



July 15, 2004

Leslie McVickar
Remedial Project Manager
EPA - New England, Region 1
1 Congress Street
Suite 1100 HBT
Boston, MA 02114-2023

Subject: Alternative Technology Analysis and Evaluation

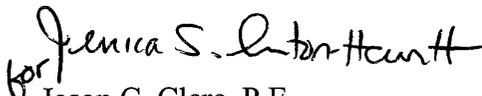
Dear Leslie:

In accordance with the approval letter dated July 7, 2004 from the U.S. Environmental Protection Agency (EPA), URS is submitting two paper and one electronic copy of the *Alternative Technology Analysis and Evaluation* report prepared by URS Corporation and originally submitted to the agency on February 13, 2004. A paper and electronic copy have also been provided to the Vermont Agency of Natural Resources and TRC.

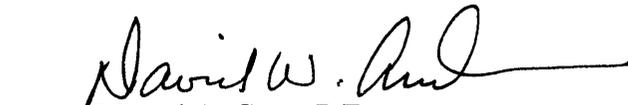
As always, if you have any questions please do not hesitate to contact us.

Sincerely,

URS CORPORATION



for Jason C. Clere, P.E.
Project Engineer



for Marcel A. Guay, P.E.
Lead Consultant

c: John Schmeltzer, VTDEC
John Young, Vermont American
Louis M. Rundio, Jr., McDermott, Will & Emery
Dale Weiss, TRC

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ALTERNATIVE TECHNOLOGY ANALYSIS AND EVALUATION

**PARKER LANDFILL
LYNDON, VERMONT**

Submitted By:



**Vermont American Corporation
715 East Gray Street
Louisville, Kentucky 40202**

July 15, 2004

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PARKER LANDFILL
LYNDON, VERMONT**

Prepared For:

**Vermont American Corporation
715 East Gray Street
Louisville, Kentucky 40202**

Prepared By:

**URS Corporation
115 Water Street, Suite 3
Hallowell, Maine 04347**

Job Number: 39459201.06001

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1.0 INTRODUCTION

Since October 1995, the Environmental Protection Agency (EPA) has encouraged Regions to review remedy decisions at sites where significant new scientific information, technological advancements, or other considerations will achieve the level of protectiveness of human health and the environment provided by the original remedy while enhancing the overall remedy effectiveness and reducing cost. On this basis, EPA established *Superfund Reform 3-2: Updated Remedy Decisions at Select Sites*. This reform was established with the goal of encouraging appropriate changes in a remedy when a different technology would result in a more cost effective cleanup or modification of the Remedial Action Objectives (RAOs) was warranted based upon limitations posed by site conditions or the nature of contamination. This analysis and evaluation documents a remedy review and recommends an updated remedial approach for groundwater remediation at the Parker Landfill.

1.1 DESCRIPTION OF WORK ACTIVITIES COMPLETED TO DATE

A remedial investigation (RI) of the Parker Landfill was completed by Vermont American Corporation during 1992. A final Remedial Investigation/Feasibility Study (RI/FS) Report was issued in 1994 (Environmental Sciences and Engineering, Inc. [ESE], 1994). The RI was performed to characterize the nature and extent of impacts to environmental media (i.e., soil, groundwater, surface water, sediment, and air) potentially related to the historical operation of the solid waste landfill, which includes a solid waste disposal area (SWDA) and three industrial waste disposal areas (i.e., IWS-1 through IWS-3) at the site (Figure 1). The following conclusions were developed based upon the findings of the RI.

- **Four significant (i.e., permeable water-bearing) hydrogeologic units underlie the study area.** These units include upper and lower proximal units comprised predominantly of sandy soils, an esker-delta deposit consisting of cross-bedded sands and gravel, and fractured bedrock. A discontinuous thin zone of highly weathered transmissive bedrock (i.e., regolith) was observed to underlie the lower

proximal and esker-delta units at certain locations. Throughout much of the northeastern portion of the property, the upper and lower proximal units are separated by a semi-confining unit of silt/clay (distal unit). The esker-delta deposit is present in the western portion of the site and transitions to fine sands in the vicinity of IWS-2 that are indistinguishable from the proximal unit.

- **Groundwater is present within the upper and lower proximal units, esker-delta unit, regolith, and fractured bedrock which form three separate but hydraulically connected systems.** A shallow overburden groundwater system is present within the upper proximal unit above the distal unit east and south of the SWDA and IWS areas and within the lower proximal unit and esker-delta unit west of the SWDA and IWS areas where the distal unit does not exist. Groundwater near the base of the lower proximal unit and within regolith form a top-of-rock groundwater system. The third groundwater system is fractured bedrock. Groundwater contained within these units flows in a west-southwesterly direction before discharging to the Passumpsic River.
- **Analytical data generated for soil samples collected during the RI indicate that subsurface soils beneath and adjacent to the IWS areas, particularly IWS-2 and IWS-3, were impacted with elevated concentrations of volatile organic compounds (VOCs) including tetrachloroethene, trichloroethene, and dichloroethenes and to a much lesser extent, semi-volatile organic compounds (SVOCs).** Impacted soils beneath these two areas extend downward to the water table. These data indicate that impacted soils at IWS-2 and IWS-3 were contributing sources of impact to groundwater. Industrial waste disposal area IWS-1 was not found to be a significant source of impact to groundwater as concentrations of constituents of interest, particularly VOCs, were observed to decrease with depth to non-detectable concentrations approximately 70 feet above the water table. With the exception of very low concentrations of trichloroethene and xylenes, VOCs were not detected in subsurface soils adjacent to the SWDA.
- **The shallow overburden, top-of-rock, and bedrock groundwater systems beneath and downgradient of two IWS areas (i.e., IWS-2 and IWS-3) and the SWDA are impacted by VOCs and to a more limited extent, SVOCs.** Based upon the distribution and types of VOCs detected in groundwater and analytical data for subsurface soils referenced above, leachate generated by precipitation infiltrating through the SWDA was judged to be a source of ketones (i.e., acetone, 2-butanone, 2-hexanone, and 4-methyl-2-pentanone) and aromatic VOCs (i.e., benzene, toluene, ethylbenzene, and xylenes) detected in groundwater.

Two primary sources of chlorinated organic compounds detected in groundwater were identified as impacted soils beneath IWS-2 located adjacent to the south end of the SWDA and IWS-3 located east of the SWDA.

Based upon recent analytical data generated during implementation of the Long-Term Monitoring Plan (LTMP), elevated concentrations of VOCs are present in groundwater contained within the shallow overburden and top-of-rock systems immediately adjacent to the SWDA/IWS areas, in particular IWS-2 and IWS-3. Elevated concentrations of VOCs (i.e., concentrations exceeding Interim

Groundwater Cleanup Levels [IGCLs]) in the shallow overburden groundwater system extend from IWS-3 south and west to monitoring well B136A (approximately 500 feet from IWS-2). Elevated concentrations of VOCs (i.e., concentrations of VOCs exceeding IGCLs) in the top-of-rock groundwater system extend approximately 1,900 feet southwest of IWS-2 and IWS-3 to monitoring well B126A. The distribution of impacted groundwater in bedrock is dictated in part by fracture orientation and interconnectedness and appears to be limited to areas immediately adjacent to or downgradient of IWS-2. The distribution of organic analytes exceeding the established IGCLs in the shallow overburden, top-of-rock, and bedrock groundwater systems based upon data collected during the October 2003 monitoring event are shown on Figures 2 through 4 and tabulated in Table 1. Impacted groundwater from the shallow overburden, top-of-rock, and bedrock groundwater systems is interpreted to ultimately discharge to the Passumpsic River located approximately 2,200 feet southwest of the SWDA and IWS areas.

In response to the findings of the RI, EPA performed a risk assessment to assess potential risks posed by impacted media identified during the RI. Findings of the risk assessment are documented in the Final Risk Assessment report (TRC Environmental Corporation [TRC], 1993).

Results of the risk assessment indicated a potential unacceptable risk associated with the ingestion of impacted groundwater if used as a residential water supply.

Vermont American completed a Feasibility Study (FS) to identify remedial measures. Subsequently, EPA's April 1995 Record of Decision (ROD) selected the array of remedial actions included as Alternative 3, which included the following components:

- Construction of multi-layer composite barrier caps over the SWDA and IWS areas to prevent contact with waste materials/impacted soils and to limit infiltration through these materials;
- Construction of surface water drainage controls to divert runoff away from the capped areas and manage surface water runoff;
- Construction and operation of gas management systems to limit gas accumulation beneath the cap and the potential for lateral migration of vapor-phase VOCs away from the SWDA and IWS areas;
- Monitored natural attenuation (MNA) of impacted groundwater located hydraulically downgradient of the capped SWDA and IWS areas;

- Construction and operation of a groundwater pump and treat system to limit migration of groundwater containing constituents of interest from the SWDA and IWS areas;
- Implementation of institutional controls to protect capped areas, prevent the use of groundwater potentially impacted by the site, and inform future purchasers of property of the groundwater restrictions associated with the property;
- Long-term monitoring of groundwater, surface water, and sediment to assess the effectiveness of the selected remedy in meeting response objectives;
- Performance monitoring and maintenance, as required, of engineered systems; and
- Five-year reviews to assure that the selected remedy is performing as designed and remains protective of human health and the environment.

All of these ROD-designated remedial actions, and modification of and additions to them, except pump and treat, have been implemented at the Parker Landfill. Specifically,

- Resource Conservation and Recovery Act (RCRA) compliant composite barrier caps and necessary surface water drainage controls and gas management systems were constructed over the SWDA and IWS- 1 and -3 between 1999 and 2000.
- Instead of constructing a cap at IWS-2, the waste materials and underlying soils above the water table at IWS-2 were relocated under the SWDA cap and a sedimentation pond was constructed within the excavation to manage runoff from the SWDA cap.
- An LTMP to evaluate trends in groundwater, surface water, and sediment quality was submitted to EPA and is being implemented. As of October 2003, thirteen LTMP sample collection events had been performed in accordance with the LTMP. Combined with the RI data, as well as with a pre-LTMP round of sampling performed in 1999, the data indicates that constituents of interest in groundwater downgradient of the SWDA and IWS areas are undergoing in situ natural attenuation.
- Institutional controls for protecting the landfill caps and restricting the use of impacted groundwater have been established by means of institutional control mechanisms. The EPA-approved Institutional Control Plan (ICP) prepared in accordance with the Administrative Order (AO) (effective date May 1, 1999) addresses downgradient, offsite groundwater use and implements groundwater reclassification, establishment of groundwater easements, and connection of residents to public water supply. Implementation of the ICP is substantially complete, including the September 2002 connection to public water of the only two remaining private water supply users located within the Institutional Control area.

- Performance monitoring of the landfill caps and gas management systems has been implemented and maintenance is performed as necessary.

Implementation of these remedial actions has met the National Contingency Plan (NCP) goal of protection of human health and the environment and achieved the groundwater RAOs established by EPA¹. Specifically,

- Construction and maintenance of the RCRA caps over the SWDA and IWS areas (including the excavation and relocation of impacted soils from IWS-2 to beneath the SWDA cap) has reduced mass loading of compounds of concern (COCs) to groundwater by substantially reducing infiltration through impacted soils and debris mass and thereby limited leachate generation. The RCRA caps have also effectively eliminated the transfer of COCs from impacted soil/waste to surface water and sediment by preventing runoff from contacting the impacted soil/waste.
- The active landfill gas extraction system installed in the SWDA and IWS-1 area is reducing concentrations of COCs in the debris mass that could otherwise continue to impact groundwater.
- All residences located hydraulically downgradient of the SWDA and IWS areas that could be affected by impacted groundwater originating from the Parker Landfill have been connected to the public water supply, residential wells which were previously used for water supply have been abandoned and/or removed, and Institutional Controls have been established which restrict the use of groundwater on properties currently or potentially affected by impacted groundwater. Therefore, the risk of ingestion or inhalation of unacceptable concentrations of VOCs in groundwater by current residents and for potential future residents has been eliminated.
- Data generated from the LTMP indicates that COCs in groundwater downgradient of the landfill are undergoing natural attenuation.

The project background is summarized in Appendix A.

An evaluation of the recent advances in groundwater remedial action technology show that groundwater pumping and above ground treatment with subsequent discharge of treated groundwater is not always cost effective and that new technologies can achieve

¹ The groundwater RAOs included in the ROD were to prevent ingestion of groundwater containing compounds of concern and to comply with ARARs. The NCP provides that a Feasibility Study is to develop alternatives that protect human health and the environment by recycling wastes or by eliminating, reducing and/or controlling risks posed through each pathway at a site (40 CFR 300.430(e)(2))

restoration of the aquifer more quickly and much less costly (i.e., EPA [1999], NRC [1994]). Furthermore, several elements which limit the cost effectiveness of the pump and treat remedy (e.g., surface water discharge requirement, multiple and varied compounds of concern requiring treatment) would be necessary features of the Parker landfill groundwater treatment system. In accordance with the provisions of Superfund Reform 3-2, URS Corporation (URS) completed a screening of new and existing technologies as applied to groundwater at the source area and downgradient of the Parker Landfill. Results of this screening are summarized in Table 2. Based on these screening results, selected remedial alternatives were retained and evaluated utilizing the detailed evaluation criteria contained in the NCP.

In accordance with EPA direction, the detailed analysis and evaluation was performed for the existing ROD selected remedy of source area pump and treat/downgradient monitored natural attenuation, for the true “No Action” alternative prescribed by the NCP, and for five new remedial alternatives based on the alternative technologies that were retained after the screening step. The retained alternatives analyzed and evaluated include:

ALTERNATIVE	SOURCE CONTROL REMEDICATION	DOWNGRADIENT REMEDICATION
NA (No Action)	None	None
1A (ROD Remedy)	Conventional groundwater extraction with above ground treatment and subsequent discharge of treated groundwater to the Passumpsic River (pump and treat)	Monitored Natural Attenuation (MNA)
1C (Contingency Remedy)	Conventional groundwater extraction with above ground treatment and subsequent discharge of treated groundwater to the Passumpsic River (pump and treat)	Conventional groundwater extraction with above ground treatment and subsequent discharge of treated groundwater to the Passumpsic River (pump and treat)
2A (In addition to No Action, retained to provide a range of alternatives)	MNA	MNA
4A	Permeable reactive barrier using zero-valent iron (PRB)	MNA
4B	PRB	Bio-Enhanced Attenuation
5B	Bio-Enhanced Attenuation	Bio-Enhanced Attenuation

In addition to this introduction, this Alternative Technology Analyses and Evaluation is presented in six sections. Section 2.0 presents an analysis of remedial action criteria including an assessment of current risks associated with groundwater, and assessment of management of migration/source control objectives, and applicable, relevant and appropriate requirements (ARARs). Section 3.0 discusses the identification and evaluation of potential remedial technologies. Section 4.0 provides a description of the assembled remedial alternatives based on the identified technologies, the screening of these alternatives, and a more detailed description and evaluation of the retained alternatives with respect to NCP evaluation criteria. Section 5.0 presents a comparative analysis of the alternatives and Section 6.0 presents conclusions developed from the technical analysis evaluation and identifies the preferred remedial action. Section 7.0

provides an implementation plan and schedule for the selected groundwater remedial action. Throughout the report, the presentation of technologies and alternatives is provided in the context of a post-ROD evaluation of significant new site related data and advancements in existing and new technologies that allow groundwater remediation to proceed at a lower cost and more quickly than it would if the ROD remedy were implemented.

2.0 REMEDIAL ACTION CRITERIA ANALYSIS

2.1 EVALUATION OF REMEDIAL ACTION OBJECTIVES

The RAOs for groundwater are described in *Section VII A. Statutory Requirements/Response Objectives* of the ROD and are as follows:

- Prevent ingestion of groundwater containing COCs in excess of federal or state standards, or posing a potential total cancer risk greater than 10^{-4} to 10^{-6} , or posing a potential hazard index greater than one;
- Comply with federal and state ARARs.

In addition, Section 300.430a(1)(iii)(F) of the NCP sets forth the expectation that usable groundwater be returned to its beneficial use wherever practical, within a timeframe that is reasonable given the particular circumstances of the site.

2.1.1 Evaluation of Current Risks for Groundwater

In 1993, EPA conducted a Risk Assessment to estimate the probability and magnitude of potential for unacceptable risk to human health and the environment related to exposure to COCs identified at the Parker Landfill. The risk assessment identified ingestion of impacted groundwater as the greatest potential risk to human health. Inhalation of airborne organic compounds generated during the potential use of impacted groundwater during showering activities was identified as a potential secondary risk to human health. These estimates of risk were based upon several assumptions including: the future use of groundwater from the Parker Property and surrounding area as a public water supply (e.g., to expand the town's current water supply); a part of the Parker Property being developed as a 25-unit residential community relying on groundwater as a water supply; and the use of groundwater as a water supply by several downgradient residences in the study area at the time of the risk assessment.

Based upon current conditions, these assumptions which were used to assess potential risk related to exposure to impacted groundwater are no longer warranted. As detailed below, without current and future groundwater users, and without exposure pathways or potential receptors, unacceptable risk related to exposure to impacted groundwater (either directly through ingestion or indirectly through inhalation of organic COCs diffusing from impacted groundwater to indoor air during showering activities) does not occur.

To support the characterization of the downgradient area as being located in an area suitable for groundwater supply well development, the ROD contains the following description of the Passumpsic River from St. Johnsbury north through Lyndonville and along the East and West Branches of the Passumpsic:

...areas underlain by thick deposits of coarse grained stratified glacial drift (which) have excellent groundwater potential. (They are) suitable for exploration to locate wells that should yield sufficient quantities of water to meet municipal and industrial requirements. Deposits are thinner and wells would be less productive along the margins of these areas.

Available information (e.g., hydrogeologic mapping) indicates that the study area is located along the referenced margin but is not located within a significant glacial drift aquifer that has sufficient yield to meet requirements for municipal or industrial use (Vermont Department of Water Resources, 1967). While there are some coarse grained soils present, hydrogeologic pre-design investigations undertaken since the ROD have confirmed that the study area contains bedrock outcrops and low permeability soils. Therefore, any future supply addition to a municipal system is unlikely to be located in the study area. Additionally, within the last four years the Town of Lyndonville has expanded its existing well field, located across town, to increase its water supply capacity. Because of this expansion, it is highly unlikely that the Town will increase its supply capacity in the future. It is also unlikely that the Town would develop a water supply downgradient of the landfill since Vermont Environmental Protection Rules, Chapter 12 (Water Supply Protection Rule) impose restrictions on the development of new water supplies potentially threatened by an existing source of contamination (e.g.,

downgradient of a landfill or in an area where sludge is spread). Part 3 of Appendix A of this rule states the following with respect to the development of new water supplies:

Proposed source site locations shall be remote from all sources of contamination, hydraulically upgradient of major sources of contamination, and situated so as to minimize the impact from water quality threats. Proposed [groundwater] source sites will not be approved by the Secretary in areas, which may create a public health hazard or unacceptable risk.

Other potential public and private water supply uses identified in the ROD included existing and future residents within the study area, mainly a proposed subdivision on Parker Properties southwest of the landfill. That subdivision will not be built and the Parker Properties are restricted for groundwater use. Currently, there are no private groundwater supplies used as a domestic water source within the study area. The two parcels most recently utilizing private wells for domestic water use (i.e., the Dodge and Sheltra properties) are now supplied with municipal water by the Town of Lyndonville and the wells formerly supplying these residences with water have been abandoned and/or removed in accordance with Vermont Water Supply Regulations. Future groundwater use within the study area will not occur because of regulatory restrictions for the development of new water supplies previously discussed and Institutional Controls. The Institutional Controls include the transfer of groundwater use rights via easement from private landowners to the State of Vermont and a local zoning restriction. These mechanisms will remain in place until the IGCLs are achieved for groundwater. The Institutional Controls also include reclassification of groundwater from Class III to Class IV (non-potable) in accordance with State of Vermont Groundwater Protection Rules,

Based upon the transfer of groundwater use rights to the State of Vermont, groundwater reclassification to Class IV, and zoning restrictions, there are no current groundwater risks and there will be no future groundwater risks that exceed EPA's risk criteria. The development of a subdivision on Parker Property anticipated in the ROD is precluded by

restrictions agreed to by Parker and EPA as part of Institutional Controls associated with landfill cap activities.

2.1.2 Management of Migration/Source Control Remedial Objectives

Based upon existing conditions at the Parker Landfill and the currently in place remedial actions at the Parker Landfill: 1) potential risk associated with possible exposure to impacted groundwater has been effectively eliminated; and 2) the aquifer is being restored as demonstrated by the LTMP data set collected from monitoring wells located within the current remedial action area of influence. Therefore, while the specific groundwater RAOs contained in the Section VII of the ROD are being met, additional RAOs can be identified for Source Control and Management of Migration of impacted groundwater:

- Limit additional mass flux of COCs from identified source areas to groundwater
- Accelerate the time required to restore the quality of groundwater adversely impacted by historical waste disposal activities at the landfill.

2.1.3 ARARs

The FS and ROD identified the following groundwater ARARs:

- Vermont Groundwater Protection Regulations (Vermont Environmental Protection Rule [EPR] 12),
- Vermont Hazardous Waste Regulations (EPR 7-502),
- Federal Safe Drinking Water Maximum Contaminant Levels (MCLs) (40 CFR 141 Subparts B, G, F, and I) and,
- Interim Groundwater Cleanup Goals.

These requirements are discussed in detail in the following sections.

2.1.3.1 Vermont Groundwater Protection Regulations

Vermont Groundwater Protection Regulations are an applicable requirement that establishes standards for groundwater quality in Vermont. Management criteria for each groundwater class (i.e., Class I to IV) are established as well as standards for groundwater protection, and response actions where a standard is exceeded. Under the Vermont Groundwater Protection Rule and Strategy, Class IV groundwater areas are to be designated where groundwater quality is not potable under existing conditions and is likely to remain non-potable (relative to the Groundwater Enforcement Standards) for a minimum of five-years. The management objectives for Class IV groundwater areas are prevention of adverse effects on adjacent Class I, II, and III groundwater areas and the achievement of groundwater quality standards to the extent possible within Class IV areas. The EPA Responsiveness Summary included in the ROD (Attachment E) states *“Containment of contaminants to allow for restoration of the aquifer is consistent with ARARs, including the management objectives for Class IV groundwater in the Vermont Groundwater Protection Rule.”* Section 12-504(2) of the Groundwater Protection Rule and Strategy provides that *“Class IV groundwaters will be managed to insure Class III standards or better at the border of the Class IV area and to improve the groundwater quality within the Class IV area.”* Also, Section 12-504(5) provides *“the Secretary will establish a program for groundwater quality monitoring within Class IV groundwater areas. The program will be updated as necessary to protect the public health, the Class IV areas, and adjacent groundwater.”* These monitoring requirements are applicable to the Class IV area, which has been established for groundwater at the Parker Landfill.

2.1.3.2 Vermont Hazardous Waste Regulations

Vermont Hazardous Waste Regulations address the operation, maintenance, and closure of licensed hazardous waste facilities. For the Parker Landfill, they relate to the type of cap required for closure. These regulations also generally require that impacts to

groundwater be remedied, however they do not prescribe the manner or levels of remediation. Instead they defer to other regulations and agencies as appropriate.

For the Parker Landfill, the Vermont Hazardous Waste Regulations look to the Vermont Groundwater Protection Regulations and the NCP for remedial criteria. Therefore, the Vermont Hazardous Waste Regulations are relevant and appropriate, but they furnish no technical requirements for groundwater RAOs.

2.1.3.3 Federal Safe Drinking Water Maximum Contaminant Levels

National Primary Drinking Water Regulations are legally enforceable water quality standards for public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in public water systems. Federal Safe Drinking Water MCLs refer to the maximum permissible level of a contaminant in water, which is delivered to any user of a public water system [40 CFR 141.2]. Maximum Contaminant Levels are based on human health risks due to exposure scenarios involving ingestion or other contact mechanisms resulting from public water system use. Maximum Contaminant Levels were included as ARARs for the Parker Landfill because 1) at the time of the ROD, water downgradient of the SWDA and IWS areas was used for domestic water wells; 2) continued residential development (e.g., a subdivision on Parker Property) was anticipated; and 3) it was thought that the plume might in the future impact “one of the few aquifers in northeast Vermont with the potential for future development of groundwater for industrial and municipal water supplies.”

These factors, which originally warranted designation of MCLs as an ARAR, are not currently present due to 1) the elimination of potential receptors of impacted groundwater by connection to the public water supply of groundwater users; and 2) the implementation of institutional controls to prevent the future development of impacted or potentially impacted groundwater as a water supply.

2.1.3.4 Interim Groundwater Cleanup Goals

Interim Groundwater Cleanup Levels were established for those COCs identified within the Baseline Risk Assessment that were found to pose an unacceptable risk to either public health or the environment. These levels have been set based on either ARARs, as available, or other suitable criteria (e.g., establishment of acceptable risk-based exposure levels). Table 1 has been provided as a compilation of those sampling locations that exceeded the respective IGCLs during the 2003 (April and October 2003) LTMP sampling events.

2.1.4 Restoration of the Aquifer

The remedial alternative designated by the ROD for the Parker Landfill was designed to restore groundwater. Through source control it restricts additional contaminants from migrating from the landfill to the downgradient area. It also allows for natural attenuation to restore groundwater downgradient of the SWDA and IWS areas. The ROD designated remedy did not include other remedial actions such as pump and treat to restore groundwater downgradient of the IWS areas or SWDA. Based on available data, in selecting the ROD remedy EPA recognized that the significantly higher costs for additional remedial actions to restore the downgradient aquifer would not provide a greater overall benefit. According to the ROD, the selected remedy was consistent with EPA's presumptive remedy for CERCLA Municipal Landfills. The Feasibility Study (ESE, 1994) provided an estimated aquifer restoration timeframe of 60 years for the remedy.

2.2 UPDATE ON REMEDIAL ACTION OBJECTIVES

Implementation of the ROD designated remedial actions and modifications and additions to them warrant a review of how the RAOs are achieved. In particular, the RAO of preventing risk posed by groundwater ingestion is currently being achieved through

remedial actions currently in place. Groundwater modeling performed as part of this analysis and evaluation confirm the opinion of the EPA as presented in the Responsiveness Summary that the impacted area is contained in a hydrogeologic closed loop between the landfill and the Passumpsic River and that the groundwater is intercepted by the river. Ongoing LTMP monitoring provides data to assess the distribution and concentration trends for COCs in groundwater to ensure that conditions do not change with regard to the nature and extent of impacts currently observed, or deviate from those forecasted by hydrogeologic modeling of the study area.

Also, as outlined in Section 2.1.3, ARARs are currently being met and the aquifer is being restored.

3.0 IDENTIFICATION AND SCREENING OF POTENTIAL REMEDIAL TECHNOLOGIES

In accordance with the provisions of Superfund Reform 3-2, and the purpose of this analysis and evaluation, URS has performed a screening of new and existing technologies that could potentially be applied to the Parker Landfill to restore groundwater more efficiently and cost effectively than the original pump and treat remedial action specified in the ROD. Technologies were evaluated with respect to the current understanding of characteristics of the study area and COCs. Study area characteristics considered during the screening process included the following:

- study area geology, hydrogeology, terrain, and climate;
- availability of resources necessary to implement the technology; and
- study area features (e.g., landfill caps, landfill gas collection system, wetlands).

The following contaminant characteristics were also considered:

- types and concentrations of COCs, and
- physical and chemical properties of the COCs (e.g., volatility, solubility, and mobility).

The technical understanding of study area characteristics and COCs has been expanded and modified since the original ROD remedy was selected, and the current state of knowledge has been incorporated into the identification of remedial technologies. Results of the initial technology screening are summarized in Table 2.

This evaluation of the groundwater remedy incorporates 1) additional field data not available in 1995 when the ROD was issued; 2) new technologies and improvements to existing technologies which may have shown success at similarly impacted facilities since completion of the FS in 1994; 3) acknowledgement by EPA (1997) that the effectiveness of pump and treat is frequently hindered and that pump and treat may be impractical at many sites; and 4) a review of the initial assumptions used to establish the

potential adverse effect to human health via ingestion of contaminated groundwater that no longer exist.

Field data included in this evaluation has been summarized in periodic LTMP reporting since January 2000, as well as monitoring well installation and testing performed in 2000 and documented in the January 2000 Long-Term Monitoring Report. The data set considered and presented herein is inclusive of the October 2003 monitoring results, which have been validated in accordance with the LTMP and submitted to EPA in the *Draft 2003 Annual Long-Term Monitoring Report* (URS, January 16, 2004).

Alternative technologies included in this analysis and evaluation are categorized in terms of general response actions. General response actions are qualitative measures for attaining compliance with RAOs and provide the basis for formulating site-specific remedial alternatives that achieve the RAOs for study area groundwater.

3.1 GENERAL RESPONSE ACTIONS

General response actions for the alternatives analyzed and evaluated as part of this assessment include:

- Containment – Containment is a means of controlling the movement of COCs in groundwater from the source area to downgradient groundwater. It can involve physical, chemical or hydraulic control measures. Containment technologies included as components of alternatives analyzed and evaluated include vertical barriers and active hydraulic controls.
- Treatment – Treatment involves measures designed to reduce the volume, toxicity, or mobility of contaminants by biological, physical, chemical, or thermal processes. Permeable reactive barriers, in situ chemical oxidation, or bio-enhanced attenuation are considered to be treatment technologies since reactive media and reagents are employed in situ to either promote reductive dechlorination or to directly oxidize organic COCs in situ to innocuous compounds (i.e., carbon dioxide and water). In the case of pump and treat, extracted groundwater is treated above ground through one or more treatment technologies. Treatment technologies under consideration for pump and treat include hydrogen peroxide oxidation, air stripping, activated carbon adsorption, and ultraviolet photolysis for treatment of VOCs, and hydroxide/carbonate precipitation, sulfide precipitation, ion exchange, and chemical fixation for

treatment of metals. Biologically mediated natural attenuation is also a treatment technology for impacted groundwater downgradient of the SWDA and IWS areas since COCs are naturally biodegraded to less toxic compounds through reductive dechlorination. Data generated as part of the LTMP confirms that natural attenuation is remediating site groundwater.

- Disposal - Disposal consists of measures to dispose of extracted groundwater and treatment residuals. Options for disposal of groundwater could be off-site disposal prior to treatment (e.g., to a publicly owned treatment works or treatment, storage and disposal [TSD] facility), off-site disposal following treatment on-site (e.g., to the Passumpsic River), or on-site disposal following treatment (i.e., infiltration or injection). Based upon the results of the initial screening summarized in Table 2, off-site disposal of groundwater at a treatment facility was judged to be prohibitively expensive and reinjection of treated groundwater on-site was judged to be infeasible since soils are stratified and not conducive to injection of large volumes (i.e., greater than 100 gallons per minute [gpm]) of water. Disposal of extracted groundwater treated on-site would have to be to the Passumpsic River via discharge pipe constructed for the purpose of conveying treated groundwater to the river for discharge. Disposal of treatment residuals (i.e., spent carbon, packing material for the air stripper, and/or sludges generated during treatment for metals) would be offsite through incineration or landfilling at a secure facility. Treatment residuals would likely be landfilled at a secure facility but ultimately, the method of disposal would be determined based upon characterization of the waste.

3.2 DESCRIPTION OF ALTERNATIVE TECHNOLOGIES

Based upon the results of initial screening of technologies summarized in Table 2, several technologies were combined into alternatives and retained for further evaluation. These alternatives were formulated by developing a matrix of viable technologies (i.e., ROD selected pump and treat remedial action with off-site disposal of residuals, in situ chemical oxidation, bio-enhanced attenuation, permeable reactive barriers, and monitored natural attenuation) applied to the source area and to downgradient areas.

As a result of discussions with EPA, this analysis and evaluation is focused on the alternative technologies of 1) The ROD specified pump and treat consisting of traditional groundwater extraction with ex situ treatment and surface water disposal of treated groundwater, 2) monitored natural attenuation 3) in situ chemical oxidation 4) permeable reactive barriers and 5) bio-enhanced attenuation. These five technologies were

subsequently evaluated in various combinations to address both source control remediation and remediation downgradient of the landfill and IWS areas. A description of these component technologies is presented in the following sections.

3.2.1 Pump and Treat and Surface Water Disposal of Treated Groundwater and Off-Site Disposal of Residuals

Groundwater pumping with ex situ treatment and on-site or off-site disposal of treated groundwater involves pumping impacted groundwater to the surface from groundwater extraction wells or trenches for treatment and subsequent disposal. Although this technology may capture and contain contaminant mass within a defined area, systems typically used to pump and treat impacted groundwater require high maintenance and generally are not considered to be an efficient or cost effective method of groundwater restoration, particularly in instances where the RAO for groundwater is restoration to drinking water standards (e.g., IGCLs). Several limitations of groundwater pump and treat contribute to the inefficiency and high cost associated with remediating groundwater using this technology. These limitations include:

- **Limitations Due to Residual Liquid Waste:** For pump and treat to be fully effective in remediating groundwater, the source of COCs must be eliminated. Otherwise, contaminant mass will continue to be added to the groundwater system. The mechanisms that contribute to groundwater impact at the Parker Landfill have been addressed through the remedial actions that are now in place. The removal of impacted soils above the water table at IWS-2 and construction of RCRA caps over the SWDA and IWS areas have significantly reduced mass loading of COCs to groundwater related to infiltration through waste and impacted soils and leachate generation. Vapor phase, and to a lesser extent liquid phase COCs are collected by the gas management system reducing the potential for diffusion of COCs into groundwater. Based upon the disposal history of the SWDA and IWS area, liquid wastes were disposed of. While non-aqueous phase liquids have not been identified or known to have been disposed at the site, small amounts of residual compounds could be present within soil pore spaces in the saturated zone. If present, removal of these wastes by pumping will be a slow process which is controlled by the dissolution (i.e., solubility) of the residual to groundwater. Even small amounts of residuals, if present, can contribute contaminant mass for extended periods and will significantly prolong and increase the cost associated with restoration of groundwater using pump and treat.

- **Limitations Due to Sorption of Contaminant Mass:** While groundwater pumping can effectively remove highly mobile compounds, concentrations of compounds that exhibit moderate to high organic carbon partitioning coefficients (including the chlorinated VOCs found at the Parker Landfill) tend to sorb onto soils and may not be efficiently or cost effectively reduced by groundwater pumping. Since groundwater velocities in impacted media are increased in response to pumping, concentrations of COCs may not build up to equilibrium concentrations and contaminant removal efficiency will be low and decrease with each pore volume extracted.

A second limitation of groundwater extraction associated with sorption of contaminant mass occurs as a result of dewatering potentially impacted soils. During pumping, a cone of depression develops as water is released from storage and drains from the soil pore space above the cone of depression. A consequence of the release of water from the pore spaces is that soils above the cone of depression are dewatered. If the dewatered soils contain significant concentrations of organic COCs, concentrations of organic COCs in the dewatered soils will not be significantly reduced until the groundwater extraction system is shutdown and groundwater levels recover to pre-pumping conditions. At that time, organic COCs will desorb from the previously dewatered soils into groundwater to concentrations potentially above IGCLs. Removal of organic COCs under such conditions may require a long period of cycled pumping (i.e., periods of active pumping followed by groundwater recovery) to flush COCs from the dewatered soils after IGCLs have been achieved in saturated soils.

- **Limitations Due to Matrix Diffusion from Heterogeneous Media:** When COCs are released to the environment and advance through relatively permeable pathways in a heterogeneous media, concentration gradients develop and can cause diffusion of COCs into adjacent less permeable media. During groundwater pumping, dissolved concentrations of COCs in the relatively permeable zones are reduced by advective flushing, causing a reversal in the initial concentration gradient and very slow diffusion of contaminants from the lower permeability to adjacent higher permeability media. Matrix diffusion often results in a rebound in concentration of COCs above cleanup goals after a groundwater extraction system has been shut down. Such rebound may require long-term cycled pumping to permanently reduce concentrations of COCs to target cleanup goals. The effects of matrix diffusion and rebound in the concentrations of COCs can be anticipated to occur over a timeframe similar to the time period over which COCs were diffusing into the less-permeable media.
- **Limitations Due to Maintenance:** Groundwater pump and treat systems involve a large number of mechanical components as well as treatment media that are subject to fouling and breakdown which can result in frequent shutdowns of the system and elevated operational costs. Based upon a review of performance data for 28 groundwater extraction and treatment systems of various sizes evaluated by EPA (1999), the average annual operating and maintenance cost for these systems was \$190,000. Twenty-one of the systems included in the evaluation required major modifications to increase performance of the system. Six of these 21

systems required significant modifications in an attempt to control maintenance costs associated with fouling and at least one system that was evaluated was dismantled and replaced with an in situ reactive barrier system due to excessive fouling and maintenance costs.

It should also be recognized that since treatment system residuals require off-site disposal at permitted disposal sites, the operation of groundwater extraction and treatment systems assumes that permitted disposal facilities with the ability to receive treatment wastes will exist through the life expectancy of the system.

In addition to the limitations described above, it is important to note that groundwater pumping with ex-situ treatment does not necessarily reduce the volume or toxicity of COCs since the treatment process generates significant volumes of concentrated metals sludge and impacted treatment media (e.g., granular activated carbon or air-stripper packing material) which requires frequent replacement and disposal.

Due to the significant saturated thickness and depth to groundwater downgradient of the SWDA, trenches could not be easily implemented on a site wide basis to extract groundwater for treatment. Thus, for the Parker Landfill, a series of groundwater extraction wells completed immediately downgradient of the SWDA and IWS areas would be used to pump impacted groundwater to the surface for treatment. Once at the surface, extracted groundwater must be treated to reduce concentrations of metals and VOCs prior to discharge to the Passumpsic River. Metals would, in all likelihood, be treated using hydroxide/carbonate precipitation, sulfide precipitation, ion exchange, or chemical fixation or a combination of these technologies. Volatile organic compounds would likely be treated using one or more of the following technologies: hydrogen peroxide oxidation, air stripping, activated carbon adsorption, and ultraviolet (UV) photolysis. Extensive long-term performance monitoring would be required to assure that the groundwater pumping system is effectively controlling the migration of COCs and that the treatment system is reducing concentrations to criteria acceptable for discharge to the Passumpsic River. Based on communications with EPA, the treatment system associated with the groundwater remedy would be required to meet applicable

surface water criteria at the point of discharge prior to dilution. Residuals generated from treatment system processes would also require analytical testing to identify appropriate methods for disposal.

3.2.2 Monitored Natural Attenuation

Monitored natural attenuation involves a reduction in concentrations of COCs through naturally occurring attenuation processes, principally sorption, dilution, dispersion, volatilization, and biodegradation, which can be evaluated through monitoring of the groundwater chemistry. The effectiveness of monitored natural attenuation is typically demonstrated by decreasing concentrations of parent COCs (i.e., those compounds disposed of during landfill operation) accompanied by the presence of transformation products, which are created only via the in situ attenuation processes. A demonstration of ongoing natural attenuation includes monitoring for the presence of geochemical conditions that indicate a favorable environment for natural attenuation (e.g., low redox potential/low dissolved oxygen concentration for reductive dechlorination of chlorinated VOCs). The EPA has identified the following advantages of monitored natural attenuation as a remedial alternative:

- Limited or no remediation wastes are generated and thus, there is reduced risk to human health and the environment related to exposure to impacted media;
- With the exception of periodic groundwater monitoring, MNA does not require intrusive activities that could result in increased exposure to impacted media or the transfer of impacted media to off-site locations for disposal;
- When combined with institutional controls restricting the development of impacted groundwater as a water supply and in the absence of the use of potentially affected groundwater as a water supply, MNA can provide equal or better protection of human health and the environment as compared to active remedial measures due to the reduced volume of remediation-derived wastes and thus exposure to these wastes;
- Monitored natural attenuation can be used in conjunction with other compatible remedial actions; and
- Costs associated with implementation of MNA are lower than those associated with remedial actions requiring ongoing activities.

The most critical component of the natural attenuation process is an adequate performance monitoring program that 1) demonstrates that natural attenuation processes are occurring and effectively reducing concentrations of COCs; 2) documents that the areas of groundwater impacts are contained within a designated area (e.g., the plume is contained by hydrogeologic boundaries); and 3) provides for the detection of conditions that could adversely impact natural attenuation (e.g., changes in geochemical conditions).

Because monitored natural attenuation is a remedial action designated in the ROD, the LTMP is structured to provide data necessary for the assessment of the effectiveness of natural attenuation processes. Data obtained from Long-Term Monitoring between January 2000 and October 2003, as documented in the periodic monitoring reports submitted to EPA, define site conditions relative to natural attenuation processes as follows.

3.2.2.1 Shallow Overburden Groundwater

Distribution of Chlorinated Volatile Organic Compounds

Chlorinated VOCs are detected in shallow overburden groundwater in areas proximal to the landfill, downgradient of the IWS-3 and former IWS-2 disposal areas. Chlorinated VOCs are consistently detected in monitoring wells B103A, B133 and B139A located downgradient of IWS-3, B136A, B126S and MW4A located downgradient of IWS-2, and B138A located west of the landfill. The distribution of chlorinated compounds that exceed the IGCLs is depicted spatially in Figure 5, and includes an area which extends approximately 1,700-feet in length and 300-feet in width. Groundwater impacts are delineated laterally by non-detections of chlorinated compounds in sidegradient monitoring wells B102A, B113A, B131B and downgradient monitoring wells B120A and B201OW.

The ratio between parent compound (e.g., trichloroethene) and degradation by-products (e.g., dichloroethenes, vinyl chloride) in impacted areas of shallow overburden

groundwater generally exceeds 1.0, indicating the concentrations of parent compounds exceed those of the degradation by-products. The ratio for the October 2003 data set, as shown in Figure 5, ranges from between 20.18 at B103A and 1.39 at B139A. This data suggests that the reductive dechlorination occurring in these areas (as evidenced by the presence of degradation by-products) is somewhat limited as concentrations of parent compounds (e.g., trichloroethene) generally exceed concentrations of by-products.

Distribution of Non-Chlorinated Organic Degradation By-Products

Non-Chlorinated VOC degradation by-products (i.e., ethylene, ethane) are not detected (with a single exception at B133) in the shallow overburden monitoring wells.

In situ Geochemistry

Geochemistry, as defined by indicator parameters such as dissolved oxygen concentrations and oxidation-reduction (redox) potential indicate a non-reducing environment with generally elevated levels of dissolved oxygen (ranging from 10.69 milligrams per liter [mg/l] to 2.54 mg/l), and positive redox potentials (ranging from +145.2 to +55.4 millivolts [mV]) as shown in Figure 5. Generally elevated concentrations of dissolved oxygen and positive redox potential are indicative of an oxygenated environment which would not support the reduction of chlorinated VOCs through in situ reductive dechlorination processes.

Methane concentration, an indicator of methanogenic conditions most favorable for natural attenuation through reductive dechlorination were non-detect, further supporting the geochemical data which indicated that conditions do not support robust reductive dechlorination of COCs.

Groundwater total organic carbon (TOC) concentration data obtained for select monitoring wells as part of the October 2002 LTMP monitoring event indicated relatively low TOC concentration from wells located with the area of shallow groundwater impacts.

Results included 2.08 mg/l at B139A, 6.81 mg/l at B133, and non-detect at B136A. Low TOC concentrations such as these observed generally do not support reductive dechlorination processes as TOC acts as a cometabolic substrate for the microbial activity, which results in reductive dechlorination.

Concentration Trends

As discussed in the periodic Long-Term Monitoring Reports, the distribution of chlorinated VOCs in shallow overburden groundwater is limited in extent and may be influenced through recharge to this groundwater flow zone by oxygenated precipitation infiltration and surface water infiltration. Of the currently impacted wells within this zone, concentrations of chlorinated VOCs are decreasing in monitoring wells B133, B103A, and B139A, likely resulting from recently completed landfill closure activities. Monitoring well B136A, where exceedences of IGCLs have also been observed, exhibits stable to slightly increasing concentrations. Concentration decreases at MW4A have resulted in concentrations no longer exceeding IGCLs. Figures 6 through 10 depict these trends as monitored during the course of the LTMP implementation.

3.2.2.2 Top-of-Rock and Bedrock Groundwater

Distribution of Chlorinated Volatile Organic Compounds

Chlorinated VOCs are detected in top-of-rock and bedrock groundwater in areas located downgradient of IWS-3 and IWS-2, and in the vicinity of IWS-1. Chlorinated VOCs are observed at concentrations exceeding IGCLs in monitoring wells B113BB, B138B, and B131C located downgradient of the western edge of the landfill (including IWS-1), and in top-of-rock/shallow bedrock monitoring well couplets B132/B132B, B136B/B136C, B125A/B125B, B120C/B120D, B126A/B126B and B145B/B145C located downgradient of IWS-2. The distribution is depicted spatially in Figures 3 and 4, and includes an area which extends approximately 2,200-feet in length. The plume is delineated laterally by non-exceedences of chlorinated compounds in side gradient monitoring wells

B118B/B118C, B119C/B119D, B122 and B144B/B144C, and by upgradient monitoring wells B143, B139C, B103C, B101B, and B102B.

As shown in Figure 11, the ratio between parent compound (e.g., trichloroethene) and degradation by-products (e.g., dichloroethenes, vinyl chloride) in the area downgradient of the western edge of the SWDA is much less than 1.0, indicating the concentrations of parent compounds are significantly lower than concentrations of the degradation by-products, and for the October 2003 data set ranges from between 0.0044 at B113BB and 0.62 at B131C. These ratios indicate robust degradation of the chlorinated compounds is occurring in this area.

Chlorinated degradation by-products are also detected in groundwater located downgradient of IWS-3 and the former IWS-2, with the ratio of parent compound to degradation by-product generally between 0.75 and 2.5, ranging from 0.053 at B132B to 9.70 at B120C, indicating that the ongoing reductive dechlorination is less robust in the downgradient area than in the groundwater located in upgradient areas closer to the source.

Distribution of Non-Chlorinated Organic Degradation By-Products

Concentrations of ethylene and ethane are detected in top-of-rock and bedrock groundwater. However low concentrations cannot generally be observed in the samples due to elevated detection levels resulting from high concentrations of methane detected in these wells. Ethane and/or ethene were detected in B113BB, B120C, B120D, B125B, B126A, B131C, B132B, B136B, B136C, and B138B during the October 2003 LTMP sampling event. Methane, also a potential degradation by-product, is detected at the highest concentrations within the portion of the groundwater impact area downgradient of the western edge of the SWDA, with October 2003 concentrations ranging from 23 mg/l at B137B to 44 mg/l at B131C. Methane concentrations associated with the portion of groundwater impacts located downgradient of IWS-3 and the former IWS-2 were more

varied, ranging from 37 mg/l at B136C to non-detect at B132/B132B, but were generally less than 7 mg/l.

In situ Geochemistry

Reduced concentrations of dissolved oxygen representative of anoxic conditions, and negative redox potentials are indicative of a reducing groundwater environment which would support the reduction of chlorinated VOCs through in situ reductive dechlorination processes. These attributes are observed in top-of-rock and bedrock groundwater tested from areas of chlorinated VOC impacts.

For the area of groundwater impacts situated downgradient of the western edge of the SWDA, redox potentials are less than -180 mV, and dissolved oxygen concentrations are less than 0.65 mg/l, indicative of a strongly reducing environment consistent with the high degree of degradation observed in the area monitoring wells (i.e., low parent to degradation by-product concentration ratio).

For the area of groundwater impacts located downgradient of IWS-3 and the former IWS-2 (with the exception of B132), redox potentials are less than 0 mv, and dissolved oxygen concentrations are less than 1.0 mg/l, indicating favorable conditions for reductive dechlorination, consistent with the observed degradation, as defined by the presence of degradation by-products at concentrations of similar magnitude to parent compounds (e.g., parent/degradation by-product concentration ratio generally less than 1.5).

Groundwater TOC concentration obtained for select monitoring wells as part of the October 2002 LTMP monitoring event indicated elevated TOC concentrations in sampled wells located downgradient of the western edge of the SWDA, including 571 mg/l at B113BB, 196 mg/l at B138B, and 94.7 mg/l at B131C. These elevated TOC concentrations further support the apparently robust attenuation occurring in this portion of the aquifer by providing for the cometabolic substrate necessary to sustain the microbial activity which results in reductive dechlorination. Wells located downgradient

of the former IWS-2 area which were sampled for TOC included B136B (3.89 mg/l) and B120C (non detect). These low concentrations of TOC may act to limit the ability of the reductive dechlorinate process to significantly degrade the parent compounds in groundwater.

Concentration Trends

Decreasing concentration trends are evident in the analytical results from monitoring wells located in the northern portion of the groundwater impact area, adjacent to the west side of the SWDA, including monitoring wells B113BB, B138B, and B131C. These trends are depicted graphically on Figures 12 through 14.

Concentration trends in top-of-rock and bedrock monitoring wells located downgradient of IWS-3 and the former IWS-2 and close to the source areas indicate generally decreasing concentration trends, as evident in monitoring wells B132, B132B and B136C. Concentration trends in areas located further downgradient of IWS3 and the former IWS-2 indicate generally increasing concentration trends, as evident in monitoring wells B126A, B125B, B126B, B136B and B120C. As all these wells have exhibited impacts throughout the period of LTMP implementation (i.e., since 1999), there is no evidence of spreading of the plume, but rather a migration of VOC mass into the downgradient areas. At the time of the RI, groundwater impacts had not yet reached the downgradient flow area represented by B120C. Due to variability in sample collection methods, the data collected from B120D cannot be used to infer trends. These trends are depicted graphically in Figures 15 through 23.

Based on estimated travel times, the elevated concentrations of chlorinated VOCs observed at B136B over the last three years are likely the result of construction activities occurring in 1999, which disturbed and exposed impacted soils at IWS-2 during relocation of the unsaturated portion of the disposal area. As evident in Figure 19, sharp increases in concentrations of chlorinated VOCs are evident in the data set and occur at non-uniform time periods, with the more mobile (less retarded) compounds observed to

spike higher at earlier times (e.g., vinyl chloride) as compared to the more highly retarded compounds (e.g., tetrachloroethene). In general VOC concentrations at B136B have been decreasing since October 2002.

3.2.3 In situ Chemical Oxidation

In situ chemical oxidation is a remedial technology that permanently reduces the volume and toxicity of organic COCs, in particular halogenated alkenes such as those present in site groundwater (i.e., tetrachloroethene, trichloroethene, dichloroethenes, and vinyl chloride). In situ chemical oxidation involves the introduction of reagents into the groundwater to rapidly oxidize organic COCs including chlorinated alkenes and, to a lesser extent, chlorinated alkanes (e.g., 1,1,1-trichloroethane and dichloroethanes) to innocuous byproducts (i.e., carbon dioxide, water, and chloride ions). Reagents typically used include hydrogen peroxide, Fenton's Reagent, ozone, potassium permanganate, or sodium permanganate. The reaction stoichiometry for the oxidation of constituents of interest at the Parker Landfill is well understood and published in remediation literature (Siegrist et al., 2001; Interstate Technology and Regulatory Cooperation Work Group).

Factors affecting the successful implementation of in situ chemical oxidation include:

- Contaminants of interest targeted for chemical oxidation;
- Contaminant phase (i.e., dissolved, sorbed, or non-aqueous phase liquid);
- Mass of non-VOC organic carbon in the groundwater system;
- Groundwater flow system characteristics (i.e., hydraulic conductivity and presence of heterogeneities); and
- Presence of redox sensitive metals.

Each of these criteria as they apply to the Parker Landfill is discussed below.

In situ chemical oxidation is capable of treating a wide range of organic compounds including chlorinated alkenes, polycyclic aromatic hydrocarbons, aromatic volatile organic compounds, petroleum products and, to a lesser extent, chlorinated alkanes.

While most of the reagents listed above are capable of oxidizing organic COCs at the site (i.e., tetrachloroethene, trichloroethene, dichloroethenes, and vinyl chloride), permanganate and Fenton's Reagent are considered to be the most efficient and effective reagent for oxidizing these particular compounds.

In situ chemical oxidation is effective in treating a wide range of contaminant concentrations ranging from part per million (ppm) to part per billion (ppb) levels. Significant reductions in concentrations of VOCs have been reported within a very short time period after application (i.e., days to weeks) at sites where in situ chemical oxidation has been employed. In situ chemical oxidation does not appear to be limited by concentrations of the target constituents. However, multiple applications of reagent may be required to achieve remedial goals at sites where significant contaminant mass is present as residual non-aqueous phase liquid or in a sorbed phase.

A major drawback of in situ chemical oxidation is that reagents are non-selective with respect to organic carbon. Both natural and anthropogenic sources of carbon (i.e., fatty acids in leachate as well as VOCs) will be oxidized by the reagent. Therefore, the volume and dose of reagent required to achieve remedial objectives will be greatly influenced by the amount of organic carbon in saturated soil and groundwater. High concentrations of organic carbon (i.e., greater than 50 mg/l) will increase the cost. Selected groundwater samples collected during the October 2002 long-term monitoring event were analyzed for total organic carbon to provide data to assist in estimating the volume of reagent required to treat constituents of interest at the site and associated costs. These wells included shallow overburden monitoring wells B133, B136A, B138A, and B139A and top-of-rock wells B113BB, B120C, B131C, B132, B136B, and B138B. The total organic carbon concentration for top-of-rock wells located in the immediate vicinity of the SWDA and IWS areas (i.e., monitoring wells B113BB, B138B, and B132) ranged from 1.2 mg/l at monitoring well B132 to 571 mg/l at monitoring well B113BB and exhibited a geometric mean concentration of approximately 51 mg/l. As expected, the geometric mean concentration of total organic carbon for groundwater in the top-of-rock groundwater system downgradient of the SWDA and IWS areas based upon data from

the remaining top-of-rock monitoring wells was significantly lower (i.e., 7 mg/l). Total organic carbon concentrations in shallow overburden groundwater ranged from not detected at a reporting limit of 1.0 mg/l at monitoring well B136A and B138A to 6.81 mg/l at monitoring well B133. These data indicate that with the exception of a localized area in the vicinity of monitoring well B113BB and B138B immediately adjacent to the SWDA, organic carbon demand is within a reasonable range for implementation of in situ chemical oxidation, however, a higher dose and application rate of reagent would be required to satisfy the oxidant demand in the top-of-rock zone immediately southeast of the SWDA.

The effectiveness of in situ chemical oxidation is dependent, in part, on the ability to deliver reagents to the media impacted by constituents of interest. Consequently, an understanding of heterogeneities in a groundwater flow system and the hydraulic conductivity of saturated soils targeted for treatment will determine the suitability and effectiveness of in situ chemical oxidation as a remedial technology at a particular location. Saturated soils exhibiting a hydraulic conductivity of 1×10^{-4} centimeter per second (cm/sec) or higher are best suited for the delivery of reagents to impacted groundwater. Based upon data presented in the RI report (i.e., Table 3-5) and pre-design investigation activities, the horizontal hydraulic conductivity of the groundwater flow systems in the vicinity of the IWS areas are on the order of 1×10^{-4} cm/sec to 1×10^{-5} cm/sec and thus, hydraulic conductivity may be a potential limiting factor for in situ chemical oxidation at the Parker Landfill.

Geologic information obtained during and subsequent to the RI indicates that saturated soils in the area of the IWS areas and SWDA are somewhat heterogeneous and characterized by cross-bedded sands and silty sands of varying grain-size. It should be noted that in situ chemical oxidation is more effective than groundwater extraction at reducing concentrations of COCs in heterogeneous lower permeability media since the high concentrations of reagents used for in situ chemical oxidation result in the development of strong inward concentration gradients that deliver the reagent into low permeability media that may contain COCs. This inward concentration gradient for the

reagent is typically much greater (by orders of magnitude) than the outward concentration gradient produced by the diffusion or desorption of COCs from the lower permeability media. For this reason, in situ chemical oxidation can result in more rapid remediation of groundwater as compared to groundwater pumping.

Because saturated soils in the area of the IWS areas and SWDA are heterogeneous, the method used to introduce reagents must be designed to assure that reagents are effectively circulated throughout the impacted zones. Reagents used are typically introduced into the groundwater targeted for treatment through one of the following methods:

- 1) Direct pressure injection to discrete targeted intervals through direct-push or augered probes with regularly spaced perforated intervals; or
- 2) Closed loop recirculation via a series of horizontal or vertical injection wells for reagent delivery and extraction wells to promote recirculation of the reagent through impacted areas of the groundwater system.

The method of reagent delivery for the Parker Landfill may utilize one or a combination of these methods depending on several factors including accessibility, depth of injection, volume of reagent required for treatment, anticipated need for multiple injections to achieve cleanup goals, and cost. Ultimately, the method of delivery would be determined during the design phase of the project.

Factors affecting the implementability of this alternative are; 1) the technology has been proven effective for remediation of chlorinated VOCs in groundwater; 2) the chemicals could be applied to affected groundwater using proven methods (e.g., geoprobe or vertical wells); and 3) services and materials associated with this technology are readily available. Coordination with regulatory agencies will be necessary to assure that requirements of the Vermont Underground Injection Control (UIC) program for the application of in situ chemical oxidation are met.

At some sites, certain redox-sensitive metals (notably chromium, nickel, and selenium) that may be sorbed onto soils in reducing environments with near neutral pH, have been reported to be mobilized as a result of changes in redox (reduced to highly oxidizing environment) and pH that occur in response to the application. Based upon a preliminary review of the data that is available for subsurface soils at the Parker Landfill presented in the RI, concentrations of redox-sensitive metals detected in subsurface soils may not be sufficient to result in elevated metals concentrations in groundwater. The potential for mobilizing unacceptable concentrations of metals from soil in areas proposed for treatment can be evaluated as part of bench scale or pilot-scale testing. If warranted, metals mobility could be controlled through the use of less concentrated reagents or process controls such as sequestering agents.

Additionally, certain reagents (e.g., potassium permanganate) used to treat chlorinated VOCs can contain naturally occurring salts or metals for which there may be relevant criteria or standards. Reagents that limit the potential introduction of unacceptable concentrations of naturally occurring metals or salts into the targeted groundwater systems would be identified for use in applications at the site.

As noted above, changes in groundwater redox and pH occur in response to chemical oxidation. These changes are generally independent of the specific reagents used. While changes in redox and pH have the potential for mobilizing certain redox sensitive metals as noted above, other redox-sensitive metals (e.g., arsenic, iron, and manganese) may precipitate as metal oxides under oxidizing conditions. Based upon case studies of in situ chemical oxidation, some researchers have reported up to an order of magnitude reduction in hydraulic conductivity in response to the formation of iron and/or manganese oxides whereas other researchers have reported increases in hydraulic conductivity following in situ chemical oxidation (Siegrist et al., 2001). Treatability tests can be performed to identify appropriate dosing rates to help minimize the potential for adverse impacts related to the formation of metal oxides during treatment.

In addition to the factors described above that affect the effectiveness of in situ chemical oxidation as a technology for reducing concentrations of organic COCs in groundwater, it should be noted that reagents used will temporarily modify geochemical conditions in the target groundwater system (i.e., increase the redox potential and reduce pH). Consequently, facultative anaerobes may assume a more prominent role in natural attenuation of organic COCs following the application as compared to anaerobic microorganisms.

In summary, conditions at the Parker Landfill appear to be favorable for in situ chemical oxidation. Specifically,

- In situ chemical oxidation has been demonstrated to be effective in reducing concentrations of organic compounds including chlorinated alkenes such as those existing in impacted groundwater at the Parker Landfill;
- Constituents of concern are amenable to treatment; and
- Hydraulic characteristics (hydraulic conductivity) of impacted groundwater flow systems at the Parker Landfill appear to be moderately favorable.

Methods for limiting mobilization or introduction of redox sensitive metals and adverse impacts related to the formation of metal oxides or impacts to microorganisms in the target groundwater system would be assessed and addressed during treatability testing and design.

3.2.4 Zero-Valent Iron Permeable Reactive Barrier

Permeable Reactive Barrier (PRB) technologies using a reactive media of granular zero-valent iron have been successful in treating chlorinated COCs in groundwater by permanently reducing the volume and toxicity of the contaminants through reductive dehalogenation as electrons transfer from the iron to halogenated VOC at the contact point, which is the iron surface. The result is halogen ions being replaced by hydrogen species that yield the non-halogenated compounds ethene or ethane, which are in turn mineralized by biodegradation in the aquifer downgradient of the treatment cell. The contact between the

iron and the halogenated compounds occurs within the constructed treatment cell, which is designed to optimize groundwater contact and residence time while minimizing limitation on hydraulic conductivity. For shallow applications diversion barriers may be used in combination with reactive media treatment cells to direct groundwater into the treatment cell, with both the diversion barrier and the treatment cell being constructed using trenching technologies. For deeper applications, treatment cells are generally designed in the form of a permeable barrier to intercept the impacted groundwater flowing under natural flow gradients. These treatment cells are generally constructed using biopolymer slurry trenching or subsurface injection technology and have been constructed at depths of up to 125 feet below ground surface. In either case, the hydraulic gradient acts to transmit impacted groundwater into and through the treatment cell without active measures (e.g., pumping).

For trichloroethene, which is the primary compound in terms of contaminant mass within the aquifer downgradient of the Parker Landfill, complete degradation to ethene/ethane has been achieved at full-scale applications using zero-valent iron. The degradation pathways identified include sequential hydrogenolysis, which generates chlorinated daughter products (i.e., dichloroethene, vinyl chloride), which subsequently undergo reductive dehalogenation but at sequentially slower rates; and reductive beta-elimination, which produces the intermediate compound chloroacetylene, which is rapidly reduced to ethene.

The EPA has recognized zero-valent iron PRBs as being effective in the remediation of groundwater contamination at sites while achieving significant cost savings compared to more traditional pump-and-treat methods (EPA, 1998). EPA (1998) has recognized the advantages of PRBs include: 1) the capacity to completely degrade chlorinated VOCs to inert, non-chlorinated by-products; 2) the minimal maintenance and energy requirements associated with the passive treatment remedy; 3) having contaminants remain in situ during the treatment process; and 4) minimal maintenance requirements following installation.

One of the primary design components of the PRB is the estimation of required residence times for groundwater within the treatment zone to allow for the degradation of the parent compound and all halogenated daughter products that are generated within the cell. Column

testing of zero-valent iron using site groundwater from monitoring well B136B was performed to: 1) identify the most effective reactive media for treating chlorinated VOCs in groundwater; 2) determine the required residence time for groundwater passing through the reactive treatment media to permit adequate treatment; and 3) assess potential fouling of the reactive treatment media resulting from precipitation of metals or biological growth on the media.

Column testing of study area groundwater indicated that chlorinated VOCs present in groundwater can be degraded to concentrations below IGCLs using commercially available zero-valent iron. Results of the column testing were subsequently used to develop a model to identify the residence time necessary to reduce concentrations of chlorinated VOCs detected in groundwater in the source area to IGCLs. The residence time required to degrade chlorinated VOC concentrations to achieve IGCLs using the most efficient zero-valent iron tested is approximately 3.2 days. Although mineral precipitates (e.g., carbonates) might form on reactive media in a field scale PRB, the formation of these precipitates is unlikely to occur during initial years of operation and the chemistry of study area groundwater does not indicate that the reaction of groundwater with zero-valent iron will be unusually prone to the formation of precipitates. Using a reactive medium with a hydraulic conductivity one to two orders of magnitude greater than the surrounding geologic media should limit the potential for unacceptable fouling of the PRB.

A field investigation program was implemented in the study area downgradient of IWS-3 (i.e., source area) to assess the factors critical to the design and implementation of a PRB (e.g., vertical and lateral extent of impacts, groundwater seepage velocity, soil stratigraphy). A total of twenty-two monitoring wells were installed to obtain the data necessary to determine the above design factors. As outlined in *the Draft Source Pre-Design Technical Report for Groundwater Remediation* (URS, January 9, 2004), the hydraulic characteristics of the groundwater system and study area geology were determined to be favorable for the successful implementation of PRB technology to address impacted groundwater at the Parker Landfill.

3.2.5 Bio-Enhanced Attenuation

Bio-enhanced natural attenuation is a proven remedial technology that utilizes indigenous or amended microbial populations in situ to degrade non-anthropogenic carbon sources (e.g., chlorinated hydrocarbons). Use of this technology incorporates the application and delivery of reagents (e.g., organic carbon) to the subsurface environment to create a favorable environment for the growth of the existing microbial populations that utilize constituents of interest as an electron acceptor. Potential enhancing reagents include such products as hydrogen release compounds (HRC), sodium lactate, and molasses. These amendments provide the carbon source for the microorganisms to increase and subsequently to metabolize various electron acceptors (e.g., chlorinated VOCs, nitrate, sulfate).

Data collected at the Parker Landfill during the LTMP sampling events and pre-design investigation activities indicate that impacted groundwater in the downgradient study area is reduced and anaerobic. Chlorinated VOCs tend to degrade more quickly under anaerobic conditions than aerobic conditions. Findings from the pre-design investigation indicate that conditions are favorable for the use of bio-enhanced natural attenuation to remediate downgradient groundwater at the Parker Landfill. Criteria that were determined to be favorable for the implementation of this technology include: 1) hydraulic conductivity and grain-size distribution; 2) presence of degradation products; 3) absence of non-aqueous phase liquids (NAPL); 4) alkalinity conditions; and, 5) temperature, pH, and redox potential conditions. Each of these criteria is discussed in the following paragraphs.

1. To effectively deliver the nutrients and other reagents to the subsurface environment, the hydraulic conductivity needs to be a minimum of 10^{-4} centimeters per second (cm/sec) and should exhibit a wide range in grain-size distribution. Subsurface soils with lower hydraulic conductivities (e.g., silts, clays) can hinder the delivery of reagents and tend to be more vulnerable to biofouling and metal precipitation. The mean hydraulic conductivity of the downgradient study area was determined to be approximately 5.4×10^{-4} cm/sec. Data obtained during the subsurface field investigation activities indicate the soil unit is a poorly graded sand, which was judged to be favorable for bio-enhanced

natural attenuation because the variation in grain-size means biofouling is much less likely.

2. The analytical results collected during the LTMP implementation and pre-design activities have consistently detected the presence of degradation products (e.g., dichloroethene, vinyl chloride, chloride, ethene, and ethane) formed as a result of the biodegradation of higher order chlorinated organic compounds (e.g., trichloroethene). Biodegradation of higher order chlorinated compounds is currently occurring in situ, indicating that microorganisms capable of degrading chlorinated compounds are present in soil and/or groundwater (as confirmed through microbiological testing during the pre-design investigation).
3. The presence of NAPL has not been observed in study area groundwater (if present, NAPL could make the biodegradation process less effective and efficient).
4. Alkalinity levels in groundwater are indicative of microbial activity. The presence of elevated alkalinity concentrations (concentrations greater than two times the background levels) suggests that carbon dioxide produced during biodegradation is interacting with calcite minerals in the groundwater system and resulting in the elevated groundwater alkalinity.
5. Temperature, pH, and redox potentials were generally within an acceptable range established for optimal microbial activity (Wiedemeier et al, 1994).

Potential limitations associated with this technology may be related to the microbial analyses performed as part of the pre-design investigation. As detailed in the *Draft Downgradient Pre-Design Technical Report for Groundwater Remediation* (URS, November 7, 2003), groundwater samples were submitted to Microbe Inotech to quantify and identify the microbial populations present in downgradient groundwater. Five different bacterial strains were identified by aerobic and anaerobic heterotrophic plate count. These strains were subsequently used in endpoint assay to determine their ability to use a specific substrate/contaminant (i.e., trichloroethene, cis-1,2-dichloroethene) as their only source of carbon. The growth success for one strain cultured under aerobic conditions and one strain cultured under anaerobic conditions using trichloroethene and/or cis-1,2-dichloroethene as a sole carbon source was determined to be minimal. The growth of the remaining three strains appeared to be inhibited. This inhibited growth was likely due to the nutrient chemistry of the subsurface environment (i.e., the aquifer was identified to be both nutrient and carbon limited. The low diversity of microorganisms is likely due to the lack of nutrients and carbon sources. Elevated sulfate concentrations

may also be responsible for inhibiting biodegradation of the chlorinated solvents during the tests because sulfate-reducing microorganisms are typically able to out-compete the microbial degraders of chlorinated solvents.

4.0 EVALUATION OF ALTERNATIVE TECHNOLOGIES

The technologies described in Section 3.0 are used as the basis for developing the potential groundwater remedial alternatives evaluated in this Section. The remedial alternatives developed in this section address the remedial action objectives discussed in Section 2.0.

4.1 REMEDY STATUS

Currently the ROD designated remedial actions and modifications of and additions to them have achieved the elimination of risk to human health within the vicinity of the source area and have improved groundwater quality. Consistent with the data interpretation provided in the 2003 Annual LTMP Report, as well as previous LTMP reports, concentrations of constituents of interest are decreasing in the majority of impacted monitoring wells located proximal to the SWDA and IWS source areas, including monitoring wells B103A, B132, B133, B139A, B137B, and B138B. The decreasing concentration trends since the completion of construction support the conclusion that the current ROD remedy, as implemented to date, has resulted in improvements to groundwater quality in these areas where groundwater velocities and transport rates have allowed for comparative observations to be made. However, the current ROD remedy has not prevented the migration of contamination to the downgradient area. The impact of these remedial actions on risk elimination and restoration of groundwater is discussed in the following sections.

4.1.1 Implemented Source Control Measures Benefiting Groundwater Quality

The groundwater Source Control remedial actions of landfill capping, relocating and isolating IWS-2, and implementing an active landfill gas collection system have substantially reduced or eliminated ongoing impacts to groundwater quality. The relocation and capping activities remediated sources by reducing infiltration through the debris mass and impacted soils and thus, reducing the potential for mobilization of COCs in these media to groundwater. Calculated travel times for COCs already in the

upgradient aquifer indicate that an appreciable improvement in overall groundwater quality in downgradient monitoring wells could take several years following cap completion. However, a reduction in COC concentrations has been documented in several monitoring wells located in close proximity to the SWDA and IWS areas (e.g., monitoring wells B103A, B133, B139A, MW4A, B132, B132B, B131C, B138B, and B136C) since relocation of impacted soils from IWS-2, construction of the RCRA caps, and implementation of the landfill gas collection system.

Construction and operation of the active landfill gas collection system, which collects and thermally destroys organic COCs contained in landfill gas, has provided a significant reduction in the mass of COCs within the landfill that would otherwise have contributed to groundwater impacts. Information provided to URS indicates that approximately 9,200 pounds (lbs) of non-methane organic compounds, including approximately 170 lbs of chlorinated VOCs, were estimated to have been collected by the active gas system in the year 2000 based on reported monitoring data [Harding Lawson Associates (HLA), 2000]. Mass removal estimates provided for specific COCs for year 2000 included approximately 3.8 lbs of 1,1,1-trichloroethane; 32 lbs of 1,1-dichloroethane; 36 lbs of cis-1,2-dichloroethene; 7.5 lbs of tetrachloroethene; 12 lbs of trichloroethene, and 76.5 lbs of vinyl chloride. The continued operation of the active gas collection system will result in ongoing improvement to groundwater quality by further reducing concentrations of organic COCs that could otherwise impact groundwater.

4.1.2 Institutional Controls

The function of the ICP is to prevent the use of impacted or potentially impacted groundwater and to inform current residents and future property owners of groundwater restrictions associated with the property. Component performance standards for Institutional Controls, as presented in the statement of work (SOW), include the following items.

- The ICP will establish restrictions which will prevent the use of impacted or potentially impacted groundwater.

- The ICP establishes a buffer zone around the impacted area adequate to ensure that new private or public water supply wells in the vicinity of the Parker Landfill will not induce movement of impacted groundwater into unimpacted areas, or interfere with remedial actions at the landfill.
- The ICP may be modified, as appropriate, to prevent use of groundwater in areas identified as impacted in the future.
- The Institutional Controls will remain in effect until IGCLs downgradient of the point of compliance are met.
- The ICP will provide a public drinking water supply hook-up to current or future residences within the area of groundwater restrictions.

The EPA-approved ICP is currently being implemented. The State of Vermont has also required groundwater reclassification as a component of Institutional Controls for the landfill. A Class IV Groundwater Reclassification Petition was submitted to the Vermont Agency of Natural Resources Groundwater Coordinating Committee in March 2002 and approved in Fall 2003.

Additional Institutional Controls are being placed on the Parker Properties by parties to the Consent Decree (CD) to address groundwater use restrictions, land-use limitations associated with the RCRA caps, and conservation limitations placed on the unnamed stream and associated wetlands, which further prevent the use of site groundwater.

4.1.3 Long-Term Monitoring

Long-Term monitoring of the study area is currently being performed in accordance with the EPA-approved LTMP. The LTMP components currently include periodic groundwater, surface water, and sediment monitoring. Long-term monitoring results indicate that groundwater in certain areas of the site exceed IGCLs and that the area of impacts is not expanding; however, these exceedences are not currently posing an unacceptable risk to human health or the environment nor are these exceedences expected to pose unacceptable risk to human health or the environment under foreseeable future conditions as potential exposure pathways for impacted groundwater have been eliminated.

4.2 DEVELOPMENT AND SCREENING OF REMEDIAL ACTION ALTERNATIVES

Fifteen potential groundwater remedial alternatives were developed from the retained technologies. Consistent with the NCP, a screening step was utilized to reduce the number of remedial alternatives carried through the more detailed analysis. A description of the components of each alternative and subsequent remedial alternative screening is provided in the following paragraphs.

4.2.1 Viability of Alternative Technologies to Source Area and Downgradient Area

A total of five remedial technologies were considered in this analysis and evaluation, including 1) The ROD designated pump and treat consisting of traditional groundwater extraction with ex situ treatment and surface water disposal of treated groundwater, 2) monitored natural attenuation 3) in situ chemical oxidation 4) permeable reactive barriers and 5) bio-enhanced attenuation. These five technologies were analyzed and evaluated in various combinations to address both source control remediation and remediation downgradient of the landfill and IWS areas. Specifically, the technical feasibility of applying these technologies for treatment of groundwater at the source (in close proximity to the SWDA, IWS-2 and IWS-3) and downgradient (in the vicinity of monitoring well locations B136B and B120C) was considered. Technologies were eliminated from further consideration if the study area characteristics (in particular hydrogeologic conditions investigated during the post-ROD pre-design tasks) made application of a technology infeasible or if a technology proved impractical when compared to other technologies under consideration.

For source control in the vicinity of the SWDA and IWS-2 and IWS-3, all five technologies were considered potentially viable. Based on the investigative findings of the LTMP and pre-design efforts, the depth to bedrock, the subsurface stratigraphy, and the contaminant distribution would not adversely affect the technical feasibility of implementing any of the five technologies close to the landfill. However, for the

downgradient area, in situ chemical oxidation and a PRB were eliminated from further consideration. In the case of a PRB, as a result of downgradient pre-design investigations conducted in 2003, it was determined that the depth of overburden groundwater impacts in the downgradient area ranged from 132 to 186 feet below ground surface. Construction technologies potentially capable of installing PRBs to such depths have not been proven. Although the groundwater velocity and concentrations of contaminants were determined to be suitable to the application of the PRB technology, the depth required makes construction impracticable in the downgradient area.

The application of in situ chemical oxidation to the downgradient area was also eliminated from further consideration. The depth and extent of impacts, the heterogeneity of the downgradient deep overburden aquifer, and the metals concentrations in groundwater are factors that would increase the cost and negatively affect the implementability of this technology downgradient. The ability to effectively control migration of the injected chemicals or to deliver them uniformly to maximize the area of treatment is diminished. In addition, the potential exists to mobilize unacceptable levels of redox sensitive metals. While in situ chemical oxidation in the downgradient area might be technically feasible, the risks associated with its implementation, and its greater costs when compared to the other downgradient technologies, make it an impractical alternative technology.

Consequently, five source area groundwater remediation technologies were retained, and three downgradient groundwater remediation technologies were retained to be assembled into viable remedial alternatives.

4.2.2 Screening Potential Alternatives Using NCP Criteria

The five source control and three downgradient remedial technologies that remained were assembled into a range of remedial alternatives that were designed to meet the remedial objectives for groundwater and represent a range of remedial actions. By combining the technologies in a matrix (5 source area by 3 downgradient), a total of 15 potential

remedial alternatives were assembled. In order to reduce the number of alternatives undergoing a detailed evaluation, and consistent with the NCP, the 15 potential remedial alternatives were initially screened against the three general criteria of effectiveness, implementability, and cost. The following sections describe this screening step.

Technologies applied to the source area were numbered 1 through 5 as follows:

1. Groundwater extraction and ex situ treatment, surface water discharge.
2. Monitored natural attenuation
3. In situ chemical oxidation
4. Permeable reactive barrier
5. Bio-enhanced attenuation

Technologies applied to the downgradient area were assigned letters as follows:

- A. Monitored natural attenuation
- B. Bio-enhanced attenuation
- C. Groundwater extraction and ex situ treatment, surface water discharge

Thus, remedial alternative 1A, for example, would incorporate groundwater extraction and ex situ treatment at the landfill, combined with monitored natural attenuation for the downgradient plume. Table 3 describes the fifteen remedial alternatives and the outcome of the initial screening step. The screening step was undertaken to reduce the number of alternatives that will be carried through detailed evaluation. The initial screening process is general, with comparisons being made on an equivalent basis between similar alternatives, carrying forward only the most promising. To the extent possible, a range of alternatives was retained after screening. Regardless of the results of the screening analysis, the ROD remedy 1A (pump and treat in the source area and monitored natural attenuation downgradient) is retained as the benchmark for this analyses and evaluation.

The initial screening step incorporates an evaluation of the assembled alternatives for short and long-term effectiveness, for implementability, and for cost. Each of the 15

alternatives was rated against these three criteria using a general qualitative rating scale of low, moderate, high or very high. The screening evaluations are summarized below.

4.2.2.1 Short- and Long- Term Effectiveness

The short and long-term effectiveness evaluation considered each alternative's relative ability to protect human health and the environment during the short term (construction and startup) and long-term (post construction). How quickly the alternative achieves IGCLs and the reductions in toxicity, mobility or volume each alternative could potentially achieve were also included in the effectiveness evaluation. For all of the alternatives, a high level of protection of human health has already been achieved through the application of institutional controls and the source control remedial actions that are currently in place.

The three alternatives that incorporate groundwater extraction and treatment for the source area with one of the three downgradient alternatives all achieve a high to moderate level of effectiveness. Reduction of toxicity, mobility and volume is achieved in groundwater, but the constituents are transferred to other media, which then require treatment. Alternatives 1B and 1C are more effective in the long-term than 1A because they actively address the downgradient migration of contaminants. Construction and startup of the injection or extraction wells downgradient will affect short-term effectiveness for 1B and 1C respectively. Estimated time periods to achieve IGCLs for alternatives 1A, 1B and 1C are anticipated to be similar.

The three monitored natural attenuation alternatives (2A through 2C) achieve low to moderate levels of short and long-term effectiveness. The addition of bio-enhanced attenuation or groundwater extraction and treatment downgradient will not significantly improve the overall effectiveness.

The three alternatives that incorporate a PRB at the source area combined with one of the three downgradient alternatives (4A through 4C) all achieve a high level of short and

long-term effectiveness. The PRB more effectively reduces the mobility, toxicity and volume of contaminants at the source compared to the other alternatives, and does not create a residual risk by transfer of constituents to other media. The PRB provides more effective reduction in migration of contaminants downgradient than the alternatives that rely on wells to inject chemical or nutrients for aquifer treatment. The addition of bio-enhanced attenuation downgradient of the PRB would be more effective in the long-term both in reducing toxicity, mobility and volume and in shortening the time required to restore the aquifer. The addition of pump and treat to the PRB alternatives would be the least effective, because downgradient constituents would be transferred to other media rather than treated and because significant operation and maintenance would be required.

The two alternatives that rely on injection of a treatment catalyst into the groundwater at the source would be moderately effective. Chemical oxidation (alternatives 3A through 3C) would be marginally more effective than bio-enhanced attenuation at eliminating migration of constituents from the source, but neither technology would eliminate further migration of impacts. Short-term effectiveness of the chemical oxidation could be impacted by metals precipitation. The effective delivery and application of both chemical oxidation and bio-enhanced attenuation could potentially be impacted by the heterogeneity of the subsurface environment. Data obtained during pre-design investigations indicates that the ability to deliver reagents to the media impacted may be adversely affected by the hydraulic conductivity of the distal unit and by the interbedded layers of silty sands and sands of varying grain-size in the upper geologic unit. Uniform distribution of the reagents within the subsurface may be quite difficult to achieve.

Table 3 summarizes the qualitative analysis of each of the 15 alternatives in terms of effectiveness.

4.2.2.2 Implementability

The overall implementability of the alternatives considered during the screening step incorporates an evaluation of technical and administrative feasibility of the components of the alternatives under site specific conditions. Factors such as constructability, reliability, achievement of action specific ARARs, and operation and maintenance requirements are included when considering technical implementability. The implementability evaluation during the screening step also includes administrative factors such as permit and approval requirements and the availability of required equipment, specialists, or off site disposal capacity.

The three alternatives incorporating groundwater extraction and treatment for the source area (1A through 1C), and all the remaining alternatives that incorporate extraction and treatment for the downgradient area (2C, 3C, 4C, and 5C) rate moderate to low for implementability. These ratings stem predominantly from the extensive operation and maintenance required to keep the extraction and treatment systems running until IGCLs can be achieved. Reliability of the pump and treat alternatives is dependent upon human intervention because systems are subject to mechanical or operational failure and potential fouling. Administratively, the pump and treat alternatives require National Pollutant Discharge Elimination System (NPDES) permitting (for the river discharge), air permitting (for emissions treatment) and easements across private property, roads, and rail right-of-ways for construction. Supplies of raw materials and off site disposal capacity for waste residuals are presently available, but that may not always be the case over the long period of time for which pump and treat would be in operation.

The MNA alternatives that do not involve groundwater extraction (2A and 2B) are highly implementable. Minimal administrative requirements will need to be met, the most significant of which is the potential for meeting the administrative and technical requirements of Underground Injection Control (UIC) permitting requirements to the injection of certain nutrients associated with downgradient bio-enhanced attenuation (for

2B). Equipment, staff, and supply needs are minimal and are readily available. These alternatives have minor operation and maintenance requirements and are reliable under steady state conditions.

The remaining alternatives that utilize chemical oxidation (3A and 3B) are moderately to highly implementable. Chemical storage and handling would increase operation and maintenance requirements. These alternatives' destructive restoration mechanisms are reliable, and the equipment, staff, and supplies are readily available both to construct the chemical oxidation system and to operate it long-term. Administratively, UIC permitting requirements would need to be addressed, and wetlands impacts may be unavoidable during construction. Reagents used for chemical oxidation are non-selective with respect to the source of organic carbon; therefore, the volume and dose of reagent required to achieve remedial objectives will be greatly influenced by the amount of organic carbon present in saturated soil and groundwater. Multiple applications of the reagent may be required to achieve remedial goals. Also, the potential for mobilizing unacceptable concentrations of metals from soil in areas proposed for treatment would also need to be addressed.

Similarly, the alternatives that rely on bio-enhanced attenuation for source area treatment (5A and 5B) are moderately to highly implementable. Administrative issues comparable to chemical oxidation would also be encountered with bio-enhanced attenuation. Operation and maintenance would be similar, although the storage and handling of nutrients would be less hazardous than with oxidizing chemicals.

Alternatives with source area treatment by a PRB (4A and 4B) are highly implementable. Once constructed, operation and maintenance of the PRB is minimal compared to alternatives that require injection into or extraction of groundwater. A source area PRB can be installed using proven technology and the required equipment, staff, and supplies are readily available. Administratively, UIC permitting requirements may need to be addressed for the combined PRB and bio-enhanced attenuation alternative. In addition,

impacts to the wetlands will be unavoidable during construction of a PRB in the source area.

Table 3 summarizes the qualitative analysis of the 15 alternatives in terms of implementability.

4.2.2.3 Cost

The screening step considers relative comparable costs of the 15 alternatives, including both short-term construction costs and long-term operation and maintenance costs. At this screening stage, costs are considered baseline estimates developed from a conceptual understanding of the proposed alternatives. More detailed cost evaluations are developed in, and evaluated as part of, the detailed analysis. Combined costs for both construction and operation and maintenance (O&M) are considered low if the estimates are less than \$5 million, moderate if they are between \$5 and \$10 million, high if they are between \$10 and \$15 million, and very high if they are greater than \$15 million.

The three alternatives incorporating groundwater extraction and treatment for the source area (1A through 1C), and all the alternatives that incorporate extraction and treatment for the downgradient area (2C, 3C, 4C, and 5C) result in very high costs in excess of \$30 million. The very high costs for these alternatives stem from the construction and long-term (thirty year) operation of a multiple process treatment train that is necessary to meet effluent discharge limits (for discharge to the river) and air emissions limits. A more simplified and less expensive treatment train (e.g. only air strippers) would not meet these action specific ARARs.

Alternatives that rely only on MNA, or natural attenuation combined with downgradient bio-enhanced attenuation have the lowest cost of all 15 alternatives, in the range of \$1.9 million over thirty years. Alternatives that rely on bio-enhanced attenuation are expected to cost in the moderate to high range, between \$7.9 million and \$13.3 million depending on the number of injection wells and quantity of nutrients required. Chemical oxidation

costs are also moderate to high, on the order of \$7.9 million. Alternatives with the source area PRB are also expected to be moderate to high, approximately \$5.3 million to 10.8 million. Table 3 summarizes the qualitative analysis of the 15 alternatives in terms of cost.

4.2.3 Summary of Screening and Alternatives Retained After Screening

The alternatives screening for this analyses and evaluation considered all 15 alternatives in terms of effectiveness, implementability, and cost with the goal of reducing the number of alternatives down to a more manageable number of 5 or 6. In addition to the remedial alternatives retained after screening, a true No Action alternative (Alternative NA) has been carried through (without screening) to the detailed analysis. Alternative 1A, the ROD designated remedy, was retained as a baseline. Alternative 1C was also retained at the request of EPA as a contingency to the ROD designated remedy if MNA in the downgradient area was later found to be ineffective. Alternative 2A, MNA for both the source area and downgradient was retained to provide a range of alternatives (effectively Alternative 2A is a no further action alternative that is compliant with the requirements of the LTMP and the AO). The remaining alternatives were selected by identifying the lowest cost alternatives that would achieve the highest levels of effectiveness and implementability. For example, Alternative 4A (PRB at the source) would be less expensive and more effective at minimizing the downgradient migration of COCs compared to alternatives that rely on chemical oxidation to provide this control.

As a result of the initial screening of potential remedial alternatives, a total of 7 alternatives were retained for further analysis utilizing the detailed analysis criteria contained in the NCP. The seven remaining remedial alternatives are briefly described in the following paragraphs and tabulated in Table 4.

4.2.3.1 Alternative 1A: ROD Designated Pump and Treat for Source Area and Monitored Natural Attenuation Downgradient

Alternative 1A is the pump and treat and monitored material attenuation remedial actions designated in the ROD. Components of Alternative 1A include:

- Pumping of groundwater at the point of compliance using extraction wells to achieve a measure of hydraulic control;
- Ex situ on site treatment of pumped groundwater for elevated hardness, inorganic compound concentrations, and VOC concentrations;
- Discharge of treated groundwater to the Passumpsic River;
- Transportation of treatment residues for off-site disposal;
- Monitoring the effectiveness of the remedial action through groundwater and treatment system sampling;
- Monitoring the effectiveness of the natural attenuation processes in restoring impacted groundwater through groundwater sampling for VOCs, transformation products (i.e., ethene and ethane) and geochemical parameters (i.e., redox potential and pH); and
- Evaluating the progress of the remedy in achieving RAOs for site groundwater as part of 5-year reviews, as per the AO/SOW.

The layout of Alternative 1A is depicted on Figure 24.

4.2.3.2 Alternative 1C: Pump and Treat for Source Area and Downgradient

Alternative 1C combines pump and treat for the downgradient groundwater with the source area pump and treat. The components of this alternative would be the same as for Alternative 1A, but substituting additional downgradient extraction wells in place of downgradient MNA. This alternative includes conveying the additional extracted groundwater to the onsite ex situ water treatment facility. Both expansion of the source area water treatment facility to accommodate the additional influent volume, and construction of a stand alone water treatment plant for the downgradient area were considered, but economy of scale made the single treatment plant a more viable option.

Downgradient pump and treat is included in this analyses and evaluation as a contingency remedy only. The 1994 FS, and the 1995 EPA ROD eliminated implementation of pump and treat at the downgradient area because “Extraction and treatment in the downgradient plume would not appreciably reduce the time for restoration of this area to drinking water standards”.

The layout of Alternative 1C is depicted on Figure 25.

4.2.3.3 Alternative 2A: Monitored Natural Attenuation for Source Area and Downgradient

Monitored natural attenuation for both source area and downgradient groundwater has been included in this evaluation to provide a baseline (in addition to the No Action alternative) for comparison of the remaining alternatives assuming that the remedial actions already in place, specifically the ICP and the LTMP, are continued. Alternative 2A is consistent with the NCP requirement that one alternative be considered that involves little or no treatment, but provides protection primarily by preventing exposure. As one of the baseline alternatives, it will be compared to the range of alternatives that employ treatment as a primary component and vary in the length of time required to achieve aquifer restoration.

Alternative 2A serves as the No Further Action alternative in the context of this analyses and evaluation whose purpose is to evaluate modifying the ROD designated remedial approach. In accordance with the NCP, the 1994 FS and 1995 EPA ROD included a No Action alternative as the baseline. This true “No Action” included only essential monitoring sufficient to produce the statutorily required 5-year review. The No Action alternative is being reconsidered within this document as Alternative NA at the request of EPA, even though the ROD and AO require implementation of the ICP and the LTMP, which together encompass a larger scope of work than the original No Action alternative. Alternative 2A is considered a “No Further Action” alternative recognizing that a significant amount of remedial action is already occurring at the Parker Landfill.

Thus, this MNA alternative provides the mandatory, minimum scope of groundwater remediation that would be considered viable in a range of alternatives under consideration. The components of Alternative 2A include:

- Monitoring the effectiveness of the remedial action through groundwater sampling;
- Monitoring the effectiveness of the natural attenuation processes in restoring impacted groundwater through groundwater sampling for VOCs, transformation products (i.e., ethene and ethane) and geochemical parameters (i.e., redox potential and pH); and
- Evaluating the progress of the remedy in achieving RAOs for site groundwater as part of 5-year reviews, as per the AO/SOW.

4.2.3.4 Alternative 4A: Permeable Reactive Barrier for Source Area and Monitored Natural Attenuation Downgradient

Alternative 4A is a permeable reactive barrier system within the source area using a treatment cell with zero-valent iron filings to intercept contaminated groundwater and reduce concentrations of COCs to byproducts such as carbon dioxide and water. Components of Alternative 4A include:

- Constructing a PRB to intercept and treat groundwater impacted by chlorinated VOCs through induced, in situ reductive dechlorination processes;
- Locating the PRB across (perpendicular to the direction of flow) the source area portion of the plume adjacent to the eastern edge of the SWDA and downgradient of IWS-3;
- Long-term monitoring of groundwater to document PRB effectiveness;
- Monitoring the effectiveness of the natural attenuation processes downgradient of the PRB in restoring impacted groundwater through groundwater sampling for VOCs, transformation products (i.e., ethene and ethane), and geochemical parameters (i.e., redox potential and pH); and
- Evaluating the progress of the remedial action in achieving RAOs for site groundwater as part of 5-year reviews, as per the AO/SOW.

The proposed PRB orientation under Alternative 4A is presented in Figure 26.

4.2.3.5 Alternative 4B: Permeable Reactive Barrier for Source Area and Bio-Enhanced Attenuation Downgradient

Alternative 4B combines a PRB at the source area with treatment of the downgradient portion of the plume through bio-enhanced attenuation. Components of Alternative 4B include:

- Constructing a PRB to intercept and treat groundwater impacted by chlorinated VOCs through induced, in situ reductive dechlorination processes;
- Locating the PRB across (perpendicular to the direction of flow) the source area portion of the plume adjacent to the eastern edge of the SWDA and downgradient of IWS-3;
- In situ bio-enhanced attenuation through injection of reagent (e.g., a source of carbon) at a highly impacted area of the plume downgradient of the PRB;
- Monitoring the effectiveness of the natural attenuation processes outside of the PRB and bio-enhancement/injection areas through groundwater sampling for VOCs, transformation products (i.e., volatile fatty acids, ethane, ethane) and geochemical parameters (i.e., redox potential and pH);
- Long-term monitoring of groundwater to document PRB and attenuation effectiveness; and
- Evaluating the progress of the remedial action in achieving RAOs for site groundwater as part of 5-year reviews, as per the AO/SOW.

The proposed upgradient PRB layout and downgradient application area for bio-enhanced attenuation under Alternative 4B is presented in Figure 27.

4.2.3.6 Alternative 5B: Bio-Enhanced Attenuation for Source Area and Downgradient

Alternative 5B incorporates the results of the LTMP, bench and pilot-scale testing performed subsequent to the ROD to determine how well the existing conditions support natural attenuation, and the opportunities for enhancing this attenuation process through the addition of reagents. In situ biological degradation was passed over as an applicable technology in the 1994 FS due to the levels of metals present in groundwater and the

perceived low permeability of the aquifer. The LTMP and pre-design studies, however, provided additional data that supports this process through enhancing the biological component of natural attenuation.

The components of Alternative 5B include:

- In situ bio-enhanced attenuation through injection of reagent (e.g., a source of carbon) within the most highly impacted areas of the plume at the source area and at the downgradient property boundary;
- Monitoring the effectiveness of the natural attenuation processes outside of the bio-enhancement/injection areas through groundwater sampling for VOCs, transformation products (i.e., volatile fatty acids, ethane, ethane) and geochemical parameters (i.e., redox potential and pH);
- Long-term groundwater monitoring of groundwater to document attenuation effectiveness; and
- Evaluating the progress of the remedial action in achieving RAOs for site groundwater as part of 5-year reviews, as per the AO/SOW.

The layout of Alternative 5B is depicted in Figure 28.

4.2.3.7 Alternative NA: No Action Alternative

Alternative NA has been included at the request of EPA to complete this evaluation with the NCP defined No Action alternative serving as the baseline for comparison of the other alternatives. Under this alternative, no effort would be made to treat or to prevent the further migration of contaminated groundwater in either the source area or downgradient area. Access restrictions and institutional controls, although already implemented under the AO, would not be maintained, and compliance inspections would not occur. Monitoring for natural attenuation, already implemented under the LTMP in compliance with the AO, would not be continued under this alternative. The only component of Alternative NA is the periodic monitoring of groundwater, surface water, and sediment and evaluation of the site data every five years.

4.3 EVALUATION OF REMEDIAL ACTION ALTERNATIVES

In accordance with the FS and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), each of the six remedial actions (excluding alternative NA) has been evaluated based on seven specific criteria, which provide the basis for conducting a detailed analysis of remedial actions. The calibrated study area groundwater flow and solute transport model (URS, 2002) has been used as a tool to assist in the analysis and evaluation of alternatives relative to:

- The layout of each alternative, including identifying optimal well location and pumping rates; and
- Operational timeframes associated with the implementation of each remedial action.

Each of the remedial actions is evaluated in the context of the currently in place remedial actions of RCRA caps over the SWDA and IWS areas; excavation and relocation (i.e., isolation) of IWS-2 under the SWDA cap; installation and operation of an active gas collection system; establishment of Institutional Controls to protect the cap and prevent the use of groundwater; connection of residences to the public water supply; and implementation of the LTMP to evaluate the effectiveness of the source control measures that have already been implemented.

These currently in place remedial actions have achieved the goal of protection of human health and the environment, and each alternative is evaluated with this in mind. In particular, human health and the environment are protected by:

- Excavation and relocation of IWS-2 and associated unsaturated impacted soils to the SWDA, implementation of the RCRA Subtitle C cap over the SWDA and IWS-3 area, and operation of an active landfill gas collection system have significantly reduced or eliminated mass loading of COCs to groundwater.
- In accordance with the provisions of the ICP, all residences within the Institution Control Area downgradient of the landfill have been supplied with municipal water,

and existing former residential supply wells in the area have been abandoned. This eliminates impacted groundwater as a current exposure pathway.

- Institutional Controls are being implemented which restrict future development of the Parker Property to commercial or industrial use, restricting the development of groundwater as a water supply, transfer all groundwater right to the State of Vermont, and reclassify groundwater to Class IV (non potable). These Institutional Controls effectively eliminate impacted groundwater as a potential future exposure pathway.
- Based upon the conceptual hydrogeologic model, impacted groundwater discharges to the Passumpsic River approximately 2,200 feet southwest of the landfill. The Risk Assessment concluded that surface water and sediment within the study area do not pose unacceptable risk to human or environmental receptors.
- Worst case concentrations of total VOCs that could potentially be present in the Passumpsic River as a result of study area discharge were calculated to be approximately $2/10^{\text{th}}$ of one microgram per liter (ug/l) (i.e., 0.0002 mg/l). This estimate was based upon conservative estimates of concentrations of VOCs in groundwater at the downgradient edge of the study area, the estimated groundwater discharge rate to the river from the area of impacts, and the annual 7-day minimum river flow with a recurrence interval of 10 years (i.e., 7Q10 flow) for the Passumpsic River at the study area. The assessment of discharge impacts is provided in Appendix B. The concentrations of individual site-related VOCs that could be present in the river were calculated to be below detectable levels, several orders of magnitude less than Vermont Water Quality Standards.
- VOCs do not bioaccumulate in aquatic organisms such as fish. Therefore, unacceptable risk to ecological receptors is not anticipated with this alternative.
- Non-background metal impacts exceeding IGCLs are limited to areas proximal to the landfill (e.g., B103A, B132B, B139A) and have not shown to be mobile within groundwater.

4.3.1 Remedial Alternative Evaluation Criteria

Of the nine FS evaluation criteria, two criteria are threshold criteria and must be met by each remedial alternative to be considered applicable and appropriate for the remedy.

These include:

- Overall protection of human health and the environment; and,
- Compliance with ARARs.

The next five remaining criteria are referred to as balancing criteria by which the alternatives are compared and upon which the analysis is based. These include:

- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility, or volume;
- Short-term effectiveness;
- Implementability; and,
- Cost

The remaining two modifying criteria, state acceptance and community acceptance, are not discussed in this analyses and evaluation, but were considered thoroughly by EPA prior to selection of the original ROD remedy. Each of the seven threshold and balancing criteria are explained in the following paragraphs.

4.3.1.1 Overall Protection of Human Health and the Environment

Protection of human health and the environment is based on an evaluation of the remedial alternative's ability to be protective of human health and the environment. This evaluation also looks at the potential risks to human health and the environment during implementation and operation of the alternative.

4.3.1.2 Compliance with ARARs

Each remedial alternative is evaluated against ARARs to determine compliance.

4.3.1.3 Long-Term Effectiveness and Permanence

Each remedial alternative is evaluated as to magnitude of long-term risks, adequacy of controls, and reliability of long-term management controls in restoring groundwater.

The calibrated groundwater flow and solute transport model serves as one of the mechanisms used in evaluating the effectiveness of the remedial alternatives. As part of the evaluation of long-term effectiveness and permanence the calibrated groundwater flow and solute transport model was used as a basis for modeling fate and transport of trichloroethene resulting from the implementation of each alternative. Model-derived predictions of the time for aquifer restoration presented in this report are estimates. They are limited by the accuracy level achievable by numerical modeling and are best suited for comparative purposes. The simulation of each alternative is discussed in Section 4.4.

As directed by EPA in its October 31, 2002 letter on use of the model, the starting point concentration distribution was set to reflect current (i.e., October 2003) conditions as defined by field data. Figures 29 and 30 depict the starting point groundwater impact configuration used for predictive modeling. Table 5 presents the model starting point concentration versus field-measured data. All source concentrations and transport and fate variables are as presented in the model report (URS, 2002)².

4.3.1.4 Reduction of Toxicity, Mobility, or Volume

The remedial alternatives are evaluated for permanence and completeness of the remedial action in significantly reducing the toxicity, mobility or volume of hazardous materials. Each alternative is evaluated based on the degree to which it destroys or treats hazardous materials; the expected reduction in toxicity, mobility, or volume provided by the alternative; the extent to which the treatment is irreversible; and the types and quantities of residuals that will remain following treatment. The groundwater flow and solute transport model, applied as discussed in Section 4.4, serves as one of the mechanisms used in evaluating aquifer response for each alternative relative to these criteria.

² The groundwater flow and solute transport simulations were performed using the model reviewed by EPA and applied in support of the 2003 Draft Technology Evaluation Report, with the following exception: the lower no-flow boundary of the model was revised to reflect conditions encountered during 2003 pre-design field sampling activities. The calibration of the updated flow model to field conditions is similar to the previous calibration, with a mean error (predicted – actual) of 0.29-feet and a standard error of the estimate of 0.24-feet.

4.3.1.5 Short-Term Effectiveness

The evaluation of short-term effectiveness is based on the degree of protectiveness of human health achieved during construction and implementation of the remedy. Potential implementation risks to the community and to site workers and mitigation measures for addressing those risks are included in this evaluation.

4.3.1.6 Implementability

Implementability is based on the evaluation of technical feasibility, administrative feasibility, and the availability of services and materials. Technical feasibility considers difficulties, which may be inherent during construction and operation of the remedy, the reliability of the remedial processes involved, and the ability to monitor the effectiveness of the remedy. Administrative feasibility considers permitting and regulatory approval.

4.3.1.7 Cost

Implementation costs for each remedial alternative are evaluated, including an estimate of capital costs as well as operation and maintenance costs. An EPA-approved cost-estimating program (*A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, EPA, 2000) was employed to provide both the implementation costs associated with each remedial alternative and consistency between cost estimates. A level of uncertainty is associated with the cost estimates presented with this pre-design phase evaluation, but the level of accuracy is consistent with FS guidance documents. As variability will be approximately equal for each remedial alternative, cost estimates provide a suitable basis for comparative purposes. Alternative costs have been estimated using a present worth for 30 years at a discount rate of 7 percent.

4.4 DETAILED EVALUATION OF ALTERNATIVE TECHNOLOGIES

4.4.1 Alternative 1A: ROD Designated Pump and Treat for Source Area and Monitored Natural Attenuation Downgradient

Alternative 1A is the groundwater pump and treat source control component of the ROD-selected remedy, identified as FS Alternative No. 3 (source control component), modified in accordance with the site conceptual model. Alternative 1A includes a groundwater pumping system designed to implement hydraulic control to prevent further migration of impacted groundwater from the compliance boundary at the landfill. This alternative also includes MNA downgradient of the hydraulic controls at the compliance boundary to assess the progress of aquifer restoration within the existing plume outside the source area.

Based on numerical modeling, the location and pumping rates of each extraction well were evaluated and optimized to provide hydraulic control at the point of compliance. A layout of pumping well locations and flow rates are depicted on Figure 24. Influent groundwater chemistry was then estimated based on LTMP data collected from monitoring wells located proximal to the proposed pumping well locations. The treatment system discharge is required to meet water quality standards for the Passumpsic River at the point of discharge prior to dilution (in accordance with information provided in EPA communication). Based on anticipated influent quality, required discharge quality, modeled flow rates, and associated groundwater characterization data, the components of the treatment system for Alternative 1A likely will include:

- A pumping system including 3 extraction wells completed in the top-of-rock and overburden groundwater flow systems operating at a combined pumping rate of approximately 110 gpm;
- Ex situ treatment to remove inorganics and reduce hardness using a coagulation and precipitation system;
- Ex situ treatment to remove organic compounds using a combination of UV photolysis/chemical oxidation (i.e., hydrogen peroxide), air stripping, and granular activated carbon adsorption;
- Ex situ treatment to remove residual inorganics to meet surface water discharge criteria using an ion exchange unit;
- Discharge of the treated groundwater to the Passumpsic River;

- Transportation of treatment residuals for off-site disposal;
- Groundwater and treatment system monitoring to assess the effectiveness of the remedial action; and
- Five-year reviews.

A detailed discussion of the components of Alternative 1A is provided in the following paragraphs.

Source Component

Three overburden groundwater extraction wells would be required to remove impacted groundwater from locations to the east, west, and south of the SWDA. Two of the extraction wells, one located approximately 500 feet southwest of the former IWS-1 area and one located southwest of the former IWS-2 area, would each extract overburden groundwater at a pumping rate of approximately 50 gpm. A third extraction well located to the southwest of the IWS-3 cap would extract overburden groundwater at a pumping rate of approximately 10 gpm. These pumping rates were derived using a calibrated groundwater flow and solute transport model developed for the study area (URS, 2002) to achieve hydraulic control at the point of compliance. These pumping rates are similar to those previously established in the original feasibility study written for the Parker Landfill. The proposed location of the treatment building is to the southwest of the SWDA, in the vicinity of the landfill gas flare and the B113 monitoring well cluster.

Inorganic pretreatment will be required to reduce both hardness and elevated concentrations of iron, to prevent system fouling (i.e., Ultraviolet/Oxidation process, air stripper, liquid activated carbon, piping, meters and pumps), improve efficiency of VOC removal, and to meet surface water discharge requirements. A coagulation and precipitation system consisting of a flash mixer, flocculation tank, and inclined plate clarifier followed by pressure sand filters would be used for inorganic pretreatment. Sludge generated during this process would be collected and subsequently dewatered and consolidated using a sludge press prior to disposal in order to reduce the volume of solids being manifested offsite. Use

of a coagulation and precipitation system will reduce iron concentrations to less than 1 ppm and hardness to less than approximately 40 mg/l.

Following the first treatment process to reduce select inorganic compound concentrations, the second treatment process will adjust the pH of the waste stream prior to VOC treatment. The next treatment process is a multi-step VOC treatment process using a combination of UV photolysis and chemical oxidation, air stripping, and carbon adsorption. Ultraviolet light coupled with hydrogen peroxide (UV/Oxidation) would be employed to destroy organic compounds in the aqueous phase. The use of UV light combined with chemical oxidation will destroy approximately 95-percent of the alkenes (e.g., trichloroethene) and potentially some component of the alkanes (e.g., 1,1,1-trichloroethane) and methylene chloride. Although the UV/Oxidation processes will not treat groundwater sufficiently to meet discharge criteria, the VOC mass in the aqueous stream would be substantially reduced for subsequent treatment by air stripping and carbon adsorption; with the cost savings from decreased carbon consumption more than offsetting the costs associated with the UV/Oxidation system. Additionally, UV/Oxidation is generally presumed to be a necessary treatment component to meet the Vermont Category I Stationary Source Hazardous Air Impact Standards for systems which must treat elevated levels of vinyl chloride. Vinyl chloride is present in the influent and cannot be treated sufficiently by vapor phase carbon alone due to low carbon retentivity of the compound.

The next step in this treatment process train is the removal of the remaining VOCs from the extracted groundwater. This will be achieved by an air stripper coupled with carbon adsorption. Use of an air stripper will target the removal of approximately 95-percent of the alkanes and reduce the volume of residuals produced in the form of liquid or vapor phase activated carbon. Air stripping consists of passing a countercurrent air stream through the aqueous stream within a packing media tower. The media disperses the aqueous stream into droplets with a high surface area, thereby increasing water-air contact. The air stripper, by optimizing contact between the air stream and the aqueous stream, enables a mass transfer of strippable VOCs from the groundwater to the air stream in accordance with the principle of Henry's Law. Both the liquid stream and the

air stream discharging from the air stripper undergo the next treatment process of carbon adsorption to remove entrained VOCs (with strippable VOCs contained within the air stream, and non-strippable VOCs within the aqueous stream).

The aqueous stream from the air stripper will flow through bag filters prior to polish-treatment by the liquid-phase activated carbon system. The bag filter treatment process is necessary to remove suspended solids captured in the air stripper and to eliminate the need to backwash the liquid-phase granular activated carbon (LGAC) canisters. This eliminates the need for a source of high pressure backwash water. The LGAC treatment process will remove SVOCS and reduce the concentration of 4-methyl-2-pentanone, 2-butanone, and acetone from the extracted groundwater as well as those organic compounds that may have passed through the UV/oxidation system and air stripper. Activated carbon selectively adsorbs constituents by the surface attraction of organic compounds to the internal pore surfaces of the carbon particles and will treat the more soluble constituents in the extracted groundwater so that these compounds meet Vermont Water Quality Criteria (VT WQC) for surface water discharge. The airstream off the stripper will be adjusted for humidity and temperature to optimize removal and meet air emission requirements. After this treatment process, its next treatment is passing through vapor-phase activated carbon.

Next, dissolved concentrations of heavy metals exceeding the VT WQCs within the extracted groundwater must be addressed. This is done through either an ion exchange system or activated alumina technology following the liquid-phase activated carbon treatment. An ion exchange system involves pumping the aqueous stream through an ion exchange vessel filled with either anionic or cationic resins to remove targeted dissolved metals. Inorganic compounds retained by the resin would be periodically backwashed and the resin regenerated, producing a heavy metal-bearing liquid slurry. This treatment residual will be condensed by evaporation and then transported for offsite disposal. Activated alumina is a potential alternative for the removal of dissolved heavy metals. However, the effectiveness of this particular technology cannot be ascertained prior to the implementation of bench scale testing. Because different resins are available to

accommodate the specific metals within a particular waste stream, ion exchange is generally a more versatile technology than activated alumina. The initial capital cost for a typical ion exchange system exceeds initial capital costs for activated alumina technology. However the operation and maintenance costs of manifesting the spent activated alumina off-site likely would offset the lower capital costs for this technology, making this treatment process a more costly method to implement. Therefore, for the purposes of this analysis an ion exchange system is included as the treatment process to effectively address concentrations of heavy metals.

Treated groundwater would be discharged via a pumped forced main from the treatment building to the Passumpsic River. Based on information from the Vermont Department of Environmental Conservation (VTDEC), discharge of treated groundwater to the Passumpsic River via a pumped forced main would be acceptable as long as water quality standards are met. The discharge would be required to meet the substantive requirements of the Vermont NPDES discharge program. The program requires monitoring of the treatment system for compliance with specified operation limits. Actual operational discharge limits would be determined during the permitting process; EPA has indicated that Vermont WQCs would be applicable as comparison criteria for the surface water discharge limits prior to dilution.

Management of Migration Component

Monitored Natural Attenuation, the ROD-designated remedial action for groundwater downgradient of the point of compliance, is also as a component of Alternative 1A. Natural attenuation is the in situ reduction of contaminant concentrations, mass, toxicity, and mobility through naturally occurring processes including dispersion, sorption, volatilization, chemical transformation and biological transformation, or mineralization. Monitored Natural Attenuation is the documenting of the progression of these intrinsic processes in achieving remediation goals. Monitored Natural Attenuation typically requires study area characterization, modeling of solute transport, and long-term monitoring of geochemical conditions within groundwater (i.e., redox potential, dissolved

oxygen, and pH) and concentrations of COCs to tell when objectives are met and aquifer restoration is complete.

The natural attenuation of chlorinated hydrocarbons at the Parker Landfill follows the reductive dechlorination process in which chlorinated hydrocarbons such as trichloroethene are used as an electron acceptor in reactions, resulting in the replacement of a chlorine atom from the molecule with a hydrogen atom. Indicators of reductive dechlorination that have been identified during long-term monitoring include:

- Depleted dissolved oxygen concentrations in areas corresponding to the extent of VOC impacts;
- Oxidation-reduction potentials in groundwater indicating reducing environments corresponding to the extent of VOC impacts;
- The presence of daughter products in groundwater including reduced chlorine compounds (i.e., 1,2-dichloroethene and vinyl chloride) consistent with reductive dechlorination process by-products;
- The presence of non-chlorinated daughter products in groundwater (i.e., ethene and ethane) consistent with reductive dechlorination processes and indicative of complete dehalogenation; and,
- Elevated concentrations of methane corresponding to areas of elevated VOCs in groundwater indicating strongly reducing, methanogenic conditions, which are generally associated with robust biodegradation of chlorinated compounds. Methane itself can be a metabolic byproduct of biodegradation.

For the Parker Landfill study area, the natural attenuation mechanisms observed through LTMP monitoring are discussed in Section 3.2.2. The effects of the attenuation process on groundwater quality have been approximated using the calibrated groundwater flow and solute transport model developed for the study area (URS, 2002). The groundwater flow and solute transport model was used to predict the extent and distribution of a target analyte over time based on the attenuation process rates currently identified within the study area groundwater. Trichloroethene was selected as the conservative indicator compound for the model simulations to assess the effectiveness of various remedial alternatives based on the following considerations:

- Trichloroethene is the main parent compound detected in study area groundwater, it is associated with each of the source areas, and its distribution generally mirrors the area of impacted groundwater downgradient of the landfill.
- Trichloroethene is the most frequently detected VOC and is present at elevated concentrations as compared to other VOCs in study area groundwater.
- The IGCL for trichloroethene is low relative to observed concentrations in comparison to other VOCs (e.g., cis-1,2-dichloroethene) identified in study area groundwater downgradient of the source areas.
- The organic carbon partitioning coefficient (K_{oc}), and the corresponding retardation factor is higher for trichloroethene than for its daughter compounds cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride, and the model calibrated decay half-life for trichloroethene is longer than published values of decay half-lives for the daughter compounds. The K_{oc} for trichloroethene is 126 milliliters per gram (ml/g) as compared to K_{oc} values of 49 ml/g for cis-1,2-DCE and 57 ml/g for vinyl chloride (EPA 1980; EPA 1988). These data indicate that both cis-1,2-DCE and vinyl chloride will be removed from the groundwater at a faster rate than trichloroethene. This faster rate applies to cis-1,2-DCE and vinyl chloride generated as a result of the biotransformation of trichloroethene which means residual concentrations of cis-1,2-DCE and vinyl chloride are not likely to lag behind trichloroethene as it moves in groundwater.
- Based upon an assessment of the stoichiometry of trichloroethene reduction to cis-1,2-DCE and vinyl chloride, the concentrations of these daughter compounds produced during degradation is predicted to be lower than their IGCLs upon attainment of the IGCL (5 ug/l) for trichloroethene.
- Due to the complexity of the flow model and the length of pre-cap landfill operational history (e.g., 1972 to 2000), transport modeling has proven to be a time-intensive process which does not lend itself to the simulation of multiple compounds that are less extensively distributed, are not parent compounds associated with the initial source area materials, are present at significantly lower concentrations, and in most cases have significantly higher IGCLs.

The numerical model indicates that the extent of trichloroethene impacted groundwater remains relatively stable during the near-term, but that concentrations decline over time due to the RCRA caps and other source control remedial actions and due to the degenerative mechanisms. The model predicts that the current attenuation rates will achieve the IGCL for trichloroethene and other compounds exceeding IGCLs after approximately 65 years (Figure 31).

Continued LTMP monitoring and periodic reviews are needed to show that an MNA remedy continues to meet the objectives of the ROD and the project RAOs. Recent studies indicate that for sites where degradation is not driven by co-solvency mechanisms, such as the Parker landfill, it is less likely that environmental conditions will significantly change in the future and thus site conditions should not limit the effectiveness of the natural attenuation processes currently occurring at the Parker Landfill.

4.4.1.1 Overall Protection of Human Health and the Environment

The Alternative 1A groundwater pump and treat system would prevent further migration of COCs in groundwater from the source area. The simulation of the groundwater pump and treat system using the study area groundwater flow and solute transport model forecasts that trichloroethene concentrations would remain above IGCLs for approximately 65 years, during which time operation of the groundwater pump and treat system would be required to meet the RAOs. This estimate of time required to achieve complete restoration of the aquifer is generally consistent with FS projections (i.e., 60-years), which were based on the EPA batch-flushing model. Figure 31 depicts in situ groundwater trichloroethene concentrations over time as forecast by numerical modeling.

Since the goal of protection of human health has been achieved with currently in place remedial actions, protection of human health is of limited concern. Also, unacceptable environmental risks associated with Alternative 1A do not exist. Extracted groundwater would be treated to meet effluent discharge concentrations. As with any treatment system, the potential exists for breakthrough of COCs from the treatment system and periodic discharge of COCs in excess of discharge criteria. Routine monitoring of treatment system effluent will minimize the potential for and duration of discharges of unacceptable concentrations of COCs from the treatment system. Short-term risks related to exposure to impacted groundwater during MNA sampling by personnel involved in sampling activities would be unchanged from current conditions and would be managed

using protocols outlined in the site specific health and safety plan and personal protective equipment now used during long-term groundwater monitoring events.

Residuals generated during the multi-stage treatment processes (e.g., sludge derived from metals pre-treatment, spent packing material associated with the air stripper, and spent LGAC) would either require additional on-site treatment or require suitable disposal resulting in short-term risks to human health during handling and potential long-term risks to the environment depending upon the method of disposal (e.g., to a secure landfill since releases from secure facilities can occur). Transportation accidents over the 65 year period are also a consideration.

Due to the presence of low-permeability soils separating the wetlands associated with the upper portions of the unnamed stream and the water table, as well as the distance separating the extraction wells and wetlands, impacts due to groundwater extraction on wetlands is expected to be minimal. Pumping rates will have to be managed to limit adverse effects associated with induced recharge from the unnamed stream, particularly in the area downgradient of IWS-3. Reduced pumping rates however, could decrease the effectiveness of the hydraulic control.

4.4.1.2 Compliance with ARARs

Alternative 1A would achieve state and federal ARARs for source area groundwater by removing COCs from groundwater at the point of compliance. Numerical modeling simulations of Alternative 1A groundwater pumping system indicate that IGCLs would be achieved across the study area in approximately 65 years. Action specific ARARs for this alternative will also need to be met, i.e. ex situ treatment of groundwater from pump and treat would comply with 1) the substantive portions of applicable Vermont state air emissions standards and would consider proposed RCRA air emissions standards and guidance for air stripper operations; 2) the substantive requirements of the NPDES discharge program regarding effluent quality discharging from the system to the Passumpsic River; 3) the substantive requirements of the Vermont water quality

standards and federal VT WQC for treated groundwater discharging from the system to the Passumpsic River; and, 4) the requirements of the Vermont hazardous waste regulations for the management of hazardous waste generated and shipped off-site as a result of the residues from the treatment system (e.g., metals precipitation, spent carbon).

Groundwater pumped for hydraulic control would require extensive treatment for metals removal in order to meet the VT WQC and to prevent system fouling (e.g., scaling). In many cases the VT WQC are more stringent than the IGCLs and stipulate guidance criteria for additional metals not addressed under the IGCLs or other applicable federal drinking water criteria (e.g., MCLs). Table 6 summarizes the surface water discharge criteria.

This alternative achieves state and federal ARARs for downgradient groundwater by intrinsic natural restoration processes, which are currently documented to be reducing concentrations of COCs in groundwater. Groundwater has been reclassified as Class IV (non-potable) in accordance with Vermont Groundwater Protection Regulations and this alternative would remediate groundwater as required by the Vermont Hazardous Waste Regulations through natural attenuation, which was the ROD-selected remedy for groundwater downgradient of the SWDA and IWS areas.

4.4.1.3 Long-Term Effectiveness and Permanence

For Alternative 1A, groundwater quality would improve within the source area point of compliance as a result of pumping of impacted groundwater. The timeframe for aquifer improvement has been simulated using the calibrated groundwater flow and transport model for the study area. Based upon these simulations, significant improvement of groundwater quality would require several years with IGCLs achieved within approximately 65 years. Results of model simulations are presented in Figure 31.

Pumping well systems have been reliable as hydraulic containment systems. However, they have had mixed results in providing aquifer restoration to MCL-based standards for

a variety of reasons discussed in Section 3.2. At many sites, it has not been possible to achieve reductions of COCs to MCL-based standards due to non-linear and slow desorption of COCs from the soil to groundwater. In addition, significant mass can remain in dewatered portions of the groundwater flow system for long periods of time and will not be removed by conventional groundwater extraction methods. For these reasons, as IGCLs are achieved in treatment system influent, a rebound in concentrations of COCs is generally expected following shutdown of the extraction system as groundwater velocities are reduced in response to decreased hydraulic gradients or groundwater recovers into areas that were dewatered by the extraction system and COCs partition from the resaturated soil back into groundwater. Removal of the COCs often requires extensive periods of cycled pumping (dewatering followed by periods of groundwater recovery) to flush the COCs from the soils. Such cycled pumping could extend the time required to achieve IGCLs significantly beyond the timeframe for groundwater restoration predicted by the model.

Periodic maintenance and replacement of the extraction well pumps and treatment system components (i.e., pumps, chemical storage tanks, treatment vessels, mechanical parts, and treatment system media) would be required; the short-term nature of these routine maintenance items would not, in all likelihood, significantly impair the long-term effectiveness of the system, but would result in temporary shutdowns of the system and loss of hydraulic control. The groundwater treatment system components would reliably reduce the levels of COCs to discharge limits over the long-term, but breakthrough of COCs, VOCs in particular, could result in short-term discharges of COCs above discharge limits. Treatment and discharge equipment (e.g., pumps and pipe) would require periodic maintenance and replacement.

Under Alternative 1A, downgradient groundwater quality would improve in response to natural restoration mechanisms within the groundwater system. Because groundwater flowpaths downgradient of the landfill are intercepted by the Passumpsic River and because the area of impact currently extends across the entire flow path between the source area and the River, further downgradient or significant lateral expansion of

impacted groundwater is unlikely. In addition, the institutional controls now in place reliably manage and provide long-term protection from residual contamination in the downgradient aquifer until IGCLs are achieved. However, as noted above, the timeframe for improvement of groundwater quality through the remedial action of source area extraction and treatment and downgradient MNA is estimated to be about 65 years. At the conclusion of this timeframe, the downgradient groundwater will have been successfully and permanently restored.

Long-term maintenance for this alternative would involve periodic inspection and potential replacement or redevelopment of groundwater monitoring wells to ensure the integrity of groundwater monitoring data. The short-term nature of these routine maintenance activities would not impair the effectiveness of monitoring of the ongoing remedy.

4.4.1.4 Reduction of Toxicity, Mobility, or Volume

For extracted groundwater, UV/Oxidation would permanently reduce the mass and toxicity of organic COCs from groundwater processed through the treatment plant. The remaining treatment technologies employed would not reduce toxicity levels or volume since the constituents would simply be transferred to another medium (e.g., carbon). Dewatered sludge from the inorganics pretreatment system, evaporator slurry from the ion exchange system, spent carbon from the VOC treatment system, and spent packing media for the air stripper would contain significant volumes of materials with concentrated levels of COCs and would require classification as to whether they were hazardous waste and appropriate treatment, recycling, and/or disposal.

Residuals remaining after treatment associated with pump and treat would include spent carbon and packing media from the VOC treatment system, waste sludge from the inorganics pretreatment system, and/or waste evaporator slurry from the ion exchange system. Engineering estimates based on vendor information indicates vapor-phase carbon usage to be approximately 20 lbs/day; sludge generation of approximately 2,800

lbs/day raw solids (assuming 30-percent solids) or approximately 36 cubic feet per day; and condensed evaporated slurry generation of approximately 375 gallons per day. The liquid carbon usage would be minimal since it would be used to treat those VOCs that could potentially pass through previous VOC removal systems. These estimated volumes of residuals are based on current VOC and metal concentrations. Modeling indicates a moderate decline in VOC loading anticipated to occur following the initial 5- to 10-years of system operation. The sludge and evaporator slurry may be classified as a hazardous waste based on elevated metals concentrations.

The degree to which treatment would reduce the inherent hazards posed by the mobility and volume of COCs in groundwater would be minimal because currently in place remedial actions have eliminated the risk to human health. However there is risk due to exposure to treatment system residuals during handling, transport, and disposal.

4.4.1.5 Short-Term Effectiveness

The groundwater pump, treat, and discharge activities associated with this alternative should result in moderate short-term impacts to the community and to workers. Some temporary, controllable risks to workers and the community would occur during construction of the outfall pipeline between the landfill and the Passumpsic River. Compliance with a health and safety plan and erosion and sedimentation control plan would be required during construction and operation of the treatment system and associated components. Short-term risks to personnel operating the treatment system, waste transporters, and disposal facility personnel would be present due to handling, transport, and disposal of treatment residuals.

Wetland impacts associated with groundwater extraction under this alternative are anticipated to be minimal. The extraction wells and piping system would need to be designed and installed in a manner that would avoid wetland disturbance to the extent possible, although associated piping would be required to traverse the unnamed stream and wetlands.

There would be no short-term attainment of groundwater remediation goals under this Alternative.

4.4.1.6 Implementability

Factors favoring implementability of this alternative are; 1) pumping wells can be installed using proven techniques and 2) services and materials are readily available. Treatment technologies are reliable but, because of local climate, would require protection in a heated building. Air stripping and UV/Oxidation equipment, carbon, and equipment and materials required for metals treatment are readily available and have been successfully implemented, and labor required to construct and implement the system is available. Removal and treatment of residuals from the treatment system would require properly trained personnel. Effluent quality criteria developed under the Vermont NPDES program will impact the treatment system design in terms of technical ease or feasibility of attaining discharge limits.

Construction of the discharge pipeline to the Passumpsic River would utilize standard construction techniques and materials. Easements would be required from several off-site property owners, including from the Northern Vermont Railroad. A NPDES permit would not be required for discharge of the treated groundwater to the Passumpsic River; however, the substantive requirements of the NPDES program would have to be met.

Dewatered sludge from the inorganics pretreatment system and evaporator slurry from the ion exchange unit would require characterization to quantify metals content and determine hazardous characteristics and corresponding requirements for disposal. Currently there are no approved hazardous waste disposal facilities located in Vermont. Waste transportation out-of-state would be expensive and some currently operating disposal facilities have restrictions in accepting hazardous waste. Long-term disposal of hazardous waste is uncertain because of the limited number of active disposal facilities and difficulties in locating new hazardous waste disposal facilities. For sludge from the

pretreatment system, this problem is acute because of the large volume of sludge that would likely be generated from the inorganic compounds associated with study area groundwater.

Organic constituents would be concentrated in spent carbon. There are several liquid and vapor phase carbon vendors who regenerate carbon as part of their services. These companies would retrieve spent carbon, replace it with regenerated carbon, and haul the spent carbon to their recycling facility.

Organic constituents may also sorb onto packing media. Fouling of packing media frequently occurs during treatment of impacted groundwater and it reduces the effectiveness of the air stripper. Therefore, packing media will, in all likelihood, require periodic replacement.

Removal and treatment of the treatment residual materials from operation of the groundwater treatment system would require properly trained personnel.

4.4.1.7 Cost Analysis

The estimated present worth costs for the alternative technology of pump and treat over a 30-year period is approximately \$30,147,000, which includes \$4,939,000 in capital costs and \$25,208,000 in O&M costs. Modeling indicates that the system would require operation for up to 65 years before cleanup goals are achieved, thereby increasing actual project O&M costs beyond those presented as part of this 30-year estimate.

Cost estimating tables for this Alternative are provided in Appendix C.

4.4.2 Alternative 1C: Pump and Treat for Source Area and Downgradient

Alternative 1C is the ROD-designated pump and treat system combined with pumping of groundwater from the area near the downgradient edge of the Parker Properties in the

vicinity of the Riverside School and treating it ex situ for discharge to the river. Alternative 1C was developed to assess the incremental benefit of containing impacted groundwater at the property boundary. Downgradient hydraulic containment would be achieved by the installation and operation of one additional deep overburden (i.e., top-of-rock) well located east of the B120 well cluster at the Parker Property boundary. A schematic of this alternative has been provided as Figure 25. Based on simulations performed using the calibrated groundwater flow and transport model for the study area, the additional well would operate at a pumping rate of approximately 60 gpm and would provide containment of impacted groundwater flowing from the Parker Properties. However, it will not significantly accelerate the restoration time for impacted groundwater. Modeling indicates that higher pumping rates could be sustained in this area, however modeling of higher pumping rates (e.g., 200 gpm) did not substantially accelerate groundwater restoration and would significantly increase treatment costs due to the volume-based costs associated with the operation and maintenance of the groundwater treatment system (e.g., sludge generation).

Requirements for treatment would be similar to those for the hydraulic containment system of Alternative 1A based on similar groundwater chemistry. Consequently, the sequence of treatments required to treat the pumped groundwater from the downgradient pumping well is similar. Considering this requirement, and the additional costs associated with constructing, operating, and maintaining a separate treatment system near the downgradient well, it would be more cost effective to pump the extracted groundwater to a larger-capacity treatment system located near the landfill. It is assumed that Alternative 1C would not be implemented in the absence of Alternative 1A. On this basis, several of the components of Alternative 1A listed in Section 4.4.1 would already be implemented. These components include a significant portion of the treatment system construction and elements of groundwater monitoring. Those components of the pump and treat downgradient remedial action considered for cost are:

- Installation of one additional overburden pumping well operating at approximately 60 gpm;

- Piping and pumps to transfer the untreated water to the Alternative 1A treatment system located adjacent to the landfill;
- Upgrading of the treatment system components associated with Alternative 1A in order to accommodate the higher operating flow rates;
- Generation of additional amounts of treatment residuals for onsite treatment and offsite disposal; and
- Long-term monitoring of groundwater containment in the area downgradient of the SWDA and IWS areas.

4.4.2.1 Overall Protection of Human Health and the Environment

Protection of human health has been achieved with currently in place remedial actions. Conservation and operation of this pump and treat system poses the same human health issues as Alternative 1A.

Implementing Alternative 1C could potentially increase potential short-term risk to workers installing, operating, and maintaining the groundwater extraction and treatment system due to potential exposure to impacted groundwater and treatment system residuals during these activities. These potential risks could be managed, to some extent, through implementation of a site health and safety plan and use of appropriate personal protective equipment.

Based upon simulations performed using the calibrated groundwater flow and solute transport model for the site, implementing Alternative 1C would not significantly accelerate complete restoration of the aquifer as compared to monitored natural attenuation. Results of the model simulations indicate that groundwater concentrations within the study area remain above remediation goals for approximately 65 years. Figure 32 depicts in situ groundwater trichloroethene concentrations over time as forecast by numerical modeling.

As with Alternative 1A, extracted groundwater would be treated to meet discharge levels prior to discharge.

The operation of the downgradient well would pose no additional impacts to study area wetlands beyond those discussed under Alternative 1A.

4.4.2.2 Compliance with ARARs

As with other alternatives, Alternative 1C would achieve state and federal ARARs for groundwater downgradient of the study area. Groundwater has been reclassified in accordance with Vermont Groundwater Protection Regulations and this alternative would remediate groundwater as required by the Vermont Hazardous Waste Regulations. For this alternative, concentrations of COCs in groundwater downgradient of the landfill would be reduced over time to IGCLs through natural attenuation processes. Concentrations of COCs that have not fully attenuated at the property boundary would be intercepted by the extraction well and concentrations of COCs contained in recovered groundwater would be reduced to acceptable criteria through ex situ treatment prior to discharge to the Passumpsic River.

Ex-situ treatment associated with this alternative would comply with ARARs as discussed previously for Alternative 1 in Section 4.4.1.2.

4.4.2.3 Long-Term Effectiveness and Permanence

Pumping well systems have been reliable as hydraulic containment systems. However, they have had mixed results in restoring impacted groundwater to MCL-based standards for reasons discussed in Section 3.2. At many sites, it has not been possible to achieve reductions of COCs to MCL-based standards due to non-linear and slow desorption of COCs from the soil to groundwater. In addition, significant mass can remain in dewatered portions of the groundwater flow system for long periods of time and will not be removed by conventional groundwater extraction methods. Even if IGCLs were achieved in treatment system effluent, a rebound in concentrations of COCs could occur following shutdown of the extraction system as groundwater recovers into soils that were

dewatered by the extraction system and COCs partition from the resaturated soil back into groundwater. Removal of the COCs from the resaturated soil often requires extensive periods of cycled pumping (dewatering followed by periods of groundwater recovery) to flush the COCs from the soils. Such cycled pumping could extend the time required to achieve IGCLs significantly beyond the 65-year timeframe predicted by the model.

The groundwater treatment system components are based upon proven technology and would reliably reduce the levels of COCs to discharge limits.

As with Alternative 1A, periodic maintenance and replacement of the pumping well pumps, mechanical components of the treatment system, and treatment media associated with various components of the treatment system would be required. The short-term nature of these routine maintenance items would not significantly impair the long-term effectiveness of the system but would result in temporary shutdowns of the system and loss of hydraulic control.

4.4.2.4 Reduction of Toxicity, Mobility, or Volume

As with Alternative 1A, UV/Oxidation would permanently remove organic COCs from extracted groundwater. The remaining treatment technologies employed would not reduce toxicity or volume since the constituents would simply be transferred to another medium (e.g., carbon) or concentrated as a waste (e.g., sludge and evaporator slurry). Dewatered sludge from the inorganics pretreatment system, evaporator slurry from the ion exchange system, and spent carbon from the VOC treatment system would contain significant volumes of materials with concentrated levels of COCs and would require classification as to whether they were hazardous waste needing special treatment, recycling, or disposal.

Residuals remaining after treatment associated with pump and treat at a downgradient location would include spent carbon from the VOC treatment system, packing material

associated with the air stripper, waste sludge from the inorganics pretreatment system, and waste evaporator slurry from the ion exchange system. Engineering estimates based on vendor information indicates vapor-phase carbon usage to be approximately 30 lbs/day; sludge generation of approximately 4,000 lbs/day raw solids (assuming 30-percent solids) or approximately 46 cubic feet per day; and condensed evaporated slurry generation of approximately 125 gallons per day. Liquid carbon usage would be minimal since it would be used to treat those VOCs that could potentially pass through previous VOC removal systems. This estimated volume of residuals is based on current VOC and metal concentrations. Modeling indicates a moderate decline in VOC loading anticipated to occur following the initial 5- to 10-years of system operation. The sludge and evaporator slurry may be classified as a hazardous waste based on elevated metals concentrations.

Due to the operational time period required for groundwater restoration under this alternative, the degree to which treatment would reduce the inherent hazards posed by the mobility and volume of COCs in groundwater would be minimal because currently in place remedial actions have eliminated the risk to human health. However, there is risk due to exposure to treatment system residuals during handling, transport and disposal.

4.4.2.5 Short-Term Effectiveness

Implementing pump and treat downgradient could potentially increase potential short-term risk to workers installing, operating, and maintaining the groundwater extraction and treatment system due to potential exposure to impacted groundwater and treatment system residuals during these activities. The groundwater pumping, treatment, and discharge activities associated with this alternative should result in minimal impacts to the community. It should be noted that the location of the groundwater pumping well proposed under Alternative 1C is located near the Riverside School. Therefore, potential short-term risks to the community, particularly students attending the Riverside School, related to the presence of open trenches and operation of heavy equipment during construction of the discharge line should be anticipated. These risks can be managed by

standard construction safety procedures (i.e., controlling site access, proper excavation techniques such as using trench boxes, and covering or backfilling trenches at the end of each work day).

Some temporary, controllable risks to workers could occur during construction and sampling activities. Potential short-term risks to workers involved in sampling or drilling activities would be related to short-term exposure to impacted groundwater and investigation-derived waste generated during drilling and sampling.

Wetland impacts associated with groundwater extraction under this alternative are anticipated to be minimal and similar to those discussed under Alternative 1A. The downgradient well would have limited additional impact from operation or installation, provided the well and appurtenances are installed in a manner that would avoid wetland disturbance. Local drawdown from well operations is not believed to impact the unnamed stream or proximal wetlands as the surface water in this area is perched and has been classified as losing-flow areas discharging to groundwater. The impact of the downgradient pumping well on flow in the unnamed stream would be assessed based upon a pumping test completed as part of pre-design activities.

4.4.2.6 Implementability

Factors favoring implementability of this alternative are similar to those discussed for Alternative 1A in Section 4.4.1.6. Construction of the additional pumping well and associated piping would utilize standard construction techniques and materials, which are readily available. In addition, concerns have been expressed by the Riverside School regarding the performance of sampling activities at monitoring well cluster B120 during the school year. On this basis, similar concerns are expected to be expressed concerning the installation of the groundwater extraction well near the school.

4.4.2.7 Cost Analysis

The estimated present worth costs associated with Alternative 1C over a 30-year period is approximately \$37,310,000, which includes \$5,519,000 in capital and \$31,791,000 in O&M costs (including equipment replacement costs). Modeling indicates that the system would require operation for approximately 65 years before cleanup goals are achieved, thereby increasing actual project O&M costs beyond those presented as part of this 30-year estimate.

Cost estimating tables for this Alternative are provided in Appendix C.

4.4.3 Alternative 2A: Monitored Natural Attenuation

Alternative 2A is the No Further Action alternative that would be compliant with the LTMP under the AO, and assumes continued implementation of the ICP. Alternative 2A consists of Monitored Natural Attenuation in the aquifer both at the source area and downgradient. Natural attenuation is the in situ reduction of contaminant concentrations, mass, toxicity, and mobility through naturally occurring processes including dispersion, sorption, volatilization, chemical transformation and biological transformation, or mineralization. Monitored Natural Attenuation is the documenting of the progression of these intrinsic processes in achieving remediation goals. Monitored Natural Attenuation typically requires study area characterization, modeling of solute transport, and long-term monitoring of geochemical conditions within groundwater (i.e., redox potential, dissolved oxygen, and pH) and concentrations of COCs to tell when objectives are met and aquifer restoration is complete.

For natural attenuation to be monitored effectively, the underlying mechanisms occurring in situ must be understood and integrated into the conceptual model of the study area, and the monitoring procedures must include evaluating changes in groundwater geochemistry that could affect natural attenuation processes, COCs, or transformation products

produced as a result of in situ attenuation processes. The COCs and transformation products are referred to as attenuation footprints [National Research Council (NRC), 2000]. Typically, the basic processes used to document natural attenuation include:

- Development of a conceptual model of the study area defining groundwater flow patterns, velocities, contaminant distribution, and natural attenuation processes involved in reducing concentrations of COCs; and,
- Monitoring geochemical conditions and COCs concentrations to assess whether physiochemical conditions (e.g., dissolved oxygen, redox potential) remain favorable for MNA and to document decreasing concentrations trends of COCs and identify indicators of MNA including transformation products and metabolic byproducts (e.g., methane). These data are used to demonstrate that in situ processes are effectively remediating the concentrations of COCs. Monitoring the study area is required to continue until regulatory requirements are achieved.

The natural attenuation of chlorinated hydrocarbons at the Parker Landfill follows the reductive dechlorination process in which chlorinated hydrocarbons such as trichloroethene are used as an electron acceptor in reactions, resulting in the replacement of a chlorine atom from the molecule with a hydrogen atom. Indicators of reductive dechlorination that have been identified during long-term monitoring include:

- Depleted dissolved oxygen concentrations in areas corresponding to the extent of VOC impacts;
- Oxidation-reduction potentials in groundwater indicating reducing environments corresponding to the extent of VOC impacts;
- The presence of daughter products in groundwater including reduced chlorine compounds (i.e., 1,2-dichloroethene and vinyl chloride) consistent with reductive dechlorination process by-products;
- The presence of non-chlorinated daughter products in groundwater (i.e., ethene and ethane) consistent with reductive dechlorination processes and indicative of complete dehalogenation; and,
- Elevated concentrations of methane corresponding to areas of elevated VOCs in groundwater indicating strongly reducing, methanogenic conditions, which are generally associated with robust biodegradation of chlorinated compounds. Methane itself can be a metabolic byproduct of biodegradation.

For the Parker Landfill study area, the natural attenuation mechanisms observed through LTMP monitoring are discussed in Section 3.2.2. The effects of the attenuation process on groundwater quality have been approximated using the calibrated groundwater flow and solute transport model developed for the study area (URS, 2002). The groundwater flow and solute transport model was used to predict the extent and distribution of a target analyte over time based on the attenuation process rates currently identified within the study area groundwater. Trichloroethene was selected as the conservative indicator compound for the model simulations to assess the effectiveness of various remedial alternatives based on the following considerations:

- Trichloroethene is the main parent compound detected in study area groundwater, it is associated with each of the source areas, and its distribution generally mirrors the area of impacted groundwater downgradient of the landfill.
- Trichloroethene is the most frequently detected VOC and is present at elevated concentrations as compared to other VOCs in study area groundwater.
- The IGCL for trichloroethene is low relative to observed concentrations in comparison to other VOCs (e.g., cis-1,2-dichloroethene) identified in study area groundwater downgradient of the source areas.
- The organic carbon partitioning coefficient (K_{oc}), and the corresponding retardation factor is higher for trichloroethene than for its daughter compounds cis-1,2-DCE and vinyl chloride, and the model calibrated decay half-life for trichloroethene is longer than published values of decay half-lives for the daughter compounds. The K_{oc} for trichloroethene is 126 ml/g as compared to K_{oc} values of 49 ml/g for cis-1,2-DCE and 57 ml/g for vinyl chloride (EPA 1980; EPA 1988). These data indicate that both cis-1,2-DCE and vinyl chloride will be removed from the groundwater at a faster rate than trichloroethene. This faster rate applies to cis-1,2-DCE and vinyl chloride generated as a result of the biotransformation of trichloroethene which means residual concentrations of cis-1,2-DCE and vinyl chloride are not likely to lag behind trichloroethene as it moves in groundwater.
- Based upon an assessment of the stoichiometry of trichloroethene reduction to cis-1,2-DCE and vinyl chloride, the concentrations of these daughter compounds produced during degradation is predicted to be lower than their IGCLs upon attainment of the IGCL (5 ug/l) for trichloroethene.
- Due to the complexity of the flow model and the length of pre-cap landfill operational history (e.g., 1972 to 2000), transport modeling has proven to be a time-intensive process which does not lend itself to the simulation of multiple compounds that are less extensively distributed, are not parent compounds

associated with the initial source area materials, are present at significantly lower concentrations, and in most cases have significantly higher IGCLs.

The numerical model indicates that the extent of trichloroethene impacted groundwater remains relatively stable during the near-term, but that concentrations decline over time due to the RCRA caps and other source control remedial actions and due to the degenerative mechanisms. The model predicts that the current attenuation rates will achieve the IGCL for trichloroethene and other compounds exceeding IGCLs after approximately 70 years (Figure 33).

Continued LTMP monitoring and periodic reviews are needed to show that an MNA remedy continues to meet the objectives of the ROD and the project RAOs. Recent studies indicate that for sites where degradation is not driven by co-solvency mechanisms, such as the Parker landfill, it is less likely that environmental conditions will significantly change in the future and thus site conditions should not limit the effectiveness of the natural attenuation processes currently occurring at the Parker Landfill.

4.4.3.1 Overall Protection of Human Health and the Environment

As with other alternative technologies analyzed and evaluated, because the goal of protection of human health has been achieved with currently in place remedial actions, protection of human health is of limited concern. Short-term risks related to exposure to impacted groundwater during sampling by personnel involved in sampling activities would be unchanged from current conditions and would be managed using protocols outlined in the site specific health and safety plan and personal protective equipment now used during long-term groundwater monitoring events.

Monitored natural attenuation was evaluated by the study area groundwater flow and solute transport model using the calibrated parameters as described in the model documentation report (URS, 2002). Complete restoration of the aquifer under natural

attenuation mechanisms is estimated to be 70 years. Figure 33 depicts in situ groundwater trichloroethene concentrations over time as forecast by the numerical model.

4.4.3.2 Compliance with ARARs

This alternative achieves state and federal ARARs for study area groundwater by intrinsic natural restoration processes, which are currently documented to be reducing concentrations of COCs in groundwater. Groundwater has been reclassified as Class IV (non-potable) in accordance with Vermont Groundwater Protection Regulations and this alternative would remediate groundwater as required by the Vermont Hazardous Waste Regulations through natural attenuation, which was the ROD-selected remedy for groundwater downgradient of the SWDA and IWS areas. Modeling of the study area indicates that the time required to meet groundwater cleanup objectives (i.e., IGCLs) would be approximately 70 years.

4.4.3.3 Long-Term Effectiveness and Permanence

Natural attenuation processes for the remediation of chlorinated solvents in groundwater are proven effective for long-term remediation at locations where exposure pathways have been eliminated. A fundamental component of intrinsic remediation is an adequate monitoring program to verify long-term effectiveness of intrinsic processes in reducing concentrations of COCs and decreasing the lateral and vertical extent of impacted groundwater.

It is generally accepted that the supply rates of electron donors necessary to sustain the reductive dechlorination reactions are typically dependent upon sustainable electron-acceptor supply rates, such as would be anticipated in a landfill setting. The degradation rate for COCs are modeled to be low (i.e., conservative), therefore modeled reductions in concentrations to IGCLs should be achieved over the long-term, as predicted by the numerical modeling.

Under Alternative 2A, groundwater quality would improve in response to natural restoration mechanisms within the groundwater system. Because groundwater flowpaths downgradient of the landfill are intercepted by the Passumpsic River and because the area of impact currently extends across the entire flowpath between the source area and the River, further downgradient or significant lateral expansion of impacted groundwater is unlikely. The timeframe for improvement of groundwater quality through the remedial action of MNA is estimated to be about 70 years.

Long-term maintenance for this alternative would involve periodic inspection and potential replacement or redevelopment of groundwater monitoring wells to ensure the integrity of groundwater monitoring data. The short-term nature of these routine maintenance activities would not impair the effectiveness of monitoring of the ongoing remedy.

4.4.3.4 Reduction of Toxicity, Mobility, or Volume

Natural attenuation mechanisms for chlorinated VOCs (e.g., reductive dehalogenation) permanently remove chlorinated hydrocarbons from groundwater through biotic and abiotic processes. Destruction of the chlorinated hydrocarbons to non-chlorinated compounds, (i.e., ethenes and ethanes), as has been documented in study area groundwater, permanently reduces the overall toxicity, volume, and ultimately mobility of COCs in groundwater. Biologically mediated transformations of chlorinated VOCs can be limited by changes in geochemical conditions (e.g., increases in dissolved oxygen or redox potential). Because of the close proximity of the landfill which creates a local reducing environment due to degradation of organic carbon and generation of methane, it is anticipated that conditions favorable for biological degradation that now exist in the vicinity of the landfill will not change significantly in the foreseeable future.

4.4.3.5 Short-Term Effectiveness

Implementation of monitored natural attenuation does not involve construction activities, thus the protectiveness of human health related to short-term activities is considered to be high. The implementation of a monitoring program to assess the effectiveness of in situ natural attenuation should result in minimal impact to workers and no significant impact to the community. Potential short-term risks to workers involved in sampling activities would be related to short-term exposure to impacted groundwater and investigation-derived waste generated during sampling. These short-term risks would be managed through implementation of a site specific health and safety plan and use of appropriate personal protective equipment. Purge water containing COCs in excess of IGCLs would continue to be managed through on-site treatment with LGAC.

There will be no impacts to wetlands associated with this alternative.

4.4.3.6 Implementability

Natural attenuation is highly implementable at the study area as it is a natural process, which has been demonstrated to be currently occurring in study area groundwater. Implementability issues associated with this alternative are favorable because; 1) evidence indicating occurrence of natural attenuation processes has been identified downgradient of the landfill in areas of impact; 2) modeling of the fate and transport processes occurring onsite indicate that the areas of impact will not generally expand into currently unimpacted areas and concentrations will reduce to levels meeting IGCLs in response to source control remedial actions already implemented; and, 3) a long-term monitoring program that includes parameters to assess the effectiveness of natural attenuation has already been implemented and is ongoing at the site.

There are no major impediments to implementing the monitoring system.

4.4.3.7 Cost Analysis

The estimated present worth costs associated with Alternative 2A over a 30-year period is approximately \$1,901,000, which includes continuation of ongoing monitoring and required 5-year reviews of the selected remedy.

Cost estimating tables for this Alternative are provided in Appendix C.

4.4.4 Alternative 4A: Permeable Reactive Barrier for Source Area and Monitored Natural Attenuation Downgradient

Alternative 4A utilizes is a zero-valent iron PRB as the source area treatment component, combined with downgradient Monitored Natural Attenuation. This alternative will intercept organic COCs migrating from the IWS-3 area and treat the chlorinated VOCs in situ through induced reductive dehalogenation. When combined with Monitored Natural Attenuation for areas of groundwater impacts emanating from the west side of the SWDA (where attenuation is robust), and for downgradient areas, a PRB would effectively eliminate VOC mass from migrating from the landfill to downgradient areas and greatly accelerate the complete restoration of the aquifer downgradient from the Parker Property.

The emplacement of a granular zero-valent iron PRB to effect reductive dechlorination of groundwater impacts was employed as a groundwater remedy as early as 1994, and was identified in EPA Region I as a groundwater ROD remedy in 1995 (EPA, 1998). Permeable reactive barriers of zero-valent iron have been demonstrated under full-scale applications to successfully reduce chlorinated COCs in groundwater. The degradation process is abiotic reductive dehalogenation and involves the corrosion of the iron by the chlorinated hydrocarbon.

Typically, permeable reactive barriers are designed to provide adequate residence time in the treatment zone for the degradation of the parent compound and all intermediate products that are generated.

Numerous researchers have studied the reactions of chlorinated solvents with iron and other zero-valent metals. Iron is generally favored based on reactivity and cost; however studies have indicated that impurities such as carbon or other metals in combination with iron may enhance the rate of degradation, particularly of trichloroethene (Liang, et al., 1997).

The dehalogenation reaction is a surface reaction that requires physical contact between the chlorinated compound and the zero-valent metal. Consequently, the available surface area of the metal has been found to have a large effect on the reaction rate with the chlorinated solvent. A balance must be established for site conditions, which considers increased surface area of smaller-sized metal particles compared to resulting reductions in permeability. The formation of insoluble precipitates such as iron oxides and carbonates can reduce the flow rate of groundwater through the wall. Plugging of the reactive wall is typically not a concern in non-funnel and gate designs.

As the reductive capacity is limited by mass, eventually the zero-valent iron will be completely oxidized. Typical estimates are that the zero-valent iron will last 80 years in most groundwater systems. In the event that the reactive barrier is expended prior to the end of its operable requirements (i.e., prior to aquifer restoration), the wall can be regenerated or reconstructed.

To achieve maximum effectiveness, the PRB wall would be installed transverse to the predominant direction of groundwater flow and be located adjacent to the eastern edge of the SWDA and downgradient of IWS-3. In this configuration it will intersect groundwater exceeding IGCLs at the compliance boundary of the source area, effectively preventing the future migration of contaminated groundwater beyond the landfill. Natural Attenuation of the downgradient aquifer will allow for the gradual reduction in the levels of contaminants that were released many years ago.

Based upon the pre-design field investigation more than 99-percent of the mass of VOCs migrating from IWS-3 and the east edge of the SWDA would be intercepted and treated

by a PRB keyed into the upper portion of the massive silt and silt/clay unit (i.e. distal unit). Due to installation depth requirements (approximately 55 feet below the water table), conventional construction methods will most likely be employed (e.g., trenching). Permeable reactive barriers have been successfully constructed at depths of up to 125 feet below ground surface. Figure 26 depicts the approximate layout of the source area PRB.

For the highly reduced portion of the plume emanating from the western side of the landfill, natural attenuation would be monitored ensure that the reducing environment which has limited the migration of the impacts continues following completion of the SWDA cap.

Specific components of Alternative 4A include:

- Full-scale design and implementation of the PRB to intercept and treat areas of impacted groundwater at the compliance boundary of the landfill at IWS-3;
- Long-term groundwater monitoring of the area downgradient of the SWDA and IWS areas to assess the effectiveness of the PRB and natural attenuation in reducing concentrations of organic COCs; and
- Five-year reviews, as per the AO/SOW.

4.4.4.1 Overall Protection of Human Health and the Environment

In situ PRBs using zero-valent iron are a proven and reliable technology that has been accepted by regulatory agencies, including EPA Region 1, as a method for treating the migration of chlorinated VOCs in groundwater. The application of the zero-valent iron PRB under Alternative 4A would result in an effective elimination of further concentrations of organic COCs migrating from the source area. Based upon simulations performed with the calibrated groundwater flow and solute transport model for the study area, installation of the PRB would result in complete aquifer restoration in approximately 70 years, compared to 65 years for pump and treat³.

³ The simulation of the PRB using the solute transport model was achieved by fixing constant concentration cells along the proposed alignment of the PRB, with concentrations at those locations set at 0 mg/l.

Protection of human health has been achieved with currently in place remedial actions and construction of the PRB does not pose any human health risk that will not be addressed sufficiently in a health and safety plan. Based on the location of the PRB and the method of installation, impacts to the unnamed stream due to construction will likely occur, but may be minimized through engineering controls. It is possible some minor component of compensatory wetland construction would be required onsite. Impacts to wetlands are not perceived to result from the passive PRB operation based on numerical modeling estimates of the post-installation water table in the area of the PRB.

4.4.4.2 Compliance with ARARs

The alternative would achieve state and federal ARARs for groundwater for organic COCs downgradient by actively reducing chlorinated COCs mass through reductive dechlorination to carbon dioxide and water. Groundwater has been reclassified in accordance with Vermont Groundwater Protection Regulations and this alternative would remediate groundwater as required by the Vermont Hazardous Waste Regulations through a combination of in situ PRB reduction and MNA. Based on numerical modeling of the PRB, complete restoration of the aquifer would be achieved for the entire aquifer in approximately 70 years. Figure 34 depicts the aquifer restoration over time for Alternative 4A.

4.4.4.3 Long-Term Effectiveness and Permanence

Permeable reactive barriers using zero-valent iron are a proven and reliable technology for reducing concentrations of halogenated organic compounds in groundwater and converting these compounds to carbon dioxide and water. Reductions in contaminant mass, concentration, and toxicity by iron-driven reductive dechlorination processes are rapid and permanent. Since contaminants are destroyed in the PRB, it also reduces their mobility by stopping their further migration.

Permeable reactive barrier systems have been proven reliable as containment systems. Monitoring of the PRB system would be required. Maintenance of the PRB system may be necessary in the form of monitoring well reconstruction or, less likely, media replacement. The short-term nature of these activities would not impair the effectiveness of the remedy.

Under Alternative 4A, groundwater quality would improve significantly in response to the elimination of mass through reductive dechlorination within the PRB, as well as ongoing natural attenuation processes occurring in situ within the downgradient aquifer. Based on the study area groundwater flow and solute transport model, IGCLs should be achieved for study area groundwater in approximately 70 years.

4.4.4.4 Reduction of Toxicity, Mobility, or Volume

The in situ reductive dechlorination driven by the zero-valent iron of the PRB system would permanently destroy organic COCs from groundwater within the treatment cell, eliminating the overall toxicity, mobility and volume. The natural attenuation dechlorination processes also will permanently destroy organic COCs from groundwater in the remaining areas of the downgradient aquifer.

Due to the installation methods, regeneration or replacement of the reductive media could be undertaken in the future if necessary.

4.4.4.5 Short-Term Effectiveness

The PRB system should result in minimal impacts to the community and to workers. Some temporary, controllable risks to workers on site will occur during PRB construction. Compliance with a health and safety plan and erosion and sedimentation control plan would be required during construction and operation (e.g., monitoring) of the system.

Wetland impacts associated with construction of the PRB under this alternative would be minimized as practical. Any necessary wetland disturbance would require remediation measures to restore.

Based upon the isolated nature of the Parker Landfill and because installation activities will occur entirely within the site boundaries, impacts to the residents living near the site will be negligible.

4.4.4.6 Implementability

Implementability issues associated with this alternative are favorable considering; 1) the PRB system can be installed using proven methods (e.g., trenching); and 2) services and materials associated with the PRB are readily available. The zero-valent iron dehalogenation process of the PRB is reliable and a proven treatment technology for the remediation of organic COCs in site groundwater. There are no residuals generated by the PRB system that would require handling. Treatment occurs in situ, eliminating operational problems with treatment systems. There are no major impediments to implementing the PRB system due to study area and climatic conditions. This in situ remedial option is reliable and a proven treatment technology given study area conditions.

4.4.4.7 Cost Analysis

The estimated present worth costs associated with Alternative 4A over a 30-year period is approximately \$5,386,000 which includes \$2,519,000 in capital costs and \$2,867,000 in O&M costs.

Cost estimating tables for this Alternative are provided in Appendix C.

4.4.5 Alternative 4B: Permeable Reactive Barrier Using Zero Valent Iron for Source Area and Bio-Enhanced Attenuation Downgradient

Alternative 4B utilizes a zero-valent iron PRB as the source area treatment component, similar to Alternative 4A, but Alternative 4B combines the source area PRB with downgradient bio-enhanced attenuation. This alternative will intercept organic COCs migrating from the IWS-3 area and treat the chlorinated VOCs in situ through induced reductive dehalogenation. When combined with Monitored Natural Attenuation for areas of groundwater impacts emanating from the west side of the SWDA (where attenuation is robust), a PRB would effectively eliminate VOC mass from migrating from the landfill to downgradient areas and greatly accelerate the complete restoration of the aquifer downgradient from the Parker Property.

As with Alternative 4A, to achieve maximum effectiveness the PRB wall would be installed transverse to the predominant direction of groundwater flow and be located adjacent to the eastern side of the SWDA and downgradient of IWS-3. In this configuration it will intersect groundwater exceeding IGCLs at the compliance boundary of the source area, effectively preventing the future migration of contaminated groundwater beyond the landfill. The Alternative 4B addition of bio-enhanced attenuation to the downgradient aquifer will add to the treatment of contaminants that were released many years ago.

Specific components of Alternative 4B include:

- Full-scale design and implementation of the PRB to intercept and treat areas of impacted groundwater at the compliance boundary of the landfill at IWS-3;
- Completion of the ongoing pilot-scale bio-enhanced attenuation study in the downgradient area;
- In situ bio-enhanced attenuation in the area of elevated groundwater impacts (i.e., area downgradient of the source area exhibiting higher concentrations of organic COCs) using injection points/wells to deliver reagents (e.g., nutrients, a source of carbon) to the subsurface;

- Monitored Natural Attenuation of remaining/residual groundwater impacts; and
- Long-term groundwater monitoring of the area downgradient of the SWDA and IWS areas to assess the effectiveness of the PRB and natural attenuation in reducing concentrations of organic COCs; and
- Five-year reviews, as per the AO/SOW.

4.4.5.1 Overall Protection of Human Health and the Environment

In situ PRBs using zero-valent iron are a proven and reliable technology that have been accepted by regulatory agencies, including EPA Region 1, as a method for treating the migration of chlorinated VOCs in groundwater. The injection of a biological enhancing reagent into the subsurface for the purpose of mass reduction of elevated VOCs in downgradient groundwater would notably reduce the concentration of chlorinated VOCs in groundwater emanating from the Parker Property. Since the goal of protection of human health has been achieved with currently in place remedial actions (e.g., institutional controls, and groundwater reclassification), protection of human health is already being achieved. The application of the zero-valent iron PRB combined with downgradient bio-enhanced attenuation under Alternative 4B would result in a significant reduction in the concentration of organic COCs migrating offsite and reduce the time required for complete restoration of the aquifer. Based upon simulations performed with the calibrated groundwater flow and solute transport model for the study area, complete restoration of the aquifer is estimated to occur after 70 years for Alternative 4B compared with 65 years for pump and treat and 70 years for natural attenuation alone⁴.

Protection of human health has been achieved with currently in place remedial actions and construction of the PRB with downgradient bio-enhanced attenuation does not pose any human health risk that will not be addressed sufficiently in a health and safety plan. Based on the location of the PRB, and the method of installation, impacts to the unnamed stream due to construction could occur, but will be minimized through engineering controls. It is

⁴ The simulation of downgradient bio-enhanced attenuation using the solute transport model was achieved by fixing time-varying constant concentration cells along the proposed alignment of the treatment area. Constant concentrations at those cells were set by a varying scale to simulate the reduction of trichloroethene as a result of treatment by factors of an order of magnitude or less.

possible some minor component of compensatory wetland construction would be required onsite. Impacts to wetlands are not perceived to result from the passive PRB operation based on numerical modeling estimates of the post-installation water table in the area of the PRB.

4.4.5.2 Compliance with ARARs

The alternative would achieve state and federal ARARs for groundwater for organic COCs downgradient by actively reducing chlorinated COCs mass from the source area through reductive dechlorination to carbon dioxide and water. Implementation of bio-enhanced natural attenuation would achieve state and federal ARARs in groundwater for organic constituents of interest in downgradient groundwater by actively reducing the mass of chlorinated VOCs through accelerating microbial degradation rates. Downgradient concentrations of constituents of interest will be reduced to IGCLs over time through a combination of biological transformation and physical attenuation processes currently underway in study area groundwater. In addition, groundwater has been reclassified to Class IV in accordance with Vermont Groundwater Protection Regulations. Based on numerical modeling of the PRB, restoration of the aquifer would be achieved in the area between the PRB and the river (the downgradient area) in approximately 65 years. Interim groundwater cleanup levels for the entire aquifer would be achieved in approximately 70 years. Figure 35 depicts the aquifer restoration over time for Alternative 4B.

Although a permit would not be required, injection of bio-enhancing reagents would be required to meet the substantive requirements of the State of Vermont UIC program.

4.4.5.3 Long-Term Effectiveness and Permanence

Permeable reactive barriers using zero-valent iron are a proven and reliable technology for reducing concentrations of halogenated organic compounds in groundwater and converting these compounds to carbon dioxide and water. Reductions in contaminant mass,

concentration, and toxicity by iron-driven reductive dechlorination processes are rapid and permanent. Since contaminants are destroyed in the PRB, it also reduces their mobility by stopping their further migration.

Permeable reactive barrier systems have been proven reliable as containment systems. Monitoring of the PRB system would be required. Maintenance of the PRB system may be necessary in the form of monitoring well reconstruction or, less likely, media regeneration/replacement. The short-term nature of these activities would not impair the effectiveness of the remedy.

Bio-enhanced natural attenuation is a technology that is proven and reliable for reducing the concentration of chlorinated VOCs in groundwater by converting these compounds to end products such as carbon dioxide, water, and chloride. Reductions in contaminant mass, concentration, and toxicity by microbial-driven degradation processes are permanent. Monitoring of the results of the microbial actions and groundwater chemistry would be required to confirm that conditions remain favorable for degradation and to verify reductions of constituents of interest in groundwater. Additional applications of enhancing reagent may be necessary to maintain favorable conditions within the subsurface. It should be noted that typically a reduction in concentrations of higher order chlorinated compounds is observed within a relatively short timeframe following application of reagents. However, a longer acclimation period is often required before significant degradation of dichloroethene and vinyl chloride occurs.

Under Alternative 4B, groundwater quality would improve significantly in response to the elimination of mass through reductive dechlorination within the PRB, as well as acceleration of the chlorinated VOC destruction via enhanced biological processes. Based on the study area groundwater flow and solute transport model, IGCLs should be achieved for downgradient groundwater in approximately 65 years and for groundwater on the Parker Property in about 70 years.

4.4.5.4 Reduction of Toxicity, Mobility, or Volume

The in situ reductive dechlorination driven by the zero-valent iron of the PRB system would permanently destroy organic COCs from groundwater within the treatment cell, eliminating the overall toxicity, mobility and volume. The use of bio-enhanced natural attenuation permanently destroys those organic constituents of interest that undergo a complete conversion to carbon dioxide, water and chloride in the downgradient aquifer. Both of these processes eliminate overall toxicity, mobility, and volume.

Due to the installation methods, regeneration or replacement of the reductive media could be undertaken in the future if necessary.

For bio-enhanced attenuation, the increased rate of reduction of toxicity, mobility, and volume, will need additional applications of reagents or sensitizing of the delivery system should groundwater monitoring indicate that the microbial population is not reducing COC concentrations at an increased rate.

4.4.5.5 Short-Term Effectiveness

The PRB system should result in minimal impacts to the community and to workers. Some temporary, controllable risks to workers on site will occur during PRB construction and bio-enhanced attenuation system construction and operation. Compliance with a health and safety plan and erosion and sedimentation control plan would be required during construction and operation (e.g., monitoring) of the system.

Wetland impacts associated with construction of the PRB under this alternative would be minimized as much as practical. Any necessary wetland disturbance would require remediation measures to restore.

Based upon the isolated nature of the Parker Landfill and because installation and injection activities will occur entirely within the site boundaries, impacts to the residents living near the site will be negligible.

4.4.5.6 Implementability

Implementability issues associated with this alternative are favorable considering; 1) the PRB system can be installed using proven methods (e.g., trenching); and 2) services and materials associated with the PRB are readily available. The zero-valent iron dehalogenation process of the PRB is reliable and a proven treatment technology for the remediation of organic COCs in site groundwater. There are no residuals generated by the PRB system or the bio-enhanced attenuation process, which would require handling. Both the PRB and the bio-enhanced attenuation treatment occurs in situ, eliminating operational problems with treatment systems. Commercial sources of organic carbon and nutrients, as necessary, are readily available. Periodic applications of reagents can be performed using standard pumps, valves, and metering equipment.

Materials necessary for the injection process are readily available as are laboratory services required for performance monitoring. There are no major impediments to implementing the bio-enhanced attenuation and PRB systems due to site and climatic conditions. Successful applications of the PRB technology have been demonstrated to the anticipated depth of bedrock at the proposed PRB location.

Specific procedures to be used to determine the success of implementation, and the post-application monitoring requirements will be determined as part of system design. These in situ remedial actions are reliable and proven treatment technologies given study area conditions.

4.4.5.7 Cost Analysis

The estimated present worth costs associated with Alternative 4B over a 30-year period is approximately \$10,779,000, which includes \$5,276,000 in capital costs and \$5,503,000 in O&M costs⁵.

Cost estimating tables for this Alternative are provided in Appendix C.

4.4.6 Alternative 5B: Bio-Enhanced Attenuation in Source Area and Downgradient

Alternative 5B utilizes bio-enhanced attenuation to remediate impacted groundwater in both the source area and in the downgradient area. This alternative will treat the chlorinated VOCs in situ through induced reductive dehalogenation. When combined with monitored natural attenuation for areas of groundwater impacts emanating from the west side of the SWDA (where attenuation is robust), a bio-enhanced attenuation would significantly reduce VOC mass within both shallow overburden and top-of-rock groundwater from migrating off-site from the landfill and greatly accelerate the restoration of the aquifer downgradient from the Parker Property.

Specific components of Alternative 5B include:

- In situ bio-enhanced attenuation in the area of elevated overburden groundwater impacts (i.e., area downgradient of IWS-3 exhibiting higher concentrations of organic COCs) using injection points/wells to deliver reagents (e.g., nutrients, a source of carbon) to the subsurface;
- Completion of the ongoing pilot-scale bio-enhanced attenuation study in the downgradient area;
- In situ bio-enhanced attenuation in the area of elevated groundwater impacts (i.e., area downgradient of the source area exhibiting higher concentrations of organic

⁵ The cost estimate for the application of the bio-enhanced attenuation technology is based on an assumed application scenario (e.g., treatment reagent, injection type, injection frequency) prepared prior to the completion of the pilot-scale field application. The preferred scenario for the application may change as part of pre-design and design activities.

COCs) using injection points/wells to deliver reagents (e.g., nutrients, a source of carbon) to the subsurface;

- Monitored Natural Attenuation of remaining/residual groundwater impacts; and
- Long-term groundwater monitoring of the area downgradient of the SWDA and IWS areas to assess the effectiveness of the PRB and natural attenuation in reducing concentrations of organic COCs; and
- Five-year reviews, as per the AO/SOW.

4.4.6.1 Overall Protection of Human Health and the Environment

The injection of a biological enhancing reagent into the subsurface for the purpose of mass reduction of elevated VOCs would notably reduce the concentration of chlorinated VOCs in groundwater emanating from the landfill and in the downgradient area. Since the goal of protection of human health has been achieved with currently in place remedial actions (e.g., institutional controls, and groundwater reclassification), protection of human health is of limited concern. Organic carbon sources, and possibly nutrients, would have to be transported to and stored near the treatment area during the injection process. These materials likely will not pose an unmanageable threat to human health or the environment. Impacts to the unnamed stream and the associated wetland areas are not anticipated.

Based on simulations performed with the calibrated groundwater flow and solute transport model for the study area, the combination of technologies in Alternative 5B would result in restoration of the aquifer in the area between the application area and the river (the downgradient area) in approximately 55 years⁶. Interim groundwater cleanup levels for the entire aquifer would be achieved in approximately 60 years. Figure 36 depicts the aquifer restoration over time for Alternative 5B.

⁶ The simulation of downgradient bio-enhanced attenuation using the solute transport model was achieved for the downgradient area as described in Section 4.4.5.1. Simulation for the source area application was achieved by revising initial concentrations for cells located within the treatment zone (as depicted on Figure 29) to reflect source area reductions by a factor of approximately 0.2 to 0.25.

4.4.6.2 Compliance with ARARs

Implementation of bio-enhanced attenuation would achieve state and federal ARARs in groundwater for organic constituents of interest in downgradient groundwater by actively reducing the mass of chlorinated VOCs through accelerating microbial degradation rates. Concentrations of constituents of interest will be reduced to IGCLs over time through a combination of biological transformation and physical attenuation processes currently underway in study area groundwater.

In addition, groundwater has been reclassified in accordance with Vermont Groundwater Protection Regulations.

Although a permit would not be required, injection of bio-enhancing reagents would be required to meet the substantive requirements of the State of Vermont UIC program.

Based on numerical groundwater modeling performed for the study area, the implementation of Alternative 5B would result in restoration of the aquifer in approximately 60 years. Figure 36 depicts the aquifer restoration over time for Alternative 5B.

4.4.6.3 Long-Term Effectiveness and Permanence

Bio-enhanced natural attenuation is a technology that is proven and reliable for reducing the concentration of chlorinated VOCs in groundwater by converting these compounds to end products such as carbon dioxide, water, and chloride. Reductions in contaminant mass, concentration, and toxicity by microbial-driven degradation processes are permanent. Monitoring of the results of the microbial actions and groundwater chemistry would be required to confirm that conditions remain favorable for degradation and to verify reductions of constituents of interest in groundwater. Additional applications of enhancing reagent may be necessary to maintain favorable conditions within the subsurface. It should be noted that typically a reduction in concentrations of higher order

chlorinated compounds is observed within a relatively short timeframe following application of the reagents. However, a longer acclimation period is often required before significant degradation of dichloroethene and vinyl chloride occurs. Groundwater quality would improve significantly in response to the acceleration of the chlorinated VOC destruction via enhanced biological processes.

4.4.6.4 Reduction of Toxicity, Mobility, or Volume

The use of bio-enhanced natural attenuation permanently destroys those organic constituents of interest that undergo a complete conversion to carbon dioxide, water, and chloride. This process eliminates overall toxicity, mobility and volume. Additional applications of reagents or sensitizing of the delivery system may be needed should groundwater monitoring indicate that the microbial population is not reducing COC concentrations at an increased rate.

4.4.6.5 Short-Term Effectiveness

Bio-enhanced natural attenuation should result in minimal impacts to the community and workers. Some temporary, controllable risk to workers on site will occur during system construction and start-up operation. Compliance with a health and safety plan would be required during reagent injection and monitoring activities.

Based upon the nature of the materials to be used and the nature of construction, and because application activities will occur entirely within a relatively isolated portion of the study area the site boundaries, impacts to the residents living near the site will be negligible.

4.4.6.6 Implementability

Given study area conditions, bio-enhanced natural attenuation is a reliable and proven treatment technology. There are no residuals generated by the use of this technology,

which would require handling. Treatment occurs in situ and commercially available sources of organic carbon (and nutrients, as necessary) are readily available. Periodic applications of reagents can be performed using standard pumps, valves, and metering equipment. Materials necessary for the injection process are readily available as are laboratory services required for performance monitoring. Routine monitoring of the groundwater quality would be conducted to monitor the effectiveness of the remedy.

There are no major impediments to implementing this technology due to site and climatic conditions.

4.4.6.7 Cost Analysis

The estimated present worth costs associated with Alternative 5B over a 30-year period is approximately \$13,317,000 which includes \$8,780,000 in capital costs and \$4,537,000 in O&M costs⁷.

Cost estimating tables for this Alternative are provided in Appendix C. The cost associated with implementing bio-enhanced natural attenuation are based upon several factors including the number of application points required to effectively distribute reagents for the source area and for the downgradient plume, the quantity and types of reagents necessary, the frequency of applications required to maintain favorable conditions for biodegrading constituents of interest, and the frequency and duration of monitoring.

4.4.7 Alternative NA: No Action Alternative

Alternative NA is the true No Action alternative.

⁷ The cost estimate for the application of the bio-enhanced attenuation technology is based on assumed application scenarios (e.g., treatment reagents, injection types, injection frequencies). The scenarios for the application may change as part of future pre-design and design activities.

4.4.7.1 Overall Protection of Human Health and the Environment

Alternative NA does not satisfy this threshold criterion. Although natural attenuation processes would continue in groundwater, and COC levels would decline over time, without the institutional controls there would be no mechanism to prevent human exposure to COCs at levels that present a potential risk. Changes in the volume, toxicity, and mobility of the COCs in groundwater would continue through natural attenuation, but groundwater containing COCs at concentrations above IGCLs would continue to migrate from the SDWA and IWS areas downgradient toward the river.

4.4.7.2 Compliance with ARARs

Alternative NA generally would not satisfy action specific or location specific ARARs for drinking water supplies.

4.4.7.3 Long-Term Effectiveness and Permanence

Considering the need for reliable long-term management controls in restoring groundwater, Alternative NA would not perform well. Institutional controls in place to prevent exposure are assumed to be inoperative under this scenario.

4.4.7.4 Reduction of Toxicity, Mobility or Volume

Alternative NA would not result in significant near term reduction of toxicity, mobility or volume of contaminants in groundwater, but over time natural attenuation would achieve reductions.

4.4.7.5 Short-Term Effectiveness

The evaluation of short-term effectiveness is based on the degree of protectiveness of human health achieved during construction and implementation of the remedy. Because

Alternative NA does not require any short-term implementation, there would be minimal short-term risk to the community, site workers, or the environment.

4.4.7.6 Implementability

Implementability is based on the evaluation of technical feasibility, administrative feasibility, and the availability of services and materials. Alternative NA could be easily implemented since it only involves the effort required to complete 5-year reviews.

4.4.7.7 Cost Analysis

There is no capital cost associated with Alternative NA. Present worth costs associated with the implementation of the 5-year review are estimated to be \$31,000. Cost estimating tables for this Alternative are provided in Appendix C.

5.0 COMPARATIVE ANALYSIS SUMMARY

This section presents the comparative analysis of the alternative remedial technologies presented in Section 4.0. The comparison is based on the seven evaluation criteria previously presented in Section 4.0 of this report. The discussion in Section 5.1 identifies and describes the strengths and weaknesses of the alternatives relative to one another with respect to each criterion and is summarized in Table 4. Section 5.2 presents a comparative analysis summary.

5.1 COMPARATIVE ANALYSIS – EVALUATION CRITERIA

5.1.1 Overall Protection of Human Health and the Environment

The evaluation of the Overall Protection of Human Health and the Environment includes consideration of human health protection (with respect to exposure to impacted groundwater), and environmental protection (with respect to the impact of each alternative on wetlands and the Passumpsic River).

Currently in place remedial activities including the RCRA caps, waste relocation, regrading, and installation and operation of an active gas collection system 1) are eliminating the generation of leachate and further mass loading of COCs to groundwater from SWDA and IWS area sources located above the water table, and 2) actively removing COCs through gas extraction and flare destruction that otherwise could be an ongoing source of impact to groundwater. These remedial actions are improving downgradient groundwater quality.

Protection of human health has been achieved by 1) providing potential receptors of impacted groundwater from the study area with a connection to the Town of Lyndonville municipal supply and removing/abandoning existing groundwater supplies for the affected properties; and, 2) implementing institutional controls that reclassify study area groundwater to Class IV (non-potable use), restrict future use of the property to exclude

residential development and protect the landfill cap, and prohibit the development of groundwater in the immediate vicinity and downgradient of the SWDA and IWS areas as a water supply by transferring private water rights to the State of Vermont.

Because these remedial actions will continue to be in place, with the exception of Alternative NA, each of the alternatives analyzed and evaluated is of equal but limited importance regarding protection of human health, the main consideration being their potential impacts from construction and operations. Because of the LTMP, a potential risk to human health exists for workers involved in sampling environmental media. As with the ongoing monitoring program, potential long-term risks to the health of personnel involved in sampling will be managed using appropriate personal protective equipment, field monitoring, and conformance with a site health and safety plan. Alternative NA does not recognize the institutional controls and reclassification of groundwater, and as such does not provide adequate overall protection of human health.

Additionally, some potential long-term risks to human health could result from the implementation of Alternative 1A (the ROD designated remedial actions of pump and treat) and Alternative 1C. Specifically, operation of the groundwater pump and treat system will generate significant quantities of toxic material including concentrated metal sludge as well as spent carbon and air stripper packing material. These wastes will be shipped off-site for proper disposal at a licensed waste disposal facility. The potential for exposure to these wastes exists for workers operating the treatment system, waste transporters, and workers at the disposal facility receiving the waste. Depending upon the nature of the disposal facility (e.g., secure landfill or incinerator) the potential also exists for exposure of residents living near the facility to be exposed to wastes disposed of at the facility in the event of an engineering failure or improper/incomplete disposal. Potential risk to workers would be managed through use of proper personal protective equipment and operating procedures. Limiting potential risk to residents living near the disposal facility receiving treatment system wastes would be dependent on routine inspections and monitoring of the disposal facility, and implementation of corrective action, as necessary.

The physical impacts to wetlands under Alternatives NA, 1A, 1C, and 2A would be negligible. However, alternatives 4A, 4B, and 5B include construction activities in the area of the unnamed stream downgradient of IWS-3 and may require design considerations to account for wetland locations. It is possible that the final design for Alternatives 4A, 4B, and 5B may include a component of wetland restoration and/or compensatory wetland establishment.

Unacceptable impacts to the Passumpsic River related to the discharge of impacted groundwater from the study area are not occurring nor are unacceptable impacts to the river expected to occur under future conditions. Worst-case concentrations of individual site-related VOCs that could be present in the river under future conditions were calculated to be below detectable levels, and orders of magnitude less than Vermont Water Quality Standards. Therefore, implementing any of the alternative technologies presented in this analyses and evaluation would not provide an incremental benefit in water quality to the Passumpsic River. However, Alternatives 1C, 4B and 5B would actively reduce further groundwater transport of COCs offsite, reducing river loading rates over the long-term.

5.1.2 Compliance with ARARs

With the exception of Alternative NA, each remedial action included in this alternative technology analyses and evaluation complies with action and location-specific ARARs. Specifically,

- Groundwater has been being reclassified as Class IV (non potable) in compliance with Vermont Groundwater Protection Regulations; and
- Each alternative will reduce concentrations of COCs below IGCLs over various timeframes.

Ex situ treatment of groundwater associated with Alternatives 1A and 1C would comply with 1) the substantive portions of applicable Vermont State Air Emissions Standards and consider proposed RCRA air emissions standards and guidance for air stripper operations;

2) the substantive requirements of the NPDES discharge program regarding effluent quality discharging from the system to the Passumpsic River; 3) the substantive requirements of the Vermont water quality standards for treated groundwater discharging from the system to the Passumpsic River; and, 4) the requirements of the Vermont Hazardous Waste Regulations for the management of hazardous waste generated and shipped off-site as a result of the treatment system operation (e.g., metals precipitation, spent carbon).

Groundwater pumped for treatment under Alternatives 1A and 1C requires extensive treatment for metals removal in order to meet VT WQC.

Alternative 4B and 5B would, in all likelihood, be required to meet the administrative and technical requirements of the state and federal UIC program. Based upon the UIC program classification, temporary borings or wells used for the injection of reagents (e.g., organic carbon) for bio-enhanced attenuation would be considered as Class V injection wells. A requirement of Class V injection wells is that the injection of material into the well cannot cause an exceedence of a primary drinking water standard or other health based standard that could adversely affect human health. Unless a reagent is selected for use which has an established primary drinking water standard, an exceedence of primary drinking water standards or other health based standard is not anticipated to occur as a result of the remedial measure.

Although a UIC permit may not be required, information which may be required by the regulatory agency includes: latitude and longitude of each injection point, dates and depths of injection, type and volume of chemicals to be injected, injection pressure and duration, and a plan showing proposed injection locations.

5.1.3 Long-Term Effectiveness and Permanence

The evaluation of Long-Term Effectiveness and Permanence considers the magnitude of residual risk, the adequacy and reliability of controls, and the impact on groundwater quality.

With the exception of Alternative NA, each of the alternative technologies would result in an improvement in groundwater quality with complete restoration of the aquifer achieved at various times. Of the remedial actions analyzed and evaluated, Alternative 2A (Monitored Natural Attenuation) would present the least residual risk to human health and the environment for the following reasons:

- Mass loading of COCs to groundwater is being effectively eliminated through the remedial actions currently in place;
- Groundwater downgradient of the landfill is not used as a drinking water supply and institutional controls prohibit the development of potentially impacted groundwater as a water supply under future conditions;
- Data demonstrates that COCs are currently being reduced through intrinsic processes; and;
- Monitored natural attenuation will not generate the toxic wastes or treatment residuals generated with implementation of pump and treat (Alternatives 1A and 1C). Purge water and non-hazardous spent personal protective equipment are the sole residuals generated under Alternative 2A.

Alternative NA does not provide adequate controls to ensure long-term effectiveness. Alternatives 4A, 4B and 5B are more effective in reducing residual risk as compared to pump and treat (Alternatives 1A and 1C) because they result in the accelerated in situ destruction of organic COCs to carbon dioxide and water and will not generate persistent toxic treatment wastes or treatment residuals. In contrast, pump and treat will generate significant amounts of sludge containing concentrated metals as well as spent liquid and vapor phase carbon and air stripper packing material containing sorbed COCs. These residuals will pose potential residual risk to personnel involved in handling, shipping, and disposal of these residuals and possibly to persons living near the off-site disposal facility.

Each of the remedial actions will result in improvements to groundwater quality and will ultimately reduce organic COCs to IGCLs over the long-term. Based on simulations performed with the calibrated groundwater flow and solute transport model, alternative

1A and 1C both achieve overall site restoration within approximately 65 years; alternative 2B in 70 years, alternative 4A and 4B in 70 years, and alternative 5B in 60 years.

The PRB component of Alternatives 4A and 4B is reliable for reducing contaminant mass migrating from the source area and expediting restoration of the downgradient aquifer. Conditions at the Parker Landfill are favorable for implementation of this technology. Specifically,

- The types and distribution of organic COCs present in the application area are well suited to zero-valent iron PRB technology;
- In the areas where the PRB system would be installed, hydraulic conductivities and gradients are favorable for implementation of the technology;
- The terrain in the source area portion of the Parker Property is favorable for accessibility and construction methods;
- The technology does not adversely impact the natural attenuation processes occurring within the aquifer, including the areas downgradient of the proposed PRB locations.

Overall, Alternative 4B is the most reliable and effective remedial action for expediting restoration of site groundwater. Zero-valent iron PRBs have been successfully used in full-scale remedial projects to rapidly and permanently reduce concentrations of chlorinated organic compounds in groundwater. There are no known toxic byproducts formed during the oxidation of chlorinated organic compounds with the end products being carbon dioxide and water. Ninety-nine percent reductions in concentrations of organic COCs are often achieved. Also, it does not require off-site treatment. The addition of bio-enhanced attenuation downgradient of the PRB will improve the rate of contaminant destruction. Also, based on the modeling results, complete restoration will be achieved through the addition of downgradient bio-enhanced attenuation in a slightly shorter time.

While groundwater pump and treat systems (Alternatives 1A and 1C) have been found to be effective for hydraulic control, such systems are typically not efficient with respect to

restoring groundwater quality to IGCLs. For Alternative 1C, the downgradient pump and treat component only marginally improves downgradient aquifer restoration timeframes compared to what is achieved with the source area component.

Often with groundwater pumping systems, concentrations of COCs decrease asymptotically and stabilize at levels above corresponding IGCLs due to non-linear desorption and/or increased groundwater velocities that develop in response to pumping that prevent concentrations of COCs from reaching equilibrium as it moves through impacted media. In addition, saturated soils that contain COCs may be dewatered during groundwater pumping. Consequently, if IGCLs are attained following a period of active pumping, concentrations of COCs may rebound above IGCLs once the system is shutdown as dewatered soils containing COCs are resaturated and COCs desorb from these soils back into groundwater. For these reasons, the groundwater pump and treat system would need to remain in continuous operation for decades followed by a long period of cycled pumping (i.e., periods of active pumping followed by periods of groundwater recovery) in order to restore groundwater to meet IGCLs.

During this long period of operation, the ex situ groundwater treatment system would generate considerable amounts of residual materials (i.e., spent carbon, sludge, and condensed evaporator slurry), which would require offsite treatment and/or offsite disposal. In addition, extensive maintenance of the system will likely be required to address fouling and repair or replace broken or worn components. A limitation of Alternatives 1A and 1C as compared to the other alternative technologies is that with the exception of UV oxidation, the multi-stage treatment processes do not destroy COCs and they result in the generation of impacted residuals that must be managed and disposed of off-site. In effect, COCs from the Parker Landfill are transferred to a different geographic location for disposal with the potential for release to the environment and risk to human health during transport and, depending upon the method of disposal (e.g., secure landfill), following disposal.

Monitored natural attenuation (Alternative 2A) can be a reliable and effective means for reducing concentrations of COCs. Natural attenuation involves one or more of the following intrinsic processes, which act alone or in combination to reduce concentrations of organic COCs in groundwater: biologically mediated degradation, dispersion, sorption, and volatilization. Evidence of natural attenuation of organic COCs at the Parker Landfill has been documented based upon data collected during the RI and Long-term Monitoring program. Biologically mediated degradation is one of the most important intrinsic processes with respect to natural attenuation because it results in the destruction of organic COCs. As noted in Section 3.2, LTMP data indicates that robust degradation is occurring in the area west of the SWDA, and somewhat less robust degradation is occurring downgradient of IWS-3 and the former IWS-2.

5.1.4 Reduction of Toxicity, Mobility, and Volume through Treatment

The evaluation of reduction of toxicity, mobility, and volume through treatment considers the treatment processes and materials treated, the amount of hazardous materials destroyed or treated, the degree of expected reduction in toxicity, mobility, or volume, the degree to which treatment reduces the inherent hazards posed by principal threats at the site, the degree to which treatment is irreversible, and the type and quantity of residuals remaining after treatment.

Alternative NA does not involve treatment, and does not satisfy this criteria.

Alternatives 4A, 4B and 5B would be most effective in reducing toxicity and mass of organic COCs in impacted groundwater as compared to the other alternatives. Concentrations of organic COCs will be reduced through transformation to the innocuous products of carbon dioxide and water. As the PRB technology generally achieves a higher degree of complete destruction, Alternatives 4A and 4B would provide for the highest level of effectiveness. For the above alternatives reductions in concentration and contaminant mass are significant in areas treated, thereby reducing the contaminant toxicity, mobility, and volume.

For pump and treat (Alternatives 1A and 1C), the toxicity of organic COCs in the extracted groundwater would be reduced, but not eliminated, through treatment as the treatment processes include both destructive (i.e., UV/oxidation) as well as mass transfer (e.g., air stripping, carbon adsorption) technologies. A significant portion of the overall toxicity of organic compounds would be transferred to liquid and vapor phase carbon and air stripper packing material. In addition, very large amounts of sludge/slurry containing elevated and potentially toxic concentrations of metals would be generated as a result of treatment processes. These residuals would require appropriate offsite treatment and/or offsite disposal.

Monitored natural attenuation (Alternative 2A) will reduce the toxicity of the compounds of concern via destructive processes if biologically mediated processes degrade organic COCs (i.e., chlorinated ethenes) to ethane or ethene or to the ultimate end products (i.e., carbon dioxide and water). Ethene has been detected in several wells indicating that organic COCs are being degraded. There is evidence that indicates that anaerobic (i.e., low redox) conditions must be maintained to sustain biologically mediated degradation of chlorinated ethenes in groundwater, which is the primary intrinsic process responsible for reducing toxicity and volume of COCs.

5.1.5 Short-Term Effectiveness

The evaluation of Short-term effectiveness considers protection of the community and workers during the remedial action implementation and environmental impacts during the remedial actions.

With respect to short-term effectiveness, MNA-based Alternative 2A poses the lowest potential risk to the community, workers, and the environment during remedial action implementation because it does not involve construction activities and would not disrupt the wetlands in the vicinity of the site.

Short-term risks associated with Alternatives 4A, 4B and 5B are primarily associated with typical hazards encountered during trenching operations, drilling probes or wells for the delivery of media to the subsurface, and handling of reagents and media. Physical, mechanical, and chemical hazards associated with trenching and drilling (e.g., noise, use of heavy equipment, pinch/crush hazards associated with moving parts, and exposure to impacted groundwater or soil) can be managed through training, implementation of a health and safety plan, and use of proper personal protective equipment (e.g., auditory protection, hard hats, steel toe work shoes, and chemical resistant clothing, as appropriate) and monitoring equipment.

In general, bio-enhanced attenuation and zero-valent iron PRB would be performed in areas with restricted public access (i.e., in the immediate area of the landfill or downgradient in an area that is isolated from residences). There would be little risk to the community. Minor impacts to wetlands could occur under Alternatives 4A and 4B during drilling activities conducted to provide a delivery mechanism for the treatment chemicals or the iron media and thus, minor wetland restoration of disturbed areas might be required. As with other alternatives, short-term risk also exists for workers involved in performance monitoring activities, which may be exposed to impacted groundwater during sampling. These risks would not exceed current risks associated with the LTMP and can be managed through implementation of a site health and safety plan and use of appropriate personal protective equipment.

Pump and treat poses the greatest short-term risk to workers and the community. In addition to the physical, mechanical, and chemical hazards associated with drilling described above and those associated with long-term monitoring, pump and treat would also pose the following additional hazards to workers and/or the community:

- Hazards to workers and the community associated with construction of the off-site discharge line (e.g., trench instability, open trench, working in traffic, and working around heavy equipment);
- Potential worker exposure to COCs during treatment system sampling;

- Potential worker exposure to hazardous materials (e.g. hydrogen peroxide) or COCs during treatment system maintenance (e.g., replacing worn parts and/or rehabilitating treatment system components); and
- Potential worker and community exposure to treatment system residuals during loading and transport to an appropriate disposal facility and potentially following disposal.
- Potential environmental impacts associated with Alternatives 1A and 1C could include discharge of COCs to the Passumpsic River in the event of incomplete treatment due to failure of the treatment system or breakthrough from the liquid-phase carbon canisters, accidents involving haulers transporting treatment residuals to off-site disposal facilities, or potential failures at off-site disposal facilities receiving treatment system residuals.

5.1.6 Implementability

The implementability evaluation considers the ability to construct and operate the alternative technology, the ability to monitor the effectiveness of the alternative, the availability of services and materials required to implement the alternative, the administrative feasibility, and the availability and capacity of off-site transport, storage, and disposal facilities, if required as part of the alternative.

Alternatives NA and 2A are the most readily implementable as there are no additional construction activities associated with either of these alternatives. However, MNA plays a significant role in the complete restoration of the aquifer with the implementation of each of the other alternative technologies.

The bio-enhanced attenuation aspect of Alternatives 4B and 5B would require coordination with subcontractors. If a large number of proposed injection wells is used to deliver reagents to the area proposed for treatment, it is likely that multiple drill rigs would be required to implement these alternatives. Availability of drilling equipment is not anticipated to be a significant obstacle with advance notice as there are several drilling companies in New England that have committed multiple rigs to large projects in the past. Contractors have been identified that are capable of providing and injecting

reagents for full scale implementation. In addition, vendors have been identified that could readily supply the material necessary for the actual injection.

The PRB technology associated with alternatives 4A and 4B would involve the use of conventional construction equipment in order to construct and install the wall of reactive media within the subsurface. Availability of construction equipment is not anticipated to be a significant obstacle with advance notice. Contractors have been identified that are capable of providing and placing the treatment media for full scale implementation. Two suppliers of zero-valent iron have been identified. Preliminary notification has been given to these suppliers regarding the construction of a PRB at the Parker Landfill since materials are not readily available on short-term notice.

Of the remedial actions analyzed and evaluated, pump and treat (Alternatives 1A and 1C) would be the most difficult to implement administratively due to the number of subcontractors and public agencies involved in implementing these alternatives. Contractors that would be involved in implementing Alternatives 1A and 1C would include, at a minimum, the following:

- A drilling subcontractor to drill and construct extraction wells and install pumps in the wells;
- A building contractor to construct the treatment system building and install treatment system components;
- Electrical and mechanical contractors to wire and plumb components of the treatment system;
- An earthwork subcontractor to construct the approximately one-half mile long trench with at least one road crossing and one railroad crossing for the treatment system discharge line;
- A pipe contractor to install the discharge line and potentially jack the pipe beneath Red Village Road and the railroad tracks to allow for completion of the discharge line at the Passumpsic River;
- Waste haulers to transport treatment system residuals to off-site disposal facilities;
- Waste disposal facilities to receive treatment system residuals; and
- Laboratory subcontractors for analysis of samples collected from the treatment system and groundwater as part of performance monitoring.

In addition to these contractors, coordination with local and/or State transportation or highway departments and the railroad would be required for the portion of the discharge line crossing roads and the railroad tracks that parallel the Passumpsic River. Coordination may also be required with State and Federal Fish and Wildlife agencies for input concerning the construction of the discharge outfall to the river.

Third party easements would be required for construction of the discharge pipeline including construction and operating easements from the Northern Vermont Railroad in order to cross the railroad right-of-way with the discharge line.

With respect to technical implementability, installation and operation of the pumping wells, treatment system, and discharge system included under Alternatives 1A and 1C would utilize standard drilling and construction services, techniques, and materials.

5.1.7 Cost Analysis

Cost estimates were prepared for each alternative and are summarized in terms of present worth as follows:

- Alternative 1A

Capital Cost	\$ 4,939,000
Total O&M (30-years)	<u>\$ 25,208,000</u>
Total (30-years)	\$ 30,147,000

- Alternative 1C

Capital Cost	\$ 5,519,000
Total O&M (30-years)	<u>\$ 31,791,000</u>
Total (30-years)	\$ 37,310,000

• Alternative 2A		
Capital Cost	\$	--
Annual O&M (30-years)	\$	<u>1,901,000</u>
Total (30-years)	\$	1,901,000
• Alternative 4A		
Capital Cost	\$	2,519,000
Total O&M (30-years)	\$	<u>2,867,000</u>
Total (30-years)	\$	5,386,000
• Alternative 4B		
Capital Cost	\$	5,276,000
Annual O&M (30-years)	\$	<u>5,503,000</u>
Total (30-years)	\$	10,779,000
• Alternative 5B		
Capital Cost	\$	8,780,000
Annual O&M (30-years)	\$	<u>4,537,000</u>
Total (30-years)	\$	13,317,000
• Alternative NA		
Capital Cost	\$	--
Annual O&M (30-years)	\$	<u>31,000</u>
Total (30-years)	\$	31,000

Costs associated with monitored natural attenuation (Alternative 2A) are incorporated into each of the other remedial actions with the exception of alternative NA because the monitoring required to document natural attenuation processes are a required project component and the timeframe for aquifer restoration for each alternative exceeds 30-years.

The cost comparison indicates that both the capital costs and especially the O&M costs for pump and treat (Alternatives 1A and 1C) dominate the total project costs due to the significant construction requirements, extensive treatment operations, and volumes of waste generated as a by-product of groundwater treatment.

5.2 ALTERNATIVE TECHNOLOGY ANALYSIS SUMMARY

As presented in Section 3.2, the objectives are:

1. Protection of human health by preventing ingestion of groundwater impacted by the landfill that may pose a human health risk. This NCP goal has been achieved through currently in place remedial actions.
2. Comply with federal and state ARARs. Each of the alternative technologies can be implemented to meet ARARs.
3. Working toward the NCP expectation of aquifer restoration (i.e. return usable groundwater to beneficial use wherever practical, within a timeframe that is reasonable given the particular circumstances of the site).

To summarize the findings from the comparative alternatives analysis:

- Overall protection of human health and the environment are achieved for each alternative through currently in place remedial actions, therefore, there is no preferred alternative for these criteria. However, the risks associated with installation and operations are greatest for pump and treat.
- Each alternative complies with ARARs; therefore, there is no preferred alternative for these criteria.
- Alternatives 4A, 4B and 5B achieve the lowest residual risks and impact on groundwater quality with higher reliability of controls, therefore they are the preferred alternatives based on the criteria of long-term effectiveness and permanence.
- Alternatives 4A, 4B and 5B achieve the highest level of reduction of toxicity and volume without transferring significant levels of toxicity to waste streams which

require handling and disposal, therefore these alternatives are preferred based on the criteria of reduction of toxicity, mobility, or volume.

- Alternative 2A (MNA) achieves the highest degree of short-term protection of the community and workers during implementation while minimizing environmental impacts to study area wetlands, therefore Alternative 2A is preferred based on the criteria of short-term effectiveness.
- Alternative 2A (MNA) is preferred based on the criteria of implementability. This alternative is the most readily implemented, followed by the installation of a single PRB in Alternative 4A (PRB). Alternative 4A poses no additional reliability considerations beyond the natural attenuation processes, which are central to each of the other alternatives, and does not require handling of chemicals or treatment residues, which are integral to the other alternatives.
- Alternative 2A (MNA) requires the lowest cost to implement. Alternatives 1A and 1C (pump and treat) would be the most costly to implement with costs an order of magnitude greater than costs of the other alternatives. Based upon these data, the order of preference of alternatives based upon cost-comparison criteria would be Alternative 2A (MNA), Alternative 4A (PRB), Alternative 4B (PRB with bio-enhanced attenuation), Alternative 5B (bio-enhanced attenuation), Alternative 1A, and Alternative 1C.

On the basis of this analysis and evaluation, Alternative 4B is identified as the preferred alternative combination in meeting project RAOs. Both the source area treatment component (i.e., PRB) and the downgradient component (i.e., Bio-enhanced attenuation) are favorable based on the foregoing evaluation and in combination they will provide controls to the remaining significant source area while accelerating aquifer restoration in the downgradient area.

6.0 RECOMMENDED REMEDIAL ALTERNATIVE

Based on the alternative technology analyses presented in Section 4.0 and the comparison then presented in Section 5.0, the recommended groundwater remedial action is Alternative 4B, a zero-valent iron PRB in the source area combined with bio-enhanced attenuation in the area downgradient of the landfill. These remedial actions would complement the in-place source control remedial action specified in the ROD, and would replace the pump and treat system designated in the ROD. By installing the PRB at the downgradient edge of the landfill compliance boundary, this remedial action will minimize further migration of COCs from the landfill, which are currently resulting in offsite migration of COCs at concentrations above corresponding IGCLs. In addition, application of the bio-enhanced technology would be an active step in reducing the COCs, which have already been released from the source area. These remedial technologies are readily implementable and effective and would also permanently destroy COCs in a cost-effective manner.

Since the ROD was issued in 1995, zero-valent iron PRBs have been applied at numerous sites in order to achieve objectives similar to those at the Parker Landfill; while over the same period EPA has acknowledged that the pump and treat remedial action designated in the ROD often does not provide for long-term remediation when applied as a remedial measure to address impacts encountered under similar conditions to those at the Parker Landfill. Most importantly, a PRB, in addition to the use of the bio-enhanced technology, may provide for a decrease in the time for completion restoration of the aquifer downgradient of the Parker Properties.

7.0 IMPLEMENTATION PLAN AND SCHEDULE

Based upon the analyses and evaluation of the alternative technologies, a zero-valent iron PRB and bio-enhanced attenuation are the recommended technologies to address and remediate groundwater in the source and downgradient areas, respectively.

Bench scale studies have been performed to identify the optimal iron media for the PRB based upon the geochemistry of the groundwater to be treated in the source area. Characterization of the hydrogeology based upon information collected during the pre-design field investigation has identified the optimal PRB orientation and location (including depth of installation) and provided constructability data. Upon the completion of the ongoing pilot-scale bio-enhanced attenuation study in the downgradient area, an assessment will be made as to the achievable enhancement of in situ conditions (relative to available reagent types), the relative effectiveness of differing delivery technologies, and the site-specific estimated effect of the design application on groundwater COCs.

Remedial Design will include a full-scale design and implementation of the PRB in the source area, and completion of the downgradient bio-enhanced attenuation pilot study, followed by the design and implementation of this technology. A proposed implementation schedule is included as Figure 37. Assuming EPA concurrence is obtained by the end of March 2004, design activities can be initiated which will allow implementation of the PRB and bio-enhanced attenuation remedial actions during the 2004 construction season.

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9.0 ACRONYMS

AO – Administrative Order

ARARs – Applicable, Relevant and Appropriate Requirements

CD – Consent Decree

CERCLA – Comprehensive Environmental Response, Compensation & Liability Act

CFR – Code of Federal Registry

cis-1,2-DCE – cis-1,2-Dichlorethene

cm/sec – Centimeters per second

COCs – Compounds of Concern

EPA – Environmental Protection Agency

EPR – Environmental Protection Rule

ESE – Environmental Sciences and Engineering, Inc.

FS – Feasibility Study

gpm – Gallons per minute

HLA – Harding Lawson Associates

HRC – Hydrogen Release Compounds

ICP – Institutional Control Plan

IGCLs – Interim Groundwater Cleanup Levels

IWS-X – Industrial Waste Disposal Area

K_{oc} – Organic Carbon Partitioning Coefficient

lbs/day – Pounds per day

LGAC – Liquid-Phase Granular Activated Carbon

LTMP – Long-Term monitoring Plan

MCLs – Maximum Contaminant Levels

mg/l – Milligrams per liter

ml/g – Milliliters per gram

MNA – Monitored Natural Attenuation

mV – Millivolts

NAPL – Non-aqueous Phase Liquids

NCP – National Contingency Plan
NPDES – National Pollutant Discharge Elimination System
NRC – National Research Council
O&M – Operation and Maintenance
ppb – Parts per billion
ppm – Parts per million
PRB – Permeable Reactive Barrier
RAOs – Remedial Action Objectives
RCRA – Resource Conservation and Recovery Act
Redox – Oxidation Reduction
RI – Remedial Investigation
ROD – Record of Decision
SOW – Statement of Work
SVOCs – Semi-volatile Organic Compounds
SWDA – Solid Waste Disposal Area
TOC – Total Organic Compounds
TRC – TRC Environmental Corporation
TSD – Treatment, Storage and Disposal
ug/l – Microgram per liter
UIC – Underground Injection Control
URS – URS Corporation
UV – Ultraviolet Light
VOCs – Volatile Organic Compounds
VTDEC – Vermont Department of Environmental Conservation
VT WQC – Vermont Water Quality Criteria

TABLES

TABLE 1
2003 GROUNDWATER EXCEEDANCES
Remedial Technology/Remedial Alternative Evaluation
Parker Landfill
Lyndon, Vermont

Well ID	Sample Date	Compound	Dilution	Result (mg/l)	IGCL (mg/l)
VOLATILE ORGANIC COMPOUNDS					
B103A	4/30/03	Tetrachloroethene	10	0.0032 J	0.0007
	4/30/03	Trichloroethene	10	0.32	0.005
	10/3/03	Tetrachloroethene	2.5	0.0031	0.0007
	10/3/03	Trichloroethene	2.5	0.340	0.005
B113BB	4/24/03	2-Butanone (MEK)	25	1.4	0.17
	4/24/03	cis-1,2-Dichloroethene	25	0.72	0.07
	4/24/03	Trichloroethene	25	0.0092 J	0.005
	4/24/03	Vinyl chloride	25	0.16	0.002
	10/2/03	1,2-Dichloroethane	2	0.0018 J	0.0005
	10/2/03	1,2-Dichloropropane	2	0.0026	0.0006
	10/2/03	2-Butanone (MEK)	2	1.400 J	0.17
	10/2/03	2-Butanone (MEK)	10	1.300	0.17
	10/2/03	cis-1,2-Dichloroethene	2	0.980 J	0.07
	10/2/03	cis-1,2-Dichloroethene	10	1.000	0.07
	10/2/03	Trichloroethene	10	0.0059 J	0.005
	10/2/03	Vinyl chloride	2	0.100	0.002
	10/2/03	Vinyl chloride	10	0.096	0.002
	B120C	4/23/03	cis-1,2-Dichloroethene	200	0.72
4/23/03		Trichloroethene	200	6	0.005
10/6/03		cis-1,2-Dichloroethene	50	0.750	0.07
10/6/03		Trichloroethene	50	6.800	0.005
B120D	4/23/03	cis-1,2-Dichloroethene	10	0.29	0.07
	4/23/03	Trichloroethene	10	0.17	0.005
	4/23/03	Vinyl chloride	10	0.021	0.002
	10/6/03	cis-1,2-Dichloroethene	2	0.270	0.07
	10/6/03	Trichloroethene	2	0.260	0.005
	10/6/03	Vinyl chloride	2	0.017	0.002
B125A	4/23/03	Trichloroethene	1	0.016	0.005
	10/1/03	Trichloroethene	1	0.016	0.005
B125B	4/23/03	Trichloroethene	2	0.093 J	0.005
	4/23/03	Trichloroethene	2.5	0.089	0.005
	4/23/03	Vinyl chloride	2	0.0043	0.002
	4/23/03	Vinyl chloride	2.5	0.0036	0.002
	10/1/03	cis-1,2-Dichloroethene	1	0.090	0.07
	10/1/03	Trichloroethene	1	0.160	0.005
	10/1/03	Vinyl chloride	1	0.0065	0.002

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Lyndon, Vermont

Well ID	Sample Date	Compound	Dilution	Result (mg/l)	IGCL (mg/l)
VOLATILE ORGANIC COMPOUNDS					
B126A	4/21/03	cis-1,2-Dichloroethene	20	1.2 J	0.07
	4/21/03	cis-1,2-Dichloroethene	40	1.2	0.07
	4/21/03	Trichloroethene	20	0.9 J	0.005
	4/21/03	Trichloroethene	40	0.93	0.005
	4/21/03	Vinyl chloride	20	0.0072 J	0.002
	9/29/03	cis-1,2-Dichloroethene	20	2.000	0.07
	9/29/03	Trichloroethene	20	1.400	0.005
B126B	4/21/03	cis-1,2-Dichloroethene	1	0.088 J	0.07
	4/21/03	cis-1,2-Dichloroethene	2.5	0.096	0.07
	4/21/03	Trichloroethene	1	0.059 J	0.005
	4/21/03	Trichloroethene	2.5	0.063	0.005
	4/21/03	Vinyl chloride	1	0.0024	0.002
	4/21/03	Vinyl chloride	2.5	0.0026	0.002
	9/29/03	Trichloroethene	1	0.012	0.005
B126BQ	4/21/03	cis-1,2-Dichloroethene	2.5	0.091	0.07
	4/21/03	Trichloroethene	2.5	0.061	0.005
	4/21/03	Vinyl chloride	2.5	0.0026	0.002
	9/29/03	Trichloroethene	1	0.024	0.005
B131C	4/25/03	1,2-Dichloropropane	1	0.0013	0.0006
	10/2/03	1,2-Dichloroethane	1	0.0014	0.0005
	10/2/03	1,2-Dichloroethane	2.5	0.0015 J	0.0005
	10/2/03	1,2-Dichloropropane	1	0.0036	0.0006
	10/2/03	1,2-Dichloropropane	2.5	0.0028	0.0006
	10/2/03	2-Butanone (MEK)	1	0.380 J	0.17
B132	4/22/03	cis-1,2-Dichloroethene	20	0.43	0.07
	4/22/03	Tetrachloroethene	20	0.03	0.0007
	4/22/03	Trichloroethene	20	0.53	0.005
	9/29/03	cis-1,2-Dichloroethene	2	0.380	0.07
	9/29/03	cis-1,2-Dichloroethene	2.5	0.390	0.07
	9/29/03	Tetrachloroethene	2	0.028	0.0007
	9/29/03	Tetrachloroethene	2.5	0.028	0.0007
	9/29/03	Trichloroethene	2	0.460 J	0.005
	9/29/03	Trichloroethene	2.5	0.470	0.005
	B132B	4/22/03	cis-1,2-Dichloroethene	2	0.12 J
4/22/03		cis-1,2-Dichloroethene	10	0.12	0.07
4/22/03		Tetrachloroethene	2	0.0014 J	0.0007
9/29/03		cis-1,2-Dichloroethene	2	0.290	0.07
9/29/03		Tetrachloroethene	2	0.0035	0.0007
9/29/03		Trichloroethene	2	0.012	0.005
B133	4/23/03	cis-1,2-Dichloroethene	200	2.6	0.07
	4/23/03	Methylene Chloride	200	0.088 J	0.005
	4/23/03	Tetrachloroethene	200	0.15	0.0007
	4/23/03	Trichloroethene	200	6	0.005
	10/1/03	cis-1,2-Dichloroethene	20	1.000	0.07
	10/1/03	Tetrachloroethene	20	0.049	0.0007
	10/1/03	Trichloroethene	20	2.100	0.005
B136A	4/22/03	Tetrachloroethene	1	0.0014	0.0007
	4/22/03	Trichloroethene	1	0.015	0.005
	9/29/03	Tetrachloroethene	1	0.00090 J	0.0007
	9/29/03	Trichloroethene	1	0.011	0.005

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VOLATILE ORGANIC COMPOUNDS					
B136B	4/29/03	cis-1,2-Dichloroethene	100	2.5	0.07
	4/29/03	cis-1,2-Dichloroethene	200	2.6	0.07
	4/29/03	Tetrachloroethene	100	0.035 J	0.0007
	4/29/03	Trichloroethene	100	5 J	0.005
	4/29/03	Trichloroethene	200	5.2	0.005
	4/29/03	Vinyl chloride	100	0.09 J	0.002
	4/29/03	Vinyl chloride	200	0.11 J	0.002
	10/1/03	Benzene	10	0.0063 J	0.005
	10/1/03	cis-1,2-Dichloroethene	10	0.920	0.07
	10/1/03	cis-1,2-Dichloroethene	20	0.930	0.07
	10/1/03	Tetrachloroethene	10	0.017	0.0007
	10/1/03	Tetrachloroethene	20	0.022	0.0007
	10/1/03	Trichloroethene	10	2.200 J	0.005
	10/1/03	Trichloroethene	20	2.300	0.005
	10/1/03	Vinyl chloride	10	0.036	0.002
	10/1/03	Vinyl chloride	20	0.034	0.002
B136C	4/22/03	1,2-Dichloropropane	10	0.0048 J	0.0006
	4/22/03	cis-1,2-Dichloroethene	10	0.24	0.07
	4/22/03	Trichloroethene	10	0.28	0.005
	4/22/03	Vinyl chloride	10	0.025	0.002
	9/29/03	1,2-Dichloroethane	1	0.0019	0.0005
	9/29/03	1,2-Dichloroethane	2.5	0.0018	0.0005
	9/29/03	1,2-Dichloropropane	1	0.0044	0.0006
	9/29/03	1,2-Dichloropropane	2.5	0.0034	0.0006
	9/29/03	cis-1,2-Dichloroethene	1	0.150	0.07
	9/29/03	cis-1,2-Dichloroethene	2.5	0.140	0.07
	9/29/03	Trichloroethene	1	0.360 J	0.005
	9/29/03	Trichloroethene	2.5	0.390	0.005
	9/29/03	Vinyl chloride	1	0.046	0.002
9/29/03	Vinyl chloride	2.5	0.046	0.002	
B137B	4/29/03	1,2-Dichloroethane	2	0.0062	0.0005
	4/29/03	2-Butanone (MEK)	2	0.23	0.17
	10/6/03	1,2-Dichloroethane	1	0.0064	0.0005
B138B	4/24/03	1,2-Dichloroethane	5	0.0018 J	0.0005
	4/24/03	1,2-Dichloropropane	5	0.01	0.0006
	4/24/03	2-Butanone (MEK)	5	0.28	0.17
	4/24/03	cis-1,2-Dichloroethene	5	0.15	0.07
	4/24/03	Trichloroethene	5	0.066	0.005
	4/24/03	Vinyl chloride	5	0.058	0.002
	10/2/03	1,2-Dichloroethane	1	0.0016	0.0005
	10/2/03	1,2-Dichloropropane	1	0.0064	0.0006
	10/2/03	1,2-Dichloropropane	5	0.0052	0.0006
	10/2/03	2-Butanone (MEK)	1	0.760 J	0.17
	10/2/03	2-Butanone (MEK)	5	0.680	0.17
	10/2/03	cis-1,2-Dichloroethene	1	0.072	0.07
	10/2/03	Trichloroethene	1	0.032	0.005
	10/2/03	Trichloroethene	5	0.028	0.005
	10/2/03	Vinyl chloride	1	0.064	0.002
	10/2/03	Vinyl chloride	5	0.063	0.002

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VOLATILE ORGANIC COMPOUNDS					
B138BQ	4/24/03	1,2-Dichloroethane	5	0.0025	0.0005
	4/24/03	1,2-Dichloropropane	5	0.014	0.0006
	4/24/03	2-Butanone (MEK)	5	0.69	0.17
	4/24/03	cis-1,2-Dichloroethene	5	0.16	0.07
	4/24/03	Trichloroethene	5	0.055	0.005
	4/24/03	Vinyl chloride	5	0.083	0.002
	10/2/03	1,2-Dichloroethane	1	0.0016	0.0005
	10/2/03	1,2-Dichloropropane	1	0.0070	0.0006
	10/2/03	1,2-Dichloropropane	5	0.0061	0.0006
	10/2/03	2-Butanone (MEK)	1	0.740 J	0.17
	10/2/03	2-Butanone (MEK)	5	0.680	0.17
	10/2/03	cis-1,2-Dichloroethene	1	0.084	0.07
	10/2/03	cis-1,2-Dichloroethene	5	0.070	0.07
	10/2/03	Trichloroethene	1	0.037	0.005
	10/2/03	Trichloroethene	5	0.037	0.005
	10/2/03	Vinyl chloride	1	0.073	0.002
	10/2/03	Vinyl chloride	5	0.068	0.002
B139A	4/24/03	cis-1,2-Dichloroethene	20	0.48	0.07
	4/24/03	Tetrachloroethene	20	0.033	0.0007
	4/24/03	Trichloroethene	20	0.57	0.005
	10/1/03	cis-1,2-Dichloroethene	10	0.740	0.07
	10/1/03	Tetrachloroethene	10	0.045	0.0007
B139AQ	10/1/03	Trichloroethene	10	1.000	0.005
	4/24/03	cis-1,2-Dichloroethene	20	0.48	0.07
	4/24/03	Tetrachloroethene	20	0.033	0.0007
	4/24/03	Trichloroethene	20	0.59	0.005
	10/1/03	cis-1,2-Dichloroethene	10	0.720	0.07
	10/1/03	Tetrachloroethene	10	0.042	0.0007
B145B	10/1/03	Trichloroethene	10	0.950	0.005
	4/21/03	1,2-Dichloropropane	1	0.00077	0.0006
B145C	10/6/03	1,2-Dichloropropane	1	0.00097	0.0006
	4/21/03	1,2-Dichloropropane	1	0.00090	0.0006
	9/29/03	1,2-Dichloropropane	1	0.0014	0.0006

Legend/Notes:

IGCL = Interim Groundwater Cleanup Level for Contaminants of Concern (ROD, Section X.A), for all other compound concentrations listed are lesser of MCL, VAL, and VHA.

mg/L = Milligrams per liter

J = Estimated concentration.

"Q" designation following sample ID indicates duplicate.

IGCL reported for cis- and trans- 1,3-Dichloropropene is standard for total 1,3-Dichloropropene.

IGCL reported for cis- and trans- 1,2-Dichloroethene is standard total 1,2-Dichloroethene.

Quantifiable detection limit for vanadium is 0.002 mg/l.

MCL = U.S. EPA Maximum Contaminant Level (December, 2002).

VAL = Vermont Action Level (December, 2002).

VHA = Vermont Health Advisory (December, 2002).

**TABLE 2
REMEDIAL TECHNOLOGY IDENTIFICATION AND SCREENING FOR GROUNDWATER
PARKER LANDFILL
LYNDON, VERMONT**

RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Management Institutional Controls and Groundwater Reclassification	---	Deeds for the property potentially impacted by groundwater from the site would include restrictions on use of groundwater as a water supply and well installations. Groundwater that is currently impacted or becomes impacted under future conditions by the landfill would be reclassified as non potable (Class IV) under the State of Vermont Groundwater Protection Regulations. Existing water supplies downgradient of the landfill will be abandoned and affected residents would be provided with a connection to the Town of Lyndonville municipal water supply.	Implementation of institutional controls, including groundwater reclassification, will limit the potential for exposure to impacted groundwater across the study area by transferring water rights for potentially affected properties to the State of Vermont and prohibiting the development of groundwater potentially impacted by the landfill as a water supply. Since the area is supplied with municipal water and existing private water supply wells downgradient of the landfill have been abandoned, the risk of exposure to impacted groundwater originating from the site is limited. Concentrations of volatile organic compounds (VOCs) will be reduced by intrinsic processes. This technology is easily implemented as institutional controls are already in place, groundwater has been reclassified, all residents potentially affected by impacted groundwater from the landfill have been supplied with a connection to the Town of Lyndonville municipal water supply, and water supply wells located downgradient of the landfill have been abandoned.	Management of Migration (MOM)/Source Control (SC) Containment: Retained. Environmental Protection Agency (EPA)-approved Institutional Control Plan currently being implemented. Institutional controls include deed restrictions, the connection of residences to public water supply, abandonment of existing water supply wells downgradient of the landfill, and groundwater reclassification. These actions will substantially reduce or eliminate unacceptable risk to human health and the environment posed by impacted groundwater in the study area.
Monitoring	---	Periodic monitoring of groundwater conditions would be conducted to monitor changes in concentrations of constituents of concern (COC) and the lateral and vertical limits of impacted groundwater over time. Surface water monitoring would be conducted to verify that COC are not contributing unacceptable concentrations to the Passumpsic River or unnamed stream and that concentrations of COC in the unnamed stream are decreasing and attenuated.	Intrinsic processes have been demonstrated to reduce concentrations of COC in site groundwater at certain monitoring wells. Groundwater monitoring could provide data to assess the ongoing reduction in COC by intrinsic processes or reduction in concentrations of COC by more active technologies. This technology is readily implemented as a long-term monitoring program approved by EPA is ongoing at the site and labor and analytical services are readily available.	MOM/SC Containment: Retained. EPA-approved Long-Term Monitoring Plan (LTMP) currently being implemented. LTMP includes periodic monitoring of groundwater, surface water, and sediment.
Containment/Isolation Vertical Barriers	Slurry Wall	A subsurface low permeability barrier to groundwater flow would be constructed by excavating a trench and backfilling with a soil/ bentonite/water "slurry".	Demonstrated technology for limiting migration of organic compounds in relatively shallow overburden groundwater. However, significant concerns for installing barrier at depths greater than 100 feet and keying into fractured rock at bedrock surface. Implementation could result in changed groundwater flow patterns and diversion of impacted groundwater to other areas. Could be used as flow diversion barrier in combination with extraction or in situ treatment technologies, as in a funnel-and-gate system, in area downgradient of industrial waste disposal area IWS-3.	MOM/SC Containment: Eliminated. Could not be applied on a site-wide basis due to depth of impacts downgradient of the solid waste disposal area (SWDA) and former industrial waste disposal area IWS-2. Could modify groundwater flow patterns and increase the vertical and horizontal extent of impacted groundwater if used as sole technology.
Containment/Isolation (cont.)	Sheet Piling	Sheet pilings with interlocking joints are installed with a drop or vibratory hammer to form a subsurface groundwater flow barrier.	Demonstrated technology for limiting migration of organic compounds in relatively shallow overburden groundwater. However, significant concerns exist for installing barrier at depths greater than 100 feet and keying into fractured rock at bedrock surface. Some concerns exist regarding potential leakage of groundwater through interlocking joints. Implementation could result in changed groundwater flow patterns and diversion of impacted groundwater to other areas. Could be used as flow diversion barrier in combination with extraction or in situ treatment technologies; as in a funnel-and-gate system, in the area downgradient of former industrial waste disposal area IWS-3.	MOM/SC Containment: Eliminated. Could not be applied on a site-wide basis due to depth of impacts downgradient of SWDA and former industrial waste disposal area IWS-2. Could modify groundwater flow patterns and increase the vertical and horizontal extent of impacted groundwater if used as sole technology.

**TABLE 2
REMEDIAL TECHNOLOGY IDENTIFICATION AND SCREENING FOR GROUNDWATER
PARKER LANDFILL
LYNDON, VERMONT**

RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
	Grout Curtain	A subsurface barrier to groundwater flow is constructed by filling a series of adjacent, overlapping boreholes with impermeable materials.	<p>Proven technology for limiting migration of organic compounds in shallow overburden groundwater. However, significant concerns exist for installing barrier at depths greater than 100 feet and keying into fractured rock at bedrock surface. Difficult to ensure uniform low permeability barrier without voids, particularly if installed in areas of heterogeneous soils. Implementation could result in changed groundwater flow patterns and diversion of impacted groundwater to other areas. Could be difficult to verify continuity of grout curtain.</p> <p>Could be used as flow diversion barrier at shallow depths in combination with extraction or in situ treatment technologies, as in a funnel-and-gate system, in area downgradient of former industrial waste disposal area IWS-3.</p>	MOM/SC Containment: Eliminated. Could not be effectively applied on a site-wide basis due to depth of impacts and heterogeneities in area downgradient of SWDA and former industrial waste disposal area IWS-2. Could modify groundwater flow patterns and increase the vertical and horizontal extent of impacted groundwater if used as a sole technology.
	Deep Soil Mixing	Subsurface barrier to groundwater flow constructed by in situ mixing of impermeable material into soil. Typically mix overlapping soil columns to surround site.	Demonstrated technology for limiting migration of organic compounds in shallow overburden groundwater. Commercially available equipment typically limited to application depths of less than 50 feet. Significant concerns when installing barrier at depths greater than 100 feet and keying barrier into fracture rock zone at bedrock surface. Implementation could result in changed groundwater flow patterns and diversion of impacted groundwater to other areas. Could be used in combination with a permeable reactive barrier to develop funnel and gate system in area downgradient of former industrial waste disposal area IWS-3.	MOM/SC Containment: Eliminated. Installation difficulties in creating effective and adequate barrier.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Containment/Isolation (cont.)	Solidification/ Stabilization	In situ mixing of soil, groundwater, and solidification/stabilization agents to create an inert mass that will prevent contaminant migration.	Demonstrated technology for limiting migration of organic compounds in overburden groundwater. Significant concerns with uniform in situ mixing and use at depths greater than 100 feet. Also, difficult to solidify/stabilize sources under capped areas.	MOM/SC Containment: Eliminated. Difficult to ensure uniform treatment coverage in areas of soil heterogeneity; difficult to implement without compromising effectiveness of landfill caps.
	In Situ Vitrification	Stabilize/solidify contaminants in-place by melting silicates in soil to form siliceous glass mass. Soils melted by applying high voltages through large electrodes inserted in ground. Volatile organic compounds may volatilize during process and metals are typically encapsulated.	Demonstrated to be effective for removing VOCs from soil and groundwater (through volatilization and off gassing) and for encapsulating metals in remaining soil mass. Requires very large amounts of available electricity. Volatile organic compounds need to be collected and treated. Safety concerns exist associated with high voltages, high temperatures generated, and potential for fires. Additional soil vapor extraction (SVE) collection and ex situ treatment of vapor-phase compounds would be required. Not generally cost effective for treatment of VOCs in groundwater. Also, difficult to solidify/stabilize sources under capped areas.	MOM/SC Containment: Eliminated. High implementation cost. Potential safety concerns. Not feasible for groundwater treatment. Also, difficult to implement without compromising effectiveness of landfill caps.
Active Hydraulic Gradient Control	Groundwater Containment Cells	Contaminant migration in groundwater is controlled by an active hydraulic barrier using injection/withdrawal well couplets.	Technology is applicable to VOCs in unconfined aquifers; unproven for applications in geologic materials with varying permeabilities. A proven technology, equipment to install and operate wells is readily available. Less cost-effective in areas where soils are significantly stratified, making the circulating pattern difficult to achieve or decreasing the required well spacing. Elevated metals in groundwater could reduce implementability by fouling well screens and equipment.	MOM/SC Treatment: Eliminated. Significant potential difficulties exist in installing effective and adequate barrier given site geology (e.g., soil heterogeneity) and potentially groundwater chemistry (e.g., elevated metals).
In Situ Treatment (Biological)	Enhanced Aerobic Bioremediation	Biological degradation of VOCs in groundwater is stimulated or enhanced through the introduction of nutrients, oxygen, and possibly microbes that metabolize specific organic compounds under aerobic conditions.	In situ biological treatment methods are most effective in degrading simple organic compounds in water such as aromatic hydrocarbons. The success of aerobic biological degradation of higher order chlorinated solvents (e.g., tetrachloroethene and trichloroethene) has been limited.	MOM/SC Treatment: Eliminated. Technology not proven efficient in degrading chlorinated VOCs.

**TABLE 2
REMEDIAL TECHNOLOGY IDENTIFICATION AND SCREENING FOR GROUNDWATER
PARKER LANDFILL
LYNDON, VERMONT**

RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
In Situ Treatment (cont.)- Biological	Enhanced Anaerobic Bioremediation	Biological degradation of VOCs in groundwater is stimulated or enhanced through the introduction of nutrients, hydrogen releasing compounds (HRC), and possibly microbes that metabolize specific organic compounds under anaerobic conditions.	<p>Anaerobic biological treatment methods have been demonstrated to effectively degrade chlorinated organic compounds in water such as trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride. Although by-products, such as vinyl chloride, may temporarily form from the degradation of higher order chlorinated organic compounds, field conditions indicate that vinyl chloride is not recalcitrant to degradation under reduced conditions. Rate of dechlorination has been reported to decrease as the degree of chlorination decreases. Potential temporary accumulation of vinyl chloride may occur due to the slower degradation rate of vinyl chloride under anerobic conditions versus aerobic.</p> <p>Enhanced bioremediation may be implemented with conventional methods.</p>	MOM/SC Treatment: Retained. Demonstrated to reduce concentrations of chlorinated compounds. Utilization rate of HRC can be high and thus multiple injections may be required, which would result in increased costs. Could potentially be used as an alternative to in-situ chemical oxidation (ISCO).
	Co-Metabolic Augmentation	Injection of dilute solution of primary substrate (i.e., methane) into groundwater zone to support co-metabolic breakdown of VOCs, including halogenated compounds.	Limited application on field scale. Long-term remedy thus application sites have not been fully evaluated. Use not substantiated based on existing study area conditions. Could be considered as augmentation for natural attenuation in future if conditions change with respect to substrate capacity present in groundwater.	MOM/SC Treatment: Eliminated. Use not warranted based on study area conditions.
	Natural Attenuation with Monitoring	Analysis of natural attenuation mechanisms occurring in study area groundwater would be documented and monitoring would be structured to ensure continued characterization of conditions over time and the effectiveness of the remedy.	Source area contribution of compounds of concern will decrease due to removal of IWS-2, completion of the landfill caps, and operation of the active gas collection system. Remaining groundwater impacts will decrease over time due to intrinsic processes identified during LTMP monitoring and documented in the conceptual model.	MOM/SC Treatment: Retained. Record of Decision (ROD)-remedy for downgradient groundwater. In conjunction with implementation of institutional controls and continuation of the LTMP monitoring, there are no human health exposure risks during the restoration period. As VOCs do not bioaccumulate, short-term and long-term impacts to ecological receptors are minimal.

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PARKER LANDFILL
LYNDON, VERMONT**

RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
In Situ Treatment (cont).- Chemical	In Situ Chemical Oxidation	An oxidizing reagent (e.g., hydrogen peroxide, Fenton's Reagent, permanganate, or ozone) is injected into impacted groundwater or soil to rapidly oxidize VOCs to carbon dioxide and water.	<p>Case studies have documented reductions of VOCs from part per million (ppm) to part per billion (ppb) levels in timeframes measured in weeks to months. Technology will not result in the formation of recalcitrant daughter products of high end chlorinated VOCs (i.e., vinyl chloride). Most effective for remediating well defined sources of VOCs.</p> <p>In situ chemical oxidation can be implemented through injection with conventional drilling methods (borings or wells). Vendors of the in situ chemical oxidation technology have developed proprietary methods of injection. Certain oxidizing agents (e.g., Fenton's Reagent) can generate heat from exothermic reactions and could be of concern near landfill due to presence of methane. Other oxidizing agents are available that do not generate significant heat (e.g., permanganate).</p> <p>If present in soil at sufficient quantities, certain redox sensitive metals (e.g., chromium, selenium, and vanadium) could be mobilized while other metals (e.g., iron, arsenic, and manganese) could precipitate resulting in localized zones of decreased permeability of the groundwater flow system.</p> <p>Bench scale and/or pilot testing necessary to assess impact of ISCO on metals in groundwater. Vendors are available to perform ISCO.</p>	MOM/SC Treatment: Retained. Implementation would be within plume area as a single application to reduce contaminant mass. Very high implementation costs. Bench scale/pilot testing necessary to determine effect on metals and downgradient effect of oxidant on natural attenuation processes.

**TABLE 2
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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
In Situ Treatment (cont.)- Chemical	Permeable Reactive Barrier (PRB) Wall	Reactive media installed by trench or injection to provide passive treatment of contaminated groundwater flowing through media. Potential media types include: Oxygen Releasing Compounds (ORC), HRC, zero-valent iron, microorganisms, zeolite, activated carbon, peat, limestone, and sawdust for reduction of VOCs and/or metals. Treatment process typically involves contaminant degradation, sorption or precipitation.	Technology is applicable to a variety of organic and inorganic contaminants, including chlorinated VOCs and metals. Choice of media for treatment wall based upon targeted compounds. Hydrogeologic setting must be relatively conductive to minimize potential for short-circuiting. Groundwater flow should have a high degree of preference. Suitable for treatment of both organic and inorganic compounds. Technology utilizes commonly used barriers and construction techniques. Impacted groundwater could be diverted around PRB, potentially into unimpacted areas if target permeability is compromised during installation or operation. For shallow applications likely combined with containment technology to direct impacted groundwater into wall (i.e., funnel and gate) to reduce the quantity of barrier media required. For deeper applications reactive media generally applied by injection into zone of impacts to create treatment barrier.	MOM/SC Treatment: Retained. Applicable as a site-wide technology. Could effectively be implemented in area of former industrial waste disposal area IWS-3 or downgradient of SWDA/IWS-2 near property boundary.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
In Situ Treatment (cont).- Physical	Groundwater Recirculation Wells	Groundwater recirculation "cell" is created by injecting air or an inert gas into the contaminated groundwater zone through the center of a double cased stripping well which is designed with discrete upper and lower screens. Injection of air creates an "airlift pumping system" which causes the groundwater with entrained air bubbles to rise and partition VOCs from the dissolved to vapor phase. The VOC-containing carrier gas exits through annular spaces between the well casing, it is drawn to the surface with a vacuum pump. Treated groundwater re-enters the aquifer above the impacted zone through the upper screen and is then induced back into the lower portion of the aquifer and into the stripping well. Could also be used to deliver oxidizing agents or nutrients to facilitate biotic or abiotic degradation of organic COC.	Technology is applicable to VOCs. Process has been used in both unconfined and confined aquifers and has been applied to geologic materials varying in permeability. A proven technology, equipment to install recirculation wells is readily available. Additional treatment may be required to treat off-gases prior to release to atmosphere (see EX SITU TREATMENT). Less cost-effective in areas where soils are significantly stratified, making the circulating pattern difficult to achieve or decreasing the required well spacing. Elevated metals in groundwater could reduce implementability by fouling well screens and equipment.	MOM/SC Containment/Treatment: Eliminated. Elevated metals concentrations and soil heterogeneities within the saturated zones in area of application could adversely affect performance.
	In Situ Electrokinetic Separation via Electro osmosis	An electrical field established in the soil between anodes and cathodes induces migration of ions and groundwater movement. Extraction wells at the cathode collect impacted groundwater for treatment. Organic compounds removed with groundwater.	Application in variable materials and at depth is unproven. Safety issues due to electrical and explosion hazards with this technology. Ex situ groundwater treatment would be required. No inherent benefits over more proven, conventional technologies for treating COC.	MOM/SC Treatment: Eliminated. Unproven. No inherent benefits over conventional technologies. Potential safety concerns.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Withdrawal/Collection Groundwater Extraction	Extraction Wells	Groundwater extraction wells would be used to extract groundwater.	<p>Technology and equipment to install extraction wells is readily available and easily implemented by local subcontractors. Fouling due to elevated metals concentrations may require well rehabilitation or replacement in long-term. Treatment of extracted groundwater will be required to treat collected groundwater prior to discharge (see EX SITU TREATMENT).</p> <p>Pump and treat is recognized by the EPA and groundwater professionals as an inefficient technology for remediation of groundwater. Cycled pumping will likely be required after interim groundwater cleanup goals (IGCLs) are reached through continuous pumping due to rebound in COC related to non-linear desorption from impacted soils and groundwater recovery into impacted soils dewatered during active pumping.</p>	MOM/SC Containment: Retained. ROD remedy for source area groundwater.
	Interceptor Trench	Migration of impacted groundwater is controlled by withdrawal of groundwater using perforated drain pipes or trenches with highly transmissive media backfill. Water withdrawn from sump using conventional lift pump.	Trenches are simple to design and effective in collecting shallow groundwater for treatment from geologic units exhibiting a wide range of hydraulic conductivities; generally applied in low-yielding formations at relatively shallow depths. Equipment for construction is readily available. Technology limited to shallow depths. Additional treatment required to treat collected groundwater prior to discharge (see EX SITU TREATMENT).	MOM/SC Containment: Eliminated. Technology is limited to shallow depths and could not be easily implemented to collected groundwater from the top of rock flow zone due to depth constraints. Pumping test data generated during the remedial investigation indicates adequate capture achieved by groundwater extraction well technology. Wells are preferred extraction technology due to easier implementation, operational effectiveness, and cost.
In Situ Separation/Contaminant Extraction	Air Sparging/Soil Vapor Extraction(SVE)	Air is injected into impacted overburden groundwater through air sparging wells to volatilize organic compounds to soil gas. Organic compounds in soil vapor are typically extracted by SVE, although air sparging and SVE may be employed separately.	May be effective in remediating organic compounds with high Henry's Law Constants. Injected air may cause oxidation of metals on sparge well screens, significantly decreasing efficiency. Soil heterogeneities may cause preferential flow paths to develop and result in lateral dispersal of COC outside the area of influence of soil vapor extraction wells. Addition of oxygen to subsurface materials could elevate dissolved oxygen levels beyond the capture/treatment zone of the system, thereby reducing potential anaerobic degradation known to occur across the study area. Employment of air sparging in areas of deep groundwater impacts (e.g., areas south and east of SWDA) could adversely impact shallow groundwater, currently impacted by COCs (e.g., B-138A or B-113A) by mass transfer processes. Equipment and labor is available to implement this technology.	MOM/SC Containment: Eliminated. Soil heterogeneities and shallow, non-impacted groundwater in areas south and west of the SWDA could be adversely impacted by air sparging performed in deeper impacted groundwater. Soil heterogeneities could result in the development of preferential pathways for injected air resulting in the lateral spread of COC beyond the influence of vapor extraction wells. Introduction of air could introduce oxygen resulting in oxic conditions that are less favorable for reductive dechlorination.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Ex Situ Groundwater Treatment- Physical	Absorption/ Adsorption	Groundwater or an air stream is pumped through a canister or series of vessels containing adsorptive/absorptive media (i.e., granular activated carbon [GAC], polymeric components, etc.). Media requires periodic replacement or regeneration. Absorption technologies can be used in combination with other technologies to polish waste streams in liquid or vapor phases.	Carbon adsorption and other proprietary media will remove VOCs present in groundwater or vapor phase. May not be economical for treating elevated levels of COC but can be effective for polishing groundwater treated by other methods. Depending on concentration, may require frequent carbon replacement or regeneration. In addition to carbon adsorption, proprietary products, such as "RECLAIM", are also available and have been tested at full scale. May require utilization of additional pre-treatment for VOCs and metals technologies to improve efficiency and reduce the potential for fouling due to potentially elevated concentrations of iron and/or manganese in groundwater. Carbon treatment units are readily available and easily implemented into groundwater treatment systems.	MOM/SC Treatment: Retained. Activated carbon has been demonstrated effective for removing low to moderate concentrations of VOCs from both vapor phase and aqueous phase. May be used as a polishing technique for reducing concentrations of VOCs treated by other methods.
	Air Stripping	Extracted groundwater is pumped through either a countercurrent packed tower aeration system or an induced draft air stripper. Volatile organic compounds would be transferred to the vapor phase. If off-gases exceed Vermont Department of Conservation (VTDEC) action levels for COCs, off-gas treatment with vapor-phase activated carbon would be required.	Air stripping is commonly employed to remove low levels of VOCs from groundwater. Air strippers are widely available and easily incorporated into treatment systems involving multiple treatment technologies. Air emission controls (GAC, thermal incineration, or catalytic conversion) may be required if constituents in effluent gases exceed VTDEC action levels. Regeneration or replacement of packing media required during course of operation as part of operation and maintenance (O&M). Pre-treatment for metals and hardness likely to be required to reduce potential for fouling of packing media.	MOM/SC Treatment: Retained. Demonstrated effectiveness in VOC removal and easily implemented.
	Reverse Osmosis	Pressure is applied to water in a vessel to force less contaminated water across a membrane, resulting, after successive separations, in a highly concentrated waste solution (concentrate) and a purified stream (permeate).	Reverse osmosis membranes are effective in removing some, but not all, of the organic and inorganic COC in site groundwater. Pretreatment, such as filtration and chemical addition, may be required.	MOM/SC Treatment: Eliminated. No benefits derived from technology over conventional and less complex technologies for treating COC.
	Ultrafiltration	Water is pressurized across a selective membrane designed to retain particles and molecules above a specific size or molecular weight. This is often accomplished in a membrane tube configuration. Retained contaminants (concentrate) are washed down to create a waste stream.	May require pre-treatment to prevent fouling, and subsequent disposal of additional residual materials. Concentrate requires treatment with additional ex situ technology. Efficiency decreases for low discharge rates. Polishing of effluent water would be required to meet IGCLs. Not a proven technology for treating impacted groundwater at full scale remediation sites.	MOM/SC Treatment: Eliminated. Not a proven technology for treating impacted groundwater at full scale remediation sites. Would require implementation of additional technologies to meet IGCLs.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Ex Situ Groundwater Treatment (cont)-Physical	Centrifugation	Centrifugation is a physical separation process in which the components of a fluid mixture are physically separated based upon differences in density by rapidly rotating the fluid mixture in a rigid vessel.	Centrifugation is applicable to liquid mixtures where the liquids are immiscible. Not effective in treating low concentrations of VOCs and will not likely reduce COC to acceptable concentrations. Separator technology, concentrate requires implementation of ex situ treatment technology to meet IGCLs. Most advantageous when the clarified liquid can be recycled, reused, or sold.	MOM/SC Treatment: Eliminated. Study area conditions (e.g., flow rates, COC) are not optimal for technology application.
	Crystallization	Contaminated aqueous waste is passed through a refrigerated chamber where certain organic compounds are selectively crystallized out of solution.	This technology has not been demonstrated at full scale for treatment of impacted groundwater at hazardous waste sites. The crystallization process requires a constant waste stream with highly controlled operating conditions and is a separator technology, crystallized wastes require disposal or treatment processes. Not proven cost effective for VOC treatment.	MOM/SC Treatment: Eliminated. Not a proven technology for treating COC in groundwater at full scale remediation sites.
	Thin Film Evaporation	The thin film evaporation process involves the evaporation of organic compounds from a thin film of water flowing across a heat transfer surface.	Organic compounds are partially vaporized to a gaseous state while the remainder of the contaminants remain in the water and are discharged as concentrated brine. Acts as separator technology; treatment of air stream required to eliminate organic compounds released to gaseous state. Treatment of aqueous waste stream required.	MOM/SC Treatment: Eliminated. Not proven at field scale.
	High Energy Electron Irradiation	Clear liquid waste is bombarded with high energy particles to destroy organic compounds.	Successful full-scale implementation for similar scale application has not been documented.	MOM/SC Treatment: Eliminated. Not a proven technology for treating impacted groundwater.
	Steam Stripping	Extracted groundwater is injected through the top of a stripping tower filled with packing material. Steam is forced upward through organic compounds as groundwater flows downward through the packing material. Polishing for effluent steam would likely be required.	Steam stripping has been demonstrated to be effective in removing chlorinated organic compounds from impacted groundwater. Pretreatment may be necessary to limit potential for fouling of packing material. Effectiveness is comparable to air stripping for compounds of concern. A steam source would be necessary to implement this technology. Acts as separator, treatment of air emissions required. May not be cost effective compared to alternative technologies for treating compounds of concern in groundwater.	MOM/SC Treatment: Eliminated. No benefits derived from technology over conventional and less complex air stripping for COC.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Ex Situ Groundwater Treatment (cont)-Physical	Supercritical Fluid Extraction	Supercritical fluid extraction uses high temperature and pressure to enhance a fluid's ability to act as a solvent for organic compounds. Following extraction of organic compounds, the supercritical fluid is flashed off by reducing pressure leaving concentrated organic compounds for disposal.	This application has not been demonstrated at full scale for groundwater treatment of organic compounds and has only recently become available for full scale application. Acts as separator technology, effluent stream would require treatment. Has been combined with ozone injection to rapidly oxidize and completely destroy COC as an experimental technology.	MOM/SC Treatment: Eliminated. Not a proven technology for COC.
	Biological (Aerobic)	Extracted groundwater is pumped through an above-ground bioreactor where aerobic microorganisms metabolize organic constituents into less toxic byproducts. Removal process assisted by both gravity settling and adsorption. Reactor systems consist of both plug flow and batch reactors and may integrate activated sludge into the process. Disposal of sludge generated by process would be required.	Bioreactors have been used to treat chlorinated organics. Biological treatment processes do not result in significant removal of dissolved metals concentrations. High concentrations of metals could adversely affect the treatment process. Metals pretreatment may be required, however, the resulting concentrations may then be too low to sustain microbial growth. Some concerns exist regarding climatic limitations.	MOM/SC Treatment: Eliminated. Inefficient in degrading elevated concentrations of halogenated compounds present in groundwater, climatic conditions may adversely impact biological activity.
	Biological (Anaerobic)	Extracted groundwater is pumped to above ground bioreactors where anaerobic microbes metabolize constituents into biomass, carbon dioxide, and water.	Most effective in treating simple VOCs in water. Site contains complex VOCs which may degrade to by-products that are difficult to manage. Some concerns exist regarding climatic conditions.	MOM/SC Treatment: Eliminated. Limited success with complete degradation of chlorinated compounds; climatic conditions may limit biological activity.
	Powdered Activated Carbon Treatment (PACT)	PACT is a hybrid technique combining several treatment mechanisms. Extracted groundwater would be treated in mixing tanks into which powdered activated carbon is added. Biological activity is promoted, in part as an attached growth phenomenon, with the suspended carbon particles providing the attachment surface. Treatment occurs by a combination of air stripping, biological activities (both suspended and attached), adsorption, and settling.	Being a biological treatment system, PACT is susceptible to toxic inhibition by high concentrations of metals; however, not to the extent that a straight biological system would be. Pretreatment to reduce metals may result in a stream low in organics. Low seasonal temperatures would limit activity, thereby requiring a controlled environment. Compounds which are recalcitrant to biological degradation may not be effectively treated, or may require increased costs through additional nutrient augmentation.	MOM/SC Treatment: Eliminated. Although determined to be potentially feasible by the FS for contaminants present in groundwater, eliminated because air stripping and GAC selected as representative process option for VOC treatment.

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RESPONSE MEASURE/ TECHNOLOGY	PROCESS OPTION	DESCRIPTION	TECHNICAL FEASIBILITY & IMPLEMENTABILITY	STATUS/JUSTIFICATION
Ex Situ Groundwater Treatment (cont). - Chemical	Air Emission Biofilter	Vapor-phase organic contaminants are pumped through a soil-bed where materials sorb onto soil surface. Microbes breakdown contaminants during metabolism process. Augmentation of microbes may be used to enhance degradation of certain compounds of concern in air stream.	Halogenated VOCs may not be effectively or completely degraded by microbes. Low seasonal temperatures would limit activity, thereby requiring a controlled environment. Compounds which are recalcitrant to biological degradation may not be effectively treated, or may require increased costs through additional nutrient augmentation.	MOM/SC Treatment: Eliminated. Not efficient for site conditions to treat COC in air stream. Vapor phase treatment with GAC is a cost effective alternative.
	Ozonation	Ozone is used as reactive oxidant to oxidize organic compounds in aqueous waste streams with organic content of less than 10,000 ppm. By-products created are carbon dioxide, hydrochloric acid and water. Ozone contact with the groundwater occurs within a multi-stage baffled reactor. Basic systems typically consist of the reactor, air or oxygen compressor, air dryer, and an ozone generator. Ultraviolet (UV) light in combination with either ozonation system or hydrogen peroxide can significantly increase degradation of some organic compounds.	Use of pilot and full scale systems to treat chlorinated organic compounds in groundwater is well documented. Organic compounds present in site groundwater may be effectively treated using this technology. Ozonation has been proven to be effective in combination with UV photolysis and hydrogen peroxide oxidation. Safety considerations include excessive oxygen consumption (and associated storage/generation).	MOM/SC Treatment: Eliminated. Proven technology in combination with hydrogen peroxide in treating chlorinated VOCs in groundwater. Ultraviolet light in combination with hydrogen peroxide is retained as chemical treatment technologies due to lower toxicity, commercial availability, and ease of implementation over the long-term operation.
	Hydrogen Peroxide Oxidation	Hydrogen peroxide is used to oxidize organic compounds in aqueous waste streams. Primary by-products of the reaction are carbon dioxide and water. Basic system components typically include the oxidation chamber, chemical storage vessel, and metering pump. Ultraviolet light in combination with the system can increase degradation, reaction rates, and destruction efficiency.	<p>Pilot and full scale application of hydrogen peroxide oxidation system for treatment of organic compounds in groundwater is well documented and demonstrated. Chlorinated organic compounds such as those present at the site may be effectively treated. Combination with ozonation can significantly increase destruction efficiency.</p> <p>Technology is commercially available and easily implemented. Less toxic than ozone. Explosion potential is a consideration in presence of combustible materials. Can be incorporated into treatment system with other technologies.</p>	MOM/SC Treatment: Retained. Proven technology in combination with UV light to effectively treat chlorinated VOCs in groundwater. Package systems are available and can be easily incorporated into treatment system with other technologies.

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Ex Situ Groundwater Treatment (cont)-Chemical	Hydroxide/ Carbonate Precipitation	Lime or sodium hydroxide is used to remove metals from groundwater by pH adjustment, precipitation, flocculation and settling. Filtration is often used after settling.	Hydroxide/Carbonate precipitation uses readily available and proven technology, and is effective in removing most metals to the 100-200 ppb range. This treatment may also lower concentrations of organic contaminants.	MOM/SC Treatment: Retained. Representative process option for metals treatment.
	Sulfide Precipitation	Similar to the hydroxide carbonate precipitation, but very insoluble metal sulfides are precipitated out. The process involves pH adjustment and addition of soluble sodium NaHS or insoluble iron sulfide (FeS) slurry.	Sulfide precipitation is effective in removing most metals from groundwater to <10 ppb. Potentially hazardous metal sulfide sludge is generated, which would require dewatering and appropriate disposal. Technology is readily available and has been proven effective in removing most metals. Can be incorporated into treatment system with multiple technologies.	MOM/SC Treatment: Retained. Although not retained by the FS because hydroxide/carbonate precipitation was selected as representative process option for metals treatment, this technology is readily available and effective in removing most metals.
	Ion Exchange	Water is pumped through ion exchange vessels containing resins selected to exchange specific dissolved metals, which are retained in the resin bed until the bed is exhausted. Vessels are periodically backwashed and regenerated with acid, base or salt solution.	Ion exchange units are readily available and proven for removal of metals from groundwater. Proven for the removal of metals. Concentrated regeneration wastes are produced, which will require appropriate management and disposal.	MOM/SC Treatment: Retained. Although not retained by the FS because hydroxide/carbonate precipitation was selected as representative process option for metals treatment, this technology is readily available and effective in removing most metals.

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Ex Situ Groundwater Treatment (cont)-Chemical	Ultraviolet Photolysis	Ultraviolet radiation is used to photolytically destroy organic compounds in clear aqueous waste streams. By-products of the process include carbon dioxide, water, and hydrochloric acid. Ultraviolet radiation contact with water occurs in a multi-chamber reactor. Basic components consist of a quartz lined reaction vessel, UV lamps, and a power supply. Ultraviolet light in combination with either hydrogen peroxide or ozone can significantly increase degradation of some organic compounds.	<p>Effectiveness is dependent upon clarity of the aqueous waste stream. Organic compounds break down to non-specific, non-toxic by-products. Use of this technology at pilot and full scale applications is well documented.</p> <p>May require extensive pretreatment for removal of metals and suspended solids to provide clear, colorless influent to UV system. May not achieve IGCL for VOCs due to suspended solid interference.</p>	MOM/SC Treatment: Retained. Although not retained by the FS because of contaminants in groundwater (i.e., 1,1-dichloroethane (DCA), 1,1,1-trichloroethane (TCA), methylene chloride and 1,2-DCE), this is a proven technology in combination with hydrogen peroxide and ozone in treating chlorinated VOCs in groundwater.
	Chemical Fixation	Addition of chemical additives to aqueous stream (e.g., chelants, sequesterants, dispersants) which prevent precipitation/deposition of metallic oxides and salts.	Chemical additives based on chemistry of groundwater and VOC treatment alternative selected. Additive can be tailored to prevent iron and manganese deposition during air stripping. Proven at other sites, requires site-specific review during design process. Sequestering agent also binds other, non-targeted metal compounds, preventing their removal prior to discharge. Becomes inefficient in cases of elevated concentrations of inorganic compounds in influent.	MOM/SC Treatment: Eliminated. Not suited to study area conditions due to anticipated elevated inorganic compound concentrations in influent, and effluent standards/criteria associated with surface water discharge.
	Activated Alumina	Groundwater is pumped through a vessel containing activated alumina to remove select heavy metals via absorption. Media requires periodic replacement and cannot be regenerated. Absorption technologies can be used separately or in conjunction with other technologies to polish the waste streams to meet discharge criteria for inorganic compounds.	Activated alumina will remove select heavy metals from groundwater. Depending on metal concentrations, frequent replacement may be required. Disposal of media would require either incineration or landfilling. Treated effluent may not meet discharge criteria without additional technology application.	MOM/SC Treatment: Retained. Activated alumina has been demonstrated effective in removing select heavy metals from the aqueous phase.

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Ex Situ Groundwater Treatment (cont.)-Thermal Treatment	On-site Incineration	Organic compounds in groundwater or in gas phase following separation are destroyed using incineration by various mechanisms (i.e., rotary kiln, fluidized bed reactors, fuel blending infrared pyrolysis, liquid injector incinerators, supercritical waste oxidation, high energy corona, or hybrid plasma reactors). Temperatures required for destruction of most VOCs occurs between 1,100 and 1,200 Degrees F.	Not considered efficient or cost effective for treating COC in groundwater. Vapor treatment processes are suitable for COC, however destructive technologies (e.g., high energy corona) have not been documented to be successful on field scale.	MOM/SC Disposal: Eliminated. Not implemented at field scale. Not efficient for treating COC in groundwater.
Discharge of Extracted/Treated Groundwater	Groundwater ReInjection	Treated groundwater is returned to the groundwater system through infiltration galleries or injection wells.	Reinjection of oxygenated effluent could disrupt existing anaerobic environment and potentially re-distribute the downgradient groundwater plume. Effectiveness can be significantly limited by presence of soils with lower hydraulic conductivities and heterogeneities. Implementability dependent upon identifying area with high permeability soils able to receive volume of groundwater.	MOM/SC Disposal: Eliminated. Site soils exhibit heterogeneities generally not conducive to infiltration/reinjection. Volumes associated with extraction system operation could significantly alter downgradient groundwater flow patterns, possibly affecting extent of impacts.
	Discharge to Sewer/POTW	Treated groundwater is discharged to the publicly owned treatment works (POTW). There is a POTW in Lyndonville located approximately one-quarter mile south of the town center. The closest potential sewer line connection is located approximately two miles north of the Parker Landfill on Hill Street.	Feasibility Study estimated approximately 2-miles of pipeline would be required to meet the nearest POTW line. Flows may require additional upgrades to existing POTW system.	MOM/SC Disposal: Eliminated. Extensive infrastructure required to complete connection to POTW.
	Discharge to Surface Water	Treated groundwater is discharged to surface water (i.e. unnamed stream, Passumpsic River)	Surface discharge to the Passumpsic River could be implemented and operated. For discharge to the Passumpsic River, an outfall pipeline would be required. The outfall pipeline would be approximately 1/2-mile long and would require significant construction costs. Discharge into the unnamed stream would be impractical due to flow rates.	MOM/SC Disposal: Retained. Optimal discharge option associated with discharge of extracted groundwater.
Discharge of Extracted/Untreated Groundwater (Off Site Treatment)	Road transport to disposal facility	Collected groundwater would be hauled off site to a treatment facility for disposal.	Not considered efficient or cost effective for treating COC in groundwater at anticipated flow rates. Effectiveness is dependent on treatment facility efficiency and permit requirements. Health and safety concerns exist concerning handling during transit. Would require identification of treatment facility which would accept waste. Would not be as cost effective as treatment on site. Would require long-term access to and availability of third-party owned treatment/disposal facility.	MOM/SC Disposal: Eliminated. Disproportionate cost associated with continuously hauling large volumes of water in comparison to other available options. Unable to ensure long-term operation.

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	Pipe to Disposal Facility	Collected groundwater is discharged directly to nearest treatment facility via pipeline.	Not considered efficient or cost effective for treating COC in groundwater at anticipated flow rates. Capacity of local off site facility is limited. Due to the distance to the nearest potential sewer line connection, discharge to the sewer/POTW would be extremely difficult and costly.	MOM/SC Disposal: Eliminated. Infrastructure required to complete connection to POTW is extensive. Current or future limitations from receiving facility could impose influent restrictions (e.g., quantity and quality).

TABLE 3
GROUNDWATER RESPONSE ACTION SCREENING SUMMARY MATRIX
Remedial Technology/Remedial Alternative Screening
Parker Landfill
Lyndon, Vermont

	Remedial Alternative Screening Criteria			
	1	2	3	
	<i>Short- and Long-Term Effectiveness</i>	<i>Implementability</i>	<i>Cost</i>	<i>Outcome</i>
Alternative 1A (ROD) Source Area Groundwater Extraction , Ex Situ Treatment; Downgradient Area Monitored Natural Attenuation (MNA)	MODERATE TO HIGH High overall protection in short term achieved by Institutional Control Plan (ICP) implementation. Moderate long term protection by minimizing migration of contaminants from the source. Reduction of toxicity, mobility and volume in groundwater offset by generation of residuals and mass transfer of contaminants. Moderate short term construction impacts. Significant long term operation and maintenance (O&M).	MODERATE TO LOW Proven technology with equipment and experts readily available. Extensive O&M commitment and oversight required. Third party easements required for construction and operation. Need to meet the intent of Air and NPDES permits.	VERY HIGH Moderate short term construction costs driven by required treatment processes to meet discharge limits. Very high long term O&M costs driven by energy consumption, residual treatment and waste disposal.	ROD remedy retained for detailed comparison.
Alternative 1B Source Area Groundwater Extraction , Ex Situ Treatment; Downgradient Area Enhanced Natural Attenuation (ENA)	MODERATE TO HIGH High overall protection in short term achieved by ICP implementation. Moderate long term protection by minimizing migration of contaminants from the source. Reduction of toxicity, mobility and volume in groundwater offset by generation of residuals and mass transfer of contaminants. Moderate short term construction impacts. Significant long term O&M.	MODERATE TO LOW Proven source area technology with equipment and experts readily available. Extensive source area O&M commitment and oversight required. Third party easements required for construction and operation. Air and NPDES permits required for operation. Downgradient technology proven for short term applications. Construction activities and materials for downgradient ENA readily available.	VERY HIGH Moderate short term construction costs driven by required treatment processes to meet discharge limits. Very high long term O&M costs driven by energy consumption, residual treatment and waste disposal.	Eliminated. Marginal added benefit over ROD remedy.
Alternative 1C Source Area Groundwater Extraction , Ex Situ Treatment; Downgradient Area Groundwater Extraction, Ex Situ Treatment	MODERATE TO HIGH High overall protection in short term achieved by ICP implementation. Moderate long term protection by minimizing migration of contaminants from the source. Reduction of toxicity, mobility and volume in groundwater offset by generation of residuals and mass transfer of contaminants. Moderate short term construction impacts. Significant long term O&M.	MODERATE TO LOW Proven technology with equipment and experts readily available. Extensive O&M commitment and oversight required. Third party easements required for construction and operation. Air and NPDES permits required for operation.	VERY HIGH Moderate short term construction costs driven by required treatment processes to meet discharge limits. Very high long term O&M costs driven by energy consumption, residual treatment and waste disposal.	Retained per EPA request.
Alternative 2A Source Area MNA; Downgradient Area MNA	LOW TO MODERATE High overall protection in short term achieved by ICP implementation. Moderate to low long term protection. No short term construction impacts. Low long term O&M.	HIGH Proven technology, readily available. Construction activities and materials not needed.	LOW No short term construction cost. Low long term O&M costs.	Retained to provide "No Further Action" comparison with intrusive/active remedies .
Alternative 2B Source Area MNA; Downgradient Area ENA	LOW TO MODERATE High overall protection in short term achieved by ICP implementation. Moderate to low long term protection. Minimal short term construction impacts in downgradient area. Low to moderate long term O&M.	HIGH Proven source area technology, readily available. Downgradient technology proven for short term applications. Construction activities and materials for downgradient ENA readily available.	LOW Low short term construction costs. Low/moderate long term O&M costs.	Eliminated. Timeframe for ENA downgradient is extensive if no active remediation of source is provided, marginal added benefit over Alternative 2A.
Alternative 2C Source Area MNA; Downgradient Area Groundwater Extraction, Ex Situ Treatment	LOW TO MODERATE High overall protection in short term achieved by ICP implementation. Moderate to low long term protection. Moderate short term construction impacts. Reduction of toxicity, mobility and volume in groundwater offset by generation of residuals and mass transfer of contaminants. Significant long term O&M.	MODERATE TO LOW Proven technology with equipment and experts readily available. Extensive O&M commitment and oversight required. Third party easements required for construction, operation. Need to meet the intent of Air and NPDES permits.	VERY HIGH Moderate short term downgradient construction costs driven by required treatment processes to meet discharge limits. Very high long term O&M costs driven by monitoring, energy consumption and residual treatment.	Eliminated. Marginal added benefit over alternatives 2A or 2B compared to significantly higher cost.

TABLE 3
GROUNDWATER RESPONSE ACTION SCREENING SUMMARY MATRIX
Remedial Technology/Remedial Alternative Screening
Parker Landfill
Lyndon, Vermont

	Remedial Alternative Screening Criteria			Outcome
	1 <i>Short- and Long-Term Effectiveness</i>	2 <i>Implementability</i>	3 <i>Cost</i>	
Alternative 3A <u>Source Area</u> In Situ Chemical Oxidation; <u>Downgradient Area</u> MNA	MODERATE TO HIGH High overall protection in short term achieved by ICP. Results in permanent reduction in toxicity. High short term construction impacts for source area application. Reagents used for chemical oxidation are non-selective with respect to organic carbon, therefore volume and dose of reagent required to achieve remedial objectives will be greatly influenced by amount of organic carbon in saturated soil and groundwater. Potential for mobilizing unacceptable concentrations of metals from soil in areas proposed for treatment would need to be addressed.	MODERATE TO HIGH Proven technology with equipment, materials and experts readily available. Construction activities to create wetland disturbance. Lateral extent and depth requirements for application could significantly affect implementability of remedy. Coordination with regulatory agencies will be necessary to assure that requirements of the Vermont Underground Injection (UIC) program are met.	MODERATE Moderate short term source area construction costs driven by technology requirements for hydrogeologic setting. Low long term O&M costs.	Eliminated. Source area alternative comparable to PRB of Alternative 4(a-c) in effectiveness, however implementability is lower and costs are significantly greater due to lateral extent and depths required for application.
Alternative 3B <u>Source Area</u> In Situ Chemical Oxidation; <u>Downgradient Area</u> ENA	MODERATE TO HIGH High overall protection in short term achieved by ICP implementation. Results in permanent reduction in toxicity. Reagents used for chemical oxidation are non-selective with respect to organic carbon therefore, volume and dose of reagent required to achieve remedial objectives will be greatly influenced by amount of organic carbon in saturated soil and groundwater. Potential for mobilizing unacceptable concentrations of metals from soil in areas proposed for treatment would need to be addressed. High short term construction impacts for source area application.	MODERATE TO HIGH Proven technology with equipment, services and experts readily available. Lateral extent and depth requirements for application could significantly affect implementability of remedy. Coordination with regulatory agencies will be necessary to assure that requirements of the Vermont Underground Injection (UIC) program are met. Downgradient technology proven for short term applications. Construction activities to create wetland disturbance. Construction activities and materials for downgradient ENA readily available.	MODERATE TO HIGH Moderate/high short term construction costs driven by technology requirements for hydrogeologic setting. Low/moderate long term O&M costs.	Eliminated. Source area alternative comparable to PRB of Alternative 4(a-c) in effectiveness, however implementability is lower and costs are significantly greater due to lateral extent and depths required for application.
Alternative 3C <u>Source Area</u> In Situ Chemical Oxidation; <u>Downgradient Area</u> Groundwater Extraction, Ex Situ Treatment	MODERATE TO HIGH High overall protection in short term achieved by ICP implementation. Results in permanent reduction in toxicity at source area; long-term reduction of toxicity, mobility and volume in downgradient area offset by generation of residuals and mass transfer of contaminants. High short term construction impacts. Significant long term O&M.	MODERATE TO LOW Proven technology with equipment and experts readily available. Construction activities to create wetland disturbance. Lateral extent and depth requirements for application could significantly affect implementability of remedy. Extensive O&M commitment and oversight required. Third party easements required for construction, operation. Air and NPDES permits required for operation.	VERY HIGH High short term construction costs driven by technology requirements and required treatment processes to meet discharge limits. Very high long term O&M costs driven by monitoring, energy consumption and residual treatment.	Eliminated. Source area alternative comparable to PRB of Alternative 4(a-c) in effectiveness, however implementability is lower and costs are significantly greater due to lateral extent and depths required for application. Marginal added benefit over alternatives 3A or 3B compared to significantly higher cost.
Alternative 4A <u>Source Area</u> Permeable Reactive Barrier (PRB); <u>Downgradient Area</u> MNA	HIGH High overall protection in short term achieved by ICP implementation. High short term construction impacts. Destructive restoration mechanisms eliminate further migration of impacted groundwater from the source area. Results in permanent and complete reduction in toxicity. Low to moderate long term O&M.	HIGH Proven technology with equipment and experts readily available. Construction activities will create wetland disturbance.	MODERATE Moderate short term source area construction cost. Low long term O&M costs.	Retained. Cost benefits and equal or better restoration time compared to ROD warrant detailed evaluation.
Alternative 4B <u>Source Area</u> PRB; <u>Downgradient Area</u> ENA	HIGH High overall protection in short term achieved by ICP implementation. High short term construction impacts. Destructive restoration mechanisms eliminate further migration of impacted groundwater from the source area. Results in permanent and complete reduction in toxicity. Low to moderate long term O&M. Provides additional reduction in contaminant mass by implementing bio-enhanced attenuation in downgradient area.	HIGH TO MODERATE Proven source area technology with equipment and experts readily available. Construction activities will create wetland disturbance. Downgradient technology proven for short term applications with equipment and experts readily available.	HIGH Moderate short term construction cost. Moderate long term O&M costs.G39	Retained. Cost benefits and equal or better restoration time compared to ROD warrant detailed evaluation.

TABLE 3
GROUNDWATER RESPONSE ACTION SCREENING SUMMARY MATRIX
 Remedial Technology/Remedial Alternative Screening
 Parker Landfill
 Lyndon, Vermont

	Remedial Alternative Screening Criteria			Outcome
	1 <i>Short- and Long-Term Effectiveness</i>	2 <i>Implementability</i>	3 <i>Cost</i>	
Alternative 4C <u>Source Area</u> PRB; <u>Downgradient Area</u> Groundwater Extraction, Ex Situ Treatment	HIGH High overall protection in short term achieved by ICP implementation. High short term construction impacts. Destructive restoration mechanisms eliminate further offsite migration of impacted groundwater. Results in permanent and complete reduction in toxicity in source area; long term reduction of toxicity, mobility and volume in downgradient area offset by generation of residuals and mass transfer of contaminants. Significant long term O&M.	MODERATE TO LOW Proven technology with equipment and experts readily available. Construction activities will create wetland disturbance. Extensive O&M commitment and oversight required. Third party easements required for construction, operation. Air and NPDES permits required for operation.	VERY HIGH High short term construction costs driven by technology requirements and required treatment processes to meet discharge limits. Very high long term O&M costs driven by monitoring, energy consumption and residual treatment.	Eliminated. Marginal added benefit over alternatives 4A or 4B compared to significantly higher cost.
Alternative 5A <u>Source Area</u> ENA; <u>Downgradient Area</u> MNA	MODERATE TO HIGH High overall protection in short term achieved by ICP implementation. Moderate to low long term protection, reduces but may not eliminate migration of contaminants from the source. Minimal short term construction impacts. Low to moderate long term O&M.	MODERATE TO HIGH Proven technology for short term applications with equipment and experts readily available. Construction activities and materials readily available.	MODERATE Moderate short term construction costs. Low/moderate long term O&M costs.	Eliminated. Enhanced natural recovery alternative 5B provides shorter restoration timeframe.
Alternative 5B <u>Source Area</u> ENA; <u>Downgradient Area</u> ENA	MODERATE TO HIGH High overall protection in short term achieved by ICP. Moderate to low long term protection, reduces but may not eliminate migration of contaminants from the source. Minimal short term construction impacts. Low to moderate long term O&M.	MODERATE TO HIGH Proven technology for short term applications with equipment and experts readily available. Construction activities and materials readily available.	HIGH Moderate short term construction costs. Low/moderate long term O&M costs.	Retained. Benefits of restoration time reduction may balance moderate increase in cost over 5A.
Alternative 5C <u>Source Area</u> ENA; <u>Downgradient Area</u> Groundwater Extraction, Ex Situ Treatment	MODERATE TO HIGH High overall protection in short term achieved by ICP. Moderate to low long term protection, reduces but may not eliminate migration of contaminants from the source. Minimal short term construction impacts. Significant long term O&M.	MODERATE TO LOW Proven source area technology for short term applications with equipment and experts readily available. Proven downgradient area technology with equipment and experts readily available. Extensive O&M commitment and oversight required. Third party easements required for construction, operation. Air and NPDES permits required for operation.	VERY HIGH Moderate short term source area construction cost. Moderate short term downgradient construction costs driven by required treatment processes to meet discharge limits. Very high long term O&M costs driven by monitoring, energy consumption and residual treatment.	Eliminated. Marginal added benefit over alternatives 5A or 5B compared to significantly higher cost.

Cost screening based on the following generalization: **LOW** < \$5,000,000; \$5,000,000 ≤ **MODERATE** < \$10,000,000; \$10,000,000 < **HIGH** ≤ \$15,000,000; **VERY HIGH** > \$15,000,000

TABLE 4
COMPARATIVE ANALYSIS SUMMARY
Remedial Technology/Remedial Alternative Evaluation
Parker Landfill
Lyndon, Vermont

	Remedial Alternative Evaluation Criteria						
	1 <i>Overall protectiveness of human health and environment</i>	2 <i>Compliance with ARARs</i>	3 <i>Long-Term Effectiveness and Permanence</i>	4 <i>Reduction of Toxicity, Mobility or Volume</i>	5 <i>Short-Term Effectiveness</i>	6 <i>Implementability</i>	7 <i>Cost</i>
Alternative 1A Groundwater Extraction , Ex Situ Treatment (ROD)	HIGH (Protection achieved by ICP)	HIGH (Extraction of impacted groundwater at landfill cap boundary)	MODERATE (Proven technology, high maintenance requirements, predicted overall aquifer restoration time 65 years)	LOW (Generation of residuals, mass transfer of contaminants)	HIGH (Obtained through ICP implementation)	MODERATE (Extensive O&M requirements, third party easements required for construction, operation)	VERY HIGH \$30,147,000
Alternative 1C Expanded Groundwater Extraction , Ex Situ Treatment	HIGH (Protection achieved by ICP)	HIGH (Extraction of impacted groundwater at landfill cap boundary and from downgradient area)	MODERATE (Proven technology, high maintenance requirements, predicted overall aquifer restoration time 65 years)	LOW (Generation of residuals, mass transfer of contaminants)	HIGH (Obtained through ICP implementation)	MODERATE (Extensive O&M requirements, third party easements required for construction, operation)	VERY HIGH \$37,310,000
Alternative 2A Monitored Natural Attenuation	HIGH (Protection achieved by ICP)	HIGH (Destructive restoration mechanisms)	LOW (Proven technology, predicted 70 year aquifer restoration time)	HIGH (Permanent and complete)	HIGH (Obtained through ICP implementation)	HIGH (Materials not needed)	LOW \$1,901,000
Alternative 4A Permeable Reactive Barrier	HIGH (Protection achieved by ICP)	HIGH (Destructive restoration mechanisms, eliminates further offsite migration of impacted groundwater)	MODERATE (Proven technology, aquifer restoration time 70 years.)	VERY HIGH (Permanent and complete, technology achieves complete reduction directly)	HIGH (Obtained through ICP implementation)	HIGH (Materials available, technology feasible)	MODERATE \$5,386,000
Alternative 4B Permeable Reactive Barrier/Bio-Enhanced Attenuation	HIGH (Protection achieved by ICP)	HIGH (Destructive restoration mechanisms, eliminates further offsite migration of impacted groundwater)	MODERATE (Proven technology, estimated off-site (i.e., non-Parker Properties) restoration time 65 years. On site restoration time 70 years.)	VERY HIGH (Permanent and complete, technology achieves complete reduction directly)	HIGH (Obtained through ICP implementation)	HIGH/MODERATE (Materials available, technology feasible)	HIGH \$10,779,000
Alternative 5B Bio-Enhanced Attenuation	HIGH (Protection achieved by ICP)	HIGH (Destructive restoration mechanisms, reduces offsite migration of impacted groundwater)	MODERATE (Proven technology, estimated off-site (i.e., non-Parker Properties) restoration time 55 years. On site restoration time 60 years.)	HIGH (Permanent and complete for those organic compounds which undergo complete conversion to inorganic forms)	HIGH (Obtained through ICP implementation)	MODERATE (Materials available, technology feasible)	HIGH \$13,317,000

TABLE 5
STARTING POINT SOLUTE TRANSPORT MODEL CONCENTRATIONS
 Remedial Technology/Remedial Alternative Evaluation
 Parker Landfill
 Lyndon, Vermont

MODEL LAYER	MONITORING WELL	OCTOBER 2003 TRICHLOROETHENE CONCENTRATION (MG/L)	MT3D TRICHLOROETHENE CONCENTRATION, INITIAL (MG/L)
2	B103A	0.34	0.5
8	B113BB	0.0059 J	0.01
8	B120C	6.8 (0.26)	5
7	B125A	0.016 (0.160)	0.01
9	B126A	1.4 (0.012)	1.0
9	B131C	ND	0
5	B132	0.47 (0.012)	0.5
2	B133	2.1	5
5	B136A	0.011	0.01
9	B136B	2.3 (0.390)	5
5	B138A	ND	0
9	B138B	0.032	0.05
2	B139A	1	1
7	B145B	ND (ND)	0
5	MW4A	ND	0

Legend/Notes:

mg/l = Milligrams per liter

J = Estimated Concentration

1. Model Layer as defined in the *Revised Draft Groundwater Flow and Solute Transport Model Report* (URS, 2002)
 Concentrations in parentheses represent data from shallow bedrock zone of monitoring well cluster, screened through regolith (base of overburden) and into upper bedrock.

TABLE 6
SURFACE WATER DISCHARGE CRITERIA
Remedial Technology/Remedial Alternative Evaluation
Parker Landfill
Lyndon, Vermont

	Protection of Human Health	Protection of Aquatic Biota (mg/l)	
	Consumption of Water & Organisms (mg/l) ¹	Maximum Allowable Concentration - Acute Criteria (mg/l)	Average Allowable Concentration - Chronic Criteria (mg/l)
Volatile Organic Compounds			
<i>Benzene</i>	0.0012	--	--
<i>Chloroform</i>	0.0057	--	--
<i>1,2-Dichloroethane</i>	0.00038	--	--
<i>1,1-Dichloroethylene</i>	0.000057	--	--
<i>Ethylbenzene</i>	3.100	--	--
<i>Methylene Chloride</i>	0.0047	--	--
<i>Tetrachloroethylene</i>	0.0008	--	--
<i>Toluene</i>	6.800	--	--
<i>Trichloroethylene</i>	0.0027	--	--
<i>Vinyl Chloride</i>	0.002	--	--
Semi-Volatile Organic Compounds			
<i>Phenol</i>	21.000	--	--
<i>Diethyl Phthalate</i>	23.000	--	--
<i>Di-n-butyl Phthalate</i>	2.700	--	--
<i>Fluoranthene</i>	0.300	--	--
<i>Pyrene</i>	0.960	--	--
Inorganic Compounds			
<i>Antimony</i>	0.014	--	--
<i>Arsenic</i>	0.00002	0.360	0.190
<i>Cadmium</i>	--	0.0039**	0.0011**
<i>Chromium (VI)</i>	--	0.016	0.011
<i>Chromium (III)</i>	--	1.737**	0.207**
<i>Copper</i>	--	0.018**	0.012**
<i>Iron</i>	--	--	1.000
<i>Lead</i>	--	0.0816**	0.0032**
<i>Mercury</i>	0.00014	0.0024	0.000012
<i>Nickel</i>	0.610	1.418**	0.158**
<i>Selenium</i>	--	0.020	0.005
<i>Silver</i>	--	0.0041**	--
<i>Thallium</i>	0.0017	--	--
<i>Zinc</i>	--	0.117**	0.106**

Legend/Notes:

¹ = Vermont Water Quality Standards adopted June 10, 1999 Effective July 2, 2000.

mg/l = milligrams per liter

-- = Criteria not published

** = Criteria calculated using an estimated hardness of 100 mg/l.