Final Feasibility Study Report

Hansville Landfill Remedial Investigation/Feasibility Study

Prepared for

Kitsap County Department of Public Works
Solid Waste Division
614 Division Street (MS-27)
Port Orchard, Washington 98366-4686

and

Waste Management of Washington, Inc.
801 Second Avenue, Suite 614
Seattle, Washington 98104-1502

Prepared by

Parametrix
411 108th Avenue NE, Suite 1800
Bellevue, WA 98004-5571
425-458-6200
www.parametrix.com

June 15, 2009 │ 215-2966-001 (05/05)

CITATION

Parametrix. 2009. Final Feasibility Study Report
Hansville Landfill Remedial Investigation/Feasibility Study. Prepared by Parametrix,
Bellevue, Washington. June 15, 2009.

CERTIFICATION

The technical material and data contained in this document were prepared under the supervision and direction of the undersigned.

Prepared by Michael R. Warfel, L.H.G.

Approved by Kenneth T. Fellows, P.E.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

APPENDICES

EXECUTIVE SUMMARY

This document describes the results of the Feasibility Study (FS) conducted at the Hansville Landfill Site, which includes a municipal solid waste disposal facility that operated from 1962 through 1989 near the community of Hansville in northern Kitsap County, Washington. The FS is the second major component of the Remediation Investigation/Feasibility Study (RI/FS) that is being conducted in accordance with a Consent Decree entered into among the Washington State Department of Ecology (Ecology), Kitsap County (the facility owner), and Waste Management of Washington (the successor of the former facility operator).

The purpose of the FS is to develop, screen, and evaluate cleanup alternatives for the Hansville Landfill Site, in accordance with the requirements and procedures specified in Chapter 173-340 WAC, the Model Toxics Control Act (MTCA) Cleanup Regulation (Ecology 2001). The analyses of the cleanup alternatives focus on the indicator hazardous substances identified in the Hansville Landfill RI report (Parametrix 2007), which included investigations of waste sources, landfill gas, groundwater, surface water, and sediment at the Site. Chemicals identified as indicator hazardous substances in the RI report for evaluation in the FS are summarized by media as follows:

Chemicals Carried into the Feasibility Study	Groundwater	Surface Water	Sediment
Antimony			X
Arsenic	X	X	X
Bis(2-ethylhexyl)phthalate	X		
Chromium			X
Copper	X	X	
Lead	X		
Manganese	X		X
Nickel	X		X
Nitrate	X		
Silver	X		X
Vinyl Chloride	X	X	
Zinc	X	X	

The stepwise process specified by Chapter 173-340 WAC was followed in this Hansville Landfill FS, including:

- Risk assessment of chemicals carried forward from the RI report;
- Specification of cleanup standards;
- Assessment of applicable state and federal laws;
- Screening of cleanup technologies;
- Development of cleanup alternatives from the selected technologies;
- Evaluation of the alternatives per specific regulatory criteria;
- Cost-benefit analysis of alternatives; and
- Recommendation of a preferred cleanup alternative.

Seven remedial alternatives are evaluated in the FS, ranging from no additional action with natural attenuation and institutional controls, to excavation and off-site disposal of the waste materials. Table ES-1 provides a summary of the descriptions, costs, estimated cleanup times, and cost-benefit ratios for the seven alternatives.

For the cost-benefit comparison, benefit is defined using the MTCA evaluation criteria summarized below:

- Protection of human health and the environment;
- Compliance with applicable or relevant and appropriate requirements (ARARs) from State and Federal Laws;
- Short-term effectiveness;
- Long-term effectiveness;
- Permanent solutions (e.g. reduction in toxicity, mobility, and volume of contaminants through treatment);
- Implementability (technical feasibility); and
- Degree to which community concerns are addressed.

The absence of comments on the Draft RI report by the non-Tribal community in the vicinity may indicate the absence of specific concerns. A letter of support regarding remedial alternatives at the Site was also received from the Port Gamble S'Klallam Tribe (see Appendix H). Interested persons from the community will have an opportunity to communicate their thoughts about the project during the public comment period for the draft FS report. Public comments submitted during the comment period will be compiled and presented by Ecology in a Responsiveness Summary, which will accompany the final FS report.

In this analysis, each of the seven criteria is weighted equally. Each alternative receives a score from 1 to 3 under each criterion. A score of 1 indicates the alternative satisfies the MTCA criterion the least, while a score of 3 indicates the best performance. A minimum score of 7 and a total maximum score of 21 are possible. The alternative evaluation process and cost-benefit analysis are described in detail in Chapter 9.

Based on the evaluation of alternatives presented in Chapter 9 (as summarized in Table ES-1), Alternative 2 (Natural Attenuation of Groundwater with Enhanced Monitoring and Enhanced Institutional Controls) is the preferred remedial approach for the Hansville Landfill Site. This alternative provides a practical remedy at a reasonable cost, while also protecting public health and the environment.

Natural attenuation involves treatment mechanisms present in the natural environment that act to reduce the concentrations of indicator hazardous substances detected in groundwater. These processes do not depend on mechanical systems nor do they involve construction activities that could disrupt the environment and the community. The preferred alternative complies with ARARs and would be as effective and reliable as other alternatives in ultimately achieving cleanup standards. Natural attenuation would remove hazardous substances from the Upper Aquifer in an environmentally acceptable manner and immobilize arsenic and manganese in situ. Long-term monitoring would document achievement of cleanup levels.

Alternative 2 would also establish institutional controls that would include restrictions to prohibit the use of affected groundwater and surface water as drinking water and any surface disturbances that would encounter groundwater or change the hydrology of the area. Because of the availability of a safe, dependable public water supply near the Site, these institutional controls would not unreasonably burden affected Tribal Property.

Alternatives 3 through 7 offer limited benefits compared to Alternative 2, as described below:

- Source control is being provided by operation of the landfill gas control system, which is currently removing vinyl chloride from the Landfill and preventing its migration from the waste, and by the landfill cap, which is reducing infiltration and hence leachate generation by over 99 percent. Alternative 4 (Air Sparging) and Alternatives 5 and 6 (Groundwater Pump and Treat) provide no additional source control measures to reduce chemical releases to groundwater. The ability of Alternative 3 (Gas Extraction System Enhancements) to reduce vinyl chloride releases to groundwater may be ineffective if contaminant transport via leachate (rather than via landfill gas) is the principal migration pathway.
- Air sparging and groundwater pump and treat are not significantly different than natural attenuation. The intent of these treatment alternatives is primarily to remove indicator hazardous substances from the Upper Aquifer. This is already occurring naturally through adsorption onto organic carbon in the Upper Aquifer matrix and discharge of groundwater to surface water with subsequent rapid volatilization of vinyl chloride. Arsenic and manganese are being immobilized in situ in the Upper Aquifer by natural processes.
- Treatment provides no additional reduction of existing risks. Assuming appropriate institutional controls are implemented (as would occur for the preferred alternative), installation and operation of a treatment system at the Site would provide no reduction in long-term residual risk. Achieving reductions of existing risks is a key criterion for selection of an alternative under MTCA (WAC 173-340-360(3)(f)(i)).
- Construction and long-term operation of a treatment system for Alternatives 3 through 6 would be costly for the following reasons: frequent maintenance and monitoring would be required; energy resources would be consumed, which may result in the emission of air pollution and other negative environmental consequences; and vandalism of the treatment system components could potentially require increased Site security. These public and private funds and labor and energy resources would not be available for other uses if consumed by a remedial action at the Site.
- It is not certain that the treatment processes for Alternatives 3 through 6 would achieve the desired cleanup level for vinyl chloride in on-site groundwater. There are no known examples where any technology has been successfully used to achieve such a low vinyl chloride cleanup standard. Groundwater may not be fully treated by an air sparging system or fully captured by groundwater extraction wells. Indicator hazardous substances not removed from the Upper Aquifer would flow downgradient and be remediated through natural attenuation.
- Implementation of Alternatives 3 though 6 would have greater impacts on the community than Alternative 2, and Alternative 7 would likely have very high community impacts due to noise, litter, odors, vermin, and truck traffic.

Alternative 2 best satisfies the MTCA evaluation process. It satisfies each of the seven MTCA evaluation criteria and provides the best balance of costs and benefits. The cost/benefit ratio for Alternative 2 is 1.3. The cost/benefit ratios for the other alternatives range from 3.5 to 65.8, indicating that their costs are greater than their benefits. All of the other alternatives, when compared to Alternative 2, have costs that are disproportionately greater than their benefits.

Based on the analyses and evaluations completed in this FS, as summarized in the conclusions presented in Chapter 11 and this Executive Summary, the recommended alternative is Alternative 2, Natural Attenuation of Groundwater with Enhanced Monitoring and Enhanced Institutional Controls.

ACRONYMS AND ABBREVIATIONS

AKART	all known available and reasonable treatment
ARAR	applicable or relevant and appropriate requirement
BACT	Best Available Control Technology
BCF	bioconcentration factor
BKCHD	Bremerton-Kitsap County Health District
CAP	Cleanup Action Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
FS	Feasibility Study
HDPE	high-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance (Computer Model)
KCHD	Kitsap County Health District
KCSL	Kitsap County Sanitary Landfill
LAET	Lowest Apparent Effect Threshold
MCL	Maximum Contaminant Level
MTCA	Model Toxics Control Act
MW	monitoring well
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OVTS	Olympic View Transfer Station
PCL	Preliminary Cleanup Level
POC	Point of Compliance
PSCAA	Puget Sound Clean Air Agency
PW	Pumping Well
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
Redox	oxidation-reduction potential
RI	Remedial Investigation
RTA	Return Treated Water to Aquifer
SEPA	State Environmental Policy Act
SMCL	Secondary Maximum Contaminant Level
SVE	soil vapor extraction

ACRONYMS AND ABBREVIATIONS (CONTINUED)

SW	Surface Water
TBC	"To Be Considered" (Regulatory Agency Policy or Guidance)
UCL	upper confidence limit
USEPA	United States Environmental Protection Agency
UV	ultraviolet
VOC	volatile organic compound
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife

CHEMICALS AND UNITS

List of Units

cfm	cubic feet per minute
cfs	cubic feet per second
cy	cubic yards
ft	feet
g	gram
g/mole	gram per mole
gpm	gallon per minute
kg	kilogram
K_{oc}	Soil Organic Carbon/Water Partition
K_{ow}	Water Solubility and Octanol Water
L	liter
m^2/s	square meter per second
m^3	cubic meter
µg	microgram
mg	milligram
mm	millimeter
mV	millivolt
ppb	parts per billion
psi	pounds per square inch
scfm	standard cubic feet per minute

List of Chemicals

As	arsenic
As(III)	arsenic (+3 valence)
As(V)	arsenic (+5 valence)
DCA	dichloroethane
DCE	dichloroethene
Mn	manganese
Mn(II)	manganese (+2 valence)
N_2	nitrogen gas
NH_3	ammonia
NH_4^+	ammonium ion
N_2O	nitrous oxide
NO_2^-	nitrite
NO_3^-	nitrate
PCA	perchloroethane
PCE	perchloroethene
PVC	polyvinylchloride
TCE	trichloroethene
VC	vinyl chloride

GLOSSARY

Aerobic—A condition where oxygen is present.

Anaerobic—A condition where oxygen is absent.

Anion—A negatively charged atom or group of atoms.

Aquifer—Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economical quantities of water to wells and springs.

Aquitard—A geologic unit with low permeability (hydraulic conductivity) that restricts movement of water into or out of the Upper Aquifer.

British Thermal Unit (BTU)—A unit of energy; the quantity of heat required to raise the temperature of one pound of water 1 degree Fahrenheit.

Capillary Fringe—The zone above the water table in which water is drawn up and held by surface tension.

Carcinogen—Any substance or agent that produces or tends to produce cancer in humans. The term carcinogen applies to substances on the United States Environmental Protection Agency list of A (known human) and B (probable human) carcinogens, and any substance which causes a significant increased incidence of benign or malignant tumors in a single, well-conducted animal bioassay, consistent with the weight of evidence approach specified in the United States Environmental Protection Agency's Guidelines for Carcinogen Risk Assessment as set forth in 51 CFR 33992 et seq. as currently published or as subsequently amended or republished.

Cation—A positively charged atom or group of atoms.

Cleanup Action—Any remedial action, except interim actions, taken at a site to eliminate, render less toxic, stabilize, contain, immobilize, isolate, treat, destroy, or remove a hazardous substance that complies with WAC 173-340-360.

Cleanup Action Plan – The document prepared by the Department of Ecology under WAC 173-340-380 presents the selected cleanup action and specifies cleanup standards and other requirements for the cleanup action.

Cleanup Level—The concentration of a hazardous substance in soil, water, air, or sediment that is determined to be protective of human health and the environment under specific exposure conditions.

Cleanup Standards—The standards promulgated under RCW 70.105D.030(2)(e). Establishing cleanup standards requires specification of the following:

- Hazardous substance concentrations that protect human health and the environment ("cleanup levels");
- The location on a site where those cleanup levels must be attained ("points of compliance"); and
- Additional regulatory requirements that apply to a cleanup action because of the type of action and/or the location of a site. These requirements are specified in applicable state and federal laws and are generally established following the selection of a specific cleanup action.

GLOSSARY (CONTINUED)

Conceptual Site Model—A diagrammatic method of describing a hazardous waste site that identifies routes of contaminant migration, from contamination sources to human or environmental receptors.

Confined Aquifer—An aquifer overlain by low-permeability strata, such that the water level in a well drilled into the aquifer rises above the top of the aquifer.

Discharge Area—The location at which groundwater moves from an aquifer to the land surface or to a surface water body.

Downgradient—In a direction of decreasing groundwater flow potential, from an area of higher groundwater elevation to an area of lower groundwater elevation.

Driller's Log—A record of the geologic and aquifer conditions encountered by a driller during drilling of a water supply well. The State of Washington requires that a log be completed for each well.

Evapotranspiration—Loss of water due to the combined effect of evaporation and transpiration, the process by which plants give off water vapor through their leaves.

Feasibility Study (FS)—An evaluation of cleanup technologies and alternatives for a contaminated waste site, conducted in accordance with State or Federal regulations and guidelines; follows a Remedial Investigation (RI).

Geomembrane—A plastic sheet, typically made of high-density polyethylene (HDPE) or polyvinyl chloride (PVC), used as a hydraulic (water) or vapor/air barrier in environmental containment structures.

Geotextile—A permeable fabric sheet made of either woven or non-woven synthetic fibers, used as a protective cover for a geomembrane, a separation fabric between two soil layers, or a foundation layer to stabilize soft soils.

Groundwater Divide—A line separating two regions of diverging groundwater flow.

Groundwater Gradient—The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Hydraulic Evaluation of Landfill Performance (HELP) Model—A computer model developed by the USEPA that simulates water balance conditions and predicts leachate volumes generated at landfills and other waste sites. Variables such as precipitation, runoff, percolation, and evapotranspiration can be modified to depict site-specific conditions.

Hydraulic Conductivity—A coefficient of proportionality describing the rate at which water can move through a permeable medium.

Indicator Hazardous Substance—The subset of hazardous substances present at a site selected under WAC 173-340-708 for monitoring and analysis during any phase of remedial action for the purpose of characterizing a site or establishing cleanup requirements for that site.

Landfill—Includes the solid waste disposal area, the demolition waste disposal area, and the septage disposal area.

GLOSSARY (CONTINUED)

Landfill Property—The area encompassed by the Landfill Property boundary, including the Landfill, the transfer station, and all other facilities and features within the Property boundary.

Model Toxics Control Act (MTCA)—Washington State's laws governing the identification, investigation and assessment, and the cleanup and monitoring of hazardous substance release sites. Washington State Department of Ecology's authority to take action is defined by Chapter 70.105D RCW, and the rules describing when and how Ecology exercises that authority are published under Chapter 173-340 Washington Administrative Code (WAC).

On-site and Off-site—Areas on the Landfill Property and off the Landfill Property, respectively, as convenient references to areas of Landfill impacts. These terms should not be confused with "Site" as defined below.

Organic Chemicals—Generally, compounds containing hydrogen and carbon, i.e., hydrocarbons.

Partitioning—Separation of the molecules of a chemical in the presence of other chemicals.

Permeability—The relative ease with which a porous medium can transmit a liquid under a hydraulic gradient. It is a property of the porous medium and is independent of the nature of the liquid.

pH—A measure of the acidity or alkalinity of a substance, defined as the negative logarithm of the hydrogen ion activity at 25°C.

Potential Liable Party (PLP)—A person with potential liability for cleanup of a contaminated site in Washington State, by virtue of a past or present relationship the site, per RCW 70.105D.040. Ecology is required to notify PLPs of their potential liability, conduct research to assess the degree of liability, and render a determination of the liability.

PLP Group—The group of PLPs for the Hansville Landfill Property that consists of: Kitsap County, Washington; and Waste Management of Washington, Inc.

Potentiometric or Piezometric Surface—A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Preliminary Cleanup Level (PCL) — A cleanup level established for individual chemicals as part of the chemical screening process described in Chapter 8 of the RI report and Section 2.4 of this FS report. The term "preliminary" is used at the screening stage to acknowledge that "final" cleanup levels are established in this FS, and is consistent with correspondence from Ecology (2002).

Property —The area encompassed by the Landfill Property boundary, including the Landfill, the transfer station, and all other facilities and features within the Property boundary.

Putrescible—Composed of material that can be decomposed by bacteria.

Remedial Action—Any action or expenditure consistent with the purposes of Chapter 70.105D RCW to identify, eliminate, or minimize any threat posed by hazardous substances to human health or the environment, including any

GLOSSARY (CONTINUED)

investigative and monitoring activities, with respect to any release or threatened release of a hazardous substance and any health assessments or health effects studies conducted in order to determine the risk or potential risk to human health.

Remedial Investigation (RI)—An investigation of the sources, type, extent, and potential impacts to human health and the environment from contamination at a hazardous waste site. An RI is conducted in accordance with State or Federal regulations and guidelines, and precedes an FS.

Sampling and Analysis Plan (SAP)—A plan, developed in accordance with State or Federal regulations and guidelines, that specifies the objectives, rationale, methods, and procedures for collecting and analyzing samples at a hazardous waste site. The SAP is usually organized by media to be sampled (such as waste, soil, groundwater, surface water, sediments, and air).

Saturated Zone—The zone beneath the land surface in which water fills all pores at a pressure greater than or equal to atmospheric pressure.

Semi-Volatile Organic Compound (SVOC)—Organic chemicals that do not readily evaporate under atmospheric conditions and generally exhibit low solubility in water.

Site—The Hansville Landfill Property plus the estimated off-site extent of groundwater, surface water, and sediment impacts from the Hansville Landfill on Port Gamble S'Klallam Tribal property.

Study Area—Areas within and beyond the Site that are being investigated as part of this RI.

Total Petroleum Hydrocarbons (TPH)—Any fraction of crude oil that is contained in plant condensate, crankcase motor oil, gasoline, aviation fuels, kerosene, diesel motor fuel, benzol, fuel oil, and other products derived from the refining of crude oil.

Tribe—Port Gamble S'Klallam Tribe.

Upgradient—In a direction of increasing groundwater flow potential, from an area of lower groundwater elevation to an area of higher groundwater elevation.

Unconfined (Water Table) Aquifer—An aquifer which is only partially filled with water and in which the water table, or a surface in equilibrium with atmospheric pressure, forms the upper boundary.

Unsaturated Zone—The subsurface zone containing both water and air. The lower part of the unsaturated zone (capillary fringe) does not actually contain air, but is saturated with water held by suction at less than atmospheric pressure.

Vadose Zone—See "Unsaturated Zone."

Volatile Organic Compound (VOC)—Organic chemicals that readily evaporate under atmospheric conditions and are generally highly soluble in water.

Water Table—The level of underground water at which the hydraulic pressure equals atmospheric pressure.

1. INTRODUCTION

This Feasibility Study (FS) for the Hansville Landfill Site has been prepared in accordance with the Consent Decree entered into among Kitsap County, Kitsap County Sanitary Landfill, Inc. (KCSL) (now Waste Management of Washington, Inc.), and the Washington State Department of Ecology (Ecology) in October 1995. The Consent Decree sets forth the requirements for conducting a Remedial Investigation (RI) and FS at the Hansville Landfill Site located in north Kitsap County. The elements of work in the RI/FS are described in the Consent Decree Scope of Work and the Project Work Plan, both of which are incorporated into the Consent Decree.

The RI was conducted to characterize the physical features of the Site and the nature and extent of chemicals in groundwater, surface water, and sediments that may be attributed to waste disposal areas of the Landfill (Parametrix 2007). The RI identified chemicals in each medium to be addressed in the FS. The FS presents a risk assessment of these chemicals to select indicator hazardous substances, evaluates cleanup action alternatives, and recommends a preferred remedial alternative.

The following terminology is used throughout this report when referring to properties and areas associated with the Landfill:

- **Hansville Landfill (also referred to as "the Landfill")**: Refers to the solid waste disposal area, the demolition waste disposal area, and the septage disposal area (see Section 2, Figure 2-2).
- **Hansville Landfill Property (also referred to as "the Property")**: Refers to the area encompassed by the Landfill Property boundary (see Figure 2-2), which includes the closed disposal areas (solid waste disposal area, demolition waste disposal area, and septage disposal area), the transfer station, and all other facilities and features within the Property boundary. The closed disposal areas are generally defined by the limits of the final cover system constructed in 1989.
- **Hansville Landfill Site (also referred to as "the Site")**: Refers to the Hansville Landfill Property plus the estimated off-site extent of groundwater, surface water, and sediment impacts from the Hansville Landfill on Port Gamble S'Klallam Tribal property (see Figure 2-2). This definition is consistent with the definition of "Site" in the Consent Decree and Chapter 173-340 Washington Administrative Code (WAC) (Ecology 2001).
- **Study Area:** Refers to the Site and areas beyond the Site that were examined as part of the RI, generally including areas north of Little Boston Road NE and west of Hansville Road NE.
- **"on-site" and "off-site"**: Refers to areas on the Landfill Property and off the Landfill Property, respectively, as convenient references to areas of Landfill impacts. These terms should not be confused with "Site" as previously defined above.

1.1 PURPOSE AND OBJECTIVES OF THE FEASIBILITY STUDY

The purpose of this FS report is to develop and evaluate cleanup action alternatives, so that a cleanup action can be selected for the Site per the requirements of WAC 173-340-350 (Ecology 2001). This FS focuses on chemicals in groundwater, surface water, and sediment that were identified in the RI report (Parametrix 2007) as posing potential risks to human health and the environment.

The specific objectives of this FS are summarized as follows:

- Identify applicable or relevant and appropriate requirements (ARARs) pertaining to cleanup actions.
- Specify cleanup standards for affected media (surface water, groundwater, and sediment) that protect human health and the environment.
- Conduct a risk assessment to select indicator hazardous substances to be addressed in the remedial alternatives.
- Develop and evaluate remedial alternatives that reduce potential risks to human health and the environment from indicator hazardous substances originating in the disposal areas of the Landfill.
- Provide the information necessary to develop a Cleanup Action Plan (CAP) for the Site.
- Select a preferred remedy that achieves remediation levels; is practicable, reliable, proven, efficient, and cost-effective; and complies with applicable laws and Washington State Model Toxics Control Act (MTCA) regulations.

Under MTCA, a site evaluation and remedial action generally follow a process that depends upon the specifics for each site. This process is illustrated in Figure 1-1. The FS follows the RI and uses RI data to evaluate alternatives for remediating impacts from the Hansville Landfill.

1.2 REPORT ORGANIZATION

This report is organized into several chapters, briefly described below.

EXECUTIVE SUMMARY

Summarizes the FS.

Chapter 1: INTRODUCTION

States the purpose and objectives of the FS, and the relationship of the FS report to other elements in the overall cleanup of the Site.

Chapter 2: REMEDIAL INVESTIGATION SUMMARY

Summarizes findings of the RI. Presents an overview of Site conditions, including chemicals indicative of Landfill impacts (indicator hazardous substances) and their source(s), affected media, routes of potential chemical exposure, and chemical fate and transport. Also describes the extent of contamination and the effectiveness of existing Landfill controls.

Chapter 3: IDENTIFICATION OF APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

Identifies federal, state, local, and Tribal laws that may be part of the cleanup process. These ARARs are segregated into chemical-specific, location-specific, and action-specific categories.

Chapter 4: RISK ASSESSMENT

Presents an evaluation of risks to human and ecological receptors and recommends indicator hazardous substances to be addressed in the remedial alternatives analysis.

Chapter 5: CHARACTERISTICS OF CONTAMINANTS AND CONTAMINATED MEDIA

Describes the physical and chemical characteristics of the indicator hazardous substances in the affected media found at the Site.

Chapter 6: CLEANUP STANDARDS

Presents specific cleanup objectives for the Site. Also identifies a conditional point of compliance that considers the Site Boundary and the groundwater/surface water interface.

Chapter 7: TECHNOLOGY IDENTIFICATION AND SCREENING

Presents a range of remedial technologies that could be applied to the Site. Evaluates and screens these technologies to identify those that are best suited for the Site.

Chapter 8: DEVELOPMENT OF REMEDIAL ALTERNATIVES

Presents a range of remedial alternatives using the technologies identified in the previous section. These alternatives range from “no additional action” to complete waste removal with off-site disposal.

Chapter 9: EVALUATION CRITERIA FOR REMEDIAL ALTERNATIVES

Provides the framework for the evaluation of remedial alternatives. Introduces and discusses the evaluation criteria, as established by MTCA.

Chapter 10: DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

Provides a matrix evaluation of each alternative, resulting in a ranked hierarchy. The hierarchy is based primarily on environmental controls that are anticipated to be protective of human health and the environment. A secondary concern is cost, which is incorporated into the analysis for each alternative.

Chapter 11: CONCLUSIONS

Presents the findings and results of the FS.

Chapter 12: REFERENCES

APPENDICES –

A	Information from Washington State Department of Fish and Wildlife Priority Habitats and Species Database
B	Finfish Investigation Summary
C	Hydrologic Evaluation of Landfill Performance (HELP) Modeling Analysis
D	Alternative 3 – Gas Extraction System Enhancements Supporting Technical Documentation
E	Alternative 4 – Air Sparging Supporting Technical Documentation
F	Alternatives 5 and 6 – Groundwater Pump and Treat Supporting Technical Documentation
G	Cost Estimates for Remedial Alternatives
H	Letter of Support from the Port Gamble S’Klallam Tribe

2. REMEDIAL INVESTIGATION SUMMARY

The purpose of the RI was to determine the nature and extent of chemical impacts in groundwater, surface water, and sediment that may be attributable to the waste disposal areas at the Landfill, in a manner sufficient to support an assessment of the need for, and selection of, a cleanup action under WAC 173-340-360. The use of the word “sufficient” in this statement recognizes that a complete characterization of a site and full determination of the extent of chemical impacts in the environmental media is not achievable due to the complex structural dynamics of these natural systems. The Hansville Landfill RI report (Parametrix 2007) included the following investigations and evaluations:

- Waste source investigation,
- Landfill gas investigation,
- Groundwater investigation,
- Surface water investigation,
- Sediment investigation,
- Fish habitat assessment (including finfish), and
- A site-specific chemical screening and chemical fate and transport evaluation.

The focus of the RI was to investigate groundwater quality on the Landfill Property, as well as to investigate groundwater, surface water, and sediment quality downgradient on Tribal property. The evaluation of control systems for landfill gas (methane) on the Landfill Property was also part of the investigation. The RI chemical screening process identified chemicals for further evaluation in the FS. The results of the RI are briefly summarized in the following sections.

2.1 SITE BACKGROUND

The Site is located about 4 1/2 miles south of the community of Hansville, on the northernmost reach of the Kitsap Peninsula, approximately 4,000 ft east of Port Gamble Bay (Figure 2-1). The Site includes three primary areas: the Landfill, the Landfill Property, and adjacent downgradient Tribal property that has been impacted by the Landfill (Figure 2-2). Table 2-1 provides a brief summary of the history of the Landfill Property.

2.2 EXISTING SITE CONDITIONS

2.2.1 Closed Landfill Cells

The three disposal areas at the Landfill (the solid waste disposal area, demolition waste disposal area, and septage disposal area) were closed and capped in 1989. The engineered cover system placed over each of these areas is composed of seven layers, including a combination of soil, gravel, a high-density polyethylene (HDPE) liner, and a final layer of hydroseeding (Figure 2-3). The final cover system was designed to minimize leachate production and mitigate potential environmental and public health impacts associated with the closed Landfill.

2.2.2 Active Landfill Gas Extraction and Flaring System

The gas extraction and flaring system at the Landfill has five main components, designed to extract gas from the Landfill and adjacent subsurface soils, and to prevent the migration of gas beyond the Landfill boundary. These components include:

- Interior Landfill gas extraction wells and trenches (installed in refuse),
- Perimeter gas extraction wells located in native soil adjacent to the solid waste disposal area,
- Perimeter gas monitoring probes located near the Landfill Property boundary,
- Motor blower/flare facility to extract and combust the collected Landfill gas, and
- Condensate collection system.

Several modifications to the gas extraction system have been completed since the initial installation in 1989, in response to a Bremerton-Kitsap County Health District (BKCHD; now known as Kitsap County Health District, KCHD) request for corrective action to address vinyl chloride in groundwater. The first modification to the gas system was to change from a passive to active extraction system. Results of monthly monitoring conducted since 1989 show that Landfill gas migration has been controlled by the active gas system. The monitoring data also show that methane gas has not been detected in any of the perimeter gas monitoring probes since December 1992. In 2003, a downsized flare was installed to handle the decreased volume of gas generated by the solid waste disposal area.

2.2.3 Transfer Station

A transfer station operated by Kitsap County is located on the northeast portion of the Landfill Property. This Facility now operates as a drop box, accepting recyclables and self-hauled residential waste from the north end of Kitsap County.

2.3 HYDROLOGIC SYSTEM

Field investigations of groundwater and surface water conditions on the Site confirm the following physical system:

- The uppermost zone of groundwater beneath the Site occurs in a sand unit and forms the Upper Aquifer, which is 80 to 120 ft thick beneath the Site. Depths to groundwater range from 50 to 100 ft below ground surface, approximately 45 to 55 ft below the lowest depth of solid waste.
- Groundwater in the Upper Aquifer flows to the west and southwest and discharges along the outcrop of the Upper Aquifer, on the hillside west of the Landfill. This discharge creates the headwaters of streams that generally flow westward to Port Gamble Bay.
- The Upper Aquifer is underlain by a low-permeability clay unit known as the Kitsap Formation, a regionally extensive aquitard that greatly restricts downward vertical migration of groundwater to the Salmon Springs Formation, a regional aquifer (Lower Aquifer) used for water supply. The Kitsap Formation is approximately 150 ft thick beneath the Landfill.

2.4 CHEMICAL SCREENING

Groundwater, surface water, and sediment data collected during the RI were evaluated by means of a screening process in Chapter 8 of the RI report (Parametrix 2007). The first step in the screening process was to identify potentially applicable ARARs. Preliminary cleanup levels (PCLs) for each of the three environmental media were then established using the lowest ARAR for each chemical.

A second screening table for each medium was created to compare PCLs to downgradient sampling results, background data (surface water and sediment), and frequency of detection criteria. Site-specific background data were not applied to the groundwater screening process because insufficient data were available to establish background levels per Ecology requirements. An exception was arsenic, for which a state background concentration was used for comparisons (Ecology 2004). The background concentrations for organic chemicals and metals that were not analyzed in background samples were assumed to be zero, which is a conservative approach for metals.

For surface water, a range of background concentrations was obtained from two sampling events at adjacent drainages to the south and north of downgradient creeks. These background sampling stations were selected, in coordination with Ecology and the Port Gamble S'Klallam Tribe, as having (1) the same basic characteristics as headwaters of small streams originating as discharge from the Upper Aquifer, (2) locations outside of any potential influence from Landfill chemical releases, and (3) no apparent influence by chemical releases from other localized human activities.

Background sediment samples were collected in April 1997 from the same streams where background surface water was collected, using the same sampling station selection criteria. Because the data for background surface water and background sediment are limited, a statistical background value was not calculated for each chemical, and downgradient samples were compared to the range of background concentrations.

Frequency of detection was also calculated for each chemical detected in groundwater and surface water. Those chemicals that were detected in less than 5 percent of downgradient samples were removed from consideration as potential indicator hazardous substances (Ecology 2002; USEPA 1989). Because fewer than 20 downgradient freshwater sediment samples were collected, there was no possibility of a frequency of detection of 5 percent or less, so frequency of detection was not a screening factor for freshwater sediment.

The chemical screening results are summarized by medium in Table 2-2. The following chemicals will be further assessed in this FS report: antimony, arsenic, bis(2-ethylhexyl)phthalate, chromium, copper, lead, manganese, nickel, nitrate, silver, zinc, and vinyl chloride. Concentrations of all chemicals discussed in this FS report are expressed in milligrams per liter (mg/L) or milligrams per kilogram (mg/kg), a convention that was applied to the RI report.

2.5 CONCEPTUAL SITE MODEL

A conceptual site model was developed for the Hansville Landfill Site and is presented in Chapter 9 of the RI report. The conceptual site model illustrates the occurrence and migration of indicator hazardous substances from the source areas of the Landfill to potential human and ecological receptors. The conceptual model identifies potential primary and secondary sources, release mechanisms, exposure pathways, and receptors. This section briefly summarizes the components of the RI conceptual site model that describe primary and secondary sources of contamination at the Landfill. The conceptual site model is included in

Chapter 4 of this FS report (Risk Assessment) as Figure 4-3. It should be noted that the conceptual site model does not differentiate between pre- and post-closure conditions at the Landfill. Some of the source and release mechanisms identified have been significantly reduced or eliminated by source central activities such as landfill closure, engineered cap, and landfill gas extraction and flaring system, already constructed at the Landfill.

2.5.1 Primary Contaminant Sources

The primary sources of contaminants at the Landfill are the three waste disposal areas: 13-acre municipal solid waste, 4-acre construction/demolition waste, and 1/3 acre domestic septage disposal areas. There is little documentation available regarding the characteristics of wastes disposed at the Landfill. Waste characteristics were developed based on limited Site history and studies of solid waste at other landfill sites. Typical waste materials are summarized in Table 2-3 and described in detail in the RI report (Parametrix 2007).

2.5.1.1 Release Mechanisms for Primary Contaminant Sources

Landfill Gas

Landfill gas is formed by the decomposition of municipal refuse. Landfill gas at the Hansville Landfill is primarily generated in the 13-acre municipal solid waste disposal area, and to a much lesser extent in the demolition waste and septage waste disposal areas. This is confirmed by the monitoring of gas probes at the Landfill, which have historically detected landfill gas only in the immediate vicinity of the solid waste disposal area.

Landfill gas is primarily composed of methane and carbon dioxide in typical proportions of 55 percent and 40 percent, respectively, and can include volatile organic compounds (VOCs) present in the waste materials or produced through the natural decomposition of waste materials. The RI identified vinyl chloride as the only indicator chemical in landfill gas at the Landfill.

Vinyl chloride can be released from landfill gas to soils and/or groundwater beneath the landfill by convection, diffusion, and gas condensate. Prior to the installation of the active landfill gas system at the Hansville Landfill, vinyl chloride may have been released to the groundwater and soil surrounding the Landfill by a combination of all three mechanisms.

Infiltration/Percolation

Landfill leachate was formed during operation of the solid waste and demolition waste disposal areas by infiltration of precipitation through landfilled materials and by gravity drainage of septage from the lagoon disposal area. When disposal was terminated, the engineered cover system (installed in 1989–90 over the three disposal areas) was designed to achieve a 99 percent reduction in infiltration and leachate generation, while virtually eliminating infiltration of precipitation into the waste materials. However, gravity drainage of the remaining leachate within the Landfill units will continue at a decreasing rate over time until drainable moisture within the disposal area is depleted. See Section 8.2.1 for additional data regarding predicted leachate releases.

Surface Water Runoff

During the operation of the Landfill, surface water runoff from exposed disposal areas flowed downslope from these areas. Given the high permeability of the sandy surficial soils, most of the localized runoff from the Landfill likely infiltrated into the adjacent soils. Runoff from the northeasterly portion of the Landfill was directed to a topographic depression on the northeast side of the solid waste disposal area. Runoff from the remainder of the solid waste disposal area was directed to the sedimentation basin located west of this disposal area. Surface water runoff from any exposed waste was eliminated when the Landfill was capped in 1989–90. Current drainage over the closed Landfill area is primarily directed to the sedimentation pond on the west side of the solid waste disposal area.

2.5.2 Secondary Contaminant Sources

Secondary contaminant sources are soils in the unsaturated zone beneath the Landfill that have received infiltration of landfill leachate and migration of landfill gas during the operational life of the Landfill. After the Landfill was capped and the gas control system was installed, rainwater infiltration, leachate generation, and migration of gas from the Landfill were significantly reduced. Ongoing gravity drainage of residual leachate from the Landfill results in diminishing migration of leachate into the unsaturated zone. Minor amounts of landfill gas may continue to be present in the unsaturated zone beneath the Landfill. Loading of contaminants to groundwater via secondary containment sources will continue to decrease over time as the contaminant mass is depleted.

2.6 BOUNDARIES OF LANDFILL IMPACTS

The RI report provided sufficient information to delineate the area of impacts from the Landfill. The groundwater flow system characterization confirmed that groundwater in the Upper Aquifer is separated from the deeper regional Lower Aquifer by the laterally extensive clays of the Kitsap Formation. Groundwater in the Upper Aquifer flows to the west and southwest and discharges to the headwaters of creeks downgradient of the Landfill on Tribal property. These zones of discharge provide a direct means of evaluating groundwater discharge concentrations.

The distribution and trends of representative chemicals documented in the RI report demonstrate that chemical concentrations in groundwater and surface water have decreased over time, and that the extent of the Landfill impacts are stable or decreasing. These data indicate that the remedial actions (engineered cover, landfill gas extraction and flaring system, and stormwater drainage system) are working as designed, and that Landfill impacts will continue to decrease over time.

Figure 2-2 shows the estimated extent of groundwater and surface water impacts from the Landfill, based on the distribution of indicator hazardous substances presented in the RI report. This area is roughly bounded by the Landfill Property boundary to the east, the observed extent of groundwater impacts to the north (monitoring well MW-7 and surface water station SW-7) and south (monitoring well MW-11 and surface water station SW-3), the outcrop of the Kitsap Formation, and documented extent of downstream surface water impacts to the west.

3. IDENTIFICATION OF ARARs

This chapter presents the proposed applicable or relevant and appropriate requirements (ARARs) and the “to-be-considered” regulations (TBCs) that are identified for remediation of the Site. The intent is to identify potential ARARs to be used to evaluate remedial alternatives.

WAC 173-340-710 (1) specifies that site cleanup actions shall comply with “applicable state and federal laws.” This term includes legally applicable requirements and those requirements determined by Ecology to be relevant and appropriate. Legally applicable requirements include those cleanup standards, standards of control, and other environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, contaminant, remedial or cleanup action, location, or other situation at a site. Relevant and appropriate requirements are those promulgated under federal and state law that are not directly applicable, but still address problems or situations sufficiently similar to those encountered at the site that their use is well suited to the particular site.

ARARs are determined on a case-by-case basis for each site. Ecology makes the final interpretation as to whether ARARs are correctly identified and are legally applicable or relevant and appropriate. TBCs are advisory or guidance documents that are not legally binding and do not have the same status as ARARs. However, TBCs may be used in evaluating the cleanup alternatives and are included in the evaluation of ARARs.

The MTCA cleanup regulation identifies three categories of ARARs: chemical-specific, location-specific, and action-specific. These ARARs are presented in Tables 3-1, 3-2, and 3-3, respectively.

- Chemical-specific ARARs include those laws and regulations governing the release to the environment of materials possessing certain chemical or physical characteristics, or containing specific chemical compounds. These requirements include groundwater cleanup standards and surface water quality criteria.
- Location-specific ARARs are those requirements that relate solely to the geographical location or physical position of the site.
- Action-specific ARARs are requirements that define acceptable containment, treatment, storage, and disposal procedures. These requirements are triggered by the particular activities that are selected to accomplish a cleanup.

4. RISK ASSESSMENT

A process of chemical screening was applied in the RI report (Parametrix 2007) to select indicator hazardous substances for further consideration in the FS. This process was applied to chemicals detected downgradient of the Landfill in samples from groundwater monitoring wells, groundwater discharge areas, small creeks west of the Landfill (i.e., surface water), and sediments from the same groundwater discharge areas and creeks (Figure 4-1).

An overview of the chemical screening and risk assessment process is presented in Figure 4-2. The data used in the chemical screening and risk assessment was collected during the following sampling periods: the original four quarters of RI monitoring, Ecology-directed monitoring that occurred after the end of the RI monitoring (November 1996 through January 2004), and other surface water and sediment monitoring events, including sampling designed to establish surface water and freshwater sediment background concentrations. All data were collected in accordance with the Ecology-approved Sampling and Analysis Plans.

The screening and risk assessment process was developed through extensive discussions with Ecology, KCHD, the Port Gamble S'Klallam Tribe, Kitsap County, and Waste Management of Washington, Inc. The process incorporates recent correspondence from Ecology's Project Manager regarding the approach for completing the RI report (Ecology 2002, 2003, 2004, 2005). The methodology and assumptions incorporated in this screening and risk assessment process are conservative, in that chemical standards and/or some exposure scenarios were considered that have a low probability of occurrence. Consequently, this screening and risk assessment process provides results that reflect a high degree of protection of human health and the environment.

The chemicals identified as indicator hazardous substances during the RI chemical screening process are presented in Table 4-1. During the RI chemical screening process, the lowest cleanup level from all available cleanup levels, ecological or human health-based, was selected to screen each chemical. In the FS risk assessment, only chemicals exceeding cleanup levels for human health were examined for human health risk, and only chemicals exceeding ecological cleanup levels were evaluated for ecological risks.

If a chemical exceeded an ecological cleanup level but not a human health cleanup level, it was only evaluated for ecological health, and vice versa. Table 4-1 summarizes the chemicals that were evaluated by receptor (human or ecological). The remainder of the risk assessment was divided into a human health risk assessment and ecological risk assessment, and each concentrated only on those chemicals that correspondingly exceeded receptor-specific PCLs.

4.1 HUMAN HEALTH RISK ASSESSMENT

The human health risk assessment was completed consistent with the requirements identified in the Project Work Plan (Parametrix 1995) and the MTCA regulations WAC 173-340-708. For human health, potential current and future risks to the local population were evaluated for contact with all environmental media for several different scenarios:

- Consumption of on-site and off-site groundwater as a drinking water source,
- Consumption of off-site surface water as a drinking water source, and
- Recreational contact with off-site surface water and sediment.

Please note that the use of the terms "on-site" and "off-site" are used for convenience and refer to areas within and outside of the Landfill Property boundary, respectively. These terms are defined in the Glossary section at the front of this report.

These scenarios, which were specified for evaluation by Ecology, are very conservative (i.e., protective) exposure scenarios that may not reflect actual exposure conditions due to the marginal characteristics of the Upper Aquifer and the local creeks as a potential water supply such as low yield, shallow depth, and susceptibility to non-landfill originated contamination, and the presence of a public water supply. Actual use of these waters as drinking supplies or for recreation is considered unlikely.

Consistent with the requirements of WAC 173-340-708, specific exposure pathways for chemicals released from the Hansville Landfill were identified for current- and future-use scenarios. Environmental media affected by on-site releases include:

- Groundwater in the Upper Aquifer, and
- Air.

As discussed in Section 2.2 (Existing Site Conditions), the disposal area cover system prevents contact of waste materials with stormwater runoff; therefore, an on-site surface water exposure pathway does not exist.

Off-site environmental media of concern include:

- Groundwater in the Upper Aquifer,
- Air,
- Surface water, and
- Sediment.

Exposure pathways associated with each of these affected media are further discussed below and shown on the conceptual site model presented in Figure 4-3.

4.1.1 On-Site Human Health Exposure Pathways of Concern

Only complete exposure pathways are of concern in any risk assessment. For a pathway to be considered complete, each of the following key elements must be present: (1) a potential for chemical contamination in the exposure medium of interest (sediment, water, etc.); (2) a potential for human contact (intake) and/or known contact with the exposure medium; and (3) a route of entry into the body. If any of these key elements are not present, then the exposure pathway is considered incomplete. The completeness of the identified exposure pathways is discussed in the sections below.

4.1.1.1 On-Site Groundwater Exposure Pathways

Water supply wells that draw water from the Upper Aquifer do not occur within the Site boundaries (Parametrix 2007). An existing water supply well at the Landfill Property obtains water for non-potable use from the deeper regional aquifer (Lower Aquifer) that is separated from the Upper Aquifer by the Kitsap Formation clay unit (Parametrix 2006). Therefore, direct contact exposures of humans (ingestion, dermal contact, inhalation of volatiles) to groundwater beneath the Site are not occurring now, nor is this anticipated to change in the future. However, the use of groundwater from the Upper Aquifer as a potable source cannot be definitively ruled out in the future. Therefore, this pathway was considered to be complete and was conservatively evaluated in the risk assessment.

4.1.1.2 On-Site Air Exposure Pathways

As discussed in Chapter 4 of the RI report, Landfill Gas Investigation, landfill gas migrated into the soils surrounding the Landfill. This migration may have extended beyond the Landfill Property boundary. Since the active gas system was activated, it has proven effective in removing landfill gas from the surrounding soils and controlling landfill gas migration.

The active gas control system effectively removes gas generated within the Landfill and destroys the gas in a combustion flare. Accordingly, there is no inhalation pathway based on passive vapor migration and no completed human health exposure pathways for landfill gas currently existing on-site. Therefore, the Landfill gas does not present any health risks for maintenance workers or other on-site personnel.

With ongoing Site inspections, Landfill Property access restrictions, and the continued operation of the landfill gas control system, exposure conditions will not change in the future. Accordingly, there would be no potential for human contact with landfill gas constituents, and this pathway is also considered incomplete for on-site maintenance workers or other personnel and trespassers who may visit the Site.

4.1.2 Off-Site Human Health Exposure Pathways of Concern

Land use of adjacent properties was discussed in Section 2.5 of the RI report. Bordering the Landfill Property to the south and west is the Port Gamble S'Klallam Tribal Property. Surrounding the Landfill to the north, south, and east are areas that are currently zoned rural protection, interim rural forest, or industrial. At present, these areas are sparsely developed, with the nearest permanent private residence located approximately 1,500 ft east and upgradient of the Landfill. The industrial land to the east includes an industrial park and an inert landfill and commercial compost operation approved by the KCHD.

With the exception of the Tribal Property, future residential development around the Landfill Property is not expected. It is anticipated that future housing developments may be built southwest of the Landfill Property in the vicinity of Little Boston Road NE, where access to utilities is available, including the existing water supply wells in the Lower Aquifer.

4.1.2.1 Off-Site Groundwater Exposure Pathways

The general direction of off-site contaminated groundwater flow in the Upper Aquifer is west/southwest. The following is a summary of the locations and number of water supply wells in the vicinity of the Landfill that could potentially be affected.

Current water supply wells within 1 mile of the Landfill, based on data in Ecology records, are shown in Figure 4-4. All but seven of these wells obtain their water from the Lower Aquifer. There are numerous water-bearing zones occurring within the Salmon Springs Formation that collectively form the regional Lower Aquifer in the vicinity of the Site. The Lower Aquifer is separated from the Upper Aquifer by the Kitsap Formation, a low-permeability clay unit that is typically over 100 ft thick in the Study Area (Parametrix 2007). The hydraulic separation between the Upper and Lower Aquifers beneath the Landfill and the vicinity of the Landfill is documented in Chapter 5 of the RI Report (Parametrix 2007).

The seven wells mentioned in the preceding paragraph draw their water from the Upper Aquifer, but are located upgradient or across a groundwater divide with respect to the Landfill. There is, therefore, no complete off-site human health exposure pathway for Landfill contaminants to people using these domestic water wells completed in the Upper Aquifer.

For wells located between 1 and 3 miles from the Landfill, a review of the driller's logs indicated approximately 15 wells are completed in the Upper Aquifer (Parametrix 2007). All of these wells exist northeast or southeast of the Landfill, which is upgradient or cross-gradient of groundwater contamination associated with the Landfill. The remaining inventoried wells are completed in the Lower Aquifer. This includes the two active Tribal water supply wells located in the Little Boston Area (wells 8A1 and 8A2; see Figure 4-4). Wells 8A1 and 8A2 provide drinking water for all Tribal facilities and housing, including the casino and store (Fuller 2006).

In summary, the inventory and evaluation of water wells within 3 miles of the Landfill demonstrates that none of the wells completed in the Upper or Lower Aquifers are hydraulically connected to off-site contaminated groundwater flow in the Upper Aquifer. Therefore, there is no complete pathway of exposure to chemicals in groundwater associated with the Landfill at the present time.

If drinking water wells within the Upper Aquifer downgradient of the Landfill were to be installed by the Tribe or others in the future, a human health exposure pathway to chemicals is possible. Accordingly, this pathway will be considered complete and a risk assessment performed. Nevertheless, the likelihood of drinking water wells being installed in the Upper Aquifer between the Landfill Property boundary and the points of discharge to the west is unlikely for the following reasons:

1. The Upper Aquifer is too shallow and unprotected from surface activities to represent a reliable sanitary water source. The formation within which the Upper Aquifer occurs is composed of sand from the ground surface through its entire thickness. No low-permeability layers of silt or clay are present above the water table to inhibit migration of contamination sources associated with site developments such as roads, animal feed lots, septic systems, and fuel storage tanks. The depth to groundwater in the Upper Aquifer decreases to the west, from Hansville Road NE to Port Gamble Bay. As the depth to the water table decreases, the potential for adverse impacts from surficial contamination sources increases.
2. There is a better water source (i.e., an aquifer that is more protected and yields more water) at a reasonable depth below the Upper Aquifer. The Lower Aquifer, which is most commonly used for regional groundwater supply, occurs beneath the Kitsap Peninsula, and has been observed beneath the Landfill Property. If future water wells are ever proposed for the area west of the Landfill Property, they would likely be cased through the Upper Aquifer and completed in the Lower Aquifer, to obtain the yield to consistently serve domestic water supply needs.
3. Washington State Law, in particular Subsection 205 of Chapter 173-160 WAC (Construction and Maintenance of Wells), prohibits water supply wells from being located within 1,000 ft of the property boundaries of solid waste landfills. The purpose of this regulation is to prevent water wells from intercepting groundwater impacted by landfills. The 1,000-ft distance provides a buffer zone for water supply wells that might encounter undiluted groundwater contamination immediately downgradient of a landfill, and for pumping wells that might induce contaminated groundwater to flow towards those wells. This regulation applies to non-Tribal property; however, the Tribe may choose to adopt similar institutional control measures as a matter of Tribal law.
4. Wetland areas between the Landfill Property boundary and the stream heads to the west (see Figure 4-1) would not likely be selected locations for development or locations to establish a water supply.

Again, because development of water supply wells in the Upper Aquifer by the Tribe cannot be definitively ruled out in the future, a human health exposure pathway to off-site groundwater was conservatively assumed possible and evaluated.

4.1.2.2 Off-Site Air Exposure Pathways

Municipal solid waste landfills such as the Hansville Landfill generate gas from bacterial decomposition of organic matter in the solid waste. Landfill gas is composed primarily of methane, but can also contain volatile organic chemicals if present in the solid waste. If uncontrolled, landfill gas can migrate in permeable soils away from a landfill and discharge to the atmosphere at locations off the landfill property. Washington State landfill regulations require control of landfill gas.

A passive landfill gas venting and flaring system was installed at the Landfill as part of Landfill closure in 1989. Monitoring data collected in early 1991 indicated that gas migration away from the Landfill was occurring. An active landfill gas extraction and flaring system was subsequently installed and became operational in November 1991. The system was modified in 1994 and 2003 to address reduced concentrations of landfill gas, which had been significantly depleted by the active system. Monitoring of the system and perimeter gas probes has confirmed that prior gas migration has been pulled back by the extraction system and that gas migration beyond the extraction system boundary has been prevented.

Landfill gas produced within the solid waste disposal area is currently collected and combusted in the active flare system, and this process will continue in the future. Thus, any future exposure potential for the local population is eliminated beyond the Landfill Property boundary, and the pathway is considered incomplete.

4.1.2.3 Off-Site Surface Water Exposure Pathways

Drinking Water Pathway

The creeks located west of the Landfill Property boundary are not currently used as a drinking water source because they are shallow and intermittent. However, future use of the creeks for drinking water by the Tribe, though unlikely, cannot be ruled out, and this pathway was conservatively considered complete and evaluated. It should be noted, however, that the creeks would not be a desirable source of drinking water due to their vulnerability to bacterial contamination, low flow rates, and for some creeks, the intermittent nature of the flow regimes (Creeks A and B). For example, fecal coliform bacteria counts were found in RI surface water samples above 50 per 100 mL and are most likely attributable to area wildlife. The presence of fecal coliform bacteria would render this untreated water unfit for use as a drinking water supply.

Fish Consumption Pathway

The following paragraphs discuss the current situation in the upper reaches of the three creeks downgradient of the landfill (Creeks A, B, and Middle Creek), where Landfill impacts to surface water from discharging groundwater have been documented, and the lower reach of Middle Creek, a location of current and potential future fish habitat.

In the immediate vicinity of the Landfill, the upper reaches of Creeks A and B are not currently, nor are they expected to be in the future, suitable for supporting edible species of fish based on their intermittent flow, as discussed further in the RI report (Section 6.3.4 and Appendices N and Q; Parametrix 2007). The upper reaches of Middle Creek nearest and intermediate to the Landfill boundary do not currently support, nor are they expected to in the future, fish of a size that would be consumable by humans (i.e., only juvenile species occur), and thus a fish consumption pathway for the local population in these locations is considered an incomplete present pathway.

Downstream of surface water station SW-5 on Middle Creek, adequate habitat to support juvenile and adult resident fish (versus larger migratory fish) was noted during the RI. However, resident adult fish include only species such as sculpins (*Cottidae*) and three-spine stickleback (*Gasterosteus aculeatus*), neither of which are considered an edible species or of a size (a few inches typically) to be considered edible. Only small (4 to 5 in.) salmonids (i.e., cutthroat trout [*Oncorhynchus clarki clarki*] or other salmon species) can be supported by the habitat in the upper reaches of the creeks due to lack of water depth and natural habitat features. These fish would also not be of a consumable size. Therefore, fish consumption is not currently a beneficial use of Middle Creek, though salmonid rearing could be.

Future options for enhancing the lower reach of Middle Creek (near Port Gamble Bay), to provide rearing habitat and support for juvenile salmonids, have been identified by the Tribe. However, a fish consumption pathway under a future development option was initially considered incomplete in this lower reach of Middle Creek. This is because juvenile salmonids would be reared in a portion of the creek that is not currently affected by Landfill discharges, and the juvenile salmonids would not be of a consumable size prior to their release into Port Gamble Bay, where they would complete their life cycle. Based on this information, the human fish consumption pathway was initially considered an incomplete exposure pathway in all of the off-site creeks.

However, Ecology’s Water Quality program has determined that there is a potential to support fish populations in the future by means of engineered stream enhancements in the upper and lower reaches of the three creeks. For example, channel deepening and habitat enhancement in the upper stream reaches could allow fish rearing in areas where Landfill impacts have historically been present. If these improvements are combined with habitat enhancement in the lower reaches of these streams (where juvenile species can grow to consumable size, then a fish consumption exposure pathway is feasible. Therefore, fish consumption in the lower reaches of Creek A, Creek B, and Middle Creek is further examined as a potential complete pathway in Section 4.1.3.4 of this FS report, and is shown on the conceptual site model (Figure 4-3).

Dermal (Skin) Contact and Incidental Ingestion Pathways

As indicated previously, groundwater of the Upper Aquifer downgradient of the Landfill Property is hydraulically connected to Middle Creek, Creek B, and possibly to Creek A. Creek C is not hydraulically connected to groundwater from the contaminated portion of the Upper Aquifer, because this creek is located cross-gradient of the Landfill with respect to groundwater flow. The relationship of Landfill impacts to the creeks is illustrated by the attached map (Figure 4-5). Therefore, with the exception of Creek C, there is a potential for the local population to come into contact with Landfill-derived chemicals in the creek surface waters.

The completed pathways of human exposure to surface water (see Figure 4-3) are incidental surface water ingestion and surface water dermal (skin) contact, which could occur during recreational activities such as wading or splashing in the creeks. Given the very shallow and intermittent nature of these creeks, full-body contact from swimming is not considered a viable activity for adults or children, which reduces the potential for human exposure. The completed recreational exposure pathway for off-site surface water is presented in Section 4.1.3.3 of this FS report.

Volatile Inhalation from Surface Water Pathway

Though potentially a complete exposure pathway, inhalation of volatiles from surface water was considered a complete but minor exposure pathway in this assessment (see Figure 4-3) due to the very low observed concentrations of vinyl chloride and the high ambient dilutions with air that would be expected to occur prior to inhalation. Therefore, inhalation of volatile compounds in outdoor air is typically not examined under MTCA. The outdoor pathway would therefore likely not contribute substantially to human exposure from recreational activities and was not further evaluated for these types of activities. Volatile inhalation from indoor air was conservatively evaluated in Section 4.1.3.1 of this report considering the potential use of the creeks as a drinking water source, and the potential volatilization of vinyl chloride when this water is exposed to indoor air. The results of this evaluation concluded that this pathway was insignificant.

4.1.2.4 Off-Site Sediment Exposure Pathways

Hydraulic connections between contaminated groundwater in the Upper Aquifer and the surface water and sediments of Middle Creek, Creek B, and possibly Creek A suggest that sediment exposure pathways may be possible for individuals using the creeks now or in the future. Sediment contact with skin or incidental sediment ingestion from recreational activities such as wading or playing were both considered possible exposure pathways, now and in the future, because of access potential from residential areas.

The methods used to estimate health risks, and the resulting risk estimates for each medium and complete human health exposure pathway are discussed below in Section 4.1.3. Exposure potential and risk estimates are discussed only for those chemicals passing through the chemical screening (see Table 2-2).

4.1.3 Risk Analysis for Complete Human Health Exposure Pathways

Potential risks from chemicals passing through the initial screening (see Tables 4-2a, 4-2b, 4-3a, 4-3b, 4-4a, and 4-4b) were evaluated quantitatively for the following media and complete exposure pathways:

- On-site and off-site groundwater: drinking water consumption;
- Off-site surface water: drinking water consumption, recreational contact (i.e., incidental ingestion or dermal contact) and fish consumption; and
- Off-site sediments: recreational contact (i.e., incidental ingestion or dermal contact).

General methods used in conducting the human health risk assessment for these pathways follow.

4.1.3.1 Summary of General Methods

The risk assessment used the equations and parameters specified in WAC 173-340-708 to estimate the potential health risks associated with the use of groundwater and surface water as drinking sources[1]. Examination of groundwater or surface water used as a drinking water

---

[1] Non-cancer risks for these pathways can be calculated from doses using the MTCA equations, or (more simply) by taking the ratio of the 95 percent UCL mean concentration (provided in each risk table) to the Method B cleanup level. For carcinogens, the cancer risks can be calculated from doses using the MTCA equations, or (more simply) by taking the ratio as described for non-cancer risks and multiplying it by 0.000001 (1×10^{-6}). The latter expresses the risk quotient as a unitless probability of contracting cancer.

source included an inhalation correction for volatile chemicals (i.e., vinyl chloride) to account for inhalation exposure as specified in WAC-173-340-708. The latter pathway was evaluated consistent with recommendations identified in Technical Memorandum No. 7, Appendix Q, of the RI Report (Parametrix 2007), which describes the approach for use in evaluating the creeks as a drinking source. Other exposure pathways evaluated for human health (i.e., recreational exposure scenarios for surface water and sediment) followed risk assessment guidance from USEPA (1989) only when Ecology guidance was not available, and WAC 173-340. Equations and parameters used to estimate risk for groundwater and surface water drinking water pathways (and their reference sources) and recreational pathways are shown in Table 4-5.

Exposure concentrations used in the risk assessment were generally represented by the upper 95 percent confidence limit on the arithmetic mean concentration (UCL) for each chemical having at least a single detection at a sampling location (groundwater, surface water). In some cases, where an insufficient number of data points were available for calculating the UCL at a sampling location, a maximum concentration was used. Results tables indicate whether risks are based on a 95 UCL mean concentration or a maximum concentration. For groundwater, risks were evaluated on a well-by-well basis. For surface water, a potential drinking water exposure pathway at Middle Creek was evaluated at the specific surface water stations agreed upon with Ecology (Parametrix 1998a and Parametrix 2007).

Toxicity values and toxic endpoints used in the risk assessment were taken from the Integrated Risk Information System (USEPA 2005b). In the human health risk assessment, two types of general toxicity endpoints were evaluated: cancer and non-cancer effects. For the non-cancer endpoint, more specific target effects were considered for assessing additive (multiple) chemical risk, while for carcinogenic chemicals all cancer endpoints were considered additive. Table 4-6 identifies the toxicity values for non-cancer and cancer endpoints, including the target non-cancer effect for each chemical evaluated in the risk evaluation.

In identifying chemicals that may be posing unacceptable cancer risks, comparisons of estimated cancer risks were made to the benchmark 1×10^{-6} probability of contracting cancer for individual cancer-causing chemicals, and 1×10^{-5} where more than one cancer-causing chemical was present in the environmental medium evaluated. These benchmark risk levels are consistent with those identified in MTCA (Method B cleanup levels). A cancer risk benchmark of 1×10^{-5} equates to one additional person contracting cancer for every 100,000 exposed people. The cancer risk benchmark of 1×10^{-6} equates to one additional person contracting cancer per every one million exposed people.

For individual non-cancer-causing chemicals, a hazard quotient of 1.0 was established as the risk benchmark (Ecology 2001). In cases where more than one chemical shares a similar (non-cancer) target endpoint[2], the risk benchmark is called a hazard index and a benchmark value of 1.0 is also used. In either case, an exceedance of the non-cancer benchmark does not automatically imply that health risks will occur, because the toxicity reference values do not have equal accuracy or precision and are not based on the same severity of toxic effects (USEPA 1989, page 8-11).

---

[2] In the risk evaluations in this section, chemicals with similar toxic endpoints were assessed cumulatively as recommended by Ecology (2004). However, it should be noted that, in general, risk evaluation practice calls for considering the mode of toxic action in considering additive toxic effects, rather than similar toxic endpoints as is called for in the MTCA regulations (WAC 173-340-720), cited by Ecology (2001).

Typically, the significance of the exceedance is evaluated relative to the uncertainties inherent in the derived reference toxicity value. These uncertainties are accounted for in the toxicity value through the incorporation of safety factors, which are frequently large (1,000 and greater for many chemicals). Accordingly, in some situations where an exceedance of the hazard quotient benchmark of 1.0 is identified, the risk assessment may ascribe little significance to the exceedance and indicate that health risks would not be expected to occur. This is most often the case for hazard quotients at or below a value of 5 for chemicals where uncertainty is considered high in the toxicity value.

Chemicals were identified as indicator hazardous substances if a chemical exceeded the MTCA risk benchmark (cancer or non-cancer) for a particular medium. Results of the human health evaluation for groundwater, surface water, and sediments follow.

4.1.3.2 Human Health Risk Assessment Results for On-Site Groundwater

Human health risks from the consumption of on-site groundwater were evaluated on a well-by-well basis for antimony[3], arsenic, bis(2-ethylhexyl)phthalate, copper, lead, manganese, nickel, nitrate, silver, vinyl chloride, and zinc. Results of the consumption evaluations for on-site groundwater are shown for non-cancer and cancer endpoints, respectively, in Tables 4-7a and 4-7b. As shown in Table 4-7a, exceedances of the risk benchmark of 1.0 for non-cancer target endpoints were noted for arsenic and manganese at on-site wells MW-6 and MW-14. Hazard quotients ranged from 1.9 to 3.6 for arsenic and 1.3 to 2.5 for manganese. Accordingly, arsenic and manganese are recommended for retention as indicator hazardous substances in on-site groundwater.

Cancer risks associated with groundwater consumption from on-site wells are shown in Table 4-7b. In on-site wells, potential cancer risks ranging from 3×10^{-5} to 4×10^{-4} were identified. Arsenic and vinyl chloride were the chemicals that underlie the cancer risk estimates. The upper range of these predicted cancer risks is higher than the MTCA benchmark of 1×10^{-5} identified for exposure to multiple cancer-causing chemicals. Accordingly, arsenic and vinyl chloride in on-site groundwater are both recommended for retention as indicator hazardous substances.

In summary, arsenic, manganese, and vinyl chloride in on-site groundwater are recommended for retention as indicator hazardous substances for the remedial alternatives analysis in this FS report.

4.1.3.3 Human Health Risk Assessment Results for Off-Site Groundwater

Tables 4-7a and 4-7b also summarize the results for off-site groundwater evaluations of non-cancer and cancer risks, respectively. Antimony, arsenic, manganese, nitrate, vinyl chloride, and zinc did not pose non-cancer risks in off-site groundwater wells (all hazard quotients are < 1.0).

Total cancer risks in off-site groundwater wells ranged from 1×10^{-5} up to 1×10^{-4} (Table 4-7b). The high end of this range exceeds the cancer risk benchmark of 1×10^{-5} specified in MTCA. Arsenic contributes the majority of the cancer risk in the off-site groundwater wells (except MW-12I and MW-13S, where vinyl chloride contributes more). Arsenic concentrations in off-site wells ranged from 0.0006 to 0.0038 mg/L. Vinyl chloride

---

[3] Antimony was not identified by the RI chemical screening process for further evaluation in groundwater in the FS; however, since antimony shares a common toxicological endpoint with nitrate, antimony was also evaluated in this FS.

in wells MW-12I, MW-13D, and MW-13S exceeds the MTCA benchmark cancer risk level of 1 x 10^{-6}.

In summary, arsenic and vinyl chloride in off-site groundwater are recommended for retention as indicator hazardous substances in off-site groundwater for the remedial alternatives analysis in this FS report.

4.1.3.4 Human Health Risk Assessment Results for Off-Site Surface Water (Drinking Water and Fish Consumption)

Tables 4-8a and 4-8b summarize the potential non-cancer and cancer risks, respectively, for off-site surface water ingestion if the creeks were to be used as a drinking source. Tables 4-8c and 4-8d address risks from consumption of fish from off-site surface water. Risks from surface water exposure were evaluated for arsenic and vinyl chloride. As noted in Table 4-1, copper and zinc were not evaluated for human receptors because their PCLs were based on ARARs for ecological receptors.

Drinking Water

Neither arsenic nor vinyl chloride (Table 4-8a) had individual hazard quotients greater than a benchmark value of 1.0 for non-cancer health effects in off-site surface water.

Cancer risks from arsenic and vinyl chloride are presented in Table 4-8b. The cumulative cancer risk ranged from 5 x 10^{-5} to 2 x 10^{-4} across the sampling locations in Middle Creek, Creeks A and B, and Little Boston Creek. This cancer risk range translates to one to two additional cancers in every 10,000 people who may consume surface water from the affected creeks on a regular basis.

Arsenic and vinyl chloride were already recommended for retention as indicator hazardous substances in on-site and off-site groundwater (see Sections 4.1.3.2 and 4.1.3.3) and are addressed in the FS remedy selection process in Sections 7 through 10 of this FS report. Reduction of on-site and off-site concentrations of arsenic and vinyl chloride in groundwater below PCLs is protective of surface water, because groundwater in the Upper Aquifer discharges directly to surface water, and the PCLs for groundwater were set using surface water ARARs (see Section 6 of this FS report). Applying surface water PCLs, the most stringent ARARs for surface water, to groundwater means that groundwater must meet surface water quality standards before the groundwater discharges to the streams west of the Landfill and becomes surface water.

Fish Consumption

As shown in Table 4-8c, non-cancer risks from arsenic and vinyl chloride for consumption of fish from surface water do not exceed the risk benchmarks. Cumulative cancer risks from arsenic and vinyl chloride (see Table 4-8d) ranged from 2 x 10^{-5} to 4 x 10^{-5}. Thus, arsenic and vinyl chloride are also recommended for retention as indicator hazardous substances in off-site surface water for the remedial alternatives analysis in this FS report, based on fish consumption.

4.1.3.5 Human Health Risk Assessment Results for Off-Site Surface Water (Recreational Exposures)

Tables 4-9a and 4-9b summarize the potential for non-cancer and cancer health effects possible from recreational exposures to surface water in the creeks. This exposure was evaluated for arsenic and vinyl chloride. As shown in Table 4-9a, none of the chemicals in the creeks is predicted to pose non-cancer risks to people using them for recreational activities because all hazard quotients and the additive risk Hazard Index are less than 1.0.

As shown in Table 4-9b, cancer risks from recreational contact with surface water do not result in predicted cancer risks above a 1 x 10^{-6} MTCA cancer risk benchmark for arsenic and vinyl chloride. Therefore, arsenic and vinyl chloride in off-site surface water are not recommended for retention as indicator hazardous substances for the remedial alternatives analysis in this FS report, based on recreational exposures.

4.1.3.6 Human Health Risk Assessment for Off-Site Sediment Exposures

Two metals were identified from the RI chemical screening for sediments with respect to human health risk and evaluated for this exposure pathway: arsenic and chromium (see Table 4-1). The potential risks for non-cancer health effects of these chemicals from the incidental ingestion and dermal contact pathways with sediments are shown in Table 4-10a. No chemicals exceeded the MTCA risk benchmark of 1.0.

Table 4-10b summarizes the potential for contracting cancer from the incidental ingestion or dermal contact pathways for sediment. As shown, arsenic is at or below the 1 x 10^{-6} MTCA cancer risk benchmark. Therefore, none of the indicator hazardous substances evaluated in creek sediments is expected to pose health risks (cancer or non-cancer). As a result, arsenic, and chromium in sediment are not recommended for further consideration in the remedial alternatives analysis of this FS report.

4.2 ECOLOGICAL RISK ASSESSMENT

Consistent with the requirements of the Hansville Landfill Project Work Plan (Parametrix 1995), an ecological risk assessment was conducted. This evaluation includes a summary of the ecological resources in the vicinity of the Landfill, followed by an evaluation of potential current and future exposure pathways and the risks predicted for each. Any chemicals posing potentially significant risk to ecological receptors are identified for further consideration in the FS.

4.2.1 Ecological Resources in the Vicinity of the Landfill

Ecological resources include all threatened or endangered species, all State priority habitats, unique habitat features, and ecological resources off-site that may be affected by on-site impacts. The only endangered, threatened, or State species of concern in the Washington Department of Fish and Wildlife (WDFW) Priority Habitats and Species Database known to occur within 1 mile of the Landfill is an osprey (*Pandion haliaetus*) nest approximately 0.9 mile southwest of the landfill boundary near the shoreline of Port Gamble Bay (WDFW 2008). The nearest bald eagle (*Haliaeetus leucocephalus*) nesting territory is about 2 miles from the Landfill and would not be affected by the Landfill. There are no known threatened or endangered plant species in Kitsap County.

Chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*), both listed species, do not occur in any of the downgradient streams. Listed winter steelhead (*Oncorhynchus mykiss*) occur in the downstream reaches of Creek C (Salmonscape 2008). Unlisted Coho salmon are documented through most of Little Boston Creek and the lower portions of Middle Creek and Creek C (Salmonscape 2008). Fall chum salmon occur in Middle Creek and Creek C. The lower section of Creek B is reported to support anadromous and resident fish downstream of Little Boston Road NE approximately 4,000 ft downstream of the landfill boundary (WDFW 2008). Little Boston Creek has resident fish along much of its length, to within 400 ft of the landfill boundary. Creek C, which is also downgradient from the landfill, is reported to support resident and anadromous fish downstream of Little Boston Road NE. The marine waters of Port Gamble Bay support spawning sand lance (*Ammodytes* *hexapterus*), surf smelt (*Hypomesus pretiosus*), and herring (*Clupea harengus pallasi*), as well as areas of hardshell clams (WDFW 2008). There are no other records of priority habitats and species within 1 mile of the landfill boundary (WDFW 2008), as documented in Appendix A (Information from Washington Department of Fish and Wildlife Priority Habitats and Species Database).

The nearest (with respect to the Landfill) wildlife freshwater wetland and riparian habitat areas mapped by the Port Gamble S'Klallam Tribe (near the headwaters of Middle Creek and Creek B, and along sections of Little Boston Creek), are the types of habitat that typically would be considered priority habitats by the WDFW. However, these wetlands were not mentioned in the WDFW database as priority habitat. Much of the upland area surrounding these wetlands and riparian habitat consists of intensively managed forests and other disturbed areas and has limited wildlife habitat value due to lack of structural diversity, large trees, snags, and logs. The terrestrial habitats, and the wildlife species that can be expected to use them (see Table 4-11), are treated in four categories: Clearcut, Plantation, Mixed Second Growth, and Developed.

Habitat types within the study area, as mapped from aerial photos in 2006, are shown in Figure 4-6. There have been some recent land uses that have developed small areas, and the Port Gamble S'Klallam Tribe has updated wetland maps that show minor variation in the extent of the identified wetlands. However, the overall character of habitat has not changed much from the earlier mapping. None of these habitats is considered a priority habitat (WDFW [2008]; see Appendix A of this FS report) or contain rare plant communities (Washington Department of Natural Resources 1997).

4.2.1.1 Terrestrial

The clearcut habitat is a mixed shrub upland community with wetland areas caused by surface seeps. Regenerating forests along the streams are dominated by western red cedar (*Thuja plicata*), red alder (*Alnus rubra*), Douglas fir (*Pseudotsuga menziesii*), and willow (*Salix* spp.). Shrubs include salmonberry (*Rubus spectabilis*), red huckleberry (*Vaccinium parvifolium)*, red elderberry (*Sambucus racemosa*), vine maple (*Acer circinatum*), and salal (*Gaultheria shallon*). Herbaceous vegetation in the surrounding area includes cattail (*Typha latifolia*), youth-on-age (*Tolmiea menziesii*), ladyfern (*Athyrium filix-femina*), horsetail (*Equisetum* spp.), deer fern (*Blechnum spicant*), and bedstraw (*Gallium* spp.). The undergrowth is dense along the stream, and emergent vegetation is present.

A large portion of the upland habitat is a Douglas fir plantation. Timber stand improvements (pruning and thinning) conducted in the past have left a dense layer of slash and woody debris on the forest floor with undergrowth lacking. Though snags are generally absent, the habitat may be suitable for some songbird nesting, including American robins, Swainson's thrush, and flycatchers. Mountain beaver use was evident. Downed woody debris is often associated with amphibian habitat, but the dry conditions likely limit amphibian use.

The developed areas include the Landfill Property; residential, commercial, and industrial development; inert landfill; and roads and other paved areas. The habitat is monotypic with either no habitat structure or habitat that is mowed regularly. Because of frequent human activity in the area and poor habitat structure, the potential for burrowing wildlife is expected to be minimal. Therefore, the developed area is not considered viable wildlife habitat.

Mixed second-growth forest at the Site is dominated by a canopy of Douglas fir, western hemlock (*Tsuga heterophylla*), western red cedar, red alder, and big-leaf maple (*Acer macrophyllum*). The shrub layer is scattered, with huckleberry, red elderberry, salmonberry, and vine maple. The ground is sparsely vegetated with salal, sword fern (*Polystichum munitum*), Oregon grape (*Berberis nervosa*), and other perennial herbs.

A summary of the wildlife species potentially occurring in the terrestrial portions of the study area is presented in Table 4-11.

4.2.1.2 Wetlands

Three areas of wetland habitat were mapped downgradient of the Landfill. These wetlands are classified as forested, scrub-shrub, and emergent. The wetlands are fed by surface flows and seeps, and drain into unnamed streams or tributaries of Middle Creek. A summary of the wildlife species potentially occurring in the wetland areas near the stream headwaters west of the Landfill is presented in Table 4-11.

The forested wetland mapped in the Study Area is dominated by red alder, with western red cedar also present. Salmonberry is the dominant shrub species. Hydrology in this wetland is provided by seeps that collect into small channels and pools within the wetland, then flow out of the wetland through a culvert underneath a logging road. The forested wetland has quality wildlife habitat structure over an aquatic component that can support a variety of wildlife (see Table 4-11).

Amphibian species, such as northwestern salamander, long-toed salamander, red-legged frog, and Pacific tree frog, may use the ponded water in the wetlands for breeding and larval development. None of the aquatic components in the forested wetland appears large enough for substantial use by waterfowl. Passerine birds, such as black-capped chickadees, red-eyed vireos, and yellow warblers nest in marsh vegetation or cavities excavated by downy and pileated woodpeckers, as well as northern flickers. Mammals that potentially use the forested marsh include raccoon, mink, black-tailed deer, and rodents.

The scrub-shrub wetland components are situated within clearcuts. Stumps and woody debris evident in and around these sites indicate that they were formerly forested wetlands. Dominant plant species include salmonberry, fireweed (*Epilobium angustifolium*), and Pacific willow (*Salix lasiandra*). Young red alder, western red cedar, Douglas fir, and big-leaf maple are scattered throughout the wetland.

The scrub-shrub wetland has limited aquatic habitat that likely limits amphibian use to the adult life stages. The lack of cavity habitat and an overstory (tree) canopy reduces the habitat value for breeding passerine birds. Some shrub-nesting bird species such as the common yellowthroat, yellow warbler, and song sparrow may use the scrub-shrub wetland, while other species more commonly associated with shrub marsh (red-winged blackbird, varied thrush) will avoid habitat that is compromised by clearcutting. Mammals using the shrub wetland are probably limited to small rodents.

The emergent wetland in the area is also a forest remnant habitat, with water parsley (*Oenanthe sarmentosa*), skunk cabbage (*Lysichitum americana*), and false lily-of-the-valley (*Maianthemum dilatatum*) typifying the herbaceous layer. This small wetland (0.8 acre) has habitat functions limited by lack of structure, extensive clearing in the surrounding habitat, and lack of channelized or pooled aquatic component.

4.2.1.3 Aquatic

Three small creeks (< 5 cfs base flow) are formed by groundwater seeps that emanate downgradient of the Landfill Property. The largest of these, Middle Creek, is composed of approximately five small tributaries that meet about 2,000 ft east of Port Gamble Bay. The other two smaller, unnamed creeks north of Middle Creek, identified as Creeks A and B on Figure 4-1, also drain into the Bay.

The lower reaches of the creeks that discharge into Port Gamble Bay west of the Hansville Landfill were surveyed for fish habitat. This survey is summarized in Appendix B. The upper reaches of Middle Creek and Creek B, the two creeks directly downgradient of the Landfill Property boundary with respect to groundwater flow, were surveyed for fish habitat by Parametrix staff on June 7, 1997, with results described in the following paragraphs.

Surface Water Station SW-1 (Middle Creek)

At surface water station SW-1, the creek channel was roughly 2.5 ft wide, with a maximum water depth of 2 in. The channel substrate consisted of sand interspersed with small gravel. Bank vegetation was dominated by dense, small, western red cedar and salmonberry. Small-scale chutes, drops, and runs along the channel indicated that the water was well aerated.

No evidence of water quality impairment (e.g., stagnant water, water or soil discoloration, water surface scum, unusual plant or algal growth, or odor) was observed. Water temperature was 11.0°C. Habitat quantity (i.e., width, depth, and features such as pools and riffles) appeared insufficient for use by any fish but small juveniles. Further, the small size of the channel and low summer flows preclude access to the habitat by fish greater than a few inches in length.

Surface Water Station SW-2 (Middle Creek)

Aquatic habitat at surface water station SW-2, downstream of SW-1, was similar to SW-1. The creek slope was slightly flatter, creating a run, rather than the series of chutes and drops observed upstream. A total discharge of 0.22 cfs was calculated using point velocities measured across incremental cross-sectional areas of the stream (Lindsley et al. 1982).

Substrate at SW-2 contained a greater fraction of gravel than SW-1. Creek banks were dominated by dense vegetation, predominantly red alder and salmonberry. Habitat appeared adequate for juvenile salmonids, although the small channel and low summer flows would preclude access to habitat by fish greater than a few inches in length. No evidence of water quality impairment (e.g., water or soil discoloration, water surface scum, unusual plant or algal growth, or odor) was observed.

Surface Water Station SW-4 (Tributary to Middle Creek)

Aquatic habitat found along the second tributary to Middle Creek (also referred to as the North or Right Tributary in some reports) was limited in size and quantity. Near surface water station SW-4, the creek flowed under a road through an 18-in.-diameter corrugated metal pipe perched about 20 in. above the channel. The creek channel width ranged from 1 to 3 ft and was several inches deep. Riparian and emergent vegetation was dense throughout the channel, making fish access appear restricted. Flow quantity may have been adequate for juvenile fish, but the small size and quantity of natural habitat would preclude use by larger resident or migratory fish.

Surface Water Station SW-5 (Tributary to Middle Creek)

Downstream of SW-4, SW-5 was located near the tributary’s confluence with the main stem. Aquatic habitat consisted of an incised channel, scoured and downcut banks, sediment deposits, and small debris jams. The tributary channel appeared recently scoured by high flows. Channel width ranged between 2 and 4 ft. Water depth was about 2 in. through most of the channel. A total discharge of 0.06 cfs was calculated using point velocities measured across incremental cross-sectional areas of the stream (Lindsley et al. 1982).

Riparian vegetation consisted primarily of young alder. No evidence of water quality impairment (e.g., water or soil discoloration, water surface scum, unusual plant or algal growth, or odor) was observed. Upstream of SW-5 small fish (presumably juvenile salmonids) were observed in the shallow water. Habitat quantity (i.e., width, depth, and features such as pools and riffles) appeared insufficient for use by sea-run adult salmon and trout.

Downstream of the north tributary confluence with the main stem of Middle Creek (about 50 ft downstream of surface water station SW-5), the creek channel was roughly 3 ft wide and varied in depth between 3 and 5 in. A total discharge of 0.77 cfs was calculated using point velocities measured across incremental cross-sectional areas of the stream (Lindsley et al. 1982). The creek meandered through a broad, V-shaped valley. Valley walls extended 20 to 40 ft above the valley floor.

Vegetation was predominantly mature alder canopy, with large cedar stumps and a dense shrub understory. The creek channel consisted of numerous small chutes and drops over small woody debris and around small pools. Water temperature was 7°C. Substrate consisted of sand, with a small fraction of small gravel. Deposition areas contained large amounts of coarse sand.

No evidence of water quality impairment (e.g., water or soil discoloration, water surface scum, unusual plant or algal growth, or odor) was observed. Fish habitat appeared adequate for juvenile and resident adult species. Habitat quantity (i.e., width, depth, and features such as pools and riffles) appeared insufficient for use by sea-run adult salmon and trout.

Surface Water Station SW-6 (Creek B)

Surface water station SW-6, located on Creek B north of Middle Creek, was observed for aquatic habitat. No evidence of water quality impairment was observed. The channel was less than 1 ft wide and less than 3 in. deep. The channel consisted of a series of very small pools linked by shallow trickles of water. Riparian vegetation was dense enough to block most sunlight from the channel. Based on the small size of the channel and the low flow volume, fish habitat was not apparent.

In general, the segments of Creek B that were surveyed appeared to contain potential fish habitat of good quality for small salmonids (i.e., salmon and trout). Small fish (< 100 mm in length) resembling juvenile salmonids were observed in several locations upstream of the culvert under Little Boston Road NE. No structural migration barriers (e.g., log jams, waterfalls, culverts) to adult salmonid migration were identified upstream of Little Boston Road NE along the few creek segments surveyed. Creek temperatures were well below Washington Class AA limits for water temperature (i.e., 16°C). No obvious indicators of water quality impairment were observed.

Conclusions

Adult salmonid use of the upstream creek habitat segments would most likely be limited by the lack of water depth and habitat features (e.g., spawning gravel, pools), rather than exposure to Landfill-derived contaminants. Much of the surveyed area provides marginal habitat for juvenile salmonid rearing.

4.2.2 Potential On-Site Ecological Exposure Pathways

The Landfill Property includes the disposal areas as well as some adjacent forested land. Contaminated media of concern within the Landfill Property boundary are groundwater and air, as identified in the Project Work Plan (Parametrix 1995). Given the very disturbed nature of the Landfill Property, some tolerant wildlife species (rodents) may occur. With the exception of these types of species, the habitat attributes of the Landfill Property are not expected to provide any ecologically relevant characteristics (e.g., nesting, regular foraging areas) that would make the area attractive to most wildlife species. Forested areas on the Landfill Property and in the Study Area are characterized by the species identified previously in Section 4.2.1.

Species occurring within the Landfill Property are not expected to be at any risk from exposures to contaminated groundwater or air. For groundwater, no exposure is expected because the depth to the Upper Aquifer within the Landfill Property is greater than 100 ft, thus eliminating direct contact exposure pathways for any terrestrial receptors (including those that burrow). Additionally, inhalation of volatile constituents originating from groundwater is not of concern for wildlife within the Landfill Property, based on the depth of the Upper Aquifer (see RI report Chapter 5) and the presence of an operational gas control and flare system (see RI report Chapter 4). Natural surface water bodies do not occur within the Landfill Property. Thus, any potential exposures of aquatic or terrestrial biota to this medium would not occur.

4.2.3 Potential Off-Site Ecological Exposure Pathways

As discussed in RI report Chapter 5 (Groundwater Investigation) and shown in the conceptual site model (see Figure 4-3), off-site migration of the chemicals released from the waste disposal areas occurs through groundwater transport. Groundwater from the Upper Aquifer discharges approximately 1,200 to 2,000 ft from the western Landfill Property boundary as seeps. Three of these seeps are located within the area estimated to receive groundwater flow from beneath the Landfill (see Figure 4-1). Therefore, a potential exists for chemicals in groundwater to enter these three creeks and result in exposure pathways (surface water, sediment) to ecological receptors residing in, or using, the creeks. Possible exposure pathways are discussed below for each medium.

4.2.3.1 Off-Site Surface Water Exposure Pathways

Several exposure pathways are considered for ecological receptors using the creeks outside of the Site Boundary. These pathways include:

- Direct contact (gill uptake, epithelial uptake) by aquatic life,
- Dietary uptake (food chain transfer) to aquatic life,
- Surface water ingestion by terrestrial wildlife,
- Dermal contact by terrestrial wildlife,
- Dietary uptake (food chain transfer) to terrestrial wildlife, and
- Volatile inhalation by terrestrial wildlife.

Each potential pathway and its importance at the Site are discussed in the following paragraphs.

The chemical screening (see Table 2-2) identified arsenic, copper, zinc, and vinyl chloride for further evaluation in surface water (see Table 4-3b). No PCLs were available for surface water to screen vinyl chloride for potential impacts to aquatic life, and further evaluation of the risk potential for this chemical from direct contact pathways was conducted for both aquatic life and terrestrial wildlife, based on available toxicity data from the scientific literature. Volatile chemicals are not of concern for dietary pathways. Ecological exposure pathways for arsenic were not evaluated, because this chemical did not exceed ecological-based ARARs (see Table 4-1).

Direct Contact with Surface Water by Aquatic Life

Direct contact for aquatic organisms includes exposures from gill uptake or dermal (epithelial) contact. The survey of ecological resources conducted in the vicinity of the Landfill Site (Section 4.2.1) indicates that parts of the upper reaches of Middle Creek can support a limited aquatic community. Walks of the creeks indicated the presence of a number of very small (juvenile) fishes, presumably small cutthroat trout (*Oncorhynchus clarki*), sculpins (*Cottidae*), or threespine stickleback (*Gasterosteus aculeatus*).

Presumably some aquatic invertebrates (insects) are also present in the creeks, given the presence of small fishes. Therefore, this pathway is potentially complete for aquatic organisms living in downstream portions of the creeks and was further evaluated for surface water chemicals identified from the RI chemical screening: copper, vinyl chloride, and zinc. The completeness of the potential exposure pathways evaluated for these chemicals is discussed in the sections that follow.

Dietary Uptake from Surface Water by Aquatic Life

The USEPA (1994a) indicates that chemicals with bioconcentration factors (BCFs) greater than 100 may bioaccumulate to potentially significant levels in aquatic life and therefore may be of concern. It is also recognized that the BCF for essential metals is a poor indicator of accumulation potential. Copper has a BCF of 36, zinc has a BCF of 47, and vinyl chloride has a BCF of 1.2 (Ecology 2005).

The bioaccumulation of metals is very complex, particularly for those metals that are essential for the health of aquatic life such as zinc and copper (Chapman et al. 1996). The essential nature of these metals to aquatic life is not factored into regulatory guidance (such as USEPA 1994a and Ecology 2005), which suggests the use of a single generic accumulation factor in assessing hazard potential from aquatic exposure pathways is insufficient. In this situation, Parametrix applied best available science to supplement the regulatory guidance. Thus, in the case of zinc, the use of the BCF "trigger" for evaluating dietary exposure pathways is not particularly relevant, based on the findings of Chapman et al. (1996), because aquatic organisms have the ability to control and maintain internal metal concentrations in the presence of significant variations in external concentrations[4].

Chapman et al. (1996) reviewed the scientific literature to evaluate the appropriateness of using BCF values for classifying and regulating essential metals. Their review found that zinc concentrations in tissues of aquatic organisms were often maintained at fairly constant levels for measured zinc concentrations in water ranging up to two orders of magnitude. Thus, high ranges in aquatic zinc concentrations tend to result in fairly constant tissue burdens. Further, Chapman et al. (1996) found that the range of BCFs in the data sets for essential metals was not correlated with toxic or adverse effects.

---

[4] This fairly constant range of zinc body burdens over wide-ranging water concentrations suggests homeostatic mechanisms are employed by the organisms. Thus, BCFs for these types of metals would be expected to be highly variable.

Therefore, though zinc may be bioaccumulated to some degree by aquatic organisms in the creeks downgradient of the Landfill, it is not likely to result in dietary toxicity due to internal regulation by aquatic organisms over a wide range of water concentrations (Chapman et al. 1996). The dietary pathway is thus considered complete but minor for zinc and is not further evaluated for aquatic life. Vinyl chloride is not expected to contribute risk to aquatic life through dietary pathways based on a review of its chemical properties. The partitioning coefficients frequently used as indicators of bioaccumulation or biomagnification for this chemical are of a low magnitude and below the “trigger” values usually considered for evaluating dietary pathways. Specifically, vinyl chloride has a log octanol-water partition coefficient much less than 3, indicating little affinity for accumulation in organic media such as organism tissues. Thus, the aquatic dietary pathway is considered incomplete for this chemical and it is not evaluated further.

Surface Water Ingestion by Terrestrial Wildlife

The Site ecological resource survey, as well as information from contacted resource agencies, indicates that a number of common wildlife species can potentially inhabit the forested and marsh areas immediately surrounding the Landfill. Common mammals include small rodents, raccoons (*Procyon lotor*), mink (*Mustela vison*), and mountain beaver (*Aplodontia rufa*). Birds are limited to passerine species (see Section 4.2.1).

Though the creeks are generally very small and extremely low-flowing in the areas closest to the Landfill Property boundary, where chemicals potentially associated with the Landfill have been detected, there is an opportunity for terrestrial wildlife to drink the surface water of the creeks. This type of exposure would likely be limited in Middle Creek and Creeks A and B for many terrestrial wildlife species, due to the availability of other water sources in the study area. These water sources include surface water bodies outside of the influence of the contaminated groundwater attributed to the Landfill (e.g., Little Boston Creek), as well as biologically available water in the food of many wildlife species.

The biologically available water can also serve to reduce or eliminate the need for regular consumption of drinking water by some species. For example, birds drink less water than do mammals of equivalent body weights, because their relatively high metabolic rate results in a greater quantity of biologically available water produced (USEPA 1993). Birds satisfy some of their water needs by oxidative food metabolism, but the balance is supplied from the water contained in foods such as insects or succulent plant material, as well as from drinking water (USEPA 1993).

Though other sources of drinking water for wildlife are available in the Study Area, the drinking water pathway is considered to be a complete exposure pathway for terrestrial wildlife and is further evaluated for all of the surface water chemicals passing through the chemical screen.

Dermal Contact with Surface Water by Terrestrial Wildlife

Dermal contact with surface water (or sediment) is not likely to be a significant exposure pathway for terrestrial wildlife. Fur or feathers on wildlife species that are designed to provide effective insulation from the elements impede any contact of water with the skin of wildlife. Additionally, any preening or grooming of feathers and fur results ultimately in an incidental surface water ingestion pathway, which is already evaluated. Therefore, the dermal exposure pathway to creek water is considered a complete but minor exposure pathway for terrestrial wildlife and is not evaluated further.

Dietary Uptake from Surface Water by Terrestrial Wildlife

The dietary pathway was conservatively evaluated for copper, zinc, and vinyl chloride for terrestrial wildlife. The pathways are considered complete but minor because the BCFs are less than 100, above which the potential for bioaccumulation is indicated (USEPA 1994a).

Volatile Inhalation from Surface Water by Terrestrial Wildlife

This pathway would be applicable to vinyl chloride because it is the only volatile chemical detected in surface water. As with human health, inhalation by terrestrial wildlife of volatile constituents from the creeks is considered a complete but minor exposure pathway, based on: (1) the very low concentrations of vinyl chloride detected in the surface water; and (2) the resulting large dilutions with ambient air that would occur prior to inhalation by any wildlife species. Accordingly, the inhalation dose to wildlife is expected to be negligible based on the above factors, and the pathway is considered complete but minor and not further evaluated.

4.2.3.2 Off-Site Sediment Exposure Pathways

Sediment exposure pathways are evaluated for those chemicals passing through the chemical screen for sediments: antimony, arsenic, chromium, manganese, nickel, and silver. Ecological exposure pathways for arsenic were not evaluated because this chemical did not exceed ecological-based ARARs (see Table 4-1). For sediments, certain exposure pathways are possible for aquatic and terrestrial wildlife. These include:

- Direct contact with aquatic life through gill uptake or epithelial uptake of leached chemicals, and
- Direct contact with terrestrial wildlife.

Both pathways are further discussed in the following paragraphs.

Direct Contact with Sediments for Aquatic Life

Observations of Middle Creek confirm that fish, including cutthroat trout, live in the creeks. It is assumed that some aquatic invertebrates may also be living in portions of the creeks, though this has not been confirmed through biological assessments. In many parts of the creeks the bottom substrate is generally sandy and cobbly, and sediment exists in locations where aquatic life could reside, resulting in potential exposure. It is recognized, though, that aquatic life will only occur in areas of the creeks with suitable conditions, such as sufficient water volume and depth, substrate, and areas that are not subject to seasonal dry out. Thus, further evaluation of the risk potential for the aquatic life sediment pathway is provided based on the standards and guidelines used for antimony, chromium, manganese, nickel, and silver in the chemical screening (Section 2.4) to determine whether risk potential exists.

Direct Contact with Sediments for Terrestrial Wildlife

Surface water contact has already been identified as a pathway that could bring terrestrial wildlife (birds, mammals) into contact with surface water in the creeks. It is also possible that incidental contact with the sediments in the creeks (i.e., incidental sediment ingestion or dermal contact) could occur during contact activities with the surface water, or unintentionally through probing in the creeks.

Dermal contact could also occur with sediments, though this type of exposure would ultimately result in incidental ingestion through grooming of fur and feathers. Accordingly, dermal contact was considered a complete but minor pathway that is not evaluated further. The incidental sediment ingestion pathway, however, was considered complete and potentially significant and was further evaluated for all of the sediment chemicals passing through the chemical screen.

4.2.4 Risk Analysis for Complete Ecological Exposure Pathways

Risks were quantified for ecological exposure pathways previously discussed using available guidance from USEPA (1997a). This guidance is consistent with and referenced by the site-specific terrestrial ecological evaluation procedures (WAC 173-340-7493) of Ecology (2001). The methods used for quantifying pathway risks are discussed below followed by summaries of the pathway specific risk results for surface water and sediments.

4.2.4.1 General Ecological Risk Assessment Methods

The ecological risk assessment followed the general guidance provided by Ecology and contained in the Project Work Plan for the Hansville Landfill (Parametrix 1995). Equations and parameters used to estimate doses to wildlife are shown in Table 4-12, including references.

Exposure concentrations used in the risk assessment for aquatic life and wildlife were generally represented by the upper 95 percent UCL for each chemical having at least a single detection at a sampling location. In some cases, where an insufficient number of data points were available for calculating the UCL at a sampling location, a maximum concentration was used.

For aquatic life, comparisons of surface water concentrations with aquatic life criteria were based on dissolved concentrations, consistent with USEPA interpretation and implementation of aquatic life criteria for metals (Prothro 1993). Dissolved concentrations are used because these more accurately represent the bioavailable fraction of the chemical to aquatic life.

Exceedances of aquatic life criteria or wildlife toxicity values do not necessarily imply that adverse health effects will occur. This is because assumptions regarding exposure or the toxicity data used to establish risk potential may not be appropriate when site conditions are considered. Thus, for some chemicals, there may be uncertainties associated with low hazard quotients (less than 5), where little significance may be ascribed to the exceedance. Where this occurs, specific factors are cited to support risk conclusions.

The results of the ecological risk assessment for surface water and sediments are summarized in the following paragraphs.

4.2.4.2 Results of the Ecological Risk Assessment

Direct Contact with Surface Water by Aquatic Life

Table 4-13 summarizes the chemical concentrations and hazard quotients for copper, zinc, and vinyl chloride. As shown by the hazard quotients in Table 4-13, zinc was at or just slightly above a risk benchmark of 1.0 in Creeks A and B. The habitat in Creek A does not support aquatic life such as benthic and water column organisms, which are the types of organisms used to develop the surface water quality standards for zinc. Specifically, the location where the single exceedance in Creek A occurred (Station SW-7; see Figure 4-1) is not considered a true aquatic habitat because water does not flow regularly in this area. Additionally, three out of four samples collected in this creek since 1996 have not exceeded the zinc criterion, and the fourth value (0.089 mg/L) barely exceeded the chronic criterion of 0.070 mg/L.

Data from the other creeks supports the assumption of no risk for zinc. Of the 18 samples from the creeks in which dissolved zinc was detected, the highest concentration was

0.05 mg/L, which is below the chronic criterion for zinc (0.07 mg/L; see Table 4-13). Given these factors, the single exceedance by zinc is considered to be an isolated occurrence at an area where aquatic life would not reside and is therefore not of concern to aquatic life in Creek A. Therefore, zinc in surface water is not recommended for retention for the remedial alternatives analysis in this FS report. Copper and vinyl chloride were both below a hazard quotient value of 1.0 and are also not recommended for retention as indicator hazardous substances in this FS report.

Surface Water Ingestion by Wildlife

Table 4-14 summarizes the concentrations and risk quotients for representative wildlife (American robin, mink) that could consume water from the off-site creeks downgradient of the Landfill Property. The robin and mink were selected as representative wildlife receptors because they are expected to have relatively higher exposures than other wildlife due to considerations such as their ingestion rate to body ratios and their feeding habits. Results show that none of the chemicals passing the screening process will pose risks to wildlife species ingesting creek water (all hazard quotients are significantly less than 1.0). Therefore, copper, zinc, and vinyl chloride in the off-site creeks do not pose a risk to wildlife ingesting surface water. As a result, creek water is not recommended for retention for the remedial alternatives analysis in this FS report.

Dietary Exposures by Wildlife

Table 4-15 summarizes the concentrations and hazard quotients for zinc, copper, and vinyl chloride for the aquatic dietary exposure pathway that was conservatively evaluated for mink. Mink were selected as a representative mammalian receptor because they are known to consume aquatic organisms from these types of habitats and, therefore, would likely have similar or perhaps greater exposure to potential Landfill-related chemicals than other mammals (e.g., raccoon). As shown in Table 4-15, hazard quotients for all chemicals in all creeks were well below a hazard quotient value of 1.0, indicating that no risk will be posed to wildlife species consuming aquatic organisms that occur downstream of the Landfill. Therefore, none of the three assessed chemicals is recommended for retention as an indicator hazardous substance in creek surface water for the remedial alternatives analysis in this FS report.

Direct Contact with Sediments by Aquatic Life

Antimony, chromium, manganese, nickel, and silver were shown to exceed PCLs in the chemical screen for freshwater sediment (see Table 4-4b). The screening values used were based on Lowest Apparent Effect Thresholds (LAETs) derived for freshwater sediments, with the exception of arsenic. The arsenic PCL was based upon the human health MTCA soil value because it was lower than the available LAETs. The LAET sediment values are intended for application at sites where sediment fauna will reside to ensure their protection from chemical exposures. Further evaluation of these exposures indicates that they do not pose a risk potential for creek aquatic life, as discussed below.

Table 4-16 summarizes the sediment concentrations at three sampling stations identified during the screening process. Also shown in Table 4-15 are the LAET values used in the screening process. For antimony, chromium, manganese, and silver, LAET values were exceeded, though only in the upper marsh areas of Middle Creek and Creek B that cannot be considered true aquatic habitat because these areas would not support the types of organisms normally associated with aquatic sediments. Therefore, exposure of aquatic organisms would not be occurring in the creeks until much further downstream of the marsh areas where appropriate habitat begin to occur. Further, concentrations of these metals farther downstream were below LAET values. Accordingly, antimony, chromium, manganese, and silver do not pose any risk to aquatic life occurring in the creeks at locations where true aquatic habitat is present.

Nickel was shown to occur at a concentration equivalent to the LAET value at one location, Station SD-10, which is located well downstream of the headwaters of Middle Creek previously discussed (Table 4-16). However, this concentration of nickel is not expected to pose a concern for aquatic life for two reasons. First, the LAET is based on a microtox luminescence endpoint, which has little relevance to effects on survival, growth, and reproduction (Bennett and Cubbage 1992), the toxicological endpoints that are the chief focus of ecological risk assessments (USEPA 1997b). Second, the next lowest LAET for nickel is 113 mg/kg and is based on an evaluation of both survivorship and growth endpoints, both ecologically relevant, for typical sediment organisms. The nickel concentration at SD-10 is well below this nickel LAET. Accordingly, nickel should not pose a risk to any sediment organisms occurring in any of the off-site creeks.

In summary, antimony, chromium, manganese, nickel, and silver are not expected to pose a risk to sediment organisms where aquatic habitat occurs, and therefore none is recommended for retention as an indicator hazardous substance for the remedial alternatives analysis in this FS report.

Sediment Ingestion by Wildlife

Table 4-17 summarizes the evaluations of potential risk for the sediment ingestion pathway for terrestrial wildlife. As shown, aquatic-feeding receptors represented by mink are not expected to be at risk from incidentally ingesting sediment at any of the sediment locations evaluated (all hazard quotients are below a value of 1.0). Therefore, antimony, chromium, manganese, nickel, and silver in Creek B or Middle Creek sediments are not recommended for further consideration in the FS.

4.3 SUMMARY OF RISK ASSESSMENT RESULTS

Based on the technical analysis described above in Sections 4.1 and 4.2, no complete current on-site exposure pathway has been identified for either human health or any ecological receptor. The human health groundwater consumption pathway for groundwater was conservatively evaluated. However, evaluation of potential future scenarios for groundwater use resulted in identification of arsenic, manganese, and vinyl chloride in on-site groundwater as posing potential risks above MTCA risk benchmarks, although future use of on-site groundwater for drinking water supply would be very unlikely. These chemicals are recommended for retention as indicator hazardous substances for consideration in evaluating remedial alternatives in this FS report.

Although the off-site Upper Aquifer is not currently used, the off-site human health groundwater consumption pathway was conservatively evaluated. As a result, arsenic and vinyl chloride were identified as posing potential risks in the event people were to consume this groundwater in the future. However, several factors were identified and discussed, which indicate that it is unlikely that this water will be consumed in the future.

Of the completed off-site human health surface water exposure pathways evaluated, vinyl chloride and arsenic were identified as posing risks to the local population if the creeks were to be used as a drinking water source or for fish consumption. As noted in Section 4.1.3.4, if lower than the groundwater PCL, surface water PCLs were applied to groundwater per WAC 173-340-720(8)(d)(i). The creeks obtain their flow directly from groundwater flow discharging from the Upper Aquifer; therefore, assessment of human health risks from arsenic and vinyl chloride in groundwater (see Sections 4.1.3.2 and 4.1.3.3) also addresses theses risks in surface water.

A survey of ecological resources at the Site was also conducted as part of the ecological risk assessment. Risk potential for completed off-site surface water exposure pathways was assessed in part using information identified in the resource survey. None of the completed off-site exposure pathways evaluated for wildlife (e.g., drinking surface water, sediment ingestion, dietary) pose a risk to exposed receptors. Similarly, no surface water concentrations were found to pose risks to exposed aquatic organisms living in the creeks.

Completed exposure pathways to both human and ecological receptors are depicted graphically in Figure 4-3. In addition, a summary of the results from the chemical screening and risk assessment process are presented in Table 4-18. The chemicals identified as indicator hazardous substances to be considered in evaluating remedial alternatives based on the results of the risk assessment are arsenic, manganese, and vinyl chloride.

5. CHARACTERISTICS OF CONTAMINANTS AND CONTAMINATED MEDIA

An understanding of the physical and chemical characteristics of contaminants and affected media is essential for selecting the appropriate remediation methods. Knowledge of a compound's physical-chemical tendencies provides the basis for altering its fate and transport in the environment or developing treatment methods to destroy or immobilize it. This chapter provides information regarding the physical-chemical characteristics of the three indicator hazardous substances selected for further evaluation in this FS report (vinyl chloride, manganese, and arsenic) and explains why certain methods of treatment may be more effective than others. This information is used in Chapter 7, where remediation technologies are identified and screened.

5.1 AQUIFER AND SOIL PROPERTIES

Aquifer soil characteristics have a major effect on the transport of chemicals in an aquifer and on the feasibility of their extraction by means of pumping or remediation in situ. The Upper Aquifer matrix at the Site is characterized in the RI as consisting of fine- and medium-grain sand with trace amounts of silt and gravel. These characteristics are considered to be favorable for remediation.

The Upper Aquifer matrix is porous enough to allow for relatively rapid movement and mixing of water. This allows for either natural attenuation during transport through the Upper Aquifer or implementation of active treatment processes, such as groundwater pump and treat and air sparging. In contrast, for aquifers that contain appreciable amounts of silt and clay, active remediation is often impractical due to the low permeability of these materials.

Sandy soils usually contain only a small fraction of natural organic carbon, on the order of a tenth of a percent. Organic carbon has the tendency to retard the movement of organic contaminants through an aquifer by adsorption. At the Site, organic chemicals like vinyl chloride are expected to move relatively freely through the Upper Aquifer. This means that cleanup standards can be achieved within a reasonable period of time by allowing the groundwater to flow through and discharge from the Upper Aquifer naturally or by actively pumping groundwater from this aquifer.

It is shown later in this FS report that even the low levels of organic carbon in the Upper Aquifer matrix at the Site can have a significant effect on cleanup times. The estimated retardation factor for vinyl chloride due to adsorption to trace amounts of natural organic material is between 1.4 and 2, meaning that vinyl chloride moves through the Upper Aquifer at as slow as one-half the speed of groundwater flow. Stated another way, it may take up to two pore volumes of Upper Aquifer water to remove vinyl chloride from the system.

A pore volume is the volume of water contained within the Upper Aquifer, estimated as the total bulk aquifer volume within the contaminated area multiplied by the depth of contaminants in the Upper Aquifer saturated zone, minus the volume of the solid particles that make up the Upper Aquifer soil matrix. However, a retardation factor of 2 is low in comparison to many other problematic organic compounds and is indicative of relatively unrestricted movement (USEPA 1992b).

5.2 PHYSICAL/CHEMICAL PROPERTIES OF INDICATOR HAZARDOUS SUBSTANCES

5.2.1 Vinyl Chloride

Physical and chemical properties of vinyl chloride are shown in Table 5-1. These properties are used to explain important fate, transport, and treatment mechanisms.

5.2.1.1 Volatilization

Volatilization is the change in the physical state of a substance from a liquid to a gas. Table 5-1 shows that vinyl chloride has a high vapor pressure, which is the tendency of a pure liquid substance to volatilize, and a moderate solubility, which is the ability of a substance to mix with water. These two properties give vinyl chloride a high Henry's Constant, the relationship between the concentration of a dilute solution of a substance in water and the corresponding equilibrium concentration in air. Essentially, this means that vinyl chloride is easily removed from water by volatilization processes, including natural dissipation, and by technologies that facilitate this process. This validates the RI findings that vinyl chloride does not remain long in flowing surface water.

The half-life of a substance is the time required to reduce the concentration of a substance to half the starting value. Vinyl chloride in surface water has a half-life of about ½ hour (Callahan et al. 1979). Once introduced into an open aquatic system, vinyl chloride is quickly transferred into the atmosphere through volatilization. In the troposphere, it reacts at an extremely rapid rate with hydroxyl radicals, exhibiting a half-life on the order of a few hours (Callahan et al. 1979). As a result, vinyl chloride should be decomposed within a day or two of release into the atmosphere.

In groundwater, however, volatilization is relatively slow because convective flow is not available to transfer vinyl chloride to the top of the saturated zone (the water table). Vinyl chloride must move to the water table before it can volatilize into the saturated zone. Without turbulence to cause appreciable mixing, vinyl chloride transport to groundwater is primarily limited to diffusion, which is extremely slow, as indicated by the small water-phase diffusivity constant in Table 5-1.

The limited amount of vinyl chloride that does volatilize from the groundwater into the vadose zone may exist in three different forms: (1) as vapor in the interstitial soil gas, (2) dissolved in soil moisture, or (3) adsorbed on sorption sites in the soil. Within the vadose zone, vinyl chloride is subject to several fate and transport mechanisms, including volatilization to the atmosphere, desorption, return to the Upper Aquifer by rain water, and biological degradation.

5.2.1.2 Biological Degradation

Under anaerobic (oxygen-depleted) conditions, vinyl chloride may biologically degrade to ethene, an environmentally acceptable biotransformation product; however, the conversion is very slow and incomplete (Freedman and Gosset 1989). Conversely, under aerobic conditions, biological degradation of vinyl chloride is relatively rapid. In groundwater, the half-life of vinyl chloride under aerobic conditions is approximately 8 weeks, versus its half-life under anaerobic conditions of approximately 100 months (Aronson and Howard 1997).

There are several consequences to the biological reactivity of vinyl chloride:

- Vinyl chloride is expected to be fairly persistent in soils beneath the solid waste disposal area at the Landfill and in groundwater beneath the Landfill because these areas are known to be anaerobic.
- Vinyl chloride is expected to degrade more rapidly in off-site regions of the Upper Aquifer that may be more oxidizing and thus amenable to aerobic degradation.
- Remediation measures that produce aerobic conditions in the groundwater would be expected to degrade vinyl chloride more rapidly than under anaerobic conditions.

5.2.1.3 Sorption

As discussed in Section 5.1, sorption of vinyl chloride to soils and/or organic matter in the Upper Aquifer beneath the Landfill should be low, due to both the small amount of naturally occurring organic matter in the Upper Aquifer and the low potential for sorption of vinyl chloride to this organic matter. The value of the soil organic carbon/water partition coefficient (K_{oc}) is defined as the amount of sorption on a unit carbon basis. The relatively low value of K_{oc} for vinyl chloride shown in Table 5-1 is indicative of free transport in the Upper Aquifer, with relatively low retardation by soil or aquifer organic material (USEPA 1992b). Moreover, the Upper Aquifer matrix beneath the Site contains relatively small amounts of natural organic matter. This has several implications with regard to treatment and natural attenuation:

- Natural attenuation of vinyl chloride in the Upper Aquifer by dispersion in groundwater should occur within a reasonable time frame, because sorption to Upper Aquifer soils will be low.
- Pump and treat methods should be feasible for containing or removing vinyl chloride from the Upper Aquifer.
- Treatment of vinyl chloride by means of activated carbon, in either the liquid phase or gas phase, is extremely inefficient, and in most cases, uneconomical.

5.2.2 Manganese

The form of manganese in groundwater and surface water is largely dependent on pH and oxidation/reduction (redox) potential. A diagram showing the speciation of manganese as it relates to pH and oxidation potential is provided in Figure 5-1. In this figure, redox is expressed in terms of electrical potential (volts). A positive value of redox indicates oxidizing conditions. The higher the redox value, the more oxidizing the conditions. Redox potential can be increased by introducing oxygen into the system or by adding chemical oxidants such as chlorine, permanganate, and ozone. A negative redox value indicates reducing conditions and is usually associated with depleted or low levels of dissolved oxygen.

The conditions of the Upper Aquifer beneath the Landfill and immediately downgradient are generally reducing, with low dissolved oxygen concentrations reported in most wells. The pH of these waters is at or near neutral. Soluble manganese, Mn (+2), is prevalent under reducing conditions at neutral pH. Manganese in this form is mobile and free to move with groundwater flow. This has several important implications with regard to fate and transport:

- The reducing conditions in the Upper Aquifer under the Landfill and immediately downgradient may be responsible for a certain degree of dissolution and mobilization of manganese.

- Manganese mobility may be reduced or eliminated under oxidizing conditions, which will form insoluble manganese oxides that precipitate out of solution.
- As groundwater flows naturally from a region of low oxygen to a region of higher oxygen downgradient of the Landfill, manganese may be removed through precipitation and immobilization.

As shown on Figure 5-1, very high oxidation potentials at neutral pH are required to precipitate and immobilize manganese. Oxygen is not a strong enough oxidant to bring redox potentials into the range for formation of insoluble manganese. However, manganese removal is observed in natural environments under mildly oxidizing conditions due to mechanisms besides oxidation. For example, iron oxide is easily precipitated under mildly oxidizing conditions, and manganese adsorbs to and co-precipitates with the iron (Wetzel 1983). In addition, microorganisms that live in aerobic conditions have been shown to mediate the oxidation of reduced manganese to oxidized forms (Phillips et al. 1994; Wetzel 1983). These natural removal mechanisms account for major reductions in manganese observed in designed and natural marshes.

5.2.3 Arsenic

Like manganese, the form of arsenic in groundwater and surface water is largely dependent on pH and redox potential. In aerobic (oxidized) waters, arsenic is an oxianion represented as As (+5). Under reducing conditions, the valence state of arsenic changes from +5 to +3. The reduced form of arsenic is represented by As (+3). Arsenic (+5) is strongly sorbed onto soils and sediments, and sorption is one of the principal means by which arsenic is removed from waters. Arsenic (+5) sorbs readily to iron and manganese oxides. Co-precipitation of arsenic with iron is one of the principal water treatment methods for achieving low effluent concentrations (EPRI 1990). However, arsenic sorbed as As (+5) may be remobilized if conditions become sufficiently reducing for As (+3) to form.

The mobility of arsenic in groundwater and the means by which it may be immobilized or treated chemically follow the same principles as manganese. In oxidized or aerobic conditions in which insoluble manganese oxides are formed, arsenic is also removed by adsorption and co-precipitation. Reducing conditions that tend to solubilize and mobilize manganese also mobilizes arsenic.

5.3 CHEMICAL FATE ALONG MIGRATION PATHWAYS

5.3.1 Vinyl Chloride

Vinyl chloride may be a product of decomposition of solvents by bacteria in environments where oxygen is not present (anaerobic conditions). The typical dechlorination sequence is illustrated below (Freedman and Gossett 1989):

> perchloroethylene (PCE) ⇨ trichloroethylene (TCE) ⇨ dichloroethylene (DCE) ⇨ vinyl chloride (VC) ⇨ ethene

Depending upon the presence of bacteria and oxygen, ethanes may also be formed as secondary dechlorination byproducts. These compounds include tetrachloroethane (PCA), trichloroethane (TCA), and dichloroethane (DCA).

Vinyl chloride is commonly detected in leachate and landfill gas as a result of decomposition of materials such as cleaning products containing chlorinated solvents that are found in municipal refuse. Other potential sources of solvent precursors of vinyl chloride include refrigerants, floor tiles, plastics, drugs, and cosmetics. Until it was banned in 1974, vinyl chloride was used as a propellant in aerosol cans.

After the Landfill was capped and prior to installation of the active landfill gas extraction and flaring system, gas generated within the Landfill was documented to have migrated into the surrounding soils. This landfill gas migration created a mechanism for off-site transport of vinyl chloride because vinyl chloride tends to exist in a gas phase and is soluble in water. Some of the gas that moved away from the Landfill in unsaturated soils likely migrated upward through the soil column and dissipated to the atmosphere. Gas migrating along deeper pathways in the unsaturated zone was likely to be in contact with the groundwater in the Upper Aquifer, which created an opportunity for vinyl chloride to dissolve in groundwater in accordance with the high Henry's Constant for vinyl chloride (see Table 5-1).

A second mechanism for release of vinyl chloride into groundwater by landfill gas is through condensation of gas outside the waste. Biological activity in landfill waste results in elevated temperatures, in some cases over 100°F (Prosser and Janechek 1995). As warm landfill gas migrates into cooler surrounding soils, water vapor in the gas can condense onto soil particles. Vinyl chloride in the gas can condense with the water vapor or be absorbed by the condensed water droplets. Over time, continued condensation can accumulate and drain to groundwater, carrying vinyl chloride along with it.

With the installation of the active landfill gas control system in 1991 and subsequent confirmation from monitoring data, the pathway for off-site migration of landfill gas has been eliminated. Data from gas probes also confirm that landfill gas migration has been contained at the perimeter of the Landfill.

Although vinyl chloride volatilizes readily, it can be very stable in groundwater under anaerobic conditions and has an estimated half-life on the order of 8 years (Aronson and Howard 1997). Vinyl chloride concentrations may be attenuated in groundwater to a certain degree by adsorption to organic material and by dispersion in clean groundwater.

Vinyl chloride has been transported by groundwater discharge from the Upper Aquifer to the upper reaches of streams west of the Landfill. The RI report documented that due to the volatile nature of vinyl chloride, it dissipates to the atmosphere within a short distance from the stream headwaters. Vinyl chloride was not detected in surface waters below stations SW-2 and SW-4 on Middle Creek, and it was not detected in any RI sediment samples.

5.3.2 Arsenic and Manganese

Leachable metals contained in refuse, demolition debris, or septage disposed at the Landfill are present in leachate generated during Landfill operation. Naturally occurring metals (such as manganese and arsenic) in soils beneath the disposal areas and in the Upper Aquifer can be mobilized during percolation of leachate. Leachate and gas can lead to anaerobic conditions in groundwater, thereby increasing the tendency of some metals to dissolve or be desorbed from soil particles. In this state, metals can be mobilized by groundwater flow. As a result, concentrations of these metals may become elevated in groundwater above naturally occurring background levels.

As the chemical equilibrium of the groundwater changes with distance from the Landfill disposal areas, metals have the potential to come out of solution (precipitate) and adsorb onto Upper Aquifer particles. This process is largely due to mixing with natural groundwater and changes in dissolved gas concentrations and pH. Transport of metals in groundwater can therefore be attenuated over time with increasing distance from the release source of those metals.

Metals dissolved in groundwater are potentially transported to surface waters in the streams that originate as groundwater seeps west of the Hansville Landfill. These metals can in turn move downstream as dissolved components in surface water or can adsorb to sediments and particulate matter in the streambeds. Subsequent migration of metals absorbed in sediments can then occur under the influence of surface water flow.

6. CLEANUP STANDARDS

Cleanup standards consist of two components:

- Cleanup levels (chemical concentrations), and
- Points of compliance (at which the cleanup levels must be met).

Cleanup standards are established in accordance with WAC 173-340-700 through -760. The cleanup standard selection process for the Site is described in the following sections.

6.1 CLEANUP LEVELS

Preliminary Cleanup Levels (PCLs) were established for chemicals in groundwater, surface water, and sediments in Chapter 8, Chemical Screening, of the RI report (Parametrix 2007). These PCLs and the ARARs used in their derivation are described in Chapter 4 of this FS report (see Tables 4-2a through 4-4b).

As previously described in Section 4.3, Summary of Risk Assessment Results, the indicator hazardous substances retained for further consideration in this FS report remedial alternatives analysis are arsenic, manganese, and vinyl chloride in groundwater (see Table 4-18). As noted in Table 4-18, arsenic and vinyl chloride in surface water are addressed by their selection for further evaluation in groundwater, because groundwater discharges directly to surface water downgradient of the Landfill, and therefore must meet surface water standards. The risk assessment did not identify any other indicator hazardous substances in any of the three media (groundwater, surface water, or sediments) for further consideration in the remedial alternatives analysis. The PCLs and proposed Site Cleanup Levels are shown in Table 6-1.

6.2 POINT OF COMPLIANCE

As described in the RI report (Parametrix 2007), neither the Upper Aquifer nor downgradient surface water is currently used as a drinking water source, and therefore, there is currently no direct exposure or risk to human health. The future beneficial use of the Upper Aquifer is unknown at this time; it may or may not be used as a source of drinking water. For this reason, the FS considers the following conditional points of compliance (POC):

1. The Upper Aquifer at the Landfill Property boundary;
2. The Upper Aquifer downgradient of the Landfill Property boundary and upgradient of the creek headwaters on Tribal property; and
3. Groundwater discharge to surface water at the headwaters of Creek A, Creek B, and Middle Creek on Tribal property.

Number 1 is a POC, per WAC 173-340-720(8)(c). Numbers 2 and 3 above are off-property conditional POCs, per WAC 173-340-720(8)(d)(ii). Documentation that the conditions for 2 and 3 are met is provided in Table 6-2. The agreement for access to the off-property conditional POCs was executed between the PLP Group and the Tribe on May 2, 2007.

This FS report presents a range of remedial alternatives and associated estimates of time required to meet cleanup levels at the Landfill Property boundary POC.

7. TECHNOLOGY IDENTIFICATION AND SCREENING

A wide range of remediation technologies are identified and evaluated in this chapter in order to select the technologies that could potentially be appropriate at the Site to achieve the remedial action objectives. Technologies that are retained after applying the selected screening criteria will provide the basis for developing remedial action alternatives. Technologies that are rejected will not be considered further. Briefly, the major elements of this section chapter are intended to:

- Identify remediation technologies;
- Evaluate (screen) the technologies based on the criteria of technical feasibility, implementability, and cost; and
- Select potentially feasible technologies for further analysis as remedial alternatives.

7.1 IDENTIFICATION OF REMEDIAL TECHNOLOGIES

Remediation technologies are identified below for four general categories of interest:

- Waste/source control,
- Groundwater containment,
- Groundwater remediation for vinyl chloride, and
- Groundwater remediation for arsenic and manganese.

7.1.1 Waste/Source Control Technologies

This category includes the direct control of potential contaminant releases from the solid waste, demolition waste, and septage waste disposal areas. Waste/source control technologies address:

- Physical/chemical transformation of the waste to remove, destroy, detoxify, or immobilize contaminants; and
- Containment/source control barriers to prevent the release of leachate or gases from the wastes to the environment.

Waste/source control technologies include:

- Natural attenuation,
- Gas extraction system enhancements,
- Institutional controls,
- Impermeable bottom liner,
- Surface cap enhancement,
- Waste excavation and off-site re-disposal, and
- Waste excavation and treatment via incineration (on-site/off-site), glassification, bioremediation, leaching, or waste/soil mixing.

At the Landfill, significant source control measures (i.e., the landfill cap and the gas extraction system) have already been implemented and are currently in operation.

7.1.2 Groundwater Containment Technologies

This category includes both groundwater extraction technologies and technologies designed to prevent groundwater migration by means of engineered containment zones and institutional controls. As such, these technologies are applicable to all indicator hazardous substances in groundwater. Groundwater containment technologies are of two types:

- Isolation techniques to prevent or reduce mixing of affected groundwater with unaffected groundwater and to prevent migration of affected groundwater, and
- Extraction techniques to remove affected groundwater and/or hydraulically prevent further migration of affected groundwater. Extracted groundwater that contains indicator hazardous substances in excess of applicable regulatory standards requires treatment before discharge.

Groundwater containment technologies include:

- Institutional controls (such as signage, fencing, and land-use restrictions),
- Groundwater isolation using slurry wall or cut-off wall, and
- Groundwater extraction using wells or other methods.

Extracted and treated groundwater could be disposed of via:

- Discharge of treated groundwater to surface water,
- Return of treated groundwater to the Upper Aquifer, and
- Application of treated water to the Landfill.

7.1.3 Groundwater Remediation Technologies for Vinyl Chloride

This category includes technologies that address existing vinyl chloride concentrations in both on-site and off-site groundwater, and potential future additional vinyl chloride influxes to groundwater in the vicinity of the Landfill. The proposed technologies effect physical/chemical transformations to remove, destroy, detoxify, or immobilize vinyl chloride, both in situ and ex situ, in groundwater.

Vinyl chloride removal technologies include:

- Natural attenuation,
- Air sparging (in situ),
- Bioremediation (in situ),
- Air stripping, and
- Liquid-phase carbon adsorption.

Treatment using vapor-phase carbon adsorption or incineration may be appropriate for any off-gases generated by these technologies. Extracted groundwater may require disinfection via ultraviolet (UV) sterilization, chlorine oxidation, or ozonation to control biological fouling.

7.1.4 Groundwater Remediation Technologies for Arsenic and Manganese

This category includes technologies that address both existing arsenic and manganese concentrations in on-site and Landfill-affected off-site groundwater, and potential future releases of arsenic and manganese as the waste in the Landfill decomposes. The proposed technologies effect physical/chemical transformations to remove, destroy, detoxify, or immobilize arsenic and manganese in groundwater, both in situ and ex situ. Arsenic and manganese, while not identical, have sufficiently similar properties to be evaluated simultaneously.

Arsenic and manganese removal technologies include:

- Natural attenuation,
- Air sparging (for in situ precipitation),
- Precipitation by chemical injection (in situ),
- Greensand filtration,
- Precipitation/settling,
- Reverse osmosis, and
- Ion exchange.

7.2 TECHNOLOGY SCREENING CRITERIA

Three criteria were established to screen the potential remediation technologies identified for the Site. These include (in order of application):

- **Technical Feasibility –** Engineering factors related to the ability of the technology to function effectively and achieve meaningful progress toward the remedial action objectives, based on site-specific characteristics, including: the nature and extent of indicator chemicals, waste/source type and locations, site hydrogeology, and time required to achieve cleanup levels.
- **Implementability –** Administrative issues related to the technology, including government regulatory approvals, construction schedule, constructibility, access, monitoring, operation and maintenance, and community concerns.
- **Cost –** The relative cost of the technology, including initial capital and future annual operating, maintenance, and monitoring costs, compared to other similarly applied technologies. Estimated costs presented in this FS report are included to support the evaluation and ranking of alternatives. These costs are estimates and have varying degrees of uncertainty, as described by the methods and assumptions presented in Chapter 8, Chapter 10, and Appendix G.

The goal of the screening process is to select the most practicable technology from among each category of similar technologies.

7.3 TECHNOLOGY SCREENING

This section presents the results of the technology screening process. The results of the screening evaluation are summarized in Table 7-1. Key elements of the screening process for technical feasibility, implementability, and cost for specific technologies are summarized in Tables 7-2 to 7-5. Details of the screening are described in the screening matrices of Tables 7-6 through 7-9.

8. DEVELOPMENT OF REMEDIAL ALTERNATIVES

This chapter describes the remedial alternatives developed for the Hansville Landfill Site from the technologies that were retained in the screening process presented in Chapter 7. All of the retained technologies were incorporated in at least one alternative, and some alternatives combine multiple technologies. The alternatives are summarized in Table 8-1.

The intent in developing remedial alternatives for the Site was to provide a range of treatment levels ranging from no additional action to complete removal of all waste materials from the Landfill. Each alternative was developed as a stand-alone approach, with additive technologies as appropriate, to enhance treatment and recovery, such as groundwater extraction alternatives with differing treatment technologies. Some alternatives address controlling future releases of indicator hazardous substances from the Landfill; others provide for cleanup of groundwater containing indicator hazardous substances. The final remedy may incorporate more than one alternative to fully address the remedial aspects of the Site.

8.1 ASSUMPTIONS

For each alternative incorporating an active treatment process, an average and an upper-bound treatment condition were identified. The intent of identifying two treatment conditions was to provide ranges of conditions and costs for evaluating alternatives. The average condition was based on average values of relevant input parameters, such as indicator hazardous substance concentrations and Upper Aquifer properties. The upper-bound treatment condition was based on higher values for the input parameters, such as upper-bound 97.5 percent confidence interval for indicator hazardous substance concentrations in groundwater.

In some cases, the upper-bound values were specifically calculated results from detailed analyses. In other cases, they were technical judgments based on past experience with similar projects. For each alternative, the upper-bound treatment condition provides a conservatively high estimate of factors and costs associated with the alternative, but do not indicate the maximum possible cost.

Capital, operating and maintenance, and present-worth costs were developed for each alternative. Costs are presented in detail in Appendix G and summarized in this chapter. These costs have sufficient accuracy for comparing and evaluating the costs and benefits of alternatives at the conceptual design and feasibility study level, but these costs are not sufficiently accurate to be used for construction cost estimates.

The estimates include costs for design, purchase, installation, operation, maintenance, and monitoring for each remedial action treatment system for a specified project duration. Costs for normal landfill post-closure operation and maintenance (including environmental monitoring and operation of the landfill gas system) were included as part of the remedial alternative cost estimates. Present worth costs were determined using a standard engineering economy calculation. An interest rate of 5 percent was assumed as appropriate for estimating the time-value of costs for up to 23 years into the future, the anticipated project duration of the lengthiest alternative.

A preliminary identification of monitoring program details such as analyses and number of samples was necessary to estimate operating costs of each alternative. The monitoring program identified sample collection frequencies, sampling locations, and analytical testing parameters for landfill gas, groundwater, surface water, and treatment processes.

The monitoring locations, frequencies, and analysis parameters would be refined for the selected alternative during the remedial design. Costs for landfill post-closure monitoring, as required by state regulations, would occur regardless of the remedial alternative selected, and are included in the cost estimate for Alternative 1 (No Additional Action with Natural Attenuation). The monitoring programs and institutional controls described in Alternative 2 (Natural Attenuation of Groundwater with Enhanced Monitoring and Enhanced Institutional Controls) are also integrated into Alternatives 3 through 6.

8.2 BASIS FOR DEVELOPMENT OF ALTERNATIVES

This section describes the data that provide the basis for the development and comparison of alternatives. These data include projected landfill leachate generation rates, Upper Aquifer hydraulic properties, and concentrations of indicator hazardous substances.

8.2.1 Predicted Landfill Leachate Release Rates

The RI reported that, prior to installation of the landfill cap by the Landfill operator, the Landfill produced approximately 4.5 million gallons of leachate per year. Leachate release rates from the Landfill following installation of the cap were predicted using the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994b). Additional discussion and computer output for the HELP modeling analysis is provided in Appendix C.

The results from the modeling analysis, summarized in Table 8-2, predict that the impermeable cap installed at the Landfill in 1989 has provided a beneficial effect in reducing leachate release quantities. Based upon this model analysis, the leachate release rate from the Landfill was less than 100,000 gallons per year in 1999. The model predicts that the leachate generation rate in 2008 and 2018 would be 40,000 gallons per year and 24,000 gallons per year, respectively. These results show that although leachate releases would decline significantly with time, small quantities of leachate may continue to drain from the Landfill for several decades as moisture accumulated prior to installation of the cap is released and as the waste biologically decomposes.

8.2.2 Physical Properties of the Upper Aquifer

Physical properties of the Upper Aquifer documented in the RI report (Parametrix 2007) include horizontal hydraulic conductivity and aquifer hydraulic gradient. The hydrostratigraphy of the Upper Aquifer was characterized in the RI as consisting primarily of poorly graded, fine- and medium-grained sand with trace amounts of silt and gravel. Sandy aquifer material of this nature is generally fairly porous (porosity ≈ 0.2) and contains very little organic carbon (0.02 percent to 1 percent; Yang 1998).

Groundwater flow velocities and travel times are important for estimating remediation rates for several alternatives. Estimates of groundwater flow velocities were presented in Tables 5-7 and 5-8 of the RI report (Parametrix 2007). Results indicated that the expected groundwater travel time from the Landfill to Middle Creek is between 2 and 15 years. The groundwater travel time is the estimated time for a particle of water in the Upper Aquifer to flow from the Landfill to the headwaters of downgradient creeks. The travel time also represents the time required to discharge one pore volume of water through the Upper Aquifer. A pore volume is the volume of water contained within the Upper Aquifer (i.e., the total bulk aquifer volume minus the volume of the solid particles that make up the Upper Aquifer matrix).

The travel times for organic compounds such as vinyl chloride are affected by other fate and transport processes, including biological degradation and sorption to organic carbon in Upper Aquifer soils. Biological degradation rates of vinyl chloride are expected to be very low due to the generally low oxygen conditions in the Upper Aquifer immediately beneath and downgradient of the Landfill. As noted in Chapter 5, the anaerobic half-life of vinyl chloride in groundwater is on the order of 100 months.

Sorption is the chemical attachment of one substance to another without a chemical reaction. Sorption normally involves relatively weak forces and is therefore often temporary and reversible. Sorption, however, may have an influence by decreasing vinyl chloride travel times and cleanup rates, even though the organic carbon fraction of sandy material, which provides the sorption sites in the Upper Aquifer, is very low.

As explained in Appendix F, cleanup times were estimated for vinyl chloride assuming retardation factors due to sorption of between 1.4 and 2.0 for the average and upper-bound remediation cases, respectively. These results are displayed in Table 8-3. As shown, taking into account sorption effects leads to a potential doubling of the travel times or pore volumes needed to eliminate vinyl chloride from the Upper Aquifer. These results do not apply to arsenic or manganese because these indicator hazardous substances do not sorb to organic material.

The estimated vinyl chloride travel times in Table 8-3 provide an indication of the time to purge residual vinyl chloride from the Upper Aquifer to surface water, after the Landfill stops releasing vinyl chloride to groundwater in concentrations that exceed the Site cleanup levels. Landfill closure in 1989 controlled landfill gas and greatly reduced leachate generation rates (see Table 8-2), thereby greatly reducing the quantity of vinyl chloride released to groundwater.

The RI documented low concentrations of vinyl chloride in groundwater (i.e., less than 0.011 mg/L in on-site monitoring wells [MW-1 through MW-7 and MW-14]) and confirmed that these concentrations are declining over time. The concentrations of vinyl chloride currently present in on-site and off-site groundwater are reflective of the reduced rate of input of vinyl chloride from the Landfill to groundwater. The observed concentrations in groundwater represent residual levels of vinyl chloride that have not yet discharged to surface water.

8.2.3 Groundwater Chemistry of the Upper Aquifer

8.2.3.1 Overview of Monitoring Data

Table 8-4 presents a summary of concentrations for indicator hazardous substances and other parameters of interest in the Upper Aquifer, based on the required four quarters of monitoring completed during the RI. Two of these four monitoring events included testing for a wide range of chemicals, which supports the identification of indicator hazardous substances in Table 8-4.

Data from Ecology-directed monitoring following the four initial RI sampling events confirm that concentrations of indicator hazardous substances are decreasing over time. Data from the Ecology-directed sampling events are discussed qualitatively where necessary to document changes that have occurred since the four RI sampling events. Use of data from the RI sampling events is conservative and provides worst-case concentrations of indicator hazardous substances in groundwater because decreasing groundwater concentrations of indicator hazardous substances have been observed in the Ecology-directed monitoring data collected through January 2004 (Parametrix 2007). Table 8-4 presents groundwater concentrations as follows:

- <u>"On-site Concentrations" (monitoring wells MW-4, MW-6, MW-8D, and MW-14):</u> These wells generally contain the highest concentrations of indicator hazardous substances and other parameters measured during the RI and are representative of groundwater that would be treated at the Landfill Property boundary.
- <u>"Off-site Concentrations" (monitoring wells MW-9, MW-10, MW-12, MW-12I, MW-13S, and MW-13D):</u> In comparing the concentrations of indicator hazardous substances and other parameters from well to well, the concentrations are highly variable but are representative of groundwater flowing to Middle Creek and of groundwater that would be treated beyond the Landfill Property boundary.
- <u>Upgradient (monitoring well MW-5):</u> This well represents groundwater quality upgradient of the waste disposal areas of the Landfill.

For each of these areas, the following groundwater chemical concentrations are presented in Table 8-4: average, upper-bound (except upgradient well), and maximum concentrations. The upper-bound concentrations are upper-bound, 97.5 percent confidence interval values. The upper-bound confidence interval is a standard statistical tool for evaluating these types of data. These data were used in the development of the cleanup alternatives discussed in the following chapters of this report.

Groundwater monitoring data presented in the RI report (Parametrix 2007) show that both on-site and off-site vinyl chloride concentrations are decreasing with time. These results demonstrate that installation of the landfill cap and active gas control system in 1991 has been effective at reducing inputs of vinyl chloride to groundwater and that natural attenuation is reducing vinyl chloride concentrations in groundwater from their historical maximums.

8.2.3.2 Trends in Indicator Hazardous Substances

Time-series plots of quarterly data from monitoring wells and surface water stations at the Site provide useful insights regarding chemical releases from the Landfill since closure in 1989. Vinyl chloride, arsenic, and manganese, indicator hazardous substances identified by the risk assessment for groundwater and surface water (see Table 4-17), are plotted on Figures 8-1 through 8-6. The year 1997 is used as a reference because all monitoring wells and surface water stations were installed by this year. These figures illustrate the following trends:

- Vinyl chloride in groundwater and surface water (Figures 8-1 and 8-2) is decreasing at rates that would likely drop below the Site cleanup level of 0.000025 mg/L at the Landfill Property boundary POC within 23 years.
- Arsenic in groundwater (Figure 8-3) downgradient of the Property has been below the Site cleanup level of 0.005 mg/L since 1997 and in surface water (Figure 8-4) since late 2003 for all but three events. Arsenic concentrations in monitoring wells MW-6 and MW-14 on Landfill Property continue to exceed the Site cleanup level but show a relatively stable trend that would likely drop below the cleanup level at the Landfill Property boundary POC within 23 years.
- Manganese in all on- and off-site monitoring wells (Figure 8-5) except MW-14 has been below the Site cleanup level of 2.24 mg/L since late 2001. The recent trend in MW-14 data indicates that manganese at this location would likely drop below the Site cleanup level at the Landfill Property boundary POC within 4 to 8 years.

Manganese in surface water (Figure 8-6) has always been below the Site cleanup level.

These data trends indicate that impacts to groundwater and surface water from the Landfill are declining at rates that would result in compliance with Site cleanup levels at the Landfill Property boundary POC within an estimated time frame of 23 years. This cleanup time frame is incorporated into the evaluation of remedial alternatives presented in following sections.

8.3 ALTERNATIVE 1: NO ADDITIONAL ACTION WITH NATURAL ATTENUATION AND INSTITUTIONAL CONTROLS

8.3.1 Description

8.3.1.1 Overview

This alternative would continue source-control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation, an active landfill gas control to remove vinyl chloride and prevent gas migration from the waste, and an engineered stormwater management system, implemented at a combined cost of $2.3 million at the time of construction (1989 to 1994). Natural attenuation of indicator hazardous substances in groundwater, surface water, and landfill gas would continue, as would compliance with requirements of State and Local regulations for landfill post-closure (WAC 173-304; KCHD Landfill Post Closure Permit). No additional actions directly supporting Site cleanup would be implemented; these actions are included in Alternatives 2 through 9.

8.3.1.2 Institutional Controls

Institutional controls would likely consist of signage and existing regulatory requirements that prohibit the installation of water supply wells on non-Tribal land within 1,000 ft of the Landfill Property boundary and use of groundwater from the affected portion of the Upper Aquifer beneath the Site. These restrictions would be enacted or enforced on non-Tribal property within the Site Boundary. The proposed boundary for application of institutional controls is shown on Figure 8-7.

Subsection (3)(b)(vi) of WAC 173-160-171 (Construction and Maintenance of Wells) prohibits water supply wells from being located within 1,000 ft of the property boundary of a solid waste landfill. This existing institutional control would apply to the Landfill Property itself and the non-Tribal private properties to the north and east of the Landfill Property (see Figure 8-7). However, property located west and south of the Landfill Property is held in trust by the Federal government for the Port Gamble S'Klallam Tribe and is not directly subject to state water-well regulations.

Establishment of groundwater institutional controls as shown would not affect existing water supply wells. Currently, there are no water supply wells within the 1,000-ft restricted area that withdraw water from the Upper Aquifer (see Figure 4-4). A review of water well records on file with Ecology was conducted during the RI review (see Section 4.1.2.1). The review indicated that only three nearby wells are screened into the Upper Aquifer, and these are located to the east (hydraulically upgradient) of the Landfill.

8.3.1.3 Natural Attenuation Processes

Alternative 2 relies upon natural attenuation processes (within the context of controlled and monitored Site conditions) to achieve specific remedial objectives. Natural attenuation is the process by which concentrations of chemicals introduced into the environment are reduced over time by natural physical, biological, and chemical processes. Natural attenuation has been shown to effectively reduce the concentrations of inorganic and organic contaminants in groundwater.

Natural attenuation as a remediation alternative is most appropriate for sites with the following characteristics (WAC 173-340-370(7)):

- Source control is concurrently and effectively applied;
- Human health and the environment are protected;
- Site-specific remediation objectives can be achieved in a reasonable time frame;
- Migration of groundwater is limited;
- Transformation of contaminants into more mobile or more toxic substances is unlikely;
- Transformation processes are irreversible;
- Effectiveness of attenuation processes can be supported with site-specific data;
- Methods to monitor remediation progress are available; and
- Backup or contingency plans are available.

Table 8-5 describes how the Hansville Landfill Site meets these criteria.

As discussed in detail in the RI report (Parametrix 2007), landfills typically follow a pattern of activity with age. Initially, biological activity is intense, but as moisture declines following capping of the waste and the most readily degradable wastes are consumed, biological activity declines. Leachate and gas generation rates also decline with time after closure.

Biological activity has been and is continuing to decompose waste materials in the disposal areas at the Landfill. Because of the Landfill cap and the age of the waste, it is anticipated that gas and leachate generation rates would continue to decline with time.

Trichloroethylene, a common solvent found in commercial cleaning products, and therefore in municipal refuse, is a potential source of vinyl chloride present in landfill gas and leachate. Other potential sources of vinyl chloride include refrigerants, floor tiles, plastics, drugs, and cosmetics. Most of the vinyl chloride precursors originally present in the Landfill are completely decomposed, as indicated by steadily declining concentrations of dichloroethane and dichloroethylene in groundwater over time. In the absence of further generation of vinyl chloride, concentrations of vinyl chloride in landfill gas, leachate, and groundwater beneath the Landfill would continue to decline with time.

Natural attenuation processes at the Site that may reduce vinyl chloride concentrations in groundwater during transport downgradient are dispersion, biodegradation, and volatilization. Natural processes at the Site that may reduce arsenic and manganese concentrations in the groundwater are dispersion and geochemical precipitation/fixation as a result of oxidation reactions. The magnitude of the potential concentration reductions from natural attenuation processes is discussed in the following sections of this report.

Dispersion of indicator hazardous substances in groundwater during flow downgradient of the Landfill provides a benchmark for assessing the magnitude of other natural attenuation processes. Approximate dispersion rates for groundwater between the Landfill and Middle Creek were estimated by taking the ratio of concentrations of conserved substances at each location, after subtracting background concentrations, as shown in Table 8-6.

Conserved substances are those that are unlikely to engage in natural attenuation processes other than dispersion. These substances include chloride, sulfate, sodium, and specific conductivity. Using average groundwater concentration data collected over the four quarters of RI monitoring, this analysis indicates that groundwater is dispersed by an average factor of approximately 2.5, which was calculated for flow from monitoring wells on the Landfill Property to downgradient wells located on Tribal Property.

Natural Attenuation of Vinyl Chloride

Based on RI data, monitoring well MW-6, immediately adjacent to the solid waste disposal area, contained about 0.01 mg/L of vinyl chloride, while off-site well MW-12I contained about 0.0035 mg/L, for a ratio of 2.9. This is nearly equal to the general groundwater dispersion ratio of 2.5, calculated above, indicating that processes other than dispersion (biodegradation and volatilization) are not likely to be significant factors that affect groundwater vinyl chloride concentrations. For vinyl chloride in surface water, the RI documented that volatilization is the primary natural attenuation process that has quickly reduced concentrations to non-detectable levels.

Natural Attenuation of Arsenic and Manganese

Attenuation processes other than dispersion appear to be providing significant beneficial reductions in arsenic and manganese concentrations. Comparison of arsenic concentrations in the on-site wells (0.008 mg/L) and in the off-site wells (0.001 mg/L) indicates that the concentrations have been reduced to levels similar to those found in the upgradient well (MW-5), and have experienced reductions in concentration in excess of what was expected strictly from groundwater dispersion. Repeating this comparison for manganese also indicates substantial reductions in manganese concentrations (from 2.8 mg/L to 0.08 mg/L) that were in excess of concentrations expected due to only the groundwater dispersion rate. These reductions are probably a result of oxidation reactions that cause precipitation and immobilization of manganese. Arsenic is known to co-precipitate with and adsorb to iron and manganese, and this may be the mechanism responsible for its removal. Note that iron levels in groundwater are also elevated adjacent to the solid waste disposal areas (about 1 mg/L), but return to levels observed upgradient at off-site monitoring locations (0.04 mg/L).

Oxidation reactions of this sort are further supported by the dissolved oxygen levels shown in Table 8-4. Dissolved oxygen levels in groundwater beneath the Landfill Property are low (< 1 mg/L), indicative of reducing conditions that have a tendency to mobilize iron and manganese. In contrast, the dissolved oxygen concentrations in off-site wells are greater than 2 mg/L and indicative of oxidizing conditions, which have a tendency to precipitate and immobilize iron and manganese.

8.3.2 Costs

Alternative 1 costs consist of post-closure monitoring and operation of the landfill gas control system. The cost of post-closure monitoring and gas system operation (assuming routine post-closure) is estimated to have a present-worth cost of about $638,000. This cost is based on an estimated 23 years for cleanup by natural attenuation to be complete, and monitoring of four wells (one upgradient and three downgradient) and four surface water monitoring stations. Detailed costs for Alternative 1 are provided in Appendix G.

8.3.3 Advantages/Disadvantages

The advantages of Alternative 1 are low cost, simplicity, and ease of implementation. In addition, concentrations of indicator hazardous substances would continue to decrease through ongoing natural attenuation. The disadvantage of Alternative 1 is no assurance of complete protection of human health and the environment due to absence of enhanced monitoring to demonstrate natural attenuation and enhanced institutional controls to address potential human exposures to groundwater on Tribal property.

8.4 ALTERNATIVE 2: NATURAL ATTENUATION OF GROUNDWATER WITH ENHANCED MONITORING AND ENHANCED INSTITUTIONAL CONTROLS

This alternative would establish institutional controls on the Site to provide a legal basis for restricting access to affected groundwater and surface water. Existing source control and natural attenuation processes would continue to reduce concentrations of indicator hazardous substances. Enhanced monitoring would be implemented to quantitatively measure the progress of natural attenuation and to measure the progress of these reductions toward achievement of cleanup standards. This alternative may be combined with other alternatives involving active treatment to provide additional treatment of indicator hazardous substances.

This alternative would continue and build on source control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation and an active landfill gas control to remove vinyl chloride and prevent gas migration from the waste.

8.4.1 Description

8.4.1.1 Enhanced Institutional Controls

In addition to the institutional controls described for Alternative 1, enhanced institutional controls for Alternative 2 would incorporate property restrictions (including restrictions on the use of groundwater and surface water) on the Tribal lands, per the agreement of the Tribe and the PLP Group executed on May 2, 2007. Institutional controls would remain in place until concentrations of indicator hazardous substances in groundwater beneath Tribal property fall below Site cleanup levels. Using data from the ongoing groundwater monitoring program, property restrictions would be reviewed at 5-year intervals to determine if additional restrictions are warranted, or if previously enacted restrictions could be eliminated or reduced in the area.

Institutional controls on Tribal Property would also prohibit use of surface water in the upper reach of the northern tributary of Middle Creek as a source of drinking water. Establishment of surface water institutional controls as shown would not affect existing water supplies. Currently, surface water from the upper segments of Middle Creek and from the other streams on Tribal property is not used as a source of drinking water. Surface water institutional controls would remain in place until concentrations of indicator hazardous substances in surface water fall below Site cleanup levels.

8.4.1.2 Enhanced Monitoring

A key element of any remedial action is a groundwater and surface water monitoring program designed to assess the progress toward achievement of remedial action objectives and cleanup standards. In order to demonstrate natural attenuation per regulatory requirements [WAC 173-340-370(7)(d)] and technical guidance (Ecology 2005), the monitoring program for Alternative 2 includes enhanced monitoring that includes testing of chemicals indicative of natural attenuation, and selecting existing groundwater and surface water sampling stations to provide optimal spatial coverage to monitor natural attenuation processes.

8.4.2 Costs

The estimated capital, operating, monitoring, and maintenance, and present worth costs for Alternative 2 are:

Item	Average [1]
Capital Cost	$5,000
Operating, Monitoring, and Maintenance	$1,175,000
Present Worth	$1,180,000

[1] An upper-bound cost does not apply to Alternative 2 because the operating, monitoring, and maintenance costs are fixed. Detailed supporting cost information is included in Appendix G.

8.4.3 Advantages/Disadvantages

The advantages of this alternative are as follows:

- Simple in concept.
- Easy to implement.
- Protects human health and the environment by providing a legally enforceable mechanism to prevent exposures to groundwater and surface water, both on-site and off-site.
- Monitoring requirements are not significantly greater than for an active treatment system.
- Low cost.
- Indicator hazardous substances are reduced through natural attenuation processes.
- Technology required for implementation is proven and available.

The disadvantages are as follows:

- Based on leachate generation projections, trends in concentrations of indicator hazardous substances, and estimated groundwater flow velocities, a time period on the order of 23 years would be required before cleanup standards are achieved, meaning that affected groundwater and surface water would remain unusable as a drinking water source for this period of time.

- Does not provide for containment of indicator hazardous substances in groundwater at Landfill Property boundary.
- Provides no active treatment to reduce toxicity, mobility, or volume of indicator hazardous substances.

8.5 ALTERNATIVE 3: GAS EXTRACTION SYSTEM ENHANCEMENTS

Alternative 3, which also incorporates Alternative 2, would implement enhancements to the existing gas extraction system to reduce transport of vinyl chloride to groundwater, which would reduce vinyl chloride concentrations in groundwater beneath the Landfill, downgradient of the Landfill, and eventually in surface water on Tribal property. In addition to reducing vinyl chloride transport, the enhancements would improve oxygen transfer to the Upper Aquifer below the Landfill Property and thus promote oxidizing conditions, which have a tendency to immobilize certain metals (including iron and manganese).

The intent of this alternative is to provide a flow of air through the vadose zone below the Landfill at a velocity that is sufficient to overcome the downward vinyl chloride diffusion velocity. Vinyl chloride would continue to diffuse from the waste and leachate; however, it would be transported by the flow of air through the vadose zone to the soil vapor extraction (SVE) wells and recovered. The extracted soil vapor is expected to have low methane content and thus combustion in the existing flare is not feasible. Vinyl chloride emissions are expected to be very low and would be vented to the atmosphere without treatment (see Appendices D and E).

Use of a gas extraction system to control diffusion of contaminant migration in the vadose zone is innovative, and the effectiveness of this technology is uncertain. If the gas extraction system enhancements do not achieve complete control of indicator hazardous substances entering groundwater at the Landfill, cleanup standards (particularly the very low cleanup standard for vinyl chloride) likely would not be achieved in the on-site and off-site monitoring wells in a reasonable time period, thus negating a significant potential benefit of this alternative.

This alternative would continue and build on source control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation and an active landfill gas control to remove vinyl chloride and prevent gas migration from the waste.

8.5.1 Description

8.5.1.1 Enhanced Gas Extraction System

The gas extraction system enhancements would consist of the installation of several SVE wells on the east side of the solid waste disposal area. Air would be allowed to infiltrate into the vadose zone through new and existing perimeter gas extraction wells (PW-1 to PW-5), which in turn would be extracted from the new SVE wells on the west side of the Landfill wells.

A proposed layout of the gas extraction system enhancements is shown on Figure 8-8. A cross section of the Landfill showing well depths is shown on Figure 8-9. In general, air infiltration wells would be installed on approximately 250-ft centers downgradient (west) of the Landfill, and SVE wells would be installed upgradient (east) of the Landfill. With this orientation, the air flow would move in the opposite direction of groundwater flow. In this manner, the fresh air from the vadose zone air infiltration wells would be in contact with groundwater under the Landfill to promote volatilization of vinyl chloride from the groundwater within the vadose zone. It would also reoxygenate the area below the Landfill, which would tend to immobilize certain metals.

The air infiltration wells would be installed to a depth just above groundwater and would have perforations 5 ft above the known high groundwater level. There are two mechanisms that would cause air to enter the vadose zone through the air infiltration wells. The primary mechanism would be the pressure gradient caused by the SVE wells upgradient of the Landfill. The SVE wells would be installed on 400-ft centers and connected to a vacuum blower. Thus, the vacuum provided by the blower would draw air through the vadose zone from the surrounding soil and through air infiltration wells. The wells would be installed with perforations extending a few feet above the highest known groundwater level (Figure 8-9). Since the existing gas control systems pumps landfill gas from the in-refuse gas wells (located approximately 85 ft above the air infiltration/SVE wells, Alternative 3 would not be expected to decrease the effectiveness of the existing landfill gas control system.

The second mechanism for introducing air into the vadose zone would be caused by barometric pumping. Barometric pressure changes throughout the day cause a difference in pressure to occur between the vadose zone pressure and atmosphere. Barometric pressure is typically high in the morning and decreases in the afternoon. Because of the barometric pressure changes, air would tend to enter the vadose zone through the air infiltration well at a greater rate in the morning. In the afternoon, the air flow would tend to move in the opposite direction. To reduce the flow of air out of the vadose zone, check valves would be installed in each of the air infiltration wells.

This type of system is not able to completely prevent the flux of vinyl chloride into groundwater. It may, however, reduce the vinyl chloride transport rate by sweeping air through the vadose zone, thus interrupting this migration pathway. The flow rate of air through the vadose zone is estimated to be 15 scfm from each air infiltration well. The air velocity under the Landfill is estimated to be 0.0009 ft/minute (475 ft per year).

Approximate estimates of annual vinyl chloride emission rates from the SVE wells were calculated by determining the flux of vinyl chloride in groundwater under the Landfill. These calculations are provided in Appendix D. Off-gases from the SVE system are expected to meet air quality standards without further treatment.

This alternative may also provide significant control of manganese and arsenic. Operation of the enhanced gas extraction system provides a continual flow of oxygen into the vadose zone where it can diffuse to groundwater. As discussed for Alternative 2, increases in groundwater dissolved oxygen concentration are expected to cause oxidation of some of the existing soluble manganese and arsenic to insoluble forms, thus immobilizing them in situ.

As shown in Table 8-4, dissolved oxygen concentrations in groundwater under the Landfill are currently very low. Assuming a SVE operation rate of 100 scfm, about 1,000,000 pounds of oxygen would flow into the vadose zone beneath the Landfill each year. Therefore, significant increases in groundwater dissolved oxygen concentrations are likely.

The enhanced gas extraction system is expected to require continuous operation until specific cleanup levels for indicator hazardous substances have been achieved at the Landfill Property boundary point of compliance and vinyl chloride releases from the Landfill are substantially reduced. Vinyl chloride releases from the Landfill are anticipated to significantly decline with time in conjunction with declining gas and leachate generation rates from the Landfill.

Under Alternative 3, remediation of the Upper Aquifer would be achieved using monitored natural attenuation, as described for Alternative 2. Institutional controls would be implemented to provide a mechanism to prevent exposure to groundwater and surface water containing indicator hazardous substances. Assuming 100 percent control of vinyl chloride releases from the Landfill is achieved, and discharge of two pore volumes from the Upper Aquifer are required to achieve the vinyl chloride cleanup level, the total groundwater remediation time for vinyl chloride would be between 7 and 23 years at the surface water point of compliance.

The actual remediation time might be less than the estimated values due to the increased oxygen in the groundwater that would promote aerobic biodegradation of the vinyl chloride. However, the magnitude of the reduction due to biodegradation is not quantifiable at this time. Assuming 100 percent control of arsenic and manganese at the Landfill, the remediation time for these substances is estimated to be between 3 and 13 years because their movement is not retarded by organic matter in the Upper Aquifer as is vinyl chloride (see Section 5.3.2). Immobilization of arsenic and manganese by in situ oxidation and precipitation caused by the aerobic conditions produced by the gas extraction system enhancements would further reduce groundwater concentrations of these substances and would decrease remediation times. However, as with vinyl chloride, the reduction in remediation time is not quantifiable.

8.5.1.2 Monitoring

Monitoring of groundwater, surface water, and landfill gas would be conducted as described for Alternative 2. In addition, the main gas extraction header and each SVE well would be monitored for vinyl chloride. Long-term monitoring would be conducted at a reduced frequency.

8.5.2 Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 3 are:

Item	Average	Upper-bound
Capital Cost	$637,000	$835,000
Operating, Monitoring, and Maintenance	$2,273,000	$2,495,000
Present Worth	$2,909,000	$3,330,000

Detailed supporting cost information is provided in Appendix G.

8.5.3 Advantages/Disadvantages

Alternative 3 is unique among the other alternatives considered in this FS in that it provides for control of vinyl chloride releases from the Landfill before they reach the groundwater. However, the effectiveness of this alternative for control of vinyl chloride releases to groundwater is uncertain and may range between 50 and 100 percent. Enhancements to the gas extraction system may be ineffective at reducing vinyl chloride releases to groundwater if transport via leachate is a significant release pathway, although the flow of air through the vadose zone may be able to strip vinyl chloride from the leachate.

Other advantages are as follows:

- Provides for direct source control and may prevent vinyl chloride from migrating to groundwater.
- Expected to reduce (but may not eliminate) vinyl chloride releases to groundwater.
- Future releases of arsenic and manganese may be immobilized in situ.

- Little Site disturbance due to construction.
- Off-gas from the SVE wells would not require treatment to remove vinyl chloride.

The disadvantages are as follows:

- Unless 100 percent effective, it may not achieve groundwater cleanup levels substantially more quickly than Alternative 2.
- Introduction of air into the vadose zone under the Landfill may allow oxygen to enter the Landfill, enhancing conditions for underground fires within the refuse. Alternatively, excessive vacuum in the SVE wells may draw gas from the Landfill. Thus, the enhanced gas system requires careful design, operation, and monitoring to balance these conditions.
- Theoretically, this methodology should provide effective removal of indicator hazardous substances. However, it has not been tested under these specific site conditions and may not fully meet cleanup standards at the point of compliance.
- When gas extraction ceases, concentrations may increase due to a "rebound" effect. This would be mitigated by alternatively pulsing and resting the system to remove residual contamination that is released after these cycles.

8.6 ALTERNATIVE 4: AIR SPARGING SYSTEM

Alternative 4, which incorporates Alternative 2, includes a line of air sparging wells along the west Landfill Property boundary, to provide a means of intercepting and removing vinyl chloride in groundwater, thus preventing its migration onto Tribal Property. Air sparging as a barrier to control contaminant migration and achieve cleanup levels in a flowing aquifer is an innovative use of this technology; however, its effectiveness when used in this manner is uncertain. If the air sparging system does not achieve complete control of indicator hazardous substances migrating off-site, cleanup standards likely would not be achieved in a time frame much different than Alternative 2, thus negating a significant potential benefit of this alternative.

Air sparging is an in situ process in which air is bubbled through a contaminated aquifer to remove VOCs from groundwater. Injected air bubbles move vertically and horizontally through the saturated soil zone, creating an underground air stripping process that removes contaminants through volatilization. Volatile compounds exposed to the sparged air convert to gas phase and are carried by the air into the vadose zone. Vapor extraction is generally used with air sparging to remove vapors from the vadose zone.

This alternative would continue and build on source control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation and an active landfill gas control system to remove vinyl chloride and prevent gas migration from the waste.

8.6.1 Description

An air sparging system is composed of four basic elements: air sparging wells, an air compressor or blower, a soil vapor extraction system, and a monitoring system. Each of these elements is briefly described in the following paragraphs. A computer-based model, summarized below and described in detail in Appendix E, was used to estimate the size of system components and predict remediation rates.

8.6.1.1 Air Sparging Wells

The mechanics of an air sparge/vent system is shown on Figure 8-10a. An air sparging well is usually constructed of 2-in.-diameter polyvinyl chloride (PVC) pipe. The bottom of the well consists of 2 ft of pervious section (well screen or porous pipe diffuser) connected to a pipe extending from the well screen to the surface (see Figure 8-10b). The sparge well is completed by placing a sand pack around the well screen. A 1- to 2-ft-thick bentonite or cement seal is placed around the sand pack. The well bore is then grouted to the top of the water table.

The vertical profile of a typical sparging system that would be screened in the Upper Aquifer at the Landfill is shown on Figure 8-11. At the Landfill, sparging wells would be installed to a depth of approximately 20 ft below the Upper Aquifer surface. The maximum practical depth of an air sparging well is approximately 30 ft below the groundwater table (Rast 2003). This depth was selected to conservatively reach the vertical extent of groundwater contamination from the Landfill. Near the Landfill, dissolved indicator hazardous substances (vinyl chloride, manganese, and arsenic) are expected to be confined to the shallow zone of the Upper Aquifer.

A computer-based air sparging model was used to estimate the radius of influence and separation distance of sparging wells in stagnant (non-flowing) groundwater. Sparging wells with a depth of 20 ft and an effective radius of 30 ft were predicted by the model to achieve remediation goals for vinyl chloride at the Landfill Property boundary point of compliance within a 200-day period. Figure 8-12 shows the remediation rate of vinyl chloride by air sparging, at an assumed starting concentration of 0.005 mg/L. For remediation in stagnant groundwater, this would imply that sparging wells should be located over the entire zone of contamination and operated for 200 days to achieve the desired Site cleanup standards.

At the Site, groundwater is continuously flowing, not stagnant as assumed in the sparging modeling analysis. Therefore, the air sparging system would have to operate for as long as vinyl chloride flows into the sparging area. Sparging wells would need to be installed over an area having a width across the groundwater flow direction that is equal to the zone of occurrence of vinyl chloride in groundwater (approximately the width of the solid waste disposal area). The sparging area would have a length parallel to the groundwater flow direction equal to the distance required to achieve a 200-day residence time within the sparging zone. Based on a calculated mean groundwater velocity in the vicinity of well MW-14, of 0.47 ft per day (Parametrix 2007), groundwater would travel approximately 90 ft in a 200-day period. Thus, a sparging system with a double line of wells having a 30-ft radius of influence appears adequate to achieve the vinyl chloride cleanup standard, based on the modeling results.

The proposed locations of the sparging wells are shown on Figure 8-13. This figure shows tightly spaced sparging wells, with overlapping radii of influence in the most heavily impacted region between wells MW-6 and MW-14. The wells would be spaced further from one another in the less impacted regions north of MW-6 and south of MW-14. The average remediation condition assumes 30 sparging wells, and the upper-bound remediation condition assumes 60 sparging wells. The actual well spacing and total number of wells would be determined on the basis of field results.

The air sparging system at the Landfill is estimated to require operation for 23 years from start-up. The actual life span of the project is difficult to estimate and is dependent upon numerous factors, including the groundwater flow characteristics, future leachate generation rates from the Landfill, and the future leachate and groundwater concentrations of indicator hazardous substances. During this operating period, the system would be surged and rested in cycles to diminish the "rebound" effect prior to system shut down.

The line of sparging wells would provide a means to intercept and remove vinyl chloride in groundwater at the Landfill Property boundary, thus preventing vinyl chloride migration. Air sparging as a barrier to control contaminant migration is an innovative use of this technology. Its effectiveness when used in this manner is uncertain. Injection of air into the Upper Aquifer has the potential to lower the hydraulic conductivity and create an impediment to groundwater flow. If groundwater containing vinyl chloride were to flow under or around the air sparging zone, concentrations of vinyl chloride in the Upper Aquifer downgradient of the Landfill Property boundary would likely exceed the cleanup standard.

The air sparging model results do not consider the influence of biological degradation and are therefore conservative estimates. Air sparging is expected to convert the Upper Aquifer from a reduced, low-oxygen state to a highly oxygenated state, favoring biological degradation of vinyl chloride. The half-life of vinyl chloride in an aerobic aquifer has been reported to be on the order of 56 days (Aronson and Howard 1997). Therefore, several half-life reductions of vinyl chloride are expected to occur through biological degradation. This removal would be in addition to volatilization from air sparging. The oxygenated state produced by sparging is also expected to oxidize and thus immobilize soluble manganese and iron in the Upper Aquifer. The system would be pulsed to mitigate rebound effects (see Section 8.5.3). The time frame for the air sparging remedy accounts for the potential rebound effect (temporary increase in concentrations of indicator hazardous chemicals in the soil gas) as part of the overall system operation.

8.6.1.2 Blower System

Air would be injected into sparging wells under pressure with a mechanical blower. A pipe manifold constructed of small-diameter PVC pipe is typically used to convey air from the blower to each well. The manifold may be located above or below grade. Air injection pressure is governed by the static water head above the sparge point, the air entry pressure of the saturated soils, and the gas injection flow rate. Working pressures on the order of 15 psi are typical. Air flow rates typically used in the field are between 3 to 10 scfm (Rast 2003). An air flow of 5 scfm per well was assumed in the air sparging model.

Scientific studies have determined that sparging air bubbles move through an aquifer in persistent preferred channels (Wilson et al. 1994; Burns and Zhang 2001). This means that VOCs must move in the aqueous phase by diffusion and dispersion through these air-carrying channels in order to be removed. Studies also have shown that mass transfer rates can be greatly improved by pulsing the flow of air into the sparging well. By pulsing the air flow from the blower, the remediation time can be greatly reduced. Figure 8-14 shows the effects of pulsed air flow on the cleanup time for vinyl chloride. The figure was created with the computerized air sparging model described previously, and shows that increasing dispersivity through pulsing can potentially lead to significant reductions in cleanup times.

In the air sparging model, the dispersivity constant, D, relates to the transport characteristics of VOCs in an aquifer and is a function of molecular diffusion and air dispersion. Molecular diffusion is a physical property unique to a given compound and cannot be controlled by the air sparging process. Dispersion of the sparging gas, on the other hand, is a property that can be controlled by varying the air flow rate or by pulsing the air flow through the well. Aquifer cleanup times depend on dispersivity. A high dispersivity constant implies that the VOC moves relatively quickly from groundwater to the nearest air bubble.

8.6.1.3 Soil Vapor Extraction System

Vapors that are mobilized by air sparging are controlled by the application of a SVE system. The vapor extraction well may be located within the same well boring as the sparging well, as shown in Figure 8-10b. It is similarly constructed of small-diameter PVC piping and extends to the water table. The extraction well is typically screened at approximately 8 ft in the vadose zone, just above the water table.

Alternatively, the perimeter gas wells may be suitable for removing vapors from the vadose zone. As shown on Figure 8-13, the sparging wells are located in proximity to the perimeter gas wells. The existing perimeter wells are screened approximately 10 ft above the water table. The relative vertical positions of sparging wells and gas extraction wells are shown on Figure 8-11. Thus, the perimeter wells may serve to extract all or part of the vapors from the air sparging system. Following installation, field tests would be performed to evaluate the effectiveness of perimeter wells. Each sparging well would be equipped with an SVE well to be used in the event that perimeter wells are found to be less than satisfactory.

An analysis of off-gas quality anticipated from the SVE system was completed (Appendix E). The results indicate that emissions would meet air quality regulations without treatment.

8.6.1.4 Options to Combine with Other Alternatives

Alternative 4 would be combined with enhanced institutional controls (Alternative 2) to ensure that the affected aquifer is not used as a drinking water source during remediation. Alternative 4 may also be combined with Alternative 3, Gas Extraction System Enhancements. By combining the two alternatives, the sparging air would be allowed to sweep across the vadose zone beneath the Landfill. This air would be relatively very low in vinyl chloride and high in oxygen. The SVE system would be located on the east side of the Landfill (as described in Alternative 3), as opposed to being located directly above each sparging well. This combination of alternatives would provide containment of groundwater indicator hazardous substances at the Landfill Property boundary by the sparging wells and enhanced removal of landfill gases beneath the Landfill by the SVE system. The total cost of Alternatives 3 and 4 would not be significantly greater than Alternative 4 by itself.

8.6.1.5 Monitoring

A number of parameters may be used to monitor the performance of an air sparging system. The most common are dissolved oxygen (DO), water table elevation, soil gas vacuum from the SVE system, and VOC concentration. The proposed locations of sparging wells relative to existing groundwater wells and gas probes are shown on Figure 8-13. Existing monitoring wells MW-6 and MW-14 are located along the line of sparging wells and could serve as performance monitoring wells. Because these are the most heavily impacted wells, they could be used as a direct indicator of the performance of vinyl chloride removal from the Upper Aquifer. They could also be used to measure the radius of influence of sparging wells, as indicated by DO and water table measurements.

8.6.2 Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 4 are:

Item	Average	Upper-bound
Capital Cost	$1,985,000	$3,604,000
Operating, Monitoring, and Maintenance	$3,109,000	$4,402,000
Present Worth	$5,094,000	$8,006,000

Detailed supporting cost information is provided in Appendix G.

8.6.3 Review of Application of Air Sparging at Other Sites

The ability of air sparging systems to successfully remediate vinyl chloride contaminated sites to a cleanup level of less than 0.001 mg/L has not been documented. Air sparging has been most commonly used to remediate relatively small sites contaminated with gasoline or other fuels. For National Priorities List (NPL) sites (i.e., "Superfund" sites), soil vapor extraction has been selected as the remedy at approximately 196 sites and air sparging has been used at approximately 48 sites (WEPA 2001). Unfortunately, the sites were not specifically identified, and the number of sites remediating vinyl chloride could not be determined.

The few sites with published data that are using air sparging to treat vinyl chloride in groundwater have established cleanup levels between 0.001 and 0.002 mg/L, which is approximately equal to the Maximum Contaminant Level (MCL) for vinyl chloride. These low concentrations are also approximately 50 to 100 times higher than the MTCA cleanup level proposed for vinyl chloride in groundwater at the Hansville Landfill Site.

The experience gained with air sparging at other sites is of limited applicability to the Hansville Landfill. While vinyl chloride has been found in at least 410 NPL sites (USEPA 2007), it is rarely the sole organic contaminant, as is the case at the Hansville Landfill. More commonly, it co-occurs with other organic solvents. As discussed in Section 5.3.1, vinyl chloride can be formed as a product of the biodegradation of other chlorinated solvents. Frequently, these original chlorinated solvents are present in pure liquid form, either in groundwater or in soil, and provide an ongoing source of solvents (and vinyl chloride) to dissolve into groundwater as cleanup is attempted.

Cleanup of these sites has been slowed by lack of effective source control to remove the concentrated solvents. Typically, the concentrations of the dissolved solvents in groundwater can be readily reduced, but the concentrations rebound substantially following termination of treatment. Thus, treatment must be continued for many years. Most sites with this problem have not yet achieved the originally proposed cleanup levels and are continuing remediation efforts. No pure liquid-form vinyl chloride has been identified at the Hansville Landfill Site; the future release of vinyl chloride currently sorbed to organic matter in the Upper Aquifer may provide a similar ongoing source of vinyl chloride, thus necessitating continued operation of the air sparging system for many years.

The Landfill 4 site at Fort Lewis, Washington (USACE 2000) provides a local example of the difficulty associated with remediating chlorinated solvents in soil and groundwater using air sparging. Groundwater at Fort Lewis was determined to contain up to 0.33 mg/L TCE and up to 0.008 mg/L vinyl chloride, with cleanup standards of 0.005 and 0.001 mg/L, respectively. Air sparging was implemented in 1996 to remediate an area approximately 800 ft in diameter.

Because of the shallow groundwater at the Fort Lewis site, the area was also capped with an impermeable barrier to prevent the SVE system from drawing air into the soil. Remediation using air sparging has not achieved the remedial objectives. In 1999, due to problems with high concentrations of TCE in soil (i.e., the "smear zone" at the soil/groundwater interface) that provided an ongoing source of TCE and vinyl chloride to groundwater, and caused substantial rebound in contaminant concentrations, the air sparging system was permanently shut down (Goth 2000). The remedy was subsequently revised by USEPA to monitored natural attenuation with institutional controls, and long-term monitoring continues (USEPA 2002a).

The Wayne Waste Oil site in Indiana successfully used air sparging to reduce vinyl chloride levels in stagnant groundwater (contained within a slurry wall) from up to 1 mg/L to a cleanup level equal to the MCL of 0.002 mg/L (USEPA 1999a; Gore 2000). While this represents a reduction of approximately three orders of magnitude, high concentrations are known to be more readily treated than low concentrations because mass transfer processes such as diffusion are proportional to concentration. The SVE system and monitoring network were modified in 2002 to make the remedy more efficient. The 5-year preview conducted in June 2004 found that the site remedy remains protective of human health and the environment (USEPA 2006).

Vinyl chloride at the Wayne Waste Oil site co-occurred with high concentrations of other chlorinated solvents and petroleum products. Combined with oxygenation of the groundwater by air sparging, this allowed for aerobic biodegradation of contaminants. Thus, vinyl chloride remediation levels were likely achieved by a combination of volatilization and biodegradation. It is uncertain whether similar biodegradation of vinyl chloride would occur in groundwater at the Hansville Landfill Site, due to the very low concentrations of vinyl chloride and the apparent lack of a food source (such as petroleum) necessary to maintain an active microbial population. The technology screening process presented in Chapter 7 determined that bioremediation of vinyl chloride in groundwater was not technically feasible for the Site.

8.6.4 Advantages/Disadvantages

There are three primary technical advantages that could be expected to result from air sparging:

- In situ stripping of dissolved and adsorbed vinyl chloride from the Upper Aquifer,
- Enhanced biodegradation of adsorbed and dissolved vinyl chloride in the Upper Aquifer due to increased oxygenation, and
- Oxidation and immobilization of manganese and arsenic due to increased oxygenation.

Other advantages of Alternative 4 are listed as follows:

- Simple and mechanically reliable equipment is used.
- Based on the air sparging modeling results, cleanup standards would be potentially achieved in a relatively short period of time at the Landfill Property boundary.
- No off-gas treatment would be necessary to meet the applicable air quality regulations. Detailed calculations of emission rates and dispersion modeling results are contained in Appendix E.
- Very little Site disturbance caused by construction.
- Construction of air injection points allows precise targeting of aeration effect.

Disadvantages of Alternative 4 are as follows:

- Requires operation of the treatment process until the Landfill ceases releasing indicator hazardous substances to groundwater, and seeks only to limit the future spread of indicator hazardous substances rather than provide source control.
- Although outcomes of treatment by air sparging are similar to those of natural attenuation, the cost is much greater. The intent of an air sparging system is primarily to remove vinyl chloride from the Upper Aquifer. This is already occurring naturally

through discharges of groundwater to surface water with subsequent rapid volatilization of vinyl chloride. Source control is being provided by operation of the gas control system already in place at the Landfill, which is currently removing vinyl chloride from the Landfill and preventing its migration from the waste, and by the landfill cap, which is reducing infiltration and hence, leachate generation, by over 99 percent.

- Treatment provides no reduction of existing risks. Assuming appropriate institutional controls are implemented, installation and operation of an air sparging treatment system would provide no reduction in long-term or residual risk. Achieving reductions of existing risks is a key criterion for selection of an alternative under MTCA (WAC 173-340-360(2)(a)).
- Construction and long-term operation of an air sparging system would: (1) be costly due to a need for frequent maintenance and monitoring; (2) consume energy resources, which may result in the emission of air pollution and other negative environmental consequences; and (3) be subject to vandalism, potentially requiring increased site security. These public and private funds and labor, and energy resources would not be available for other uses if consumed in a remedial action at the Site.
- It is not certain that an air sparging system would achieve the desired cleanup level for vinyl chloride (0.0.000025 mg/L) in on-site groundwater. There are no known examples where this technology has been used to achieve such a low vinyl chloride cleanup standard or to immobilize metals in situ. Indicator hazardous substances in groundwater not removed by air sparging would flow off-site and be remediated through natural attenuation. Monitoring of the off-site groundwater and surface water would be needed as a precaution against changes in treatment system performance or other unforeseen events.
- This technology assumes indicator hazardous substances are confined to the upper portion of the Upper Aquifer. The maximum practical depth for air sparging is approximately 30 ft below the Upper Aquifer surface. Sparging below this depth is not feasible.
- Air sparging as a barrier to achieve cleanup levels in a flowing aquifer is an innovative use of the technology. Its effectiveness when used in this manner is uncertain.
- Longer cleanup time of the off-site portion of the Upper Aquifer relative to the pump and treat alternatives.
- Costs are relatively high due to long-term operation and maintenance of sparging and SVE systems.

8.7 ALTERNATIVE 5: GROUNDWATER PUMP AND TREAT AT LANDFILL PROPERTY BOUNDARY

Alternative 5, which incorporates Alternative 2, provides remediation of the Upper Aquifer by extracting groundwater at the Landfill and treating it to remove contaminants prior to discharge of the treated water to Middle Creek. Construction and operation of a discharge pipeline to Middle Creek for treated groundwater would require the consent of the Port Gamble S’Klallam Tribe.

Groundwater extraction at the Landfill Property boundary would function to (1) extract indicator hazardous substances from the Upper Aquifer in the vicinity of and upgradient of the extraction well, and (2) provide a barrier to hydraulically create a zone of groundwater capture spanning the width of the Landfill Property, to prevent continued migration of indicator hazardous substances to off-site groundwater. Natural attenuation would be used to remediate off-site groundwater and surface water.

Alternative 5 incorporates variations of treated water discharge (i.e., surface water discharge or groundwater reinjection). The following section describes the base alternative. Variations are described in subsequent sections.

This alternative would continue and build on source control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation and an active landfill gas control to remove vinyl chloride and prevent gas migration from the waste.

8.7.1 Description

A groundwater pump and treat program has three components: groundwater extraction, groundwater treatment, and treated groundwater discharge. These components are discussed individually in the following sections.

8.7.1.1 Groundwater Extraction

The important factors for groundwater extraction are the number of extraction wells, their locations, and their extraction rates. These factors were analyzed using a computer-based two-dimensional groundwater flow model. Results of the modeling analysis are presented in detail in Appendix F and summarized here.

The modeling analysis indicates that, for groundwater extraction at the Landfill, an effective system configuration is a single extraction well located west/southwest of the solid waste disposal area and just south of MW-6, pumping at a rate of 70 gallons per minute (gpm). Figure 8-15 illustrates the groundwater flow lines and zone of capture based on this analysis, and shows that theoretically, the well would completely capture groundwater flowing beneath the solid waste disposal area at the Landfill. For redundancy, the groundwater extraction system would be designed with two closely spaced wells, each fitted with a pump capable of extracting 70 gpm. Only one pump would be operated at any given time.

The groundwater modeling analysis is based on the geometric mean value of the Upper Aquifer hydraulic conductivities measured during the RI using slug tests. However, slug tests are not highly accurate for measuring aquifer hydraulic conductivity. Therefore, due to potential variability of the Upper Aquifer hydraulic conductivity, a pumping rate up to two times the base flow rate, or 140 gpm, is estimated as an upper-bound value that may be required to achieve complete capture. Groundwater pump and treat systems based on both 70 gpm and 140 gpm are evaluated as representative of average and upper-bound treatment conditions. An aquifer pumping test would be necessary during remedial design to more accurately determine aquifer properties.

The groundwater extraction system at the Landfill is estimated to require operation for approximately 23 years from start-up. The actual life span of the project is difficult to estimate and is dependent upon numerous factors, including the groundwater flow characteristics, future leachate generation rates from the Landfill, and the future leachate and groundwater concentrations of indicator hazardous substances.

8.7.1.2 Groundwater Treatment

Extracted groundwater would be treated using greensand filtration to remove arsenic and manganese, and air stripping to remove vinyl chloride (Figure 8-16). Based on predictions of treatment efficiency, treatment of off-gas from the air stripper would meet air quality ARARs, indicating further treatment unnecessary. An analysis of air emission impacts is included in Appendix E.

Possible effluent limits for discharge of treated groundwater to surface water are summarized in Table 8-7. Treated water discharged to surface water must provide all known available and reasonable treatment (AKART), prevent degradation of existing water quality, and meet state water quality criteria. Final discharge limits for treated groundwater would be determined during remedial design through negotiations with Ecology to meet the substantive requirements of the NPDES permit program.

Discharge limits are identified in this FS to size equipment and develop cost estimates for treatment processes. The discharge limits presented in Table 8-7 are equal to the Site cleanup levels. The Site cleanup levels are based on human health criteria and are lower than applicable acute and chronic surface water quality criteria set forth in Ecology regulations (Chapter 173-201A WAC). The discharge limits are not intended to represent proposed or final values for remedial action.

Arsenic and manganese removal from groundwater would be accomplished by manganese greensand filtration. This technology has been commonly used for years to remove manganese from drinking water (Patterson 1985; AWWA 1990). Arsenic chemistry is such that arsenic ions are simultaneously removed by the greensand along with the manganese ions. The process consists of using a filter bed of sand grains containing high concentrations of manganese dioxide. Manganese ions in the water, upon contact with the filter bed, adsorb to the sand particles.

Greensand is either continuously or intermittently regenerated with potassium permanganate. For continuous regeneration of the bed, low concentrations of potassium permanganate may be added to the water upstream of the filter to oxidize the adsorbed manganese ions to manganese dioxide. The oxidized manganese can then adsorb additional manganese ions.

For intermittent regeneration, filter beds are backwashed periodically with a 0.5 to 1 percent solution of potassium permanganate, to remove accumulated suspended solids. Backwash water is settled to remove solids, and then settled solids are dried and shipped off-site for disposal. It is estimated that filter beds require replacement every 2 years. The depleted sand is shipped off-site for disposal along with backwash solids. This solid waste is non-hazardous.

The greensand filter units for this Site are sized based on literature data indicating a typical flow rate of 3 gpm per square foot (Patterson 1985). A typical sand bed depth is 2 ft. The factors affecting selection and sizing of the treatment equipment are water flow rate and the influent and effluent arsenic and manganese concentrations. Flow rates for Alternative 5 are presented in Table 8-7. Greensand filter system parameters based on these rates are provided in Table 8-8.

Vinyl chloride removal from extracted groundwater is accomplished using an air stripping tower. A computer-based model (Clark and Adams 1988) was used to estimate appropriate diameters and depths of packing. The model analyses are presented in detail in Appendix F and are summarized in Table 8-9 for average and upper-bound conditions.

Total coliform results in the RI report showed elevated concentrations in monitoring well MW-14. Total coliform does not have a surface water quality standard. Fecal coliform is regulated under the State Surface Water Quality Standards, but total coliform is not necessarily an indication of fecal coliform. Future groundwater samples would be tested for the presence of fecal coliform. Extracted groundwater may require disinfection using UV sterilization to prevent potential release of harmful bacteria upon discharge of the treated water to surface water, or to prevent biological fouling of the treatment equipment. Ultraviolet sterilization is a nearly instantaneous process that involves exposing water in a small contact chamber to high-intensity ultraviolet light. Ultraviolet light with a wavelength of 2,500 to 2,600 angstroms acts as a germicide that would destroy biological hazards associated with fecal coliform.

8.7.1.3 Treated Groundwater Discharge to Surface Water

For the base alternative, the treated groundwater is assumed to be discharged to surface water. The discharge point would be the upstream end of the central tributary to Middle Creek, located just southwest of monitoring well MW-12. Because of the relatively high hydraulic conductivity of the Upper Aquifer, groundwater extraction on the Landfill Property is not anticipated to have a significant effect on flow volumes of any of the creeks. Groundwater elevations in off-site monitoring wells would be used to assess impacts from upgradient groundwater extraction. If significant drawdowns are observed at these wells, creek flows would be evaluated. If required, flow rates would be supplemented with a portion of the discharge water from the treatment process.

8.7.1.4 Monitoring

For this alternative, two points of compliance for assessing progress towards achieving the cleanup levels would be established. The first is the Landfill Property boundary, a conditional point of compliance. The second is the Upper Aquifer groundwater and surface water on Tribal Property that receive groundwater containing indicator hazardous substances, which is an off-Property conditional point of compliance.

Monitoring for this alternative would be performed to assess the effectiveness of treatment system operations. This monitoring would include selected monitoring wells and surface water stations sampled in the RI (Parametrix 2007). Influent and effluent monitoring would be conducted frequently during treatment system startup, then continue at a reduced frequency. Samples would be analyzed for field parameters, vinyl chloride, arsenic, manganese, selected conventional parameters (to assess potential for scale formation in air stripping tower), and fecal coliform bacteria. Monitoring would continue until project cleanup standards are achieved.

8.7.2 Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 5 are:

	Average	Upper-bound
Capital Cost	$1,687,000	$2,039,000
Operating, Monitoring, and Maintenance	$4,582,000	$5,035,000
Present Worth	$6,269,000	$7,074,000

Detailed supporting cost information is provided in Appendix G.

8.7.3 Review of Application of Groundwater Extraction and Treatment at Other Sites

The ability of a groundwater extraction and treatment system to successfully remediate vinyl chloride at contaminated sites to a cleanup level of less than 0.001 mg/L has not been documented. Most sites with published data that have used groundwater extraction and treatment to remediate vinyl chloride in groundwater have established cleanup levels between 0.001 and 0.002 mg/L (approximately equal to the MCL for vinyl chloride), which is approximately 50 to 100 times higher than the proposed cleanup level for vinyl chloride in groundwater at the Hansville Landfill Site.

USEPA has concluded that expectations for the effectiveness of groundwater extraction and treatment may be too high (USEPA 2002b). A review of the application of groundwater extraction and treatment at a wide variety of sites has confirmed that many of these sites have failed to achieve cleanup standards set at MCL levels. In another study, even after 10 years of groundwater extraction and treatment vinyl chloride concentrations in groundwater were reduced from 0.59 mg/L to 0.16 mg/L, which is well above the MCL in drinking water of 0.002 mg/L (U.S. Department of Health 2005). Thus, it is uncertain whether groundwater extraction and treatment can achieve the proposed vinyl chloride cleanup standards in groundwater of 0.000025 mg/L, which is nearly two orders of magnitude less than the MCL.

Only one site (Merlin Landfill in Grants Pass, Oregon) has been identified with a groundwater vinyl chloride cleanup standard (0.00003 mg/L) similar to the level proposed for the Site. The Merlin Landfill is similar in many aspects to the Site, including groundwater vinyl chloride concentrations of about 0.010 mg/L, a landfill as a potential ongoing source of contaminants, and no documented non-aqueous phase liquids. One significant difference is that the Merlin Landfill is still operating and accepting waste.

A groundwater extraction and treatment system was implemented at the Merlin Landfill in 1994. The system has a groundwater extraction rate of 75 gpm and is similar to the system proposed for Alternative 5. To date, the system appears to only be containing the vinyl chloride plume in groundwater. The remedial action has achieved no significant progress in terms of reducing concentrations of vinyl chloride in groundwater or shrinking the area affected by the vinyl chloride plume (Armhein 2000). In addition, the groundwater extraction system has had operational problems with iron fouling, biofouling, and mineral scaling, which have increased operation and maintenance costs and reduced the efficiency of the treatment system. The remediation system was shut down in 2005 (ODEQ 2007).

8.7.4 Advantages/Disadvantages

The advantages of operating a groundwater pump and treat program on the Landfill Property are as follows:

- Provides effective control of future releases of leachate and indicator hazardous substances from the Landfill; natural attenuation processes are relied upon only to remediate indicator hazardous substances from past releases that are beyond the zone of influence of the pump and treat system.
- May achieve cleanup standards in the on-site portion of the Upper Aquifer in a reasonable timeframe of 5 to 15 years, based on groundwater travel time analysis presented in the RI.
- Provides treatment for indicator hazardous substances to reduce their toxicity, mobility, and volume.

- Pump and treat is a proven technology that has been used for many years; therefore, equipment required for implementation of this technology is proven and readily available.

Implementation of a groundwater pump and treat system at the site presents disadvantages compared to natural attenuation and other alternatives, which are as follows:

- Requires operation of the treatment process until the Landfill ceases releasing indicator hazardous substances to groundwater. This alternative seeks only to limit the future spread of indicator hazardous substances rather than provide source control.
- Treatment is not significantly different than natural attenuation but at a greater cost. The intent of a groundwater pump and treat system is primarily to remove indicator hazardous substances from the Upper Aquifer. This is already occurring naturally through discharge of groundwater to surface water with subsequent rapid volatilization of vinyl chloride. Source control is being provided by operation of the landfill gas control system, which is currently removing vinyl chloride from the Landfill and preventing its migration from the waste, and by the landfill cap, which is reducing infiltration and hence leachate generation, by over 99 percent.
- Treatment provides no reduction of existing on-site and off-site risks. The risk assessment concluded that indicator hazardous substances do not pose risks to human health or wildlife due to incomplete exposure pathways or low concentrations of indicator hazardous substances. Assuming appropriate institutional controls are implemented, installation and operation of a groundwater pump and treat system would provide no reduction in long-term or residual risk, compared to natural attenuation. Achieving reductions of existing risks is a key criterion for selection of an alternative under MTCA (WAC 173-340-360(2)(a)).
- Construction and long-term operation of a groundwater pump and treat system would (1) be costly due to a need for frequent maintenance and monitoring; (2) consume energy resources, which may result in the emission of air pollution and other negative environmental consequences; and (3) be subject to vandalism, potentially requiring increased Site security. These public and private funds and labor and energy resources would not be available for other uses if consumed in a remedial action at the Site.
- It is not certain that a groundwater pump and treat system would achieve the desired cleanup level for vinyl chloride (0.000025 mg/L) in on-site groundwater. There are no known examples where this technology has been used to achieve such a low vinyl chloride cleanup standard. Groundwater may not be fully captured by the extraction wells, allowing indicator hazardous substances to flow to off-site groundwater or surface water. Indicator hazardous substances not removed from the Upper Aquifer would flow downgradient and be remediated through natural attenuation. Monitoring of off-site groundwater and surface water would be needed as a precaution against changes in treatment system performance or other unforeseen events.
- Costs are relatively high due to operation and maintenance costs associated with long-term operation.
- Provides no direct or immediate reduction in vinyl chloride concentrations in surface water.

- Requires the consent of the Port Gamble S'Klallam Tribe to construct and operate a discharge pipeline for treated groundwater, and to discharge treated water to surface water on Tribal Property.
- The system components (extraction wells, treatment, and discharge) comprise a complex mechanical system that requires frequent observation, monitoring, and maintenance to ensure proper operation.
- May be ineffective at removing vinyl chloride sorbed to natural organic carbon in the Upper Aquifer matrix.
- Alters surface water flow through temporary influx of treated groundwater.

8.7.5 Alternative 5+RTA: Groundwater Pump and Treat at Landfill Boundary, Return Treated Water to Upper Aquifer

This alternative is a variation of Alternative 5. Treated groundwater would be returned to the Upper Aquifer upgradient of the Landfill as shown on Figure 8-17, rather than discharged to surface water as for Alternative 5. In all other respects, this alternative is identical to Alternative 5. Alternative 5+RTA also incorporates Alternative 2.

Return of Treated Water to Aquifer

Treated groundwater would be returned to groundwater upgradient of the Landfill via drain field infiltration. As shown in Figure 8-17, the conceptual location of proposed infiltration is northeast of monitoring well MW-5. Boring log data from well MW-5 shows that clean fine-to-medium grained sand is present from a depth of 2 ft below ground surface down to the Upper Aquifer. This sand has the same characteristics as the sands at lower depths that comprise the Upper Aquifer. Drainage of water to the Upper Aquifer is expected to occur rapidly, with minimal lateral spread, although some mounding of the groundwater would occur. The treated water contains precipitable materials such as iron and calcium, which have a tendency to plug aquifer infiltration systems.

Reinfiltrated groundwater to the Upper Aquifer was analyzed using a computer-based two-dimensional groundwater flow model. The modeling analysis is discussed in detail in Appendix F and summarized here. This modeling analysis supplemented the modeling analysis performed for Alternative 5. For this alternative, groundwater flow was re-analyzed assuming a 70 gpm extraction rate plus return of treated groundwater to the Upper Aquifer upgradient from the Landfill. The groundwater flow lines and capture zone for this case are shown in Figure 8-17. Additional modeling analyses indicated that locating the recharge drain field closer to the Landfill than shown on Figure 8-17 is not feasible, due to a reduction in the width of the extraction well capture zone.

Water returned to the Upper Aquifer would be saturated with oxygen from treatment in the air stripping tower, and thus would cause some in situ oxidation and precipitation of manganese and arsenic, and may potentially cause some in situ biodegradation of vinyl chloride under aerobic conditions. The effects of returning treated water to the Upper Aquifer are very difficult to assess quantitatively. Inflowing oxygen may significantly alter the existing geochemical balance. Over the project life, the extraction and return of water to the Upper Aquifer would set up a system resembling a closed-loop process. Although it may take several years, the environment under the Landfill would likely become significantly oxygenated.

The treated water would be expected to meet ARARs for discharge to groundwater. Chemical-specific ARARs for groundwater discharge of indicator hazardous substances are found in Chapter 4, and became the basis for the Site groundwater cleanup standards:

Vinyl Chloride	0.000025 mg/L
Arsenic	0.005 mg/L
Manganese	2.25 mg/L

Alternative 5+RTA would not be expected to reduce flow volumes to the downgradient creeks because groundwater extracted from the Upper Aquifer would be returned in equal quantity. Groundwater elevations in off-site monitoring wells would be monitored to ensure that the extraction system would not affect the flow to the creeks.

Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 5+RTA are:

Item	Average	Upper-bound
Capital Cost	$1,714,000	$2,069,000
Operating, Monitoring, and Maintenance	$4,991,000	$5,081,000
Present Worth	$6,705,000	$7,150,000

Detailed supporting cost information is provided in Appendix G.

Advantages/Disadvantages

The advantages of this alternative are as follows:

- Provides oxygenated conditions in the Upper Aquifer below the Landfill, potentially leading to immobilization and degradation of indicator hazardous substances in situ.
- Eliminates the need for surface water discharge or creek flow augmentation.
- May be slightly less costly than surface water discharge due to elimination of the need to construct a lengthy discharge pipeline and maintenance roadway through a densely forested area.

Disadvantages are listed as follows:

- Impacts of return of treated water to the Upper Aquifer are uncertain.
- Cleanup times are not likely to be improved significantly over the base alternative.
- Complicates groundwater flow patterns in the Upper Aquifer and creates the potential for escape of indicator hazardous substances from predicted capture zone.
- Long-term reliability may be problematic due to scaling problems in the drain field and vadose zone.
- Obtaining approvals from regulatory agencies may be difficult and time consuming.
- Higher energy consumption compared to surface water discharge because the drain field would likely be at a higher elevation than the treatment system; thus, pumping would be required.
- Location of drain field requires purchase or lease of land to the northeast of the Landfill. The land has been cleared of some trees and is currently being developed.

8.8 ALTERNATIVE 6: GROUNDWATER PUMP AND TREAT AT THE LANDFILL AND OFF-SITE

Alternative 6, which incorporates Alternative 2, implements a groundwater pump and treat system that extracts groundwater from the Upper Aquifer at two locations, as shown on Figure 8-18. One location would be just southwest of the solid waste disposal area of the Landfill, as described for Alternative 5. The second location would be approximately ¼ mile west/southwest of the Landfill, near monitoring well MW-12. This location is just upgradient of the seeps that create the tributaries of Middle Creek. This location is not within the Landfill Property; therefore, installation of a groundwater extraction system would require the consent of the Port Gamble S'Klallam Tribe.

As with Alternative 5, the intent of this alternative is to recover indicator hazardous substances released from the Landfill and form a barrier to groundwater flow to hydraulically prevent indicator hazardous substances from migrating beyond the Landfill Property boundary. However, Alternative 6 provides an additional off-site groundwater extraction point in the Upper Aquifer to recover indicator hazardous substances that have already migrated west from the Landfill in groundwater. Extracted groundwater would be treated as in Alternative 5 using greensand filtration and air stripping (see Figure 8-16).

This alternative would continue and build on source control actions previously completed for the Landfill. These actions included installation of an impermeable Landfill cap to reduce leachate generation and an active landfill gas control to remove vinyl chloride and prevent gas migration from the waste.

8.8.1 Description

8.8.1.1 Groundwater Extraction

Average and upper-bound groundwater extraction rates and concentrations for each indicator hazardous substance are shown in Table 8-10 and are identified to provide a range of treatment conditions for this alternative. Figure 8-18 illustrates the predicted groundwater flow lines and zone of capture determined using average aquifer properties as measured during the RI. Detailed results of groundwater modeling are included in Appendix F.

Assuming the groundwater extraction system achieves 100 percent capture of groundwater and indicator hazardous substances, this alternative is expected to meet the remedial action objectives for containment of indicator hazardous substances at the Landfill Property boundary and in groundwater and surface water on Tribal Property within 20 years after system start-up. The actual life span of the project is difficult to estimate and is dependent upon numerous factors, including the groundwater flow characteristics, future leachate generation rates from the Landfill, and the future leachate and groundwater concentrations of indicator hazardous substances.

8.8.1.2 Groundwater Treatment

For this alternative, vinyl chloride would be removed from the Upper Aquifer via the treatment system and discharged to the atmosphere. Manganese and arsenic would also be removed from the Upper Aquifer, captured and concentrated by the treatment system, and shipped off-site for disposal, in accordance with regulatory requirements. A full description of the groundwater treatment process is included under Alternative 5. System parameters for the greensand treatment system are provided in Table 8-11. System parameters for the air stripping tower are provided in Table 8-12. Appendix F contains additional technical supporting documentation for this alternative, including why the discharge to air does not require treatment.

Extracted groundwater may require disinfection using UV sterilization prior to treatment, to prevent biological fouling of the greensand filters and the air stripping tower, or to prevent release of harmful bacteria upon discharge of the treated water to surface water.

8.8.1.3 Discharge of Treated Water to Surface Water

Treated groundwater would be discharged to surface water. As with Alternative 5, the treatment system is expected to meet discharge standards for surface water. Groundwater extraction at the off-site well has the potential to significantly reduce the flow volume of the central tributary of Middle Creek, and possibly other tributaries as well. Therefore, it may be necessary to discharge a portion of the treated water to each tributary.

8.8.1.4 Monitoring

Monitoring for this alternative is identical to that described for Alternative 5.

8.8.2 Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 6 are:

Item	Average	Upper-bound
Capital Cost	$2,694,000	$3,547,000
Operating, Monitoring, and Maintenance	$5,105,000	$5,860,000
Present Worth	$7,799,000	$9,407,000

Detailed supporting cost information is provided in Appendix G.

8.8.3 Advantages/Disadvantages

Advantages and disadvantages of groundwater pump and treat are discussed for Alternative 5 in Section 8.7.3. The advantages of additional remediation by extracting and treating groundwater in the off-site Upper Aquifer are as follows:

- May achieve cleanup standards beneath the Site in a timeframe of 20 years.
- Provides treatment for indicator hazardous substances in off-site groundwater to reduce their toxicity, mobility, and volume.

The disadvantages are as follows:

- Ability of this technology to achieve the vinyl chloride cleanup level in a timely manner is uncertain.
- Potential adverse impacts to in-stream flow volumes in surface water downstream of the off-site extraction wells.
- Requires construction of extraction wells, discharge pipelines, outlet structures, and an access/maintenance roadway on existing forested lands.
- Significantly higher cost than on-site groundwater pump and treat with little additional benefit through reductions in existing risks.

- Requires the consent of the Port Gamble S'Klallam Tribe to construct and operate the off-site remediation facilities, and to discharge treated water to surface water on Tribal Property.

8.8.4 Alternative 6+RTA: Groundwater Pump and Treat at the Landfill and Off-Site, Return Treated Water to Upper Aquifer

As with Alternative 5+RTA, this potential variation consists of discharge of treated water back into the Upper Aquifer upgradient of the Landfill. Groundwater flow patterns for Alternative 6+RTA are shown in Figure 8-19. Alternative 6+RTA also incorporates Alternative 2.

The estimated capital, operating and maintenance, and present worth costs for the alternative variations are:

Item	Average	Upper-bound
Capital Cost	$2,527,000	$2,985,000
Operating, Monitoring, and Maintenance	$4,398,000	$5,175,000
Present Worth	$6,925,000	$8,160,000

Detailed supporting cost information is provided in Appendix G. Note that the cost of returning treated water to the Upper Aquifer is estimated to be slightly less than discharging treated water to surface water. This is due to the extensive piping (see Figure 8-12) associated with discharging water to four creeks to mitigate potential effects on creek flow due to operation of the off-site extraction well. The RTA option would require significantly less construction.

8.9 ALTERNATIVE 7: WASTE EXCAVATION AND OFF-SITE RE-DISPOSAL

This alternative provides for removal of waste material previously disposed of at the Landfill, including municipal solid waste, demolition debris, and septage pumpings. Some materials such as concrete, steel, and soil/material designated as inert, based on particle size and chemical concentrations might remain on site (CH2M Hill 1999). Excavated wastes would be placed in intermodal containers and hauled by truck to the Olympic View Transfer Station (OVTS) in southern Kitsap County. At OVTS, the containers would be transferred to railcars for transport to an existing landfill in northeastern Oregon. This alternative provides source control to greatly reduce or eliminate further releases of indicator hazardous substances to the Upper Aquifer. However, it would not provide remediation of contaminants already in groundwater. To provide for groundwater remediation, this alternative would need to be coupled with one of the previously described alternatives.

8.9.1 Description

8.9.1.1 Waste Reclamation

Excavation of previously disposed wastes for re-disposal in a more environmentally acceptable manner is known as landfill reclamation. Reclamation may include waste separation so that only the environmentally detrimental portion of the waste is disposed of off-site. Reclamation may also include recovery of selected materials for recycle.

Waste reclamation that leaves some of the waste on-site is fundamentally different from reclamation that removes all of the waste. Removal of all waste from the Site would provide maximum source control and ensure elimination of all future releases of indicator hazardous substances to groundwater, which could eliminate the need for long-term groundwater treatment. In contrast, any non-inert waste and contaminated soil left on site may continue to generate gas and leachate containing indicator hazardous substances (although likely at a much reduced rate from current levels), thus potentially requiring long-term groundwater monitoring and treatment. Any decision to leave materials on site would be based on analytical results from material testing and costs associated with material sorting, handling, transport, and disposal.

The scope of the RI did not include the sampling or analyses required for assessing the feasibility of reclamation of the Hansville Landfill. However, a waste excavation feasibility study was done at the Bainbridge Island Landfill located in north Kitsap County (CH2M Hill 1999). Although the two landfills differ significantly, the cost of the Bainbridge Island Landfill remedial alternative was used to develop costs for this site.

The primary differences between the Hansville Landfill and the Bainbridge Island Landfill were the volume of waste, the type of operation, and the type and number of years since closure. The Bainbridge Island Landfill operated for 29 years from 1946 to 1975, and comprised the following disposal areas: main landfill area, west end area, septage pits, and Trench 3; Trench 3 was remediated in 1992. As part of the normal landfill operations, the waste was burned regularly and the total volume of waste accepted was significantly less than the Hansville Landfill; 170,000 tons reported for the Bainbridge Island Landfill as compared to the estimated volume of 600,000 tons for the Hansville Landfill (Parametrix 1998b). At closure, the Bainbridge Island landfill was capped with soil.

The Bainbridge Island Landfill wastes were regularly burned, whereas burning of wastes had not been reported at Hansville Landfill. Burning dramatically reduces the organic content of waste, resulting in less putrescible waste in the landfill that would need to be transported to a permitted off-site disposal as part of reclamation. Wastes at the Bainbridge Landfill were also significantly older and likely more biodegraded than wastes at the Hansville Landfill, because the Bainbridge Island Landfill stopped accepting waste in 1975, whereas the Hansville Landfill accepted waste until 1989.

Degradation of the putrescible portion of the waste in the Hansville Landfill has likely been limited by the impermeable geomembrane cap that was installed in 1989. This cap has caused a substantial reduction in the water content of at least the upper portion of the Landfill, which would correspondingly limit the biological activity necessary to degrade putrescible waste to inert matter. In contrast, the Bainbridge Island Landfill had a soil cap that likely was less effective at reducing infiltration and biodegradation. For the above reasons, the Hansville Landfill likely has a much larger fraction of putrescible waste than the Bainbridge Island Landfill.

Emissions of gas and odors are also predicted to be a significant problem during waste reclamation at the Hansville Landfill, due to the increased fraction of putrescible waste at the Hansville Landfill and the relatively younger age of the waste, as compared to the Bainbridge Island Landfill. The putrescible fraction of the waste is the primary cause of gas and odors from the landfill.

It is assumed that the waste from the Hansville Landfill would not designate as dangerous waste; however, acceptance at another landfill would be dependent on demonstrating that the chemical constituents of the waste meet the landfill's acceptance requirements. In addition to characterizing the waste for acceptance at other landfills, the inert fraction (as defined at the Bainbridge Island Landfill by CH2M Hill (1999) as waste screened to less than 1.5 inches) would also need to be chemically tested to determine possible remedial alternatives. This would require a detailed waste investigation and pilot study to evaluate the feasibility and environmental benefits and consequences of reclamation of the Hansville Landfill.

8.9.1.2 Waste Excavation

Several types of waste materials that exist at the Site require excavation for this alternative. First, to provide access to the refuse, approximately 70,000 cubic yards (cy) of uncontaminated cap materials would be carefully removed and stockpiled on-site for use as backfill material during site restoration. The cap consists of approximately 15 acres of heavy plastic liner that would have no salvage value and thus would require disposal off-site in an approved landfill.

Once the cap is removed, waste material would be excavated. Estimated average and upper-bound waste volumes are 600,000 cy and 900,000 cy, respectively. These values were determined based on existing Site surface contours and estimates of landfill waste depths and areas. For the purposes of estimating costs for this alternative, it is assumed that, for the average remediation condition, 30 percent of the waste at the Landfill would be inert and retained on-site. The other 70 percent of the waste would require disposal at an off-site facility. For the upper-bound remediation condition, it is assumed that all waste would be excavated and removed from the Landfill Property.

To complete excavation in 1 year, five high-capacity excavators would be used. The waste in the Landfill is likely well-compacted, especially in the deeper zones of the Landfill. It is estimated that excavated waste would occupy a volume that is 50 percent greater than the volume of the in-place waste. Excavation would be completed in sections to have as little of the waste as possible exposed at any given time. However, in the later stages of work, essentially all waste zones would be exposed.

The waste includes garbage, wood and concrete debris, septic pit pumpings, and large discrete items such as appliances. The intermix of the various waste components would make excavation significantly more difficult, time consuming, and costly than for excavation of normal soil. Larger-sized waste items need to be individually handled and placed in trucks for off-site transport. Much of the waste may be partially decomposed and have a high moisture content. Some of the septic pit pumpings may still be liquids and require special handling.

The waste also contains soils that were used as daily and intermediate cover. These soils cannot be easily separated from the waste, and most likely contain indicator hazardous substances and other substances that would necessitate their off-site disposal along with waste materials.

Soils under the Landfill likely contain indicator hazardous substances at concentrations exceeding regulatory cleanup levels. The extent and volume of these soils is not known. The average remediation condition assumes no soil under the waste would be excavated or disposed of off-site. For the upper-bound remediation condition, the thickness of the contaminated soil layer requiring removal is assumed to be 2 ft, corresponding to a soil volume of 220,000 cy over the area of the Landfill.

Excavation-related off-site impacts from fugitive dusts, blowing litter, odors, and noise may be severe and uncontrollable. Fugitive dusts could be somewhat reduced, but not eliminated, using water sprays. Fugitive dusts may contain indicator hazardous substances or hazardous or toxic substances. Temporary perimeter fences would be used to capture litter; however, some litter is likely to be blown from the Site.

Based on experiences with excavations at other landfills, odorous emissions could be a significant problem. Odorous emissions are essentially uncontrollable, but could be partially mitigated using an odor suppression system.

Noise impacts from excavator operations and truck traffic could be significant, and may occur up to 6 days per week. The risk of a fire as a result of opening the Landfill is anticipated to be low.

Control of surface water would be important to prevent large quantities of water from entering the waste during excavation. Significant infiltration of water into the waste could cause an increase in leachate generation and increase odorous emissions. Runoff from the Landfill excavation would require control to prevent the spread of waste. Surface water would be controlled by keeping exposed waste areas covered with plastic weighted by sand bags. Surface water would be prevented from flowing into waste areas by diverting it around the excavations. This could require pumping with on-site or off-site treatment of contaminated water.

8.9.1.3 Waste Transportation

Municipal solid waste is typically transported using trucks only for short distance hauls (within cities). Long distance hauls are more commonly by rail. For this remedial alternative, it is proposed that wastes and contaminated soils would be loaded at the Landfill into intermodal containers and trucked to OVTS, an intermodal facility. Containers would then be transferred to railcars for transport to the disposal site.

Transportation of wastes via truck to OVTS would generate significant community impacts. These impacts include noise, vehicle emissions, traffic congestion, and increased potential for serious vehicle accidents. These impacts would occur along the entire route between the Site and the proposed truck-to-rail transfer station in Tacoma.

Assuming intermodal containers would hold a total of 30 tons per load, the estimated number of truck trips required to remove the waste and underlying soil is 14,000 and 37,000 for average and upper-bound remediation conditions, respectively. Assuming a 6-day per week work schedule over a 1-year period, the average and upper-bound number of truck round trips per day would be 90 and 231, respectively. The upper-bound rate equates to one truck entering or leaving the Site approximately every 2 minutes throughout each 8-hour workday.

The intermodal containers would require containment liners to prevent the release of potentially hazardous or toxic liquids that could drain from the waste during transport. These liners are at risk of puncture due to sharp objects in the waste; thus, a covering of thin plywood or other material could be required between the liners and the waste. Assuming each intermodal container can transport 20 cy of waste, up to 50,000 liner bags would be needed.

8.9.1.4 Waste Disposal

Excavated waste and soil would require disposal in an approved landfill. The new disposal location would need to be a landfill that meets the requirements of State regulations or similar regulations if the landfill is located in another state. These regulations require landfills to have bottom liners and leachate collection systems to prevent leachate releases to the environment. Much of the solid waste generated in the Puget Sound area is disposed of in landfills located in north-central Oregon or south-central Washington. Disposal of excavated wastes at one of these landfills is considered feasible.

8.9.1.5 Site Restoration

After all wastes and affected underlying soils are excavated and removed from the Site, the excavation area would be partially backfilled using the inert waste fractions (if any), stockpiled cover materials, and other backfill soils excavated from the Site. The Site would be graded only to the extent necessary to provide for surface water runoff and drainage and to eliminate unstable slopes. Graded areas would be covered with 6 in. of topsoil and hydroseeded to establish a grass cover to prevent erosion.

8.9.1.6 Environmental Impact Evaluation

Implementation of this alternative may potentially cause large impacts to communities near the Site and along the length of the truck transport route. Potential impacts include odors, hazardous gases, noise, blowing litter, scavengers (birds, rats, and flies), and increased truck traffic (with the related noise, emissions, and vehicle accidents). Temporary closure of the drop-box operation may also be required. Assessment of the impacts may require preparation of a detailed Environmental Impact Statement (EIS) complying with the requirements of the State Environmental Policy Act (SEPA) and MTCA, which would require a substantial amount of time.

8.9.2 Costs

The estimated capital, operating and maintenance, and present worth costs for Alternative 7 are:

Item	Average	Upper-bound
Capital Cost	$62,532,000	$137,581,000
Present Worth	$62,532,000	$137,581,000

Detailed supporting cost information is provided in Appendix G.

8.9.3 Advantages/Disadvantages

The advantages of this alternative are as follows:

- Long-term protection of human health and the environment at the Site obtained by complete and permanent removal of the source of indicator hazardous substances, if all waste is removed from the Landfill.
- Eliminates the possibility of future releases of indicator hazardous substances to groundwater, if all waste is removed from the Landfill, or significantly reduces potential for releases of indicator hazardous substances, if only inert waste remains on the Landfill Property.

Disadvantages are:

- Complete source control not achieved if some wastes remain on the Landfill Property.
- Transfer of waste from one landfill to another provides no long-term benefit, other than better containment achieved by the liners and leachate collection system at the receiving landfill.
- Treatment not provided to reduce toxicity or volume of the waste.

- Potential short-term impacts to human health and the environment due to potentially toxic dusts, gases, and odors released from the Landfill during excavation.
- Potential short-term impacts from truck traffic-related vehicle emissions and traffic congestion along entire truck transport route.
- Very high cost.
- Groundwater treatment and cleanup not achieved, other than by natural attenuation, although the sources of indicator hazardous substances would be removed.
- Possible short-term impacts to groundwater from leachate generated by rain falling on exposed refuse.
- May result in temporary closure of the drop-box disposal facility at the Landfill.
- Costs associated with mitigating potential impacts to workers from exposure to dusts, gases, and odors released during excavation.

9. EVALUATION CRITERIA FOR REMEDIAL ALTERNATIVES

MTCA, as implemented by Chapter 173-340 WAC, specifies criteria for evaluating remedial action alternatives. The MTCA remedial action alternative evaluation criteria are summarized below:

- Protection of human health and the environment,
- Compliance with ARARs,
- Short-term effectiveness,
- Long-term effectiveness,
- Permanent solutions (reduction in toxicity, mobility, and volume of contaminants through treatment),
- Implementability (technical feasibility),
- Degree to which community concerns are addressed, and
- Cost.

The ultimate goal of MTCA is the selection of a permanent solution that achieves cleanup levels at points of compliance identified for the Site to the maximum extent practicable. Highest preference is given to reuse, recycling, destruction, or detoxification of contaminants. Lesser preference is given to on-site immobilization/containment, off-site disposal, and institutional controls. The remainder of this chapter provides a detailed description of MTCA criteria used to evaluate the remedial alternatives.

9.1 OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

The MTCA criteria comprises three elements:

- **Degree of reduction of existing risk –** Future risks can be minimized by achieving cleanup levels and by implementing appropriate institutional controls.
- **Time required to reduce risks and attain cleanup standards (or other applicable remediation levels) –** The time required to achieve cleanup levels would be estimated.
- **On-site/off-site risks due to remedial actions –** Remedial activities may create risks that previously did not exist. An example is toxic dusts and vapors that might occur from excavation activities if waste at the Landfill is excavated and the waste materials are moved to an off-site location.

9.2 COMPLIANCE WITH ARARs

Each remedial alternative is assessed for its compliance with ARARs. Compliance factors include the consistency of Federal, State, and local requirements, the activities necessary to coordinate with government agencies, and the ability and time required to obtain any necessary authorization from government agencies. ARARs are tabulated and discussed in Chapter 3 of this report. Compliance with three types of ARARs would be evaluated:

- **Chemical-specific ARARs –** Chemical-specific ARARs include:
    - Compliance with cleanup standards: The capability to reduce concentrations of each contaminant to its respective cleanup standard at each point of compliance.
    - Compliance with other chemical-specific ARARs.
- **Location-specific ARARS –** Location-specific ARARs are those requirements that apply solely to the geographic location or physical position of the Site.
- A**ction-specific ARARs –** Action-specific ARARs define requirements applicable to a specific activity that may or may not occur as part of the remedial action.

9.3 SHORT-TERM EFFECTIVENESS

Each remedial alternative is assessed for its short-term effectiveness in achieving cleanup standards by considering the following:

- **Protection of human health and the environment during implementation of the remedial action –** This criterion considers the potential impacts to on-site workers and adjacent communities during implementation of the remedial action and the effectiveness and reliability of protective or mitigation measures.
- **Degree of risk prior to attaining the cleanup standards –** Existing risks may continue or increase during the planning, design, and construction phases of the remedial action. Risks may also change during operation of the remedial action. Risks may vary based on the nature of the contaminant reduction process versus time (i.e., constant reduction compared to rapid initial reduction with a long period to final reduction). Also, some alternatives may cause formation of toxic intermediates and/or may increase exposures prior to completion of the remedy.

9.4 LONG-TERM EFFECTIVENESS

Each remedial alternative is assessed for its long-term effectiveness in achieving cleanup standards by considering the following:

- **Degree of certainty of the cleanup process –** The potential success of an alternative based on the existence of a fully developed theoretical basis, available design data, existing successfully operating facilities for similar applications, and availability of commercial vendors.
- L**ong-term reliability –** The nature, degree, and certainties or uncertainties of any long-term management.
- **Magnitude of residual risk and degree of reduction in risk –** The risk associated with any sources or areas of contamination remaining after achievement of cleanup standards, less any risk reduction achieved through management of the exposure pathways. The characteristics of the residual contaminants are considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, propensity to bioaccumulate, and propensity to degrade.

- **Management of treatment wastes –** The benefits or problems resulting from recycling, destroying, detoxifying, transporting, or containing on-site or off-site contaminants extracted, processed, or accumulated during the treatment processes used for the remedial action.
- **Management of wastes remaining untreated –** The effectiveness of the containment strategies, such as engineering or institutional controls, used to manage risks from areas containing residual contaminants.

9.5 REDUCTION OF TOXICITY, MOBILITY, AND VOLUME THROUGH TREATMENT (PERMANENCE)

Each remedial alternative is assessed for its reduction in toxicity, mobility, and volume of waste through treatment and the permanence of the treatment in achieving cleanup standards by considering the following:

- **Treatment capability –** The degree to which the waste is treated.
- **Reduction or elimination of releases –** The effectiveness of measures to control the source of releases or reduce the magnitude of releases.
- **Reduction of future releases (source control) –** The adequacy of controls to manage the risk posed by contaminants remaining at the Site following the remedial action. This criterion also applies to off-site treatment, storage, or disposal facilities used for management of contaminated material from the Site.
- **Irreversibility of treatment –** The permanence of the treatment technology as evidenced by the chemical and/or physical transformation of the contaminants during the treatment process.
- **Quantity/quality of wastes –** The quantity and toxicity of the wastes generated by the treatment technology compared to the amount of material processed and the amount of original contaminant present.

9.6 IMPLEMENTABILITY

Each remedial alternative is assessed for its implementability by considering the following:

- **Technical Feasibility**
  - *Ability to achieve cleanup standards* – The ability of the remedial alternative to achieve the cleanup standards identified for each contaminant and medium.
  - *Constructability* – The practical, technical, legal difficulties, and unknowns associated with the construction and implementation of a technology, engineering control, or institutional control, including potential schedule delays.
- **Availability of necessary off-site support facilities –** The availability of off-site transport, storage, treatment, and disposal services with the required capacities, based on the anticipated nature and quantities of materials to be managed.
- A**vailability of necessary services and materials –** The availability of necessary services, material, equipment, and specialists to implement the remedial technology.

- **Administrative requirements**
  - *Regulatory and permitting requirements* – The difficulty and time required to comply with ARARs, coordinate with government agencies, obtain the necessary authorizations, and comply with the substantive requirements of permit programs to implement the remedial action.
  - *Schedule requirements* – The time necessary to plan, design, construct, operate, and monitor the remedial action, including time to obtain authorizations from adjacent property owners and government agencies.
  - *Monitoring requirements* – The monitoring necessary to ensure effective progress of the remedial action toward achievement of cleanup standards and to ensure proper operation of the treatment equipment.
  - *Construction access* – The physical, legal, and contractual barriers to installing and operating the facilities for the remedial action and to perform short- and long-term monitoring.
  - *Operation and maintenance requirements* – The level-of-effort and relative costs associated with operation and maintenance, including the need for trained and experienced personnel and equipment complexity and potential downtime.
  - *Integration with current Site operations* – The possible conflicts with existing use of the Site as a solid waste transfer station and use of the surrounding areas.
  - *Integration with other remedial actions* – The possible conflicts between constructing and operating separate treatment systems necessary to address individual contaminants or contaminated areas.

9.7 COST

Each remedial alternative is assessed for its cost by considering the following:

- **Present capital cost –** The present capital cost includes all costs for equipment purchases and installation, Site improvements, utility connections, contractor fees, engineering design fees, permitting fees, and sales tax.
- **Operation, maintenance, and monitoring costs –** Operating costs include expenses for labor, electricity, chemical treatment additives, fuel, waste disposal, and utilities.

  Maintenance costs include expenses for routine equipment maintenance, emergency repairs, and scheduled equipment replacement.

  Monitoring costs include expenses to assess progress towards achieving cleanup standards, verify treatment equipment performance, and monitor treatment equipment emissions (i.e., to air or water).
- **Net present worth of capital and operating costs –** Net present worth represents the total remedial action project cost in today’s dollars. It is calculated from present capital cost and annual operating, maintenance, and monitoring costs based on the expected project duration and an assumed future interest rate.
- **Incremental costs –** The cost differences of remedial alternatives compared to the differences in their capability to achieve the Site cleanup standards, per application of Ecology’s disproportionate cost analysis (WAC 173-340-360[3][e]).

9.8 COMMUNITY CONCERNS

Each remedial alternative is assessed for its ability to address community concerns. MTCA requires evaluating community concerns in advance of the public involvement process. Therefore, the following potential community concerns have been identified:

- **Protection of human health –** The results achieved by the remedial action to reduce actual or potential threats to human health in the areas surrounding the Landfill.
- **Protection of fish and wildlife habitat –** The positive or negative impacts associated with changes in surface water quality, sediments, and habitat during construction and operation of the alternative and after completion of the remedial action.
- **Control of further releases –** The ability of the remedial action to permanently "fix" the problem and to eliminate the Landfill as a concern for the community.
- **Community impacts –** The impacts to the community from construction and operation of the remedial action, including air pollution, odors, noise, vehicle traffic, and other concerns.

The specific concerns of the community around the Site are not known at this time. Interested persons from the community will have an opportunity to communicate their thoughts about the project during the public comment period for the draft FS report. Public comments submitted during the comment period will be compiled and presented by Ecology in a Responsiveness Summary, which will accompany the final FS report.

10. DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

The purpose of this chapter is to evaluate the remedial alternatives against one another using the remedy selection criteria described in Chapter 9. Following the evaluation, a preferred alternative is identified.

10.1 ALTERNATIVE 2 AS BASE ALTERNATIVE

In this chapter, alternatives are evaluated in terms of the seven selection criteria presented in the previous chapter and compared against one another using a disproportionate cost analysis approach. Alternative 2, Natural Attenuation with Enhanced Monitoring and Enhanced Institutional Controls, is considered to be the base alternative because it represents a viable remedy with the lowest cost. The benefits and costs of all other alternatives are compared to the base alternative to determine if their higher costs are in proportion to their expected increased benefit. This procedure is termed the "disproportionate cost analysis" and is one of the evaluation steps referenced under MTCA.

For the disproportionate cost analysis, benefit is defined in terms of the evaluation criteria presented in the previous chapter. In this analysis, each of the seven criteria is weighted equally. Each alternative receives a score from 1 to 3 under each criterion. A score of 1 indicates the alternative satisfies the MTCA criterion the least, while a score of 3 indicates the best performance. A minimum score of 7 and a total maximum score of 21 is possible. The basis for scoring under each criterion is described below. Alternatives are evaluated and scored in Table 10-1.

10.1.1 Basis for Benefit Scoring

This section indicates the specific factors for each of the MTCA criteria used to assign a score between 1 and 3 to the alternatives.

Overall Protection of Human Health and the Environment

1. Protection of human health and the environment is uncertain.
2. Achieves remedial objectives for preventing exposure to indicator hazardous substances. Provides limited control of future releases to groundwater and surface water. Cleanup standards achieved over a long period of time.
3. Prevents exposure to indicator hazardous substances. Eliminates future releases to groundwater and surface water. Cleanup standards are achieved relatively quickly.

Compliance with ARARs

1. Compliance with ARARs is uncertain. Approvals may be difficult to obtain or require a lengthy process.
2. Complies with ARARs. Approvals from agencies and affected parties are likely to be obtainable.
3. Complies with ARARs. Cleanup standards are readily achievable. Approvals from agencies and affected parties are likely to be readily obtainable.

Short-term Effectiveness

1. Protection of human health and the environment is uncertain. May not reduce risks prior to attainment of cleanup standards.

2. Protects human health and the environment. Moderately reduces risks prior to attainment of cleanup standards.
3. Protects human health and the environment. Greatly reduces risks prior to attainment of cleanup standards.

Long-term Effectiveness

1. Cleanup success and long-term reliability are uncertain. Management of treatment wastes and untreated indicator hazardous substances is uncertain.
2. Moderate probability of cleanup success and long-term reliability. Management approaches for indicator hazardous substances are moderately certain to succeed.
3. High probability of cleanup success and long-term reliability. Management approaches for indicator hazardous substances are highly likely to succeed.

Reduction of Toxicity/Mobility/Volume through Treatment

1. Other than existing source controls, such as a geomembrane cap and gas extraction system, indicator hazardous substances are not permanently reduced in toxicity, mobility, or volume, nor are they irreversibly immobilized or destroyed.
2. Some indicator hazardous substances would likely be permanently reduced in toxicity, mobility, or volume.
3. Most indicator hazardous substances would be permanently reduced in toxicity, mobility, or volume.

Implementability

1. Technology has technical or administrative constraints.
2. Technology that may have some technical or administrative constraints.
3. Conventional and readily available technology with no expected technical or administrative constraints.

Degree to which Community Concerns Are Addressed

Community concerns are not known at this time. Therefore, potential community concerns were identified and used as the basis for alternative scoring. The list of community concerns will be updated to reflect actual issues brought forth during the public comment period for the draft FS.

1. Does not address community concerns.
2. Partially addresses community concerns, such as reducing long-term releases to groundwater and surface water.
3. Addresses community concerns, such as eliminating future releases to groundwater and surface water, and restoring Upper Aquifer and surface water to drinking water quality relatively quickly.

10.1.2 Cost Basis

Present worth costs for each alternative are presented in Chapter 8 and are summarized again in Table 10-2 (average remediation condition) and Table 10-3 (upper-bound remediation condition). A present worth cost is one in which all future costs have been adjusted to the present (using an assumed interest rate to reflect the anticipated time value of money), to account for the fact that funds expended in the future have a lesser value (in today's dollars) than funds expended today. The lesser value of future expenses is due to several factors, including inflation, ability to invest unspent funds, anticipation of greater income in the future, and anticipation that future events may alter the need to expend funds.

10.2 DISPROPORTIONATE COST ANALYSIS

As an aid to selecting a preferred remedial alternative, costs versus benefits were assessed for each alternative, as shown in Table 10-4 (average remediation condition) and Table 10-5 (upper-bound remediation condition). The key result of the cost versus benefit evaluation is the cost/benefit ratio, shown in the far right column. This ratio indicates how the cost and benefit of each alternative varies relative to the base alternatives. Alternative 2 (Natural Attenuation with Enhanced Monitoring and Enhanced Institutional Controls) was used as the base cost alternative because it is a viable alternative and predicted to have the lowest cost. Benefit ratios were determined relative to the base case of Alternative 6 (On-site and Off-site Groundwater Pump and Treat) because it has the highest benefit score.

A cost-benefit ratio of 1 indicates that an alternative’s benefits are in proportion to its cost. If the ratio is greater than 1, it indicates that the cost is disproportionate to the benefit. As shown in Table 10-4, all alternatives were judged to have costs that are disproportionate to benefits. Alternative 2 has a cost-benefit ratio of 1.1, indicating that its cost only slightly exceeds its benefit. All of the other alternatives have much higher cost-benefit ratios than Alternative 2, indicating their costs exceed their benefits to a much greater degree than for Alternative 2. The cost of Alternative 7, Waste Excavation and Off-site Disposal, greatly exceeds its benefit. Figure 10-1 provides a graphical illustration of cost and benefit scores.

Cost benefit comparisons were also made for upper-bound costs, as shown in Table 10-5. Under these assumptions, all of the alternatives have costs that are disproportionate to benefits as compared to the baseline alternative.

11. CONCLUSIONS

Based on the detailed evaluation of alternatives presented in Chapter 10, Alternative 2 (Natural Attenuation with Enhanced Monitoring and Enhanced Institutional Controls) is the preferred remedial approach for the Site. This alternative provides a practical remedy at a reasonable cost, while protecting public health and the environment. Natural attenuation involves treatment mechanisms present in the natural environment that act to reduce the concentrations of the indicator hazardous substances. These processes do not depend on mechanical systems nor do they involve construction activities that could disrupt the environment and community.

The preferred alternative complies with ARARs and would be as effective and reliable as other alternatives in ultimately achieving cleanup standards. Natural attenuation would remove indicator hazardous substances from the Upper Aquifer in an environmentally acceptable manner and immobilize arsenic and manganese in situ. Long-term monitoring would document achievement of cleanup levels.

Alternative 2 would establish institutional controls in the form of restrictions to prohibit the use of affected groundwater and surface water as drinking water. Because of the availability of a safe, dependable public water supply near the Site, these institutional controls would not unreasonably burden affected landowners.

Effective source control in the form of the landfill cap and the gas control system has already been implemented. The preferred alternative builds on these source control measures. Installation of the impermeable Landfill cap has reduced leachate generation rates. Operation of the active landfill gas control system is removing vinyl chloride from the Landfill and is also preventing migration of landfill gas from the waste.

Only Alternative 3 (Gas Extraction System Enhancements) and Alternative 7 (Waste Excavation and Off-site Disposal) would provide additional source control measures to further reduce releases of indicator hazardous substances to groundwater. Alternative 3, however, is based on an unproven technology, and it is likely that Alternative 3 would provide only partial control of indicator hazardous substances. Uncaptured indicator hazardous substances would continue to affect groundwater and surface water, necessitating institutional controls similar to the preferred alternative. Alternative 7 would likely have very high community impacts due to noise, litter, odors, vermin, and truck traffic (with associated energy consumption, air pollution from vehicle emissions, and potential for vehicle accidents). Alternative 7 also has an unreasonably high cost.

Alternatives 3 through 7 offer limited additional benefits compared to Alternative 2, as described below:

- Source control is being provided by operation of the landfill gas control system, which is currently removing vinyl chloride from the Landfill and preventing its migration from the waste, and by the landfill cap, which is reducing infiltration and hence leachate generation by over 99 percent. Alternative 4 (Air Sparging) and Alternatives 5 and 6 (Groundwater Pump and Treat) provide no additional source control measures to reduce releases of indicator hazardous substances to groundwater.

- Treatment is not significantly different than natural attenuation. The intent of the air sparging and groundwater pump and treat alternatives is primarily to remove indicator hazardous substances from the Upper Aquifer. This is already occurring naturally through discharge of groundwater to surface water with subsequent rapid volatilization of vinyl chloride. Arsenic and manganese are being immobilized in situ in the Upper Aquifer by natural processes. Arsenic and manganese in surface water are not indicator hazardous substances, as described in Section 4.3.

- Treatment provides no reduction of existing risks. Assuming appropriate institutional controls are implemented as would occur for the preferred alternative, installation and operation of a treatment system at the Site would provide no reduction in long-term or residual risk. Achieving reductions of existing risks is a key criterion for selection of an alternative under MTCA [WAC 173-340-360(5)(d)(i)].
- Construction and long-term operation of a treatment system for Alternatives 3 through 6 would (1) be costly due to a need for frequent maintenance and monitoring; (2) consume energy resources, which may result in the emission of air pollution and other negative environmental consequences; and (3) be subject to vandalism, potentially requiring increased Site security. These public and private funds and labor and energy resources would not be available for other uses if consumed in a remedial action at the Site.
- It is not certain that the treatment processes for Alternatives 3 through 6 would achieve the desired cleanup level for vinyl chloride (0.000025 mg/L) in on-site groundwater. There are no known examples where any technology has been successfully used to achieve such a low vinyl chloride cleanup standard. Groundwater may not be fully treated by an air sparging system or fully captured by groundwater extraction wells. Indicator hazardous substances not removed from the Upper Aquifer would flow downgradient and be remediated through natural attenuation.
- Implementation of Alternatives 3 through 6 would have greater impacts to the community than Alternative 2, and Alternative 7 would likely have very high community impacts due to noise, litter, odors, vermin, and truck traffic.

Alternative 2 best satisfies the MTCA evaluation process. It satisfies each of the seven MTCA evaluation criteria and provides the best balance of costs and benefits. The cost/benefit ratio for Alternative 2 is 1.3. The cost/benefit ratio for the other alternatives range from 3.5 to 65.8, indicating that their costs are greater than their benefits. All of the other alternatives, when compared to Alternative 2, have costs that are disproportionately greater than their benefits.

Based on the analyses and evaluations completed in this FS report, as summarized in the conclusions presented in this chapter, the recommended remedial alternative is Alternative 2: Natural Attenuation with Enhanced Monitoring and Enhanced Institutional Controls.

12. REFERENCES

Ambrose, A.M., P.S. Larson, J.F. Borzelleca, and G.R. Hennigar, Jr. 1976. Long-Term Toxicologic Assessment of Nickel in Rats and Dogs. J. Food Sci. Tech. 13: 181-187.

Amiard, J.C., Amiard-Triquet, C., Berthet, B. & Metayer, C. 1987. Comparative Study of the Patterns of Bioaccumulation of Essential (Cu, Zn) and Non-Essential (Cd, Pb) Trace Metals in Various Estuarine and Coastal Organisms. J. Exp. Mar. Biol. Ecol., 106, 73-89.

Armhein, Mark. 2000. Personal Communication by Ken Fellows, Parametrix, Inc. with Mark Armhein, Solid Waste Engineer, City of Grants Pass, Oregon, 1/7/00.

ATSDR. 1996. Toxicological Profile for Vinyl Chloride. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. September 1997.

AWWA (American Water Works Association). 1990. Removal of Soluble Manganese From Water by Oxide-Coated Filter Media, AWWA Research Foundation, March.

Bennett, J. and J. Cubbage. 1992. Review and Evaluation of Microtox Test for Freshwater Sediments. Washington Department of Ecology. November 1992.

Burns, S.E., and M. Zhang. 2001. Effects of system parameters on the physical characteristics of bubbles produced through air sparging. Environmental Science and Technology, Vol. 35, issue 1. January 1, 2001.

Brown, R.A., and F. Jasiolewicz. 1992. Air Sparging: A New Model for Remediation. Pollution Engineering. July 1992.

Callahan, M.A., M.W. Slimak, N.W. Gabel. 1979. Water Related Environmental Fate of 129 Priority Pollutants, Volume I, Office of Water Planning and Standards and Office of Water and Waste Management. U.S. EPA. EPA-440/4-79-029a.

CH2M Hill. 1999. Final Bainbridge Island Landfill Feasibility Study: Landfill Reclamation Sampling Plan. Prepared for Kitsap County. August 6, 1999.

Chapman, P.M., Allen, H.E., Godtfredsen K., and M.N. Z'Graggen. 1996. Evaluation of Bioaccumulation Factors in Regulating Metals. Environmental Science & Technology. Vol. 30, No. 10. 448A-452A.

Clark, A.N., D.J. Wilson, R.D. Norris. 1996. Using Models for Improving In-Situ Cleanup of Groundwater. Environmental Technology. July/August.

Clark, R.M. and J.Q. Adams. 1988. USEPA's Drinking Water and Groundwater Remediation Cost Evaluation: Air Stripping. Lewis Publishers.

Corbitt, R. 1990. Standard Handbook of Environmental Engineering, McGraw-Hill, Inc.

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm. (Version 04DEC98).

Cubbage, J., D. Batts, and J. Breidenbach. 1997. Creation and Analysis of Freshwater Sediment Quality Values in Washington State. Washington State Department of Ecology, Olympia, Washington. Pub. No. 97-323A.

Ecology (Washington State Department of Ecology). 2001. The Model Toxics Control Act Cleanup Regulation. Chapter 173-340 WAC. Amended February 12, 2001. Publication No. 94-06.

Ecology. 2002. Memorandum Regarding Comments on Draft Remedial Investigation for the Hansville Landfill Site. Submitted to Brian Sato. Prepared by Craig McCormack and Michael Feldcamp. November 27, 2002.

Ecology. 2003. Development of Freshwater Sediment Quality Values for Use in Washington State. Phase II Report: Development and recommendation of SQVs for Freshwater Sediments in Washington State. Publication Number 03-09-088. September 2003.

Ecology. 2004. Memorandum Regarding Response to Proposed Approach for Completion of the RI Report, Hansville Landfill RI/FS. Prepared for Parametrix, Inc. Prepared by Brian Sato, Washington State Department of Ecology. April 27, 2004.

Ecology. 2005. Cleanup Levels and Risk Calculations (CLARC) database and Web Page: https://fortress.wa.gov/ecy/clave/CLARCHome.aspx.

Environmental Technology. 1997. Technical Resources: Remediation Technologies, 1997 Resource Guide.

EPRI (Electric Power Research Institute). 1990. Trace Element Removal by Adsorption/Co-precipitation: Process Design Manual, GS-7005. Palo Alto, CA.

Ficek, K.J. 1996. Remove Heavy Metals with Greensand Permanganate. Water Technology 19(4):84-88.

Freedman, D.L. and J.M. Gossett. 1989. Biological Reductive Dechlorination of Tetrachloroethylene and Trichloroethylene to Ethylene under Methanogenic Conditions. Applied and Environmental Microbiology, Volume 55, No. 9, September 1989.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice Hall, Inc., Englewood Cliffs, NJ.
Fuller, D. 2004a. Personal Communication from Water Resources Manager, Port Gamble S'Klallam Tribe Natural Resources Department, Kingston, Washington, to Parametrix, Inc. on May 11, 2004. Electronic data files containing map surface features and improvements.

Fuller, D. 2004b. Personal Communication from Water Resources Manager, Port Gamble S'Klallam Tribe Natural Resources Department, Kingston, Washington to Parametrix, Inc. on September 10, 2004.

Fuller, D. 2006. Personal Communication from Water Resources Manager, Port Gamble S'Klallam Tribe Natural Resources Department, Kingston, Washington, to Parametrix, Inc. on November 21, 2006.

Gore, Jeff. 2000. Personal Communication by Ken Fellows, Parametrix, Inc, with Jeff Gore, Remedial Project Manager, USEPA Region 5, 1/4/00.

Goth, Bill. 2000. Personal Communication by Ken Fellows, Parametrix, Inc, with Bill Goth, U.S. Army Corps of Engineers, Seattle District, 1/7/00.

Hinchee, R.E., et al. 1994. Air Sparging for Side Remediation, Battelle Press.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko. 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, MI.

Jensen, F.B. 1996. Uptake, Elimination and Effects of Nitrite and Nitrate in Freshwater Crayfish (*Astacus astacus*). Aquat. Toxicol. 34: 95–104.

Laskey, J. W., and F. W. Edens. 1985. Effects of Chronic High-Level Manganese Exposure on Male Behavior in the Japanese Quail (*Cotirnix coturnix japonica*). Poult. Sci. 64: 579-584.

Lindsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. Hydrology for Engineers. Published by McGraw-Hill, Inc. New York, New York. 508p.

Mackenzie, R. D., R. U. Byerrum, C. F. Decker, C. A. Hoppert, and R. F. Langham. 1958. Chronic Toxicity Studies, II. Hexavalent and Trivalent Chromium Administered in Drinking Water to Rats. Am. Med. Assoc. Arch. Ind. Health. 18: 232-234.

Marley, M.C. and D.J. Hazebrouck. 1992. The Application of *In Situ* Air Sparging as an Innovative Soils and Ground Water Remediation Technology. GWMR. Spring, 1992.

Matuk Y, Ghosh M, McCulloch C. 1981. Distribution of Silver in the Eyes and Plasma Proteins of The Albino Rat. Can J Ophthalmol 16:145-150.

Northwestern Carbon. 1998. Facsimile Communication from Richard Coolly, NWC, to Ken Fellows, Parametrix, Inc. February 19, 1998.

Oregon Department of Environental Quality (ODEQ). 2007. Environmental Site Cleanup Information Database, Site Summary Report, Merlin Landfill. http://www.deq. State.or.us/wmc/ecsi/escidetail.asp?seqnbr=286

ORNL (Oak Ridge National Laboratory). 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. ES/ER/TM-86/R3. Prepared by Sample, B.E., D.M. Opresko, and G.W. Suter II. Prepared for the U.S. Department of Energy, Office of Environmental Management by Lockheed Martin Energy Systems, Inc. managing the activities at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, USA.

Parametrix, Inc. 1994. Hansville Sanitary Landfill Final Closure Plan. Prepared for Kitsap County Sanitary Landfill, Inc. June 1994.

Parametrix, Inc. 1995. Project Work Plan. Hansville Landfill Remedial Investigation/Feasibility Study. Prepared for Kitsap County Sanitary Landfill, Inc. and Kitsap County. July 3, 1995.

Parametrix. 1998a. Technical Memorandum No. 7, Hansville Landfill RI/FS Risk Evaluation of Creeks as a Drinking Water Supply. From Thair Jorgenson of Parametrix, Inc. to Brian Sato of the Washington State Department of Ecology. July 8, 1998.

Parametrix. 1998b. Memorandum to file, Hansville Landfill RI/FS Volume calculation. From Ken Fellows January 15, 1998.

Parametrix, Inc. 2006. Public Review Draft, Revised Remedial Investigation Report, Hansville Landfill Remedial Investigation/Feasibility Study. September 22, 2006.

Parametrix, Inc. 2007. Remedial Investigation Report, Hansville Landfill Remedial Investigation/Feasibility Study. Prepared for Kitsap County, Washington and Waste Management of Washington, Inc. July 13, 2007.

Patterson, J.W. 1985. Industrial Wastewater Treatment and Technology, Second Edition, Butterworth Publishers. Stoneham, MA.

Port Gamble S'Klallam Tribe. 2002. Water Quality Standard for Surface Water. Resolution No. 02-A-088. Adopted August 13, 2002.

Phillips, P., J. Bender, R. Simms, S. Rodrigues-Easton and C. Britt. 1994. Manganese and Iron Removal from Coal Mine Drainage by User of a Green Algae-Microbial Mat Consortium. Proceedings of the International Land Reclamation and Mine Drainage Conference, U.S. Bureau of Mines Special Publication SP06A-94, pp 99-108.

Prosser, R. and A. Janechek. 1995. Landfill Gas and Groundwater Contamination. Published in the Proceedings of the October 1995 American Society of Civil Engineers (ASCE Convention).

Prothro, M. 1993. Memorandum Concerning "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria." October 1.

Rast, R.R. 2003. Environmental Remediation Estimating Methods. 2nd Edition. RS Means.

RTECS. 1997. Toxicological Information Identified from the Registry of Toxic Effects of Chemical Substances (RTECS). Maintained and updated by the National Institutes of Occupational Safety and Health (NIOSH).

Salmonscape. 2008. Washington Department of Fish and Wildlife Salmonscape. http://wdfw.wa.gov/mapping/salmonscape/index.html. Accessed February 11, 2008.

Schroeder, H. A., M. Mitchener, J. J. Balassa, M. Kanisawa, and A. P. Nason. 1968b. Zirconium, Niobium, Antimony, and Fluorine in Mice: Effects on Growth, Survival and Tissue Levels. J. Nutr. 95: 95-101.

Scott, G. and R.L. Crunkilton. 2000. Acute and Chronic Toxicity of Nitrate to Fathead Minnows (*Pimephales promelas*, *Ceriodaphnia dubia*, and *Daphnia magna*). Environ. Toxicol. Chem. 19(12): 2918-2922.

Stahl, J. L., J. L. Greger, and M. E. Cook. 1990. Breeding-Hen and Progeny Performance When Hens are Fed Excessive Dietary Zinc. Poult. Sci. 69: 259-263.

Stormer J., Jensen F.B., and J.C. Rankin. 1996. Uptake of Nitrite, Nitrate, and Bromide in Rainbow Trout (*Oncorhynchus mykiss*): Effects of Ionic Balance. Can. J. Fish. Aquat. Sci. 53: 1943–1950 (1996).

USACE (U.S. Army Corps of Engineers). 2000. Landfill 4, Fort Lewis, Washington, HTRW Design Center, www.nws.usace.army.mil/geotech/lf4/lf4.htm, 1/3/00.

U.S. Department of Health and Human Services. 2005. Health Consultation, Acme Solvents, Inc. Site, New Milford, Winnabago County, Illinois. Agency for Toxic substances and disease registry. Atlanta, Georgia. March 17, 2005.

USEPA (United States Environmental Protection Agency). 1987. Ambient Water Quality Criteria for Zinc. U.S. Environmental Protection Agency. Office of Water Regulations and Standards. USEPA/440/587/003.

USEPA. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final. Washington, D.C.

USEPA. 1989. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A) (interim final). Toxics Integration Branch, Office of Emergency and Remedial Response, Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, Washington, D.C. USEPA/540/1-89/002.

USEPA. 1992a. Dermal Exposure Assessment: Principles and Applications. Interim Report. Office of Health and Environmental Assessment. United States Environmental Protection Agency, Washington, D.C. USEPA/600/8/91/011B.

USEPA. 1992b. Groundwater Issue: TCE Removal From Contaminated Soil and Groundwater. USEPA/540/S-92/002.

USEPA. 1993. Wildlife Exposure Factors Handbook. Volumes I and II. Office of Research and Development. United States Environmental Protection Agency, Washington, D.C. USEPA/600/R/93/187a.

USEPA. 1994a. Water Quality Standards Handbook: Second Edition. U.S. Environmental Protection Agency, Office of Water. USEPA-823-B-94-005a.

USEPA. 1994b. Hydrologic Evaluation of Landfill Performance (HELP) model, Version 3.01, October 14, 1994.

USEPA. 1997a. Exposure Factors Handbook Volume I: General Factors. U.S. Environmental Protection Agency, Office of Research and Development. USEPA-600-P-95-002Fa. August 1997.

USEPA. 1997b. Ecological Risk Assessment Guidance for Superfund. Process for Designing and Conducting Ecological Risk Assessments. Interim Final. Office of Solid Waste and Emergency Response. United States Environmental Protection Agency, Washington, D.C. USEPA/540/R/97/006.

USEPA. 1999a. Wayne Waste Oil Remediation Summary, www.epa.gov./R5Super/npl/ind/IND048989479.htm, August 29, 1999, downloaded 1/3/00.

USEPA. 1999b. Groundwater Cleanup: Overview of Operating Experience at 28 Sites, USEPA 542-R-99-006. September 1999.

USEPA. 2001. A Citizen's Guide to Soil Vapor Extraction and Air Sparging. EPA 542-F-01-006. April 2001.

USEPA. 2002a. Second Five-year Review for Logistics Center, Fort Lewis, Pierce County, Washington. Prepared by U.S. Army Corps of Engineers Seattle District. Prepared for Fort Lewis Department of Public Works. September 2002.

USEPA. 2002b. National Recommended Water Quality Criteria 2002. U.S. Environmental Protection Agency, Office of Water. USEPA-822-R-02-047. November 2002.

USEPA. 2002c. Elements for Effective Management of Operating Pump and Treat Systems. Office of Solid Waste and Emergency Response (OSWER) 9355.4-27FS-A. Cincinnati, Ohio. December 2002.

USEPA. 2005a. Letter from Michael F. Gearheard to Ronald G. Charles, Port Gamble S'Klallam Tribe. September 27, 2005.

USEPA. 2005b. USEPA Integrated Risk Information System. Online Database of Toxicity Information. Maintained by the USEPA. http://www.epa.gov/iriswebp/iris/index.html.

USEPA. 2006. NPL Fact Sheet, Wayne Waste Oil. http://www.epa.gov/R5Super/hpl/indiane/IN048989479.html. Last updated September 2006..

USEPA. 2007. Contaminants found at Hazardous Waste Sites. http://www.epa.gov/superfund/accomp/ei/contam.htm. Last updated July 17, 2007.

Van Assche F, van Tilborg W. and Waeterschoot H. 1996. "Environmental Risk Assessment for Essential Elements - Case Study Zinc", in "Report of the International Workshop on Risk Assessment of Metals and their Inorganic Compounds". ICME, Ottawa, Publ. P. 171-180.

WDFW (Washington Department of Fish and Wildlife). 2008. Priority Habitats and Species Habitats and Species Report in the vicinity of T27 R02E, Section 9, February 14, 2008.

Washington Department of Natural Resources. 1997. Rare Plants and Plant Communities Information. Maintained by the Washington National Heritage Program. Washington Department of Natural Resources. http://www.dnr.wa.gov/nhp/refdesk/plants.html.

Wetzel, R.G. 1983. Limnology Second Edition. Saunders College Publishing, San Francisco, CA. 767 pp.

Wilson, D.J., C. Gomez-Lahot, and J.M. Rodriguez-Maroto. 1994. Groundwater Cleanup by In-Situ Sparging. VIII. Effect of Air Channeling on Dissolved Volatile Organic Compounds Removal Efficiency. Separation Science and Technology, Vol. 29, pp. 2,387– 2,418.

Wilson, D.J. 1995. Modeling of In-Situ Techniques for Treatment of Contaminated Soils: Soil Vapor Extraction, Sparging, and Bioventing. Technomic Publishing Co., Lancaster, PA.

Yang, Y., J. Parker, and R.A. Parker. 1998. Maximizing the Efficiency of Pump-and-Treat Systems. Chemical Engineering, February 1998, p. 129.

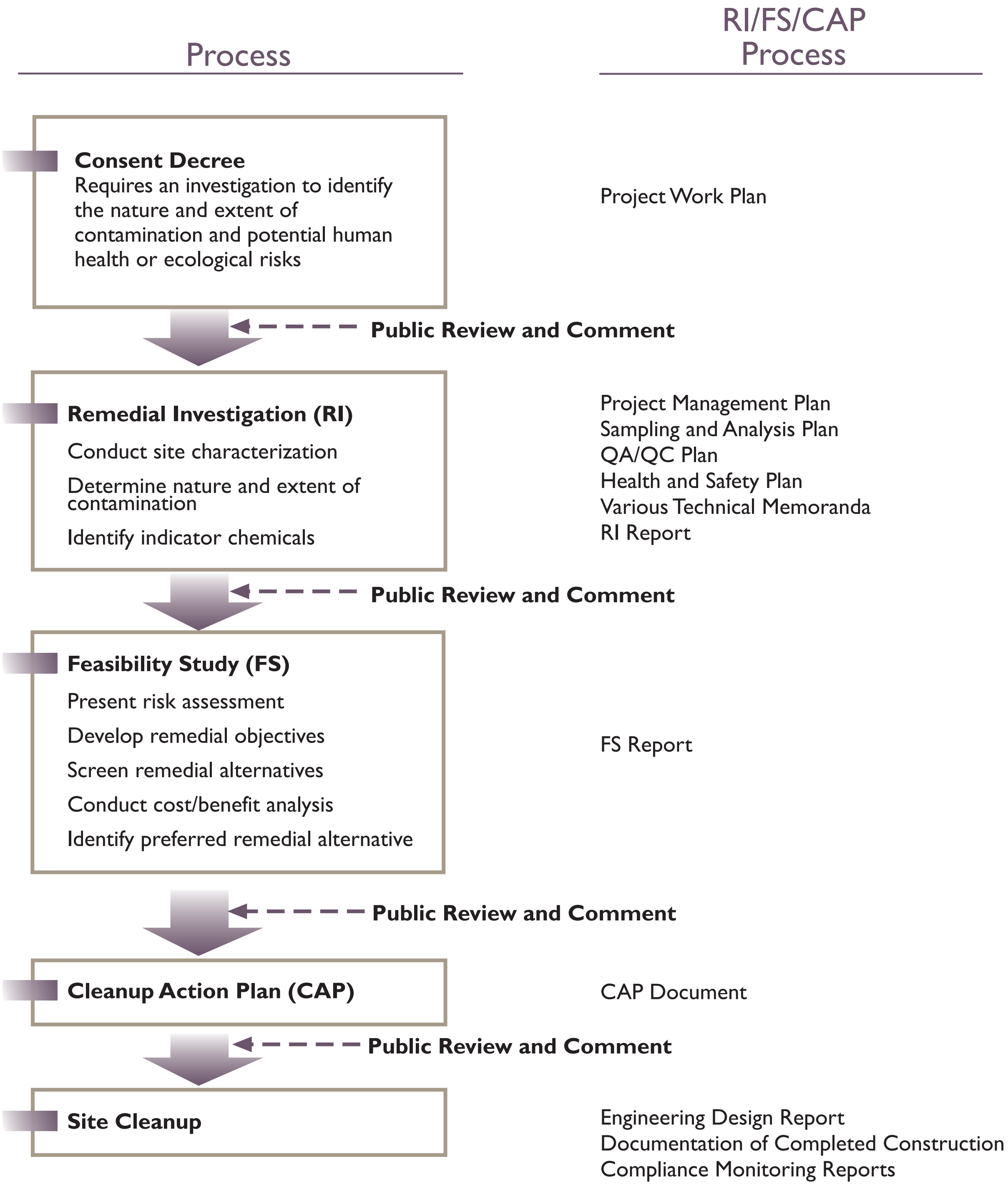
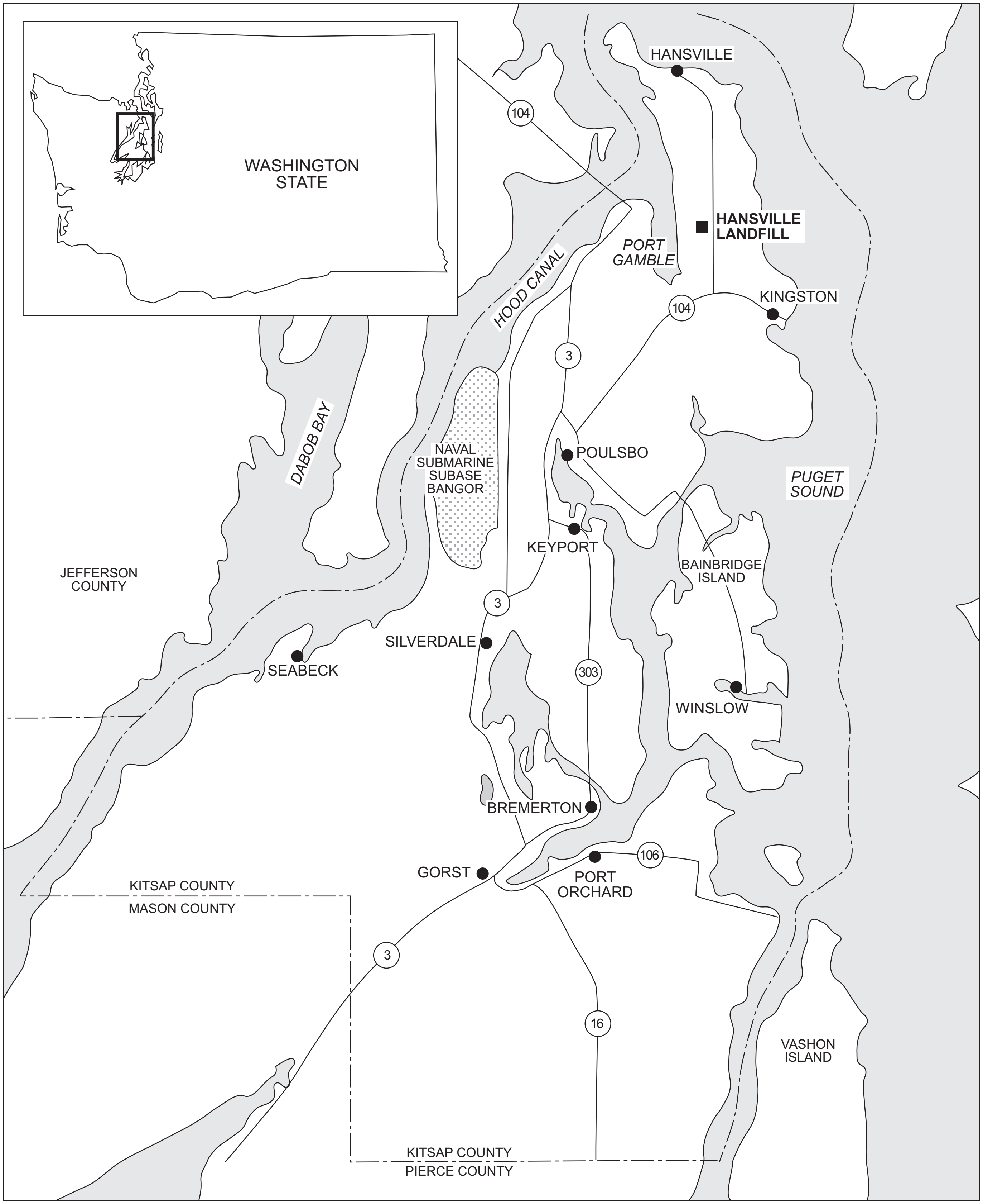


Figure 1-1
RI/FS/CAP Process
Hansville Landfill FS Report



Parametrix Hansville Landfill FS 555-2966-002/02(01) 5/09 (B)

Figure 2-1
Site Location Map
Hansville Landfill FS Report

Figure 2-2
Hansville Landfill Site Boundary
Hansville Landfill FS Report

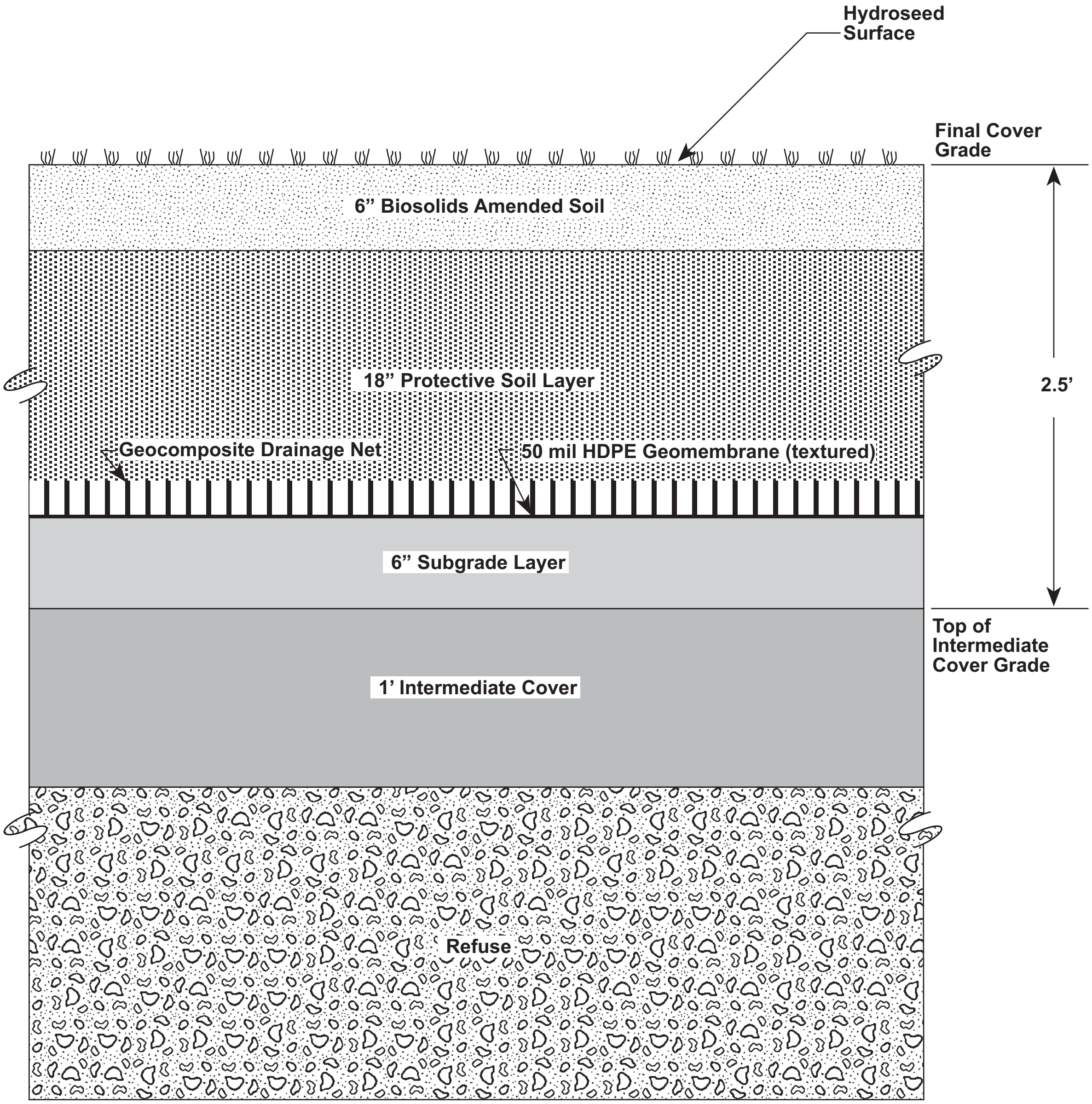
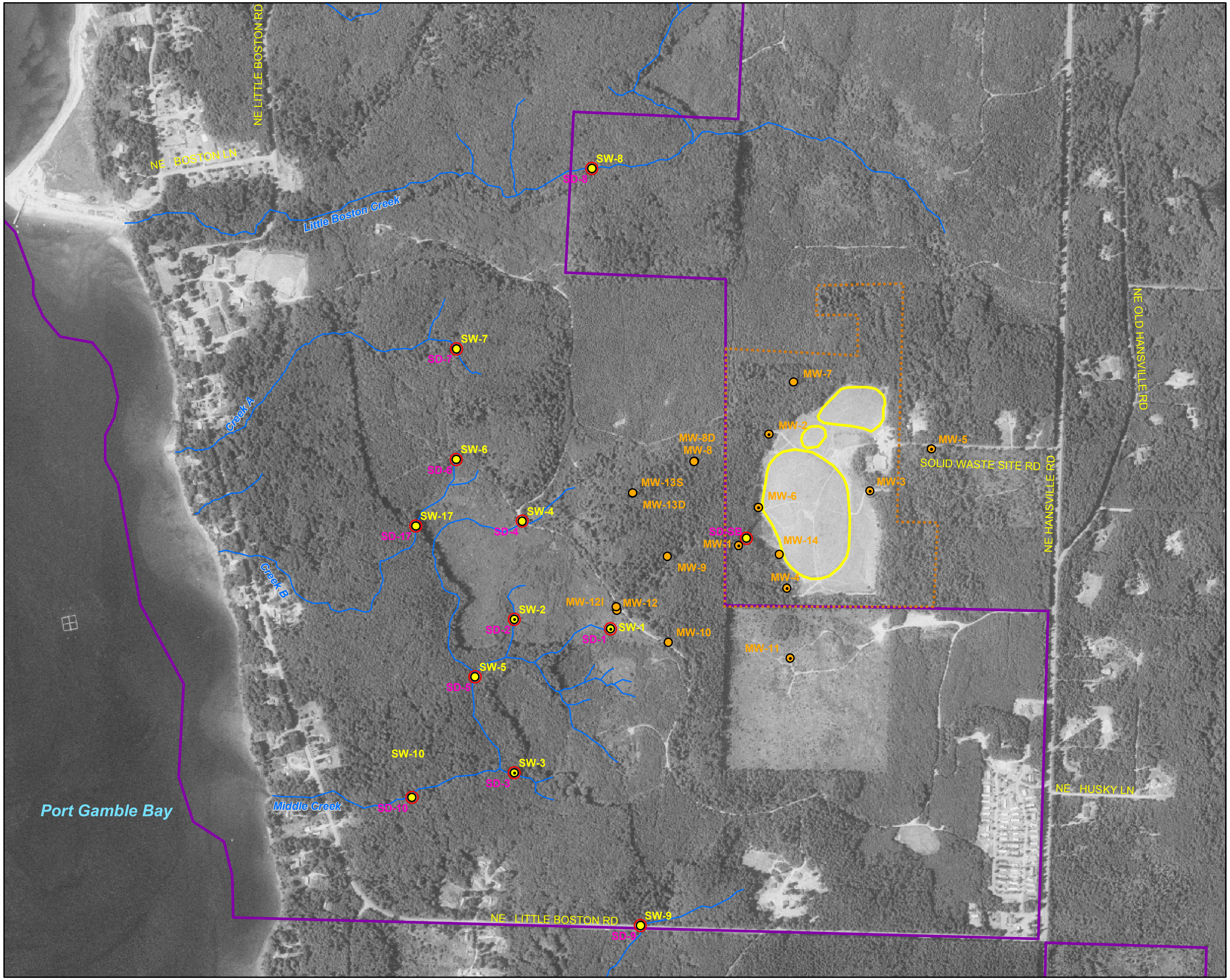


Figure 2-3
Cover System Cross Section
Hansville Landfill FS Report

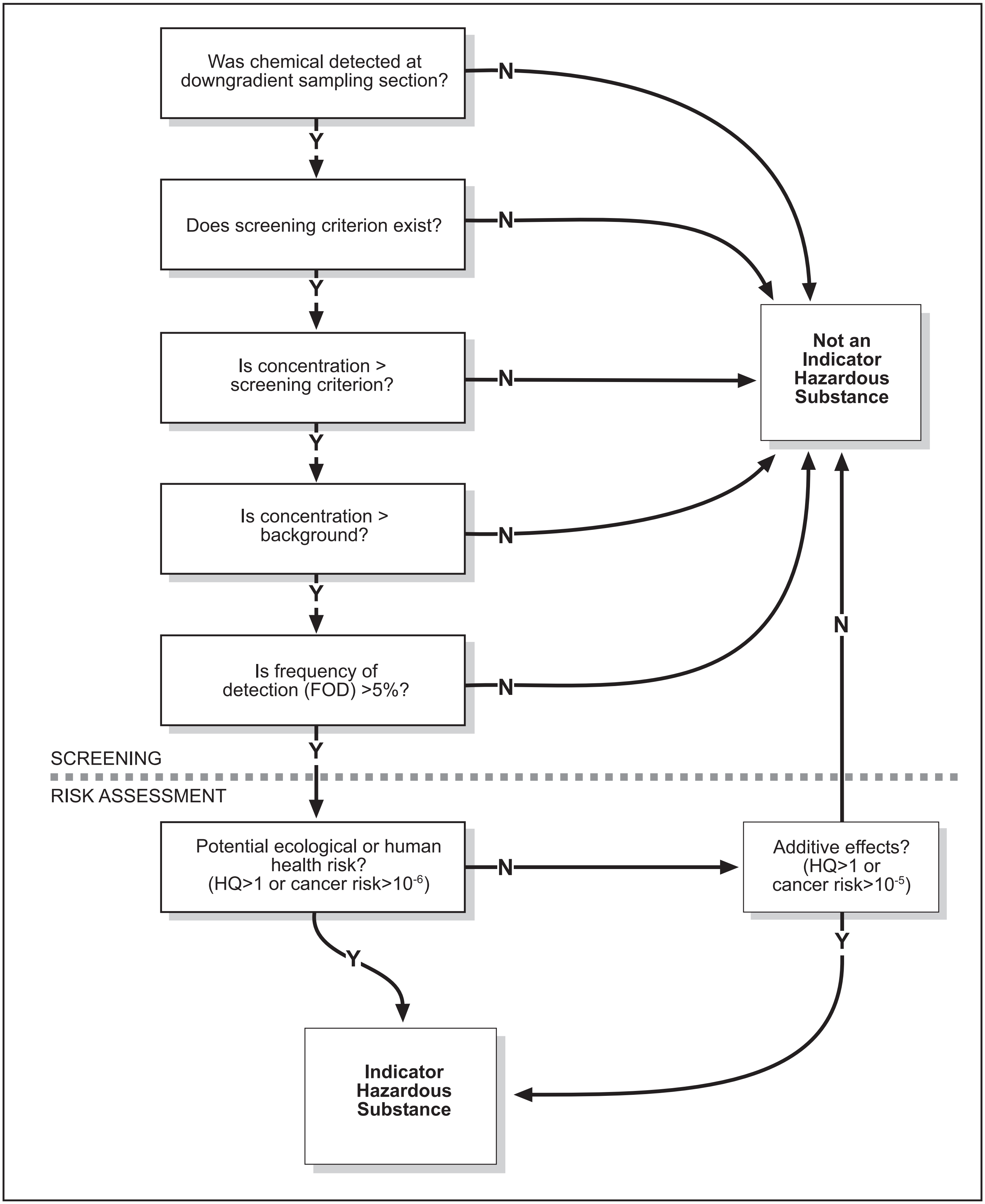


Orthophoto, April 11, 2002
Source: Port Gamble S'Klallam Tribe

Parametrix

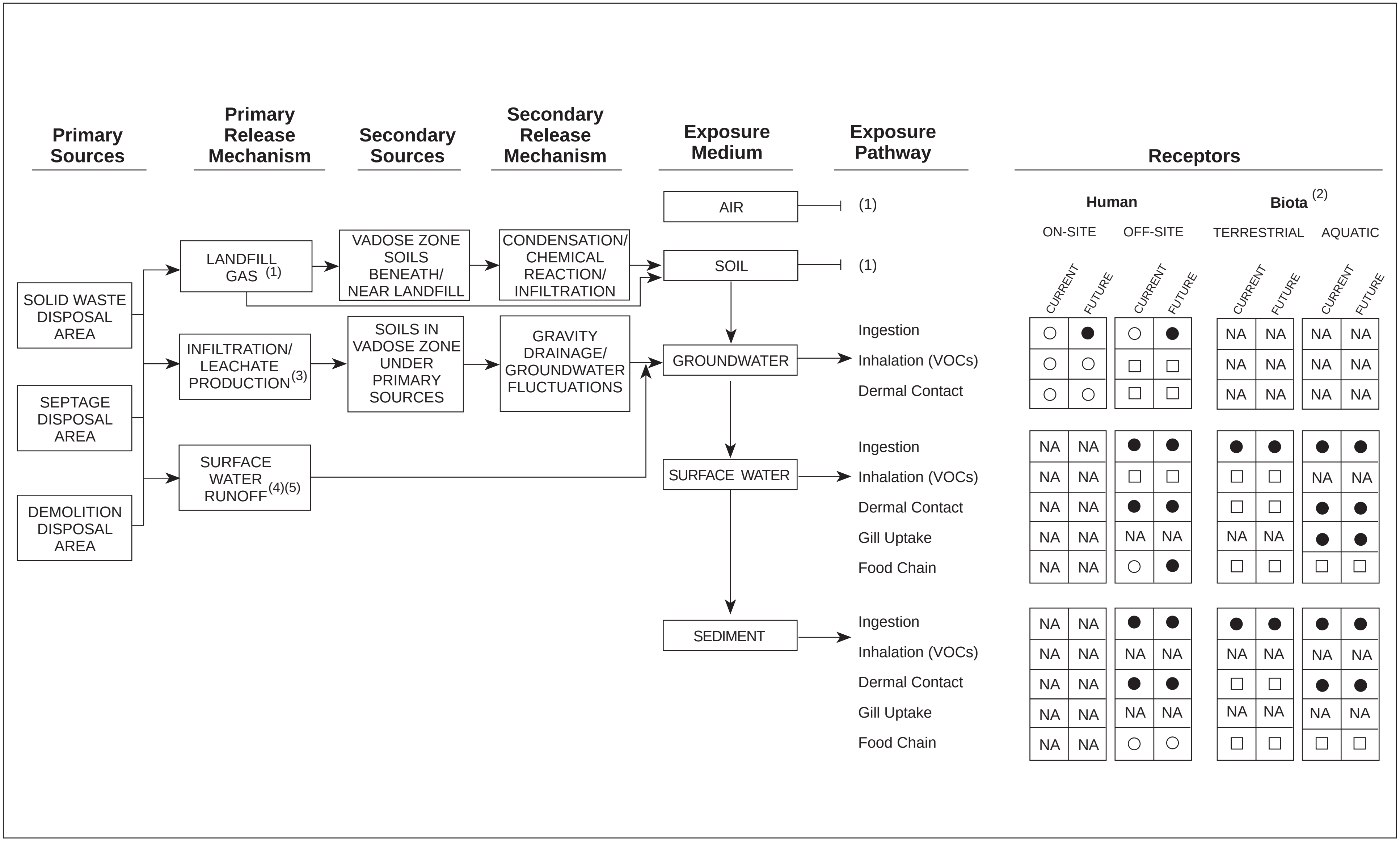
Figure 4-1
Location of Groundwater, Surface Water, and Sediment Sample Stations
Hansville Landfill FS Report

K:\gis\2966\5552966002\Support\MapDocuments\BaseMapAerial052709.mxd - 5/27/2009 @ 10:01:46 AM



Parametrix Hansville Landfill FS 555-2966-002/02(01) 5/09 (B)

Figure 4-2
Overview of Screening and Risk Evaluation Process to Select Indicator Hazardous Substances, Hansville Landfill FS Report



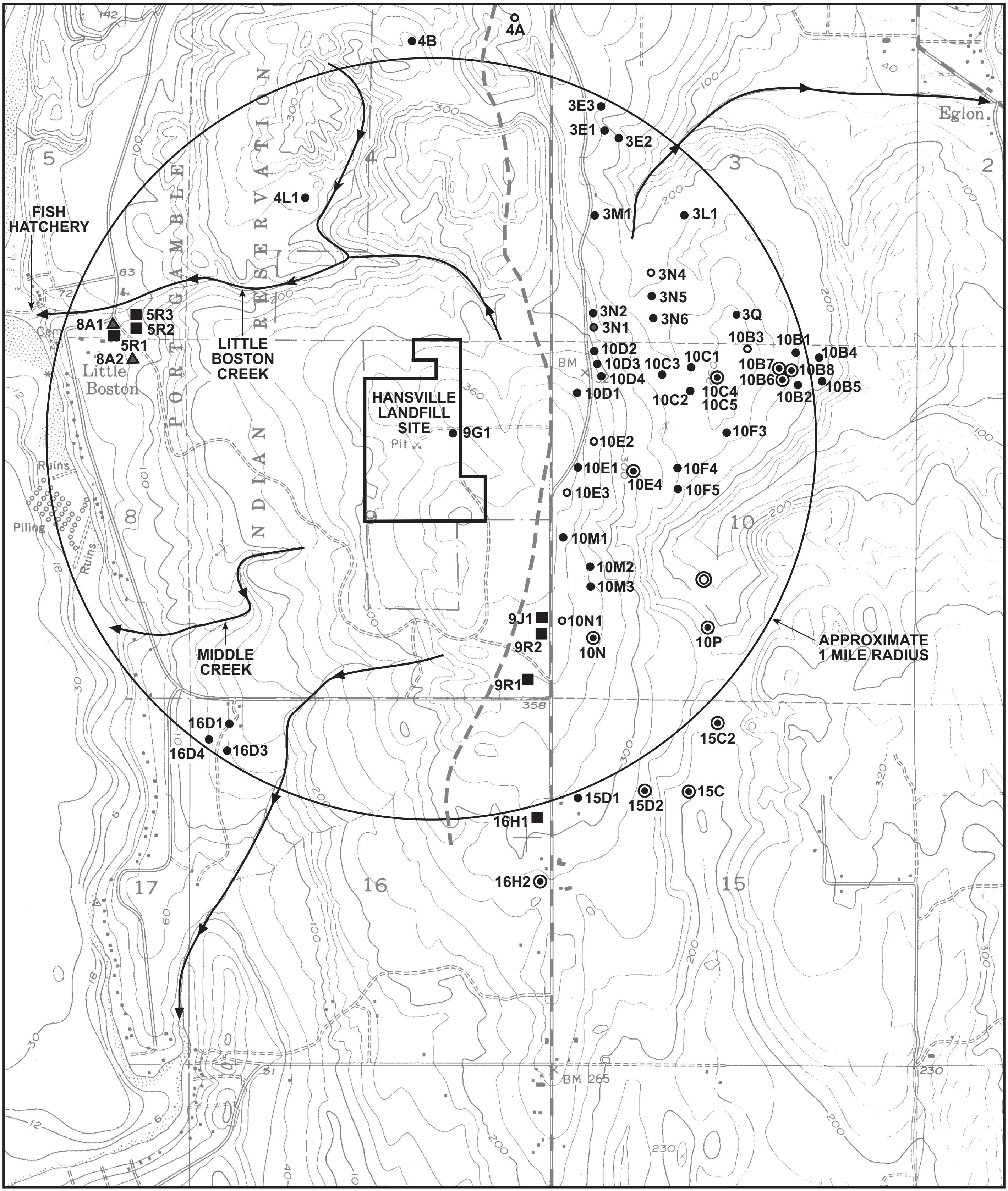
Exposure Medium	Exposure Pathway	Human ON-SITE CURRENT	Human ON-SITE FUTURE	Human OFF-SITE CURRENT	Human OFF-SITE FUTURE	Biota (2) TERRESTRIAL CURRENT	Biota (2) TERRESTRIAL FUTURE	Biota (2) AQUATIC CURRENT	Biota (2) AQUATIC FUTURE
AIR	(1)								
SOIL	(1)								
GROUNDWATER	Ingestion	○	●	○	●	NA	NA	NA	NA
	Inhalation (VOCs)	○	○	□	□	NA	NA	NA	NA
	Dermal Contact	○	○	□	□	NA	NA	NA	NA
SURFACE WATER	Ingestion	NA	NA	●	●	●	●	●	●
	Inhalation (VOCs)	NA	NA	□	□	□	□	NA	NA
	Dermal Contact	NA	NA	●	●	□	□	●	●
	Gill Uptake	NA	NA	NA	NA	NA	NA	●	●
	Food Chain	NA	NA	○	●	□	□	□	□
SEDIMENT	Ingestion	NA	NA	●	●	●	●	●	●
	Inhalation (VOCs)	NA	NA	NA	NA	NA	NA	NA	NA
	Dermal Contact	NA	NA	●	●	□	□	●	●
	Gill Uptake	NA	NA	NA	NA	NA	NA	NA	NA
	Food Chain	NA	NA	○	○	□	□	□	□

Notes: NA = Not Applicable

(1) Historical release mechanism was controlled by installation of landfill gas control system in 1991.
(2) Historical release mechanism was greatly reduced by installation of a temporarygeomembrane cap in 1988.
(3) Historical release mechanism was eliminated by installation of a permanent geomembrane cap in 1989.
(4) Surface water rapidly percolates into the various soils at the site; no streams exist on-site.

● Complete Exposure Pathway
○ Incomplete Exposure Pathway
□ Complete but Minor Exposure Pathway

Figure 4-3
Conceptual Site Model
Hansville Landfill FS Report



Parametrix Hansville Landfill FS/555-2966-002/02(01) 5/09 (B)

▲ Active Water Supply Wells, Port Gamble S'Klallam Tribe, Lower Aquifer

9R1 ■ Community Supply Wells, Lower Aquifer

15D1 ● Residential Supply Wells (pre-1999), Lower Aquifer

◉ New Wells (2000 through 2004), Lower Aquifer

15D1 ○ Residential Supply Wells (pre-1999), Upper Aquifer

◎ New Wells (2000 through 2004), Upper Aquifer

→ Creek and Flow Direction

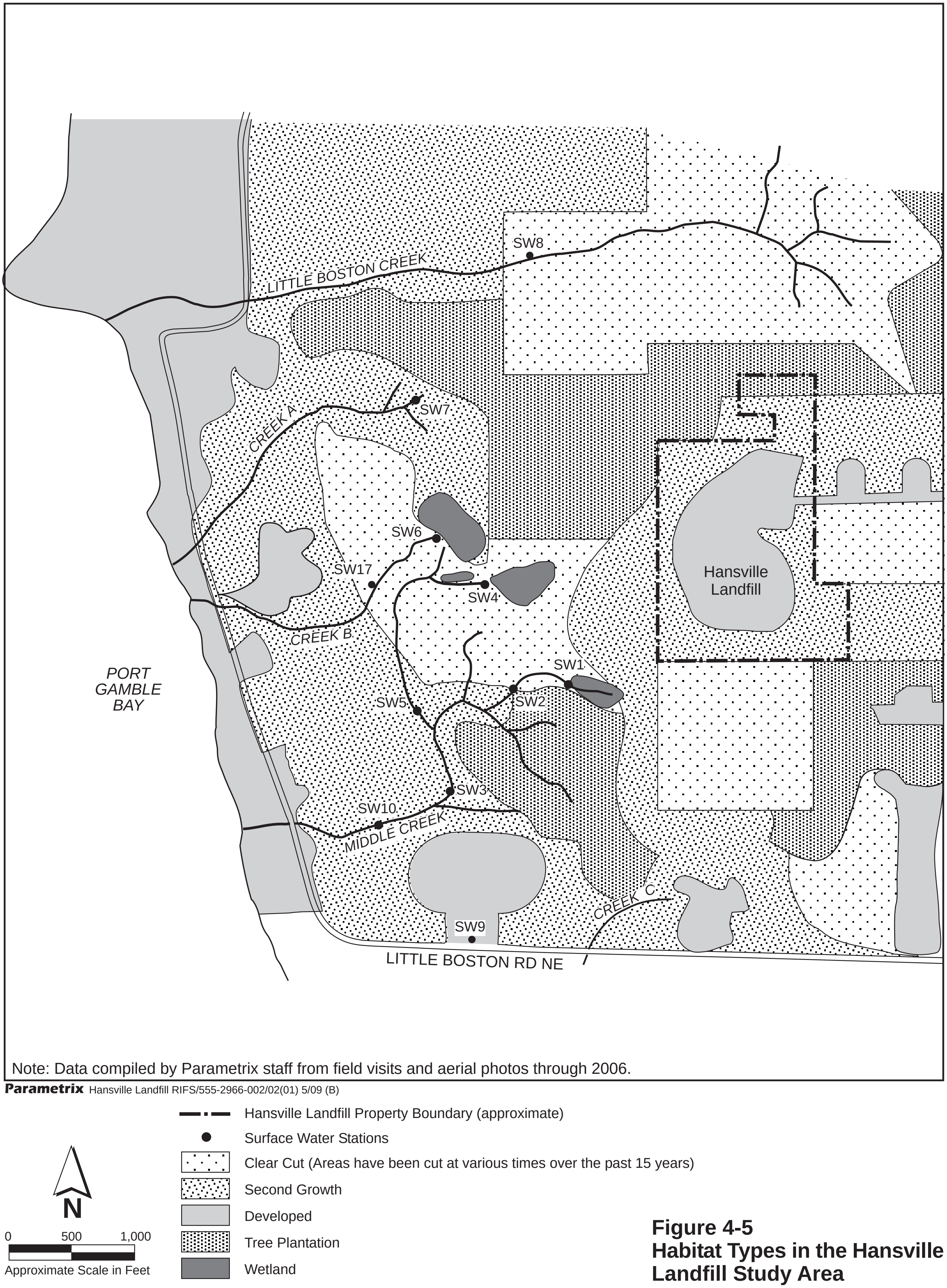
– – Approximate Regional Groundwater Divide

N

0 2,000

SCALE IN FEET

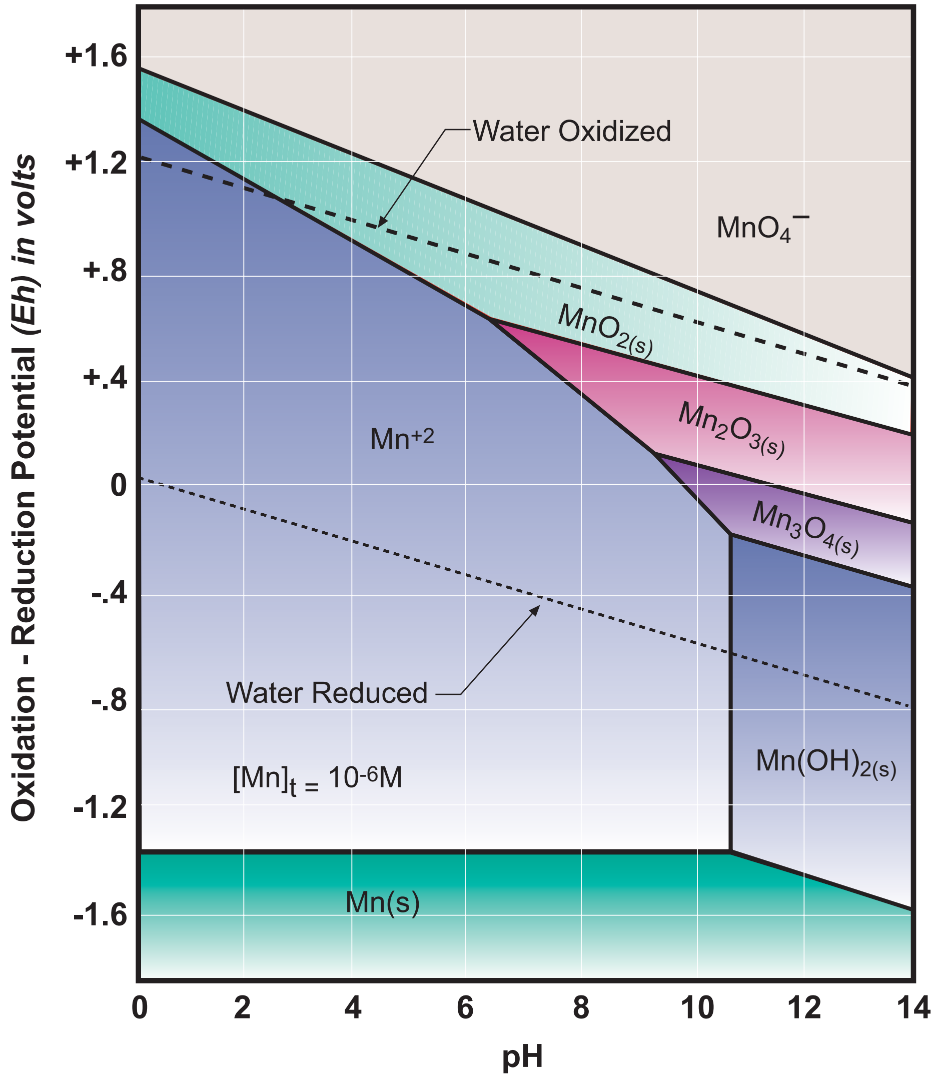
Figure 4-4
Approximate Locations of Water Wells Within 1 Mile of the Hansville Landfill
Hansville Landfill FS Report



Note: Data compiled by Parametrix staff from field visits and aerial photos through 2006.

Parametrix Hansville Landfill RIFS/555-2966-002/02(01) 5/09 (B)

Figure 4-5
Habitat Types in the Hansville Landfill Study Area
Hansville Landfill FS Report



Notes

[Mn] = Manganese concentration
t = Total
M = Moles

From AWWA (1990)

Figure 5-1
Redox Stability Diagram for Various Manganese Species in Water at 25°C
Hansville Landfill FS Report

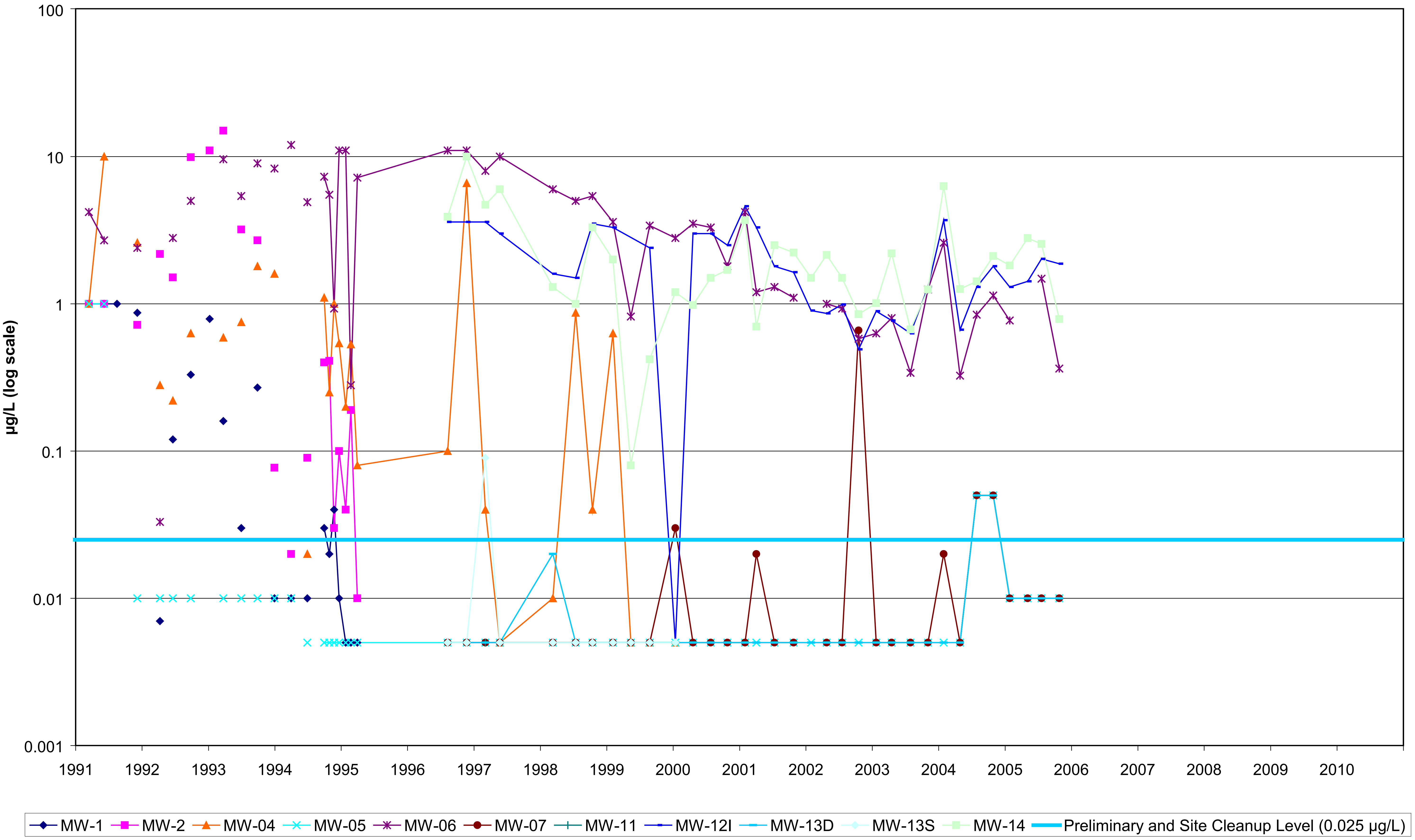


Figure 8-1
Time-Series Plot of Vinyl Chloride in Groundwater
Hansville Landfill FS Report

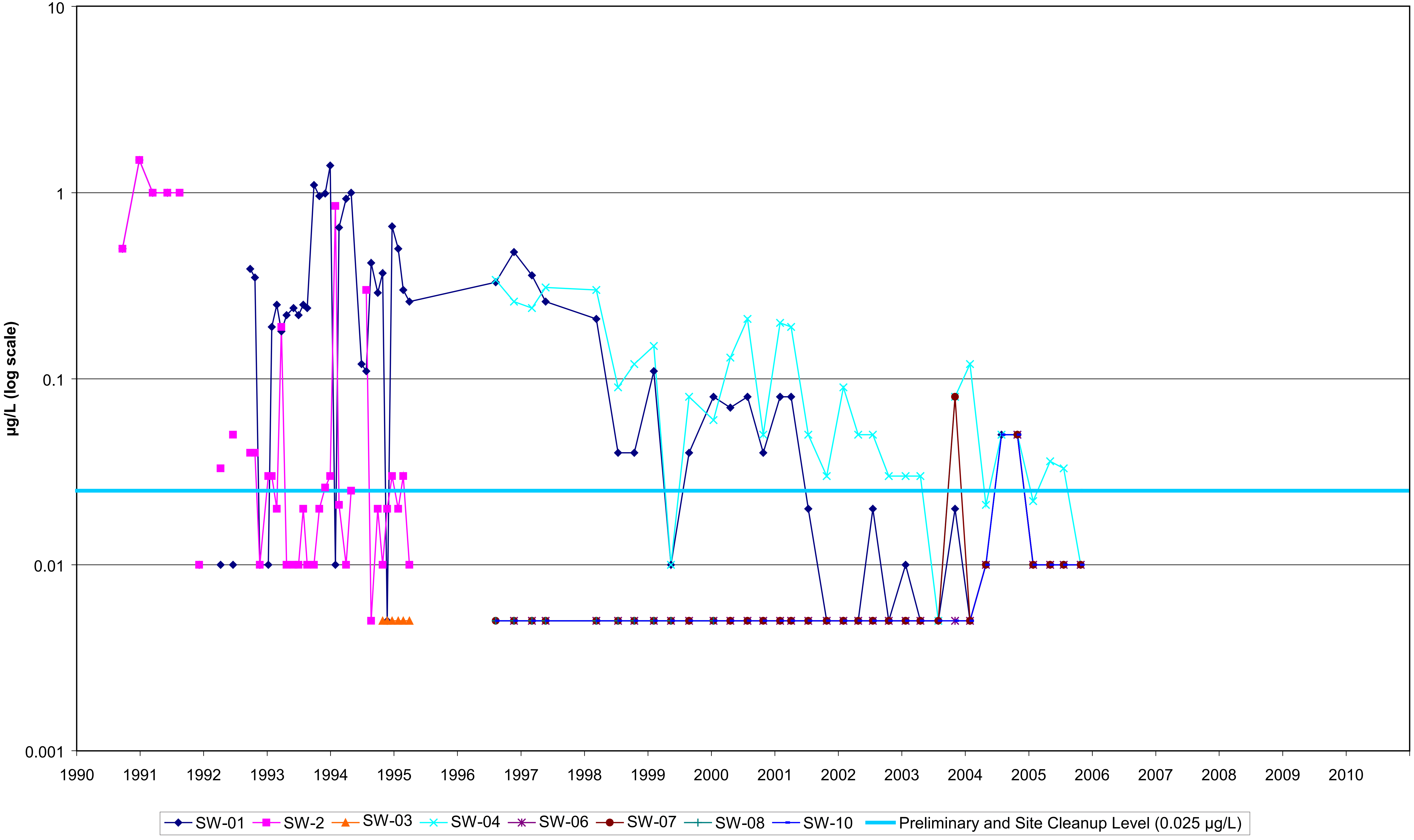


Figure 8-2
Time-Series Plot of Vinyl Chloride in Surface Water
Hansville Landfill FS Report

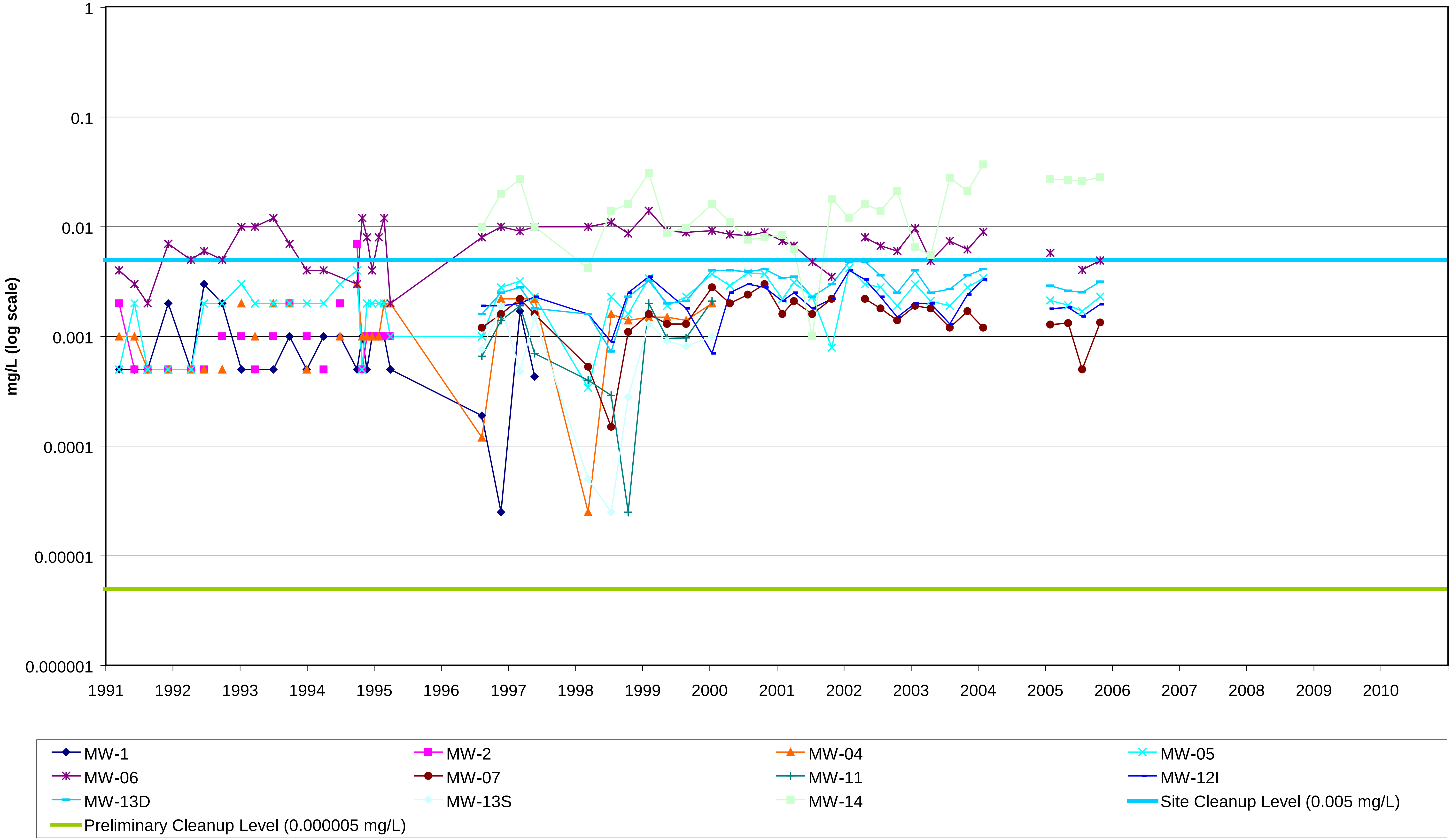


Figure 8-3
Time-Series Plot of Arsenic in Groundwater
Hansville Landfill FS Report

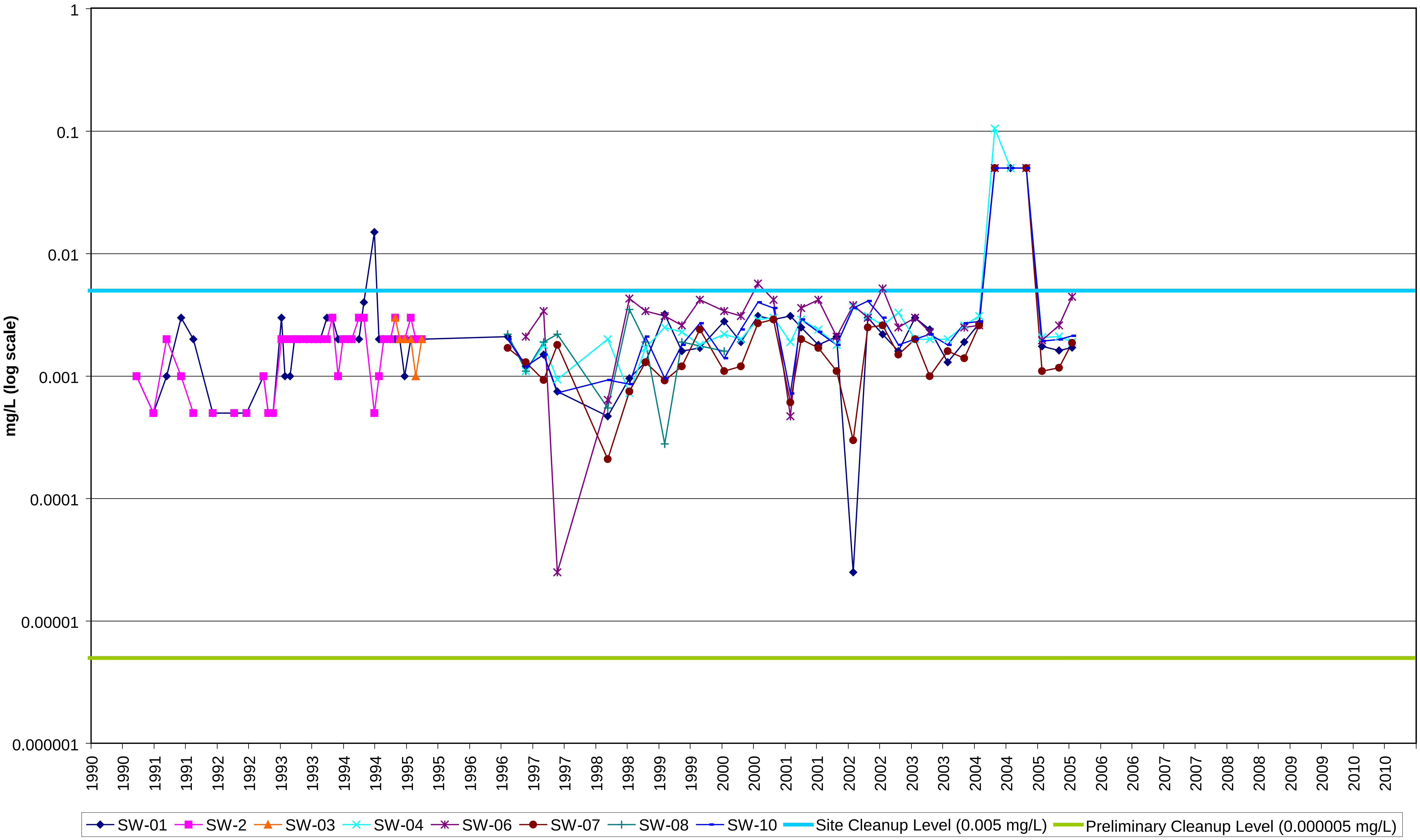


Figure 8-4
Time-Series Plot of Arsenic in Surface Water
Hansville Landfill FS Report

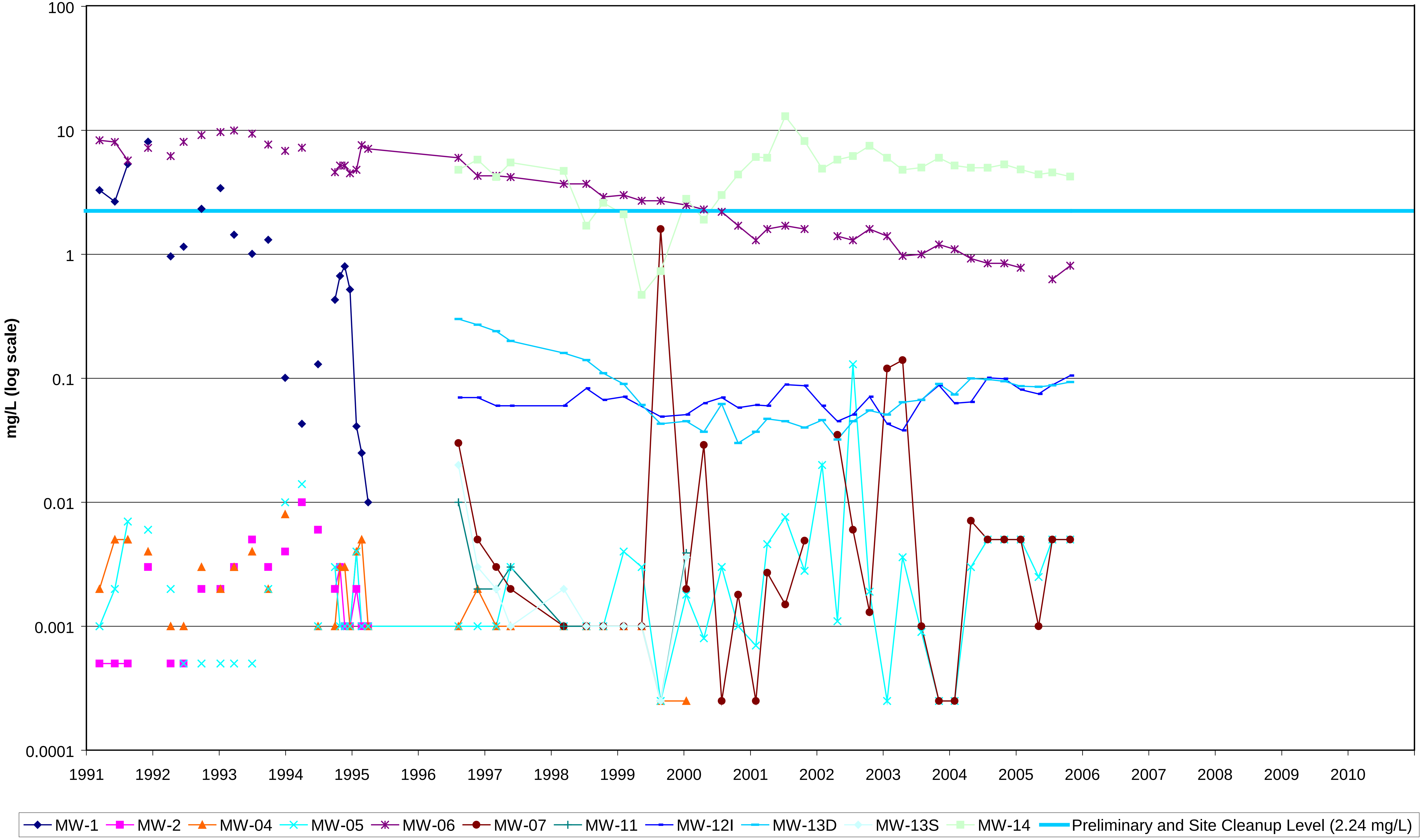


Figure 8-5
Time-Series Plot of Manganese in Groundwater
Hansville Landfill FS Report

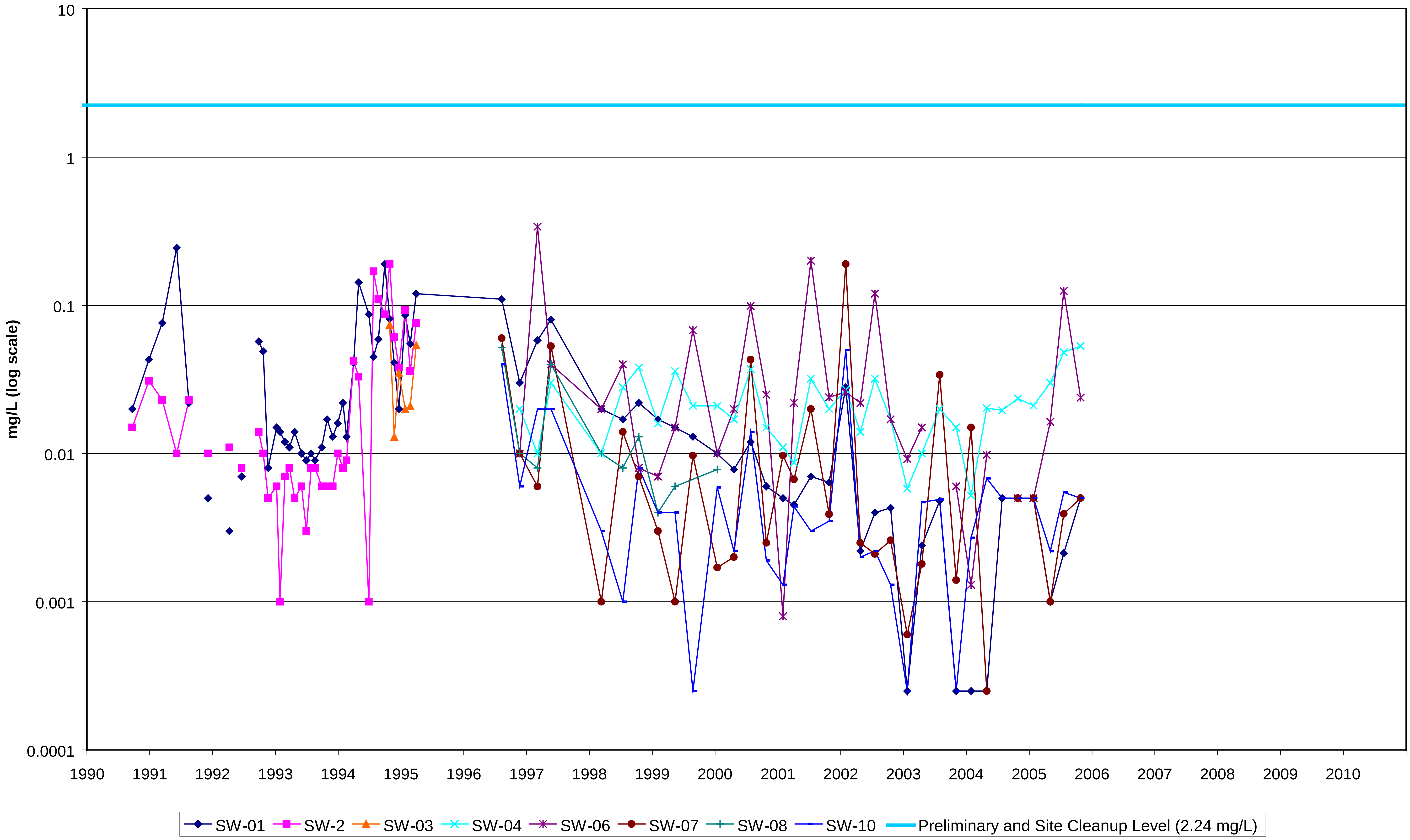
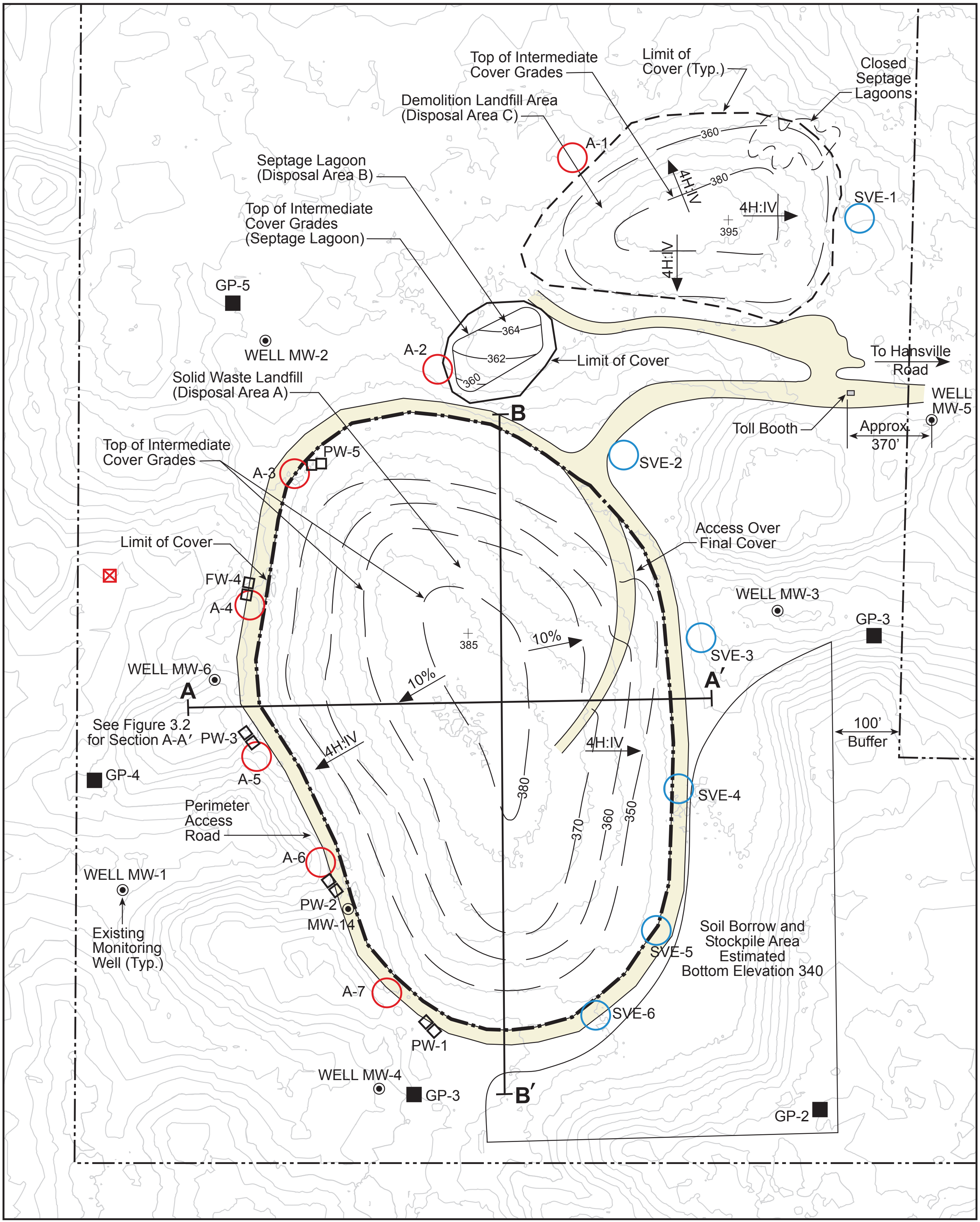


Figure 8-6
Time-Series Plot of Manganese in Surface Water
Hansville Landfill FS Report



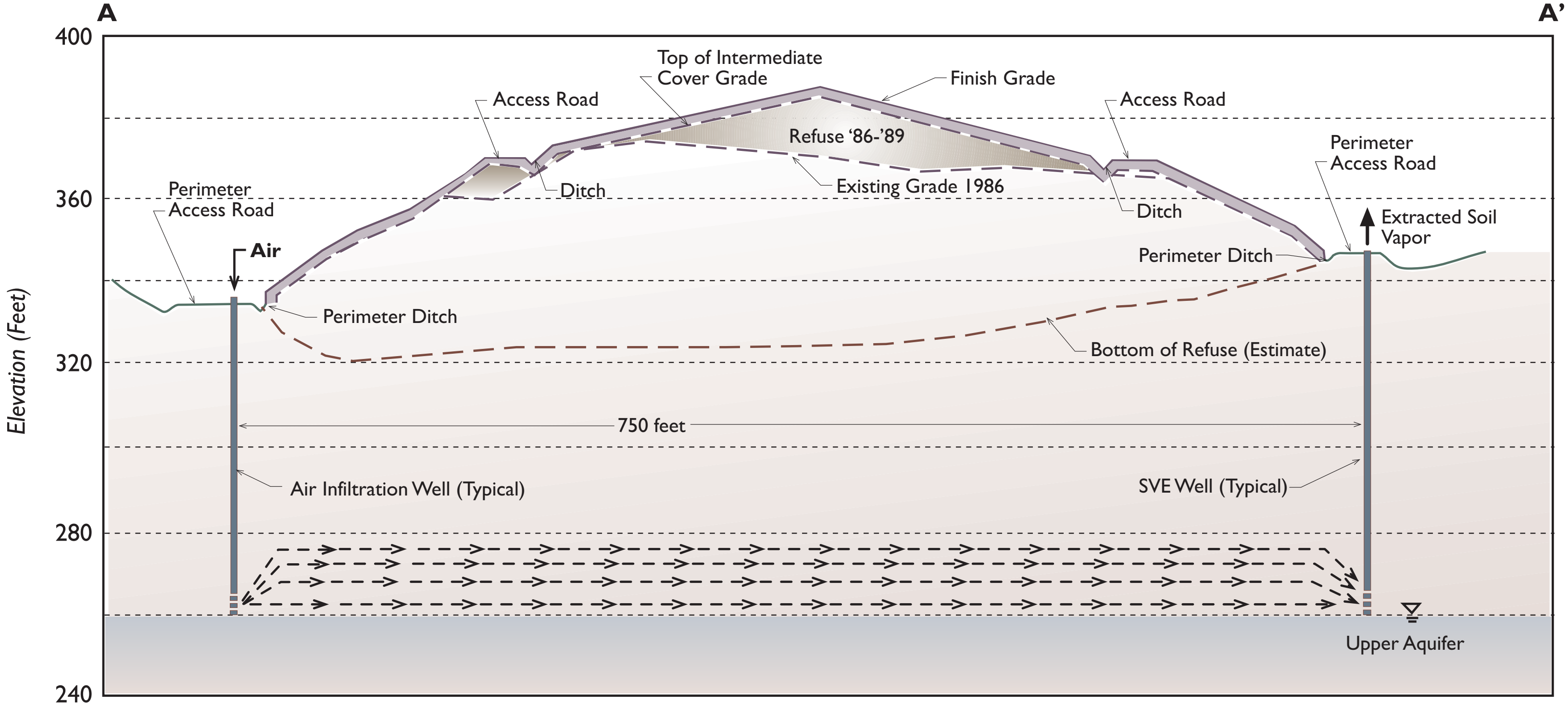
Parametrix Hansville Landfill FS 555-2966-002/02(01) 5/09 (B)

N

0 200
APPROXIMATE SCALE IN FEET

○ Air Infiltration Well
○ SVE Well
☒ Proposed New Monitoring Well
▭ Access Roads
◇ Perimeter Gas Extraction Well (Existing)
⊙ Groundwater Monitoring Well (Existing)
■ Gas Probe (Existing)

Figure 8-8
Alternative 3 Gas System Enhancements Plan View
Hansville Landfill FS Report

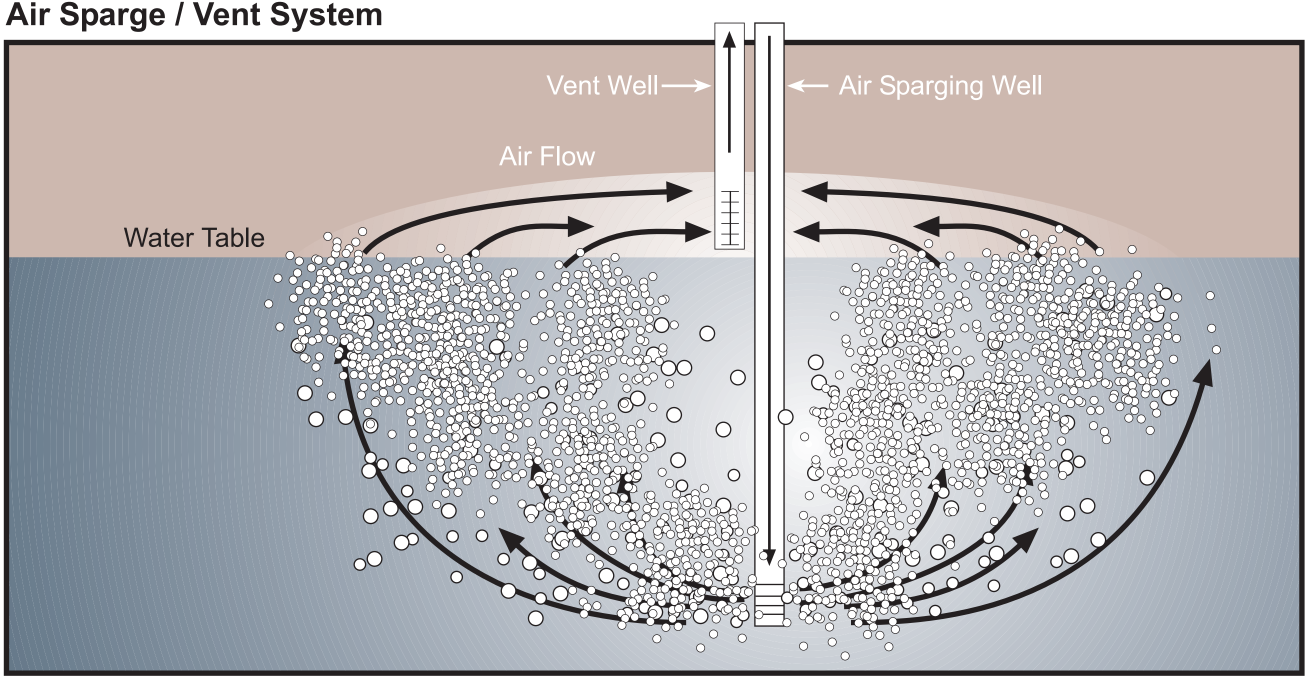


Location of cross section is shown on Figure 8-8

- - -> Air Flow

Figure 8-9
Alternative 3: Gas System Enhancements: Schematic Cross Section
Hansville Landfill FS Report

Figure 8-10a
Air Sparge / Vent System



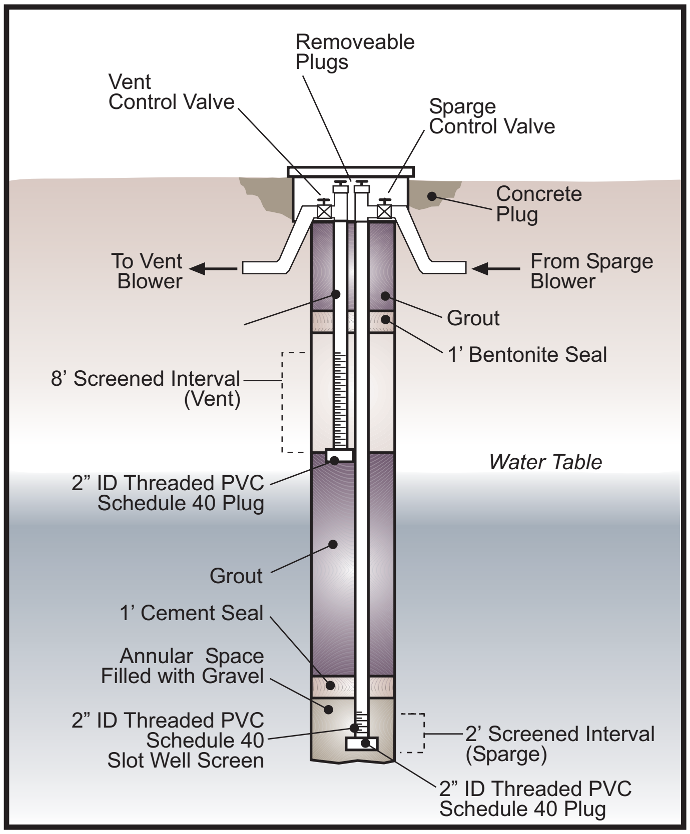
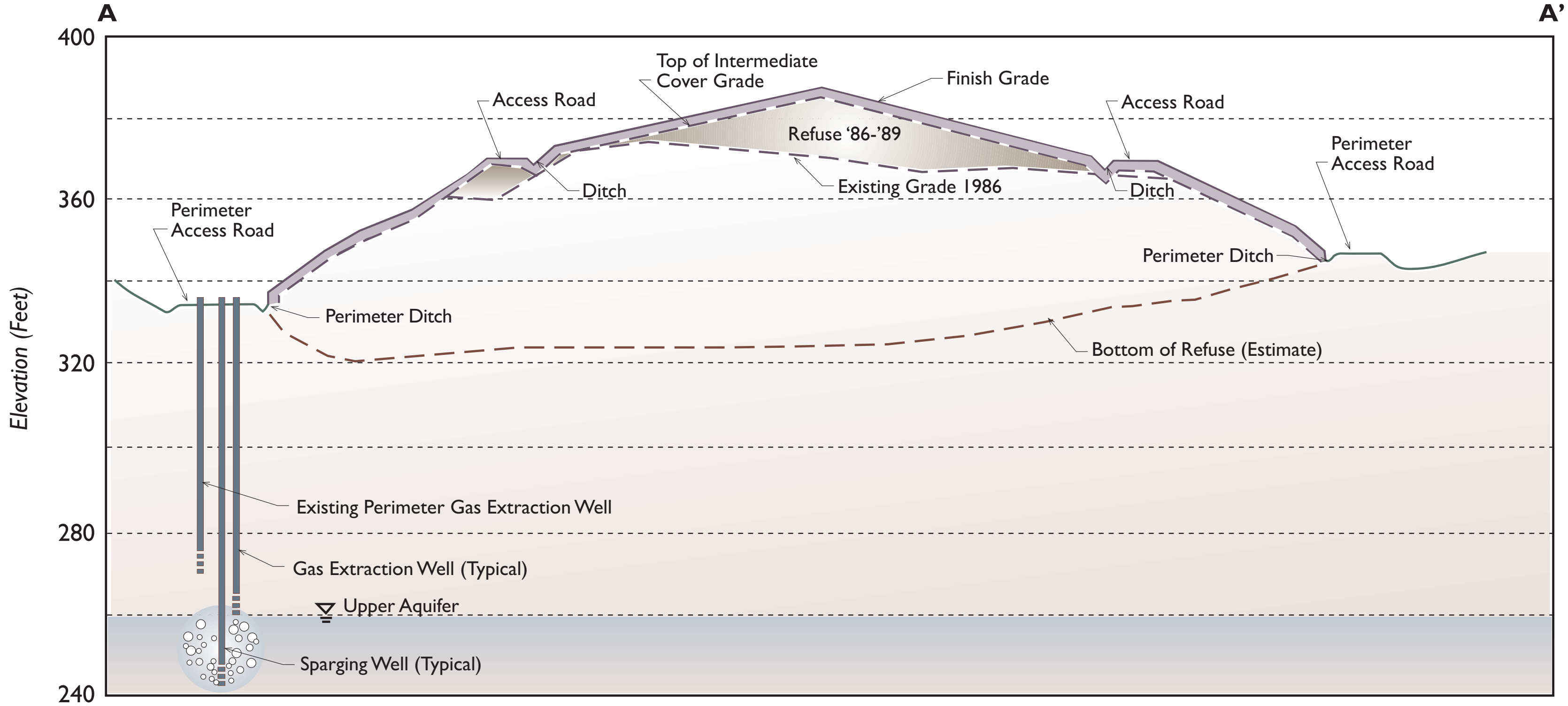


Figure 8-10b
Vertical Section
of Air Sparge Well

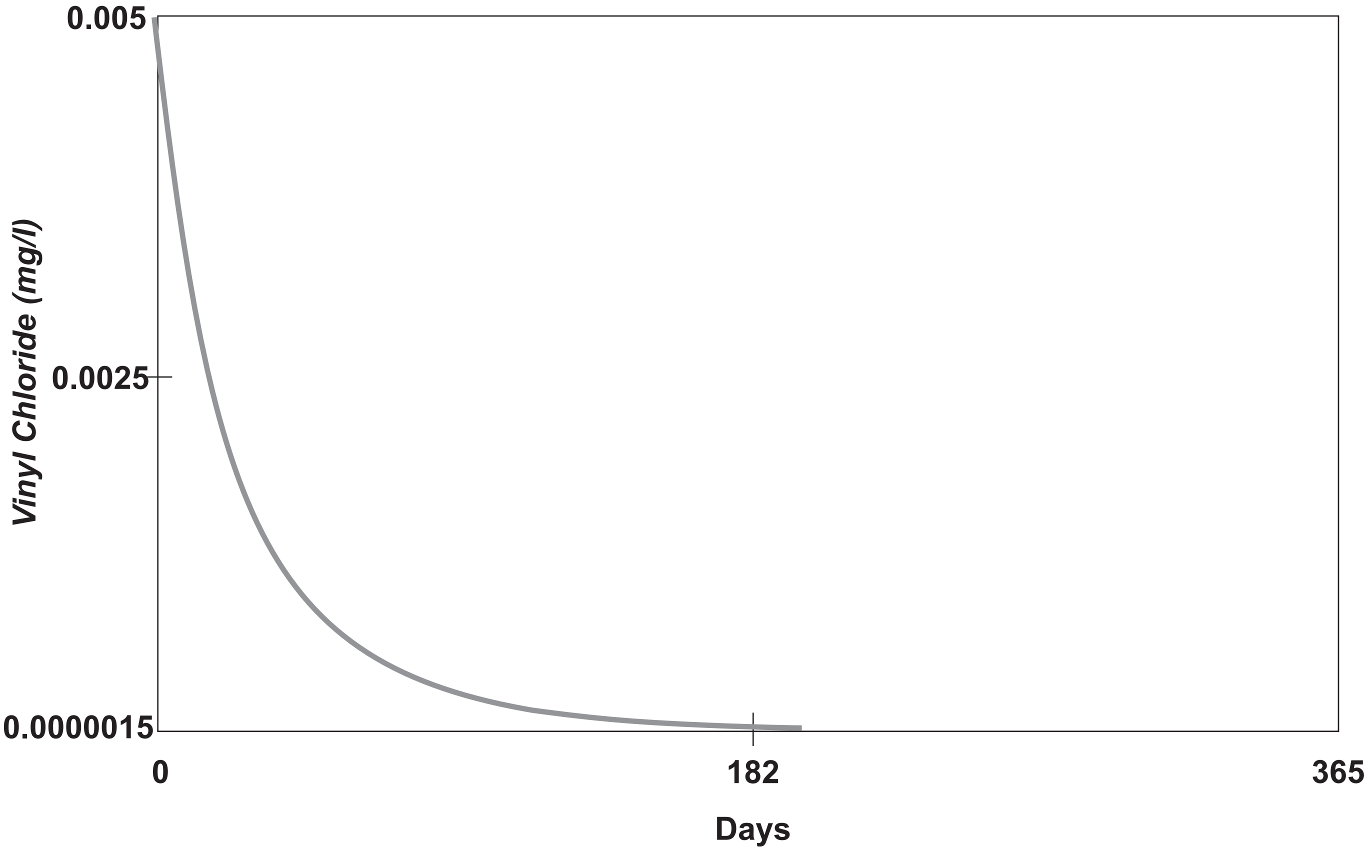
Figure 8-10
Typical Sparge/Vent System
Hansville Landfill FS Report



Location of cross section is shown on Figure 8-13

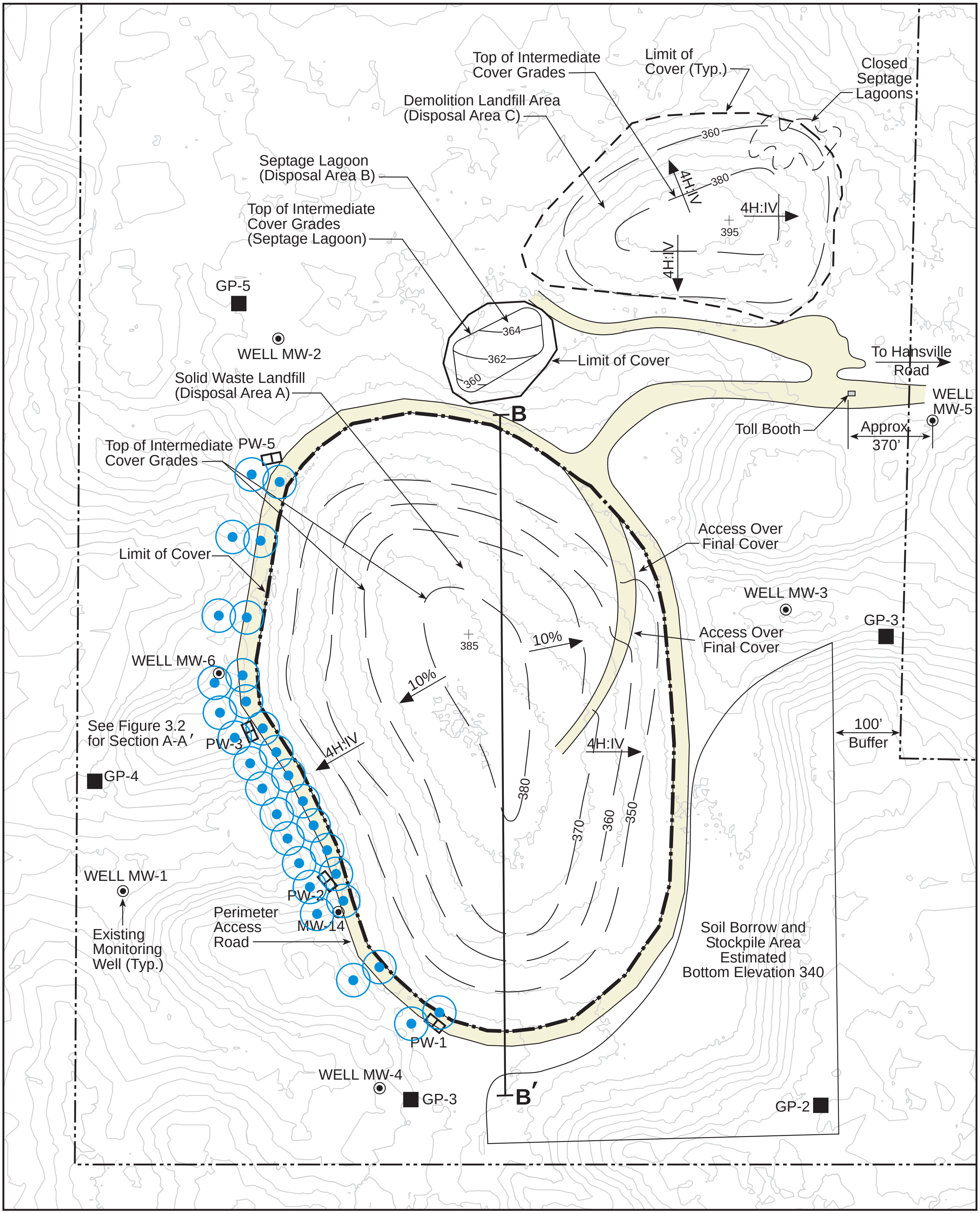
--→ Air Flow

Figure 8-11
Alternative 4: Air Sparging: Schematic Cross Section
Hansville Landfill FS Report



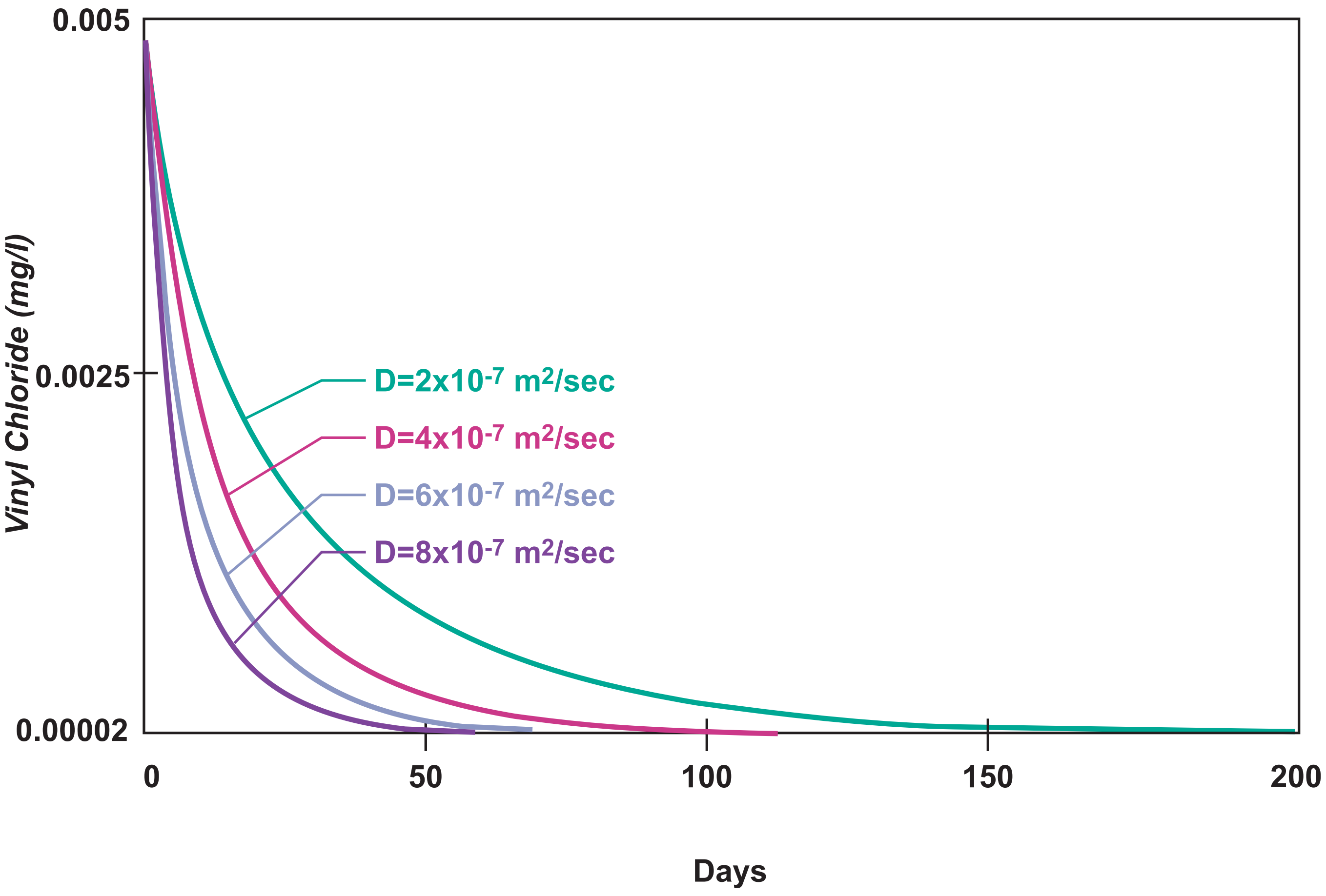
Note: The aquifer at the Hansville Landfill is flowing, not stagnant as assumed in the hypothetical modeling analysis shown above. The air sparging system is intended to function as a barrier to capture vinyl chloride released from the Landfill and prevent its migration to the off-site aquifer. The Landfill may continue to release vinyl chloride for many years. The air sparging system would need to operate until releases of vinyl chloride from the Landfill ceased and then until the residual vinyl chloride was captured.

Figure 8-12
Modeled Remediation Rate
of Vinyl Chloride by Air Sparging
in Hypothetical Stagnant Aquifer
Hansville Landfill FS Report



Parametrix Hansville Landfill FS 555-2966-002/02(01) 5/09 (B)

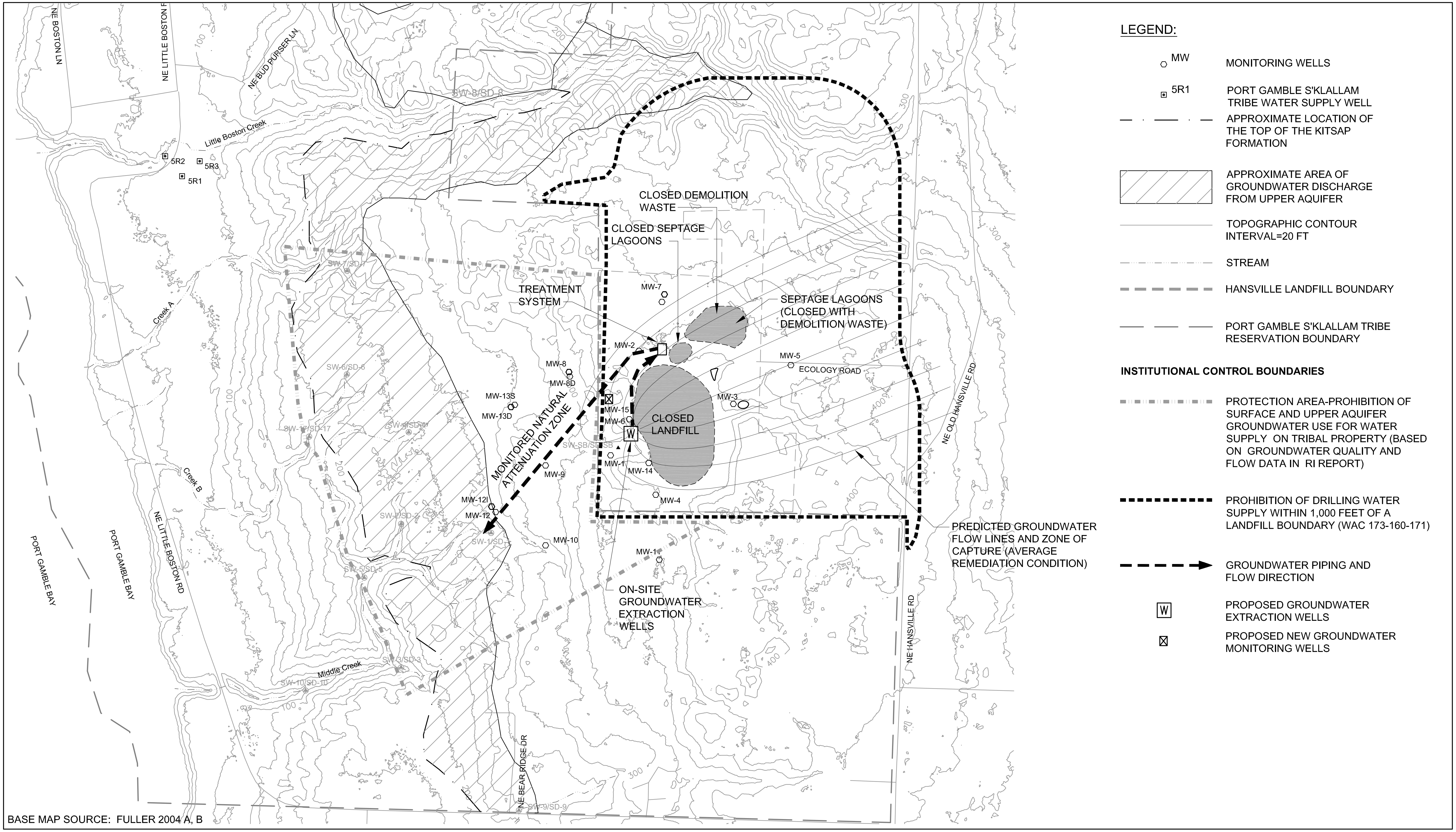
Figure 8-13
Alternative 4
Air Sparging Well Locations
Hansville Landfill FS Report



D = Dispersivity

As D is increased by pulsing of the air flow, vinyl chloride concentrations decrease faster over time.

Figure 8-14
Effects of Air Pulsing on
Groundwater Remediation Rates
Hansville Landfill FS Report



Parametrix DATE: 05/27/09 10:36am FILE: BL2966002P01T02-F-08-09

VERTICAL DATUM: NAVD 83

Figure 8-15
Alternative 5, Groundwater Pump and Treat at Landfill Boundary
Hansville Landfill FS Report

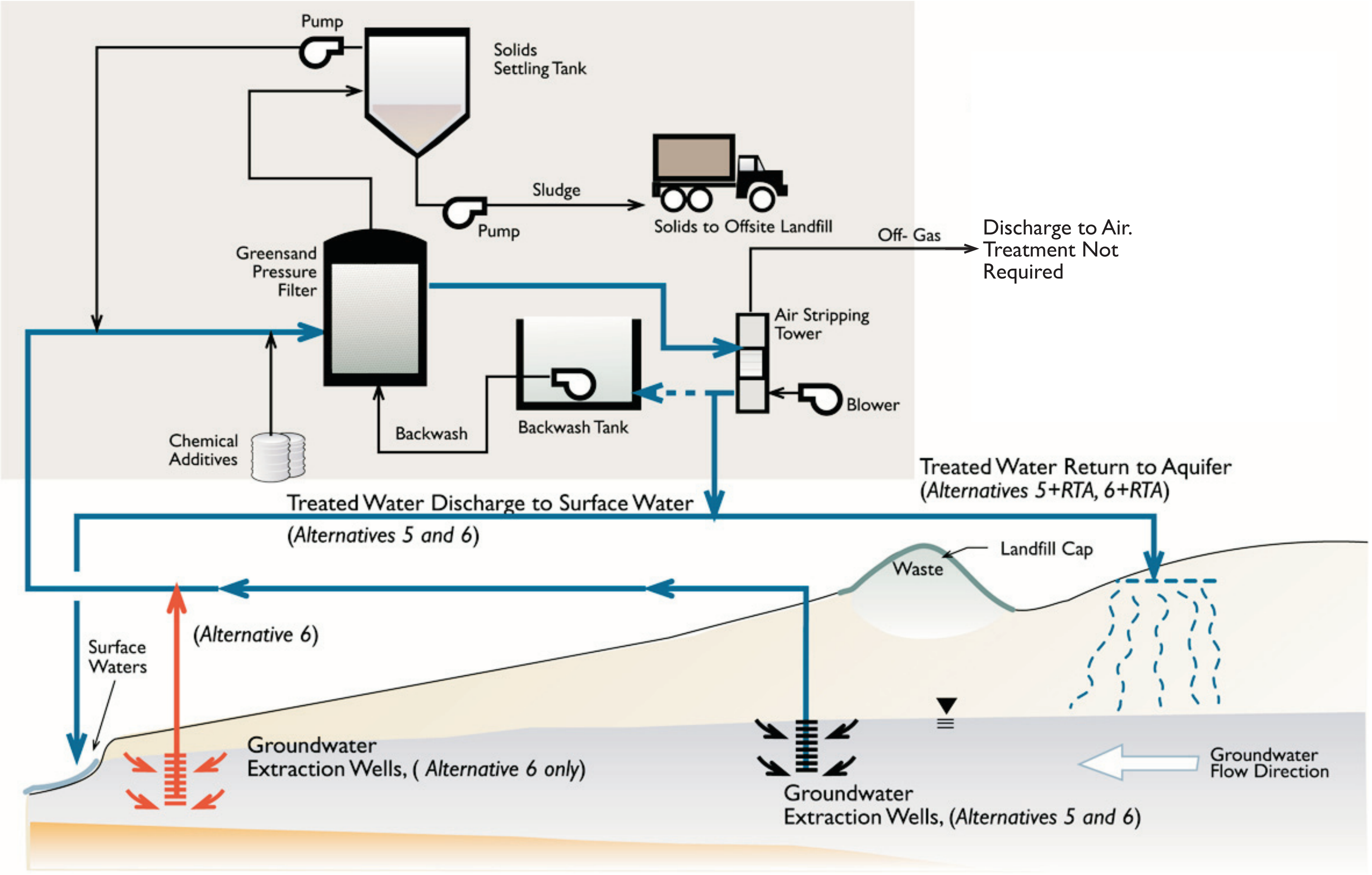
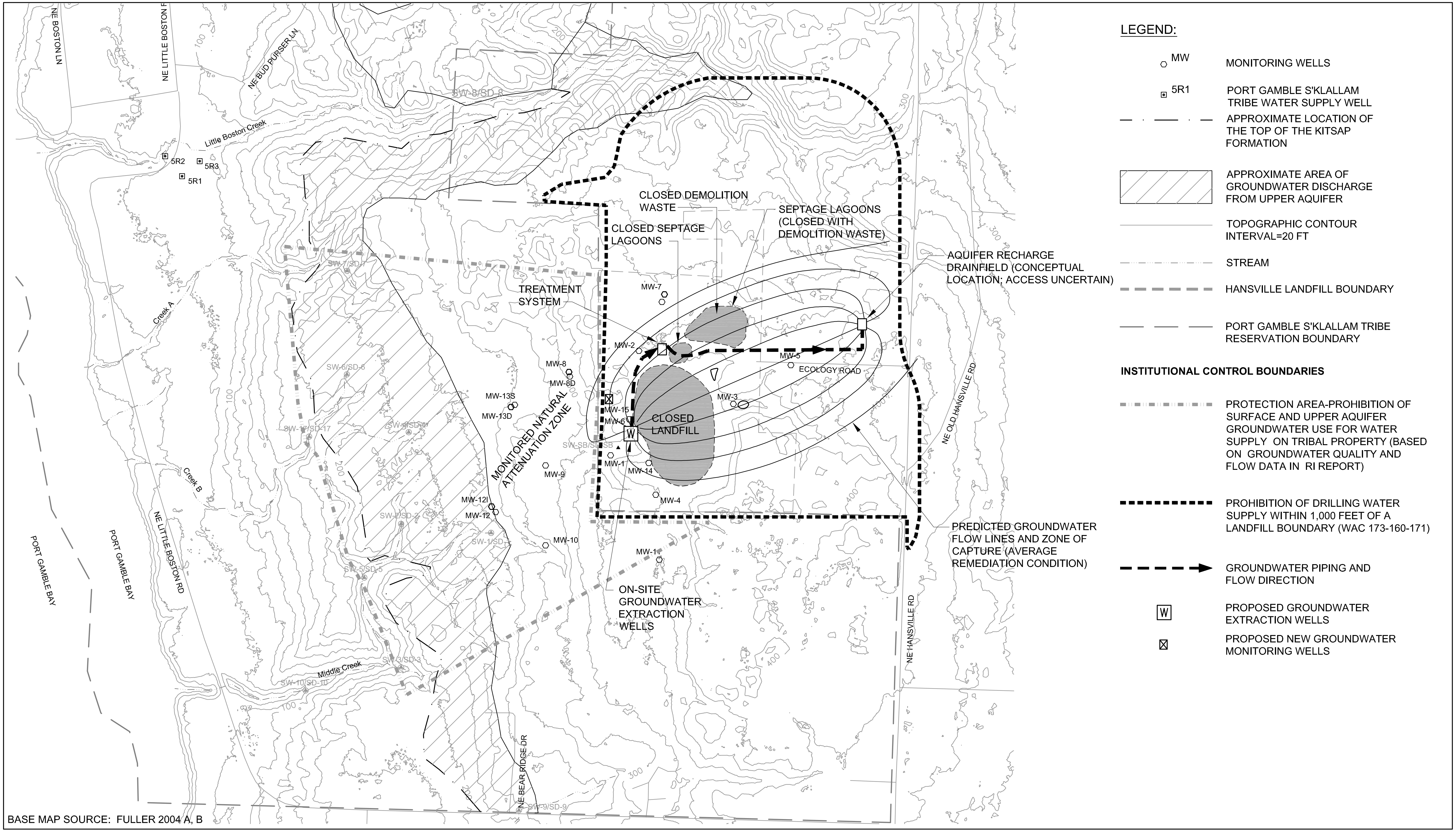


Figure 8-16
Alternatives 5 and 6: Groudwater Pump and Treat Systems
Hansville Landfill FS Report



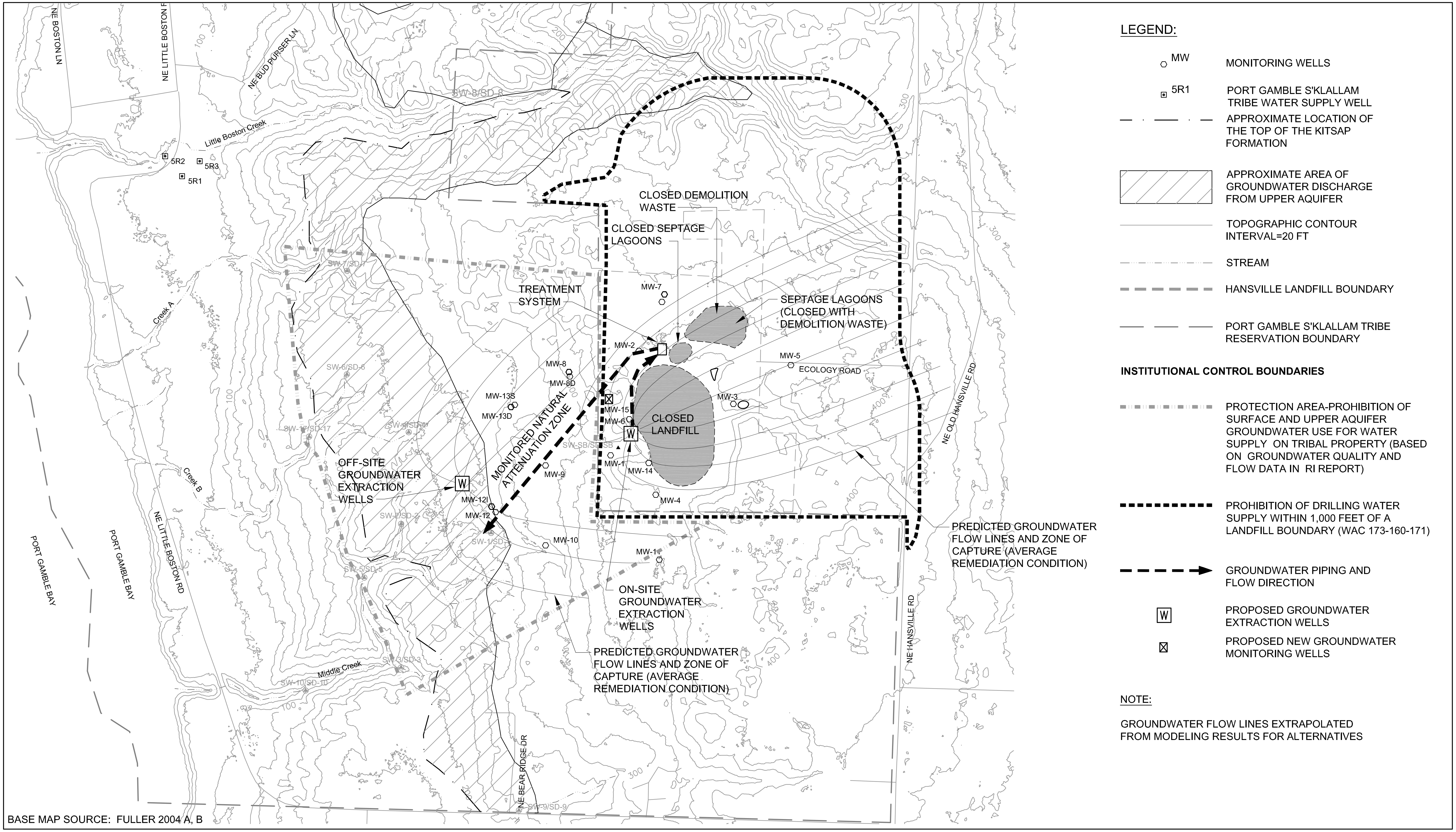
Parametrix DATE: 05/27/09 10:38am FILE: BL2966002P01T02-F-08-11

N

0 600
SCALE IN FEET

VERTICAL DATUM: NAVD 83

Figure 8-17
Alternative 5+RTA, Groundwater Pump and Treat at Landfill - Return to Aquifer
Hansville Landfill FS Report



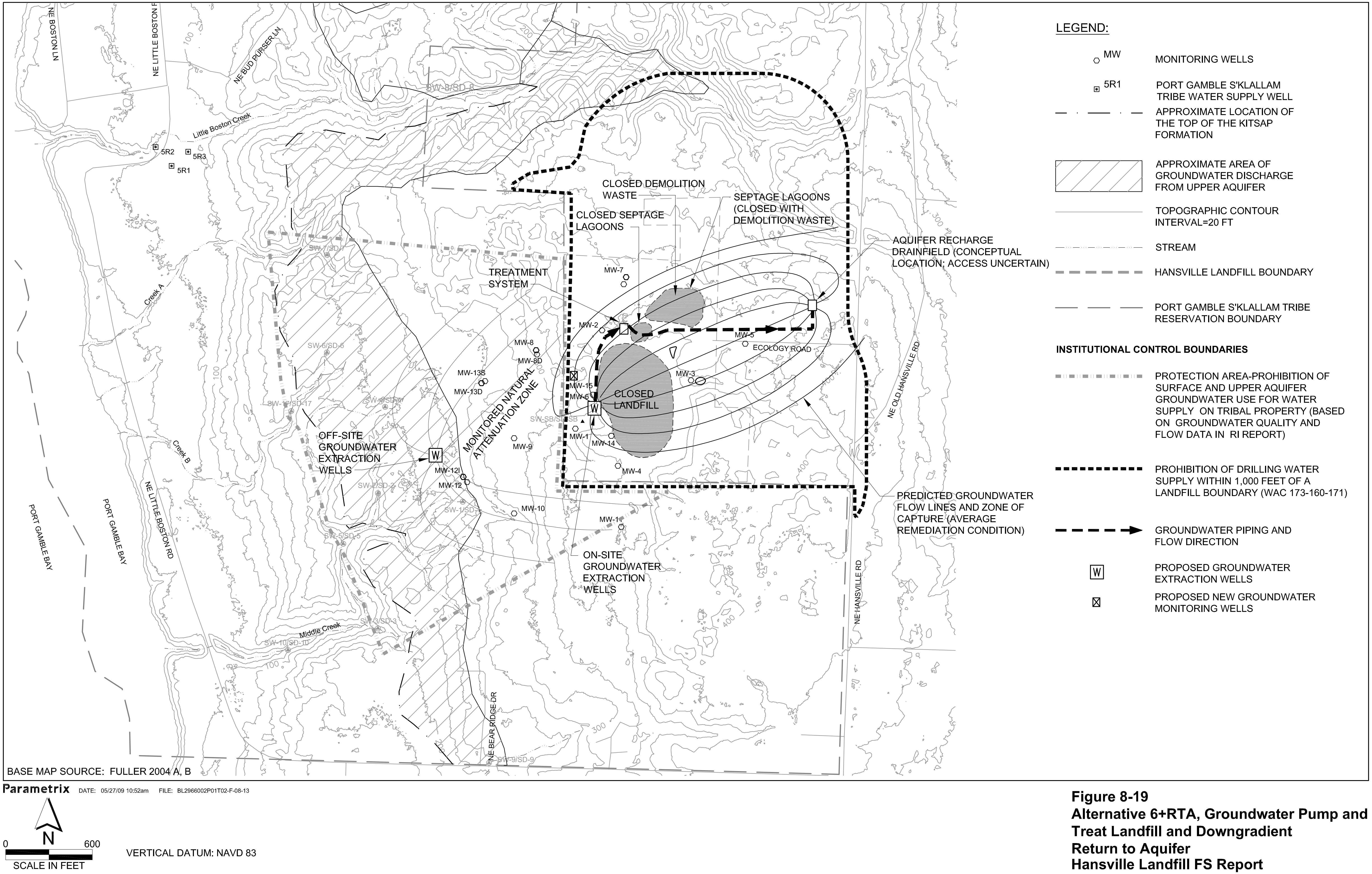
Parametrix DATE: 05/27/09 10:51am FILE: BL2966002P01T02-F-08-12

N

0 600
SCALE IN FEET

VERTICAL DATUM: NAVD 83

Figure 8-18
Alternative 6, Groundwater Pump and Treat at Landfill Boundary and Downgradient
Hansville Landfill FS Report



Parametrix DATE: 05/27/09 10:52am FILE: BL2966002P01T02-F-08-13

Figure 8-19
Alternative 6+RTA, Groundwater Pump and Treat Landfill and Downgradient Return to Aquifer
Hansville Landfill FS Report

Table 2-1. Landfill Property Background Summary

	Hansville Landfill	Surrounding Area
Size	72.5 acres. Three (former) disposal areas: mixed solid waste (13 acres); construction/ demolition/septage waste (4 acres); and a domestic septage lagoon (1/3 acre). Remaining area is comprised of access roads, a solid waste transfer station, a soil borrow area, and wooded land.	Sparsely populated, primarily forested land.
Ownership	Kitsap County. Multiple landfill operators managed the site under a lease from the County. These operators were Hudson Disposal Co., Inc., North Sound Sanitation, and Kitsap County Sanitary Landfill, Inc. (KCSL), and Waste Management of Washington, Kitsap County did not operate the landfill.	Bordering the landfill to the south and west is Port Gamble S'Klallam tribal land. Adjacent properties to the north and east are owned by private firms or individuals.
Past Use	1962 – Landfill began operation as an open dump under a lease from Kitsap County. 1973 – New state regulations led to improvements at the Landfill, to comply with requirements for handling and disposal of mixed municipal solid wastes, construction/demolition waste, and domestic septage waste. Three disposal areas were designated for these waste categories. 1982 – Landfill ceased receiving domestic septage waste; groundwater monitoring began. 1989-90 – Landfill ceased all waste disposal activities and constructed final cover system on disposal areas. A transfer station was constructed. 1990 – Monitoring of downstream surface water stations began.	Residential and recreational uses. Management and utilization of forests on surrounding private and Port Gamble S'Klallam tribal lands.
Current Use	Since 1989, the Landfill has been closed to receipt of refuse. All disposal areas have been capped. An active gas extraction system operates to remove and destroy landfill gas generated from the refuse. Monthly and quarterly monitoring of groundwater and surface water has been conducted. Landfill gas and soil gas have also been monitored. The transfer station continues to operate as a drop box and recycling facility for residential customers only.	Primarily residential and recreational uses to the north, west, south, and northeast. New industrial development on the adjacent parcel east of the Landfill Property. Management and utilization of forests on surrounding private and tribal lands. Port Gamble S'Klallam Tribe finfish and shellfish harvesting in Port Gamble Bay.

Table 2-2. Chemicals from the RI Screening Process to be Evaluated in the Feasibility Study

Chemicals Carried into the Feasibility Study	Groundwater	Surface Water	Sediment
Antimony			X
Arsenic	X	X	X
Bis(2-ethylhexyl)phthalate	X		
Chromium			X
Copper	X	X	
Lead	X		
Manganese	X		X
Nickel	X		X
Nitrate	X		
Silver	X		X
Vinyl Chloride	X	X	
Zinc	X	X	

Table 2-3. Waste Characteristics

Waste Type	Components	Characteristics
Municipal Solid Waste	Garbage, rubbish, glass, metals, paper, plastic, organics, rubber, and household hazardous waste.	Leachate generated from mixed solid wastes is typically moderately high in biological oxygen demand (BOD) and chemical oxygen demand (COD). May contain metals (including iron and manganese), anaerobic degradation products, and methanogenic degradation by-products.
Construction/ Demolition	Wood waste, concrete, asphalt, steel, glass, masonry, and household fixtures.	Relatively low in organic matter. Leachate typically has low BOD.
Domestic Septage	Sludge, fatty materials, and wastewater removed during septic tank pumping. Includes grit, grease, and hair.	Heavy metal content is generally low relative to municipal wastewater sludges. High in BOD, COD, and nitrogen compounds (nitrate). Anaerobic degradation of domestic sewage.

Table 3-1. Chemical-Specific ARARs

Statute/Regulation	Status	Requirements	Discussion
Federal ARARs			
Federal Water Pollution Control Act (a.k.a. Clean Water Act), **Surface Water Quality Standards** *Citation* 33 USC Sec. 303, 304 40 CFR 131. Quality Criteria for Water (EPA, 1986, rev. 1987)	Applicable	SW quality standards for Arsenic: Acute: 0.36 mg/L 1-hr avg. Chronic: 0.19 mg/L 4-day avg.	Applies to potential discharge of treated groundwater to surface water. Untreated groundwater arsenic concentrations are below these levels.
Federal Safe Drinking Water Act *Citation* 42 USC 300f et seq. 40 CFR 141, 143	Relevant and Appropriate	Defines Maximum Contaminant Levels for drinking water	
Tribal ARARs			
Tribal Water Quality Standards for Surface Water (USEPA 2005)	Relevant and Appropriate	Defines criteria for surface water quality on tribal property	Approved with conditions by USEPA (2005a).
State of Washington ARARs			
Model Toxics Control Act *Citation* RCW 70.105D Chapter 173-340 WAC	Applicable	Identifies procedures for establishing cleanup levels for groundwater, surface water, sediments, and soil	
State Water Pollution Control Act, Water Quality Standards for Surface Water *Citation* RCW 90.48 Chapter 173-201A WAC	Applicable		
State Water Pollution Control Act, State Water Resources Act of 1971 *Citation* RCW 90.48, 90.54 Water Quality Standards for Groundwaters *Citation* Chapter 173-200 WAC	Relevant and Appropriate	GW quality standards: As: 0.00005 mg/L Mn: 0.05 mg/L (Secondary) VC: 0.00002 mg/L (Carcinogen)	Applies to potential return of treated groundwater to aquifer (Note: requirement that water returned to aquifer must meet standards is unpromulgated State policy). MTCA Method A Cleanup Level (State background value) used for arsenic.

Table 3-2. Location-Specific ARARs

Statute/Regulation	Status	Requirements	Discussion
Tribal ARARs			
Tribal Regulations	Relevant and Appropriate	Regulations governing construction activities on Tribal property.	Construction plans reviewed by Tribal representatives.
State of Washington and County ARARs			
Water Well Construction *Citation* RCW 18.104 WAC 173-160-171 Kitsap County Board of Health Ordinance 2004-2	Applicable	No water wells to be located within 1,000 ft of the property boundary of a solid waste landfill.	No wells in upper aquifer are within the restricted area.
Kitsap County Board of Health *Citation* Ordinance 2004-2	Applicable	Requires methane testing for buildings within 1,000 ft of the active area of an active, closed, or abandoned landfill.	Applies to new buildings added as part of remediation (no existing buildings are within affected area).
Kitsap County Board of Health *Citation* Ordinance 2004-2	Applicable	Adopts Chapter 173-304, Minimum Functional Standards for Solid Waste Handling, by reference.	Chapter 173-304 includes provisions for quarterly groundwater monitoring, until trends are clearly established.
Kitsap County Local Development Ordinances *Citation* KCC Title 12	Relevant and Appropriate	Local codes provide standards for all construction activities, including stormwater management and grading.	Plans review and building permit not required, but planned facilities must meet substantive requirements of applicable codes for stormwater, grading, and other factors.

Table 3-3 Action-Specific ARARs

Statute/Regulation	Status	Requirements	Discussion
Federal ARARs			
Federal Resource Conservation and Recovery Act (RCRA) *Citation* 42 USC 6902 et seq.	Applicable	Defines hazardous waste management requirements.	Applies to management of hazardous/dangerous waste. If wastes are removed from the disposal areas, they will be managed in accordance with these requirements.
RCRA, HWMA *Citation* 40 CFR 261, 262, 264 49 CFR 171, 172, 173, 177	Applicable	Defines requirements for off-site transportation of waste.	Applies to transportation of waste off-site. Actions will comply with these requirements.
RCRA, HWMA *Citation* 40 CFR 263	Applicable	Defines pre-treatment and land disposal restrictions for certain wastes.	Applies to disposal of hazardous/dangerous wastes off-site. Wastes probably will not require additional treatment or be subject to restrictions.
RCRA, HWMA *Citation* 40 CFR 268	Applicable	Defines requirements for solid waste management and disposal facilities.	Applies to closure of solid waste landfill including capping, installation of gas system and environmental monitoring. Future site actions will comply with these regulations regardless of remediation alternative selected (including No Action).
RCRA, HWMA *Citation* 40 CFR 241, 251	Applicable	Defines requirements for solid waste management and disposal facilities.	Applies to disposal at new landfill of solid waste/soil excavated from site. These regulations apply if new landfill is in Washington; however, disposal will likely occur at one of two landfills in Oregon. If so, these regulations do not apply, but Oregon regulations would apply.
Federal Endangered Species Act (1973) *Citation* 16 USC 1531 et seq. 50 CFR 200, 402	Applicable	Establishes program to conserve and protect threatened or endangered species.	Applies to discharge of treated groundwater to surface water. Remedial investigation did not identify any threatened or endangered species at site or in adjacent areas, except that Middle Creek may be a potential habitat area for anadromous fish (i.e., salmon). Certain salmonid species have been listed as threatened species. Discharges of treated groundwater to Middle Creek may require additional review by state or federal agencies if salmonids are present and affected.

Table 3-3 Action-Specific ARARs (continued)

Statute/Regulation	Status	Requirements	Discussion
Federal Water Pollution Control Act (a.k.a. Clean Water Act), **National Pollutant Discharge Elimination System** (NPDES) *Citation* 33 USC Sec. 303, 304 40 CFR Part 122, 125	Relevant and Appropriate	Establishes State permit program for discharge of pollutants and wastewater to surface waters. Requires all known, available, and reasonable methods of treatment (AKART).	Applies to discharge of extracted, treated groundwater to surface water. Discharges to surface waters will comply with substantive requirements of these regulations; however, permit not required per MTCA exemption.
Federal Water Pollution Control Act (a.k.a. Clean Water Act) *Citation* 33 USC 1251-1387 33 CFR 320-330 40 CFR 230	Relevant and Appropriate	Establishes permit program for activities performed within 200 ft of shorelines.	Applies to construction of outfall for discharge of treated groundwater to surface water. Construction activities will comply with substantive requirements of these regulations; however, permit not required per MTCA exemption.
Federal Clean Air Act: New Source Performance Standards, National Emission Standards for Hazardous Air Pollutants, National Ambient Air Quality Standards *Citation* 42 USC 7401-7642 40 CFR Subpart 50, 60, 61, 63	Relevant and Appropriate	Establishes program for source registration and fee payment to restrict emissions, use Best Available Control Technology (BACT), and ensure compliance with air quality standards.	Applies to installing or operating source having emissions to atmosphere. Alternatives emitting contaminants to atmosphere will comply with substantive requirements of these regulations; however, source registration not required per MTCA exemption.
U.S. Fish and Wildlife Coordination Act *Citation* 16 USC 661 et seq.	Relevant and Appropriate	Prohibits water pollution with any substance deleterious to fish, plant life, or bird life.	Discharges to surface water controlled through state NPDES program. However, discharges to surface water may require a consultation with the United States Fish and Wildlife Service.

Table 3-3 Action-Specific ARARs (continued)

Statute/Regulation	Status	Requirements	Discussion
State of Washington ARARs			
Model Toxics Control Act *Citation* RCW 70.105D.090	Applicable	Defines hazardous waste cleanup policies. Actions conducted under consent decree are exempt from the procedural requirements of RCW 70.94, 70.95, 70.105, 75.20, 90.48, and 90.58 and the procedural requirements of any laws requiring or authorizing government permits or approvals for remedial actions. Actions shall comply with substantive requirements adopted pursuant to such laws and shall consult with government agencies charged with implementing such laws.	Performing cleanup under Consent Decree. Remedial activities will comply with substantive requirements of ARARs.
Model Toxics Control Act Regulations WAC 173-340	Applicable	Establishes administrative processes and standards to identify, investigate, and clean up facilities where hazardous substances have come to be located.	Applies to any facility (including landfills) where hazardous substance releases to the environment have been confirmed. Also specifies application of cleanup levels.
WAC 173-304 State Minimum Functional Standards for Landfills Solid Waste Disposal Facilities	Applicable	Defines requirements for solid waste management and disposal facilities.	Applies to closure of solid waste landfill, including capping, installation of gas system, and environmental monitoring. Future site actions will comply with these regulations regardless of remediation alternative selected (including No Action).
Chapter 173-351 WAC State Minimum Functional Standards for Landfills	Applicable	Defines requirements for solid waste management and disposal facilities.	Applies to disposal at new landfill of solid waste/soil excavated from site. These regulations apply if new landfill is in Washington; however, disposal will likely occur at one of two landfills in Oregon. If so, these regulations do not apply, but Oregon regulations would apply.
State Hazardous Waste Management Act (HWMA) *Citation* RCW 70.105 Definition/generation of hazardous/dangerous waste	Applicable	Defines threshold levels and criteria to determine whether materials are hazardous/ dangerous wastes.	Applies to designation, handling, and disposal of wastes. Treatment residuals meeting these criteria will be handled and disposed of in accordance with regulatory requirements.

Table 3-3 Action-Specific ARARs (continued)

Statute/Regulation	Status	Requirements	Discussion
Chapter 173-303-140 WAC Disposal Requirements and Land Disposal Restrictions Solid Waste Disposal Facilities	Applicable	Defines pre-treatment and land disposal restrictions for certain wastes.	Applies to disposal of hazardous/dangerous wastes off-site. Wastes probably will not require additional treatment or be subject to restrictions.
WAC 446-50 Transportation of hazardous/dangerous waste	Applicable	Defines requirements for off-site transportation of waste.	Applies to transportation of waste off-site. Actions will comply with these requirements.
State Environmental Policy Act (SEPA) *Citation* RCW 43.21C Chapter 197-11 WAC	Applicable	Defines requirements for evaluating environmental impacts of a governmental action, such as Ecology selecting a remedy.	Applies to the evaluation of environmental impacts of various remedial activities. Remedial activities will require submittal of a checklist describing the environmental impacts of the proposed project, public notice, and possibly additional project analyses and public involvement. All alternatives are anticipated to receive a Determination of Non-Significance, except Alternative 7 (see Section 7) may require an environmental impact statement.
State Water Pollution Control Act, NPDES Regulations *Citation* RCW 90.48 Chapter 173-220 WAC	Relevant and Appropriate	Establishes program for permitting discharges to surface waters.	Applies to discharge of treated groundwater to surface water.
State Hydraulics Act *Citation* RCW 75.20 Chapter 220-110 WAC	Relevant and Appropriate	Establishes permit program under Dept. of Wildlife/ Fisheries for projects that may change natural flow of "waters of the state."	Applies to discharge of treated groundwater to surface water (additional flow to creek is a "change"). Construction activities will comply with substantive requirements of these regulations; however, permit not required per MTCA exemption.
State Clean Air Act: Source Registration, Emissions Limits, Air Quality Standards *Citation* RCW 70.94 Chapter 173-400 WAC	Relevant and Appropriate	Establishes state approved program for source registration and fee payment to restrict emissions, use of BACT, and ensures compliance with air quality standards.	Applies to installing or operating source having emissions to atmosphere. Alternatives emitting contaminants to atmosphere will comply with substantive requirements of these regulations.

Table 3-3 Action-Specific ARARs (continued)

Statute/Regulation	Status	Requirements	Discussion
Puget Sound Clean Air Agency (PSCAA), **Source Registration, Emission Limits, Air Quality Standards** *Citation* Regulation I, III	Relevant and Appropriate	Establishes local approved program for source registration and fee payment to restrict emissions, use of BACT, and ensures compliance with air quality standards.	Applies to installing or operating source having emissions to atmosphere. Alternatives emitting contaminants to atmosphere will comply with substantive requirements of these regulations.
Puget Sound Clean Air Agency (PSCAA) *Citation* Regulation III	Relevant and Appropriate	Local air quality standards for toxics.	Applies to installing source emitting regulated toxic air pollutants to the atmosphere.
State Clean Air Laws: Controls for Air Toxics (Air Quality Standards) *Citation* RCW 70.94 Chapter 173-460 WAC	Relevant and Appropriate	Air quality standards for toxics: Vinyl chloride: 0.012 $\mu g/m^3$, annual average	Applies to installing source emitting regulated toxic air pollutant to atmosphere. Alternatives emitting vinyl chloride to atmosphere may require off-gas treatment. No As or Mn emissions to atmosphere anticipated.
State Water Code and Water Rights *Citation* RCW 90.03, 90.04 Chapters 173-150, 154 WAC	Relevant and Appropriate	Establishes rights of well owners to have adequate water supplies and establishes permit program for groundwater withdrawal.	Applies to groundwater extraction. No water shortage anticipated. Aquifer yields are relatively high and water demands are low near this site. Activities will comply with substantive requirements of this regulation; however, permit not required per MTCA exemption.
Shoreline Management Act (1971) *Citation* RCW 90.58 WAC 173-27	Relevant and Appropriate	Establishes State permit program for activities performed within 200 ft of shorelines.	Applies to any activity that affects water level or shoreline character of any water body.

Table 4-1. Summary of RI Chemical Screening Results by Receptor Evaluated in the FS

Chemicals > PCL	Evaluated For Human Receptors	Evaluated for Ecological Receptors
Groundwater		
Antimony[1]	Yes	N/A
Arsenic	Yes	N/A
Bis(2-ethylhexyl)phthalate	Yes	N/A
Copper	No[2]	Yes
Lead	No[2]	Yes
Manganese	Yes	N/A
Nickel	No[2]	Yes
Nitrate	Yes	N/A
Silver	No[2]	Yes
Vinyl Chloride	Yes	N/A
Zinc	No[2]	Yes
Surface Water		
Arsenic	Yes	No[3]
Copper	No[2]	Yes
Vinyl Chloride	Yes	Yes[4]
Zinc	No[2]	Yes
Sediment		
Antimony	No[2]	Yes
Arsenic	Yes	No[3]
Chromium	Yes	Yes
Manganese	No[2]	Yes
Nickel	No[2]	Yes
Silver	No[2]	Yes

[1] Not identified by the RI for further evaluation in the FS; evaluated in the FS due to common toxicological endpoint with nitrate.

[2] The PCL was based on an ARAR for ecological receptors. These chemicals did not exceed any human health-based ARARs; thus, these chemicals were only considered to be of concern for ecological receptors.

[3] The PCL was based on an ARAR for human health. This chemical did not exceed any ecological-based ARARs; thus, this chemical was only considered to be of concern for human health receptors.

[4] The PCL was based on an ARAR for human health. There were no ecological ARARs available for comparison; thus, this chemical was evaluated for both ecological and human health receptors.

N/A – Groundwater is not applicable for ecological receptors.

Table 4-2a. Potentially Applicable State and Federal Laws and Preliminary Cleanup Levels for Groundwater (mg/L)

Chemical	Surface Water Preliminary Cleanup Level [1]	MCL (Drinking Water)	MTCA Method B (Groundwater Quality)	Preliminary Cleanup Level	Method Detection Limit (MDL) [2]
METALS					
Antimony	0.0056	0.006	0.0064	0.0056	0.001
Arsenic	0.000005	0.01	0.005 [3]	0.000005	0.00005
Barium	1	2	3.2	1	0.003
Cadmium	0.000094	0.005	0.008	0.000094	0.0005
Calcium	none	none	none	none	0.1
Chromium	0.01	0.1	0.048	0.01	0.006
Copper	0.00274	1.3	0.592	0.00274	0.001
Iron	0.3 [5]	0.3 [5]	none	0.3 [5]	0.005
Lead	0.000541	0.015	none	0.000541	0.001
Magnesium	none	none	none	none	0.1
Manganese	2.24 / 0.05 [5]	0.05 [5]	2.24	2.24 / 0.05 [5]	0.0005
Mercury	0.000002	0.002	0.0048	0.000002	0.0002
Nickel	0.016	0.1	0.32	0.016	0.01
Potassium	none	none	none	none	1
Selenium	0.005	0.05	0.08	0.005	0.001
Silver	0.0003 / 0.1 [5]	0.1 [5]	0.08	0.0003 / 0.1 [5]	0.0001
Sodium	none	none	none	none	0.5
Thallium	0.00024	0.002	0.00112	0.00024	0.001
Zinc	0.032 / 5.0 [5]	5 [5]	4.8	0.032 / 5.0 [5]	0.002
CONVENTIONALS					
Ammonia-N	none	none	none	none	0.005
Chloride	250 [5]	250 [5]	none	250 [5]	1
Nitrate-N	10	10	25.6	10	0.01
Sulfate	250 [5]	250 [5]	none	250 [5]	not reported
VOLATILE ORGANICS					
1,1-Dichloroethane	0.8	none	0.8	0.8	0.001
1,2-Dichloroethylene [4]	0.070-0.100	0.070-0.100	0.080-0.160	0.070-0.100	0.001
Chloroform	0.0045	0.08	0.00717	0.0045	0.005
Methylene Chloride	0.0044	0.005	0.00583	0.0044	0.001
Trichlorofluoromethane	2.4	none	2.4	2.4	0.001
Vinyl Chloride	0.000025	0.002	0.000029	0.000025	0.00001
SEMIVOLATILE ORGANICS					
bis(2-ethylhexyl)phthalate	0.00024	none	0.00625	0.00024	0.002
Diethyl phthalate	4.5	none	12.8	4.5	0.002

[1] Surface water PCL from Table 4-3a.
[2] Lowest Method Detection Limit (MDL) for groundwater from Site database.
[3] MTCA Method A cleanup level used for arsenic, per Department of Ecology policy (Ecology 2004).
[4] Federal MCL and MTCA B represent range of "cis" and "trans" isomers.
[5] Value represents a secondary MCL based on aesthetics instead of ingestion.
MCL = Maximum Contaminant Level (Chapter 246-290 WAC)
MTCA = Model Toxics Control Act (Chapter 173-340 WAC)

Table 4-2b. Summary of Chemical Screening for Groundwater

Chemical[1]		Preliminary Cleanup Level (PCL) (mg/L)	Method Detection Limit (MDL)	Number of Downgradient Samples > Preliminary Cleanup Level [Data Range in ( )]	Background Concentration (mg/L) [2]	Number of Downgradient Samples > Preliminary Cleanup Level and > Background	Frequency of Detection (%)	Downgradient Samples > Preliminary Cleanup Level and > Background and FOD > 5%?	Risk	Comments
METALS										
Antimony	Antimony	0.0056	0.001	1 (0.008)			3.8	no	yes	Low frequency of detection
Arsenic	Arsenic	0.000005	0.00005	177 (0.00012-0.037)	0.005	48	96.7	☐ yes	yes	48 samples > PCL and background
Barium	Barium	1	0.003	none			98.2	no	no	No samples > screening criteria
Cadmium	Cadmium	0.000094	0.0005	none			0.0	no	no	No samples > screening criteria
Chromium	Chromium	0.01	0.006	none			0.0	no		No samples > screening criteria
Copper	Copper	0.00274	0.001	38 (0.003 - 0.035)			29.1	☐ yes	no	38 samples > PCL
Iron	Iron	0.3 [4]	0.005	30 (0.32-2.9)			62.6	no	yes	PCL is aesthetic secondary MCL
Lead	Lead	0.000541	0.001	14 (0.001-0.01)			7.7	☐ yes	yes	14 samples > PCL
Manganese	Manganese	2.24 / 0.05 [4]	0.0005	33 / 106 (2.2-13) / (0.06-13)			83	☐ yes	yes	33 samples > MTCA B
Mercury	Mercury	0.000002	0.0002	none			3.8	no	no	No samples > screening criteria
Nickel	Nickel	0.016	0.01	19 (0.02-0.08)			24	☐ yes	no	19 samples > PCL
Selenium	Selenium	0.005	0.001	none			9.6	no	no	No samples > screening criteria
Silver	Silver	0.0003 / 0.1 [4]	0.0001	5 (0.0004-0.0008)			15.4	☐ yes	no	5 samples > PCL
Thallium	Thallium	0.00024	0.001	1 (0.002)			1.0	no	yes	Low frequency of detection
Zinc	Zinc	0.032 / 5.0 [4]	0.002	3 (0.04 - 0.08)			87.5	☐ yes	no	3 samples > PCL
CONVENTIONALS										
Chloride	Chloride	250 [4]	1	7 (260-470)			97	no	yes	PCL is aesthetic secondary MCL
Nitrate-N	Nitrate-N	10	0.01	8 (11-18)			67	☐ yes	yes	8 samples > PCL
Sulfate	Sulfate	250 [4]	not reported	none			100	no	no	No samples > screening criteria
VOLATILE ORGANICS										
1,1-Dichloroethane	1,1-Dichloroetha	0.8	0.001	none			18.4	no	no	no samples > screening criteria
1,2-Dichloroethylene[3]	1,2-Dichloroethy	0.070-0.100	0.001	none			7	no	no	no samples > screening criteria
Chloroform	Chloroform	0.0045	0.005	none			4.2	no	no	no samples > screening criteria
Methylene Chloride	Methylene Chlor	0.0044	0.001	none			3.5	no	no	no samples > screening criteria
Trichlorofluoromethane	Trichlorofluorom	2.4	0.001	none			3.5	no	no	no samples > screening criteria
Vinyl Chloride	Vinyl Chloride	0.000025	0.00001	87 (0.00004-0.011)			39.1	☐ yes	yes	87 samples > PCL
SEMIVOLATILE ORGANICS										
bis(2-ethylhexyl)phthalate	bis(2-ethylhexyl)	0.00024	0.002	2 (0.0034 - 0.0042)		2	7.1	no	yes	2 samples > PCL
Diethyl phthalate	Diethyl phthalat	4.5	0.002	none			3.6	no	no	no samples > screening criteria

[1] This table includes all chemicals that were detected in one or more downgradient samples and for which a preliminary cleanup level was identified.

[2] Method A cleanup level for arsenic represents state background of natural arsenic, per Department of Ecology policy (Ecology 2004).

[3] Federal MCL and MTCA B represent range of "cis" and "trans" isomers.

[4] Value represents a secondary MCL; chemicals that exceed the secondary MCL, do not need to be addressed in the Feasibility Study (Ecology 2004).

MCL = Maximum Contaminant Level (Chapter 246-290 WAC)
MTCA = Model Toxics Control Act (Chapter 173-340 WAC)

☐ **Chemical evaluated in this FS report.**

Table 4-3a. Potentially Applicable State and Federal Laws and Preliminary Cleanup Levels for Surface Water (mg/L)

	Aquatic				Human Health									
Chemical	**Freshwater Chronic Standard (SWQS)**	**USEPA Chronic Criterion for Aquatic Life[1]**	**WQS (freshwater chronic criteria)[11]**	**Lowest Aquatic Criteria**	**USEPA Human Health Criterion[2]**	**NTR - Human Health Criterion[3]**	**MTCA-B Surface Water (fish consumption)**	**MTCA[4] (Tribal surface water)**	**MTCA-B Groundwater (ingestion)**	**USEPA MCL (ingestion)**	**WQS (human health, water and organisms)**	**Lowest Human Health Criteria**	**Preliminary Cleanup Level**	**Method Detection Limit (MDL)[10]**
METALS														
Antimony	none	none	none	none	0.0056	0.014	1.04	0.39	0.0064	0.006	0.013	0.0056	0.0056	0.001
Arsenic	0.19	0.15	0.15 [6]	0.15	0.000018	0.000018	0.0000982	0.000037	0.0000583	0.01	0.000005 [7]	0.000005	0.000005	0.00005
Barium	none	none	none	none	1	none	none	none	3.2	2	none	1	1	0.003
Cadmium	0.000369	0.000094	0.00025	0.000094	none	none	0.0203	0.00135	0.008	0.005	none	0.00135	0.000094	0.0005
Calcium	none	none	none	none	none	none	none	none	none	none	none	none	none	0.1
Chromium	0.01 [8]	0.0238	0.011 [8]	0.01	none	none	0.486	0.184	0.048	0.1	none	0.1	0.01	0.006
Copper	0.00347	0.00274	0.009	0.00274	1.3	none	2.66	1.01	0.592	1.3	none	0.59200	0.00274	0.001
Iron	none	none	1	1	0.3	none	none	none	none	0.3 [5]	0.3	0.3 [5]	0.3 [5]	0.005
Lead	0.000541	0.000541	0.0025	0.000541	none	none	none	none	none	0.015	none	0.015	0.000541	0.001
Magnesium	none	none	none	none	none	none	none	none	none	none	none	none	none	0.1
Manganese	none	none	none	none	0.05	none	none	none	2.24	0.05 [5]	0.05	2.24 / 0.05 [5]	2.24 / 0.05 [5]	0.0005
Mercury	0.000012	0.00077	0.00077	0.000012	none	0.00014	none	none	0.0048	0.002	0.000002	0.000002	0.000002	0.0002
Nickel	0.049	0.016	0.052	0.016	0.61	0.61	1.10	0.418	0.32	0.1	0.16	0.100	0.016	0.005
Potassium	none	none	none	none	none	none	none	none	none	none	none	none	none	1
Selenium	0.005	0.005	0.005	0.005	0.170	none	2.7	1.024	0.08	0.05	none	0.05	0.005	0.001
Silver	0.00032 [9]	0.00030	0.0034	0.00030	none	none	25.9	9.831	0.08	0.1 [5]	none	0.1 [5]	0.0003 / 0.1 [5]	0.0001
Sodium	none	none	none	none	none	none	none	none	none	none	none	none	none	0.5
Thallium	none	none	none	none	0.00024	0.0017	0.00156	0.00059	0.00112	0.002	0.00025	0.00024	0.00024	0.001
Zinc	0.032	0.036	0.12	0.032	7.4	none	16.5	6.275	4.8	5.0 [5]	none	5.0 [5]	0.032 / 5.0 [5]	0.002
CONVENTIONALS														
Ammonia	none	none	none	none	none	none	none	none	none	none	none	none	none	0.005
Chloride	none	none	230	230	none	none	none	none	none	250 [5]	none	250 [5]	250 [5]	1
Nitrate-N	none	none	none	none	none	none	none	none	25.6	10	10	10	10	0.01
Sulfate	none	none	none	none	none	none	none	none	none	250 [5]	none	250 [5]	250 [5]	not reported
VOLATILE ORGANICS														
1,1-Dichloroethane	none	none	none	none	none	none	none	none	0.8	none	none	0.8	0.8	0.001
1,2-Dichloroethene	140	none	none	140	none	none	33	none	0.080-0.160	0.070-0.100	0.63	0.070-0.100	0.070-0.100	0.001
Carbon disulfide	none	none	none	none	none	none	none	none	0.8	none	none	0.8	0.8	0.001
Chloroform	none	none	none	none	0.0057	0.0057	0.28	0.283	0.00717	0.08	0.0045	0.0045	0.0045	0.001
Methylene chloride	none	none	none	none	0.0046	0.0047	0.96	0.364	0.005	0.005	0.0044	0.0044	0.0044	0.001
Phenol	none	none	none	none	21	21	1,110	421	4.8	none	19	4.8	4.8	0.002
Trichlorofluoromethane	none	none	none	none	none	none	none	none	2.4	none	none	2.4	2.4	0.001
Vinyl chloride	none	none	none	none	0.000025	0.002	0.00369	0.0014	0.000029	0.002	0.0019	0.000025	0.000025	0.00001
SEMIVOLATILE ORGANICS														
bis(2-ethylhexyl)phthalate	none	none	none	none	0.0012	0.0018	0.0036	none	0.0063	0.006	0.00024	0.00024	0.00024	0.002
Diethyl phthalate	none	none	none	none	17	23	28	none	12.8	none	4.5	4.5	4.5	0.002

[1] Chronic criteria are from USEPA (2002a), assumes 25 mg/L hardness for hardness-dependent metals criteria.

[2] Human health criteria for consumption of water and organisms (USEPA 2004a).

[3] Values shown are applicable criteria for water supply (domestic) for Washington State, as identified in 40 CFR, Section 131.36 (7-1-03 Edition).

[4] These values represent MTCA method B surface water cleanup levels based on a tribal consumption rate of 142.4 grams/day rather than the default 54 grams/day.

[5] Value represents a secondary MCL based on aesthetics instead of ingestion.

[6] Criteria refer to trivalent form only.

[7] Criteria refer to inorganic form only.

[8] Cr (VI).

[9] Acute criteria.

[10] Lowest Method Detection Limit (MDL) for groundwater from Hansville database.

[11] Aquatic life criteria approved by EPA subject to completion of consultation under Endangered Species Act.

MTCA = Model Toxics Control Act (Chapter 173-340 WAC); Method B values were used for all chemicals except arsenic, lead, and methylene chloride, for which Method A was used in the absence of Method B values.
SWQS = Surface Water Quality Standard (Chapter 173-201A WAC), assumes 25 mg/L hardness for hardness-dependent metals criteria (minimum hardness measured at all stations).
WQS = Port Gamble S'Klallam Tribe Water Quality Standards for Surface Waters; dissolved metals values are a function of total hardness and correspond to a hardness of 100 mg/L.

Table 4-3b. Summary of Chemical Screening for Surface Water

Chemical[1]	Preliminary Cleanup Level (PCL), (mg/L)	Method Detection Limit (MDL)	Number of Downstream Samples > Preliminary Cleanup Level [Data Range in ( )]	Background Concentration (mg/L)	Number of Downstream Samples > Preliminary Cleanup Level and > Background[2]	Frequency of Detection (FOD) (%)	Downstream Samples > Preliminary Cleanup Level and > Background and FOD > 5%?	Comments
METALS								
Antimony	0.0056	0.001	none	not available	none	21.9	no	No samples > screening criteria
Arsenic	0.000005	0.00005	113 (0.00021-0.0057)	0.00021 to 0.0032	11	99.1	yes	11 samples > PCL & Background
Barium	1	0.003	none	not available	none	100	no	No samples > screening criteria
Cadmium	0.000094	0.0005	none	all <0.0005	none	13.3	no	No samples > screening criteria
Chromium	0.01	0.006	none	<0.001 to 0.004	none	6.7	no	No samples > screening criteria
Copper	0.00274	0.001	19 (0.003-0.011)	<0.001 to 0.005	3	21.4	yes	3 samples > PCL & Background
Iron	0.3[3]	0.005	7 (0.31-0.64)	<0.005 to 0.54	1	78.9	no	1 sample > secondary MCL and background
Lead	0.000541	0.001	5 (0.001-0.007)	<0.001 to 0.002	2	3.8	no	FOD ≤ 5%
Manganese	2.24 / 0.05[3]	0.0005	none / 5 (0.1-0.2)	<0.0005 to 0.013	none / 5	92.1	no	5 samples > secondary MCL
Mercury	0.000002	0.0002	1 (0.0004)	all <0.0002	1	4.2	no	FOD ≤ 5%
Nickel	0.016	0.005	none	all < 0.017	none	0.0	no	No samples > screening criteria
Selenium	0.005	0.001	none	not available	none	5.6	no	No samples > screening criteria
Silver	0.0003 / 0.1[3]	0.0001	none	not available	none	26.7	no	No samples > screening criteria
Thallium	0.00024	0.001	2 (0.001)	not available	2	3.1	no	FOD ≤ 5%
Zinc	0.032 / 5.0[3]	0.002	3 (0.04-0.089) / none	<0.001 to 0.007	3 / none	88.2	yes	3 samples > PCL & Background
CONVENTIONALS								
Chloride	250[3]	1	none	not available	none	100	no	No samples > screening criteria
Nitrate-N	10	0.01	none	0.23 - 2.0	none	91.1	no	No samples > screening criteria
Sulfate	250[3]	not reported	none	not available	none	100	no	No samples > screening criteria
VOLATILE ORGANICS								
1,1-Dichloroethane	0.08	0.001	none	not available	none	0.0	no	No samples > screening criteria
1,2-Dichloroethene	0.070-0.100	0.001	none	not available	none	0.0	no	No samples > screening criteria
Carbon disulfide	0.8	0.001	none	not available	none	1.2	no	No samples > screening criteria
Chloroform	0.0045	0.001	none	not available	none	0.0	no	No samples > screening criteria
Methylene chloride	0.0044	0.001	none	not available	none	1.2	no	No samples > screening criteria
Phenol	9.6	0.002	none	not available	none	3.2	no	No samples > screening criteria
Vinyl chloride	0.000025	0.001	42 (0.00003 - 0.00048)	not available	42	24.7	yes	42 samples > screening criteria
SEMIVOLATILE ORGANICS								
bis(2-ethylhexyl)phthalate	0.00024	0.002	none	not available	none	0.0	no	No samples > screening criteria
Diethyl phthalate	4.5	0.002	none	not available	none	0.0	no	No samples > screening criteria

---

[1] This table includes all chemicals that were detected in one or more downgradient samples and for which a preliminary cleanup level was identified. (SW-08, SW-09, and SD-SW are not downgradient sampling locations.)

[2] Background surface water samples collected at SW-15,SW-17B, SW-18, SW-19, and SW-20 in November 2002.

[3] Value represents a secondary MCL; chemicals that exceed the secondary MCL do not need to be addressed in the Feasibility Study (Ecology 2004).

☐ **Chemical evaluated in this FS report.**

Table 4-4a. Potentially Applicable State Guidelines, Laws, and Preliminary Cleanup Levels for Freshwater Sediment (mg/kg)

Chemical	Freshwater Sediment Quality Value [1]	Lowest Apparent Effects Threshold [2]	MTCA Soil Cleanup Level[3]	Preliminary Cleanup Level (mg/kg)
METALS				
Antimony	none	0.6	32	0.6
Arsenic	57	31.4	20	20
Barium	none	none	5,600	5,600
Beryllium	none	0.46	160	0.46
Cadmium	5.1	2.39	80	2.39
Chromium	260	95	240	95
Copper	390	619	2,960	390
Lead	450	335	250	250
Manganese	none	1,800	11,200	1,800
Mercury	0.41	0.8	24	0.41
Nickel	none	53.1	1,600	53.1
Selenium	none	none	400	400
Silver	6.1	0.545	400	0.545
Thallium	none	none	5.6	5.60
Zinc	410	683	24,000	410

[1] Freshwater Sediment Quality Values from Cubbage et al. (1997).

[2] Lowest Apparent Effect Thresholds (LAETs) from Ecology (2003), except manganese from Cubbage et al. (1997).

[3] MTCA Method B soil cleanup levels were used for all metals except arsenic and lead, to which MTCA Method A soil cleanup levels were applied. MTCA soil cleanup levels applied as required by Ecology (2002).

MTCA = Model Toxics Control Act (Chapter 173-340 WAC).

Table 4-4b. Summary of Chemical Screening Results for Freshwater Sediment

Chemical[1]	Preliminary Cleanup Level (mg/kg)	Number of Downgradient Samples > Preliminary Cleanup Level [2] [Data Range in ( )]	Background Concentrations (mg/kg)[3]	Downgradient Samples > Preliminary Cleanup Level and > Background ?	Comments
METALS					
Antimony	0.6	three samples (0.9-13)	<0.25 to <2.4	yes	1 sample > preliminary cleanup level and > background
Arsenic	20	one sample (28)	2.1 to 11	yes	1 sample > preliminary cleanup level and > background
Barium	5,600	none	46 to 83	no	No samples > preliminary cleanup level
Beryllium	0.46	none	0.07 to <0.5	no	No samples > preliminary cleanup level
Cadmium	2.39	none	<0.27 to <2.4	no	No samples > preliminary cleanup level
Chromium	95	one sample (310)	19 to 120	yes	1 sample > preliminary cleanup level and > background
Copper	390	none	2.3 to 39	no	No samples > preliminary cleanup level
Lead	250	none	3.6 to 25	no	No samples > preliminary cleanup level
Manganese	1,800	two samples (2700-4100)	220 to 890	yes	2 samples > preliminary cleanup level and > background
Mercury	0.41	none	<0.04 to <0.2	no	No samples > preliminary cleanup level
Nickel	53.1	one sample (54)	16 to 37	yes	Triplicate samples SD-10a,b,c all < screening criterion
Selenium	400	none	<0.25 to <1.2	no	No samples > preliminary cleanup level
Silver	0.545	two samples (0.55-1.5)	<0.02 to 0.6	yes	1 sample > preliminary cleanup level and > background
Thallium	5.60	none	<0.24 to <2.4	no	No samples > preliminary cleanup level
Zinc	410	none	5.5 to 95	no	No samples > preliminary cleanup level
VOLATILE ORGANICS					
Methylene Chloride	133	none	not available	none	No samples > preliminary cleanup level

[1] This table includes all chemicals that were detected in one or more downgradient samples and have preliminary cleanup levels.
SD-08, SD-09, SD-11 through SD-16, and SD-SB are not downgradient sampling locations.

[2] Multiple replicated samples > preliminary cleanup level are only counted as one occurrence.

[3] Background samples were collected at Stations SD-11, SD-12, SD-14, SD-15, and SD-16 in April 1997.

▭ **Chemical to be evaluated in the FS report.**

Table 4-5. Exposure Assumptions and Dose Equations Used in the Human Health Risk Calculations

Exposure Assumption	Units	Values	Description	Reference
Human Health Exposure Parameters				
Drinking Water Exposure Parameters				
Drinking water body weight for noncarcinogens	kg	16	Average body weight during period of exposure	Ecology 1993
Drinking water body weight for carcinogens	kg	70	Average body weight during period of exposure	Ecology 1993
Drinking water ingestion rate for noncarcinogens	L/day	1		Ecology 1993
Drinking water ingestion rate for carcinogens	L/day	2		Ecology 1993
Drinking water exposure duration	years	30		Ecology 1993
Drinking water lifetime	years	75		Ecology 1993
Fish Consumption Exposure Parameters				
Fish Consumption body weight	kg	70	Average body weight during period of exposure	Ecology 1993
Fish Consumption ingestion rate for noncarcinogens	g/day	54		Ecology 1993
Fish Consumption ingestion rate for carcinogens	g/day	54		Ecology 1993
Fish Diet Fraction	Unitless	0.5		
Fish Consumption Exposure Duration	years	30		Ecology 1993
Fish Consumption lifetime	years	75		Ecology 1993
Recreational Exposure Parameters				
Adult and child water incidental ingestion rate	mL/hour	50	Average for drinking water	USEPA 1989b
Child sediment ingestion rate	mg/day	100	Average incidental soil ingestion by children	USEPA 1997b
Adult sediment ingestion rate	mg/day	50	Average incidental soil ingestion by adults	USEPA 1997b
Adult exposure duration	years	33	95th percentile for residences	USEPA 1997b
Child exposure duration	years	6	Ages 1 - 7	Best Professional Judgment
Adult body weight	kg	70	Average of male and female body weights, 18-70.	USEPA 1997b
Child body weight	kg	17	Avg. of mean boy and girl body weights, ages 1-6	USEPA 1997b
Averaging time for children for noncarcinogens	years	6	Assumed equal to exposure duration	USEPA 1989b
Averaging time for adults for noncarcinogens	years	33	Assumed equal to exposure duration	USEPA 1989b
Lifetime	years	70	Approximate life expectancy in USA	USEPA 1989b
Exposure time	hours/day	1	Assumption	Best Professional Judgment
Child exposure frequency	days/year	20	Assumes once per month for five months	Best Professional Judgment
Adult exposure frequency	days/year	20	Assumes once per month for five months	Best Professional Judgment
Child sediment deposition rate to skin	ng/sq.cm/	16	Weighted average soil adherence to child by body part.	USEPA 1997b
Adult sediment deposition rate to skin	ng/sq.cm/	0.36	Estimate of soil adherence to adult arms during reed gathering in tidal flats.	USEPA 1997b
Absorption Fraction	unitless	0.01	Assumed value for all inorganics	USEPA 1995
Child Exposed Skin Area	sq.cm	2,466	Avg. area of hands, feet, one-half of arms, and one-half of legs of 3-4 year old	USEPA 1989b
Adult Exposed Skin Area	sq.cm	3,100	Avg. area of hands, forearms, and feet of adult male	USEPA 1992

Drinking Water Exposures:
ADI = Wat. Conc.*Wat. Ing. Rate (Noncarc.)/BW (Noncarc.)
LADI = (Wat. Conc.*Wat. Ing. Rate (Carc.)*Exp. Duration)/(BW (Carc.)*Lifetime)
Note: a factor of 2 is applied to the numerator of the dose equation for volatiles such as vinyl chloride.

Recreational Exposures:
Water Ingestion ADI = (Wat. Conc.*Exp. Time*Exp. Freq.*Exp. Duration*Wat. Ing. Rate*10^{-3} L/mL)/(Body Wt.*Averaging Time*365 d/yr)
Water Ingestion LADI = (Wat. Conc.*Exp. Time*Exp. Freq.*Exp. Duration*Wat. Ing. Rate*10^{-3} L/mL)/(Body Wt.*Lifetime*365 d/yr)

Water Contact ADI (inorganics) = (Wat. Conc.*Kp*Exp. Time*0.001 L/cm^3*Exposed Skin Area*Exp. Freq.*Exp. Duration)/(Body Wt.*Averaging Time*365 d/yr)
Water Contact LADI (organics) = ((Wat. Conc.*Kp*0.001*((1/(1+B))+(2*T*((1+(3*B))/(1+B)))))*Exposed Skin Area*Exp. Time*Exp. Freq.*Exp. Duration)/(Body Wt.*Lifetime*365 d/yr)

Fish Ingestion = (Wat. Conc.*BCF*Fish Ing.*Fish Fraction)/(BW)
Fish Ingestion = (Wat. Conc.*BCF*Fish Ing.*Fish Fraction*Fish Exp. Duration)/(BW (Carc.)*Lifetime)

Sediment Ingestion ADI = (Sed. Conc.*Exp. Freq.*Exp. Duration*Sed. Ing. Rate*10^{-6} kg/mg)/(Body Wt.*Averaging Time*365 d/yr)
Sediment Ingestion LADI = (Sed. Conc.*Exp. Freq.*Exp. Duration*Sed. Ing. Rate*10^{-6} kg/mg)/(Body Wt.*Lifetime*365 d/yr)

Sediment Contact ADI = (Sed. Conc.*Exposed Skin Area*Exp. Freq.*Exp. Duration*Sed. Deposition Rate*Absorption Fraction)/(Body Wt.*Averaging Time*365 d/yr*1000000 mg/kg)
Sediment Contact LADI = (Sed. Conc.*Exposed Skin Area*Exp. Freq.*Exp. Duration*Sed. Deposition Rate*Absorption Fraction)/(Body Wt.*Lifetime*365 d/yr*1000000 mg/kg)

Table 4-6. Human Health Toxicity Values and Supporting Information

Chemical	Effect	EPA Reference Dose (mg/kg-day)[1]	RfD Study Test Organism	Effect Type and Uncertainty / Modifying Factors[2,3]	Cancer Slope (mg/kg-day^{-1})[1]
METALS					
Antimony [4]	Hemotoxicity	0.0004	Rat	LOAEL, UF =1000	Not Applicable
Arsenic	Skin	0.0003	Human	NOAEL, UF = 3, MF = 1	1.5
Chromium	No Effects Observed	1.5	Rat	NOAEL, UF = 100, MF = 10	Not Applicable
Manganese	CNS Effects	0.14	Human	NOAEL, UF = 1, MF = 1	Not Applicable
Zinc [4]	(Dec. ESOD)	0.3	Human	LOAEL, UF = 3, MF = 1	Not Applicable
CONVENTIONALS					
Nitrate-N	hemoglobin)	1.6	Human	NOAEL, UF = 1, MF = 1	Not Applicable
VOLATILE ORGANICS					
Vinyl Chloride	Liver Toxicity	0.003	Rat	NOAEL, UF = 30, MF = 1	1.5
SEMIVOLATILE ORGANICS					
bis(2-ethylhexyl)phthalate	Liver Toxicity	2.00E-02	Guinea pig	LOAEL, UF = 1000, MF = 1	1.40E-02

[1] Taken from Integrated Risk Information System (USEPA 2005b).

[2] UF = Uncertainty Factor; intended to account for (1) variation in susceptibility among the members of the human population (i.e., inter-individual or intraspecies variability); (2) uncertainty in extrapolating animal data to humans (i.e., interspecies uncertainty); (3) uncertainty in extrapolating from data obtained in a study with less-than-lifetime exposure (i.e., extrapolating from subchronic to chronic exposure); (4) uncertainty in extrapolating from a LOAEL rather than from a NOAEL; and (5) uncertainty associated with extrapolation when the database is incomplete.

[3] MF = Modifying Factor; a factor used in the derivation of a reference dose or reference concentration. The magnitude of the MF reflects the scientific uncertainties of the study and database not explicitly treated with standard uncertainty factors (e.g., the completeness of the overall database). An MF is greater than zero and less than or equal to 10, and the default value for the MF is 1.

[4] Antimony and zinc were not found to be chemicals of concern through evaluation of cleanup levels. However, since they share a common toxic endpoint as nitrate, they were further evaluated in the groundwater assessment for human health.

NOAEL = No Observed Adverse Effect Level
LOAEL = Low Observed Adverse Effect Level

Table 4-7a. Non-Carcinogenic Risks to Human Health from Drinking Water (Groundwater)

Chemical	**Reference Dose (RfD)[1] (mg/kg/d)**	**Groundwater Concentration[2] (mg/L)**							**Water Ingestion Hazard Quotient (HQ)**						
On-Site Wells		MW-1	MW-2	MW-3	MW-4	MW-6	MW-7	MW-14	MW-1	MW-2	MW-3	MW-4	MW-6	MW-7	MW-14
Antimony [3]	0.0004	0.000625	ND	ND	0.000636	ND	ND	0.001227	0.10	ND	ND	0.10	ND	ND	0.19
Arsenic	0.0003	0.0015	0.0018	0.0037	0.0019	0.009	0.002	0.017	0.31	0.37	0.77	0.39	1.87	0.39	3.59
Manganese	0.14	0.22	0.0090	0.12	0.0012	2.8	0.181	5.6	0.10	0.004	0.05	0.001	1.26	0.08	2.51
Nitrate	1.6	0.98	4.08	0.45	1.16	0.08	6.79	3.49	0.04	0.16	0.02	0.05	0.003	0.27	0.14
Vinyl chloride	0.003	0.000009	ND	ND	0.0021	0.0042	0.0009	0.0030	0.0004	ND	ND	0.09	0.18	0.04	0.12
Zinc [3]	0.3	0.01	0.01	0.0185	0.0100	0.0100	0.01	0.0352	0.002	0.002	0.004	0.002	0.002	0.002	0.01
bis(2-ethylhexyl)phthalate	0.02	0.004	0.0034	0.011	ND	ND	ND	ND	0.013	0.011	0.034	ND	ND	ND	ND
Hazard Index:									**0.56**	**0.54**	**0.87**	**0.63**	**3.31**	**0.78**	**6.57**
Hazard Index Hepatotoxins (Vinyl Chloride, bis(2-ethylhexyl)phthalate)									**0.01**	**0.01**	**0.03**	**0.09**	**0.18**	**0.04**	**0.12**
Hazard Index Hemotoxins (Sb, Zn, Nitrate)[3]									**0.14**	**0.16**	**0.02**	**0.15**	**0.01**	**0.27**	**0.34**

Chemical	**Reference Dose (RfD)[1] (mg/kg/d)**	**Groundwater Concentration[2] (mg/L)**										**Water Ingestion Hazard Quotient (HQ)**									
Off-Site Wells		MW-5	MW-8	MW-8D	MW-9	MW-10	MW-11	MW-12	MW-12I	MW-13D	MW-13S	MW-5	MW-8	MW-8D	MW-9	MW-10	MW-11	MW-12	MW-12I	MW-13D	MW-13S
Antimony	0.0004	0.000571	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic	0.0003	0.0032	0.00062	0.0038	0.0019	0.0018	0.0014	0.00090	0.0025	0.0034	0.0011	0.68	0.13	0.79	0.40	0.37	0.30	0.19	0.52	0.72	0.24
Manganese	0.14	0.0151	0.53	1.2	0.043	0.14	0.0039	0.078	0.068	0.12	0.006	0.01	0.24	0.52	0.02	0.06	0.002	0.03	0.03	0.05	0.003
Nitrate	1.6	0.12	4.74	0.01	2.83	0.20	0.59	3.58	0.14	0.05	1.30	0.005	0.18	0.0002	0.11	0.01	0.02	0.14	0.01	0.002	0.05
Vinyl chloride	0.003	0.0009	ND	ND	ND	ND	0.003	ND	0.0025	0.0009	0.0014	0.04	ND	ND	ND	ND	0.12	ND	0.11	0.04	0.06
Zinc	0.3	0.0144	0.0686	0.01	0.0172	0.0272	0.0255	0.0349	0.0100	0.0100	0.0266	0.003	0.01	0.0021	0.004	0.01	0.01	0.01	0.002	0.002	0.01
bis(2-ethylhexyl)phthalate	0.02	0.0064	0.0042	ND	ND	ND	0.0095	ND	ND	ND	ND	0.020	0.013	ND	ND	ND	0.030	ND	ND	ND	ND
Hazard Index:												**0.84**	**0.58**	**1.31**	**0.53**	**0.45**	**0.47**	**0.37**	**0.66**	**0.81**	**0.36**
Hazard Index Hepatotoxins (Vinyl Chloride, bis(2-ethylhexyl)phthalate)												**0.06**	**0.01**	**ND**	**ND**	**ND**	**0.15**	**ND**	**0.11**	**0.04**	**0.06**
Hazard Index Hemotoxins (Sb, Zn, Nitrate)[3]												**0.10**	**0.20**	**0.002**	**0.11**	**0.01**	**0.03**	**0.15**	**0.01**	**0.004**	**0.06**

Table 4-7b. Carcinogenic Risks to Human Health from Drinking Water (Groundwater)

Chemical	**Slope Factor[1] (mg/kg/d)$^{-1}$**	**Groundwater Concentration[2] (mg/L)**							**Water Ingestion Cancer Risk**						
On-Site Wells		MW-1	MW-2	MW-3	MW-4	MW-6	MW-7	MW-14	MW-1	MW-2	MW-3	MW-4	MW-6	MW-7	MW-14
Arsenic	1.5	0.0015	0.0018	0.0037	0.0019	0.009	0.002	0.017	3.E-05	3.E-05	6.E-05	3.E-05	2.E-04	3.E-05	3.E-04
Vinyl chloride	1.5	0.000009	ND	ND	0.0021	0.0042	0.0009	0.0030	3.E-07	ND	ND	7.E-05	1.E-04	3.E-05	1.E-04
bis(2-ethylhexyl)phthalate	1.40E-02	0.004	0.0034	0.011	ND	ND	ND	ND	6.E-07	5.E-07	2.E-06	ND	ND	ND	ND
Total Cancer Risk:									**3E-05**	**3E-05**	**6E-05**	**1E-04**	**3E-04**	**6E-05**	**4E-04**

Chemical	**Slope Factor[1] (mg/kg/d)$^{-1}$**	**Groundwater Concentration[2] (mg/L)**										**Water Ingestion Cancer Risk**									
Off-Site Wells		MW-5	MW-8	MW-8D	MW-9	MW-10	MW-11	MW-12	MW-12I	MW-13D	MW-13S	MW-5	MW-8	MW-8D	MW-9	MW-10	MW-11	MW-12	MW-12I	MW-13D	MW-13S
Arsenic	1.5	0.0032	0.00062	0.0038	0.0019	0.0018	0.0014	0.00090	0.0025	0.0034	0.0011	6.E-05	1.E-05	6.E-05	3.E-05	3.E-05	2.E-05	2.E-05	4.E-05	6.E-05	2.E-05
Vinyl chloride	1.5	0.0009	ND	ND	ND	ND	0.003	ND	0.0025	0.0009	0.0014	3.E-05	ND	ND	ND	ND	1.E-04	ND	9.E-05	3.E-05	5.E-05
bis(2-ethylhexyl)phthalate	1.40E-02	0.0064	0.0042	ND	ND	ND	0.0095	ND	ND	ND	ND	1.E-06	7.E-07	ND	ND	ND	2.E-06	ND	ND	ND	ND
Total Cancer Risk:												**9E-05**	**1E-05**	**6E-05**	**3E-05**	**3E-05**	**1E-04**	**2E-05**	**1E-04**	**9E-05**	**7E-05**

[1] RfDs and Slope factors from Integrated Risk Information System (USEPA 2005b).
[2] All concentrations based on 95% UCL on the mean except for bis(2-ethylhexyl)phthalate, which is based on the maximum of two samples, and nitrate for which there is only one sample.
[3] Antimony and zinc were not found to be chemicals of concern through evaluation of cleanup levels. However, since they share a common toxicological endpoint as nitrate they were further evaluated in the groundwater assessment for human health.

RfD = Reference dose
ND = non detected
UCL = Upper Confidence Limit

Table 4-8a. Non-Carcinogenic Risks to Human Health from Using Surface Water as a Drinking Water Source

		Surface Water Concentration[2] (mg/L)							Hazard Quotient (unitless)					
	RfD[1]	Creek A	Creek B	Middle Creek			Little Boston Creek		Creek A	Creek B	Middle Creek			Little Boston Creek
Chemical	**mg/(kg-d)**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**		**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**
Arsenic	0.0003	0.0018	0.0036	0.003	0.003	0	0.0029		0.38	0.75	0.63	0.54	0.83	0.60
Vinyl chloride	0.003	0.0011	0.0012	0.00003	0.004	ND	ND		0.05	0.05	0.001	0.18	ND	ND
								Hazard Index:	**0.42**	**0.80**	**0.63**	**0.72**	**0.83**	**0.60**

Table 4-8b. Carcinogenic Risks to Human Health from Using Surface Water as a Drinking Water Source

		Surface Water Concentrations (mg/L)							Cancer Risk					
	Slope Factor [1]	Creek A	Creek B	Middle Creek			Little Boston Creek		Creek A	Creek B	Middle Creek			Little Boston Creek
Chemical	**(mg/kg-d)$^{-1}$**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**		**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**
Arsenic	1.5	0.0018	0.0036	0.003	0.003	0	0.0029		3.E-05	6.E-05	5.E-05	4.E-05	7.E-05	5.E-05
Vinyl chloride	1.5	0.0011	0.001	0.00003	0.004	ND	ND		4.E-05	4.E-05	1.E-06	2.E-04	ND	ND
								Total Cancer Risk:	**7E-05**	**1E-04**	**5E-05**	**2E-04**	**7E-05**	**5E-05**

[1] RfDs and Slope factors from Integrated Risk Information System (USEPA 2005b).

[2] Based on maximum concentrations if only two data points available, otherwise the 95% UCL on the mean was used.

[3] Per Parametrix (1998), potential risks at Middle Creek are to be evaluated using the headwater stations of the northern tributary and the main branch (SW-4 and SW-2, respectively). If risks are estimated at these stations, risks at SW-5 are to be evaluated.

RfD = Reference Dose
ND = Not Detected
UCL = Upper Confidence Limit

Table 4-8c. Non-Carcinogenic Risks to Human Health from Consumption of Fish

			Surface Water Concentration[2] (mg/L)						**Hazard Quotient (unitless)**					
	RfD[1]		**Creek A**	**Creek B**	**Middle Creek**			**Little Boston Creek**	**Creek A**	**Creek B**	**Middle Creek**			**Little Boston Creek**
Chemical	**mg/(kg-d)**	**BCF (L/kg) [4]**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**
Arsenic	0.0003	44	0.0018	0.0036	0.003	0.003	0	0.0029	0.10	0.20	0.17	0.15	0.23	0.16
Vinyl chloride	0.003	1.2	0.0011	0.0012	0.00003	0.004	ND	ND	0.0002	0.0002	0.000005	0.001	ND	ND
								Hazard Index:	**0.10**	**0.20**	**0.17**	**0.15**	**0.23**	**0.16**

Table 4-8d. Carcinogenic Risks to Human Health from Consumption of Fish

			Surface Water Concentrations (mg/L)						**Cancer Risk**					
	Slope Factor [1]		**Creek A**	**Creek B**	**Middle Creek**			**Little Boston Creek**	**Creek A**	**Creek B**	**Middle Creek**			**Little Boston Creek**
Chemical	**$(mg/kg\text{-}d)^{-1}$**	**BCF (L/kg) [4]**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**	**SW-7**	**SW-6**	**SW-2[3]**	**SW-4[3]**	**SW-5**	**SW-8**
Arsenic	1.5	44	0.0018	0.0036	0.003	0.003	0	0.0029	2E-05	4E-05	3E-05	3E-05	4E-05	3E-05
Vinyl chloride	1.5	1.2	0.0011	0.001	0.00003	0.004	ND	ND	3E-07	3E-07	8E-09	1E-06	ND	ND
								Total Cancer Risk:	**2E-05**	**4E-05**	**3E-05**	**3E-05**	**4E-05**	**3E-05**

[1] RfDs and Slope factors from Integrated Risk Information System (USEPA 2005b).
[2] Based on maximum concentrations if only two data points available, otherwise the 95% UCL on the mean was used.
[3] Per Parametrix (1998), potential risks at Middle Creek are to be evaluated using the headwater stations of the northern tributary and the main branch (SW-4 and SW-2, respectively). If risks are estimated at these stations, risks at SW-5 are to be evaluated.
[4] BCF from CLARC Database (Ecology 2005).
RfD = Reference Dose
ND = Not Detected
UCL = Upper Confidence Limit

Table 4-9a. Non-Carcinogenic Risks to Human Health from Recreational Surface Water Exposure Pathways

										Hazard Quotient (unitless)															
						Surface Water Concentration[3] (mg/L)				Creek A				Creek B				Middle Creek				Little Boston Creek			
Chemical	**RfD[1] mg/(kg-d)**	**Kp[2] (cm/hr)**	**T[2] (hr)**	**Tss[2] (hr)**	**B[2] (unitless)**	**Creek A SW-7**	**Creek B SW-6**	**Middle Creek**	**Little Boston Creek SW-8**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**
Arsenic	0.0003	0.001				0.0018	0.0036	0.0026	0.0029	9.7E-04	2.3E-04	4.8E-05	1.5E-05	1.9E-03	4.7E-04	9.5E-05	2.9E-05	1.4E-03	3.4E-04	6.9E-05	2.1E-05	1.6E-03	3.8E-04	7.7E-05	2.3E-05
Vinyl chloride	0.003	3.97E-03	0.212	0.509	9.77E-04	0.0011	0.0012	0.0036	ND	6.1E-05	1.5E-05	1.7E-05	5.2E-06	6.4E-05	1.6E-05	1.8E-05	5.5E-06	1.9E-04	4.7E-05	5.4E-05	1.6E-05	ND	ND	ND	ND
									Hazard Index:	**1.0E-03**	**2.5E-04**	**6.5E-05**	**2.0E-05**	**2.0E-03**	**4.9E-04**	**1.1E-04**	**3.5E-05**	**1.6E-03**	**3.9E-04**	**1.2E-04**	**3.8E-05**	**1.6E-03**	**3.8E-04**	**7.7E-05**	**2.3E-05**

Table 4-9b. Carcinogenic Risks to Human Health from Recreational Surface Water Exposure Pathways

										Cancer Risk															
						Surface Water Concentration[3] (mg/L)				Creek A				Creek B				Middle Creek				Little Boston Creek			
Chemical	**Slope Factor[1] (kg-d)/mg**	**Kp[2] (cm/hr)**	**T[2] (hr)**	**Tss[2] (hr)**	**B[2] (unitless)**	**Creek A SW-7**	**Creek B SW-6**	**Middle Creek**	**Little Boston Creek SW-8**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**	**Child Wat. Ing.**	**Adult Wat. Ing.**	**Child Wat. Cont.**	**Adult Wat. Cont.**
Arsenic	1.5	0.001				0.0018	0.0036	0.0026	0.0029	4E-08	2E-08	2E-09	3E-09	7E-08	4E-08	4E-09	6E-09	5E-08	3E-08	3E-09	4E-09	6E-08	4E-08	3E-09	5E-09
Vinyl chloride	1.5	3.97E-03	0.212	0.509	9.77E-04	0.0011	0.0012	0.0036	ND	2E-08	1E-08	7E-09	1E-08	2E-08	1E-08	7E-09	1E-08	7E-08	4E-08	2E-08	3E-08	ND	ND	ND	ND
									Total Cancer Risk:	**6E-08**	**4E-08**	**8E-09**	**1E-08**	**1E-07**	**6E-08**	**1E-08**	**2E-08**	**1E-07**	**8E-08**	**2E-08**	**4E-08**	**6E-08**	**4E-08**	**3E-09**	**5E-09**

[1] RfDs and Slope factors from Integrated Risk Information System (USEPA 2005b).

[2] Dermal exposure parameters from Dermal Exposure Assessment: Principles and Applications (USEPA 1992a).

[3] Based on maximum concentrations if only two data points available, otherwise the 95% UCL on the mean was used.

RfD = Reference Dose
Wat. Ing. = Water Ingestion
Wat. Cont. = Water Contact (dermal)
ND = Not Detected
UCL = Upper Confidence Limit

Table 4-10a. Non-Carcinogenic Risks to Human Health from Recreational Sediment Exposure Pathways

		Sediment Concentration (mg/kg wet)[2]			**Hazard Quotient (unitless)**											
					SD-06 (Creek B)				**SD-10 (Middle Creek)**				**SD-01 (Middle Creek)**			
Chemical	**RfD[1] (mg/kg-d)**	**SD-06 (RI)**	**SD-10 (RI)**	**SD-01 (RI)**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**
Arsenic	0.0003	6.44	2.69	1.40	6.9E-03	8.4E-04	2.7E-02	1.9E-04	2.9E-03	3.5E-04	1.1E-02	7.8E-05	1.5E-03	1.8E-04	5.9E-03	4.1E-05
Chromium	1.5	7.36	33.28	28.83	1.6E-06	1.9E-07	6.2E-06	4.3E-08	7.2E-06	8.7E-07	2.8E-05	1.9E-07	6.2E-06	7.5E-07	2.4E-05	1.7E-07
				Hazard Index:	**6.9E-03**	**8.4E-04**	**2.7E-02**	**1.9E-04**	**2.9E-03**	**3.5E-04**	**1.1E-02**	**7.8E-05**	**1.5E-03**	**1.8E-04**	**5.9E-03**	**4.1E-05**

Table 4-10b. Carcinogenic Risks to Human Health from Recreational Sediment Exposure Pathways

		Sediment Concentration (mg/kg wet)[2]			**Cancer Risk (unitless)**											
					SD-06 (Creek B)				**SD-10 (Middle Creek)**				**SD-01 (Middle Creek)**			
Chemical	**Slope Factor[1] (kg-d)/mg**	**SD-06 (RI)**	**SD-10 (RI)**	**SD-01 (RI)**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**	**Child Sed. Ing.**	**Adult Sed. Ing.**	**Child Sed Cont.**	**Adult Sed. Cont.**
Arsenic	1.5	6.44	2.69	1.40	3E-07	2E-07	1E-06	4E-08	1E-07	7E-08	4E-07	2E-08	6E-08	4E-08	2E-07	9E-09

[1] RfDs and Slope factors from Integrated Risk Information System (USEPA 2005b).

[2] Fraction solids:

0.23	SD-06 (RI)
0.64	SD-10 (RI)
0.093	SD-01 (RI)

Sed. Ing. = Sediment Ingestion
Sed. Cont. = Sediment Contact (dermal)
RfD = Reference Dose

Table 4-11. Potential Wildlife Species in the Study Area

	Terrestrial				Wetland		
Species	**Regenerating Clearcut**	**Plantation**	**Developed**	**Mixed Second Growth**	**Emergent Wetland**	**Shrub Wetland**	**Forested Wetland**
Amphibians							
Northwestern salamander		X		X	X	X	X
Long toed salamander	X	X		X	X	X	X
Pacific giant salamander				X			
Rough skinned newt	X	X		X			
Ensatina		X	X	X			
Pacific treefrog		X	X	X	X	X	X
Red legged frog		X		X	X	X	X
Reptiles							
Common garter snake	X	X	X	X	X	X	X
Western garter snake	X			X	X	X	X
Northwestern garter snake	X			X			
Birds							
Osprey							
Bald eagle							
Sharp skinned hawk		X		X			
Red tailed hawk		X	X	X			X
Ruffed grouse		X		X			
California quail							
Band tailed pigeon				X			
Great horned owl		X		X			X
Barred owl		X		X			
Rufous hummingbird	X	X	X	X		X	
Red breasted sapsucker		X		X			X
Downy woodpecker		X		X			X
Hairy woodpecker		X		X			
Northern flicker			X	X			X
Olive sided flycatcher		X		X			
Western wood pewee		X		X			
Willow flycatcher	X			X		X	
Western flycatcher		X		X			
Steller's jay		X	X	X			
American/Northwestern crow		X	X	X		X	
Black capped chickadee	X			X		X	
Chestnut backed chickadee		X		X			
Bushtit	X			X		X	
Red breasted nuthatch		X		X			
Bewick's wren	X			X		X	
Winter wren		X		X			
Golden crowned kinglet		X		X			
Ruby crowned kinglet	X	X		X		X	
Swainson's thrush		X		X		X	
American robin		X	X	X		X	
Varied thrush		X		X		X	
Cedar waxwing				X		X	
European starling			X	X		X	
Red eyed vireo						X	
Orange crowned warbler				X		X	
Yellow warbler	X				X	X	
Yellow rumped warbler		X		X		X	
Black throated gray warbler		X		X		X	
Townsend's warbler		X		X			
MacGillivray's warbler	X	X		X	X	X	
Common yellowthroat					X	X	
Wilson's warbler	X			X		X	
Western tanager		X		X			
Black headed grosbeak				X		X	
Rufous sided towhee	X		X	X		X	
Fox sparrow							X
Song sparrow	X			X	X		X
Lincoln's sparrow					X		
Dark eyed junco	X	X		X			X
Red winged blackbird					X		
Purple finch				X			X
House finch	X		X	X			
Pine siskin		X		X			X
American goldfinch	X						X
Evening grosbeak				X			
Mammals							
Common opossum		X	X	X			
Vagrant shrew							
Dusky shrew		X		X			
Shrew mole		X		X			
Townsend's mole	X			X			
Pacific mole				X			
Eastern cottontail	X			X			
Mountain beaver		X		X			
Townsend's chipmunk		X		X			
Douglas's squirrel		X		X			
Northern flying squirrel		X		X			
Deer mouse	X	X		X			
Bushy tailed woodrat		X		X			
Oregon vole		X		X			
Pacific jumping mouse	X				X		X
Porcupine		X		X			
Black bear	X	X		X			
Raccoon		X	X	X	X	X	X
Short tailed weasel	X			X			
Long tailed weasel		X		X			
Mink						X	
Striped skunk	X	X	X	X			X
Coyote	X	X	X	X			
Red fox	X	X		X			
Bobcat		X		X			
Black tailed deer	X	X	X	X			

Table 4-12. Exposure Assumptions and Dose Equations Used in the Ecological Risk Calculations

Exposure Assumption	Units	Values	Description	Reference
Wildlife Exposure Parameters				
American robin body weight	kg	0.0773		USEPA 1993
American robin water ingestion rate	L/day	0.011	0.14 g water/g BW/day	USEPA 1993
Mink body weight	kg	1.137		USEPA 1993
Mink water ingestion rate	L/day	0.032	0.028 g water/g BW/day	USEPA 1993
Mink sediment ingestion rate	kg/day	0.005		USEPA 1993; Best Professional Judgment
Mink food ingestion rate	kg/day	0.25		USEPA 1993

Wildlife Dose Equations

Drinking Water Exposures:
Wildlife Water Ingestion Dose = Wat. Conc.*Wat. Ing. Rate/Body Wt.   Wat = water; Ing = ingestion   L = liter; kg = kilogram; g = gram; BW = body weight

Dietary Exposures:
Wildlife Dietary Dose = Wat. Conc.*BCF*Food. Ing. Rate/Body Wt.   Conc = Concentration; BCF = Bioconcentration Factor

Table 4-13. Hazard Quotients for Aquatic Life in Off-Site Surface Waters

		Water Concentration[1] (mg/L)				Hazard Quotient			
Chemical	**Chronic Criteria (mg/L)**	**Creek A SW-7**	**Creek B SW-6**	**Middle Creek**	**Little Boston Creek SW-8**	**Creek A SW-7**	**Creek B SW-6**	**Middle Creek**	**Little Boston Creek SW-8**
Copper	Hardness-dependent[2]	0.0012	0.002	0.003	ND	0.0002	0.0004	0.0002	ND
Zinc	Hardness-dependent[2]	0.089	0.05	0.029	0.012	1.3	0.9	0.13	0.2
Vinyl chloride[3]	0.388	0.0011	0.0012	0.0036	ND	0.0029332	ND	0.0093	ND

[1] Based on maximum concentrations for Creek A, Creek B, and Little Boston Creek. For Middle Creek, the 95% UCL on the mean for all Middle Creek stations was used. Given the short duration that can constitute a chronic exposure for aquatic life, the maximum 95% UCL on the mean calculated for each sampling event was used. Note that for metals, only concentrations based on the same measurement (i.e., total, total recoverable, dissolved) were averaged.

[2] Hardness-dependent criteria:

		Chronic Criterion (mg/L)	
Creek	Hardness	Zinc	Copper
Creek A	52	0.07	5.12
Creek B	41	0.06	4.18
Middle Creek	203	0.22	16.40
Little Boston Creek	63	0.08	6.03

[3] No preliminary cleanup level for screening. Aquatic toxicity data for vinyl chloride are extremely limited but it was evaluated in the risk screen based on available data. A concentration of 388 mg/L killed 15 of 15 northern pike in 10 days. Even after applying an uncertainty factor of 1000, resulting in a toxicity value of 0.388 mg/L, one-half the vinyl chloride detection limit of 0.005 mg/L is still over two orders of magnitude less than this value.

ND = Not Detected
UCL = Upper Confidence Limit

Table 4-14. Risks to the American Robin and Mink from Exposures to Off-Site Surface Waters

Chemical	Avian NOAEL[1] (mg/kg/d)	Mammalian NOAEL[2] (mg/kg/d)	Water Concentration[3] (mg/L) Creek A	Creek B	Middle Creek	Little Boston Cr.	Robin Water Ingestion HQ Creek A	Creek B	Middle Creek	Little Boston Cr.	Mink Water Ingestion HQ Creek A	Creek B	Middle Creek	Little Boston Cr.
Copper	47	11.7	0.0012	0.002	0.003	ND	3.58E-06	4.97E-06	8.16E-06	ND	2.85E-06	3.95E-06	6.49E-06	ND
Zinc	131	79	0.089	0.05	0.029	0.012	9.67E-05	5.43E-05	3.15E-05	1.33E-05	3.17E-05	1.78E-05	1.03E-05	4.35E-06
Vinyl chloride	0.17	0.17	0.0011	0.0012	0.0036	ND	ND	ND	3.02E-03	ND	ND	ND	5.96E-04	ND

[1] The avian NOAELs are from ORNL (1996) for arsenic and copper, and Stahl et al. (1990) for zinc. No avian NOAELs were available for nitrate or vinyl chloride, so the mammalian NOAELs were assumed.

[2] The mammalian NOAELs are from ORNL (1996) for copper, nitrate, and arsenic; Laskey et al. (1985) for manganese; RTECS (1997) for zinc; and ATSDR (1996) for vinyl chloride.

[3] Based on maximum concentrations for Creek A, Creek B, and Little Boston Creek. For Middle Creek, the 95% UCL on the mean based on all stations was used. Given the relatively short duration that can constitute a chronic exposure for wildlife, the maximum 95% UCL on the mean calculated for each sampling event was used. Note that for metals, only concentrations based on the same measurement (i.e., total, total recoverable, dissolved) were averaged.

NOAEL = No Observed Adverse Effects Level
HQ = Hazard Quotient
ND = Not Detected
UCL = Upper Confidence Limit
mg = milligram
L = liter

Table 4-15. Risks to Mink from Dietary Exposures to Off-Site Surface Waters

Chemical	Mammalian NOAEL[1] (mg/kg/d)	Fish BCF [4] (L/kg)	Water Concentration[2] (mg/L) Creek A	Water Concentration[2] (mg/L) Creek B	Water Concentration[2] (mg/L) Middle Creek	Water Concentration[2] (mg/L) Little Boston Cr.	Estimated Tissue Concentration[3] (mg/kg) Creek A	Estimated Tissue Concentration[3] (mg/kg) Creek B	Estimated Tissue Concentration[3] (mg/kg) Middle Creek[3]	Estimated Tissue Concentration[3] (mg/kg) Little Boston Cr.	Mink Dietary HQ Creek A	Mink Dietary HQ Wat. Ing. Creek B	Mink Dietary HQ Middle Creek[3]	Mink Dietary HQ Little Boston Cr.
Copper	11.7	36	0.0012	0.002	0.003	ND	0.04	0.06	0.10	ND	0.001	0.001	0.002	ND
Zinc	79	47	0.089	0.05	0.029	0.012	4.18	2.35	1.36	0.57	0.01	0.01	0.004	0.002
Vinyl Chloride	0.131	1.2	0.0011	0.0012	0.0036	ND	0.001	0.001	0.004	ND	0.002	0.002	0.01	ND

[1] The mammalian NOAEL is from the Registry of Toxic Effects of Chemical Substances ([RTECS] 1997) for zinc.

[2] Based on maximum concentrations for Creek A, Creek B, and Little Boston Creek. For Middle Creek, 95% UCL on the mean for all Middle Creek stations was used. Given the relatively short duration that can constitute a chronic exposure for wildlife, the maximum 95% UCL on the mean calculated for each sampling event was used. Note that for metals, only concentrations based on the same measurement (i.e., total, total recoverable, dissolved) were averaged.

[3] Estimated tissue concentration = surface water concentration x BCF.

[4] BCF from Ecology (2005).
NOAEL = No Observed Adverse Effects Level
HQ = Hazard Quotient
ND = Not Detected
UCL = Upper Confidence Limit

Table 4-16. Sediment Concentrations Exceeding Screening Values

	Station:	**SD-01**	**SD-06**	**SD-10**
	Description of Habitat Type at Station:	**Boggy muck substrate, percolating ground water**	**Boggy muck substrate, percolating ground water**	**Free-flowing perennial stream with habitat**
Analyte	**LAET (mg/kg)**	**Maximum Value of Metal Detected at Station (mg/kg)**		
Antimony	0.6	13	2	0.44 U
Chromium	95	310	32	52
Manganese	1,800	4100	2700	640
Nickel	53.1	27	33	54
Silver	0.54	0.54 U	1.5	1.1 U

* Only one sample collected at each location, therefore 95% UCL could not be calculated.
U = Less than indicated detection limit
LAET = Lowest Apparent Effects Threshold

Table 4-17. Risks to Mink from Exposures to Off-Site Sediment

Chemical	**Mammalian NOAEL[1] (mg/kg/d)**	**Uncertainty Factor [2]**	**Sediment Concentration (mg/kg wet)**			**Mink Sediment Ingestion HQ**		
			SD-06 (RI) Creek B	**SD-10 (RI) Middle Cr.**	**SD-01 (RI) Middle Cr.**	**SD-06 (RI) Creek B**	**SD-10 (RI) Middle Cr.**	**SD-01 (RI) Middle Cr.**
Antimony	0.125	10	0.46	ND	1.21	0.016	ND	0.04
Chromium	3.3	None	7.36	33.28	28.83	0.010	0.04	0.04
Manganese	88	None	621	410	381.3	0.0004	0.02	0.02
Nickel	30.77	None	7.59	34.56	2.51	0.0011	0.005	0.0004
Silver	17.08	10	0.345	ND	ND	0.00009	ND	ND

[1] The mammalian NOAELs are from Schroeder et al. (1968) for antimony, Mackenzie et al. (1958) for chromium, Laskey et al. (1982) for manganese, Ambrose et al. (1976) for nickel, Oak Ridge National Laboratory (ORNL 1996) for arsenic, and Matuk et al. (1981) for silver.

[2] Uncertainty factor used to estimate a NOAEL from a LOAEL (Lowest observed adverse effect level).

NOAEL = No Observed Adverse Effects Level
HQ = Hazard Quotient

Fraction of solids factors used to convert dry-weight concentrations to wet-weight concentrations (Concentration x Fraction Solids):

Sample	Factor
SD-01 (RI)	0.093
SD-06 (RI)	0.23
SD-10 (RI)	0.64

d = day
mg = milligram
kg = kilogram
RI = Remedial Investigation (Parametrix 2007)

Table 4-18. Chemical Screening and Risk Evaluation Summary

	Groundwater Samples					Surface Water Samples						Sediment Samples					
	> Preliminary Cleanup Level	> Background Concentration	> 5% Frequency of Detection	> Acceptable Noncancer or Cancer Risk Level	Futher Evaluation in FS	> Preliminary Cleanup Level	> Background Concentration	> 5% Frequency of Detection	> Acceptable Noncancer or Cancer Risk Level	Elevated Aquatic or Wildlife Risks	Futher Evaluation in FS	> Preliminary Cleanup Level	> Background Concentration	> 5% Frequency of Detection	> Acceptable Noncancer or Cancer Risk Level	Elevated Aquatic or Wildlife Risks	Futher Evaluation in FS
METALS																	
Antimony	Yes	N/A	No	N/EV	No (1)	No	N/A	Yes	N/EV	N/EV	No	Yes	Yes	Yes	N/EV	No	No
Arsenic	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/EV	No (2)	Yes	Yes	Yes	No	N/EV	No
Barium	No	N/A	Yes	N/EV	No	No	N/A	Yes	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Cadmium	No	N/A	No	N/EV	No	No	No	Yes	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Chromium	No	N/A	No	N/EV	No	No	No	Yes	N/EV	N/EV	No	Yes	Yes	Yes	No	No	No
Copper	Yes	N/A	Yes	N/EV	No	Yes	Yes	Yes	N/EV	No	No	No	No	Yes	N/EV	N/EV	No
Iron	No	N/A	Yes	N/EV	No	No	Yes	Yes	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Lead	Yes	N/A	Yes	N/EV	No	Yes	Yes	No	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Manganese	Yes	N/A	Yes	Yes	Yes	No	No	Yes	N/EV	N/EV	No	Yes	Yes	Yes	N/EV	No	No
Mercury	No	N/A	No	N/EV	No	Yes	Yes	No	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Nickel	Yes	N/A	Yes	N/EV	No	No	No	No	N/EV	N/EV	No	Yes	Yes	Yes	N/EV	No	No
Selenium	No	N/A	Yes	N/EV	No	No	N/A	Yes	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Silver	Yes	N/A	Yes	N/EV	No	No	N/A	Yes	N/EV	N/EV	No	Yes	Yes	Yes	N/EV	No	No
Thallium	Yes	N/A	No	N/EV	No	Yes	N/A	No	N/EV	N/EV	No	No	No	Yes	N/EV	N/EV	No
Zinc	Yes	N/A	Yes	N/EV	No	Yes	Yes	Yes	N/EV	No	No	No	No	Yes	N/EV	N/EV	No
CONVENTIONALS																	
Chloride	Yes	N/A	Yes	N/EV	No	No	N/A	Yes	N/EV	N/EV	No	N/AV	N/AV	N/AV	N/EV	N/EV	No
Nitrate-N	Yes	N/A	Yes	No	No	No	No	Yes	N/EV	N/EV	No	N/AV	N/AV	N/AV	N/EV	N/EV	No
Sulfate	No	N/A	Yes	N/EV	No	No	N/A	Yes	N/EV	N/EV	No	N/AV	N/AV	N/AV	N/EV	N/EV	No
VOLATILE ORGANICS																	
1,1-Dichloroethane	No	N/A	Yes	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
1,2-Dichloroethylene	No	N/A	Yes	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Carbon disulfide	No	N/A	No	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Chloroform	No	N/A	No	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Methylene chloride	No	N/A	No	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Trichlorofluoromethane	No	N/A	No	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Vinyl Chloride	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	Yes	No	No (2)	No	N/AV	No	N/EV	N/EV	No
SEMIVOLATILE ORGANICS																	
bis(2-ethylhexyl)phthalate	Yes	N/A	Yes	No	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No
Diethyl phthalate	No	N/A	No	N/EV	No	No	N/A	No	N/EV	N/EV	No	No	N/AV	No	N/EV	N/EV	No

N/A = Not available

N/EV = Not evaluated due to elimination by the screening process

(1) Not identified in the RI for further evaluation in the FS; evaluated in the FS due to a common toxicological endpoint with nitrate.

(2) Not an indicator hazardous substance in surface water. The PCL selected for groundwater was the ARAR for surface water, because this chemical was already considered under the ARAR for groundwater in the Upper Aquifer. This groundwater discharges directly to surface water at the headwaters of the streams west of the Landfill (the conditional point of compliance). Therefore, this chemical is is not considered an indicator here.

Yes Indicator Hazardous Substance Included in the Remedial Alternatives Evaluation in this FS Report.

Table 5-1. Properties of Vinyl Chloride (at 10°C)

Property	Unit of Measure	Value
Vapor Pressure	torr	2,580
Water Solubility	mg/L	1,000
Log octanol/water, K_{ow}	dimensionless	0.6
Henry's Constant	dimensionless	0.6456
Molecular Weight	g/mole	62.4
Diffusivity (in water)	m^2/s	8.8×10^{-10}
Diffusivity (in air)	m^2/s	1.1×10^{-5}
Organic Carbon, K_{oc}	cm^3/g	66
Chemical Formula	–	$CH_2=CH\text{-}Cl$

Table 7-1. Summary of Technology Screening Evaluation

Category	Retained Technologies	Rejected Technologies
1. Waste/Source Control		
General	• General Response Action • Natural attenuation • Institutional controls • Gas extraction system enhancement	• Surface cap enhancement • Impermeable bottom liner
Waste Excavation and Re-Disposal/Treatment	• Waste removal • Off-site re-disposal in an existing landfill	• On-site re-disposal in new landfill • Off-site re-disposal in a new landfill
Waste *Ex Situ* Treatment		• Incineration (on-site/off-site)
Waste *In Situ* Treatment		• Glassification • Active Bioremediation • Leaching • Waste/soil mixing
2. Groundwater Containment/Disposal		
General	• Institutional controls	
Containment	• Groundwater extraction wells	• Slurry wall • Cut-off wall • Infiltration trenches and well points
Disposal of Extracted Groundwater	• Discharge of treated groundwater to Middle Creek • Return of treated groundwater to aquifer (aquifer recharge)	• Discharge of treated groundwater to other area creeks • Application of treated water to landfill • Injection wells
3. Remediation of Vinyl Chloride in Groundwater		
General	• Natural attenuation	
Ex Situ Treatment	• Air stripping • Disinfection by ultraviolet exposure	• Carbon absorption • Disinfection by chlorine oxidation • Disinfection by ozone sterilization
In Situ Treatment	• Air sparging	• Active bioremediation
Off-Gas Treatment	• Vapor-phase carbon adsorption	• Incineration
4. Remediation of Arsenic and Manganese in Groundwater		
General	• Natural attenuation	
Ex Situ Treatment	• Greensand filtration	• Precipitation/settling • Reverse osmosis • Ion exchange
In Situ Treatment	• In situ precipitation by air sparging	• In Situ Precipitation by chemical injection • Mobilization

Table 7-2. Technologies Screening Summary: Waste/Source Control

This table identifies and screens remediation technologies that are applicable for treatment of the wastes buried at the Landfill. These wastes include municipal solid waste, septic sludge, and demolition debris. The text below is split into two columns. The left-hand column describes the general principles of each technology, and the right-hand column explains the potential for application of the technology at the Hansville Landfill Site.

Specific comments related to the three technology screening criteria of technical feasibility, implementability, and cost are presented in Table 7-6. Landfill maintenance and monitoring will continue during the post-closure period as required by state regulations (Minimum Functional Standards for Solid Waste Landfills, Chapter 173-304 WAC). Existing source control measures (i.e., the landfill cap and gas extraction system) will also continue to be maintained and operated as required by this regulation. The existing landfill cap is designed to reduce surface water and precipitation infiltration by over 99 percent, thus minimizing future leachate production. The existing landfill gas extraction system has proven effective at reducing gas pressures and preventing migration of gas (and vinyl chloride) from the Landfill.

Technology Description	Application of Technology at Hansville Landfill
General Response Action Continued compliance with State Landfill Regulations, Chapter 173-304 WAC (applies to all response actions).	***Retained*** – Existing cap and gas extraction system meet State regulation requirements and are effective in minimizing surface water infiltration, leachate generation, and gas migration. Maintenance of Landfill Property and surface cap and operation of gas extraction system in accordance with State regulations will be continued as required.
Natural Attenuation Natural attenuation as a remediation technology is the reliance on natural processes (within the context of a controlled and monitored site cleanup approach) to achieve specific remedial objectives within a reasonable time. Natural attenuation describes existing processes that reduce the toxicity and mobility of the waste. These processes include physical, biological and/or chemical transformations and degradation of contaminants.	***Retained*** – Natural biodegradation of wastes is occurring and is reducing the toxicity of the waste and the mobility of indicator chemicals. The quantities of leachate and gas produced by the Landfill are declining over time, as predicted by the HELP modeling results and results documented for other landfills in the literature. Biodegradation of Landfill wastes can be monitored indirectly via tracking landfill gas generation rates and methane concentrations.
Institutional Controls Institutional controls are legal methods such as deed or access restrictions or other non-engineering practices such as signs or educational programs to reduce human contact with and possible health effects occurring from contacting the waste. Institutional controls can be used to prevent inappropriate activities such as building on the site that could damage the engineered landfill structures (i.e., surface cap and gas extraction system).	***Retained*** – Institutional controls for Landfill maintenance and monitoring are currently in effect and will continue as required by State regulations (Minimum Functional Standards for Solid Waste Landfills, Chapter 173-304 WAC). These controls restrict access to the Landfill Property and prevent site uses that are incompatible with maintaining the integrity of the engineered Landfill structures and monitoring systems.

Table 7-2. Technologies Screening Summary: Waste/Source Control (continued)

Technology Description	Application of Technology at Hansville Landfill
Leachate Containment *Surface Cap Enhancements* – Surface water infiltrating the landfill surface can migrate downward through the waste and mobilize contaminants contained in the waste. Drainage from the landfill bottom, known as leachate, can cause contamination of groundwater. Preventing the infiltration of surface water by capping the landfill with an impermeable cover can reduce leachate generation. Leachate releases can be almost completely eliminated by placing an impermeable cap over the waste, although liquid already in the waste may continue to drain for many years.	***Rejected*** –The existing engineered impermeable cap installed in 1989–90 met state regulatory requirements for landfill closure at the time it was installed. This cap includes a geomembrane liner and geosynthetic drainage net that provides an estimated 99 percent or greater reduction in infiltration of surface water into the Landfill. Because there is no evidence that this capping system is damaged or malfunctioning, further enhancement to the landfill cap would have little benefit to site remediation. No additions or enhancements of the existing cap are proposed.
Impermeable Bottom Liner – An impermeable liner of clay or plastic under the waste, combined with a leachate collection system as is required for new landfills under Chapter 173-351 WAC, is effective for minimizing leachate releases. For retrofit of an impermeable barrier to an existing landfill, grout could be injected at high pressure under the landfill to provide a barrier against leachate drainage and/or landfill gas movement below the landfill.	***Rejected*** – A grout barrier under the landfill is unlikely to achieve a complete seal and thus would not adequately contain leachate and/or landfill gases from migrating out of the disposal areas.
Gas Extraction System Enhancement Landfill gas is generated by biological decomposition of organic material in refuse. Initial biological action in the waste is aerobic (oxygen dependent). Aerobic bacteria can deplete the oxygen within the waste, particularly after a landfill has been capped. Further biological action is then anaerobic (occurs in the absence of oxygen), which produces methane gas in relatively large quantities. This gas production causes a buildup of pressure within the landfill, resulting in gas migration that can transport contaminants into surrounding soils and to groundwater. Most landfill gas extraction systems attempt only to prevent convective (pressure-driven) migration of gas from the waste (as is the case for the existing system at the Hansville Landfill). However, contaminants may still migrate via diffusion (concentration-driven) from the landfill and into the groundwater. Thus, an enhanced gas extraction system could be used to control contaminant diffusion by establishing a convective flow of soil gas beneath the landfill, not just within the waste or at the landfill perimeter. An enhanced gas extraction system might also draw oxygen into the soils under the waste to destroy or immobilize contaminants through increased natural biological activity or oxidation. An enhanced system could also potentially increase volatilization of volatile contaminants from leachate as it drains to groundwater.	***Retained*** – The existing landfill gas extraction system has proven effective at reducing gas pressures and preventing convective (pressure-driven) migration of gas from the Landfill. However, diffusion (concentration-driven migration) may be an ongoing mechanism for transport of vinyl chloride to groundwater. The landfill gas extraction system will continue to be operated as required by State regulations (Chapter 173-304 WAC). An enhanced gas extraction system might contain several injection wells on one side of the Landfill and several gas extraction wells on the opposite side to create a convective flow under the Landfill, sufficient to partially or fully overcome contaminant diffusion. This system would also oxygenate the soils under the Landfill, potentially reducing leachate concentrations of indicator hazardous substances through volatilization and biological degradation of vinyl chloride and oxidation and precipitation of arsenic and manganese. The existing landfill gas extraction system contains five native soil extraction wells outside the perimeter of the main solid waste disposal area that are not currently in use due to reduced gas generation rates. Use of these wells and/or new wells as part of the enhanced gas extraction system may be feasible.

Table 7-2. Technologies Screening Summary: Waste/Source Control (continued)

Technology Description	Application of Technology at Hansville Landfill
Waste Removal Removal of wastes from a landfill provides effective source control that prevents future releases of contaminants.	***Retained*** – Excavation to remove existing HDPE liner, cover soils, waste, and contaminated bottom soils is possible, and will be retained as a remedial alternative for comparison purposes. However, this alternative would have a large environmental impact (truck traffic with associated emissions, odors, blowing dust and debris, etc.) and a very high cost. Waste treatment and/or disposal activities that result from waste removal are discussed below.
Waste Re-Disposal Untreated excavated wastes and soils require disposal in an approved landfill. The new disposal location must be a new or existing landfill that meets the requirements of state regulations (Minimum Functional Standards for Solid Waste Landfills, Chapter 173-351 WAC, or other state equivalent). Off-site disposal requires transport of material to the new location.	***Rejected*** *–On-site Re-disposal* – Due to the limited land area available on the Landfill Property, on-site re-disposal is not feasible. Also, environmental impacts associated with temporarily storing wastes would be high. Problems include fugitive dust, strong odors, and possible hazardous gas emissions. ***Rejected –*** *Off-Site Re-Disposal (New Landfill)* – A new landfill requires substantial time and effort to permit and would likely meet with significant public resistance, and is therefore considered not feasible. Environmental impacts of heavy truck traffic would be high in communities adjacent to both old and new landfills. ***Retained*** – *Off-Site Re-Disposal (Existing Landfill)* – Off-site disposal in an existing landfill would be the most appropriate option compared to other potential re-disposal options. Much of the solid waste generated in the Puget Sound area is disposed of in one of several regional landfills in the Columbia Gorge region (south central Washington and north central Oregon). Use of one of these landfills is considered feasible. Environmental impacts associated with heavy truck traffic in the community would be high. Waste could be transferred to railcars at an intermediate location for more economical long-distance transport.

Table 7-2. Technologies Screening Summary: Waste/Source Control (continued)

Technology Description	Application of Technology at Hansville Landfill
Waste *Ex Situ* Treatment Treatment of excavated waste is potentially warranted to reduce waste toxicity and volume, and contaminant mobility. Incineration is identified as the most commonly used technology to treat large volumes of solid waste, although it has rarely been used for previously buried waste. Intermixed soils used for waste daily cover would also require incineration. Waste incineration could be accomplished on-site or off-site. Solid waste and soil incinerators are large complex furnaces fired with supplement fuel to elevate the waste temperature to destroy organic materials. Inorganic contaminants and metals are not substantially affected. Extensive air pollution control systems are required to treat the incinerator off-gas. Incineration reduces the volume of solid waste by approximately 90 percent. Soils are not significantly reduced in volume. The ash material remaining following incineration requires disposal at an approved landfill. The stockpiling of the excavated partially decomposed waste prior to incineration would require engineered lined areas that would likely release odors and possibly hazardous gas emissions. Incineration of the high-moisture content solid waste/soil material removed from a landfill would require special handling equipment and a significantly greater fuel supplement than is typically required for incineration of conventional solid waste.	***Rejected*** – Although this technology is the only waste source control measure that provides for a substantial reduction in waste toxicity, mobility, and volume of the source waste, it is considered to be cost-prohibitive. Incineration is a technically feasible technology to treat waste from the Landfill, but implementation and cost issues preclude its use. The cost of incinerating the waste, either on-site or off-site, would be very high, both due to the large volume of material requiring treatment and the nature of the waste. *On-Site Incineration* – Community resistance to a large on-site incineration program would likely be significant. *Off-Site Incineration* – Off-site incineration would have large environmental impacts from heavy truck traffic and associated emissions. The closest large solid waste incinerator is the Tacoma Steam Plant No. 2; however, this facility can only burn refuse-derived fuel, not raw solid waste. Large mass burn incinerators are located in Marion County, Oregon and Spokane County, Washington. These facilities could require extensive permit modifications to burn waste from the Landfill. Incineration of all waste at the Landfill would take several years, at a minimum.
Waste *In Situ* Treatment *Glassification* – Glassification involves passing a large electrical current between two electrodes located in the ground approximately 10 ft apart. The electrical current melts the waste and soil and permanently immobilizes waste in a glassified block. Glassification is not a proven technology, requires a very large amount of power, and requires a complex air pollution control system to capture and treat gases generated during the process. Glassification appears most suitable for contaminants located above the water table in sandy soils at shallow depths (less than 20 ft below ground surface).	***Rejected*** – This technology is not feasible at this Landfill, due to the depth of the waste (greater than 75 ft in some locations).

Table 7-2. Technologies Screening Summary: Waste/Source Control (continued)

Technology Description	Application of Technology at Hansville Landfill
Active Bioremediation – To encourage biological action to breakdown organic compounds in the waste, bioremediation involves the planned in situ introduction of one or more of the following: moisture, nutrients, oxygen, and microbes. Active bioremediation is most commonly used to degrade petroleum hydrocarbons, although some sites have successfully treated chlorinated organic compounds. This technology is best suited to sites with a single or a few organic contaminants in a uniform and homogeneous soil structure. Metals, plastics, and complex organic compounds cannot readily be biodegraded.	***Rejected*** – This technology is not applicable to the waste areas of the Landfill due to the heterogeneous nature of the waste.
Leaching – Leaching involves the application of water to the surface of a landfill to solubilize contaminants from the waste. The leachate that drains from the bottom of the landfill is then collected and treated to remove contaminants prior to being reapplied to the landfill surface. The increase in moisture content of the waste can also increase biological activity and speed destruction of organic compounds.	***Rejected*** – This technology is not feasible because the Landfill has no leachate collection system. Installation of a leachate collection system is not feasible because the waste is already in place and the bottom of the Landfill is uneven. The cap prevents application of water to the Landfill surface, and was installed in accordance with State regulations to minimize leachate generation.
Waste/Soil Mixing – Soil mixing consists of using large augers to mix columns of soil in place while simultaneously injecting chemicals such as portland cement to fix contaminants in place.	***Rejected*** – This technology is not feasible for this Landfill, primarily due to the depth of the waste (greater than 75 ft in some locations). Also, this technology requires removing the existing landfill cap and gas extraction system. In addition, large waste items such as lumber, appliances, or other items would jam the augers and prevent adequate mixing and access to lower portions of the Landfill.

Table 7-3. Technologies Screening Summary: Groundwater Containment/Disposal

This table identifies and screens remediation technologies that are applicable for the physical containment or extraction of groundwater in the upper aquifer beneath the Landfill property and beneath adjacent properties. Table 7-7 presents the screening of technologies based on the criteria of technical feasibility, implementability, and cost. Treatment processes and technologies for indicator hazardous substances in groundwater are discussed in Tables 7-4 and 7-5.

Technology Description	Application of Technology at Hansville Landfill
Institutional Controls In general, institutional controls are legal methods (such as deed or access restrictions), structural barriers (such as fencing), or non-structural practices (such as signs or educational programs) that may be used to reduce public contact with and possible health effects from the contaminated media at a site. For the Hansville Landfill, institutional controls can be used to prevent activities such as installing a drinking water well into the upper aquifer, downgradient from the Landfill.	***Retained*** – Institutional controls, such as a prohibition on the installation of wells or use of groundwater from the aquifer, are suitable for this Site. The groundwater flow paths in the upper aquifer are well characterized and relatively simple, and indicator hazardous substances are limited to a known area. Further, the RI report did not identify any existing wells completed in the upper aquifer and located within the Study Area to be affected by institutional controls.
Containment Groundwater containment seeks to prevent the migration of contaminated water to new locations and, if treatment is proposed, to prevent dispersion of contaminants to minimize the volume of groundwater requiring treatment.	
Physical Containment – Two proven groundwater physical containment methods are the slurry wall and the cut-off wall. Both methods require relatively shallow depths to a continuous impermeable soil layer, or aquitard. The containment walls are placed to partially penetrate the aquitard to ensure that groundwater does not flow out beneath the containment structures. Depending on groundwater flow characteristics, the walls are constructed to either block groundwater flow or to completely encircle the contaminated area. A *slurry wall* is constructed by excavating a trench and then filling it with an impermeable material such as bentonite grout. Trench excavation limits the slurry wall construction to a depth of approximately 25 ft. A *cut-off wall* is constructed by driving interlocking metal sheet piles into the ground to form a continuous wall. Cut-off walls often are not completely impermeable to groundwater flow because the piles do not form watertight seals with adjacent piles. Cut-off walls are generally limited to depths less than 100 ft in soils that are not overly dense, and may not be usable in over-consolidated soils (where glacial ice formerly rode over and greatly compacted the soils) especially where cobbles and boulders are present.	***Rejected*** – Physical containment of groundwater is not feasible at this Site. One containment strategy would be to encircle the Landfill with a groundwater containment wall; however, at the Landfill's west property boundary, the depth to the aquitard is approximately 150 ft below ground surface, and is therefore too deep to be contained by available methods. A second strategy would be to construct a groundwater flow barrier to prevent groundwater from reaching the creeks. This is feasible only immediately uphill from the seeps at the headwaters of the creeks, where the depth to the aquitard is approximately 50 ft or less below ground surface. Unfortunately, the groundwater surface at these locations is essentially at the ground surface. If a barrier to groundwater flow were installed upgradient of the creeks, the regional westerly groundwater flow would likely cause the water table to rise, thereby causing new seeps to emerge uphill from the groundwater flow barrier, negating its effectiveness. Further upgradient towards the Landfill, the depth to the aquitard is infeasibly deep.

Table 7-3. Technologies Screening Summary: Groundwater Containment (continued)

Technology Description	Application of Technology at Hansville Landfill
Hydraulic Containment (Extraction) – Groundwater extraction works both to remove contaminated groundwater from an aquifer and to hydraulically contain the spread of contamination. Groundwater is commonly extracted using wells and/or infiltration trenches located in a manner to intercept the contaminant plume downgradient of the source area. A well is a cased hole with a screened section within the water-bearing zone, allowing groundwater to be pumped to the ground surface. Unless the well is very shallow (less than about 12 ft), pumps are located in the lower portion of the well itself. For shallow wells, a central pump can extract water from multiple well points. Infiltration trenches are dug from the ground surface and filled with gravel to allow groundwater to accumulate. Accumulated groundwater is removed from the trench by wells located at intervals along the length of the trench. Alternatively, the trench may drain by gravity into a culvert or piping system. Frequently, an infiltration trench is used in the presence of a shallow aquitard to intercept the full depth of groundwater flow. Extracted groundwater is usually treated prior to release to a surface water body or returned to the aquifer.	***Retained*** – Groundwater extraction using wells is feasible. The aquifer consists of mixed strata of sands and gravels that allow individual wells to produce substantial quantities of groundwater and to affect its movement over a wide area. ***Rejected*** – Infiltration trenches and well points are not feasible at this Site due to the great depth to the groundwater surface.
<u>Disposal of Extracted Groundwater</u> Extracted groundwater requires disposal following treatment. Potential disposal alternatives are discharge to surface water, aquifer recharge, or application to the landfill surface.	
Surface Water – Discharge of treated groundwater to surface water requires construction of a pipeline from the treatment system to the surface water body. Permits for discharges and construction of outfall structures are typically required.	***Retained*** – Disposal of treated groundwater via discharge to Middle Creek to the west of the Landfill is feasible for this Site. The elevation of the Landfill above the creeks and the terrain topography would allow use of a gravity drain pipeline. ***Rejected*** – Discharge of treated groundwater to Creek A, Creek B, Little Boston Creek, or directly to Port Gamble Bay is rejected as more costly due to the longer distances for piping that would be required. Discharge to these water bodies provides no additional environmental benefit.
Aquifer Recharge – Aquifer recharge is accomplished using injection wells, infiltration basins (artificial ponds), or drain fields.	***Retained*** – Aquifer recharge may promote biodegradation or immobilization of indicator chemicals in groundwater due to increased oxygen levels in the aquifer. Based on aquifer water demands, recharge is not necessary; water in the upper aquifer is available in large quantities, but is not used for water supply or irrigation in the immediate vicinity of the Landfill.
Application to Landfill Waste Areas – Treated groundwater can be applied to the surface of a landfill to infiltrate into the waste and assist with contaminant leaching.	***Rejected*** – Application of water to landfill waste areas increases leachate production, which is not desirable, and at this Site not feasible due to the existing impermeable cap installed over the waste cells. Application of water to the Landfill is discussed under the topic "Leaching" in Table 7-2.

Table 7-4. Technologies Screening Summary: Remediation of Vinyl Chloride in Groundwater

This table identifies and screens remediation technologies that are applicable for the treatment of vinyl chloride in groundwater, both in situ and ex situ. In situ technologies are those that can be applied directly within the aquifer without first extracting the groundwater. Ex situ technologies are those that first require groundwater extraction. Groundwater extracted from the aquifer may also require disinfection following other treatment processes. Table 7-8 presents the screening of the technologies based on the criteria of technical feasibility, implementability, and cost.

Technology Description	Application of Technology at Hansville Landfill
<u>Natural Attenuation</u> Natural attenuation as a remediation technology is the reliance on natural processes to achieve specific remedial objectives within a reasonable time. Natural attenuation describes existing processes that may be reducing the toxicity, mobility, or volume of the contaminated groundwater. These processes include physical, biological, and/or chemical transformations and degradation of contaminants.	***Retained*** – Natural attenuation processes at the Site that may reduce vinyl chloride concentrations in the groundwater are biodegradation and volatilization. Sorption of vinyl chloride to aquifer soils is estimated to be low. A long-term groundwater-monitoring program is currently in effect and will continue, as required by State regulations (Minimum Functional Standards for Solid Waste Landfills, Chapter 173-304 WAC).
<u>Ex situ Groundwater Treatment</u> *Air Stripping* – Air stripping is the physical transfer of a volatile compound from the groundwater to the air, usually in a counter-current tower where water is sprayed in at the top and air is blown in at the bottom. Once in the vapor phase, the compound may be emitted to the atmosphere without treatment or treated via additional technologies (discussed below).	***Retained*** – Air stripping is a feasible technology. Vinyl chloride is very volatile and readily transfers to air. A potential problem is that the groundwater at the Site is highly mineralized, and air stripping would likely cause these minerals to precipitate and severely scale the air stripper. Pretreatment of the water to remove oxidizable minerals may be necessary. An air stripping tower might be damaged by vandalism.
Carbon Adsorption – Adsorption of contaminants directly from the water phase using granular activated carbon (GAC) is a commonly used treatment method to remove unwanted substances from water. GAC is specially manufactured carbon with a high surface area that is capable of adsorbing a large variety of substances. GAC is not compound-specific and simultaneously adsorbs multiple compounds at different rates, depending on a number of factors. After the GAC has adsorbed to its full capacity, it can be regenerated on-site using steam to drive off the adsorbed compounds (that then require additional treatment) or the GAC can be sent off-site for regeneration.	***Rejected*** – Vinyl chloride adsorbs poorly to GAC in the water phase, thus requiring extremely large quantities of carbon and very frequent replacement or regeneration. Additional potential problems are that the groundwater at the Site is mineralized and severe scaling would likely occur in the GAC beds, further reducing its effectiveness. Pretreatment of the water to remove scaling minerals would most likely be necessary.
Disinfection – Extracted groundwater may require disinfection to control biological fouling of other treatment equipment. Proven disinfection processes are oxidation with chlorine, ozonation, and ultraviolet light exposure. Chlorine oxidation requires the addition of gaseous chlorine or sodium hypochlorite to water to oxidize organic matter. Ozonation consists of adding ozone to the water in a reaction chamber. The free radical oxygen molecules associated with the ozone chemically destroy biological organisms. Ultraviolet (UV) light exposure involves exposing the groundwater to a strong source of ultraviolet light, which destroys bacteria, viruses, and other biological contaminants.	***Rejected*** – Chlorine Oxidation. Chlorine oxidation is more commonly used than ozone degradation or UV exposure. However, residual chlorine in the water maintains its disinfecting ability after treatment. While this is beneficial for drinking water systems, it is not desirable for water released to surface water or returned to the aquifer. ***Rejected*** – Ozone Sterilization. Oxygen released from the breakdown of the ozone would cause severe mineral scaling from precipitation of minerals in the water. ***Retained*** – UV Exposure. This is a proven, reliable technology for water disinfection. Undesirable effects are minimal.

Table 7-4. Technologies Screening Summary: Remediation of Vinyl Chloride in Groundwater (continued)

Technology Description	Application of Technology at Hansville Landfill
In Situ Groundwater Treatment	
Air Sparging – In situ air sparging is commonly used for removal of gasoline and associated compounds (benzene, toluene, ethylbenzene, xylene) from groundwater; however, it has also been used for other volatile compounds including TCE, PCE, DCE, and vinyl chloride. Air sparging consists of injecting clean air into the aquifer below the water table to induce the transfer of contaminants to the vapor phase, which are then transported with the rising air into the vadose zone. Soil gas and vapor-phase contaminants in the vadose zone are then extracted using a gas extraction system similar to the system currently in place at the Site, to control landfill gas. The movement of air through the aquifer and the vadose zone transfers oxygen into the groundwater and soil pore spaces. The presence of oxygen establishes aerobic conditions and increases the potential for biodegradation of organic contaminants. The oxygen also chemically oxidizes many metals and salts present in the groundwater and soil, causing them to precipitate (see Table 7-9 for a further discussion of the applicability of this technology for remediating metals contamination in groundwater).	***Retained*** – Air sparging is a potentially feasible technology for use at the Site. Vinyl chloride has a moderately high Henry's Law coefficient and thus would transfer from the groundwater into the vapor-phase. The feasibility of soil vapor extraction is proven for this Site by the successful operation of the landfill gas extraction system. The technology has several limitations including the following: • Maximum sparging depth limited to approximately 30 ft. • Attainment of the vinyl chloride cleanup standard is theoretically possible, but unproven. • Some remobilization of arsenic and manganese could occur when sparging wells are turned off at completion of remediation. • Above-ground components of an air sparging system might be damaged by vandalism.
Active Bioremediation – To encourage biological action and to break down organic compounds, bioremediation involves the planned in situ introduction of one or more of the following: nutrients, oxygen, or microbes. Active bioremediation is most commonly used to degrade petroleum hydrocarbons, although some sites have successfully treated chlorinated organic compounds. This technology is best suited to sites with a single or a few organic contaminants in a uniform and homogeneous soil structure. Metals and complex organic compounds, including many chlorinated organic compounds, cannot readily be biodegraded.	***Rejected*** – Active bioremediation is not a feasible technology for this Site. Vinyl chloride concentrations are too low and spread over too large an area. It is well documented that the biodegradation rate of vinyl chloride is extremely low. Vinyl chloride contamination from landfills is common and is often the end result of the natural biological degradation of other chlorinated organic compounds, such as PCE and TCE. In addition, vinyl chloride s not known to have been successfully biodegraded at any contaminated sites.

Table 7-4. Technologies Screening Summary: Remediation of Vinyl Chloride in Groundwater (continued)

Technology Description	Application of Technology at Hansville Landfill
Off-Gas Treatment Off-gas treatment technologies include capture by vapor-phase activated carbon adsorption and destruction by incineration. Activated carbon adsorbs contaminants in varying quantities, depending upon the specific contaminant and the process conditions. After the activated carbon has adsorbed its limit of a contaminant, it is no longer effective and must be replaced with fresh carbon. The used carbon is then sent off-site to a carbon regeneration plant. Incineration converts contaminants via thermal processes to more basic chemical structures that are less toxic. Incineration requires combustion of supplemental fuel.	*Note* – Several technologies may generate off-gas containing vinyl chloride. These technologies are air stripping, air sparging, and enhancements to the landfill gas extraction system. The need for treatment of off-gas to reduce vinyl chloride emissions is based upon regulatory requirements and is evaluated in Chapter 8.
	Retained – Carbon Adsorption. Carbon adsorption of vinyl chloride is feasible if the off-gas from the air stripping tower is first heated to at least 75° F to reduce its relative humidity which the existing landfill gas flare could provide. Although carbon absorbs less vinyl chloride at higher temperatures and requires frequent replacement, carbon adsorption is the only viable alternative of those evaluated.
	Rejected – Incineration, The air stripping tower off-gas has little heating value and requires a substantial amount of supplemental fuel for combustion, resulting in generation of significant quantities of combustion-related pollutants. Incineration of off-gas from the air stripping tower in the existing landfill gas flare is not feasible since the flare is too small. The current operating rate is about 40 cfm due to low methane production in the landfill waste. The anticipated air stripper off-gas flow rate is approximately 1,000 cfm or greater, and the off-gas would have no fuel value.

Table 7-5. Technologies Screening Summary: Remediation of Arsenic and Manganese in Groundwater

This table identifies and screens remediation technologies that are applicable for the treatment of arsenic and manganese in groundwater, both in situ and ex situ. The chemical properties (as related to treatment) of arsenic and manganese are similar and thus are discussed simultaneously. Table 7-9 presents the screening of the technologies based on the criteria of technical feasibility, implementability, and cost. Groundwater extracted from the aquifer may also require disinfection following other treatment processes. Disinfection options for groundwater following ex situ treatment are discussed in Table 7-4.

Technology Description	Application of Technology at Hansville Landfill
Natural Attenuation Natural attenuation as a remediation technology is the reliance on natural processes to achieve specific remedial objectives within a reasonable time. Natural attenuation describes existing processes that may be reducing the toxicity, mobility, or volume of the contaminated groundwater. These processes include physical, biological, and/or chemical transformations and degradation of contaminants.	***Retained*** – Natural processes at the Site that may reduce arsenic and manganese concentrations in the groundwater are oxidation and geochemical fixation/precipitation. A long-term groundwater-monitoring program is currently in effect and will continue as required by State regulations (Minimum Functional Standards for Solid Waste Landfills, Chapter 173-304 WAC).
Ex Situ Groundwater Treatment *Greensand filtration* is a commonly used process for removal of manganese from drinking water (Ficek 1996). The process consists of using a filter bed of sand grains containing high concentrations of manganese oxide. Manganese ions in the water, upon contact with the filter bed, adsorb to the sand particles. Low concentrations of an oxidizing agent such as chlorine may be added to the water upstream of the filter, to oxidize the adsorbed manganese ions to manganese dioxide. The oxidized manganese can then adsorb additional manganese ions. Use of higher concentrations of oxidants or use of a strong oxidant such as ozone can cause premature precipitation of manganese upstream of the filter bed. In this case, the manganese precipitate is often colloidal in nature and is not retained in the filter bed. The filter beds are periodically backwashed to remove accumulated suspended solids. Backwash water is settled to remove solids, and then settled solids are shipped off-site for disposal. During some backwash cycles, a strong oxidizing agent such as potassium permanganate is added to remove the accumulated manganese oxide coating from the greensand.	***Retained*** – Greensand filtration is a relatively low-cost, effective, and proven technology for manganese removal. An added benefit is that arsenic chemistry is such that arsenic ions co-adsorb to the greensand along with the manganese ions. Regenerative backwashing would be anticipated to occur several times per year. Regeneration water would require on-site treatment to remove manganese and arsenic. Potential treatment methods include oxidation using air or ozone injection, or chlorination to precipitate and settle the manganese. Arsenic would be co-precipitated. Due to the long anticipated settling times (up to 3 months) and relatively small water volume (compared to municipal-scale drinking water treatment plants), a small inclined plate settling tank or conical bottom tank would likely be adequate. Depending on the settling effectiveness, use of a filter press may be warranted to further dewater the sludge. Sludge would then be shipped off-site for disposal. The sludge is not expected to be a hazardous waste. Determination of the optimum process parameters for the greensand filtration unit and the solids settling system require detailed treatability studies. These studies would be performed during the remedial design.
Precipitation/Settling – Precipitation/settling is a widely used process for treating both industrial wastewaters and drinking waters. Water is treated to remove dissolved metals by adjusting the pH to alkaline using lime, caustic, ferric chloride, or other agent in a stirred tank reactor to cause the metals to precipitate. Then alum or other coagulation/flocculation agent is added to agglomerate (floc) the precipitated metal particles. Finally, the flocs are settled in a clarifier. Most metals have solubilities in water that reach a minimum at a pH between 8 and 10, depending on the specific metal. Precipitation of metals with minimum solubilities at different pH values requires multiple treatment stages.	***Rejected*** – Precipitation/settling is a potentially feasible technology for removing arsenic and manganese from groundwater, but can be inefficient and expensive to scale down to small flows volumes expected at the Hansville Landfill. Arsenic can exist in any of several chemical states that affect the type of treatment required and the resulting removal efficiencies. Lime addition to pH 12 is reportedly effective, but the large quantities of lime required generate large sludge volumes that require dewatering and disposal.

Table 7-5. Technologies Screening Summary: Remediation of Arsenic and Manganese in Groundwater (continued)

Technology Description	Application of Technology at Hansville Landfill
Reverse Osmosis – Reverse osmosis is essentially a filtration process. Water is pumped under high pressure through a membrane that blocks the passage of particulates and most ions, including most dissolved-phase metal ions. About 80 to 95 percent of the influent water passes the membrane and is cleaned. The remaining 5 to 20 percent of the influent water flow does not pass the membrane and contains the ions rejected by the membrane. This brine requires treatment by another process (such as precipitation/settling). Reverse osmosis (RO) systems effectively concentrate ions into a smaller volume of water. The benefit of the RO process is that the following precipitation/settling treatment equipment can be much smaller, due to the smaller volume of water to be treated. The higher concentration of metals in the water actually makes the precipitation/settling process work more effectively. The primary disadvantages of RO systems are their high initial and operating costs, and the need for a secondary treatment process for the brine. RO systems are commonly used in 1) industry where recovery of metals provides economic incentives, or 2) drinking water pre-treatment, where the brine contains no toxic constituents and can be discharged to the sanitary sewer without additional treatment.	***Rejected*** – Reverse osmosis is a feasible technology for removing arsenic and manganese from groundwater. Manganese removal efficiencies by RO are typically high. Arsenic removal efficiencies depend on the form of the arsenic ion, but are generally high. However, the high chloride levels in the groundwater at the Site can rapidly degrade many RO membranes; specialty membranes or pre-treatment of groundwater to remove chloride and possible other ions may be needed. Iron concentrations in groundwater are low and are not expected to be a significant problem. Disinfection of groundwater prior to treatment may be necessary, with UV light exposure the preferred technology. The need for brine treatment without the economic incentive of metals recovery makes the RO process substantially more costly than other technologies in this subsection that are being retained.
Ion Exchange – Ion exchange removes dissolved ionic metals in dilute solutions from water by adsorbing some ions and releasing others from the resin matrix. Typically, the released ions are salts. Ion exchange systems work well for high-volume, low-concentration wastewaters. There are numerous types of resins; the appropriate resins for an application depend upon the characteristics of the water and the substances to be removed. Primary problems with ion exchange systems are fouling of the resins with biological growth or scale. Disinfection of groundwater prior to treatment may be necessary, with UV light exposure the preferred technology. Ion exchange resins require regeneration (either on-site or off-site) after they have absorbed to their capacity. Sodium hydroxide is a common regenerative agent. The regenerative solution requires additional treatment; however, as described for RO systems, the solution is concentrated, allowing for less costly and more effective treatment.	***Rejected*** – Use of the ion exchange process to remove arsenic and manganese requires two separate ion-exchange units. Arsenic is most commonly in an anionic state in water and is best removed by a weak-base anionic resin. Manganese is in a cationic state and is best removed with a strong cationic resin. A primary disadvantage of ion exchange systems is the non-selective removal of non-target ions. The groundwater at the Site is highly mineralized and has a high hardness. Most of these minerals would also be unnecessarily removed by an ion exchange system, significantly increasing costs. The need for treatment of the resin regeneration solutions also adds complexity to the system and increases costs compared to other technologies.

Table 7-5. Technologies Screening Summary: Remediation of Arsenic and Manganese in Groundwater (continued)

Technology Description	Application of Technology at Hansville Landfill
In Situ Groundwater Treatment	
In situ Precipitation by Chemical Injection – In situ precipitation follows the same basic chemical principles as ex situ precipitation, discussed above. In situ precipitation can occur by two processes: pH adjustment or oxidation (by air or other chemical agents). In situ pH adjustment involves the injection into the aquifer of a solution containing lime, caustic, sulfide, or other chemical agents to cause the formation of an insoluble metal precipitate, thereby reducing the mobility of the metal. This process may be coupled with a groundwater extraction system to remove excess precipitation agents. In situ precipitation of metals via oxidation is possible by injection of potassium permanganate or other oxidizing chemicals into the aquifer. Chemical injection as a cleanup method is best suited for sites that have distinct isolated zones of contamination in well-defined, homogeneous aquifers or that have groundwater containment structures that surround the contaminated area.	***Rejected*** – In situ precipitation technologies that involve injection of chemical oxidizing agents are rejected as not feasible. Many of these injected chemicals are hazardous or toxic and could migrate into surface waters or uncontrolled portions of the aquifer. At this Site, the isolation of indicator hazardous substances with containment structures is not feasible, as discussed in Table 7-3.
In Situ Precipitation by Air Sparging – Injecting air into the aquifer can oxidize and precipitate some metals.	***Retained*** – Oxidation and precipitation of arsenic and manganese using air sparging is a potentially feasible technology. Some manganese would likely oxidize and precipitate. The chemistry of arsenic is more complex; testing is warranted to evaluate the potential effectiveness of this technology. Some remobilization of arsenic and manganese could occur when sparging wells are turned off at completion of remediation.
In-situ mobilization by Chemical Injection – This alternative involves the injection of dilute solutions of acids into the aquifer to dissolve and mobilize metals so that they can be removed from the aquifer using a groundwater extraction system. Extracted groundwater then requires ex situ treatment. Chemical injection in this manner as a cleanup method is best suited for sites that have distinct isolated zones of contamination in well-defined homogeneous aquifers, or that have groundwater containment structures that surround the contaminated area.	***Rejected*** – All of these technologies work by injecting various chemicals into the aquifer. Many of these chemicals injected are hazardous or toxic and could migrate into surface waters or into uncontrolled portions of the aquifer. At this site, the isolation of indicator hazardous substances with containment structures is not feasible, as discussed in Table 7-3.

Table 7-6. Screening Matrix of Waste/Source Control Remedial Technologies

General Response Action	Technology	Process Option	Action	Technical Feasibility	Implementability	Cost	Retained/ Rejected
Continued Compliance with State Landfill Regulations, Chapter 173-304 WAC (applies to all response actions)	Standard and proven landfill closure technologies.	Not Applicable	Existing cap and gas extraction system meet State regulation requirements and are effective in minimizing surface water infiltration, leachate generation, and gas migration. Maintenance of Landfill Property, surface cap, and operation of gas extraction system in accordance with State regulations will continue as required.	Feasible	In Effect; High	Very low	Retained
Natural Attenuation	Available testing technology allows monitoring of the natural process	Not Applicable	Natural processes including dispersion, volatilization, and biodegradation will reduce concentrations.	Feasible	In Effect: High. Biodegradation of waste is occurring. Leachate and gas generation rates are declining with time.	Very low	Retained
Institutional Controls	Access Restrictions to Waste Areas.	Signs	Maintain and enhance existing control access to Landfill Property.	Feasible	In Effect: High. Post warning signs. Access road restricted by gate and ecology blocks.	Very low	Retained
	Land Use Restrictions to Waste Areas.	Deed Restrictions	Prevent future land uses that may expose human health and/or the environment to unacceptable risks.	Feasible	In Effect: High. Land use restrictions on County and Tribal Property established.	Very low	Retained
Containment (Leachate)	Impermeable Cap Enhancements	Physical changes to existing Landfill cap	Existing cap is over 99 percent effective in preventing surface water infiltration, thus minimizing leachate generation.	Feasible	Low: Although enhancement of cap is feasible, it would provide negligible additional prevention of surface water infiltration.	Very high	Rejected
	Impermeable Bottom Layer	Waste excavation/replacement liner installation.	Excavate waste and install engineered impermeable lining system and leachate collection system in accordance with State regulations; backfill waste onto liner.	Infeasible: Waste is too deep to safely be removed.	Low: see Technical feasibility	Very high	Rejected
		Pressure Grout	Inject impermeable grout at high pressure into soil beneath the Landfill to provide seal to prevent leachate drainage to groundwater.	Infeasible	Low: Complete seal unlikely to be achieved due to insufficient information on limits of waste. Any unsealed area will continue to release leachate.	Very high	Rejected
Containment (Landfill Gas)	Landfill Gas Extraction System Enhancements	System reconfiguration	The existing system prevents gas migration from waste and Landfill Property. Enhanced system could reduce transport of vinyl chloride to groundwater, and also draw oxygen into soils under waste areas to increase bio-chemical degradation or immobilization of indicator hazardous substances in leachate before it drains to groundwater. Also, system potentially could increase volatilization of vinyl chloride from leachate and groundwater.	Potentially Feasible: Process is difficult to control precisely; underground fires could occur if waste is oxygenated to combustible levels.	Medium: Existing system contains numerous vapor extraction wells that are not currently in use due to reduced gas generation rates. Use of these wells and/or new wells could oxygenate environment under the Landfill.	Low	Retained
Waste Removal	Excavation of Waste/ Contaminated Soils	Excavation backfill	Most complete source control option. Excavation of waste and soils is required prior to re-disposal or treatment. Waste disposal and treatment technologies are discussed below.	Feasible: Waste will be wet and may require special handling equipment and excavation processes.	Low: Environmental impacts likely to be high. Problems include fugitive dusts, odors, hazardous gas emissions, blowing litter, and surface water control. Possible hazardous gas emissions may require significant worker protection measures.	Very high	Retained

Table 7-6. Screening Matrix of Waste/Source Control Remedial Technologies (continued)

General Response Action	Technology	Process Option	Action	Technical Feasibility	Implementability	Cost	Retained/ Rejected
Waste Excavation and Re-Disposal	Re-Disposal in engineered landfill	On-Site	Install engineered impermeable lining system and leachate collection system in accordance with Chapter 173-351 WAC regulations. Backfill previously excavated waste onto liner.	Feasible: Temporary stockpile area requires engineered liner.	Low: Insufficient suitable space on-site to temporarily stockpile waste during construction of new landfill. Environmental impacts of temporarily storing excavated waste likely to be high. Potential problems include fugitive dusts, odors, and hazardous gas emissions.	Very high	Rejected
		Off-Site (New Facility)	Construct new landfill in Kitsap County, in accordance with Chapter 173-351 WAC regulations.	Infeasible	Low: During the recent revision to the Solid Waste Management Plan, no suitable site was found. This resulted in the development of the regional transfer station.	Very high	Rejected
		Off-Site (Existing Facility)	Dispose waste in existing off-site landfill.	Feasible	Medium: The most practical disposal solution compared to other alternatives. Disposal of waste most likely to occur at landfills in Oregon or Eastern Washington. Heavy truck traffic will cause large community impacts. Long distance transport may be by railcar.	Very high	Retained
Waste *Ex Situ* Treatment	Incineration	On-Site	Burn waste in on-site incinerator with off-gas pollution control. Dispose of ash off-site.	Potentially Feasible: Waste is most likely wet. Non-burnable waste (appliances, etc.) is difficult to separate from burnable waste.	Low: Community concerns make obtaining government agency approvals unlikely.	Very high	Rejected
		Off-Site	Transport of waste/contaminated soils off-site to existing commercial incinerator, off-site ash disposal.	Potentially Feasible: Waste is most likely wet. Non-burnable waste (appliances, etc.) is difficult to separate from burnable waste.	Low: Closest large off-site incinerators are in Marion County, Oregon, and Spokane County, Washington. Incineration of all waste at Landfill would take several years. Heavy truck traffic will have significant community impacts.	Very high	Rejected
Waste *In Situ* Treatment	Glassification	See “Action”	Glassify waste using subsurface electrodes and high electrical current.	Infeasible: Not a proven technology.	Low: Majority of waste is located too deep below ground surface. High electrical power requirements.	Very High	Rejected
	Active Bioremediation	See “Action”	Planned injection of nutrients, oxygen, and/or microbes into waste.	Infeasible: Aerobic (oxygen-based) biodegradation may cause waste fires.	Low: Heterogeneous nature of waste prevents uniform distribution of additives. Leachate production may increase due to injection of liquid nutrients.	High	Rejected
	Leaching	See “Action”	Application of water to surface of the Landfill to drive contaminants from waste.	Infeasible	Low: Requires removal of existing cover. Will cause dramatic increase in leachate production; no leachate collection system exists.	High	Rejected
	Soil Mixing/Solidification	See “Action”	Mixes soils/wastes using large augers while injecting cement or other solidifying agent.	Infeasible	Low: Requires removal of existing cap and gas collection system. Large objects in waste cannot be mixed.	High	Rejected

Table 7-7. Screening Matrix of Groundwater Containment Technologies

General Response Action	Technology	Process Option	Description	Technical Feasibility	Implementability	Cost	Retained/ Rejected
Institutional Controls	Aquifer Use Restrictions	Property deed restrictions	Prevents use of off-site aquifer as water supply.	Feasible	In Effect: High since no users of upper aquifer in affected area were identified.	Very Low	Retained
Containment	Physical Barriers	Slurry wall	Impermeable wall of bentonite trenched from ground surface to intercept aquitard, forming barrier to groundwater flow.	Infeasible: Aquitard too deep.	Low	Very High	Rejected
		Cutoff wall	Metal sheet piles driven into ground to form barrier to groundwater flow.	Infeasible: Aquitard too deep.	Low	Very High	Rejected
	Hydraulic Containment (Extraction)	Wells	Extraction wells with submersible pumps.	Feasible; Aquifer characteristics are favorable.	Medium: extracted groundwater requires treatment and discharge (see below).	Moderate	Retained
		Well points	Groundwater extracted from multiple shallow wells using central pump.	Infeasible: Aquifer too deep.	Low	Very High	Rejected
		Infiltration trenches	Gravel fill trenches to intercept groundwater for collection.	Infeasible: Aquifer and aquitard too deep.	Low	Very High	Rejected
Disposal of Extracted Groundwater	Discharge to Surface Water	Discharge to Middle Creek	Discharge of treated groundwater to branch of creek closest to Landfill.	Feasible: Gravity drain pipeline.	Medium	Low	Retained
		Discharge to Port Gamble Bay	Discharge of treated groundwater to Port Gamble Bay or other creeks.	Feasible: Gravity drain pipeline.	Medium	High	Rejected
	Aquifer Recharge	Injection Wells	Water pumped into aquifer below water table.	Feasible	High: Requires treating water to groundwater quality standard before return to aquifer. State regulations discourage use of injection wells.	Moderate	Rejected
		Recharge basins (artificial ponds)	Water discharged to basins for infiltration into ground and eventually to aquifer.	Feasible	High: Requires treating water to groundwater quality standard before return to aquifer.	Low	Retained
	Application to Landfill	Leachate spray or irrigation system	Water applied to landfill surface for infiltration into waste. Increases leachate production.	Infeasible: Requires cover removal and will increase leachate production.	Low	High	Rejected

Table 7-8. Screening Matrix of Groundwater Remedial Technologies (Vinyl Chloride)

General Response Action	**Technology**	**Process Option**	**Description**	**Technical Feasibility**	**Implementability**	**Cost**	**Retained/ Rejected**
Natural Attenuation	Not Applicable	Not Applicable	Natural processes including dispersion, volatilization, and biodegradation will reduce concentrations.	Feasible	In Effect: High	Very Low	Retained
Ex Situ Groundwater Treatment (after extraction of groundwater from aquifer, see Table 7-4)	Air Stripping	No Off-Gas Control	Transfer of vinyl chloride from water to air in an air-stripping tower. Vinyl chloride released to atmosphere.	Feasible: attainment of vinyl chloride cleanup levels unproven. Vinyl chloride very suitable for air stripping. Pretreatment may be required to prevent scaling.	High: Off-gas may require treatment to control vinyl chloride emissions to atmosphere (see below).	Low-Moderate	Retained
	Carbon Adsorption	Water Phase Adsorption	Vinyl chloride recovery from groundwater by adsorption onto granular activated carbon.	Low feasibility: Vinyl chloride adsorbs poorly to activated carbon. Large carbon quantities and frequent replacement required.	Medium	Moderate	Rejected
	Disinfection	Chlorine Oxidation	Addition of chlorine gas for sterilization to kill potentially harmful bacteria and other organisms.	Feasible: Routinely used for water sterilization.	Medium: Chlorine gas requires special handling procedures and leaves residual chlorine that may harm aquatic organisms.	Low	Rejected
		Ozone Sterilization	Addition of ozone for sterilization. Ozone generated on-site. Leaves no residual sterilizing agents.	Feasible: Routinely used for water sterilization.	Medium: May cause severe scaling.	Moderate	Rejected
		UV Exposure	Exposure to ultraviolet light for sterilization. Leaves no residual sterilizing agents.	Feasible: Routinely used for water sterilization.	Medium	Moderate	Retained
In Situ Groundwater Treatment	Air Sparging	Not Applicable	Air injected into aquifer and recovered above water table using vapor extraction system. Vinyl chloride removed by volatilization.	Feasible: attainment of vinyl chloride cleanup levels unproven: Vinyl chloride volatilizes readily.	Low: Maximum depth of sparging limited to 30 ft.Off-gas may require treatment to control vinyl chloride emissions to atmosphere (see below).	Moderate	Retained
	Bioremediation	Not Applicable	Planned injection of nutrients, oxygen, and/or microbes into groundwater for biological destruction of contaminants.	Infeasible: Vinyl chloride concentrations are too low.	– – –	– – –	Rejected
Off-Gas Treatment	Carbon Adsorption	Carbon Adsorption through the addition of heat to reduce relatively humidity.	Vinyl chloride recovery from treatment equipment off-gas by adsorption onto activated carbon. Carbon requires periodic regeneration or replacement.	Feasible: Existing flare will need modification or replacement to heat off-gas.	Medium: Off-gas will be saturated with moisture. Vinyl chloride adsorbs extremely poorly to activated carbon unless off-gas is heated to approximately 75°F to reduce its relative humidity. At reduced relative humidity, adsorption is moderately effective. Landfill gas has sufficient fuel value to heat off-gas. Alternatively, supplement fuel (propane) could be used.	Moderate to High	Retained
	External Incineration Unit	Supplemental fuel source.	Thermal destruction of vinyl chloride into carbon dioxide, water, and chorine by heating with supplemental fuel to approximately 1500°F.	Infeasible: Large quantities of supplemental fuel required. Generates combustion-related pollutants. Supplemental fuel would be propane or diesel fuel. Natural gas is not available.	Low	Very High	Rejected
	Incineration	Incineration Off-Gas Control in Existing Flare	Existing landfill gas flare could burn off-gas.	Infeasible: Existing flare operation rate is too small to burn anticipated quantity of air stripping tower off-gas.	Low	– – –	Rejected

Table 7-9. Screening Matrix of Groundwater Remedial Technologies (Arsenic and Manganese)

General Response Action	Technology	Process Option	Description	Technical Feasibility	Implementability	Cost	Retained/ Rejected
Natural Attenuation	Not Applicable	Not Applicable	Natural processes including dispersion, oxidation, and precipitation will reduce concentrations.	Feasible	In Effect: High	Very Low	Retained
Ex Situ Groundwater Treatment	Greensand Filtration	See Description	Adsorption of manganese and arsenic on filter bed of manganese coated sand.	Feasible: Proven technology for manganese removal from drinking water. Arsenic co-adsorbs.	Medium: Bed requires periodic regeneration to remove accumulated manganese and arsenic. Regeneration solution requires additional treatment by settling.	Moderate	Retained
	Precipitation/Settling	See Description	Chemical addition adjustment of pH to proper range causes metals to precipitate so they can be settled using a flocculating agent.	Potentially feasible: Arsenic chemistry is complex and feasibility of achieving desired effluent limits is uncertain.	Low: Laboratory testing of arsenic and manganese removal processes is warranted.	Moderate to High	Rejected
	Reverse Osmosis	See Description	“Filtration” of dissolved ions under high pressure through osmotic membrane. Contaminants concentrated in waste stream of 5 to 20 percent of influent flow rate. Additional treatment of concentrate stream required (see precipitation/settling, above), but treatment system is smaller than for full influent flow.	Potentially feasible: Desired effluent limits may not be achievable.	Medium: High chloride levels in groundwater may attack membrane. Iron fouling expected to be minimal due to low iron levels.	High	Rejected
	Ion Exchange	See Description	Removal of dissolved ions by exchange for salt ions retained on resin matrix. Periodic regeneration of resin required.	Infeasible: Groundwater is highly mineralized. Ion exchange is non-selective and will remove most ions. Regeneration rates would be excessively frequent.	– – –	– – –	Rejected
In Situ Groundwater Treatment	Precipitation	Chemical Injection	Injection of lime or caustic solution into aquifer to immobilize metal ions.	Infeasible: An absence of groundwater containment creates risk of uncontrolled migration of injected hazardous chemicals.	– – –	– – –	Rejected
		Air Sparging	Injection of air into aquifer with vapor recovery above water table. Metal ions may be immobilized by oxidation and precipitation	Feasible: Same basic technology as enhanced as control by air sparging.	Medium	Moderate	Retained
	Mobilization	Chemical Injection	Injection of diluted acids into aquifer to mobilize metals. Extraction by wells, followed by ex situ treatment.	Infeasible: Absence of groundwater containment creates risk of uncontrolled migration of injected hazardous chemicals.	– – –	– – –	Rejected

Table 8-1. Summary of Remedial Alternatives

Alt. No.	Description of Remedial Alternative	Potential Options	Estimated Present Worth Cost (millions of $)
1	**NO ADDITIONAL ACTION WITH NATURAL ATTENUATION** (includes compliance with State landfill regulations including continued Landfill maintenance and monitoring, and operation of gas control system.)		0.6
2	**NATURAL ATTENUATION OF GROUNDWATER WITH ENHANCED MONITORING AND ENHANCED INSTITUTIONAL CONTROLS** Groundwater: Institutional Controls – Prohibition on use of groundwater from upper aquifer in area containing indicator hazardous substances Surface water: Institutional Controls – Prohibition on use of surface water from northern reaches of the tributary of Middle Creek	Combined with other alternatives 3 through 6 shown below	1.2
3	**GAS EXTRACTION SYSTEM ENHANCEMENTS** Location: Along east and west boundaries of waste disposal areas Groundwater (on-site): Natural attenuation with institutional controls Groundwater and Surface Water (off-site): Natural attenuation with enhanced monitoring and institutional controls		2.9-3.3
4	**AIR SPARGING** Location: Along west boundary of waste disposal areas Groundwater (on-site): In situ treatment by air sparging): Natural attenuation with enhanced monitoring Groundwater and Surface Water (off-site): Natural attenuation with enhanced monitoring and enhanced institutional controls		5.1-8.0
5 5+RTA	**GROUNDWATER PUMP AND TREAT (At Landfill Boundary)** Location: Along west boundary of waste disposal areas Groundwater (on-site): Groundwater extraction (70 to 140 gpm), with treatment by greensand filtration and air stripping Groundwater and Surface Water (off-site): Natural attenuation with enhanced monitoring and enhanced institutional controls	Option 5: Return treated water to Middle Creek Option 5+RTA: Return treated water to aquifer	6.3-7.2
6 6+RTA	**GROUNDWATER PUMP AND TREAT (AT LANDFILL BOUNDARY AND OFF-SITE)** Location: Along west boundary of waste disposal areas and just upgradient from springs feeding affected creeks Groundwater: Groundwater extraction on-site (70 to 140 gpm) and off-site (100 to 200 gpm), with treatment by greensand filtration and air stripping Groundwater and Surface Water (off-site): Natural attenuation with enhanced monitoring and institutional controls	Option 6: Return Treated water to Middle Creek Option 6+RTA: Return treated water to aquifer	6.9-9.4
7	**WASTE EXCAVATION AND OFF-SITE RE-DISPOSAL** Waste: Excavate and transport by truck off-site. Dispose of waste at off-site landfill. No treatment of groundwater or surface water (select one of the above alternatives)		63-138

Table 8-2. Predicted Leachate Generation Rate from the Hansville Landfill Solid Waste Disposal Area

Model Run Year	Actual Year Equivalent	Predicted Leachate Generation Rate (gallons)
1[(1)]	1989	4,500,000[(2)]
2	1990	851,000
3	1991	458,000
4	1992	308,000
5	1993	227,000
6	1994	178,000
7	1995	146,000
8	1996	124,000
9	1997	106,000
10	1998	93,000
11	1999	83,000
12	2000	74,000
13	2001	67,000
14	2002	61,000
15	2003	56,000
16	2004	52,000
17	2005	48,000
18	2006	45,000
19	2007	42,000
20	2008	40,000
21	2009	37,000
22	2010	35,000
23	2011	33,000
24	2012	32,000
25	2013	30,000
26	2014	29,000
27	2015	28,000
28	2016	26,000
29	2017	25,000
30	2018	24,000

(1) Landfill cap installed.

(2) From Parametrix 2007b. Estimated leachate generation rate prior to installation of the landfill cap.

Table 8-3. Estimated Vinyl Chloride Travel Times in Groundwater

Parameter	Units	Average Case		Upper-bound Case	
Groundwater Flow Path[1]		MW-14 to SW-1	MW-2 to SW-4	MW-14 to SW-1	MW-2 to SW-4
Groundwater Travel Time[1]	years	2.5	13	2.5	13
Vinyl Chloride Retardation Factor (see Appendix D)	--	1.4	1.4	2.0	2.0
Vinyl Chloride Travel Time	years	3.5	18	5	26

(1) From Parametrix (2007b); see Figure 4-1 of this FS Report for locations of monitoring wells and surface water stations.

Table 8-4. Summary of Groundwater Concentrations for Selected Parameters (Four Quarters of RI Monitoring)

		On-Site Concentrations: Monitoring Wells MW-4, MW-6, MW-8D, & MW-14			Off-Site Concentrations: Monitoring Wells MW-9, MW-10, MW-12, MW-12I, MW-13S, & MW-13D			Upgradient Well MW-5	
Analyte	**Units**	**Average Conc.**	**Upper-bound 97.5% CI Conc.**	**Maximum Conc.**	**Average Conc.**	**Upper-bound 97.5% CI Conc.**	**Maximum Conc.**	**Average Conc.**	**Maximum Conc.**
Field Parameters									
Specific Conductivity	μmhos/cm	914	1133	1562	471	627	1327	149	162
Dissolved Oxygen	mg/L	0.1	0.25	0.6	2.5	3.9	5.9	6.7	7.2
pH		6.8	7.2	8.4	6.5	6.9	8.2	6.7	7.5
Temperature	C	14	15	17	12	13	18	13	18
Conventionals									
Alkalinity (as $CaCO_3$)	mg/L	346	447	740	147	197	440	57	66
Ammonia Nitrogen	mg/L	0.08	0.17	0.78	0.013	0.016	0.03	0.014	0.022
Carbonate (as $CaCO_3$)	mg/L	ND(1.0)	--	ND(1.0)	ND(1.0)	--	ND(1.0)	ND(1.0)	ND(1.0)
Chem. Oxygen Demand	mg/L	21	29	58	11	12	18	10	11
Chloride	mg/L	93	143	300	55	94	320	5.2	8.2
Hardness	mg/L	393	536	790	201	284	530	57	59
Nitrate + Nitrite	mg/L	0.1	0.15	0.7	0.9	1.3	4	0.10	0.10
Nitrite Nitrogen	mg/L	0.003	0.006	0.020	0.002	0.002	0.005	ND(0.001)	ND(0.001)
Bicarb. (as $CaCO_3$)	mg/L	346	447	740	147	197	440	57	66
Sulfate	mg/L	27	39	84	20	24	39	11	12
Total Organic Carbon	mg/L	2.2	3.8	10	2.2	3.3	12	ND(1.0)	ND(1.0)
Volatile Organic Compound									
Vinyl Chloride	mg/L	0.0045	0.0067	0.011	0.00059	0.0011	0.0036	ND(0.00001)	ND(0.00001)

Table 8-4. Summary of Groundwater Concentrations for Selected Parameters (4 Quarters of RI Monitoring) (continued)

		On-Site Concentrations: Monitoring Wells MW-4, MW-6, MW-8D, & MW-14			Off-Site Concentrations: Monitoring Wells MW-9, MW-10, MW-12, MW-12I, MW-13S, & MW-13D			Upgradient Well MW-5	
Analyte	**Units**	**Average Conc.**	**Upper-bound 97.5% CI Conc.**	**Maximum Conc.**	**Average Conc.**	**Upper-bound 97.5% CI Conc.**	**Maximum Conc.**	**Average Conc.**	**Maximum Conc.**
Metals									
Arsenic	mg/L	0.008	0.012	0.027	0.001	0.002	0.003	0.002	0.003
Barium	mg/L	0.051	0.066	0.10	0.018	0.023	0.040	0.004	0.004
Calcium	mg/L	56	71	100	28	37	66	7.8	8.0
Iron	mg/L	1.0	1.5	2.9	0.03	0.04	0.16	0.040	0.090
Lead	mg/L	ND(0.001)	--	ND(0.001)	ND(0.001)	0.002	0.009	ND(0.001)	ND(0.001)
Magnesium	mg/L	64	86	140	34	47	88	9.4	9.9
Manganese	mg/L	2.7	3.9	6.0	0.08	0.11	0.3	ND(0.002)	0.003
Potassium	mg/L	4.9	5.9	9.3	2.6	3.2	5.8	1.5	1.8
Sodium	mg/L	42	61	110	15	20	42	5.8	6.1
Zinc	mg/L	0.011	0.016	0.041	0.013	0.017	0.049	0.012	0.030
Bacteriological									
Total Coliform(1)	CFU/100ml	9	29	6,400(78)[1]	7	14	40	ND(1)	ND(1)

Note: RI sampling events were completed in 1997

ND = Not Detected at indicated concentration in ( )

(1)Highest coliform count was 6400 CFU/100 ml in MW-14 and was excluded from average value calculations.

The 78 cfu/100 ml is the representative maximum concentration used to calculate the average.

Table 8-5. Application of Natural Attenuation Criteria to Hansville Landfill Site

Natural Attenuation Site Criteria	Hansville Landfill Site
Source control is concurrently and effectively applied.	The existing cap and gas control system provide source control, resulting in declining releases of indicator hazardous substances to groundwater over time.
Human health and the environment are protected.	Institutional controls would prevent exposure to indicator hazardous substances in impacted groundwater and surface water.
Cleanup standards can be achieved in a reasonable timeframe.	Meets the remedial objectives for protectiveness. The time required to achieve cleanup standards is estimated to be up to 23 years. Releases of indicator hazardous substances to groundwater may continue for several years, during which time the aquifer would remain unusable as a drinking water source.
Migration of groundwater is limited.	Migration of groundwater is limited by aquifer outcropping west of the site. Groundwater flow is well characterized.
Transformation of contaminants into more mobile or more toxic substances is unlikely.	Vinyl chloride degrades to ethene which is not considered hazardous. Mobility of both vinyl chloride and ethene are not expected to be significantly influenced by the sand matrix of the aquifer.
	Oxidation and precipitation processes for manganese and arsenic result in less mobile and less toxic substances, and hence lower concentrations.
Transformation processes are irreversible.	Attenuation processes for vinyl chloride are irreversible. Attenuation processes for arsenic and manganese are potentially reversible; however, oxidizing conditions in the off-site aquifer favor irreversibility.
Effectiveness of attenuation processes can be thoroughly and adequately supported with site-specific data.	Effectiveness of existing source controls and natural attenuation are evident from RI data that show declining concentrations of indicator hazardous substances with time and lower concentrations of indicator hazardous substances in off-site wells and surface water, relative to concentrations within Landfill Property boundaries.
Methods to monitor remediation progress are available.	A program for monitoring landfill gas, groundwater, and surface water can be established based on data collected since closure.
Backup or contingency plans are available.	Possible backup plans include using active treatment systems described in this section.

[1] per WAC 173-340-370(7)

Table 8-6. Evaluation of Dispersion of Conserved Substances[1] in the Upper Aquifer

		A	B	C	D	E	F
Analyte	**Units**	**On-site Concentration(2)**	**Off-site Concentration(2)**	**Background Concentration(2)**	**On-site Concentration Minus Background (A minus C)**	**Off-site Concentration Minus Background (B minus C)**	**Groundwater Dispersion Ratio (D/E)**
Field Parameters							
Specific Conductivity	µmhos/cm	914	471	149	765	322	2.4
Conventionals							
Alkalinity (as $CaCO_3$)	mg/L	346	147	57	289	90	3.2
Chloride	mg/L	93	55	5.2	88	50	1.8
Hardness	mg/L	393	201	57	336	143	2.3
Sulfate	mg/L	27	20	11	16	9.0	1.7
Metals							
Calcium	mg/L	56	28	7.8	48	20	2.4
Magnesium	mg/L	64	34	9.4	55	25	2.2
Potassium	mg/L	4.9	2.6	1.5	3.4	1.1	3.1
Sodium	mg/L	42	15	5.8	36	9.6	3.8
Average							**2.5**

(1)Conserved substances are unlikely to engage in significant natural attenuation processes other than dispersion. Data from four quarters of RI monitoring.

(2)Data shown are average groundwater concentrations for the four quarters of RI monitoring.

Table 8-7. Concentrations of Indicator Hazardous Substances in On-Site Monitoring Wells Used for Alternative 5 Calculations(1)

Alternative 5 Groundwater Extraction Rate	Average On-site Groundwater Concentration (mg/L)	Upper-bound On-site Groundwater Concentration (mg/L)	Discharge Limit (Site Cleanup Level) (mg/L)
70 gpm (lower bound)			
Vinyl Chloride	0.0045	--	0.00025
Arsenic	0.008	--	0.005
Manganese	2.7	--	2.24
140 gpm (upper bound)			
Vinyl Chloride	--	0.0067	0.00025
Arsenic	--	0.012	0.005
Manganese	--	3.9	2.24

(1) Data from four quarters of RI monitoring.

Table 8-8. Greensand Filter System Design Parameters Used for Alternative 5 Calculations

Water Flow Rate (gpm)	Filter Area (sq. ft.)	Filter Volume (cubic ft.)	Greensand Weight (120 lb/cf) (lb)
70	24	48	6,000
140	48	144	18,000

Table 8-9. Air Stripping System Design Parameters Used for Alternative 5 Calculations

Groundwater Flow (gpm)	Vinyl Chloride Influent Concentration (mg/L)	Packing Height (ft)	Tower Diameter (ft)	Air Flow Rate (cfm)	Blower Size (HP)	Overall Tower Height (ft)
70	0.0045	24	1.7	470	3	34
140	0.0067	26	2.4	940	6	36

Table 8-10. Concentrations of Indicator Hazardous Substances in On-Site and Off-Site Groundwater Used for Alternative 6 Calculations[1]

Alternative 6 Groundwater Extraction Rate	Average Groundwater Concentration (mg/L)	Upper-bound Groundwater Concentration (mg/L)	Flow Weighted Average Concentration (mg/L)
On-Site Well Conditions			
Average: 70 gpm			
Vinyl Chloride	0.0045	--	--
Arsenic	0.008	--	--
Manganese	2.7	--	--
Upper-Bound: 140 gpm			
Vinyl Chloride	--	0.0067	--
Arsenic	--	0.012	--
Manganese	--	3.9	--
Off-Site Well Conditions			
Average: 100 gpm			
Vinyl Chloride	0.00059	--	--
Arsenic	0.001	--	--
Manganese	0.08	--	--
Upper-Bound: 200 gpm			
Vinyl Chloride	--	0.0011	--
Arsenic	--	0.002	--
Manganese	--	0.11	--
Combined Conditions (On-Site + Off-Site)			
Average: 170			
Vinyl Chloride	--	--	0.0022
Arsenic	--	--	0.0039
Manganese	--	--	1.16
Upper-Bound: 340 gpm			
Vinyl Chloride	--	--	0.0034
Arsenic	--	--	0.0061
Manganese	--	--	1.67

(1)Data from four quarters of RI monitoring.

Table 8-11. Greensand Filter System Design Parameters Used for Alternative 6 Calculations

Water Flow Rate (gpm)	Filter Area (sq. ft.)	Filter Volume (cubic ft.)	Greensand Weight (120 lb/cf)
170	60	120	14,400
340	120	360	43,200

Table 8-12. Air Stripping System Design Parameters Used for Alternative 6 Calculations

Groundwater Flow (gpm)	Vinyl Chloride Influent Concentration (mg/L)	Packing Height (ft)	Tower Diameter (ft)	Air Flow Rate (cfm)	Blower Size (HP)	Tower Height (ft)
170	0.0022	20	2.7	1,140	6	30
340	0.0034	23	3.8	2,300	13	33

Table 10-1. Benefit Matrix: Evaluation and Benefit Scoring of Alternatives

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity/ Mobility/Volume through Treatment	Implementability	Degree to Which Potential Community Concerns are Addressed(1)	Total Rating
	• Degree of reduction of existing risk • Time required to reduce risk and attain cleanup standards • Onsite/offsite risks due to remedial actions	**• Compliance with cleanup standards • Compliance with other ARARs • Ability and time required to obtain necessary authorization**	**• Protection of human health and the environment during implementation • Degree of risk prior to attainment of cleanup standards**	**• Degree of certainty of cleanup success • Long-term reliability • Magnitude of residual risk • Management of treatment wastes • Management of wastes remaining untreated**	**• Treatment capability • Reduction or elimination of releases • Management of sources of releases • Permanent solution • Quantity/quality of treatment wastes**	**• Technical feasibility • Availability of necessary off-site facilities • Availability of necessary services and materials • Administrative (permitting, scheduling, monitoring, construction access, O&M, integration with current site and other remedial actions) requirements**	**• Protection of fish and wildlife habitat • Protection of human health • Control of further releases**	**Aggregate rating from all scores**
1.No Additional Action with Natural Attenuation	• Does not fully protect against potential future groundwater exposure • Natural attenuation processes likely to reduce concentrations of indicator hazardous substances in groundwater and surface water • Through natural and surface water attenuation, property will be useable in the future	• Expected to comply with ARARs over cleanup time frame	• Incomplete protection of human health and the environment during implementation (absence of enhanced institutional controls)	• Long-term risks may be significant if aquifer is used for drinking water • Provides no long-term monitoring program to assess long-term risks	• Existing landfill cap and gas extraction system provide source control • Leachate and gas generation will likely continue at decreasing rates •	• Simple to implement	• Not likely to gain community acceptance	
	RATING: 1	**RATING: 2**	**RATING: 1**	**RATING: 1**	**RATING: 1**	**RATING: 3**	**RATING: 1**	**10**
2.Natural Attenuation with Enhanced Monitoring and Enhanced Institutional Controls	• Institutional controls prevent exposure to indicator hazardous substances in groundwater and surface water • Natural attenuation processes likely to reduce concentrations of indicator hazardous substances in groundwater and surface water • Through natural and surface water attenuation, property will be useable in the future • Up to 23 years to achieve cleanup standards	• Expected to comply with ARARs over cleanup time frame	• Enhanced institutional controls will provide immediate protection of human health	• Deed restrictions on non-Tribal property provides legally-enforceable mechanism to prevent exposures to groundwater and surface water • Natural attenuation will reduce concentrations of indicator hazardous substances over cleanup time frame	• Existing landfill cap and gas extraction system provide source controls • Leachate and gas generation will likely continue at decreasing rates • Natural attenuation processes likely to reduce concentrations of indicator hazardous substances	• Simple to implement • Does not impact any existing private or community wells • Land use restrictions have been successfully negotiated with the Tribe and agencies	• Restricts use of upper aquifer and surface water for drinking water during term of institutional controls	
	RATING: 2	**RATING: 2**	**RATING: 3**	**RATING: 3**	**RATING: 1**	**RATING: 3**	**RATING: 2**	**16**
3.Gas Extraction System Enhancements	• Improved gas extraction between the bottom of refuse and the water table could potentially reduce future releases to groundwater and reduce time required to achieve cleanup standards (less than 23 years)	• Expected to comply with ARARs over cleanup time frame • Complies with all other ARARs	• Remedial activities will not significantly increase risk • Vinyl chloride emissions are likely during implementation; however, emissions will not exceed regulatory limits	• Effectiveness in providing complete control of future releases of indicator hazardous substances from landfill gas to groundwater from the Landfill is uncertain	• May reduce additional releases of indicator hazardous substances • Vinyl chloride is diverted (untreated) to the air	• Technical feasibility is uncertain	• Restricts use of upper aquifer and surface water during term of institutional controls • May significantly reduce releases of indicator hazardous substances from Landfill	
	RATING: 2	**RATING: 2**	**RATING: 3**	**RATING: 1**	**RATING: 2**	**RATING: 1**	**RATING: 2**	**13**

Table 10-1. Benefit Matrix: Evaluation and Benefit Scoring of Alternatives (continued)

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity/ Mobility/Volume through Treatment	Implementability	Degree to Which Potential Community Concerns are Addressed(1)	Total Rating
	• **Degree of reduction of existing risk** • **Time required to reduce risk and attain cleanup standards** • **Onsite/offsite risks due to remedial actions**	• **Compliance with cleanup standards** • **Compliance with other ARARs** • **Ability and time required to obtain necessary authorization**	• **Protection of human health and the environment during implementation** • **Degree of risk prior to attainment of cleanup standards**	• **Degree of certainty of cleanup success** • **Long-term reliability** • **Magnitude of residual risk** • **Management of treatment wastes** • **Management of wastes remaining untreated**	• **Treatment capability** • **Reduction or elimination of releases** • **Management of sources of releases** • **Permanent solution** • **Quantity/quality of treatment wastes**	• **Technical feasibility** • **Availability of necessary off-site facilities** • **Availability of necessary services and materials** • **Administrative (permitting, scheduling, monitoring, construction access, O&M, integration with current site and other remedial actions) requirements**	• **Protection of fish and wildlife habitat** • **Protection of human health** • **Control of further releases**	**Aggregate rating from all scores**
4.Air Sparging	• Institutional controls prevent exposure to indicator hazardous substances in groundwater and surface water • If successful, off-site migration of indicator hazardous substances would be greatly reduced	• Ability to achieve MTCA groundwater cleanup standard for vinyl chloride is uncertain • Complies with all other ARARs	• Remedial activities will not increase risk • Vinyl chloride emissions are likely during implementation; however, emissions will not exceed regulatory limits	• Provides higher degree of reliability than Alternative 3 that indicator hazardous substances will not migrate beyond landfill boundary • Off-site aquifer still relies on natural attenuation for cleanup • Technology requires field test to verify effectiveness • Effectiveness of using air sparging as a barrier to remove indicator hazardous substances in flowing groundwater is uncertain	• Vinyl chloride is stripped from groundwater to air (similar to Alt. 2) • Some treatment of manganese and arsenic is provided by in situ oxidation, however, some remobilization could occur when sparging wells are turned off at completion of remediation (similar to Alt. 2)	• Technology is available, but innovative • Requires no permits for offsite discharge • Pilot testing required; full implementation may be delayed pending results of testing	• Restricts use of upper aquifer and surface water for drinking water during term of institutional controls • May eliminate future releases of indicator hazardous substances to off-site groundwater	
	RATING: 2	**RATING: 2**	**RATING: 3**	**RATING: 2**	**RATING: 1**	**RATING: 2**	**RATING: 2**	**14**
5. Groundwater Pump and Treat at Landfill Boundary								
5: Discharge to surface water; no treatment of air stripper off-gas	• Institutional controls prevent exposure to indicator hazardous substances in groundwater and surface water • If effective source control is achieved, time required to achieve cleanup standards may be reduced to less than 23 years	• Ability to achieve MTCA groundwater cleanup standard for vinyl chloride is uncertain • Complies with all other ARARs	• Remedial activities will not increase risk • Vinyl chloride emissions are likely during implementation; however, emissions will not exceed regulatory limits	• Provides higher degree of reliability than Alternatives 3 and 4 that indicator hazardous substances will not migrate beyond Landfill Boundary • Treatment wastes are sent off-site and contained in a permitted facility • Ability of groundwater pump and treat to achieve MTCA groundwater cleanup standard for vinyl chloride is uncertain	• Vinyl chloride is extracted from groundwater to air (similar to Alt. 2) • Treatment of manganese and arsenic is achieved following extraction from groundwater	• Common technology; no technical barriers to implementation • Would require agency approval for discharge to surface waters • Potential disruption to natural surface water flows will be mitigated • Would require consent by the Port Gamble S'Klallam Tribe to construct and operate a discharge pipeline for treated groundwater	• Restricts use of upper aquifer and surface water for drinking water during term of institutional controls • May eliminate future releases of indicator hazardous substances to off-site groundwater and surface water	
	RATING: 2	**RATING: 2**	**RATING: 3**	**RATING: 2**	**RATING: 2**	**RATING: 3**	**RATING: 2**	**16**
5+RTA: Return treated water to aquifer rather than discharge to surface water	• Same as 5	• Same as 5	• Same as 5	• Effectiveness of returning treated water to aquifer is uncertain	• Oxygenation of aquifer may increase potential for biodegradation of vinyl chloride, and immobilization of arsenic and manganese under the Landfill	• May be difficult to obtain authorization for discharge to groundwater	• Same as 5	
	RATING: 2	**RATING: 2**	**RATING: 3**	**RATING: 2**	**RATING: 2**	**RATING: 1**	**RATING: 3**	**15**

Table 10-1. Benefit Matrix: Evaluation and Benefit Scoring of Alternatives (continued)

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity/ Mobility/Volume through Treatment	Implementability	Degree to Which Potential Community Concerns are Addressed$^{(1)}$	Total Rating
	• **Degree of reduction of existing risk** • **Time required to reduce risk and attain cleanup standards** • **Onsite/offsite risks due to remedial actions**	• **Compliance with cleanup standards** • **Compliance with other ARARs** • **Ability and time required to obtain necessary authorization**	• **Protection of human health and the environment during implementation** • **Degree of risk prior to attainment of cleanup standards**	• **Degree of certainty of cleanup success** • **Long-term reliability** • **Magnitude of residual risk** • **Management of treatment wastes** • **Management of wastes remaining untreated**	• **Treatment capability** • **Reduction or elimination of releases** • **Management of sources of releases** • **Permanent solution** • **Quantity/quality of treatment wastes**	• **Technical feasibility** • **Availability of necessary off-site facilities** • **Availability of necessary services and materials** • **Administrative (permitting, scheduling, monitoring, construction access, O&M, integration with current site and other remedial actions) requirements**	• **Protection of fish and wildlife habitat** • **Protection of human health** • **Control of further releases**	**Aggregate rating from all scores**
6. Groundwater Pump and Treat at Landfill Boundary and Downgradient								
6: Discharge to surface water; no treatment of air stripper off-gas	• Cleanup timeframe may be shortened to less than 20 years	• May achieve MTCA groundwater standards • Complies with all other ARARs	• Remedial activities will not increase risk • Vinyl chloride emissions are likely during implementation; however, these emissions will not exceed regulatory limits	• Provides higher degree of reliability than Alternatives 3, 4, or 5 that indicator hazardous substances will not migrate beyond Landfill Boundary or into surface water • Treatment wastes are sent off-site and contained in a permitted facility • Reduces potential for migration of indicator hazardous substances to surface water • Ability of groundwater pump and treat to achieve MTCA groundwater cleanup standard for vinyl chloride is uncertain	• Vinyl chloride is extracted from groundwater to air • Treatment of manganese and arsenic is achieved following extraction from groundwater	• Common technology; no technical barriers to implementation • Will require agency approval for discharge to surface waters • Flow augmentation may be required in tributaries located within downgradient zone • Would require consent by the Port Gamble S'Klallam Tribe to construct and operate remediation facilities (extraction wells, treated water discharge pipelines, etc.)	• Restricts use of upper aquifer and surface water for drinking water during term of institutional controls • May eliminate future releases of indicator hazardous substances to off-site groundwater and surface water	
	RATING: 3	**RATING: 2**	**RATING: 3**	**RATING: 2**	**RATING: 2**	**RATING: 3**	**RATING: 3**	**18**
6+RTA: Return treated water to aquifer, rather than discharge to surface water	• Same as 6	• Same as 6	• Same as 6	• Effectiveness of returning treated water to aquifer is uncertain	• Oxygenation of aquifer may increase potential for biodegradation of vinyl chloride, and immobilization of arsenic and manganese under the Landfill	• May be difficult to obtain authorization for discharge to groundwater	• Same as 6	
	RATING 3	**RATING 2**	**RATING 3**	**RATING 2**	**RATING 2**	**RATING: 1**	**RATING: 3**	**16**
7. Waste Excavation and Off-site Re-Disposal	• Provides maximum source control of wastes and indicator hazardous substances • Existing groundwater contamination will reduce more rapidly over time, and time required to achieve cleanup standards may be reduced to less than 23 years, the estimated time for cleanup by natural attenuation to be complete	• Potential violation of air quality standards may occur during implementation due to fugitive dusts, odors, and toxic substances	• May create significant risk through short-term releases of toxic dusts and vapors • Potentially significant impacts of noise, odor, and traffic during remediation	• High degree of likelihood for long-term cleanup success	• Provides no active treatment of previously released indicator hazardous substances in groundwater and surface water	• Technically difficult to implement	• Dust, noise, odor and truck traffic are likely to be objectionable to community • Provides maximum source control for wastes and indicator hazardous substances	
	RATING: 3	**RATING: 2**	**RATING: 1**	**RATING: 3**	**RATING: 2**	**RATING: 1**	**RATING: 2**	**14**

Table 10-2. Summary of Alternative Costs (Average Remediation Condition) Hansville Landfill Feasibility Study

	Average Cost($)				
			Operation and Maintenance Cost		
Alternative No. and Description	**Present Worth Cost**	**Initial Capital Cost**	**Annual Equivalent Subtotal[1]**	**Present Worth Equipment and Supplies**	**Present Worth Monitoring and Labor**
Alt. 1: No Additional Action with Natural Attn.	$638,000	$5,000	$51,000	$98,000	$535,000
Alt. 2: Nat. Attn./Enhanced Mon./Enhanced Inst. Controls	$1,180,000	$5,000	$64,000	$98,000	$1,077,000
Alt. 3: Gas Extraction	$2,909,000	$637,000	$148,000	$681,000	$1,592,000
Alt. 4: Air Sparging	$5,094,000	$1,985,000	$202,000	$1,482,000	$1,627,000
Alt. 5: GW P/T (On-site) w/Surface Water Discharge	$6,269,000	$1,687,000	$298,000	$1,035,000	$3,547,000
Alt. 5+RTA: GW P/T (On-site) w/Aquifer Recharge	$6,705,000	$1,714,000	$325,000	$1,137,000	$3,854,000
Alt. 6: GW P/T (On-site and Off-site) w/Surface Water Discharge	$7,799,000	$2,694,000	$332,000	$1,687,000	$3,418,000
Alt. 6+RTA: GW P/T (On-site and Off-site) w/Aquifer Recharge	$6.925,000	$2,527,000	$286,000	$1,634,000	$2,764,000
Alt. 7: Waste Excavation & Off-site disposal	$62,532,000	$62,532,000	—	—	—

(1) Calculated from Present Worth Costs for equipment and supplies and labor and monitoring assuming an interest rate of 5%. Estimated project life times are 23 years for Alternatives 1 through 5 and Alternative 7, and 18 years for Alternatives 6 and 6+RTA (due to adding a pumping center on Tribal Property).

Table 10-3. Summary of Alternative Costs (Upper-Bound Remediation Condition) Hansville Landfill Feasibility Study

	Upper-Bound Cost($)				
			Operation and Maintenance Cost		
Alternative No. and Description	**Present Worth Cost**	**Initial Capital Cost**	**Annual Equivalent Subtotal[1]**	**Present Worth Equipment and Supplies**	**Present Worth Monitoring and Labor**
Alt. 1: No Additional Action with Nat. Attn.	$638,000	$5,000	$51,000	$98,000	$535,000
Alt. 2: Nat. Attn./Enhanced Mon./ Enhanced Inst. Controls	$1,180,000	$5,000	$64,000	$98,000	$1,077,000
Alt. 3: Gas Extraction	$3,330,000	$835,000	$162,000	$865,000	$1,630,000
Alt. 4: Air Sparging	$8,006,000	$3,604,000	$286,000	$2,726,000	$1,676,000
Alt. 5: GW P/T (On-site) w/Surface Water Discharge	$7,074,000	$2,039,000	$328,000	$1,475,000	$3,559,000
Alt. 5+RTA: GW P/T (On-site) w/Aquifer Recharge	$7,150,000	$2,069,000	$331,000	$1,531,000	$3,550,000
Alt. 6: GW P/T (On-site and Off-site) w/Surface Water Discharge	$9,407,000	$3,547,000	$381,000	$2,439,000	$3,422,000
Alt. 6+RTA: GW P/T (On-site and Off-site) w/Aquifer Recharge	$8,160,000	$2,985,000	$337,000	$2,408,000	$2,767,000
Alt. 7: Waste Excavation & Off-Site disposal	$137,581,000	$137,581,000	–	–	–

(1) Calculated from Present Worth Costs for equipment and supplies and labor and monitoring assuming an interest rate of 5%. Estimated project life times are 23 years for Alternatives 1 through 5 and Alternative 7, and 18 years for Alternatives 6 and 6+RTA (due to adding a pumping center on Tribal Property).

Table 10-4. Cost/Benefit Analysis (Average Condition) Hansville Landfill Feasibility Study

Alternative No. and Description	Benefit Score[(1)]	Base Score	Benefit Ratio	Present Worth Cost	Cost Ratio[(2)]	Cost/Benefit Ratio[(3)]
Alt. 1: No Additional Action with Nat. Attn.	10	19	0.5	$638,000	0.5	1.0
Alt. 2: Nat. Attn./Enhanced Mon./Enhanced Inst. Controls	16	19	0.8	$1,180,000	1.0	1.3
Alt. 3: Gas Extraction	13	19	0.7	$2,909,000	2.5	3.6
Alt. 4: Air Sparging	14	19	0.7	$5,094,000	4.3	6.1
Alt. 5: GW P/T (On-site) with Surface Water Discharge	17	19	0.9	$6,269,000	5.3	5.9
Alt. 5+RTA: GW P/T (On-site) with Aquifer Recharge	14	19	0.7	$6,705,000	5.7	8.1
Alt. 6: GW P/T (On-site and Off-site) with Surface Water Discharge	19	19	1.0	$7,799,000	6.6	6.6
Alt. 6+RTA: GW P/T (On-site and Off-site) with Aquifer Recharge	16	19	08	$6,925,000	5.9	7.4
Alt. 7: Waste Excavation and Off-site disposal	14	19	0.7	$62,532,000	53.0	75.7

(1)Base Benefit Score = Highest benefit score (19 for Alt. 6).

(2)Cost /Base Cost; Base Cost = Present Worth Cost of Alternative 2.

(3)Values greater than 1 indicate a cost that is disproportionately great relative to the benefit score.

Table 10-5. Cost/Benefit Analysis (Upper-Bound Condition) Hansville Landfill Feasibility Study

Alternative No. and Description	Benefit Score	Base Score	Benefit Ratio	Cost	Cost Ratio[1]	Cost/Benefit Ratio[2]
Alt. 1: No Additional Action with Nat. Attn.	10	18	0.6	$638,000	0.5	0.8
Alt. 2: Nat. Attn./Enhanced Mon./ Enhanced Inst. Controls	16	18	0.9	$1,180,000	1.0	1.1
Alt. 3: Gas Extraction	13	18	0.7	$3,330,000	2.8	4.0
Alt. 4: Air Sparging	14	18	0.8	$8,006,000	6.8	8.5
Alt. 5: GW P/T (On-site) with Surface Water Discharge	16	18	0.9	$7,074,000	6.0	6.7
Alt. 5+RTA: GW P/T (On-site) with Aquifer Recharge	15	18	0.8	$ 7,150,000	6.1	7.6
Alt. 6: GW P/T (On-site and Off-site) with Surface Water Discharge	18	18	1.0	$9,407,000	8.0	8.0
Alt. 6+RTA: GW P/T (On-site and Off-site) with Aquifer Recharge	16	18	0.9	$8,160,000	6.9	7.7
Alt. 7: Waste Excavation and Off-site disposal	14	18	0.8	$137,581,000	116.6	145.8

[1] Cost ÷ Base Cost; Base Cost = Present Worth Cost of Alternative 2 (value = 18).

[2] Values greater than 1 indicate a cost that is disproportionately great relative to the benefit score.