. Well S61D has consistently contained low levels of cis-1,2-DCE and VC.

Well S62B has contained very low levels of cis-1,2-DCE. Well S62C has contained consistent levels of cis- and trans-1,2-DCE (below the MCL) and VC (above the MCL, maximum of six micrograms per liter [μg/L]). Well S62D has never contained VOCs above the reporting limit.

VC and cis-1,2-DCE appeared in well S63B in 1999 and have been detected at low levels since (VC at a maximum of 3.8 μg/L). Well S63C has contained 1,1-DCE, cis- and trans-1,2-DCE, and 1,1-dichloroethane below their MCLs and VC above its MCL. Well S63D has contained cis- and trans-1,2-DCE below their MCLs and VC above its MCL.

Figure 5 is a three-dimensional representation of the VC plume as modeled by Environmental Visualization Systems software. Figure 5 shows the VC plume from the middle of Building 100 to near the property boundary, Figure 6 shows a cross-section from well S57 to well S66 at the east property boundary, and Figure 7 shows a cross-section from well S57 to well 0512 at the south property boundary. As can be seen in the cross sections, the VC plume is as shallow as the top of the water table at some locations, and is as deep as the Hawthorn surface at other locations.

In summary, a plume of VC at concentrations above the cleanup goal extends from under Building 100 to the east to wells S66B, C, and D and to the south to well 21–0512. No other COPCs have been detected above their MCLs in wells adjacent to the property boundary within the last three years. Therefore, VC is the principle contaminant that must be treated or contained by the plume control technology. Although the VC plume appears to occur only at intermediate depth near the property boundary, the plume control technology needs to be able to control the plume for the entire saturated depth of the surficial aquifer, based on the plume distribution in upgradient wells.

Historically, PCE, TCE, cis- and trans-1,2-DCE, 1,1-DCE, 1,1-dichloroethane, or chloroethane have been detected above their MCLs in wells 0513, 0514, 0524, 0525, S61, and S63. Well S61 is the closest of these wells to the property boundary, being located approximately 185 ft from the boundary. Considering this distance from the boundary, an estimated maximum groundwater velocity of 6 ft/year (Section 2.1.2), and the fact that these contaminants travel slower than the groundwater, it appears unlikely that any of these other COPCs will reach the property boundary prior to the completion of the remediation at the Building 100 Area, scheduled for October 2010. However, as a conservative approach, the evaluation will also consider control of a plume of these other contaminants.

2.2.2 Geochemistry

Geochemical parameters measured within the last year at the Building 100 Area are summarized in Table 4. Groundwater temperatures are relatively warm because of the subtropical climate, and pH is generally near neutral. As indicated by the average values, most dissolved oxygen and oxidation-reduction potential measurements were low, indicating that reducing conditions are present throughout most of the surficial aquifer. The higher dissolved oxygen values generally
are measured in the shallow wells, with lower dissolved oxygen values measured in the deeper wells.

### 2.2.3 Data Gaps

Past characterization efforts southeast of Building 100 were intended to determine whether a plume of contaminants was located hydraulically downgradient from the building. A plume has been confirmed, although the locations of the wells currently in place are inadequate to allow the design of a plume control technology. For example, the distance between the 0504/0505 location and the 0502/0503 locations is approximately 665 ft, with only well 0512 in the plume within this interval. Clearly, additional investigation is required to define the plume width as it nears the property boundary.

Therefore, a baseline sampling effort will be necessary along the south and east property boundaries to better define the extent of the contaminant plume in these areas. Without these additional data, broad assumptions would be necessary for remediation technology design. It is likely that these broad assumptions would result in significantly higher remediation costs relative to systems with designs based on more detailed data.

### 2.3 Remediation History

Building 100 is the most notable feature of the Center, covering approximately 11 acres in the southeastern corner of the Center (Figure 1). This structure housed the DOE Pinellas Area Office and the majority of former laboratory and production facilities located at the site. Building 100 Area background and operational history is discussed in detail in the *Building 100 Area Remediation Technology Screening Report* (DOE 2001).

An RFI was conducted in 1991 (DOE 1991). Based on the findings during the RFI, EPA notified DOE of the requirement for a corrective measures study (CMS) for the Old Drum Storage Site and the Industrial Drain Leaks - Building 100. The CMS Report for the Building 100 Area and Old Drum Storage Site (DOE 1994) proposed remediation of these two SWMUs together (collectively referred to as the Building 100 Area), with the preferred corrective measure being groundwater pumping and treatment of recovered groundwater with an air stripping system.

As detailed in the *Building 100 Area Corrective Measures Implementation Plan* (CMIP) (DOE 1996a), implementation of corrective measures at the Building 100 Area included installation of two groundwater recovery wells near the northwest corner of Building 100. These wells pump extracted groundwater through secondary containment piping to the Northeast Site treatment system for pretreatment, air stripping, and discharge to the Center industrial wastewater neutralization facility prior to transfer to the publicly owned treatment works. These wells currently are in operation.

The location of these two recovery wells was based on modeling done in the CMS Report (DOE 1994). This modeling was based on data collected during the RFI from PIN06 and PIN12 monitoring wells located near the northwest corner and around the periphery of Building 100. These monitoring wells were screened from 3 to 13 ft bls; no deeper wells existed at that time. The results from four sampling events in 1990 and 1991 showed that contamination was limited to relatively low levels at the northwest corner of Building 100. Based on these data, the
modeling demonstrated that two recovery wells would be sufficient to clean up the contamination in this area.

Subsequently, additional investigations were conducted by installing wells and sampling points at multiple depths both outside the building and through the floor of the building. These investigations are summarized in the Building 100 Subsurface Investigation (DOE 1996b) and the Building 100 Area Data Report (DOE 1996c). Results of these investigations indicated that significant contaminant concentrations were present at intermediate and deep depths under the building, and that low levels of contamination were present at the south and east sides of the building. The Building 100 Area Data Report (DOE 1996c) recommended that:

- the two recovery wells installed under the CMIP continue operation,
- additional characterization under the building and east of the building was necessary,
- additional contaminant transport modeling was necessary, and
- the potential for occurrence of dense non-aqueous phase liquids be evaluated.

The recommendations were addressed in the Building 100 Area CMIP Addendum (DOE 1998a). Several different pumping scenarios were modeled, and it was recommended that the installation of two additional recovery wells at the southeast corner of Building 100 be implemented as the supplemental alternative. Additionally, enhanced bioremediation and PRB walls were retained as potential enhancements for the pump and treat remediation at the Building 100 Area (DOE 1998a).

In June 1998, the FDEP responded to the CMIP Addendum with several comments, including the suggestion that installation of the two additional recovery wells should be delayed until an additional hydrogeologic assessment is completed. In response to these comments, DOE sent the FDEP a letter in October 1999 that contained a proposal to evaluate the potential installation of a PRB wall and further evaluate other treatment technologies for remediation of the contaminant plume beneath Building 100.

The first part of the DOE proposal was accomplished in December 1999 with the completion of a bench-scale treatability report for treatment of dissolved VOCs present in groundwater at the Building 100 Area. The results from this study indicated that a reactive wall would degrade the chlorinated VOCs to MCLs using iron metal as the reactive medium. This treatability study report was included in a document that evaluated the suitability of a PRB wall at the Building 100 Area (DOE 2000), and concluded that a PRB wall would effectively treat the contaminants at the Building 100 Area.

The screening conducted in the Building 100 Area Remediation Technology Screening Report (DOE 2001) retained the PRB wall technology for further consideration, and that option is evaluated in this document. Currently, remediation activities at the Building 100 Area consist solely of the two original recovery wells located at the northwest corner of the building.

2.4 Utility Locations

The southeast corner of the Building 100 Area is located adjacent to two major thoroughfares, Belcher Road and Bryan Dairy Road (Figure 4). There is a high density of utilities on the Center property adjacent to these roads (Figure 8). These utilities potentially could complicate the
implementation of a plume control technology, so this factor will be considered during this evaluation.

2.5 Young-Rainey STAR Center Information

With completion of the DOE mission at Pinellas, the Center was sold to Pinellas County in 1995, with the understanding that DOE remains committed to environmental restoration of the property in a timely manner. The change in ownership involved a transition from the DOE mission to County operation of the facility as a technical business park with private tenants. This transition has been successful, with the number of jobs increasing from approximately 1,200 at the time of DOE closure to approximately 1,800 currently. This work force is distributed among approximately 25 companies, ranging from large manufacturing companies with more than 1,000 employees to small companies with fewer than five employees. Building 100 covers approximately 11 acres and houses most of the tenants. Other tenants are housed in other buildings around the site, including a children’s day care facility situated due east of Building 100 near Belcher Road.

Because of the Center’s importance to the local economy, DOE’s continued commitment to environmental restoration is balanced with sensitivity to tenant activities and perceptions. On this basis, DOE maintains an ongoing community relations program to ensure that Center management, tenants, and the local community keep up to date on environmental restoration program status, progress, plans, objectives, and schedules. It is through this community relations program that DOE communicates its awareness of potential interference with daily activities or work processes and its efforts to minimize adverse impacts.

The local high population density and associated intense demand for building space lend urgency to DOE’s desire to shorten the time horizon for cleanup and returning property to landowners.
3.0 Description of Selected Plume Control Technologies

This section contains a description of each technology, summaries of relevant case studies, lists of advantages and disadvantages, and cost estimate information.

3.1 Enhanced Bioremediation

Enhanced bioremediation is defined by the EPA (2000) as “bioremediation of organic contaminants by microbes supplemented by increasing the concentration of electron acceptors, electron donors, or nutrients in groundwater, surface water, or soil.” Electron acceptors and donors are chemical species capable of accepting or donating electrons during bioremediation processes. Microorganisms obtain energy by mediating the transfer of these electrons. Enhancement chemicals include methanol, acetate, benzoate, lactate, molasses, toluene, propane, methane, oxygen, Oxygen Release Compound (ORC®), Hydrogen Release Compound (HRC®), nitrogen, phosphorus, and a number of other chemicals.

Bioremediation mechanisms of chlorinated ethene compounds can generally be divided into two categories: anaerobic reductive dechlorination and aerobic oxidation. TCE, DCE, and VC may biodegrade via anaerobic reductive dechlorination, and VC may degrade via aerobic oxidation as well (EPA 2000). During the anaerobic reductive dechlorination process, a compound like TCE accepts electrons, loses a chlorine atom, gains a hydrogen atom, and thus is transformed into DCE (Figure 9). Further, DCE can accept electrons and transform to VC, which can also accept electrons and transform to ethene, ethane, or other compounds.

This type of degradation probably is occurring naturally in the subsurface at the Building 100 Area. However, based on the identification of VC over a large part of the Building 100 Area, it appears that this reaction is not continuing to ethene, but continuing only to VC. VC may be slowly degrading, but at a rate so slow that it appears that the compound is accumulating. The objective of enhanced bioremediation for control of the VC plume would be to simply add the correct chemical to the subsurface to aid the microorganisms in removing the last chlorine atom from the VC molecule. This may be accomplished through either an aerobic or an anaerobic process.

It is important to distinguish between enhanced bioremediation and monitored natural attenuation. Monitored natural attenuation is a remediation approach that utilizes the degradative capabilities of the natural microbial consortium with no enhancements. Long term monitoring is used to demonstrate that the contaminants will eventually degrade to below the cleanup levels. This approach is possible only at sites where long time frames (years to decades, and possibly longer) are available to reach cleanup goals. Therefore, because of the immediate need for plume control at the Center, this approach was screened out previously (DOE 2001).

Another aspect of enhanced bioremediation is bioaugmentation, which is the addition of supplemental microorganisms to the subsurface. As discussed in the Dover Air Force Base case study in Section 3.1.1, the microorganisms at the Center seem capable of degrading the contaminants at the Building 100 Area. Therefore, addition of microorganisms probably is not necessary, so bioaugmentation is not evaluated here.
Design configurations of interest for enhanced bioremediation systems include direct injection, groundwater recirculation, and passive systems (EPA 2000; Interstate Technology Regulatory Cooperation [ITRC] 1998). Direct injection involves simply injecting the enhancement chemical into the treatment zone (Figure 10). Direct injection may be accomplished using temporary injection points installed using a direct push technology, or by installation of permanent injection wells. Groundwater recirculation involves extraction of contaminated groundwater adding the enhancement chemical to the extracted water, and then reinjecting the mixture into the subsurface. Passive systems involve placement of amendment chemicals into the screened intervals of wells as solids or in cartridges, where the chemical then slowly dissolves into the groundwater and disperses into the aquifer.

Enhanced bioremediation can also be implemented through PRB walls. For the purposes of this evaluation, PRB walls utilized to enhance bioremediation will be considered in the enhanced bioremediation section and other types of PRBs will be treated separately and are discussed in Section 3.4.

There are regulatory concerns associated with enhanced bioremediation (ITRC 1998), and these will need to be considered during this evaluation. These include the reinjection of contaminated groundwater in groundwater recirculation systems, as well as the introduction of the enhancement chemicals themselves into the subsurface. The use of a regulated enhancement chemical, such as toluene, may be problematic. However, several enhancement chemicals, such as lactate, molasses, HRC®, and ORC®, are non-toxic, and therefore obtaining regulatory approval for use of these compounds should be easier.

### 3.1.1 Case Studies

Enhanced bioremediation has been implemented many times in both pilot- and full-scale applications. A selection of relevant case studies is presented here.

#### 3.1.1.1 Pinellas STAR Center

A pilot study of anaerobic enhanced bioremediation was conducted at the Center in 1997 under the Innovative Treatment Remediation Demonstration (ITRD) Program (DOE 1998b; Sewell et al. 1998). A groundwater recirculation system was implemented using horizontal wells and infiltration trenches to recirculate groundwater while benzoate, lactate, and methanol were injected. The selection of the enhancement compounds was based on prior treatability studies.

The treatment area was located at the northern part of the Northeast Site at the Center, and consisted of a 45 ft by 45 ft area with a saturated thickness of approximately 26 ft, for a total of 1,950 cubic yards (yd³). The system operated for almost five months, and recirculated approximately two pore volumes of water at a rate of 1.5 gallons per minute (gpm). The enhancement chemicals were delivered to 90% of the treatment area, and resulted in a 70 to 90% decline in VOCs concentrations. Significant reductions in the concentration of TCE, DCE, VC, methylene chloride, and toluene were observed.

The technology was generally effective at treating VC, although significant concentrations remained in some locations following treatment. These high VC concentrations probably were a result of the relatively short time allowed for the demonstration, indicating that, under the
conditions of this test, more time is necessary for TCE, DCE, and VC to degrade completely to ethene.

Observations and lessons learned from this demonstration include:

- Enhancement of anaerobic biodegradation is a feasible, cost effective remediation approach at the Northeast Site.

- Laboratory batch and column studies using site soil and groundwater can be used to (1) determine whether the existing microorganisms are capable of degrading site contaminants, and (2) determine which enhancements can facilitate contaminant degradation.

- Good distribution of the enhancement chemical is critical for effective enhancement of contaminant degradation. Hydrological field testing and numerical modeling should be used to help identify the best enhancement delivery system.

- The enhancement chemicals were not observed at a few low permeability areas of the site, and limited contaminant degradation was observed at these locations.

- The recirculation system was effective at the pilot scale, and no wastewater was generated. However, one design problem observed by site personnel was the occasional flooding of the surface with groundwater. This was probably due to injection rates being too high for the low permeability subsurface, combined with the shallow depth to groundwater (approximately three to four ft bgs).

The contaminants at the Building 100 Area are similar to the suite of contaminants treated at the Northeast Site. Therefore, this site-specific study indicates that it is probable that enhanced bioremediation would work at the Building 100 Area.

3.1.1.2 Dover Air Force Base

Researchers have used microorganisms collected from the Center to enhance bioremediation at Dover Air Force Base in Delaware (Harkness et al. 1999; Ellis et al. 2000). In this bioaugmentation project, the Center microorganisms were injected along with an electron donor/nutrient solution to degrade TCE completely to ethene, without accumulation of VC. This is an important finding because it demonstrates that the native microbial consortium at the Center potentially has the ability to degrade VC given the correct enhancement. The injected solution at Dover Air Force Base consisted of lactate as the electron donor and a phosphate and ammonia solution as the nutrient solution.

3.1.1.3 Test Area North

Lactate injection was used at Test Area North at the Idaho National Engineering and Environmental Laboratory to enhance biodegradation of TCE, DCE, and VC (Sorenson 2000). Following the initiation of lactate injection, significant changes in redox conditions were observed after 30 days, and significant reductions in TCE concentrations were observed in less than five months. After eight months, complete dechlorination of TCE to ethene was observed. Degradation of TCE to DCE occurred under sulfate reducing conditions, and degradation of
DCE and VC to ethene occurred under methanogenic conditions. Transformation of VC to ethene was quick, and VC did not accumulate.

3.1.1.4 Central Ohio Industrial Site

Molasses and sulfate were used to enhance bioremediation of cis-1,2-DCE and VC using direct injection (Peeples et al. 2000). Results indicated that cis-1,2-DCE and VC could be degraded to levels near drinking water MCLs after less than 200 days of treatment.

3.1.1.5 Avco Lycoming Superfund Site

This site in Pennsylvania had groundwater contaminated with TCE, DCE, VC, and metals (EPA 2000; EPA 2001b). As part of a full-scale remediation project, molasses was injected to enhance bioremediation, with the concentrations of most contaminants reduced to below the cleanup goals after 18 months of treatment. During treatment, DCE and VC concentrations increased (probably due to TCE degradation) and then decreased to below cleanup goals.

3.1.1.6 New Jersey Paint Manufacturing Site

Nitrogen and phosphorus were injected to degrade a suite of contaminants, including DCE and VC (Raes et al. 2000). VC concentrations were reduced to below the detection limit, but DCE concentrations were reduced by 32 to 70%, and increased in one well.

3.1.1.7 Texas Gulf Coast Site

Methanol, nitrogen, and phosphorus were used in a groundwater recirculation system to enhance bioremediation of TCE, DCE, and VC (EPA 2000). TCE concentrations were reduced by 99%, DCE by 87%, and VC by 30%, but concentrations remained above drinking water MCLs.

3.1.1.8 ORC® and HRC® Sites

HRC® and ORC® are bioremediation enhancement chemicals made by the Regenesis Company. These chemicals have been used at numerous sites, and a few relevant case studies are presented here. One of the advantages of ORC® and HRC® is that these chemicals are “slow release,” meaning that, because of their chemical structure, they generally remain effective for longer periods of time relative to other enhancement chemicals. Depending on the site, ORC® or HRC® can remain effective for several months to more than a year.

Ohio Manufacturing Site: Two field pilot tests were conducted to evaluate the effectiveness of HRC® and ORC® at facilitating anaerobic and aerobic bioremediation of cis-1,2-DCE and VC (Cornuet et al. 2000). These tests were designed to inject the HRC® and ORC® in a line across the plume to evaluate these chemicals’ effectiveness at controlling the DCE and VC plume. Initial VC concentrations ranged from 450 to 1,700 μg/L. During the six-month test, VC concentrations decreased by 66% in the aerobic test and 94% in the anaerobic test, to near the 1 μg/L MCL.

Light Industrial Property: HRC® was injected into a silty clay soil using direct push injection techniques to treat TCE, DCE, and VC (Zahiraleslamzadeh and Bensch 2000). Results indicated a good distribution of HRC® was achieved, and data demonstrated that
VC was degrading to ethene, although VC concentrations did increase in some wells as a result of TCE and DCE degradation.

Manufacturing Site: HRC® was used to remediate TCE, DCE, and VC at a manufacturing facility in the central United States in a pilot study using a barrier implant configuration (Sheldon and Armstrong 2000). The barrier implant configuration consisted of a series of four ft long perforated canisters containing HRC® that were suspended inside wells. As groundwater moved through the well, HRC® dissolved into the groundwater and was carried into the surrounding aquifer. Using this configuration, TCE and DCE concentrations were significantly reduced, and VC concentrations were reduced from 134 μg/L to <1 μg/L in downgradient monitoring wells.

Superfund Site in Ohio: HRC® was used to treat DCE and VC in an anaerobic, high permeability aquifer in Ohio (Bourquin et al. 2001). A field pilot study indicated that HRC® was not effective at treating DCE and VC, and the current design uses lactate instead of HRC®. Consideration is being given to implementing an aerobic enhancement to degrade VC.

New Jersey Certification: In February 2001, HRC® was evaluated and certified under the New Jersey Department of Environmental Protection Innovative Environmental Technology Certification (Shinn 2001). This certification verified that HRC®: (1) lasts in the subsurface for four months to a year, (2) produces hydrogen which can act as an electron donor to facilitate biological reductive dechlorination at potentially elevated rates, and (3) has been shown to degrade PCE and TCE. This certification discusses some of the limitations of HRC®, and states that HRC® frequently degrades VC to ethene, and that some sites may benefit from using both HRC® and ORC® concurrently or sequentially to aid anaerobic and aerobic degradation of DCE and VC. Additionally, HRC® was certified in 2000 by the Canada Environmental Technology Verification Program.

Midwestern U.S. Aluminum Coating Facility: Direct injection of ORC® was used to treat a low-concentration (<37 μg/L) VC plume (Tacy 1999). Results indicated that VC concentrations were reduced to less than the quantitation limit of the analytical method (limit not specified, but appears to be lower than 5 μg/L) within one to three months. Some rebound was noted after four months, probably due to (1) lack of complete plume treatment due to sparse injection well placement, and (2) insufficient ORC® mass.

Unidentified Site: Pilot studies were used to determine that injection of a nutrient mixture combined with ORC® degraded DCE without formation of VC in an aerobic aquifer (Larsen and Voegeli 2001).

Minnesota Site: A one-year pilot study was conducted using a passive system to apply ORC® to treat a plume of TCE, DCE, and VC in an aquifer with relatively high groundwater velocities (Verhagen et al. 1999). VC concentrations were as high as 94 μg/L, and the remediation goal was 2 μg/L. Results indicated that VC concentrations declined temporarily in some wells, but generally increased. This lack of reduction in VC concentrations may be due to (1) TCE and DCE degrading to VC, (2) the rapid groundwater flow may have spent the ORC® quicker than anticipated, and (3) an iron
precipitate observed on the ORC® container may have limited the transfer of oxygen to the aquifer.

3.1.2 Cost Estimate

The cost of enhanced bioremediation depends on the price of the specific amendment chemical used, the amount of the chemical required (including potential future applications), the complexity of the delivery system, and the effectiveness of the amendment at treating the contaminants (EPA 2001c).

The ITRD demonstration of enhanced anaerobic bioremediation at the Center’s Northeast Site cost $397,074 and treated 1,950 yd³, producing a rate of $204/yd³. However, this cost included $238,310 in monitoring costs for biweekly sampling and analysis of a number of different parameters. Because this type of sampling would not be necessary with a full-scale system, subtraction of these costs from the total results in a cost of $81/yd³. It is likely that implementing this technology on a full scale would result in a less expensive cost/yd³.

The cost for implementing direct injection of an enhancement chemical such as lactate or molasses would probably be considerably lower than the ITRD groundwater recirculation pilot test. The direct injection method uses low cost injection techniques, is implemented over a short period of time, and subsequent operation and maintenance (O&M) consists only of additional injections events, if necessary. Another option is the direct injection of ORC® or HRC®. These chemicals are more expensive than lactate or molasses, but they usually can be injected less often because of their “slow release” capability.

A cost comparison for plume control using HRC®, an iron PRB wall, and pump and treat was conducted for the Regenesis Company by an independent consulting company. At a hypothetical site, the cost to treat a TCE plume 200 ft wide and 50 ft deep for five years was $176,000 for HRC®, $777,000 for the PRB wall, and $757,000 for pump and treat (Regenesis 2001). While this marketing information should be viewed with caution, it at least indicates that enhanced bioremediation with HRC® would likely be less costly than the other technologies.

The Groundwater Remediation Technologies Analysis Center conducted a review of bioremediation and states that enhanced bioremediation costs could be 50% to 75% of the costs for pump and treat systems (Van Cauwenberghe and Roote 1998). The EPA also considers enhanced bioremediation to be less expensive than pump and treat (EPA 2000). Based on the cost information for the other technologies in the following sections, pump and treat is less expensive than DPE, PRB walls, or vertical barriers. Therefore, the cost of enhanced bioremediation with direct injection probably is lower than the other technologies.

3.1.3 Advantages and Disadvantages

The advantages of enhanced bioremediation are as follows.

- Site conditions are conducive to stimulation of biological activity.
- Contaminants are treated in situ.
- Little or no waste is generated.
• Contaminants may be degraded quickly.

• Contaminant concentrations probably can be reduced to MCLs or below.

• Cost is low compared to other technologies.

• Impact to public perception is low during implementation.

• Impact to public perception is low subsequent to implementation. Some enhancement chemicals can last for months to a year or more before injection of additional chemical is necessary.

• Impact to the surrounding environment, including flora and fauna, at the Center would be minimal.

• The injection of the non-toxic bioremediation enhancement chemicals is generally acceptable to regulators.

• Technology is relatively easy to implement around utilities.

• Regular O&M is unnecessary with direct injection, except for potential future injection events.

• This technology would allow continuation of the long-term pump and treat remediation strategy, and would allow implementation of other technologies if enhanced bioremediation was ineffective.

The disadvantages of enhanced bioremediation are as follows.

• Site hydrogeology may result in incomplete contact with treatment area.

• Injection wells may clog due to chemical or microbial action.

3.2 Dual Phase Extraction

DPE, also known as multi-phase extraction or vacuum-enhanced extraction, is a technology that uses a high vacuum system to remove both contaminated groundwater and contaminant vapors from the subsurface. The vacuum extraction well includes a screened section in the zone of contaminated groundwater (Figure 11). The system lowers the water table around the well, exposing more of the formation. Volatile contaminants in the newly exposed vadose zone are then accessible to vapor extraction. Once above ground, the extracted vapors and groundwater are separated and treated. The implementation of DPE for plume control could require construction of a new treatment system. Influent rates for recovered groundwater entering the current groundwater treatment system at the Center’s Northeast Site are currently being optimized to make full use of the capacity of the treatment system.
3.2.1 Case Studies

3.2.1.1 Pinellas STAR Center

A full-scale DPE system operated at the Center from August 1997 through September 1999. The goal of applying the DPE system was to enhance the pump and treat remediation of VOCs (primarily VC, toluene, TCE, and DCE) from a shallow surficial aquifer at the Center’s 4.5 Acre Site. Initial operating data for the DPE system demonstrated an aggressive groundwater recovery rate; however, influent groundwater contaminant concentrations were less than those experienced with the pump and treat system that had operated previously at the site. In addition, multiple issues complicated initial operations. Following numerous system and operational changes, the system responded with consistent on-line time and daily operation, although contaminant recovery rates did not increase. Additionally, the system allowed significant contaminant concentrations to remain near the bottom of the aquifer.

3.2.1.2 Johannsen Cleaners

DPE was used at this site in Lebanon, Oregon, to remediate high concentrations of PCE and TCE and low levels of DCE and VC (EPA 2001c). Details of the results were not listed, but the summary states that enhanced bioremediation probably would have been a better choice than DPE for this site.

3.2.1.3 Defense Supply Center

This site in Richmond, Virginia, contained high concentrations of PCE, TCE, and DCE (EPA 2001c). After one year of DPE operation, contaminant concentrations remained above the drinking water standards.

3.2.1.4 Tinkham’s Garage Superfund Site

This site in Londonderry, New Hampshire, used 33 DPE wells to remediate high concentrations of PCE and TCE in groundwater (EPA 2001c). Significant contaminant mass was removed by the system, but concentrations still remain above drinking water standards.

3.2.2 Cost Estimate

Because of the number of variables involved, establishing general costs for dual phase extraction is difficult. A representative cost is $2,500 to $4,000 per month (Federal Remediation Technologies Roundtable [FRTR] 2001). Estimated cost ranges per site are from $85,000 to $500,000 per site.

The full scale DPE system at the 4.5 Acre Site cost a total of $688,287 for 25 months of operation using 22 DPE wells. Construction costs totaled $206,000, and O&M, power, and water treatment costs composed the remainder. Therefore the cost of operating the DPE system was approximately $19,000 per month. This cost is high due to a number of modifications that were implemented to optimize system performance. The cost for DPE is moderate to high relative to the other technologies.
3.2.3 Advantages and Disadvantages

DPE advantages are as follows.

- The groundwater pumping component of DPE may be effective at plume control.
- The technology has been accepted by the regulators at other areas of the site.
- The technology is consistent with the long-term remediation strategy.

DPE disadvantages are as follows.

- DPE requires handling, treatment, and disposal of both water and vapor.
- DPE potentially requires its own treatment system.
- DPE may not be effective at treating low concentrations of contaminants, and may not attain MCLs.
- DPE is more expensive than groundwater pumping.
- Does not conserve groundwater resources.
- Moderate to high impact to public perception during installation of wells and trenching for piping. Low to moderate impact during operation.

3.3 Groundwater Pumping

Groundwater pumping involves the use of groundwater extraction wells and pumps to pump groundwater from the subsurface (Figure 12). Recovered groundwater is usually treated at the surface using methods selected to remove the contaminants of concern. The objectives of groundwater pumping systems are: (1) hydraulically contain and control the movement of contaminated groundwater to prevent continued expansion of the contamination zone; or (2) reduce dissolved contaminant concentrations to comply with cleanup standards. For the purposes of this evaluation, only the plume control aspect of groundwater pumping will be considered.

For the use of groundwater pumping for plume containment, success is usually defined as the achievement of hydrodynamic control at the outer limits (horizontal and vertical) of the contaminant plume such that hydraulic gradients are inward to the pumping system (EPA 1994). The implementation of groundwater pumping for plume control could require construction of a new treatment system. Influent rates for recovered groundwater entering the current groundwater treatment system at the Center’s Northeast Site are currently being optimized to make full use of the capacity of the treatment system.

3.3.1 Case Studies

Hydraulic containment of dissolved contaminants by pumping groundwater from wells has been implemented at numerous sites. A few relevant case studies are presented in this section.
3.3.1.1 Pinellas STAR Center

Groundwater pumping has been used or currently is in use at each of the four remediation areas at the Center. Groundwater pumping was successful at containing the contaminant plume at the 4.5 Acre Site, and appears to be successful at controlling the arsenic plume at the Wastewater Neutralization Area. Plume movement has been observed south of the Northeast Site, but the installation of additional recovery wells apparently has captured this plume.

3.3.1.2 City Industries Superfund Site

The goal of the groundwater pumping system at this site in Orlando, Florida, was containment of a plume of TCE, DCE, VC, and several other contaminants (EPA 2001c). From May 1994 through May 1997, total concentrations of contaminants were reduced 86% from 3,121 to 444 μg/L. However, concentrations of all VOCs remained above cleanup goals. No contaminants were detected in downgradient monitoring wells since the beginning of remedial operations, and the plume was contained.

3.3.1.3 Des Moines TCE Superfund Site

The remediation objective at this site in Iowa was reduction of TCE, DCE, and VC concentrations to levels below the cleanup goals, with the secondary objective of plume containment (EPA 2001c). Results indicate that the plume was contained, but the contaminants still exceed the cleanup goals.

3.3.1.4 Former Firestone Facility Superfund Site

This site in Salinas, California, had significant concentrations of VOCs in groundwater both on- and off-site (EPA 2001c). The main goal of the pump and treat system was remediation to cleanup goals, with the secondary goal of plume containment. Results indicated that there initially was plume movement after the system was installed, but the installation of additional wells has captured the plume.

3.3.1.5 EPA Summary

The EPA reviewed 25 sites where at least part of the remediation goal was to contain a contaminant plume using groundwater pumping (EPA 1999). The plumes were contained at all but four of the sites. No explanation was given as to why groundwater pumping failed to control the plume at these sites. However, this summary indicates that, in general, groundwater pumping is effective for plume control.

3.3.2 Cost Estimate

The EPA has summarized cost data for groundwater pumping obtained from federal agency sources (EPA 2001a). This summary of costs for 32 pump and treat sites is listed in Table 5.

This information was used to assemble a rough cost estimate for a groundwater pumping scenario for plume control. It was assumed that plume control could be accomplished by installation of four wells that would pump at a rate of 1.5 gpm, for a total of 3,153,600 gallons per year. Using EPA median costs, one year of capital costs and seven years of O&M costs results in an estimate of $600,000.
3.3.3 Advantages and Disadvantages

Groundwater pumping has the following advantages.

- Groundwater pumping has been shown to be effective for plume control.
- The technology is mature and relatively simple to implement.
- Moderately easy to implement around utilities.
- Probably less expensive than DPE, PRB walls, and vertical barriers.
- The technology has been accepted by the regulators at other areas of the site.
- The technology is consistent with the long-term remediation strategy.

Groundwater pumping has the following disadvantages.

- Requires treatment of extracted groundwater.
- Probably more expensive than enhanced bioremediation.
- Does not conserve groundwater resources.
- Moderate to high impact to public perception during installation of wells and trenching for piping. Moderate impact during operation due to above ground wellhead.
- Could require a treatment system.

3.4 Permeable Reactive Barrier Walls

The EPA defines PRB walls as, “an emplacement of reactive materials in the subsurface designed to intercept a contaminant plume, provide a flow path through the reactive media, and transform the contaminant(s) into environmentally acceptable forms to attain remediation concentration goals downgradient of the barrier” (EPA 1998b) (Figure 13). Several different types of reactive media have been used in PRB walls, the most common of which is zero valent iron (ZVI). Examples of other reactive media include microorganisms, zeolite, activated carbon, peat, phosphate, bentonite, limestone, and amorphous ferric oxide (EPA 1999).

The applicability of a PRB wall using ZVI for plume control at the Building 100 Area was evaluated previously (DOE 2000). As part of this evaluation, a treatability study was conducted by Envirometal Technologies, Inc. to evaluate the degradation of VOCs in groundwater from the Building 100 Area using ZVI. The objectives of the treatability study were:

- Determine degradation rates of VOCs in site groundwater using two sources of granular iron,
- Characterize chlorinated degradation products and evaluate the degradation rates of these products,
• Determine the magnitude of redox potential and pH changes, and
• Document changes in inorganic geochemistry as they relate to potential mineral precipitation.

The results of the column tests demonstrated conclusively that ZVI quickly degraded the Building 100 Area VOCs. Groundwater residence times that would be required to degrade VOCs in the PRB wall also were calculated. These calculations were made using a groundwater velocity of 8 ft/year (0.002 ft/ft gradient). The maximum residence time was seven days, equivalent to a PRB wall thickness of two inches.

PRB walls have been implemented at a pilot scale since the early 1990’s and at full scale since 1995. Because of this relatively short history, concerns have arisen concerning the longevity of PRB walls containing ZVI. Mineral precipitates may reduce iron activity (surface passivation) with respect to VOCs degradation or may reduce permeability through pore clogging.

During the treatability study, decreases in calcium, alkalinity, and total iron concentrations were observed as the groundwater passed through the column, indicating that mineral precipitation had occurred. A few recent studies have addressed the mineral precipitation problem (Phillips et al. 2000; Sass et al. 2001; Sivavec 2001). The general conclusions from these studies are that mineral precipitates: (1) begin to form shortly after installation; (2) are the thickest at the upgradient face of the wall; and (3) reduce wall permeability by only 10% or less. One study estimated that the lifespan of the upgradient face of a generic ZVI wall could be five to ten years, and the lifespan of the rest of the wall could be 15 years or more.

There are several different methods for installing PRB walls, but the continuous trenching method, the mandrel method, and the trench and fill method probably are the most applicable at the Center (DOE 2000). Because of the depth at which the wall would need to be installed (at least 38 ft), continuous trenching could be problematic. With the mandrel method, there are concerns about compaction of soil reducing the permeability in the vicinity of the wall, potentially leading to difficulty getting the contaminated groundwater to pass through the wall. Of the three methods, trench and fill would probably be the best choice for application at the Building 100 Area.

3.4.1 Case Studies

Since 1994, at least 48 PRB walls containing ZVI have been installed to remediate chlorinated aliphatic compounds at numerous sites around the world (ETI 1999). Thirty-one of these systems are full-scale treatment systems. Several of these are summarized below.

3.4.1.1 Sunnyvale

The first full scale PRB wall to use ZVI to degrade chlorinated solvents was installed at a site in Sunnyvale, California, in 1995. The subsurface was composed of silty fine- and medium-grained sand. The groundwater was contaminated with TCE, cis-1,2-DCE, and VC, all of which were removed to below the drinking water standards as the water passed through the wall (Table 6). A pea gravel zone was placed upgradient of the wall to distribute flow through the PRB wall. Mineral precipitation was observed in this zone, probably due to the presence of a small
percentage of ZVI in the gravel. It has been theorized that this pre-treatment zone has extended the life of the wall.

3.4.1.2 Elizabeth City

A PRB wall designed to treat TCE, cis-1,2-DCE, and VC was installed at the U.S. Coast Guard Support Center in Elizabeth City, North Carolina, in 1996. The wall is 150 ft long and two ft thick and extends from three ft to 24 ft below the surface where it intersects a low conductivity zone of silty clay and silty fine sand. Monitoring has shown removal of contaminants to less than drinking water MCLs (Table 6) with the exception of four of 29 locations. It is suspected that the plume has passed beneath the wall because the four sampling locations with MCL exceedances are screened near the bottom of the wall.

3.4.1.3 Lakewood

A Federal highway administration facility located in Lakewood, Colorado, was contaminated with TCE, cis-1,2-DCE, 1,1-DCE, and 1,1,1-trichloroethane. A PRB wall was installed in 1996. The contaminants were located in fractured claystone and gravelly sand with clay lenses with an estimated groundwater velocity of approximately five ft/day. Most contaminants were removed to less than MCLs by the wall (Table 6). Based on decreases in calcium and inorganic carbon concentrations as groundwater moves through the wall, calcite and siderite may be precipitating inside the wall. It is estimated that this precipitation could result in a potential loss of 0.5% of the porosity per year. This rate of precipitation would result in a wall lifetime of several decades.

3.4.1.4 New York Plating Facility

In 1997, a PRB wall was installed in central New York to treat TCE, cis-1,2-DCE, and VC. A continuous PRB wall was chosen over funnel and gate due to high hydraulic conductivity (16–230 ft/day). However, this wall is only one ft thick and VC concentrations exceed the MCL (Table 6) downgradient from the wall.

3.4.1.5 DOE Kansas City Plant

A PRB wall was installed at the DOE Kansas City Plant in 1998 to treat cis-1,2-DCE and VC. The subsurface consists of clay with a hydraulic conductivity of 0.75 ft/day overlying gravel (hydraulic conductivity of 34 ft/day), both overlying a relatively impermeable shale. The PRB wall is thicker in the gravel unit to compensate for the increased groundwater velocity. Monitoring has shown that the contaminants are removed to below MCLs (Table 6). A continuous wall was chosen over a funnel and gate system at this site due to predictability and cost considerations.

These case studies demonstrate the efficacy of PRB walls at degrading the same suite of contaminants that is present at the Building 100 Area. The significant problems identified by these studies are 1) inadequate safety margins and 2) bypassing. Safety margins are inadequate when the wall is too thin to provide sufficient groundwater residence time, allowing contaminants to pass through the wall without complete treatment. Bypassing occurs when contaminated groundwater flows around the wall instead of through the reactive medium.
3.4.2 Cost Estimate

As a follow-up to the PRB wall evaluation report (DOE 2000), a cost estimate was assembled for potential implementation of a wall at the Building 100 Area, and this estimate is summarized here. The overall costs are dependent on the construction technique. To partially account for this, estimates are provided for two likely construction methods.

The cost estimate was based on the following assumptions. The wall would be 700 ft long and at least four inches thick (double the thickness from the treatability study for safety), and 38 ft deep (8,867 cubic feet). Although other installation methods are possible, the most applicable methods would be the mandrel or trench and fill using a bioslurry. A 15% license fee to ETI/University of Waterloo was added, as well as a 20% contingency fee. The costs for additional characterization, ZVI, mobilization and demobilization, design and construction, post construction monitoring, and license and contingency fees for the mandrel method and the trench and fill methods are $1,435,560 and $1,467,660, respectively.

The EPA (2001a) summarized cost data for 16 PRB wall sites (Table 7), and identified a median cost of $680,000. The cost estimate for the potential PRB wall at the Building 100 Area is higher than the costs summarized by the EPA because the length of the Building 100 Area wall was longer than any of the walls reviewed by the EPA. Therefore, the estimated cost of a PRB wall at the Building 100 Area is high relative to the PRB walls reviewed by EPA, and probably is high relative to the other technologies evaluated in this report.

3.4.3 Advantages and Disadvantages

The advantages of PRB walls are as follows.

- Site-specific treatability study has demonstrated that the technology will treat the contaminants, and therefore probably will control the plume.
- After installation, requires little or no O&M.
- Low impact to public perception after installation.
- Acceptable to regulators.

Following are the disadvantages of PRB walls.

- Very high impact to public perception during installation.
- Cost is high relative to other technologies.
- Wall could leak, or contaminated groundwater could flow over or around the wall.
- Longevity of ZVI wall potentially is questionable.
- Difficult to implement around utilities.
3.5 Vertical Barriers

Vertical barriers are constructed containment systems that control horizontal migration of groundwater (Figure 14). The different types of vertical barriers are soil-bentonite, soil-cement-bentonite, cement-bentonite, sheet pile (steel or high density polyethylene), clay, geosynthetic wall, grout, deep soil mixing, frozen soil barriers, calcite barriers, and biobarriers (EPA 1998a; EPA 2001d; MSE 2001). Soil-bentonite slurry barriers are the most widely used in the United States. In some cases, PRB walls are considered vertical barriers, but for the purposes of this evaluation only impermeable or very low permeability systems are considered as vertical barriers.

One of the requirements for an effective vertical barrier is the presence of a geologic stratum that acts as an aquitard below the contaminated area, into which the vertical barrier is keyed. The Hawthorn (discussed in Section 2.1.2) probably serves as an effective aquitard, allowing the potential application of this technology at the Building 100 Area.

3.5.1 Case Studies

3.5.1.1 Pinellas STAR Center

A soil/bentonite barrier wall was installed at the Center’s Northeast Site in 1995 to enhance the pump and treat remediation system by limiting the volume of groundwater that is drawn onto the Center property from off site. The wall is located near the northern property boundary at the Northeast Site, and is approximately three ft wide, 40 ft deep, and 500 ft long. The wall has its top at land surface, and is keyed into the Hawthorn at least five ft. The wall has been effective as evidenced by the approximately five ft difference in groundwater levels on either side of the wall.

3.5.1.2 Western Processing Superfund Site

This site in Kent, Washington, originally used pump and treat to remediate a complex contaminant mixture (FRTR 2001). However, following eight years of remediation, the remedy was changed to containment based on the impracticability of achieving cleanup goals. A slurry wall 40 ft deep now encloses the 13 acre site, and has been effective at containing the contaminants.

3.5.1.3 Solvent Recovery Services of New England Superfund Site

This site in Southington, Connecticut, uses groundwater pumping and a 700 ft long downgradient steel sheet piling wall to treat and contain a plume of mixed contaminants (FRTR 2001). Plume containment was lost for four days over three years of operation.

3.5.1.4 Sylvester/Gilson Road Superfund Site

This site in Nashua, New Hampshire, used groundwater pumping and a slurry wall four ft wide, 4,000 ft long, and as much as 100 ft deep to treat a plume of mixed contaminants (FRTR 2001). The slurry wall was effective and most of the contaminant concentrations have been reduced to below MCLs by groundwater pumping.
3.5.1.5 Comprehensive EPA Study

The EPA recently conducted a comprehensive evaluation of vertical barriers that have been implemented at waste sites (EPA 1998a). EPA identified 130 sites for the study, but only 36 were evaluated because there were insufficient data to evaluate the remainder. The general major conclusions of the study were:

- Based on data from 25 of the 36 sites studied, vertical barriers are effective containment systems for the short and middle term, if properly designed and installed. None of the monitoring data reviewed indicated a decrease in effectiveness as a function of time.

- The most likely pathway for leaking of vertical barriers is in the vicinity of their keys, as a result of defective installation. Identified problems were insufficient cleaning prior to backfilling, insufficient key as specified by the design or lack of sounding, or defects in the aquitard layer below the key.

- The soil-bentonite slurry wall technology was the most widely used technique for the sites that were studied.

3.5.2 Cost Estimate

The costs of installing subsurface barriers vary widely, depending on the unique conditions at each site, the construction method used, and the type of barrier wall. In general, use of the vibrating beam method of barrier wall construction resulted in the lowest cost, and use of the trench excavation method resulted in the highest cost (EPA 1998a). The capital cost for construction of a barrier wall is expressed in dollars per square foot of sidewall area. Such costs vary from $5 to $15 per square foot (EPA 1998a). This cost does not include the installation and O&M of groundwater recovery wells, or any of the potential costs associated with treating the recovered groundwater.

The FRTR (2001) states that costs likely to be incurred in the design and installation of a standard soil-bentonite wall in soft to medium soil range from $5 to $7 per square foot (1991 dollars). These costs also do not include associated recovery wells costs.

Assuming a vertical barrier the same size as the PRB wall (700 ft by 38 ft) and using the EPA estimate of $5 to $15 per square foot, the cost of the wall alone is $133,000 to $399,000. The cost for implementation and O&M of a groundwater pump and treat system would have to be added to this cost, making the cost of a vertical barrier high relative to the other technologies.

3.5.3 Advantages and Disadvantages

The advantages of vertical barriers are as follows.

- The technology is relatively simple to implement.

- The technology has a track record of generally successful applications.

- Low impact to public perception after installation.

- May be acceptable to regulators.
Factors that may limit the applicability and effectiveness of vertical barriers include the following.

- Most of the approaches involve a large amount of heavy construction, leading to the potential for a negative impact to public and Center tenant relations during installation.

- Vertical barriers require groundwater management to remove accumulated water before it flows over or around the barrier. This factor makes this technology less applicable and more costly than groundwater pumping alone.

- Vertical barriers have the potential to leak if the key or the wall itself is poorly constructed.

- Difficult to implement around utilities.
4.0 Evaluation of Selected Technologies

The five potential plume control technologies are evaluated in this section. A technical evaluation committee consisting of an engineer, a geologist, a hydrogeologist, and a geochemist developed the evaluation criteria listed in Section 4.1, and conducted the technology evaluation presented in Section 4.2. Additionally, a Ph.D. engineer with several years experience implementing enhanced bioremediation systems was consulted by the committee during the technology evaluation. The evaluation results are summarized in Section 4.3.

4.1 Evaluation Criteria

VC is the only contaminant that currently is present above the cleanup goal near the property boundary in the Building 100 Area (Section 2.2). However, cis- and trans-1,2-DCE are present near the property boundary but below their cleanup goals, and TCE has been detected above its cleanup goal in wells hydraulically downgradient from Building 100 in the past. For the purposes of this report, the criteria developed in this section concern mainly control of the VC plume, but also consider control of a potential plume containing other contaminants such as TCE and cis-and trans-1,2-DCE that could migrate to near the property boundary in the future.

Various types of screening criteria were reviewed, including general EPA guidance for RCRA CMS. Additionally, DOE’s *Ground Water Evaluation and Remediation Strategy Guide for Department of Energy Sites* was reviewed to ensure that the evaluation criteria were consistent with the guidance in that document. After review of the criteria guidance, the remediation objectives listed in Section 1.1, and the information discussed in Section 2.0, the following screening criteria were developed.

The evaluation criteria are:

1. the technology must ensure that contaminant concentrations above the MCLs do not move off site,
2. the technology must be consistent with the long-term remediation strategy for the site, and the technology must be effective until dissolved phase remediation is complete (completion of dissolved phase remediation currently is scheduled for October 2010)
3. the technology must be acceptable to the regulators,
4. impacts to the environment, the Center, and public perception must be minimal,
5. the technology must be feasible to implement given numerous utilities and other complications, and
6. the cost to implement and operate the technology must be reasonable.

Criterion 1 states the main objective of plume control. Criterion 2 defines the time period over which the plume control technology must be effective. Together, Criteria 1 and 2 evaluate the potential effectiveness of the technology. Criterion 3 describes technology acceptability from a regulatory perspective. Criterion 4 defines one of the main issues for the technology, that it must have minimal impact to the environment, the Center, and public perception as described in
Section 2.5. Criterion 5 evaluates implementability issues, as discussed in Section 2.4. Together, Criteria 3, 4, and 5 evaluate the potential implementability issues associate with each technology. Criterion 6 evaluates the estimated technology costs on a low, moderate, and high scale, relative to each of the other technologies being evaluated. These costs include both installation and O&M costs. Each of the six criteria was approximately equally weighted for the evaluation.

4.2 Technology Evaluation

In this section, the five technologies are evaluated according to the criteria listed in Section 4.1.

4.2.1 Enhanced Bioremediation

Enhanced bioremediation satisfies Criterion 1. Based on site data, the review of a large number of case studies, and consultation with the bioremediation specialist, enhanced bioremediation would be effective for plume control. The presence of DCE and VC in the subsurface indicates that natural biodegradation is occurring at the site. The Pinellas ITRD study and the Dover Air Force Base study demonstrated that the microorganisms at the Center have the ability to degrade the contaminants.

Enhanced bioremediation can remain effective until dissolved phase remediation is complete. Based on monitoring data, subsequent enhancement chemical injection events can be conducted to ensure that bioremediation remains effective as long as is necessary, thereby satisfying Criterion 2.

There are a number of regulatory issues associated with enhanced bioremediation (ITRC 1998). However, most of the enhancement chemicals applicable at the Building 100 Area are non-toxic, food-grade chemicals that should be acceptable to the regulators, thereby satisfying Criterion 3.

Criterion 4 is where enhanced bioremediation generally has an advantage over the other technologies. For plume control, the design configuration would probably be direct injection. This would involve a minimum of equipment used for a short duration, and would leave little visible evidence at the surface after implementation. Although a few subsequent injection events probably would be necessary, these would be very low impact as well. The number of injection events depends upon the enhancement chemical chosen. All of the other technologies are higher impact to public perception, involving well installation and trenching for piping for DPE and groundwater pumping, or significant excavation for PRB walls and vertical barriers. Enhanced bioremediation also has the least impact to the environment because it degrades the contaminants in situ, requiring no energy to extract and treat the contaminants, does not add wastewater to the municipal treatment system, and conserves groundwater resources.

Considering Criterion 5, the evaluation committee determined that enhanced bioremediation is easy to implement around utilities relative to the other technologies. All that is needed to implement the technology is a series of either temporary or permanent injection points that are easily arranged to avoid utilities. Another positive attribute of implementing enhanced bioremediation is the ability to move or add the injection points if it appears that certain areas are not being fully treated.
The cost of enhanced bioremediation is low relative to the other technologies, based on evaluations conducted by the Groundwater Remediation Technologies Analysis Center and the EPA.

4.2.2 DPE

The groundwater pumping component of DPE likely would control the plume by changing the groundwater flow direction near the property boundary so that the contaminated water is drawn away from the property boundary, thereby satisfying Criterion 1. Although plume control was not its primary goal, the DPE system at the 4.5 Acre Site was effective at keeping contaminated groundwater from moving off the property. However, no case studies were found where DPE was used solely for plume control. This technology tends to be more effective at treating relatively high concentrations of VOCs, and its effectiveness is limited at lower concentrations.

DPE could be effective for plume control for the time period specified in Criterion 2. As long as the wells were properly located and the groundwater pumping component of DPE continued operation, the plume probably would be contained.

DPE probably would be acceptable to the regulators, given that the technology has been implemented previously at another area of the Center, and therefore satisfies Criterion 3.

Relative to the other technologies, DPE would have a moderate impact to the environment, the Center, and public perception. Pumping groundwater would cause a loss of groundwater resources. The recovered groundwater and vapors would probably be treated by air stripping, which would require power to run the system. The treated water would then be discharged to the municipal sewer system, requiring further treatment there. Impact to the Center and to public perception would be moderate during installation of wells and associated piping, and low to moderate during subsequent operation.

Relative to the other technologies, DPE would be moderately easy to implement around the utilities. The groundwater pumping component could potentially affect the water level in the south pond. Assuming that the recovered groundwater would be piped to the Northeast Site air stripper for treatment, the piping would have to be routed around buildings and utilities.

The cost of DPE would be moderate relative to the other technologies, assuming that the recovered groundwater and vapors could be treated by the existing Northeast Site air stripper. If a separate treatment system was required, the cost for DPE would be high relative to the other technologies.

4.2.3 Groundwater Pumping

The groundwater pumping likely would control the plume by changing the groundwater flow direction near the property boundary so that the contaminated water is drawn away from the property boundary, thereby satisfying Criterion 1. As shown in the case studies presented in Section 3.3.1, groundwater pumping generally has been effective for plume control at the Center and at numerous other sites. Implementation of groundwater pumping for plume control at the Building 100 Area would require groundwater modeling to determine the strategic placement of recovery wells.
Groundwater pumping could be effective for plume control for the time period specified in Criterion 2. As long as the wells were correctly positioned and pumping continued operation, the plume probably would be contained.

Groundwater pumping probably would be acceptable to the regulators, given that the technology has been implemented previously at other areas of the Center, and therefore satisfies Criterion 3.

Relative to the other technologies, groundwater pumping would have a moderate impact to the environment, the Center, and public perception. Pumping groundwater would cause a loss of groundwater resources. The recovered groundwater would probably be treated by air stripping, which would require power to run the system. The treated water would then be discharged to the municipal sewer system, requiring further treatment there. Impact to the Center and to public perception would be moderate during installation of wells and associated piping, and low to moderate during subsequent operation.

Relative to the other technologies, groundwater pumping would be moderately easy to implement around the utilities. Groundwater pumping could potentially affect the water level in the south pond. Assuming that the recovered groundwater would be piped to the Northeast Site air stripper for treatment, the piping would have to be routed around buildings and utilities.

The cost of groundwater pumping would be moderate relative to the other technologies, assuming that the recovered groundwater could be treated by the existing Northeast Site air stripper. If a separate treatment system was required, the cost for groundwater would be high relative to the other technologies.

4.2.4 PRB Wall

As determined by the site-specific treatability study and during review of case studies, a PRB wall containing ZVI probably would be effective at treating VC, as well as cis-1,2-DCE and TCE, to levels below the MCLs, thereby satisfying Criterion 1.

It is likely that the PRB wall would remain effective until the scheduled end of remediation in 2010, satisfying Criterion 2. If the wall was installed in 2003, it would need to be effective for approximately seven years, assuming that remediation activities remain on schedule. The main concern with wall longevity is clogging and passivation by mineral precipitates, as discussed in Section 3.4. As determined during the treatability study, mineral precipitates would form in the PRB wall. However, research reported in the literature indicates that PRB walls with ZVI should remain effective for 10 to 15 years before the precipitates cause the wall to lose its effectiveness.

The use of a PRB wall containing ZVI probably would be acceptable to the regulators, given that the site-specific treatability study demonstrated that the wall would treat the contaminants to below MCLs.

Evaluation of PRB walls under Criterion 4 resulted in the determination that impact to the Center and public perception would be severe during implementation and relatively low following implementation. Construction of a PRB wall would take place over several weeks, and would require several pieces of heavy construction equipment, stockpiling of the reactive medium before it is placed into the excavation, and stockpiling of the soil removed from the excavation. Yet once in place, the wall would have little impact to the Center or public perception because it
requires no maintenance and there is little evidence of the wall at the surface. The environmental impacts of a PRB wall would be minimal because the contaminants are treated in situ, with the only waste requiring disposal being the soil remaining from the excavation conducted to install the wall.

The large number of utilities at the southeast corner of the Building 100 Area would complicate the implementation of a PRB wall. While most of the utilities are located in the easement for road expansion, an electric line, a gas line, and a storm drain line are all located in the area where the PRB wall would be installed (Figure 8). To be effective, a PRB wall needs to be continuous, and installing the wall around these utilities could potentially result in areas around the utilities where contaminated groundwater could leak through the wall without being completely treated. Therefore, under Criterion 5, implementation of a PRB wall would be difficult relative to the other technologies.

As discussed in Section 3.4.2, the estimated cost of a PRB wall at the Building 100 Area is high relative to the costs of the 16 PRB walls reviewed by the EPA. This is probably due to the fact that the Building 100 Area PRB wall would be longer than any of the walls review by the EPA. Additionally, comparing the PRB wall cost estimate to the cost summaries for the other technologies, the cost of implementing a PRB wall would be relatively high.

### 4.2.5 Vertical Barriers

Vertical barriers probably would be effective at plume control, but would require a groundwater pumping system to ensure that contaminated groundwater would not pass around or over the wall. The case studies reviewed in Section 3.5.1 indicate that vertical barriers generally are effective for plume control.

A vertical barrier likely would be effective for the time period required in Criterion 2. The EPA summary of vertical barriers discussed in Section 3.5.1 stated that vertical barriers generally are effective for short- and medium-term plume control.

A vertical barrier would probably be acceptable to the regulators. The technology is relatively simple and has a history of successful implementation at numerous sites.

Evaluation of vertical barriers under Criterion 4 resulted in the determination that impact to the Center and public perception would be severe during implementation and relatively low following implementation. Construction of a vertical barrier would take place over several weeks, and would require several pieces of heavy construction equipment, stockpiling of the wall medium, and stockpiling of the soil removed from the excavation. Once in place, the wall would have moderate impact to public perception because, although the wall itself requires no maintenance, a pump and treat system would be required to remove groundwater that would mound behind the wall. The environmental impacts of a vertical barrier wall would be moderate because of the need to pump groundwater and treat it at the surface.

The large number of utilities at the southeast corner of the Building 100 Area would complicate the implementation of a vertical barrier. While most of the utilities are located in the easement for road expansion, an electric line, a gas line, and a storm drain line are all located in the area where the vertical barrier would be installed (Figure 8). To be effective, a vertical barrier needs to be continuous, and installing the wall around these utilities could potentially result in areas
around the utilities where contaminated groundwater could leak through the wall. Therefore, under Criterion 5, implementation of a vertical barrier would be difficult relative to the other technologies.

In terms of cost, a vertical barrier by itself is relatively inexpensive. However, due to the necessity of implementing a pump and treat system to remove groundwater that would mound behind the wall, the cost of the entire system would be high relative to the other technologies.

### 4.3 Evaluation Summary

The evaluation of the five potential plume control technologies is summarized in Table 8 and discussed in the following text. All five of the technologies satisfied Criteria 1, 2, and 3. The differences between the technologies became evident during the evaluation under Criteria 4, 5, and 6, leading to the choice of enhanced bioremediation for plume control at the Building 100 Area.

Enhanced bioremediation should have the lowest impact to the environment, the Center, and public perception, would be the easiest to implement around the utilities at the southeast corner of the Building 100 Area, and should have the lowest cost in terms of implementation and subsequent O&M. These factors combined to make enhanced bioremediation the clear choice for plume control. This choice is consistent with guidance in DOE’s *Ground Water Evaluation and Remediation Strategy Guide for Department of Energy Sites* which recommends that in situ destruction technologies be used instead of pump and treat-type technologies.

The second choice for plume control was groundwater pumping. This technology would have moderate impacts to the environment, the Center, and public perception, would be moderately easy to implement around utilities, and the cost would be moderate relative to the other technologies. If a treatment system was required to treat the recovered groundwater, the cost of pump and treat could be high.

DPE scored similarly to groundwater pumping during the evaluation. However, the vapor extraction component of DPE is not necessary for plume control, and probably would result in the cost of the technology being higher than groundwater pumping.

PRB walls would have a severe impact to the Center and to public perception of remediation activities because of the large amount of construction equipment and the excavation activities necessary to implement the technology. Although these impacts would not exist following implementation, the initial impacts would be so severe that they overshadow the subsequent low impact. This factor alone eliminates this technology from consideration for implementation at the Building 100 Area. Additionally, a PRB wall would be difficult to implement around utilities, and the cost is high relative to the other technologies.

A vertical barrier would also have a severe impact to the Center and to public perception of remediation activities due to the construction equipment and the excavation activities necessary to implement the technology. A vertical barrier would be difficult to implement around utilities. Because of the need for a pump and treat system associated with the vertical barrier, the cost would be high relative to the other technologies.
4.4 Description of the Recommended Plume Control Technology

Enhanced bioremediation is the preferred choice for plume control at the Building 100 Area for a number of reasons. Most importantly, biodegradation already is occurring naturally in the subsurface at the Building 100 Area as evidenced by the presence of DCE and VC, which probably are products from TCE degradation. Therefore, it is likely that the addition of an enhancement chemical to the subsurface will aid the microorganisms in completing the degradation process. Because the contaminant concentrations are only slightly above the MCLs near the property boundary, it is probable that the contaminants in that area can be degraded to below the MCLs in a reasonable amount of time.

Perhaps the most important advantage enhanced bioremediation has over the other technologies is the low impact to the Center and public perception. Many enhanced bioremediation sites used groundwater recirculation to apply the treatment for remediation of a plume of contaminants. However, because the application of enhanced bioremediation at the Building 100 Area is for plume control and not treatment of a large plume, the relatively more aggressive groundwater recirculation method may not be necessary. Implementation of the technology using direct injection through either temporary or permanent points would involve a minimal amount of equipment and would occur over a relatively short time scale. Although subsequent injection events probably would be necessary, the potential use of enhancement chemicals that are “slow release” would lengthen the time interval between events.

Additionally, the technology is potentially applicable for remediation of the residual source and dissolved phase plume at the Building 100 Area, and may be applicable at other areas of the Center as well. The relatively small scale of implementation for plume control could serve to evaluate the applicability of the technology to remediation activities at the rest of the Center.

The EPA (2000) and the ITRC (1998) suggests using the following steps to select and implement an enhanced bioremediation system. These steps as they relate to the Building 100 Area are discussed in the following text.

1. evaluate site characteristics,
2. identify general site conditions and engineering solutions,
3. identify primary reactants and possible additives,
4. conduct bench-scale treatability testing, and
5. conduct system design, field testing, and implementation.

In terms of evaluating site characteristics, a baseline delineation of the extent of the plume downgradient from Building 100 should be conducted prior to design of pilot tests or full-scale implementation, as discussed in Section 2.2. Additionally, some baseline geochemical characterization may be necessary to define the exact geochemical conditions in the subsurface, as recommended by the EPA (2000). Knowledge of these geochemical parameters would aid in designing an effective enhanced bioremediation system. Several of these parameters are currently measured during the quarterly sampling events, but other parameters, such as iron, sulfur, and nitrogen species, and dissolved gasses such as ethane, ethene, methane, hydrogen, and carbon dioxide should be measured as well.

Generally, site conditions are well defined. As discussed previously, the engineering solution to implement enhanced bioremediation probably will be direct injection. An evaluation should be
done to determine the exact approach for direct injection, which could consist of temporary borings, permanent injection wells, or other means.

A recent study (Harkness 2000) compared the costs of three different approaches for enhanced anaerobic bioremediation. This conceptual study used an economic analysis model developed by the DuPont Company, assumed a hypothetical site, and compared the potential costs for (1) groundwater recirculation using benzoate, (2) frequent injection using benzoate, and (3) infrequent injection using a slow release compound such as HRC®. The results indicated that the groundwater recirculation system costs were approximately 50% higher than the injection methods, and that the injection methods were similar in cost. Under the groundwater recirculation method, 57% of the costs were in O&M and labor. Under the frequent injection scenario, 43% of the costs were in O&M and labor, while under slow release injection scenario, 56% of the costs were for the enhancement chemical and only 11% were in O&M and labor. The study concluded that cost effective design should focus on optimizing the delivery system for the groundwater recirculation and frequent injection scenarios, and on optimizing the cost and efficiency of the enhancement chemical for the slow release injection scenario.

Perhaps the most difficult task is the identification of the correct enhancement chemical. While the additional geochemical characterization would aid in this process, it may be necessary to conduct a bench-scale treatability study or a field-scale pilot test. Consultation with a contracted bioremediation specialist has resulted in the determination that a bench-scale treatability study is not necessary. This is based on the fact that biodegradation is already occurring naturally in the subsurface. The specialist did, however, recommend a field-scale pilot study prior to full-scale implementation. The purpose of this study would be to evaluate the effectiveness of one or more enhancement chemicals.

During the review of case studies for this document, a few issues that may be relevant to enhanced bioremediation at the Building 100 Area were identified. These issues, presented in the following text, should be reviewed and discussed prior to the implementation of the technology.

Hansen et al. (2000) presented lessons learned from the application of enhanced bioremediation at over 20 sites. The application of a slow-release chemical may be more efficient than other enhancements in a reducing, slow groundwater velocity environment such as is present at the Building 100 Area. In low permeability situations, delivery of the enhancement chemical can be problematic, and may lead to buildup of organic acids that can create low pH conditions that could be detrimental to microorganisms. In areas of low contaminant concentrations, there may be a long lag time before results are noted.

During the ITRD enhanced bioremediation pilot project at the Center’s Northeast Site (DOE 1998b), site personnel observed a problem relating to injection of fluids into the subsurface. This study used recirculating system to apply the enhancement chemicals, and flooding of the surface with groundwater was observed several times during the project. This flooding probably occurred because the rate of reinjection of groundwater exceeded the capacity of the relatively low permeability subsurface materials. While it is unlikely that a recirculating system would be used for plume control at the Building 100 Area, this issue demonstrates that any project attempting to inject fluids into the subsurface at the Center needs to consider injection rates as they relate to the permeability of the subsurface. A product like HRC® has an advantage over other lactate-type enhancement chemicals because it contains the highest
concentration of lactate, and therefore requires less fluid to be injected compared to other lactate-type enhancement chemicals.

There is some information suggesting that high concentrations of iron in the subsurface, similar to the concentrations at the Building 100 Area, may slow the enhanced bioremediation process. This issue needs to be investigated further prior to technology implementation.
End of current text
5.0 Conclusions and Recommendations

As a result of the evaluation conducted in this document, enhanced bioremediation is recommended for control of the contaminant plume at the Building 100 Area. This technology has several distinct advantages relative to the other technologies. These advantages are discussed in detail in Sections 3.1, 4.2.1, 4.3, and 4.4.

Enhanced bioremediation is consistent with the long-term remediation strategy for the site. The Building 100 Area CMIP Addendum (DOE 1998a) recommends enhanced bioremediation as one of the potential enhancements for the pump and treat remediation strategy at the site.

A baseline delineation of the extent of the contaminant plume downgradient from Building 100 is recommended prior to remedial design because the current location of the monitoring wells is insufficient to fully characterize the plume boundaries. This delineation could be conducted using direct push technology to install temporary boreholes for water sample collection. Additionally, water samples should be collected from existing monitoring wells and analyzed for geochemical parameters. This information will aid in selection of the correct enhancement chemicals and in designing the chemical delivery system.

One factor that may affect the recommendations made in this document is the sampling and analysis for metals that is being conducted in fiscal year 2002. This sampling is being conducted as part of a site-wide review of COPCs. If it is determined that metals dissolved in groundwater should be considered as COPCs and therefore require remediation, a determination would need to be made as to whether there is a metals plume near the property boundary. If such a plume existed, the choice of enhanced bioremediation for plume control should be reviewed for its applicability to control this plume. Based on the evaluation conducted in this document, groundwater pumping would be the second choice for control of the VOCs plume. Groundwater pumping should be applicable to control the metals plume as well, so this option should be considered if metals remediation is required.

It is recommended that the Request for Proposal (RFP) process be used to choose the exact approach for implementation of enhanced bioremediation. This procurement strategy will allow for a detailed review of several different site-specific conceptual designs for enhanced bioremediation, including vendor recommendations for the specific type of enhancement chemical as well as the specific method for applying the chemical to the subsurface. A technical review committee would evaluate these conceptual designs, and make a choice based on the technical merits of the proposal. Cost would also be considered during this process. The RFP process has worked well in the past for identifying the best remediation approach.

Following the conclusion of the RFP process, an Interim Measures Work Plan should be developed. This plan would be submitted to the regulators for approval prior to implementation of the full scale technology.
End of current text
6.0 References


Figure 1. Location of the Building 100 Area at the Young-Rainey STAR Center
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Figure 2. Groundwater Elevations and Shallow Surficial Aquifer Flow at the Building 100 Area in October 2001
Figure 3. Groundwater Elevations and Deep Surficial Aquifer Flow at the Building 100 Area in October 2001
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Figure 4. Vinyl Chloride Plume at the Building 100 Area

The VC concentrations shown are the highest values measured at each location from October 2000 to October 2001. Sample points S56 to S66 consist of three co-located sampling points emplaced at different intervals. For example, S66B, S66C, and S66D are screened at 10–20, 20–30, and 30–40 ft bls, respectively. Only the highest VC concentration at any one of the three co-located points is shown on the figure.
Figure 5. Three Dimensional Vinyl Chloride Plume Map
Data from wells north and west of wells S56 and S57 were not used to construct this plume figure
Figure 6. Cross Section through the East Limb of the Vinyl Chloride Plume
Cross-section location is shown on Figure 5.
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Figure 7. Cross Section through the South Limb of the Vinyl Chloride Plume

Cross-section location is shown on Figure 5. Although the software used to make this figure does not connect the plume from S61D to 0512, it is highly probable that the plume is connected, based on site knowledge.
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Figure 8. Utility Locations at the Southeast Corner of the Building 100 Area
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Figure 9. Reductive Dechlorination Pathway for TCE, showing DCE, VC, and Ethane Degradation Products
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Figure 10. Conceptual Figure of Enhanced Bioremediation

Figure 11. Conceptual Figure Showing DPE
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Figure 12. Conceptual Figure Showing Groundwater Pumping

Figure 13. Conceptual Figure Showing a PRB Wall
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Figure 14. Conceptual Figure Showing a Vertical Barrier
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### Table 1. Estimated Hydraulic Conductivity at the Building 100 Area

<table>
<thead>
<tr>
<th>Well</th>
<th>Screened Interval (ft lbs)</th>
<th>Estimated Horizontal Hydraulic Conductivity (ft/day)</th>
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</thead>
<tbody>
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<td>PIN12–0523</td>
<td>18–28</td>
<td>2.06</td>
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<td>PIN12–0521</td>
<td>19.5–29.5</td>
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<td>PIN12–0522</td>
<td>32–42</td>
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### Table 2. Groundwater COPCs and Cleanup Goals for the Building 100 Area

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<tr>
<th>COPC</th>
<th>Cleanup Goals (FDEP Drinking Water Standards) (μg/L)a</th>
<th>Detected Above Cleanup Level Downgradient From Building 100 ?</th>
<th>Highest Detected Concentration (μg/L)</th>
<th>Well With Highest Detected Concentration</th>
<th>Date of Highest Detected Concentration</th>
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<td>Yes</td>
<td>200</td>
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<tr>
<td>Cis-1,2-DCE</td>
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<td>Yes</td>
<td>500</td>
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<td>trans-1,2-DCE</td>
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*aμg/L = micrograms per liter*
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<td>7.8</td>
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* = Analyte not detected above MCL.
Table 4. Summary of Geochemical Data From July 2000 to April 2001 for all Wells at the Building 100 Area
(Unit abbreviations are milligrams per liter [mg/L], millivolts [mV], degrees Celsius [°C], micromhos per centimeter [μmhos/cm], and nephelometric turbidity units [NTU])

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<thead>
<tr>
<th>Parameter</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Average Value</th>
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<tbody>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>0.06</td>
<td>8.22</td>
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<tr>
<td>Oxidation-Reduction Potential (mV)</td>
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<td>737</td>
<td>-87</td>
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<td>pH</td>
<td>6.35</td>
<td>9.36</td>
<td>6.82</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>21.6</td>
<td>32.4</td>
<td>25.7</td>
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<td>Specific Conductance (μmhos/cm)</td>
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<td>Turbidity (NTU)</td>
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Table 5. Summary of Pump and Treat Costs (EPA 2001a)

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<th>25th Percentile</th>
<th>Median</th>
<th>75th Percentile</th>
<th>Average</th>
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<tr>
<td>Capital Cost Per 1,000 Gallons of Groundwater Treated Per Year ($)</td>
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<tr>
<td>Average Annual Operating Cost Per 1,000 Gallons of Groundwater Treated Per Year ($)</td>
<td>5</td>
<td>16</td>
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<td>32</td>
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Table 6. Reduction in Contaminant Concentrations at PRB Wall Sites

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<tr>
<th>Contaminant</th>
<th>Initial Concentration (μg/L)</th>
<th>Post-Treatment Concentration (μg/L)</th>
<th>Removal to &lt;Drinking Water Standard</th>
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<tbody>
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<td>Sunnyvale</td>
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<tr>
<td>TCE</td>
<td>50–200</td>
<td>&lt;5</td>
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</tr>
<tr>
<td>cis-1,2-DCE</td>
<td>450–1,000</td>
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<td>VC</td>
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<tr>
<td>Elizabeth City</td>
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<td>yes</td>
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<td>VC</td>
<td>NR</td>
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<td>Lakewood</td>
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NR: data not reported
Table 7. Summary of PRB Wall Costs (EPA 2001a)

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<th>25th Percentile</th>
<th>Median</th>
<th>75th Percentile</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>444,000</td>
<td>680,000</td>
<td>1,000,000</td>
<td>730,000</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Evaluation Criteria and Results of Technology Evaluation

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Enhanced Bioremediation</th>
<th>DPE</th>
<th>Groundwater Pumping</th>
<th>PRB Walls</th>
<th>Vertical Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>the technology must ensure that contaminant concentrations above the MCLs do not move off site</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>the technology must be consistent with the long-term remediation strategy for the site, and the technology must be effective until dissolved phase remediation is complete (completion of dissolved phase remediation currently is scheduled for October 2010) and</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Criterion 3</td>
<td>the technology must be acceptable to the regulators</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Criterion 4</td>
<td>impacts to the environment, the Center, and public perception must be minimal</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Criterion 5</td>
<td>the technology must be feasible to implement given numerous utilities and other complications</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Criterion 6</td>
<td>the cost to implement and operate the technology must be reasonable</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>