REVISED AGENCY DRAFT
Ephrata Landfill Feasibility Study

Prepared for

GRANT COUNTY
STATE OF WASHINGTON

CITY OF EPHRATA
WASHINGTON

March 2018

Prepared by

Parametrix

In association with

Pacific Groundwater Group

REVISED AGENCY DRAFT
Ephrata Landfill Feasibility Study

Prepared for

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CERTIFICATION

The technical material and data contained in this document were prepared under the supervision and direction of the undersigned, whose seal, as a professional engineer licensed to practice as such, is affixed below.

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ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
City	City of Ephrata
County	Grant County
CSM	conceptual site model
CUL	proposed cleanup level
Ecology	Washington State Department of Ecology
FOD	frequency of detection
FS	feasibility study
GAC	granular activated carbon
gpm	gallon(s) per minute
gpy	gallon(s) per year
Hg	mercury
IHS	indicator hazardous substance
IRA	interim remedial action
kg	kilogram(s)
LNAPL	light non-aqueous phase liquid
LTT	liquid treatment train
mg/kg	milligram(s) per kilogram
MPE	multi-phase extraction
MTCA	Model Toxics Control Act
NES	north end soil
PGG	Pacific Groundwater Group
POC	point of compliance
RI	remedial investigation
scfm	standard cubic foot (feet) per minute
Site	Defined in Agreed Order DE 3810 as "… the extent of contamination caused by the release of hazardous substances at the Site."
SVE	soil vapor extraction
ug/m^3	microgram(s) per cubic meter
VOC	volatile organic compound
VTT	vapor treatment train
WAC	Washington Administrative Code

EXECUTIVE SUMMARY

This feasibility study (FS) was prepared for the Ephrata Landfill in Grant County, Washington, under the terms of Agreed Order DE 3810, dated January 30, 2007, and amended on November 26, 2012, and January 19, 2016, between Grant County (the County), the City of Ephrata (the City), and the Washington State Department of Ecology (Ecology). The City and County are named as the potentially liable parties in the Agreed Order. The Agreed Order, as amended, required the City and County to conduct a remedial investigation and FS, as well as perform several interim remedial actions at the landfill. Pacific Groundwater Group led the remedial investigation, and Parametrix led the FS. Both firms were involved in performing the interim remedial actions, which are summarized below. This project is being performed to comply with the Model Toxics Control Act (MTCA), Chapter 70.105D Revised Code of Washington, and its implementing regulations, Chapter 173-340 Washington Administrative Code (WAC), including WAC 173-340-350, which specifies procedures for conducting an FS. This FS replaces and supersedes a prior draft FS submitted to Ecology in 2012.

The Ephrata Landfill is located approximately 3 miles south of the city of Ephrata on the east side of Highway 28. An old, unlined landfill (original landfill) is situated on the north part of the landfill property. The City began operating the original landfill in approximately 1942 and owned and operated it until 1974. The County took over landfill operations in 1974 and now owns the original landfill. In 1975, approximately 2,350 drums containing industrial waste were brought to the Ephrata Landfill and stacked near the original landfill, which was still being filled. The drums were covered as the original landfill was filled, and they were ultimately buried. Releases from the buried drums have contaminated part of a shallow, discontinuous, saturated zone called the P1 and, to a lesser degree, deeper underlying strata.

Nine interim remedial actions were completed at the Ephrata Landfill from 2006 through 2018:

- Potholing to confirm the buried drums and obtain samples for analysis in 2007
- Removal and disposal of approximately 2,350 buried industrial waste drums and associated contaminated soil and liquids at the north end of the original landfill in 2008
- Capping of the original landfill with a geomembrane cover system and construction of landfill gas and surface water control systems in 2008
- Extraction of contaminated groundwater on a seasonal basis from 2008 to 2011
- Light non-aqueous phase liquid (LNAPL) removal from two wells at times from 2010 through 2016
- Purchase of a residential parcel and modification of the water supply well by sealing the lower bore and installing a new monitoring well in 2012
- Removal of contaminated soil to bedrock in an area north of the original landfill in 2012, and, following County purchase of the former Akerblade parcel, additional removal in 2017 and 2018
- Installation of new monitoring wells near the north landfill property line in 2016 in an area that had not been previously monitored
- Installation of new multi-phase extraction wells and observation wells, groundwater and vapor treatment facilities, and an evaporation pond starting in 2016, followed by a pilot test of multi-phase extraction from a small area of the P1 zone in 2017

The remedial investigation identified two discontinuous and low-transmissivity water-bearing zones and seven aquifers, aquitards, and formations related to the site. These are listed below from shallowest to deepest:

- P1 zone
- P2 zone
- Roza aquifer
- Interflow aquifer
- Outwash aquifer
- Ringold aquifer
- Frenchman Springs aquifer
- Vantage aquitard
- Grand Ronde formation

The remedial investigation also identified releases from the drums as a major contaminant source, along with other sources, including leachate from the original landfill, diffusion of volatile organic compounds from landfill gas, groundwater contaminant migration from a 20-foot-deep depression in the basalt surface beneath the original landfill (the Hole), and historic releases around the old scale and maintenance shop. Contaminant concentrations are high in the P1 and P2 zones in the area where the drums were, and LNAPL has been observed in the P1.

Two groundwater contaminant plumes originate from the above sources, as follows:

- The northerly plume starts in the Roza aquifer, beneath highly contaminated parts of the P1 and P2 zones. Contaminants in the P1 and P2 zones attenuate significantly as they migrate vertically to the underlying Roza aquifer, then offsite to the north. There is also some migration to the deeper Interflow aquifer.
- The landfill plume is diffuse and underlies the original landfill, extending radially outward to the west, south, and east in the Interflow aquifer and eventually to the Outwash aquifer south of the original landfill.

Since the original landfill is now capped, and contaminated soil to the north has either been capped or removed to bedrock, LNAPL in the P1 and contaminated groundwater are now the focus of site cleanup.

The above understanding of site hydrogeology and contamination was further developed into a conceptual site model of potentially complete exposure pathways to human and ecological receptors. The conceptual site model describes how people can potentially be exposed to groundwater contaminants in the northerly and landfill plumes. Indicator hazardous substances and cleanup levels were therefore calculated based on human exposure to groundwater following methods described in the MTCA cleanup regulation. The conceptual site model also identifies exposure pathways to human and ecological receptors that are either complete but minor or incomplete.

Indicator hazardous substances were identified following methods described by Ecology for potential human exposure and using contaminant concentration data from a representative well set. Data were evaluated from wells completed in the P1 zone away from LNAPL areas, the P2 zone, and the Roza, Interflow, Frenchman Springs aquifers. The resulting list of 22 contaminants was reduced based on evaluating factors listed at WAC 173-340-703(2). The contaminants were ranked based on frequency of detection, mobility, toxicity, and persistence. This resulted in the identification of 11 contaminants that contribute a small percentage of the overall threat to human health and the environment. The remaining 11 contaminants were selected as indicator hazardous substances.

Groundwater cleanup levels were calculated for the indicator hazardous substances following MTCA Method B (WAC 173-340-720(4)(b) and 705). Since the indicator hazardous substance list includes eight carcinogens, cleanup levels were reduced primarily based on total excess cancer risk, as well as non-cancer toxic effects.

The MTCA cleanup regulation describes that cleanup levels, along with a point or points of compliance are essential to define the cleanup standards for a site. Ecology guidance suggests that landfills are a prime example of sites where a conditional point of compliance is appropriate, since it is not feasible to completely remove the refuse and underlying contaminants. For the Ephrata Landfill, the PLPs and Ecology have agreed on a groundwater point of compliance comprising the west, east, and north landfill parcel boundaries, and an east-west line immediately south of the original landfill. Since the refuse and remaining contaminated soils are now capped by engineered geomembrane liner systems, liner depth is proposed as the soil point of compliance.

Groundwater cleanup action technologies were vetted for technical feasibility, implementability, and relative cost, resulting in a focus on groundwater pumping and treatment and soil vapor extraction to remove volatile organic compounds from the P1 zone as the main cleanup technologies for Ephrata Landfill. These technologies were incorporated into several cleanup action components.

The cleanup action components comprise several groundwater pumping and treatment and soil vapor extraction options, landfill gas system activation, compliance monitoring, and institutional controls, resulting in 10 main components, as summarized below:

1. Reactivate the existing multi-phase extraction system to dewater a small area of the P1 zone and resume soil vapor extraction.
2. Expand dewatering and soil vapor extraction in the highly contaminated area of the P1 zone, which is likely impacted by LNAPL.
3. Pump groundwater to dewater the Hole.
4. Hydraulically capture the northerly plume by pumping groundwater from a high-transmissivity zone of the Roza aquifer near the northwest corner of the landfill parcel and treat the extracted groundwater for disposal by infiltration into the Outwash aquifer.
5. Pump somewhat contaminated groundwater from a targeted area of the Roza aquifer near the middle of the north landfill parcel boundary.
6. Evaporate groundwater from the existing evaporation pond.
7. Add evaporative capacity with a second pond or mechanical additions, scaled depending on the groundwater pump rates for a particular alternative.
8. Activate the existing landfill gas system, which currently vents through a flare due to natural, slightly positive gas pressure within the original landfill, by installing a blower at the existing flare facility to extract landfill gas under vacuum.
9. Implement a compliance monitoring program as required in the MTCA cleanup regulation, scaled to the particular alternative.
10. Implement institutional controls as required in the MTCA cleanup regulation, scaled to the particular alternative.

The seven cleanup action alternatives evaluated in this FS, which are based on different combinations of the above components, are summarized below:

> **Alternative 1** – Reactivate the existing multi-phase extraction system, activate the landfill gas system, and dewater a small area of the P1 to resume soil vapor extraction.
>
> **Alternative 2** – Expand the multi-phase extraction system, activate the landfill gas system, and expand dewatering and soil vapor extraction in the highly contaminated area of the P1 zone, which is likely impacted by LNAPL.
>
> **Alternative 3** – Add pumping groundwater to dewater the Hole to Alternative 2.
>
> **Alternative 4** – Add targeted Roza aquifer pumping and increased evaporation to Alternative 2.
>
> **Alternative 5** – Add northerly plume hydraulic capture in the Roza aquifer, groundwater treatment, infiltration, and increased evaporation to Alternative 2.
>
> **Alternative 6** – Add pumping groundwater to dewater the Hole, targeted Roza aquifer pumping, and increased evaporation to Alternative 2.
>
> **Alternative 7** – Add pumping groundwater to dewater the Hole, northerly plume hydraulic capture in the Roza aquifer, groundwater treatment, infiltration, and increased evaporation to Alternative 2.

The seven alternatives were evaluated and compared based on estimated quantity of volatile organic compounds that would be removed from the P1 zone and plumes, time needed to meet cleanup standards by achieving cleanup levels at and outside of the point of compliance, and cost. Table ES1, which is also Table 8 in the FS, summarizes the results of this evaluation.

Although any of the seven alternatives would meet cleanup action objectives, Alternative 1 is not recommended because it would remove the least amount of contamination from a small area of the P1 zone and take the longest to meet cleanup standards. Conversely, Alternatives 5 and 7, which both involve northerly plume hydraulic capture, would entail treating and discharging high groundwater volumes at significant cost, with little additional contaminant removal compared to Alternatives 2, 3, 4, and 6. Alternatives 5 and 7 are therefore considered disproportionately costly, and are also not recommended. Since it requires the fewest new facilities and is relatively straightforward to implement, Alternative 2 is presented as the baseline for comparisons between alternatives.

Candidates for the preferred cleanup action alternative at Ephrata Landfill include Alternatives 2, 3, 4, and 6. Any of these would meet cleanup objectives within a reasonable time frame. As Table ES1 shows, the estimate total costs in unadjusted 2018 dollars range from \$16.6 to \$18.2 million. Alternative 3, which would disrupt any contaminant migration through the Hole, would not require added evaporation capacity and has merit for that reason. Alternatives 4 and 6 would remove more contamination and meet cleanup standards in less time than Alternative 2, yet the estimated costs per kilogram of volatile organic compounds removed in the first year and first decade is the lowest for Alternative 4. Alternative 6, while slightly more costly than Alternative 4, includes the disruption of any contaminant migration through the Hole.

Alternative 6 is recommended as the preferred cleanup action alternative for Ephrata Landfill for the following reasons:

1. It would provide comparably high VOC removal at a first-year cost per kg that is the third-lowest and a 10-year cost that is the second-lowest among the alternatives.
2. It should achieve compliance with cleanup standards at the point of compliance within 20 years.
3. It should achieve compliance with cleanup standards in all areas outside the point of compliance within 25 years.
4. It should fully disrupt contaminant transport from the P1 zone.
5. It should fully disrupt contaminant transport through the Hole, and particularly the transport of vinyl chloride.
6. It would directly remove contaminants from the northerly plume inside and outside the north point of compliance and partly disrupt the Roza transport pathway.

The 2012 draft FS evaluated alternatives based on present worth, so for comparison, Alternative 6 was similarly evaluated. The estimated present worth of Alternative 6 is $12.6 million.

Table ES1. Cleanup Action Alternative and Component Performance and Cost Summary

	Cost Summary[1]						
Component	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**
Contaminant Removal Components							
Existing P1 Zone MPE System Reactivation	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000
P1 Zone MPE System Modifications and Well Field Expansion		$2,498,000	$2,498,000	$2,498,000	$2,498,000	$2,498,000	$2,498,000
Groundwater Extraction from the Hole			$775,000			$775,000	$775,000
LFG System Activation	$233,000	$233,000	$233,000	$233,000	$233,000	$233,000	$233,000
Northerly Plume Hydraulic Capture (Treatment and Infiltration)					$10,650,000		$10,650,000
Targeted Pumping from the Northerly Plume				$578,000		$578,000	
Evaporation Disposal Components							
Evaporation, Existing Pond	$384,000	$384,000	$384,000	$384,000	$558,000	$384,000	$558,000
Evaporation, Additional Capacity				$1,020,000	$1,020,000	$1,595,000	$1,020,000
Other Components							
Compliance Monitoring	$16,870,000	$10,620,000	$11,070,000	$8,590,000	$7,460,000	$8,920,000	$7,360,000
Institutional Controls	$11,640	$7,800	$7,800	$143,360	$215,220	$143,360	$215,220
Total Estimated Cost	**$20,619,640**	**$16,863,800**	**$18,088,800**	**$16,567,360**	**$25,755,220**	**$18,247,360**	**$26,430,220**

	Performance and Cost Comparison						
Basis of Comparison	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**
1-Year Removal of VOCs (kg)[2]	85	240	240	253	253	253	253
10-Year Removal of VOCs (kg)[2]	85	240	240	299	301	299	301
1-Year Cost per Unit of VOCs Removed ($/kg)	$242,507	$70,121	$75,215	$65,356	$101,600	$71,983	$104,263
10-Year Cost per Unit of VOCs Removed ($/kg)	$242,507	$70,121	$75,215	$55,317	$85,425	$60,927	$87,664
Estimated Years Until Compliance with Cleanup Standards	34 to 66	34	34	25	20	25	20
Estimated Years Until Completion of Active Measures	10	34	34	20	20	20	20

Notes:

[1] Costs are in 2018 dollars based on a compliance year time interval and as detailed in Appendix H.

[2] VOC removal from Site media only.

Definitions:

kg - kilogram.
LFG – landfill gas.
MPE – multi-phase extraction.

1. INTRODUCTION

This feasibility study (FS) was prepared for the Ephrata Landfill in Grant County, Washington (Figure 1), under the terms of Agreed Order DE 3810, dated January 30, 2007, among Grant County (the County), the City of Ephrata (the City), and the Washington State Department of Ecology (Ecology). The Agreed Order, as amended, provides the administrative framework for conducting and documenting the Remedial Investigation (RI), conducting interim remedial actions (IRAs), and developing the FS. This FS was developed in coordination with the RI led and performed primarily by Pacific Groundwater Group (PGG).

The original RI report was submitted in 2010 (PGG 2010), and continuing RI activities are summarized in two addenda to the RI (PGG 2012, 2017). A draft FS was submitted to Ecology in 2012 (Parametrix 2012a). Since 2012, a contaminated soil removal IRA was completed under the first amendment to the Agreed Order, and a multi-phase extraction (MPE) pilot test was performed under the second amendment to the Agreed Order. These IRAs have resulted in substantive changes to the site, including contaminated soil removal and capping, installation of MPE pilot test facilities and equipment, and contaminant removal during the 4.5-month MPE pilot test. In addition, the MPE pilot test and continuing RI work provided new site knowledge.

This updated draft FS was developed to reflect site improvements, new site knowledge, and contaminant removal and containment during completed IRAs. The following sections provide general site background, a summary of the completed IRAs, the purpose and regulatory framework of this FS, and an overview of the FS document.

1.1 SITE BACKGROUND

The Ephrata Landfill is located approximately 3 miles south of the city of Ephrata on the east side of Highway 28 in the western portion of Section 33, Township 21 North, Range 26 East, Willamette Meridian (Figure 1). An old, unlined landfill (original landfill) is situated on the north part of the landfill property and a new, lined landfill (new landfill) occupies the south part of the property (Figure 1). The City began operating the original landfill in approximately 1942 and owned and operated it until 1974. The City owned the original landfill and leased additional property from the U.S. Bureau of Reclamation. In 1974, the City and the County entered into the first of a series of agreements under which the County leased the original landfill and operated the facility. The Bureau of Reclamation transferred its property to the County in 1990, and the City deeded the original landfill property to the County in 1994. Both properties are now the Ephrata Landfill property.

Filling began in the northwest portion of the original landfill and expanded south and east until the new landfill was opened in 2004. Burning was allowed in the early history of the original landfill, but practices were not documented. Unintentional fires have also occurred in the original landfill. The original landfill was permitted by Grant County Health District, first under Chapter 173-301 Washington Administrative Code (WAC), then Chapter 173-304 WAC, and finally Chapter 173-351 WAC. The new landfill is permitted under Chapter 173-351 WAC. Current solid waste-related facilities at the landfill are shown in Figure 1 and consist of the original landfill, the new landfill, a leachate evaporation pond, a scale and maintenance shop, a water supply well, two lysimeters, and numerous landfill gas and groundwater monitoring wells. The original landfill was capped in 2008 as an IRA under the Agreed Order. The new landfill is the primary solid waste disposal facility for Grant County.

In 1975. approximately 2,350 drums containing industrial waste were brought to the Ephrata Landfill and stacked near the original landfill, which was still being filled. The drums were covered as the original landfill was filled, and they were ultimately buried. Releases from the buried drums have contaminated part of a shallow, groundwater-bearing basalt zone called the

P1 and, to a lesser degree, deeper underlying strata (Section 2). The drums and surrounding contaminated soil and refuse were removed in an IRA under the Agreed Order in 2008, as further described in Section 1.2.

Groundwater monitoring and investigations at the Ephrata Landfill started in 1989 and has since expanded to include 70 monitoring wells used for both solid waste compliance monitoring and remedial investigative work.

In April 2012, the County acquired the Whitson parcel, which abuts the northeast corner of the landfill property (Figure 1). With this acquisition, the County had the Whitson water supply well modified to seal the lower portion of the boring and install a new 2-inch monitoring well in accordance with Chapter 173-160 WAC. The new well was completed in the Interflow aquifer. The Whitson well was an open boring from 19 to 294 feet below ground surface between 1997 and 2012 and is believed to have enhanced vertical migration of shallow groundwater contaminants to deeper aquifers. Sealing the lower portion of the boring has now reduced the potential for vertical migration.

In the fall of 2012, the County moved into a new scale and maintenance shop built just east of the landfill property, adjacent to the area between the original and new landfills. The old scale and maintenance shop, which were located on the northwest corner of the landfill property, were removed.

Also, in the fall of 2012, the County extended Neva Lake Road across the north end of the landfill property. The Neva Lake Road corridor intersected an area of contaminated soil and refuse (north end soil; NES) which PGG had identified during the RI. NES was removed to bedrock from the Neva Lake Road corridor and north to the landfill property line or to bedrock outcrops on the landfill parcel in a 2012 IRA under the first Agreed Order amendment (Section 1.2). In 2012, the County did not have access to NES north of the landfill property line.

The County acquired the parcel directly north of the landfill property, previously owned by the Akerblade family (Figure 1), in 2017. NES previously left in place there and around three monitoring wells was removed to bedrock in 2017 and 2018 in a minor addition to the 2012 IRA (Parametrix 2017, 2018). All NES in the Neva Lake Road corridor and to the north has now been removed to bedrock.

As described in the RI (PGG 2010) and Section 2, a groundwater contaminant plume (northerly plume) extends north of the landfill property line beneath the former Akerblade parcel. Another plume (landfill plume) originates beneath the original landfill and extends radially in the Interflow aquifer to the west, south, and east (Figure 2).

1.2 INTERIM REMEDIAL ACTIONS

Nine IRAs were authorized and completed at the Ephrata Landfill from 2006 through 2018.

The first seven[1] IRAs, which were authorized under the first IRA Plan (Parametrix 2006), included the following:

- Potholing to confirm the approximate perimeter of the buried drums and obtain samples for analysis (2007)
- Removal and disposal of approximately 2,350 buried industrial waste drums and associated contaminated soil and liquids at the north end of the original landfill in 2008 (Parametrix 2016)

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[1] The LNAPL removal and Whitson well modification IRAs fell within the broad scope of work formally authorized in the first IRA Plan and were performed with Ecology’s informal concurrence.

- Capping of the original landfill, including the drum area, and the construction of landfill gas and surface water control systems in 2008
- Extraction of contaminated groundwater from the Hole[2] in 2008 and 2009
- Extraction of contaminated groundwater from the P1 zone between 2009 and 2011 near where the drums were removed
- Light non-aqueous phase liquid (LNAPL) removal from wells MW-34p1 and MW-36p1 (completed in the P1 zone) with absorbent socks (2010 through 2016)
- Modification of the Whitson well by sealing the lower bore and installing a new monitoring well (2012)

The IRA Plan for the Neva Lake Road extension (Parametrix 2012b) authorized removal of NES within the Neva Lake Road corridor and north to the landfill property line (Figure 1). In this IRA, NES was removed to bedrock, and samples from the excavation side slopes were analyzed (PGG 2013). NES south of the Neva Lake Road corridor (i.e., between the Neva Lake Road corridor and the original landfill) was left in place. The County did not have access to the parcel north of the landfill in 2012, so roughly 250 cubic yards of slightly contaminated NES were also left in place north of the landfill property line. In addition, roughly 70 cubic yards of slightly contaminated NES were left in place around monitoring wells MW-40p2 and MW-41a and roughly 12 cubic yards were left around monitoring well MW-3b to avoid disturbing the wells. The County acquired the Akerblade parcel in 2017, providing access to NES north of the landfill property line. In addition, MW-40p2 and MW-41a were deemed unnecessary for future monitoring and decommissioned. MW-3b, a Roza aquifer monitoring well, also had to be decommissioned to remove NES and will be replaced. All the remaining NES north of the property line and around the wells was thus removed to bedrock in the fall of 2017 as a minor addition to the original Neva Lake Road IRA. Confirmation samples from the 2017 removal contained arsenic above the soil background level estimated in the RI (3.2 milligrams per kilogram [mg/kg]). The soils with elevated arsenic were delineated and removed to bedrock in February 2018.

The last IRA at the Ephrata Landfill, an MPE pilot test of the P1 zone, was authorized under a supplement to the first IRA Plan (Parametrix 2015) and the second Agreed Order amendment. The 4.5-month MPE pilot test was completed in October 2017, and the results and observations were summarized in an IRA report (Parametrix and PGG 2018). The facilities listed below were installed to conduct and monitor the MPE pilot test:

- Three extraction wells and four monitoring wells in the P1 zone south of the drum area
- A liquid treatment train (LTT) and vapor treatment train (VTT) facility, field piping, and well pumps and transducers
- A prefabricated metal building for operations support and storage
- A lined pond for the evaporation of treated groundwater
- Monitoring equipment and programmable logic controller

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[2] The Hole is a 20-foot-deep depression in the basalt surface beneath the original landfill (Figure 1). Water level measurements indicate the lower 5 to 7 feet of soil/refuse within this depression are saturated with groundwater. The area of saturation in the Hole is about 1.5 acres, and the volume of saturated refuse is about 8,000 cubic yards.

MPE pilot test facilities are suitable for continued use, including potential expansion and modification, and the pilot test results show that a vadose zone can be established and vapor-phase contaminants extracted from the highly contaminated part of the P1 zone. The MPE pilot test IRA thus supports refinement of the preferred cleanup action alternative in the first draft FS with emphasis on MPE from the highly contaminated part of the P1 zone.

In addition to the pilot test, two new monitoring well nests were installed near the north landfill property boundary (Figure 1), as follows:

- MW-57b, MW-58c, MW-59p0, and MW-60p2 in the east group
- MW-61p1, MW-62c, and MW-63b in the west group

The new wells provide data along a stretch of the property boundary that was previously unmonitored.

NES between the original landfill and the Neva Lake Road corridor were capped by the evaporation pond liner (Figure 1), and over 2,000 cubic yards of NES comprising mainly refuse were removed to establish the evaporation pond subgrade.

The combined result of NES removal for the Neva Lake Road extension, later removal of the remaining NES around wells and north of the property line, and removal and capping of NES for the MPE pilot test fully addressed the physical remediation of NES at the Ephrata Landfill. This in turn simplifies the conceptual site model (CSM) used in the 2012 draft FS, eliminates the need to quantify soil cleanup levels for the protection of groundwater (Section 4), and precludes the need to evaluate soil-oriented cleanup technologies and cleanup action components (Section 6). The remaining cleanup action components (Section 6) have thus been simplified compared to the 2012 draft FS.

1.3 PURPOSE AND REGULATORY FRAMEWORK

This FS was developed to evaluate cleanup action alternatives for the Ephrata Landfill and recommend a preferred alternative. The completion of IRAs and the RI support the focus of this FS on the highly contaminated part of the P1 zone, other sources, and off-site contaminants. Other cleanup action components addressing treatment of extracted groundwater and vapor, natural attenuation, monitoring, and institutional controls are also evaluated.

This FS is consistent with the Agreed Order, as amended. It complies with the Model Toxics Control Act (MTCA), Chapter 70.105D Revised Code of Washington, and its implementing regulations, Chapter 173-340 WAC, including WAC 173-340-350, procedures for conducting an FS, and the Feasibility Study Checklist (Ecology 2016). The purpose of the FS is to develop and evaluate cleanup action alternatives to enable a cleanup action to be selected for the Site. Each alternative comprises one or more cleanup action components. Specific requirements under the MTCA cleanup regulations for identifying, screening, and evaluating cleanup actions are noted where appropriate throughout this FS.

1.4 OVERVIEW OF THE FEASIBILITY STUDY

This FS is presented in eight sections.

- **Section 1, Introduction**, includes the purpose and regulatory framework for completing this FS, as well as landfill and interim action background summary information.
- **Section 2, Hydrogeologic Understanding**, summarizes key information from the RI activities, including the nature and extent of contamination and identification of contaminants, and additional hydrogeologic calculations supporting the FS.
- **Section 3, Applicable Local, State, and Federal Laws**, summarizes the approach for complying with substantive requirements of applicable local, state, and federal laws, including legally applicable requirements and relevant and appropriate requirements.
- **Section 4, Identification of Indicator Hazardous Substances and Development of Cleanup Levels**, describes the CSM, identification of indicator hazardous substances (IHSs), and development of proposed cleanup levels (CULs).
- **Section 5, Proposed Cleanup Standards**, discusses the selection of CULs and points of compliance (POCs) for soil and groundwater.
- **Section 6, Cleanup Action Technologies and Components**, discusses the screening of cleanup technologies and development of cleanup action components.
- **Section 7, Cleanup Action Alternatives**, develops, evaluates, and compares seven cleanup action alternatives based on threshold and other requirements, and recommends a preferred cleanup action alternative.
- **Section 8, References**. Provides complete citations for documents cited in this FS.

2. HYDROGEOLOGIC UNDERSTANDING

Results of the RI (PGG 2010), as amended (PGG 2012, 2017), provide the foundation for the FS by characterizing local and regional hydrogeology and the extent of soil, gas, and groundwater contamination. The RI describes two water-bearing zones and seven aquifers, aquitards, and formations below the Ephrata Landfill and two groundwater contaminant plumes originating from contaminant sources listed below[3]. The hydrogeologic and contaminant model in the RI is crucial for understanding the CSM (Section 4.1) and the selection and effectiveness of possible cleanup action components and alternatives (Sections 6 and 7, respectively). This section provides a brief review of the hydrogeology and groundwater contaminant plumes.

The RI identified two water-bearing zones and seven aquifers, aquitards, and formations related to the Site. These are listed below from shallowest to deepest:

- P1 zone
- P2 zone
- Roza aquifer
- Interflow aquifer
- Outwash aquifer
- Ringold aquifer
- Frenchman Springs aquifer
- Vantage aquitard[4]
- Grand Ronde formation

The RI also identified the following contaminant sources, which vary in their relative contributions to the groundwater plumes:

- Releases from the removed drums
- Leachate from the original landfill (including saturated refuse in the Hole)
- Diffusion of volatile organic compounds (VOCs) from landfill gas from the original landfill
- Historic releases around the old scale and maintenance shop north of the original landfill (NES)

Releases from the drums caused high contaminant concentrations in the P1 and P2 zones below and near the area where drums and contaminated soil were removed in 2008. Concentrations sharply decrease radially outside highly contaminated parts of the P1 and P2 zones. LNAPL has been observed in an area of the P1 zone immediately south of the drum area, although no phase-separated LNAPL has been observed in the P1 wells since 2011. Emulsified LNAPL might have been entrained in groundwater removed from the P1 zone at times during the recent

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[3] The RI also mentions a separate tetrachloroethene plume in the Ringold aquifer north-northeast of the landfill near Dodson Road and a nitrate plume likely originating from chicken manure or other localized agricultural sources. These plumes are not considered to be releases associated with the Ephrata Landfill or removed drums and are not addressed in this FS.

[4] Aquitards are low-permeability units that inhibit vertical movement of groundwater and vapors.

MPE pilot test. Other contaminant sources, which are now capped, include the original landfill, the Hole, and capped NES remaining south of the Neva Lake Road corridor. VOC and semi-VOC concentrations in the highly contaminated part of the P1 zone are substantially higher than in the other locations, and leakage from the removed drums is considered a major contaminant release.

The two plumes, both originating in the contaminated area, are described as follows:

- The northerly plume originates primarily from the highly contaminated part of the P1 and P2 zones near the drum area. Contaminants in the P1 and P2 zones attenuate significantly as they migrate vertically to the underlying Roza aquifer. Vertical leakage from the Hole also contributes contaminants to the Roza aquifer. Vertical migration of contaminants to the Roza aquifer occurs on site near the overlying sources. Those contaminants that survive into the underlying Roza aquifer then migrate horizontally off site beyond the POC with some vertical migration to the deeper Interflow aquifer. Figure 2 shows the estimated extent of the northerly plume.
- The landfill plume is a diffuse plume that underlies the original landfill and extends radially outward (in the direction of groundwater flow) to the west, south, and east in the Interflow aquifer that then subcrops and discharges to the Outwash aquifer south of the original landfill. Vertical migration to the deeper Frenchman Springs aquifer also occurs along the west side of the original landfill[5]. The dominant source of the landfill plume is assumed to be the original landfill but may include contributions from the drum area. Figure 2 shows the estimated extent of the landfill plume.

2.1 ADDITIONAL HYDROGEOLOGIC CALCULATIONS

Additional hydrogeologic calculations beyond those presented in the RI reports include:

- PGG's hydrogeologic calculations (Appendix A) to support the evaluation of possible cleanup action components and alternatives in the 2012 draft FS.
- PGG's new (2018) calculations of extraction rates and VOC mass removal rates (Appendix B).
- Hydrogeologic calculations and observations of the P1 zone in the MPE IRA Report (Parametrix and PGG 2018).

PGG's 2012 hydrogeologic calculations (Appendix A) include extraction rates, well locations and spacing, natural attenuation estimates, and source contaminant calculations in support of REMChlor fate and transport modeling (Appendix C). Using new site data collected since 2012, PGG provided new calculations that supersede some of the older 2012 calculations where applicable (Appendix B). Hydrogeologic calculations and observations of the P1 zone in the MPE IRA Report, including design recommendations for expansion of the MPE well field, also supersede any conflicting older calculations. These are further discussed in context in Sections 6 and 7.

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[5] Vertical migration to the Frenchman Springs aquifer along the west side of the landfill may have been enhanced through the open borehole of the landfill's old water supply well, which was located about 600 feet north of MW-28d near MW-9b (Figure 1). The old water supply well was decommissioned in 1993.

2.2 ADDITIONAL CONTAMINANT FATE AND TRANSPORT CALCULATIONS

The hydrogeologic calculations for the 2012 draft FS (Appendix A) also support contaminant fate and transport simulations (Appendix C), which PGG completed to support the evaluation of possible cleanup action components and alternatives. The fate and transport calculations use REMChlor modeling (Falta 2007) to simulate concentration reduction over time of three[6] contaminants in the Roza aquifer pathway for the northerly plume. Restoration time frames in this FS are based in part on results of these fate and transport simulations. The following contaminants were modeled with REMChlor:

- 1,2-dichloropropane
- Vinyl chloride
- Benzene

The above contaminants were selected based, to varying degrees, on frequency of detection, mobility, toxicity, and persistence. These contaminants are representative of substances that are anticipated to be particularly difficult to remove. Of these, vinyl chloride is expected to be the most difficult to remove.

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[6] Methylene chloride was also modeled in 2012; however, for reasons described in Section 4.2, it is no longer recommended as an IHS.

3. APPLICABLE LOCAL, STATE, AND FEDERAL LAWS

Cleanup actions under MTCA must comply with applicable local, state, and federal laws, which include legally applicable requirements and relevant and appropriate requirements (similar to the applicable or relevant and appropriate requirements [ARAR][7] approach of the federal Comprehensive Environmental Response, Compensation, and Liability Act of 1980) (WAC 173-340-710). ***Legally applicable requirements*** are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, cleanup action, location, or other circumstance at a site (WAC 173-340-710(3)). ***Relevant and appropriate requirements*** are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or county facility siting and construction laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, cleanup action, location, or other circumstance at a site, address problems or situations sufficiently similar to those encountered at the site such that their use is well-suited to the particular site (WAC 173-340-710(4)).

Potential ARARs for the Site include:

- Chemical-specific ARARs are typically health- or risk-based values that, when applied to site-specific conditions, represent cleanup standards.
- Location-specific ARARs relate to the geographical position and physical condition of the site and may affect the type of cleanup action selected for the site.
- Action-specific ARARs are usually technology- or activity-based requirements or limitations on actions or conditions taken with respect to specific hazardous substances.

Action-specific requirements do not determine the selected cleanup action alternative, but they do specify how or to what level a selected alternative must perform. Table 1 lists the ARARs identified for each medium of concern at the Site.

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[7] Although ***ARAR*** is a specific term defined by and used in federal Comprehensive Environmental Response, Compensation, and Liability Act cleanups, this acronym is similarly used here in reference to legally applicable and relevant and appropriate requirements, as specified in WAC 173-340-710.

4. IDENTIFICATION OF INDICATOR HAZARDOUS SUBSTANCES AND DEVELOPMENT OF CLEANUP LEVELS

This section describes the selection of IHSs and development of CULs (i.e., proposed) for the Ephrata Landfill cleanup action. This project meets the criteria at WAC 173-340-703 for evaluating CULs, cleanup action components, and alternatives based on those substances that contribute a large percentage of the overall threat to human health and the environment (i.e., IHSs). The IHS approach is appropriate for this site because many hazardous substances (1) are present at concentrations below levels that will adversely affect human health and the environment, (2) are detected infrequently, and (3) exhibit limited persistence, mobility, and degradation by-product toxicity. CULs were developed for the IHSs identified herein based on the reasonable maximum exposure expected to occur under both current and future site use conditions for groundwater (WAC 173-340-720(1)(a)). CULs were set at concentrations that would allow the groundwater to be safely used as a drinking water source (WAC 173-340-720(1)(a)). Appendix D summarizes the data used for IHS identification and CUL development and provides additional details regarding the methods used to identify IHSs and develop CULs.

4.1 CONCEPTUAL SITE MODEL AND EXPOSURE PATHWAYS

The RI and addenda (PGG 2010, 2012, 2017) addressed area geology, hydrology, water-bearing zones and aquifer relationships, and contaminant sources and transport pathways based on groundwater movement. Contaminant transport pathways are refined and human and ecological receptors are introduced in the CSM.

The resulting CSM thus represents potential exposure pathways and potential health threats to people and wildlife. The CSM is based on contaminant sources identified in the RI and summarized above (Section 2):

- Releases from the removed drums
- Releases from capped original landfill refuse, removed and capped NES, and diffusion of VOCs from landfill gas and leachate

Figure 3 depicts the CSM for the above releases. The CSM identifies the contaminant sources, release mechanisms, and transport pathways to the media to which human and ecological receptors could potentially be exposed.

Groundwater contaminants can move into water supply wells and surface water features located within the groundwater transport pathway and create direct exposure routes for human and ecological receptors. Groundwater contaminants can also volatilize. While volatilization reduces the contaminant concentrations in groundwater, contaminant vapors migrating from shallow groundwater can mix with indoor and outdoor air and thereby potentially expose receptors to vapor contaminants through inhalation. Similarly, once a contaminant is released to soil gas, contaminant vapors can migrate upward into indoor or outdoor air or they can dissolve into groundwater and become a source of groundwater contamination.

The CSM indicates whether an exposure pathway is complete or incomplete[8], and major or minor. Major pathways in the CSM lead to a potential threat to human health or the environment. They are evaluated quantitatively relative to regulatory limits and do not

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[8] A complete pathway consists of a series of direct links between source, release mechanism(s), transport mechanism, exposure media, and human and ecological receptors. For incomplete pathways, at least one of the links is missing.

necessarily lead to unacceptable risks. Complete but minor exposure pathways lead to negligible threat and are addressed qualitatively in this section.

Interim actions have modified or eliminated ecological exposure pathways. Capping the original landfill and remaining NES between the original landfill and the Neva Lake Road corridor eliminated the potential exposure of terrestrial wildlife to contaminants now under the cap. NES removal eliminated potential terrestrial wildlife exposure to contaminants in the soil within the Neva Lake Road corridor and north. However, ecological receptors could still be exposed to contaminated surface water. Contaminants could reach surface water; however, Neva Lake, the surface water body closest to the landfill, is considered a complete but minor exposure pathway for terrestrial and aquatic life for the same reasons discussed below for human health and is not evaluated quantitatively.

The remainder of this section addresses human health exposure pathways. People can potentially be exposed to groundwater contaminants in the northerly and landfill plumes via ingestion and inhalation exposure pathways. Human health exposure pathways for landfill workers, residents, and recreational users are shown in Figure 3 and are described below for each exposure medium: groundwater, indoor air, outdoor air, and surface water.

4.1.1 Groundwater

Contaminants can reach residential drinking water wells completed in either the northerly or landfill plume through direct or partial dissolution followed by transport. The groundwater exposure pathway is considered complete and major for residents and is evaluated quantitatively for potential human health risks (Section 4.2).

The landfill’s water supply well (33M1) (Figure 1) was sealed and completed in the Grand Ronde aquifer (PGG 2010). The supply well was tested in 1993, 2004, and 2011, and VOCs were not detected. The 2011 test was conducted in accordance with the Washington State Department of Health permitting requirements for potable use of the well for the new scale and maintenance shop. The Department of Health permitting process ensures that water supplied from a well meets drinking water standards. The supply well was not previously used for drinking. The groundwater exposure pathway for any persons at the landfill site, including landfill workers, is incomplete.

4.1.2 Indoor and Outdoor Air

The air exposure pathway includes dissolution and vapor partitioning of contaminants to groundwater, groundwater transport, followed by volatilization of contaminants into soil gas and indoor spaces of structures or outdoors. People could hypothetically be exposed by breathing vapors in air. However, where contaminant plumes in basalt aquifers underlie residences, the aquifers involved have 20 to 100 feet of hard basalt or clay aquitards that separate the basalt aquifers from the overlying Outwash sediments. The overlying Outwash sediments in this area are about 20 to 85 feet thick, such that they are separated from the land surface by about 50 to 150 feet (including aquitards and Outwash sediments). Additionally, the few VOCs detected in the domestic wells are all below MTCA Method B vapor intrusion standard formula values. Tetrachloroethene has been detected in Outwash aquifer wells near the new scale and maintenance shop, and farther east along Neva Lake Road, but concentrations are well below the MTCA Method B and Method C vapor intrusion standard formula values. MPE facilities have engineered controls (i.e., vapor barriers and ventilation or open foundations) which, in addition to basalt aquitards above the contaminant zones, interrupt the indoor and outdoor air pathways. Therefore, the indoor and outdoor air exposure pathways are considered minor and not evaluated further.

4.1.3 Surface Water

Contaminants could potentially be present in surface water through dissolution and vapor partitioning to groundwater, followed by groundwater transport to local surface water bodies. People could therefore potentially be exposed to contaminants through recreational use of these local surface water bodies, such as Neva Lake.

Neva Lake is the closest surface water feature downgradient of the landfill property (approximately 0.3 mile south) (PGG 2010). Arsenic concentrations were above background in the first sample collected in August 2009 but below background in the second sample collected in February 2010 (Appendix E). Additionally, VOCs were not detected in either of two RI samples collected in August 2009 and February 2010 from Neva Lake (PGG 2010). The exposure pathway to surface water (Neva Lake) is complete but minor. No other potentially contaminated surface water body was identified. This pathway is therefore not evaluated quantitatively.

4.2 IDENTIFICATION OF INDICATOR HAZARDOUS SUBSTANCES

This section describes the identification of IHSs based on the groundwater exposure pathway identified in Section 4.1 and the groundwater monitoring data described below. The Site meets the criteria for evaluating CULs and cleanup action components and alternatives based on hazardous substances that contribute a large percentage of the overall threat to human health and the environment (i.e., IHSs). Site management based on the IHSs will also be protective for other hazardous substances. The IHS approach is consistent with WAC 173-340-703 because many hazardous substances (1) are present at concentrations below levels that will adversely affect human health and the environment, (2) are detected infrequently, and (3) exhibit limited persistence, mobility, and degradation by-product toxicity.

To identify IHSs (and develop CULs) for the complete and major groundwater exposure pathway, data collected in 2008 through June 2017[9] from the following set of 23 wells were used to capture possible contaminants in groundwater:

- Roza aquifer (on-site or at the POC): MW-3b, MW-7b, MW-9b, MW-29b, MW-30b, MW-31b, and MW-42b
- Roza aquifer (off-site): MW-44b
- Interflow aquifer (at the POC): MW-2c, MW-5c, MW-6c, and MW-22c
- Frenchman Springs aquifer (at the POC): MW-28d
- Onsite P1 and P2: MW-37p1, MW-39p2, MW-40p2, MW-41a, and MW-43p2
- Drum area (on-site): MW-32a, MW-33p2, MW-35p2, and MW-38p2
- The Hole: EW-1

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[9] Not all 23 wells were sampled routinely between 2008 and 2017. Some of the wells were only sampled during the RI.

The above well set was originally agreed upon with Ecology in 2014 (Ecology 2014). In addition, data collected in April 2016 from 6 new wells installed along the northern POC were included in the data set used to identify IHSs:

- Roza aquifer (at the POC): MW-57b and MW-63b
- Interflow aquifer (at the POC): MW-58c and MW-62c
- P1 and P2 (at the POC): MW-60p2 and MW-61p1

One or more VOCs have been detected in each of the 29 wells included in the dataset, and collectively the wells characterize contaminants in both the northerly and landfill plumes and parts of the upper P1 and P2 zones not directly impacted by LNAPL. The following method was used to identify initial groundwater IHSs from the dataset described above:

- Substances with a frequency of detection (FOD) less than 5 percent were eliminated from consideration as IHSs[10].
- For each substance, a screening level was calculated as the minimum of standard formula values available from Ecology's Cleanup Level and Risk Calculations data tables (August 2015 Update). If no standard formula values were available for a contaminant, it was eliminated from consideration as an initial IHS.
- A substance was identified as an initial IHS if either (1) two or more concentrations exceeded the screening level or (2) a single concentration was twice the screening level or higher.

Table 2 summarizes the identification of initial IHSs for groundwater. Method B standard formula values for groundwater[11] were used to calculate the minimum standard formula values for screening. Based on the method described above, 22 contaminants were identified as initial IHSs.

The 22 initial IHSs were further evaluated using a ranking approach based on FOD/mobility, toxicity, and persistence to identify initial IHSs that contribute a large portion of the overall threat to human health and the environment at the site. Details of this evaluation are provided in Appendix D, and a brief summary is provided here.

Ranks of 0 to 4 were assigned based on 20-percent quantiles for the variables of interest (FOD/mobility, hazard quotient, and percent of screening level exceedances after 2012[12]). Higher ranks were assigned to substances that were detected more frequently (and in more wells, thus reflecting more mobility), had higher ratios of screening level exceedances (more toxicity), and exhibited continued screening level exceedances in the past 5 years (more persistence). For each initial IHS, the three ranks were then summed to provide an overall ranking (IHS ranking) of 0 to 12, with 12 indicating a substance with the highest FOD/mobility,

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[10] However, cases where a substance was detected at low detection limits but not detected at higher detection limits, as well as any substance with a limited data set indicating concentrations that could contribute significantly to overall site risk and hazard, were taken into consideration. No additional potential IHSs were identified based on high detection limits or limited data sets.

[11] The MTCA Method B groundwater standard formula values in Ecology's Cleanup Level and Risk Calculations data tables are based on the ingestion and inhalation pathways.

[12] Although 10 wells have not been sampled since 2012, the remaining 19 wells include several on-site wells, the P2 wells in the drum area, and POC wells. The 19 wells sampled since 2012 are MW-61p1, MW-33p2, MW-35p2, MW-38p2, MW-60p2, MW-3b, MW-7b, MW-9b, MW-42b, MW-44b, MW-57b, MW-63b, MW-2c, MW 5c, MW-6c, MW-22c, MW-58c, MW-62c, and MW-28d.

toxicity, and persistence. Substances with IHS rankings of 6 or higher were retained as IHSs for developing CULs, resulting in 11 IHSs. Table 3 provides results of this evaluation.

4.3 DEVELOPMENT OF GROUNDWATER CLEANUP LEVELS

Tables 4 and 5 show CULs (i.e., proposed) for IHSs in groundwater. CULs were developed as follows:

- For each IHS, an initial CUL was determined from groundwater maximum contaminant levels (40 Code of Federal Regulations 141.61) and MTCA Method B standard formula values per WAC 173-340-720(4)(b) and 705 (Table 4).
    - For each IHS with a state or federal maximum contaminant level, this standard was used as the initial CUL. If necessary, this value was downward-adjusted so that the individual excess cancer risk did not exceed $1x10^{-5}$ and the hazard quotient did not exceed 1 based on Method B standard formula values, per WAC 173-340-705(5).
    - For each IHS without a maximum contaminant level, the lowest Method B standard formula value was used as the initial CUL.
- Downward adjustments were then made to individual initial CULs, if needed, so that overall (sitewide) excess cancer risk did not exceed $1x10^{-5}$, per WAC 173-340-705(4).
- Downward adjustments were also made to individual initial CULs, if needed, to account for sitewide toxic effects, per WAC 173-340-705(4). Noncarcinogenic toxic effects (hazard indexes) based on CULs reflect additive effects of IHSs with similar chronic effects on individual human organ systems, per WAC 173-340-708(5)(b).

The downward-adjusted CULs are proposed in Table 5. They were developed in this FS to approximate cleanup standards to provide a basis for evaluating the cleanup action alternatives presented in this FS. Details of this approach are provided in Appendix D.

Per WAC 173-340-720(7) the CUL for arsenic was set at its natural background concentration (Appendix E) and excluded from the total site risk and hazard calculations.

5. CLEANUP STANDARDS

Cleanup standards under the MTCA cleanup regulations consist of the following (WAC 173-340-700(3)):

- CULs for hazardous substances present at the Site
- The location where the CULs must be met (POC)
- Other regulatory requirements applicable to the Site (ARARs)

Setting cleanup standards also involves specifying restoration time frames (WAC 173-340-700(7)). Restoration time frames described in this FS are the time intervals estimated to meet CULs at and beyond the POC for the cleanup action alternatives (Section 7).

Cleanup standards for the Site are evaluated below based on criteria in WAC 173-340-700 through 173-340-760 and the proposed CULs in Table 5. Development of CULs is described in Section 4, and ARARs are discussed in Section 3. Although cleanup standards will be confirmed in the cleanup action plan, those described in this FS serve as a basis for evaluating the alternatives (Section 7). This section focuses on identification of groundwater and soil POCs for the Site.

5.1 GROUNDWATER POINT OF COMPLIANCE

As with other landfills managed under MTCA, it is not practicable to meet groundwater CULs throughout the Site within a reasonable restoration time frame. Thus, a conditional POC is considered to avoid excavating the landfill, which is technically infeasible and disproportionately costly, as discussed in Ecology (2007). The landfill property line to the east, north, and west and an east-west line between the original and new landfills is therefore proposed as the groundwater POC[13]. Ecology has agreed with this conditional POC (Ecology 2013).

The east and west margins of original landfill refuse extend nearly to the east and west landfill property lines (Figure 4). To the south, it should be feasible to meet groundwater CULs at an east-west line across the landfill property between the original landfill and new landfill (Figure 4). Such a southern POC would maintain separation between compliance monitoring wells for the original landfill and ongoing solid waste monitoring activities at the new landfill cell and isolate effects of the original landfill.

This POC is consistent with MTCA cleanup regulations, is protective of human health and the environment, and will support selection of a cleanup action that is not disproportionately costly (WAC 173-340-720(8)(c) and WAC 173-340-360(e)(i)).

5.2 SOIL POINT OF COMPLIANCE

For human exposure to soil via direct contact or other exposure pathways where contact with the soil is required to complete the pathway, WAC 173-340-740(6) defines the standard soil POC as all soil throughout the site from the ground surface to 15 feet below ground surface. This represents a reasonable estimate of the depth of soil that could be excavated and distributed at the soil surface as a result of site development activities. This also corresponds to the POC

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[13] While technically a conditional POC under MTCA, since there is only one groundwater POC, it is referred to as a POC in this FS.

for terrestrial ecological receptors. The standard soil POC is generally applicable throughout the Site; however, a conditional POC for soil is proposed for the Ephrata Landfill.

The original landfill and remaining NES, which are capped with geomembrane cover systems (Figure 1), require a conditional POC for soil based on the cover system designs, which vary in depth below ground surface. Geomembrane depth is proposed as the conditional POC for the original landfill and remaining NES.

The landfill geomembrane cover system and skirt areas around the evaporation pond are designed in part to prevent animals and plant roots from contacting refuse. Although the pond liner system is designed to contain water, it will also prevent animals and plant roots from contacting underlying soil. As with soil at other landfills managed under MTCA, it is not practicable to meet soil CULs throughout the site within a reasonable restoration time frame (WAC 173-340-720(8)(c))[14] due to the refuse contained within the original landfill. Cleanup action alternatives that would meet soil CULs in and beneath the original landfill, which would require excavating the original landfill, would not be technically feasible (WAC 173-340-350(8)(b)(ii)), would be disproportionately costly (WAC 173-340-350(8)(b)(i)), and might not meet the minimum requirements specified in WAC 173-340-360(2), such as protection of human health and the environment.

Bedrock is shallower than 15 feet below ground surface in the area where NES was removed (i.e., the Neva Lake Road corridor and north). In principle, a conditional POC of 15 feet below ground surface or top of bedrock where shallower than 15 feet below ground surface would be proposed. Since NES has already been removed to bedrock where it would apply, establishing such a conditional POC is not necessary.

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[14] See Ecology (2007) at 4, which describes landfills as prime examples of where conditional POCs are appropriate.

6. CLEANUP ACTION TECHNOLOGIES AND COMPONENTS

Development of cleanup action alternatives started with an overview of relevant groundwater cleanup technologies (Section 6.1). Existing facilities and equipment at Ephrata Landfill that can be used in future cleanup actions are summarized (Section 6.2). Retained technologies (i.e., those potentially viable for the Site) were then used to develop cleanup action components based on the IHSs and Site information (Section 6.3).

6.1 CLEANUP ACTION TECHNOLOGIES

Groundwater cleanup action technologies were evaluated to identify potentially applicable technologies (Parametrix 2011). The evaluation considered the nature of contaminants and types of exposures to be addressed. Cleanup action technologies not applicable to Site conditions and contaminants were excluded from further consideration. Table 6 summarizes the groundwater cleanup action technology screening.

Institutional controls were evaluated in addition to cleanup action technologies. Although institutional controls provide no reduction of toxicity, volume, or mobility of contaminants, they can limit or prohibit activities that may interfere with the integrity of cleanup actions or result in exposure to hazardous substances at the Site.

The following screening criteria were used to determine applicable cleanup action technologies for the Site (WAC 173-340-350(8)(b)):

- **Technical feasibility/effectiveness.** The ability of the technology to function effectively and achieve meaningful progress toward protecting human health and the environment based on site-specific characteristics, including the nature and location of contaminants, site hydrogeology, and time required to achieve cleanup standards.
- **Implementability.** Administrative issues related to the technology, including government regulatory approvals, construction schedule, constructability, access, monitoring, operation and maintenance, and community concerns.
- **Relative cost.** The relative cost of the technology, including initial capital and future annual operating, maintenance, and monitoring costs, compared to other technologies.

Retained cleanup action technologies for groundwater are identified in Table 6. Uses of these technologies as cleanup action components are provided in Section 6.3.

6.2 EXISTING FACILITIES AND EQUIPMENT

Facilities that can be used in future cleanup actions at the Ephrata Landfill were installed to perform the IRAs summarized in Section 1.2. These facilities, which are suitable for long-term operation, include the following:

- An LTT, comprising an oil-water separator, air sparge tank, knockout tank, and granular activated carbon (GAC) filter, housed in an intermodal container
- A VTT, comprising a condensation sump, knockout tank, vacuum assisted extraction pump, heat exchanger, GAC filters, and compressor, housed in an intermodal container
- VTT and LTT controls, housed in the VTT container, including data recording capabilities

- A pre-engineered metal building with storage and office space adjacent to the VTT and LTT containers
- A lined 0.75-acre evaporation pond designed for passive evaporation of up to 682,000 gallons per year (gpy) of treated groundwater
- Evaporation pond and skirt liner systems that also cap remaining NES between the Neva Lake Road corridor and original landfill
- P1 zone monitoring wells MW-36p1, MW-64p1, MW-66p1, MW-67p1, MW-69p1, and MW-70p1, which can be converted to extraction wells
- P1 zone extraction wells MW-34p1, MW-65p1, and MW-68p1, which can be converted to monitoring wells
- A piping system connecting the existing P1 extraction wells to the treatment facility (LTT and VTT) and the treatment facility to the evaporation pond
- Hole extraction well EW-1, which can be used together with three new extraction wells for dewatering the Hole
- A closure cover over the original landfill, including a passive LFG management system with conveyance piping routed to and vented at the landfill flare station

6.3 CLEANUP ACTION COMPONENTS

Table 7 summarizes the evaluation of cleanup action components, including calculated first-year and 10-year VOC removal (Appendices B and G). Contaminant removal reduces the potential for contaminant migration in the northerly and landfill plumes and is considered a permanent cleanup action under MTCA. Some components are for groundwater treatment or disposal, which support contaminant removal components. Individual component forward costs were evaluated in 2018 dollars.

The cleanup action components described below were developed from the retained cleanup action technologies and Site hydrogeologic and contaminant fate and transport data developed for this FS. Various combinations of components were used to develop the cleanup action alternatives described in Section 7.2.

The RI Report (PGG 2010, 2012, 2017) established that contaminant reduction by natural attenuation is significant along the groundwater transport pathway in both the northerly and landfill plumes and will continue to reduce groundwater contaminant concentrations over time in addition to and following any active cleanup measures.

Natural attenuation is a component of every cleanup action alternative, and calculated restoration time frames depend on it to varying degrees. The contaminant removal rate for natural attenuation (Appendix A) is based on estimated reductions of contaminant mass flux in the northerly plume between the drum area and groundwater POC (property boundary) without factoring in the effect of active remedial measures. The calculated VOC reduction is approximately 54 kilograms (kg) and 285 kg for the first year and first decade, respectively. Contaminant removal by natural attenuation will be reduced in the areas where active remedial measures are implemented because contaminants will be removed before natural attenuation processes can occur. Calculated contaminant removal varies by component and alternative, as further described below. Reduced natural attenuation due to the active contaminant removal was not calculated for the alternatives (Section 7.2); however, natural attenuation will further reduce contamination with any alternative.

Most of the components in Table 7 can be implemented together without overlap or interference between components. The exception is northerly plume capture, which would preclude the need for targeted pumping from the northerly plume.

6.3.1 P1 Zone Existing MPE System

Contaminant mass in the P1 zone could be reduced by reactivation and operation of the MPE system that was installed as part of the MPE pilot test (Figure 5). Because of the limited size of the MPE system, this component is not assumed to completely disrupt downgradient migration of contaminants. Dewatering of the P1 zone, followed by soil vapor extraction (SVE), was demonstrated in the pilot test (Parametrix and PGG 2018). In the pilot test, two wells were successfully used as MPE wells (MW-34p1 and MW-68p1). The MPE system can establish and maintain a vadose zone in the P1 for SVE. Since contaminant migration is mainly in groundwater, dewatering the P1 zone also disrupts contaminant transport.

Pilot test results show that P1 zone groundwater discharge diminished quickly as the P1 zone was dewatered over about 6 weeks. The observed groundwater extraction rate started at about 1.5 to 3.5 gallons per minute (gpm) depending on the well and dropped to less than 0.1 gpm per well during the test. Longer-term groundwater extraction calculations in this FS are based on 0.05 gpm per well within about 1 year. Based on observed groundwater extraction during the pilot test, the first-year groundwater extraction volume for this alternative is estimated at 90,000 gallons, followed by 52,000 gpy of groundwater extraction thereafter. Although groundwater VOC concentrations were not steady during the pilot test, variation tended to remain within an order of magnitude, aside from outliers discussed in the pilot test IRA report (Parametrix and PGG 2018). Dissolved VOC removal was limited by low groundwater extraction rates once the P1 zone was dewatered.

The pilot test observations suggest an adaptive approach to P1 zone dewatering, with possible recharge intervals to increase VOC dissolution to groundwater and to extract LNAPL from within the formation (i.e., smear). This might increase dissolved VOC removal through repetitive dewatering and recharge, although increased VOC removal quantities associated with this approach are not estimated in this FS. Since VOC transport out of the P1 zone is in the dissolved phase, any adaptive decisions around recharge would also need to consider the temporary reestablishment of the groundwater transport pathway from the P1 zone.

Pilot test results also show that vapor-phase VOC removal is initially about an order of magnitude higher than dissolved phase removal, but then declines. Extrapolation of the field data suggests that the vapor-phase total VOC concentration would likely drop off exponentially to near zero within the first year. This phenomenon is modeled for future calculations (Appendix G). The rapid decrease in vapor-phase VOC removal suggests an adaptive approach to vapor extraction. One approach would be to stop vapor extraction periodically, using intervals that would need to be determined through empirical observation, then restart vapor extraction and observe possible increased VOC removal following restart. This type of cycling would need to be coordinated with possible dewatering and recharge cycling. While this might increase vapor-phase VOC removal for short intervals after the initial vapor concentrations drop, the increased concentrations after restart, and long-term effects on mass extraction, are not estimated in this FS.

Contaminant removal estimates for this component are calculated based on pilot test results and other site observations and are included in Appendix G. Calculated VOC removal with this component is approximately 85 kg for both the first year and first decade (Table 7), due to the significant drop off in removal after the first year. This includes 4 kg of VOCs via groundwater, assuming a recharged P1 zone and similar removal to that of the pilot test, and

81 kg of VOCs via SVE based on modeling pilot test results. These estimates do not include possible short-term contaminant removal increases following groundwater or vapor rebound intervals.

Typical operation, maintenance, and monitoring activities and costs associated with this component would include:

- System maintenance, including jetting pipes fouled by sediment
- GAC filter material changes
- Equipment replacement over time
- Liquid and vapor sampling and analysis
- System monitoring (i.e., equipment operating points, liquid and vapor flow rates, vacuums, temperatures, gas mixtures)
- Part-time operations staff
- Electricity
- System removal and well decommissioning

6.3.2 P1 Zone MPE System Modifications and Well Field Expansion

Contaminant mass in the P1 zone could be reduced sooner and more completely by reactivation and operation of the MPE system with an expanded well field. This component is assumed to completely disrupt migration of contaminants from the P1 source area, unlike the existing P1 zone MPE system component. Limited modifications to the extraction and treatment systems would also be implemented to improve treatment and reduce maintenance. The following process would be used to expand the footprint of the MPE system to cover the area thought to be directly affected by release of LNAPL from the drums (Figure 5).

- Outline the expansion area based on contaminant distribution in P1 zone groundwater near the former drums.
- Continue to use wells MW-34p1 and MW-68p1 as MPE wells.
- Install additional wells at key locations based on concentrations and boundaries (e.g., along the edge of the former drum area).
- Expand the well network using a relatively small well spacing of 30 to 40 feet.
- Complete wells in either MPE or observation configuration as determined by ordinary well tests and short-term (i.e., days to weeks) pumping under applied vacuum.
- Design and install final connections to new wells after wells are fully tested and the final configurations are determined.
- Avoid the placement of wells within the landfill access road, which runs between the drum area and the existing MPE wells.
- Provide vent wells on expansion-area margins and within the backfill of the excavated drums; however, the effect of vent wells was not pilot-tested.
- Conduct an inorganics treatability study as part of the final system engineering to determine the LTT modifications needed to manage precipitates.

- Plan the installation of a third vapor phase GAC unit, with pipe and valve changes to allow rapid vapor rerouting when VOC breakthrough is detected.
- Evaluate the addition of a vapor mover, such as a regenerative blower, optimized for movement of larger vapor volume in the low-vacuum range (i.e., 3.5 inches-mercury [Hg]).
- Evaluate other controls, piping, and valve changes to facilitate long-term operations and monitoring.

Nine 4-inch diameter P1 zone wells currently exist in the area planned for MPE system expansion (Figure 5). New MPE wells would be 6-inch-diameter PVC constructed in 10-inch boreholes. Vent and monitoring wells could be smaller diameter; however, which wells will work as MPE wells cannot be determined in advance. Therefore, costs assume all new wells would be 6-inch diameter wells to allow flexibility in final system design. The new wells would be screened for the full thickness of the P1 zone, which averages about 4 feet, with a 2-foot sump below the P1 zone. Costs assume that the system comprises six MPE wells, two of which already exist. Since the P1 thickness is not uniform and the hydrogeologic characteristics are heterogenous, estimates include the costs for drilling six new MPE wells, assuming only four of those would be used as extraction wells. The cost also includes an additional four wells to serve as monitoring points or vent wells on the west and north margins of the target area, for a total of 10 new wells (Figure 6).

The drum excavation backfill would not be targeted for MPE well construction since the excavation removed contaminated soils to the bottom of the P1 zone, which was hard basalt. However, to promote its function as a boundary that could feed vapor to the P1 zone south and west of the excavation, one or two of the vent wells would be drilled within the drum excavation backfill.

Each new MPE well would be fitted with transducers and a submersible pneumatic pump. Well utilities would be routed to the existing header utilities installed during the MPE pilot test. Resulting liquid and vapor streams would be routed to the existing treatment facilities with LTT and VTT modifications as discussed below. The system is assumed to operate at a relatively low vacuum (3.5 inches-Hg) to allow direct use of MPE pilot test data. The existing MPE wells were most efficient at 3.5 inches-Hg (Parametrix and PGG 2018).

During the MPE pilot test, groundwater extraction began at about 3.5 gpm from three wells (including pumping from MW-65p1, which was active during this portion of the test), for an average yield of 1.2 gpm per well. That value is biased high because higher-transmissivity wells were selected for MPE, and an expanded system is assumed to initially average 1.0 gpm from each of six MPE wells. The rate of groundwater extraction would decline as dewatering occurs over the first weeks of operation to an assumed sustained rate of less than 0.1 gpm per well for the duration of the MPE system operation. The resulting groundwater extraction rates would be 270,000 gpy for the first year and 158,000 gpy thereafter[15].

The MPE pilot test extracted 4 kg of VOCs via groundwater (Parametrix and PGG 2018), and the rate of groundwater extraction at the end of the 4.5-month pilot test was very low. MPE from the P1 zone assumes that each well would yield 0.05 gpm (six-well total of 0.30 gpm) after an initial period of dewatering when flow rates are higher. Based on the 4-kg VOC

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[15] During the pilot test, two MPE wells produced 90,000 gallons of groundwater. A three-fold increase is assumed for six MPE wells, producing 270,000 gallons in the first year. For subsequent years, 0.05 gpm per well is assumed, totaling 158,000 gallons annually.

removal via groundwater from the two-well pilot test, the six-well expanded system is expected to remove 12 kg of VOCs, assuming a recharged P1 zone. The removal is expected to occur within the first year, until the P1 zone is dewatered, resulting in minimal additional removal beyond the first year.

During the MPE pilot test, vapor extraction from the two MPE wells (MW-34p1 and MW-68p1) usually ranged from 35 to 45 standard cubic feet per minute (scfm) at 3.5 inches-Hg, with one well about twice as productive as the other. The vapor yield was relatively steady. An expanded system of six MPE wells would be estimated to yield a steady 92 scfm at 3.5 inches-Hg (Appendix G).

During the MPE pilot test, total VOC concentrations in vapor decreased from about 3,000,000 micrograms per cubic meter (ug/m^3) to 100,000 ug/m^3 over the first 2 months of operation, then remained fairly stable (Parametrix and PGG 2018). Calculations indicate that an expanded MPE system should be able to extract 240 kg VOCs in the first year of operation (12 kg from groundwater plus 228 kg from vapor [Appendix G]).

Calculated total VOC removal from vapor and groundwater with this component would be approximately 240 kg for both the first year and first decade, due to the significant drop off in removal after the first year. Cost estimates in this FS are based on running the MPE system continuously for 10 years, assuming source concentrations would be reduced to levels that would not re-contaminate the plumes once the system is shut down. Operations may use an adaptive approach, including cyclical operation of the MPE system, to evaluate possible increased contaminant removal and energy and cost efficiency following groundwater and vapor rebound intervals, as described in Section 6.3.1.

The LTT would be modified to treat LNAPL and solids differently. Based on contaminant concentration spikes in liquids extracted from the P1 zone during the initial steps of the MPE pilot test, it is likely that emulsified LNAPL was being entrained in the liquid stream; however, phase-separated LNAPL was not observed in oil-water separator effluent or at the evaporation pond. Either emulsified LNAPL was not abundantly present or the contaminants were being effectively removed by the air sparge. If LNAPL were to become more predominant, alternate (or additional) LNAPL separation methods could include installation of dissolved air floatation treatment in line after the oil-water separator.

The MPE pilot test also identified significant precipitable inorganics in the liquid stream. Precipitant accumulation in the air sparge required a shutdown to clean the tank and diffusers. A bench-scale pilot test to determine an inorganics management strategy, with implemented results, could reduce long-term operations and maintenance costs. For this FS, LTT modifications are assumed to include a bench-scale pilot test to determine an inorganics management strategy and the installation of new equipment.

Although the peak P1 pump rate was estimated at 6 gpm in MPE pilot test planning, the existing LTT was specified to treat up to 10 gpm. P1 pump rates were generally lower than estimated, so the existing LTT capacity should be adequate for flows from an expanded well field.

The VTT would be modified in response to MPE pilot test results indicating that vapor-well radius of influence was not very sensitive to applied vacuum within the range tested in the pilot test, and that vapor-well specific capacities declined with increasing vacuum. The decline indicates that electrical cost per kilogram of contaminant removed would increase with increased vacuum. Based on these findings, a different blower, with a wider capacity range at intermediate vacuums compared to the existing vacuum pump, may be added to support an expanded MPE system.

Additionally, a third VTT GAC unit and attendant pipe and valve changes would be needed to allow switch-over and continuous treatment when VOC breakthrough occurs. Two GAC units would operate in series, with the third available for use when breakthrough occurs in either of the online units. Pipe and valve changes would allow any unit to operate as either the primary (i.e., first in series) or polishing (i.e., second in series) unit.

For this FS, both the addition of an intermediate-vacuum blower and GAC changes are assumed.

Typical operation, maintenance, and monitoring activities and costs associated with this component would include:

- System maintenance, including jetting pipes fouled by sediment
- GAC filter material changes
- Equipment replacement over time
- Liquid and vapor sampling and analysis
- System monitoring (i.e., equipment operating points, liquid and vapor flow rates, vacuums, temperatures, gas mixtures)
- Part-time operations staff
- Electricity
- MPE system removal and well decommissioning

6.3.3 Groundwater Extraction from the Hole

Continuous groundwater extraction from the Hole would remove contaminant mass and substantially reduce potential contaminant transport from the Hole to underlying aquifers. Dewatering would also reduce contact between groundwater and residual contamination remaining within the refuse in the Hole.

In addition to existing well EW-1, the installation of three new wells were assumed for dewatering the Hole.

The new Hole groundwater extraction wells would be screened similar to EW-1 (i.e., about 4 feet), and spaced at relatively equal distances from each other within the Hole. All four wells would be fitted with transducers and submersible pneumatic pumps. Conduit and surface piping (heat-traced and insulated) would be installed for compressed air supply and groundwater discharge to the LTT. Piping would be specific to each well until lines could be combined into a shared header to the LTT.

The initial discharge rate to dewater the Hole is estimated at 4 gpm, or 390,000 gallons over a 40- to 70-day interval (Appendix A). Initial dewatering of the Hole would be followed by either cyclic recharge and dewatering or a reduced discharge rate to maintain the lowered groundwater level (estimated ambient groundwater flow through the Hole is 46,000 gpy) (Appendix A). It should be noted that variations in hydrogeologic parameters and other uncertainties result in ranges of calculated results; however, to evaluate cleanup action components, best-estimate values based on professional judgment were used. Pumping is assumed to be conducted for a 10-year period.

Calculated VOC removal with this component is less than 1 kg in the first decade (Appendix B). Although the total VOC mass removal from the Hole is relatively low compared to other cleanup actions, vinyl chloride accounts for about 50 percent of the total VOCs in the Hole. Pumping from the Hole might contribute to vinyl chloride reduction in the downgradient plumes, although this has not been quantified.

Typical operation, maintenance, and monitoring activities and costs associated with dewatering the Hole would include:

- System maintenance, including jetting pipes fouled by sediment
- Equipment replacement over time
- Liquid sampling and analysis
- System monitoring (i.e., equipment operating points, liquid flow rates)
- Part-time operations staff
- Electricity

6.3.4 Hydraulic Capture of the Northerly Plume in the Roza Aquifer

Significant volumes of contaminated groundwater could be extracted from the Roza aquifer high-transmissivity zone near the northwest corner of the landfill (Figure 2). It could be possible to hydraulically capture the northerly plume in the Roza aquifer at the northern landfill property boundary within about 1 year (Appendix A) by pumping about 6 gpm from two new extraction wells installed in the Roza aquifer high-transmissivity zone. Hydraulic capture of the northerly plume at the north landfill property line (hereafter referred to as northerly plume capture) is assumed to eliminate migration in the Roza aquifer north of the landfill. The new wells would be fitted with transducers and submersible pneumatic pumps, and conduit and surface piping (heat-traced and insulated) would be installed for compressed air supply and groundwater discharge to a new treatment facility. Piping would be specific to each well until lines could be combined into a shared header to the treatment facility.

Northerly plume capture should eliminate Roza aquifer contaminant migration north of the landfill; however, it would not directly remove source mass from the P1 zone or the Hole.

A new treatment facility would be needed to treat groundwater to State discharge standards for infiltration because the estimated volume of pumped groundwater is expected to exceed the space available for a new evaporation pond with adequate capacity (3.5 million gpy).

Pumped groundwater would need to be treated, then discharged to the ground (infiltration basin)[16]. Groundwater treatment would need to satisfy the conditions of a State Waste Discharge Permit. To meet the stringent discharge requirements of a State Waste Discharge Permit (Chapters 173-216 and 173-200 WAC), a multiple-stage treatment train would be needed (Figure 7). Such a treatment train would consist of:

1. **Equalization tank.** A 20,000-gallon equalization tank would provide a full day's worth of storage, allowing treatment system maintenance without cessation of groundwater pumping.

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[16] Discharge to the City of Ephrata Water Reclamation Facility is not feasible. The facility was planned and designed to accommodate limited modifications based on long-term population growth projections, which differ in magnitude from the volume estimated for groundwater extraction from Roza aquifer high-transmissivity zone.

2. **Clarification.** An inclined plate clarifier with a chemical dosing system would precipitate and reduce inorganic concentrations to avoid fouling the downstream treatment equipment. Lime precipitation with polymer would be planned for the chemical dosing processes. The clarifier would generate settled solids. Based on a typical sludge generation rate of 5 percent of influent flow, about 0.6 gpm, or 315,000 gpy, of sludge would be discharged to an evaporation pond.
3. **Air stripping.** An air stripper would be needed to remove VOCs prior to removal of the total dissolved solids. An air stripper is essentially a stacked tray system in a shroud with an air blower. Water cascades over the trays as ambient air is blown through the shroud. Water spreads on the trays, creating surface area for evaporation and advection of VOCs to the passing air. Air stripper exhausts are often equipped with carbon filters to reduce VOC emissions to the atmosphere. For the estimated flows, a six-tray system with about 240 cubic feet per minute air flow would be appropriate.
4. **Greensand pressure filter.** A vertical greensand pressure filter would remove iron and manganese to prevent fouling of the downstream reverse osmosis unit. Chlorine dosing prior to the greensand filtration would activate and regenerate the filter media for removal of iron and manganese. A greensand pressure filter would need to be backwashed regularly with relatively clean water, which could be supplied from the reverse osmosis unit permeate flow.
5. **Reverse osmosis.** Reverse osmosis would reduce the hardness and total dissolved solids to below discharge limits. A reverse osmosis unit contains membranes that remove contaminants. For the estimated groundwater discharge rates, an 18-membrane system would be appropriate. Sodium bisulfite would be added upstream of the reverse osmosis unit to remove residual chlorine. Antiscalant chemicals would also be added upstream to increase the solubility of constituents that would otherwise tend to deposit as scale on the membranes (e.g., calcium carbonate, calcium sulfate). Membranes could be maintained with a clean-in-place system consisting of a pump, mixing tank with heater, and associated controls. The reverse osmosis unit would generate concentrated brine which would be discharged to an evaporation pond. The brine generation rate is typically about 30 percent of the influent flow, including additives. Based on the estimated groundwater discharge for northerly plume capture and additives, brine generation would be about 3.5 gpm, or 1,840,000 gpy.
6. **Granular activated carbon.** Liquid-phase GAC would provide a final polishing step to remove any remaining organic compounds. For the estimated flows, two 250-pound GAC units would be appropriate.

Bench-scale treatability testing is recommended to evaluate waste generation rates, chemical dosing rates, efficacy of the individual treatment components, and efficacy of the overall treatment train. Accurate estimates of treatment results are not feasible for multiple contaminants and processes without bench-scale treatability tests.

The relatively small quantities of dangerous waste generated through groundwater treatment could be managed under the State Hazardous Waste Contract. Treatment would be needed for the duration of groundwater pumping, an estimated 20 years.

Implementation of this cleanup action component would require a State Waste Discharge Permit and may also require an air discharge permit.

A building to house the treatment system would be needed for security and for protection of costly equipment from the elements. A building of about 4,000 square feet would allow proper spacing between pieces of equipment for operation and maintenance access. A fully insulated, pre-engineered metal building on a concrete floor with office space and a control room is typical. Building temperature would need to be maintained between 40 and 90°F for treatment purposes. Utilities would include electricity, communications, potable water, and sanitary sewer.

Treated groundwater could be disposed of by infiltration under a State Waste Discharge Permit (Chapters 173-216 and 173-200 WAC). Infiltration would be seasonally limited (March through October). When infiltration is temporarily unavailable, treated groundwater would need to be diverted to the existing evaporation pond and a new one sized to handle the excess volume. Alternatively, infiltration galleries or injection wells might be feasible, although estimates for this component are based on seasonal storage and evaporation.

An infiltration basin system would include:

- Conveyance piping from the treatment facility
- A prepared surface area of about 3,600 square feet (based on estimated discharge and infiltration rates)
- Berms about 2 feet high around the basin to contain peak groundwater discharge during significant precipitation events
- Access roads
- Fencing

An infiltration basin could be located in an area identified by PGG as suitable (Appendix F), on a County-owned parcel adjacent to and east of the landfill property where the high permeable Outwash formation is near the surface. An infiltration basin would need to remain in service concurrent with associated groundwater treatment actions. Former residential parcels now owned by the County would need to be rezoned to accommodate the new facilities.

In addition to reducing migration in the Roza aquifer north of the landfill, this component would also remove VOC. Calculated VOC removal with this component (Appendix B) is approximately 13 kg and 61 kg for the first year and first decade, respectively (northerly plume capture assumes high VOC concentrations in the Roza aquifer near MW-63b would be captured by pumping from the Roza aquifer high-transmissivity zone near MW-3b and MW-7b). Those VOC removal rates include rates achievable by targeted pumping of the northerly plume, discussed below. As mentioned (Section 6.3.3), best-estimate values based on professional judgment were used to evaluate cleanup action components.

Operation, maintenance, and monitoring activities and costs associated with this component would include:

- System maintenance, including jetting pipes fouled by sediment
- Filter material changes
- Equipment replacement over time
- Liquid and solids sampling and analysis
- System monitoring (i.e., equipment operating points, liquid flow rates, pressures)
- Part-time operations staff
- Electricity

6.3.5 Targeted Pumping from the Northerly Plume in the Roza Aquifer

Contaminant mass can be removed through groundwater extraction from the Roza aquifer near where the center line of the northerly plume crosses the north end of the landfill parcel near existing well MW-63b. This area is just inside the landfill property line, and this component would capture some northerly plume contaminants before they migrate past the POC. Groundwater extraction would target the highest observed contaminant concentration in the Roza aquifer at this location, with the goal of removing contaminant mass, although it would not be possible to fully hydraulically capture the plume.

The pumping system would include replacement of existing well MW-63b, and installation of two additional Roza aquifer wells spaced approximately 30 feet on either side, west and east, of MW-63b. The spacing is preliminary and subject to change based on further analysis. MW-63b is a 2-inch diameter well installed to a depth of 60 feet. The new wells would be constructed as 6-inch diameter PVC wells in 10-inch boreholes at a 65-foot depth. It is assumed that MW-63b would have to be replaced with a larger 6-inch diameter pumping well.

The three wells would be fitted with transducers and submersible pneumatic pumps. Conduit and buried piping would be installed for compressed air supply and groundwater discharge to the LTT. Piping would be specific to each well until lines could be combined into a shared header to the treatment facility.

Sustainable well yields are assumed to be 0.5 gpm at each well, based on testing of MW-63b (PGG 2016). The total water volume extracted would be approximately 788,923 gpy. In practice, the pumping rate would be adaptable and could be reduced if volumes exceed the limits of the water treatment and disposal systems. This component assumes treatment through the LTT with discharge to either the existing evaporation pond or a new evaporation pond (Section 6.3.7). Former residential parcels now owned by the County would need to be rezoned to accommodate a new pond.

The radius of influence with the new wells is estimated to extend north of the landfill property line, outside the POC. Thus, this component would remove contaminants from the northerly plume both inside and outside the POC.

Calculated VOC removal with this component is approximately 13 kg and 59 kg for the first year and first decade, respectively (Appendix B). As mentioned (Section 6.3.3), best-estimate values based on professional judgment were used to evaluate cleanup action components.

Typical operation, maintenance, and monitoring activities and costs associated with this component would include:

- System maintenance, including jetting pipes fouled by sediment
- Equipment replacement over time
- Liquid sampling and analysis
- System monitoring (i.e., equipment operating points, liquid flow rates, pressures)
- Part-time operations staff
- Electricity

6.3.6 Evaporation from the Existing Evaporation Pond

The evaporation pond installed during the MPE pilot test is approximately 0.75 acre with passive evaporation of up to 682,000 gpy and could be used to dispose of extracted contaminated groundwater with or without treatment through the LTT. The groundwater disposal amount would be limited to the passive evaporation volume.

The evaporation pond was designed and operated consistent with the most stringent regulations at WAC 173-350-330, *Surface Impoundments and Tanks*, and 40 Code of Federal Regulations Part 264, *Standards for Owners and Operators Of Hazardous Waste Treatment, Storage, and Disposal Facilities, Subpart K – Surface Impoundments*. The pond is not ballasted, so a minimum 6-inch water depth should be maintained.

VOC air emissions would depend on the groundwater sources being discharged to the pond and LTT removal rates. Discussions regarding the likelihood of exceeding air discharge thresholds for combinations of groundwater components are included in the descriptions of alternatives in Section 7.

The evaporation pond would need to remain in service concurrent with groundwater pumping actions.

Operation, maintenance, and monitoring activities and costs associated with this component would include:

- Monitoring and maintenance of the pond and leak-detection system

Upon completion of cleanup action activities, the existing pond could be repurposed for landfill leachate management, or it could be removed, disposed, backfilled, and capped with an extension of the landfill closure system.

6.3.7 Additional Evaporation Capacity

Evaporation capacity can be increased by adding another pond or installing mechanical features, such as a flow spreader around the existing pond rim.

6.3.7.1 Additional Evaporation Pond

A second evaporation pond could be added to dispose of Roza aquifer groundwater without the need for pretreatment. Because the existing evaporation pond is located over the old landfill and is connected to the landfill closure, it would not be expanded. New pond size would depend on how much groundwater is pumped and whether other disposal options would be used if groundwater is treated. Total evaporation pond configurations under consideration vary by alternative and range from the existing 0.75-acre pond to an additional 0.75-acre pond.

Regardless of size, a second evaporation pond system would consist of:

- Conveyance piping from wells or a treatment facility
- Excavation and placement of a soil berm to form a pond subgrade
- A double-liner system, including a leak-detection system
- Access roads
- Fencing

A second evaporation pond would, like the existing pond, be designed and operated consistent with most stringent regulations at WAC 173-350-330, *Surface Impoundments and Tanks*, and

40 Code of Federal Regulations Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Subpart K – Surface Impoundments*. The new pond would also need to be ballasted with a minimum 6-inch water depth.

Evaporation in Ephrata is estimated to require 1 surface acre per million gpy of net evaporation based on precipitation and pan evaporation data from the Western Regional Climate Center (WRCC 2012a,b). Total lined area generally needs to be significantly larger than this evaporation rate to account for pond side slopes and freeboard.

A new evaporation pond should be located close to areas where groundwater would be pumped or to the treatment facility to limit transmission pipe installation and maintenance costs. The former Akerblade and Whitson parcels (both now owned by Grant County) might be suitable (Figure 1). These parcels would need to be rezoned.

A new evaporation pond would need to remain in service concurrent with groundwater pumping actions.

Operation, maintenance, and monitoring activities and costs associated with this component would include:

- Monitoring and maintenance of the pond and leak-detection system
- Conveyance system monitoring for leaks
- Conveyance system maintenance, including jetting of pipes

Upon completion of cleanup action activities, the piping and pond would be removed and disposed, and the pond area would be backfilled and restored to original conditions.

6.3.7.2 Mechanical Features

Adding a flow spreader around an evaporation pond rim would increase the annual evaporation capacity by increasing the exposed surface area of groundwater discharged to the pond. Mechanical misting systems were briefly considered, but they are not evaluated in this FS because of concerns for overspray and proximity to the Neva Lake Road corridor, and because preliminary estimates suggest a second pond would be more cost effective.

6.3.8 LFG System Activation

VOCs in the original landfill could be reduced by activating the existing passive LFG management system by installing a blower at the existing flare station (Figure 1). LFG methane comprised about 6.6 percent volume of the pilot test vapor flow on average. Methane concentrations of 5 to 15 percent volume create a flammable mixture with air. Although the MPE system is designed to process flammable mixtures, it would be preferable to avoid them by reducing methane concentrations to under 5 percent volume. LFG system activation should accomplish that goal within about 6 to 18 months, whereas it might take several years with the passive system. LFG also contains somewhat elevated vinyl chloride concentrations compared to P1 vapor. Although methane reduction in the MPE system is the primary goal of the project, it would also reduce vapor phase movement of VOCs in LFG into the P1 and reduce dissolution to groundwater. Although VOC removal through the LFG system is not quantified in the contaminant removal estimates for the alternatives, some removal would occur. LFG is not thought to be significantly involved in the northerly plume contaminant migration pathway, and the restoration time frame is not expected to be reduced by LFG system activation. However, since the MPE system can be operated more safely with LFG system activation, this component is included in every alternative.

The existing landfill flare station has space to install a blower. Conduit for electrical power supply lines has also been installed. Utility connections, conductor, and a local blower control panel would be needed in addition to the blower itself.

Operation, maintenance, and monitoring activities and costs associated with this component would include:

- Equipment and conveyance piping maintenance
- Equipment replacement allowance
- Compliance monitoring, including vapor characterization samples
- Operations staff
- Electricity

Upon completion of cleanup action activities, the active LFG management system could remain in operation through the post-closure care period of the landfill, or the system could be returned to a passive system.

6.3.9 Compliance Monitoring

Groundwater compliance monitoring is expected to be the key element of an overall compliance monitoring program. The MTCA cleanup regulations describe three types of compliance monitoring (WAC 173-340-410):

1. Protection monitoring
2. Performance monitoring
3. Confirmational monitoring

Although a groundwater compliance monitoring plan will be developed after the cleanup action plan is finalized, anticipated groundwater protection, performance, and confirmational monitoring activities are described below and provide the basis for cost estimates in this FS.

As part of a compliance monitoring program for the Site, different combinations of existing and new wells would be either gauged for water levels only or gauged and sampled for contaminant analysis, as summarized in Table 9. Figure 8 shows the monitoring well locations that are common to all the alternatives. Note that sampling of the new landfill monitoring wells associated with the detection monitoring program for its solid waste permit requirements (WAC173-351) would continue independent of compliance monitoring for the old landfill.

The following new monitoring wells would be installed for compliance monitoring (Figure 8):

- Decommissioning and replacement of MW-43p2 in the P2 zone
- Replacement of MW-3b in the Roza aquifer
- Installation of MW-71b and MW-73b in the Roza aquifer
- Installation of MW-72d in the Frenchman Springs aquifer
- Installation of MW-74c in the Interflow aquifer

All wells would be gauged for depth to water and, in the P1 zone, thickness measurements of LNAPL (if present). In addition to gauging, samples would be analyzed as described below. Table 9 identifies monitoring wells for each alternative and indicates whether each well would be used for gauging only or for gauging and sampling. Sample frequency and analytical methods will be addressed in the compliance monitoring plan.

Monitoring frequency would depend on groundwater concentrations and LNAPL occurrence and constituent concentration trends. Five years of quarterly monitoring of the wells listed in Table 9 were assumed for cost estimation. Monitoring frequency could potentially be reduced if data trends are relatively stable after 5 years, so semi-annual monitoring was assumed after year 5. Active extraction wells would be monitored to optimize and document performance (e.g., maintain appropriate drawdown, assess radius of influence and contaminant removal rates, and evaluate LNAPL accumulation).

The compliance monitoring plan will address specific reporting requirements for the cleanup action. The following reports are representative of what may be required for this type of project:

- Groundwater compliance monitoring and well maintenance plan – Describes the long-term groundwater monitoring program for the Site to comply with MTCA requirements (Chapter 173-340 WAC).
- Annual groundwater monitoring report – Describes the groundwater monitoring results for the previous year. Any modifications to the groundwater monitoring program would be recommended in the annual reports.
- Annual cleanup action activity report – Describes the cleanup action activities conducted the previous year and associated monitoring results from those activities. This report would include required regulatory reporting for the various cleanup action components implemented at the Site.
- Annual dangerous waste report – Documents the previous year's dangerous waste generation and disposal, as required in Chapter 173-303 WAC.
- Periodic (5-year) review report – Provides an overall assessment of the activities conducted at the Site during the previous 5 years, as well as any recommendations for modifications to the groundwater monitoring and cleanup action activities.

6.3.10 Institutional Controls

The cleanup action components included in the alternatives and discussed in Section 6 are engineered controls, which would be "designed and constructed to prevent or limit the movement of, or exposure to, hazardous substances" (WAC 173-340-200), while institutional controls are measures to "limit or prohibit activities that may interfere with the integrity of an interim action or a cleanup action or result in exposure to hazardous substances at the site" (WAC 173-340-200). Institutional controls that can be implemented at cleanup sites are described in the MTCA regulations (WAC 173-340-440). Institutional controls are required when CULs are established using MTCA Method B and if hazardous substances remain at a site, or if CULs are established using MTCA Method C. Institutional controls are also required if a conditional POC is established. Other than the establishment of CULs using MTCA Method C, all the above circumstances apply at this Site.

Current institutional controls for the Site include the 1,000-foot restriction for construction of domestic water supply wells near a solid waste facility (WAC 173-160-171(3)(b)(iv)) (Figure 1), landfill closure requirements (Chapter 173-304 WAC), and fencing and signage around the landfill property.

Future institutional controls could include restrictive covenants on County properties affected by contamination from the Site, and these would be enforceable upon property transfer or sale. Future controls could also include additional fencing and signage.

The County owns all the properties beneath which groundwater contaminant concentrations exceed proposed CULs. Former residential parcels now owned by the County would need to be rezoned before building any cleanup action facilities on them. There are no water supply wells currently completed in this area, but part of the area is outside the 1000-foot area within which drinking water well construction is already prohibited (Chapter 173-160 WAC). The Roza aquifer is not ordinarily targeted for water supply. Nonetheless, restrictive covenants prohibiting well completion within the Roza and deeper aquifers beneath the northerly plume are recommended.

7. CLEANUP ACTION ALTERNATIVES

This section presents the cleanup action alternatives developed for the Site, which are combinations of the cleanup action components described in Section 6.3. Alternatives are evaluated and compared relative to MTCA cleanup regulations in terms of contaminant concentration reduction in the northerly plume and contaminant mass removal from the Site. The preferred cleanup action alternative for the Site is also described. Cleanup objectives are first summarized below.

7.1 CLEANUP OBJECTIVES

Cleanup objectives for the Site are based on MTCA requirements, an evaluation of the data collected during the RI (PGG 2010, 2012, and 2017) and MPE IRA (Parametrix and PGG 2018) and summarized in Section 2, and cleanup standards (Section 5).

7.1.1 MTCA Requirements

The MTCA cleanup regulations require that all cleanup actions meet certain minimum requirements (WAC 173-340-360).

Threshold requirements (WAC 173-340-360(2)(a)) are:

- Protect human health and the environment.
- Comply with cleanup standards.
- Comply with applicable state and federal laws.
- Provide for compliance monitoring.

Other requirements (WAC 173-340-360(2)(b)) for alternatives meeting the above threshold requirements are:

- Use permanent solutions to the maximum extent practicable.
- Provide for a reasonable restoration time frame.
- Consider public concerns.

As noted above, the only medium for which cleanup alternatives are developed is groundwater. Where it is not practicable to achieve groundwater CULs at the standard POC (i.e., all soil and groundwater throughout the site) within a reasonable restoration time frame, contaminant source treatment or removal, or groundwater containment, is nonetheless required (WAC 173-340-360(2)(c)) to the maximum extent practicable.

Cleanup action alternatives shall prevent or minimize present and future releases and migration of hazardous substances in the environment (WAC 173-340-360(2)(f)).

Cleanup actions shall not rely primarily on dilution and dispersion unless the incremental costs of any active remedial measures grossly exceed the incremental degree of benefits (WAC 173-340-360(2)(g)).

7.1.2 Groundwater Cleanup Objectives

Following are Site cleanup objectives for contaminated groundwater:

- Reduce or eliminate human exposure through ingestion of groundwater containing Site contaminants at concentrations that exceed CULs.
- Prevent further migration of Site contaminants in concentrations exceeding CULs toward drinking water sources through source removal and containment.

7.2 CLEANUP ACTION ALTERNATIVES

The following seven cleanup action alternatives were developed based on MTCA requirements for cleanup action selection (WAC 173-340-360), the nature and extent of contamination at the Site, and the identified cleanup action components (Section 6.3):

1. Reactivate the existing P1 zone MPE and treatment system, with LFG system activation
2. Expand and reactivate the P1 zone MPE and treatment system, with LFG system activation
3. Expand and reactivate the P1 zone MPE system, with LFG system activation and groundwater extraction from the Hole
4. Expand and reactivate the P1 zone MPE system, with LFG system activation and northerly plume targeted pumping
5. Expand and reactivate the P1 zone MPE system, with LFG system activation and northerly plume hydraulic capture (with treatment and infiltration)
6. Expand and reactivate the P1 zone MPE system, with LFG system activation, groundwater extraction from the Hole, and northerly plume targeted pumping
7. Expand and reactivate the P1 zone MPE system, with LFG system activation, groundwater extraction from the Hole, and northerly plume hydraulic capture (with treatment and infiltration)

Table 8 summarizes the alternatives in terms of the total cost in 2018 dollars, first-year and first-decade VOC mass removal, unit cost per kg for first-year and first-decade VOC removal, and estimated time to meet cleanup standards and to complete active remedial measures. Compliance monitoring and institutional controls, needed for every alternative, are described generally in Sections 6.3.9 and 6.3.10, respectively. Natural attenuation (Section 6.3) will continue during the implementation of active measures under any of the alternatives and affect restoration time frames to different degrees for each alternative. However, specific natural attenuation rates for each alternative are not calculated, and the contaminant removal comparison by alternative excludes natural attenuation.

7.2.1 Alternative 1 – Reactivate the Existing MPE System, Activate LFG System

Alternative 1 comprises resumption of MPE with the existing facilities and natural attenuation. The following components are included:

- LFG system activation
- Resumption of P1 zone MPE using two existing wells

- Evaporation from the existing pond
- Institutional controls
- Compliance monitoring
- Natural attenuation

This alternative was developed to evaluate longer-term continuation of groundwater pumping and SVE from MW-34p1 and MW-68p1 within the P1 zone. Downgradient migration of contaminants from the P1 would be substantially reduced but may not be eliminated completely with this limited use of MPE.

Figure 5 shows the location of the existing extraction wells, treatment facility, and evaporation pond.

Alternative 1 includes LFG system activation, which comprises the addition of a blower to the existing flare facility (Figure 1). Gas system activation would reduce LFG migration into the P1 zone when vacuum is applied. This would reduce the methane concentration in MPE system piping and equipment, thus preventing potentially flammable gas mixtures in MPE system wells, piping, and equipment. Since LFG also contains somewhat elevated vinyl chloride concentrations compared to P1 vapor, LFG activation would also reduce vapor phase movement of VOCs in LFG into the P1 and reduce dissolution to groundwater.

MPE from the P1 zone would resume and provide similar results as those observed during the pilot test, assuming the P1 zone has fully recharged since the pilot test. Alternative 1 is expected to remove approximately 4 kg of VOCs via groundwater until the P1 zone is dewatered (based on recent pilot test results) resulting in minimal additional removal beyond the first year. For estimating purposes, it is assumed that MPE would continue for 10 years.

The evaporation pond, with an evaporative capacity of 682,000 gpy, would be used to dispose of the pumped groundwater, estimated at approximately 90,000 gpy for the first year and then less than 50,000 gpy thereafter (based on recent pilot test results). If the estimated 50,000 gpy pump rate is not sufficient to maintain a 6-inch minimum water depth in the pond, landfill leachate from the new, lined landfill might need to be hauled or pumped to the evaporation pond at times.

Based on vapor extraction results during the MPE pilot test, the two MPE wells are expected to operate under a 3.5 inches-Hg vacuum and yield 81 kg of VOCs removed via SVE during the first year (Appendix G). Due to the drop off in concentration, subsequent years of SVE are not expected to remove significant VOC mass, though additional VOCs may be removed if rebound occurs during cyclic operation.

VOC air emissions after treatment through the LTT and VTT are expected to be below small quantity thresholds.

The Alternative 1 first-year and 10-year VOC removal are assumed to both be 85 kg (Table 8), which is sharply lower than any of the other alternatives. Those values include mass removal from P1 vapor extraction and P1groundwater extraction (does not include natural attenuation). Although some VOC removal from the P1 might continue after the first year (especially if rebound occurs during cyclic operation), zero removal is assumed for FS calculations. The shortest restoration time frame for Alternative 1 is assumed to be greater than 34 years (the value estimated for complete source control [Appendix A]). Since complete source control is not expected with Alternative 1, the restoration time frame might approach that estimated for natural attenuation alone (66 years, Appendix B).

7.2.2 Alternative 2 – Expand MPE System, Activate LFG System

Alternative 2 consists of the following cleanup action components, in addition to those listed for Alternative 1:

- LFG system activation
- MPE well field expansion within the P1 zone
- LTT modifications to address precipitates and improve LNAPL separation
- VTT modifications, including an intermediate vacuum blower and an additional GAC unit

Alternative 2 represents the baseline cleanup action for Ephrata Landfill because it reflects the fewest additional cleanup action components recommended for the Site and provides reasonable contaminant removal and restoration time frame. Alternative 2 was developed to evaluate groundwater pumping and SVE within the broader P1 zone estimated to be impacted by LNAPL using the existing MW-34p1 and MW-68p1 wells of Alternative 1 and four new MPE wells, expansion of the monitoring well network, and addition of vent wells to enhance performance. The expanded MPE system is expected to increase contaminant mass removal and essentially eliminate further migration of contaminants out of the P1 source zone into the northerly plume. The VTT would be modified to add an intermediate vacuum blower sized for the increased number of wells and an additional GAC unit with piping and valve changes. The LTT would be modified to reduce fouling by performing a bench-scale treatability study to determine an inorganics management strategy, then installing new equipment. Figure 6 shows the location of the extraction wells, treatment facility, and evaporation pond proposed for Alternative 2. The location of new P1 extraction wells in Figure 6 are only approximate and may change during design of an expanded well field.

Alternative 2 includes LFG system activation, the same as described above for Alternative 1. This effectively carries LFG system activation through all the other alternatives, which is recommended primarily for safer MPE system operation (Section 6.3.8).

The existing evaporation pond (calculated evaporative capacity of 682,000 gpy) would be used to dispose of the pumped groundwater, estimated at approximately 270,000 gpy for the first year and then less than 158,000 gpy thereafter (based on expansion of MPE pilot test results, see Section 6.3.2). If the estimated 158,000 gpy pump rate is not sufficient to maintain a 6-inch minimum water depth in the pond, landfill leachate from the new, lined landfill might need to be hauled or pumped to the evaporation pond at times.

Based on vapor extraction results during the MPE pilot test, the six MPE wells are expected to operate under a 3.5 inches-Hg vacuum and yield 228 kg of VOCs removed via SVE during the first year (Appendix G). Due to the anticipated drop off in concentration, subsequent years of SVE are not expected to remove significant VOC mass, although cyclic operation with rebound could remove additional VOC mass. For estimating purposes, it is assumed that MPE would continue for 10 years.

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The Alternative 2 first-year and 10-year VOC mass removals are both estimated to be 240 kg (Table 8). Those values include mass removal from P1 vapor extraction and P1 groundwater extraction (but do not include natural attenuation). Although some VOC removal from the P1 might continue after the first year, zero removal is assumed for FS calculations. The restoration time frame for Alternative 2 is expected to be about 34 years (the value estimated for complete source control [Appendix A]).

7.2.3 Alternative 3 – Expand MPE System, Activate LFG System, Pump from Hole

Alternative 3 is essentially baseline Alternative 2 plus groundwater extraction from the Hole.

This alternative was developed to evaluate whether long-term dewatering of the Hole and expanded MPE within the P1 zone would increase contaminant removal. Groundwater in the Hole is in direct contact with landfill refuse, and vinyl chloride concentrations in groundwater are relatively high. Pumping from the Hole would remove contaminants from the subsurface and control discharge of contaminants to underlying aquifers along one path close to source areas.

Figure 9 shows the extraction wells and location of the evaporation pond and treatment facility. In addition to the components described in Alternative 2 (Section 7.2.2), this alternative would involve four extraction wells (one existing well [EW-1] and three new wells [EW-3, EW-4, and EW-5]) to facilitate dewatering of the Hole. Although dewatering the Hole is expected to remove small amounts of contaminants, vinyl chloride accounts for about 50 percent of the total VOCs in the Hole groundwater. Dewatering the Hole might contribute to vinyl chloride reduction in the downgradient plumes, although this has not been quantified.

Groundwater extraction from the Hole assumes a first-year extraction volume of 390,000 gallons followed by 46,000 gpy based on the groundwater recharge to the Hole (Appendix A). Calculated VOC mass removal from the Hole is directly correlated with the groundwater removal volume and is estimated at approximately 0.21 kg and 0.43 kg for the first year and first decade, respectively. Although the extent to which groundwater in the Hole contributes to the contaminants in the northerly and landfill plumes is not well characterized, dewatering would disrupt contaminant migration that might otherwise occur. For estimating purposes, it is assumed that pumping from the Hole would continue for 10 years.

The evaporation pond, with an evaporative capacity of 682,000 gpy, would be used to dispose of the pumped groundwater, estimated at approximately 640,000 gpy for the first year and then less than 204,000 gpy thereafter (combined groundwater from the P1 and Hole). If the estimated 204,000 gpy pump rate is not sufficient to maintain a 6-inch minimum water depth in the pond, landfill leachate from the new, lined landfill might need to be hauled or pumped to the evaporation pond at times.

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The Alternative 3 first-year and 10-year VOC mass removals are estimated to both be 240 kg (Table 8). Those values include mass removal from P1 vapor extraction and groundwater extraction from the P1 (but do not include natural attenuation or any increase attributable to P1 cycling). Groundwater extraction from the Hole is not expected to result in significant total VOC contaminant removal, although it could contribute to vinyl chloride reduction. The restoration time frame for Alternative 3 is 34 years, which is the same as for Alternative 2.

7.2.4 Alternative 4 – Expand MPE System, Activate LFG System, Targeted Roza Pumping, Additional Evaporation

Alternative 4 consists of baseline Alternative 2 plus targeted groundwater extraction from the Roza aquifer and additional evaporation. This alternative was developed to decrease the restoration time frame by removing Roza aquifer contaminants near where the center line of the northerly plume crosses the north end of the landfill parcel (i.e., near MW-63b). Roza groundwater near MW-63b would be pumped, treated, and evaporated. MW-63b groundwater samples contained higher contaminant concentrations than other Roza wells near the northern POC. Complete northerly plume hydraulic capture is not predicted.

In addition to the components described in Alternative 2 (Section 7.2.2), three groundwater extraction wells would be installed in the Roza aquifer (one replacing existing well MW-63b [EW-10] with a 6-inch diameter well casing and two new wells [EW-8 and EW-9]). Figure 10 shows the extraction well locations.

The combined Roza aquifer and P1 zone first-year and annual groundwater pumping rates of approximately 1,038,923 gpy and 946,923 gpy, respectively, would exceed the 682,000 gpy capacity of the existing evaporation pond. Options for optimizing or adding evaporative capacity include (1) limiting Roza pumping based on available evaporation capacity; (2) incorporating a mechanically enhanced evaporation system (i.e., level spreader); (3) adding a second evaporation pond; or (4) some combination of these options. Former residential parcels now owned by the County would need to be rezoned to accommodate cleanup facilities. For cost estimation purposes, a second evaporation pond is assumed. Since the pump rates at this site cannot be accurately predicted, due to formation heterogeneity, an adaptive approach is recommended, with test pumping from the Roza to inform the engineering design of any new evaporation capacity. The existing evaporation pond has sufficient capacity to receive Roza test discharges.

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The Alternative 4 first-year and 10-year VOC mass removals are estimated to be 253 kg and 299 kg, respectively (Table 8). Those values include mass removed in P1 vapor, P1 groundwater, and Roza groundwater (but do not include natural attenuation or any increased removal attributable to P1 cycling). Based on Roza aquifer advection rates between the P1 source area and northern POC, and on containing the P1 source through expanded MPE, it is estimated that cleanup standards would be met at the POC within 20 years. An additional 5 years is assumed to achieve cleanup standards outside the POC, since targeted pumping would not reverse the flow of groundwater past the POC in the northerly plume. A restoration time frame of 25 years is therefore used for calculations.

7.2.5 Alternative 5 – Expand MPE system, Activate LFG System, Northerly Plume Hydraulic Capture, Additional Treatment, Additional Evaporation, Infiltration

Alternative 5 consists of baseline Alternative 2 plus the following additional cleanup action components:

- Groundwater extraction from the Roza aquifer for hydraulic capture of the northerly plume
- Groundwater treatment to meet the conditions of a State Waste Discharge Permit
- Treated groundwater infiltration
- Additional evaporation

This alternative was developed to evaluate whether northerly plume capture near the north landfill property boundary could reduce restoration time frames compared with the

Alternative 2 baseline. As mentioned in Section 6.3, northerly plume hydraulic capture would preclude any need for targeted pumping.

Figure 11 shows the layout of Alternative 5. In addition to the components described in Alternative 2 (Section 7.2.2), northerly plume capture would require pumping from two new wells (EW-6 and EW-7) in the Roza aquifer high-transmissivity zone that extends under the western part of the north landfill property line (Figure 11). To manage the high volume of groundwater pumped from the Roza aquifer, treatment and infiltration is assumed for this alternative, rather than construction of a large evaporation pond.

Alternative 5 should greatly curtail, if not stop, contaminant migration north of the landfill property line. PGG estimated the northerly plume could be hydraulically captured within about 1 year of pumping at a total discharge rate of approximately 6 gpm, or 3,500,000 gpy, from the new wells (Appendix A). The 6-gpm pumping rate is assumed to be sustainable and necessary for capture in all years. The possibility of reduced pumping as drawdown develops is not considered because it is unlikely the reduction would be large enough to change water treatment and disposal recommendations.

The first-year and 10-year VOC mass removals from northerly plume hydraulic capture are estimated to be about 13 kg and 61 kg, respectively (Appendix B). These estimates were calculated using the mass removal rate from the Roza aquifer high-transmissivity zone plus the mass removal expected from targeted pumping of the Roza aquifer near the centerline of the plume, which is based on new POC data. Concentrations are assumed to decrease at a rate based on observed trends in long-term monitoring at high-transmissivity Roza wells MW-3b and MW-7b. For estimating purposes, it is assumed that northerly plume hydraulic capture would continue for 20 years.

The existing evaporation pond capacity (682,000 gpy) is insufficient for the anticipated hydraulic capture volumes, although Roza discharge could be used when needed to ballast the pond or diverted to the existing pond whenever excess pond capacity is available. The estimated 3,500,000 gpy of groundwater pumped from the high-transmissivity area of the Roza aquifer would be treated and primarily infiltrated, possibly with some seasonal storage and evaporation in a new evaporation pond. Former residential parcels now owned by the County would need to be rezoned to accommodate cleanup facilities.

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The Alternative 5 first-year and 10-year VOC mass removals are estimated to be 253 kg and 301 kg, respectively (Table 8). Those values include mass removal from P1 groundwater, P1 vapor, and groundwater from Roza plume capture (but do not include natural attenuation or contaminant removal increases attributable to P1 cycling).

Offsite locations in the northerly plume are estimated to be below proposed CULs within about 20 years of plume capture at the POC (Table 8). This restoration time frame was simulated for vinyl chloride downgradient of the POC in REMChlor (Table 3 in Appendix C). To prevent recontamination at the POC and offsite, northerly plume capture would need to continue until onsite areas are also restored to levels below those that would cause offsite areas to exceed CULs. For this alternative, onsite restoration would be achieved through MPE, natural attenuation, and advection of clean water to the POC. The advection time from the P1 source area to the POC is estimated to be 14 years or less, since the drums were received at the landfill in 1975 and the first detection of groundwater contamination at the POC (well MW-3b) was in 1989. Given a 14-year maximum advective time from the P1 source area to the POC and active restoration of groundwater through P1 source control, restoration at the POC is expected to take less than 20 years. The restoration time frame for this alternative is the time it would take offsite areas to respond to POC capture, which is 20 years.

7.2.6 Alternative 6 – Expand MPE System, Activate LFG System, Pump from Hole, Targeted Roza Pumping, Additional Evaporation

Alternative 6 consists of baseline Alternative 2 plus the following additional cleanup action components:

- Targeted groundwater extraction from the Roza aquifer
- Groundwater extraction from the Hole
- Additional evaporation

This alternative essentially explores the combined effects of components that are compatible with water disposal by evaporation. Figure 12 shows the extraction wells and location of the evaporation ponds and treatment facility.

The total annual water volume extracted would be 1,428,923 gpy for the first year and 992,923 gpy for subsequent years. In practice, however, the pumping rates could be adapted in accordance with system response or system limitations. The annual groundwater extraction rates would exceed the 682,000 gpy evaporative capacity of the existing evaporation pond. Cost estimates for this alternative assume a second, medium-sized evaporation pond with evaporative capacity of 1,141,000 gpy, although pond size may be reduced through incorporation of mechanically enhanced evaporation features. As for Alternative 4, an adaptive approach to increased evaporation is recommended, with test pumping from the Hole and Roza aquifer to inform the engineering design of any additional evaporation capacity. Former residential parcels now owned by the County would need to be rezoned to accommodate cleanup facilities.

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The Alternative 6 first-year and 10-year VOC mass removals should be 253 kg and 299 kg, respectively (Table 8). Those values include mass removal in P1 vapor, P1 groundwater, and Roza groundwater (but do not include natural attenuation or any contaminant removal increases attributable to P1 cycling). Groundwater extraction from the Hole is not expected to result in significant total VOC contaminant removal, although it could contribute to vinyl chloride reduction,

As for Alternative 4, active remediation would continue for 20 years, and calculations are based on a 25-year restoration time frame.

7.2.7 Alternative 7 – Expand MPE system, Activate LFG System, Pump from Hole, Northerly Plume Hydraulic Capture, Additional Treatment, Additional Evaporation, Infiltration

Alternative 7 consists of Alternative 5 plus dewatering the Hole. As mentioned in Section 6.3, northerly plume hydraulic capture would eliminate any need for targeted pumping. Figure 13 shows the extraction wells and location of the new infiltration facility. Former residential parcels now owned by the County would need to be rezoned to accommodate cleanup facilities.

The following groundwater and contaminant removal rates were calculated for Alternative 7:

- 3,500,000 gpy for Roza groundwater to treatment and infiltration
- 640,000 gpy for the first year and then less than 204,000 gpy thereafter for P1 and Hole groundwater to treatment and evaporation
- Cumulative first-year and 10-year VOC mass removals of 253 kg and 301 kg, respectively (Table 8).

VOC air emissions after treatment through the LTT and VTT are expected to fall below small quantity thresholds.

The estimated restoration time frame for Alternative 7 is 20 years, based on hydraulic capture of the northerly plume, as discussed for Alternative 5.

7.3 CLEANUP ACTION ALTERNATIVES EVALUATION

In this section, the seven alternatives were compared to the cleanup objectives described in Section 7.1. The respective comparisons to threshold requirements, other requirements, and groundwater cleanup objectives are summarized in Table 10. All the alternatives meet the cleanup objectives, although through different means and over different time frames.

7.3.1 Comparison to Threshold Requirements

Threshold requirements (WAC 173-340-360(2)(a)) are protection of human health and the environment, compliance with cleanup standards, compliance with ARARs, and provision for compliance monitoring.

Protection of human health and the environment would be achieved by each alternative through varied combinations of source removal and containment, protection monitoring, institutional controls, and natural attenuation.

Compliance with cleanup standards depends partly on contaminant removal and containment and partly on the determination of a reasonable restoration time frame. Alternatives that maximize source removal through expanded MPE (Alternatives 2 through 7) would provide comparatively high contaminant reduction in the source area, but plume restoration time frames are still estimated at 20 to 34 years. Northerly plume capture (Alternatives 5 and 7) is estimated to result in the attainment of groundwater CULs at and beyond the POC in 20 years. It is likely that source removal would be sufficient in 20 years to prevent rebound above CULs in the northerly plume at and in all areas outside of the POC. Alternatives 4 through 7 include more contaminant removal components than baseline Alternative 2, which should lead to restoration time frames that are shorter than for Alternative 2. The restoration time frames for Alternatives 4 and 6 is estimated to be 25 years. Alternative 1 would remove less source area contamination from the P1 than Alternatives 2 through 7, and the restoration time frame is thus expected to be 34 to 66 years.

Like compliance with cleanup standards, compliance with ARARs depends partly on contaminant containment and partly on restoration time frame.

All the alternatives would provide for compliance monitoring, as described in Section 6.3.9.

7.3.2 Comparison to Other Requirements

Other requirements (WAC 173-340-360(2)(b)) are use of permanent solutions to the extent practicable, provision for a reasonable restoration time frame, and consideration of public concerns.

Since the Site includes the Ephrata Landfill, a permanent solution is not feasible (Section 5.1). The drums, LNAPL released from the drums, and highly contaminated soil, collectively considered to be a significant source of groundwater contamination, were removed in 2008, although isolated zones of LNAPL likely remain in the P1. The comparison of permanence is therefore essentially a comparison of the degree of additional contaminant removal achievable with each alternative. All seven alternatives include contaminant removal components, and contaminant removal in the first year and first decade (Table 8) is a benchmark of the comparative degree to which permanence could be achieved with each alternative. Table 8 also shows the restoration time frame for each alternative.

Consideration of public concerns is being addressed through the administration of a public participation program by Ecology.

7.3.3 Comparison to Groundwater Cleanup Objectives

The groundwater cleanup objectives (Section 7.1.2) would be met to varying degrees under each alternative.

Comparatively low contaminant removal would be achieved with Alternative 1, which includes less source removal than the other alternatives. Comparatively high contaminant removal would be achieved with Alternatives 2 through 7, which all include expanded MPE. Alternatives 4 through 7 would provide comparatively high contaminant containment, and the northerly plume capture options (Alternatives 5 and 7) should reduce contaminant migration beyond the POC soonest.

Human exposure would also be prevented with every alternative by institutional controls (i.e., restrictive covenants) recommended on water supply well installation in the Roza aquifer and lower aquifers within the area of the northerly plume. Although northerly plume capture (Alternatives 5 and 7) is estimated to reduce northerly plume contaminant concentrations to below CULs in 20 years, it would be an engineered control and would not alone be efficient at source removal. The contaminant removal, and therefore the permanence aspect of each alternative, is due mainly to other components. Thus, northerly plume capture would need to continue beyond 20 years if source contaminants are still present at levels that could continue to contribute to plume concentrations above CULs.

7.4 DISPROPORTIONATE COST ANALYSIS

MTCA (WAC 173-340-360(3)(e)) provides for comparative evaluation of incremental degree of benefits achieved by each alternative to incremental cost, or disproportionate cost analysis. The alternatives were compared on this basis, as summarized in Table 11. The disproportionate cost analysis also considers the first-year and first-decade cost per kg of VOCs removed and the estimated time needed to achieve compliance with groundwater cleanup standards (Table 8). Alternative 2 is presented as a baseline for cost comparison because it reflects the fewest additional cleanup action components recommended for the Site and provides reasonable contaminant removal and restoration time frame. The evaluation of each alternative is summarized below.

7.4.1 Alternative 1 – Reactivate the Existing MPE System, Activate LFG System

Alternative 1, although protective, would require the longest restoration time frame since it involves the lowest active contaminant removal (85 kg) and depends the most on natural attenuation processes to deplete VOC concentrations below CULs in the northerly plume compared to the other alternatives. The minimum estimated restoration time frame would be over 34 years, and restoration could take up to 66 years with this alternative (Table 8; Appendix B). Although Alternative 1 has the lowest estimated capital cost going forward, the long-term monitoring costs are the highest of any alternative because the restoration time is much longer than the other alternatives. As a result, the Alternative 1 total cost ($20,619,640) is $3,755,840 higher than baseline Alternative 2 (Tables 8 and 11). The VOC removal rate is much lower for Alternative 1 compared to the other alternatives. Alterative 1 has the highest VOC removal unit cost at $242,507 kg per year for both the first year and first decade (Table 8). Because of the comparatively low VOC removal, high unit cost, and long restoration time frame, Alternative 1 is not recommended (Table 11).

7.4.2 Alternative 2 – Expand MPE System, Activate LFG System

Alternative 2 includes additional source removal through the expansion of MPE in the P1 zone. The estimated 34-year restoration time frame assumes source containment (Appendix B). Although the forward cost of Alternative 2 ($16,863,800) is the second lowest, other alternatives with more contaminant removal offer lower first- and 10-year VOC removal unit costs and shorter restoration time frames (Table 8). Because of the VOC removal and moderate restoration time frame, Alternative 2 represents a reasonable cleanup action alternative and is used as the baseline for comparison.

7.4.3 Alternative 3 – Expand MPE System, Activate LFG System, Pump from Hole

Alternative 3 is Alternative 2 plus dewatering the Hole. Although dewatering the Hole would disrupt a possible contaminant migration pathway to the northerly and landfill plumes, there is negligible total VOC contaminant removal associated with it, although it could contribute to reduction in vinyl chloride in downgradient plumes. The VOC removal and restoration time frame is the same as for Alternative 2 (Table 8), but the cost is $1,225,000 higher (Table 11). Alternative 3 is therefore considered a viable cleanup action alternative but is not the recommended one.

7.4.4 Alternative 4 – Expand MPE System, Activate LFG System, Targeted Roza Pumping, Additional Evaporation

Alternative 4 is Alternative 2 plus targeted pumping from the Roza aquifer. Targeted Roza pumping removes contaminants directly from the northerly plume, thus increasing contaminant removal in the first decade and reducing restoration time frame compared to baseline Alternative 2. The total forward cost is $296,440 lower than baseline Alternative 2 because of the shorter restoration time frame (Table 11). Because of the increased VOC removal, first- and 10-year unit costs are the lowest of any alternative (Table 8). Because of higher contaminant removal, shorter restoration time frame, and lowest first- and 10-year VOC removal unit costs, Alternative 4 is considered a strong candidate for the recommended alternative.

7.4.5 Alternative 5 – Expand MPE System, Activate LFG System, Northerly Plume Hydraulic Capture, Additional Treatment, Additional Evaporation, Infiltration

Alternative 5 is Alternative 2 plus hydraulic capture of the northerly plume in the Roza aquifer. Hydraulic capture should reverse contaminant migration in the northerly plume, resulting in the shortest possible restoration time frame (20 years) and increase contaminant removal compared to Alternative 2 (Table 8). However, the forward cost is $8,891,420 more than Alternative 2 (Table 11). Because of the high marginal cost, the first-and 10-year VOC removal unit costs are $101,600 and $85,425 per kg, respectively (Table 8). Although Alternative 5 is technically viable, the costs (53% higher than those of Alternative 2) are disproportionate to the increased VOC removal (no difference for the first year, less than 1% for the first decade).

7.4.6 Alternative 6 – Expand MPE System, Activate LFG System, Pump from Hole, Targeted Roza Pumping, Additional Evaporation

Alternative 6 is Alternative 2 plus targeted pumping from the Roza aquifer and dewatering the Hole. Targeted Roza pumping would provide contaminant removal directly from the northerly plume both on the landfill parcel and north of the POC. Dewatering the Hole would remove vinyl chloride from a contaminant migration pathway near the source and might also help reduce vinyl chloride in the plumes. Although the total forward cost is $1,383,560 higher (Table 11), the 10-year VOC removal unit cost is lower than that for Alternative 2 (Table 8). Because of higher contaminant removal, shorter restoration time frame, and lower 10-year VOC removal unit cost, Alternative 6 is considered a strong candidate for the recommended alternative.

7.4.7 Alternative 7 – Expand MPE System, Activate LFG System, Pump from Hole, Northerly Plume Hydraulic Capture, Additional Treatment, Additional Evaporation, Infiltration

Alternative 7 is Alternative 5 plus dewatering the Hole. The contaminant removal for Alternative 7 is therefore the same as for Alternative 5. Alternative 7 has the highest marginal cost ($9,566,420) (Table 11), which, like Alternative 5, is disproportionate to the modest VOC removal gains compared to baseline Alternative 2 (Table 8).

7.5 PREFERRED CLEANUP ACTION ALTERNATIVE

Alternative 6, which includes expanded MPE from the P1 zone, dewatering the Hole, targeted Roza aquifer pumping, and LFG system activation, is recommended as the preferred cleanup action for Ephrata Landfill for the following reasons:

1. It would provide comparably high VOC removal at a first-year cost per kg that is the third-lowest and a 10-year cost that is the second-lowest among the alternatives.
2. It should achieve compliance with cleanup standards at the POC within 20 years.
3. It should achieve compliance with cleanup standards in all areas outside the POC within 25 years.
4. It should fully disrupt contaminant transport from the P1 zone.
5. It should fully disrupt contaminant transport through the Hole, and particularly the transport of vinyl chloride.
6. It would directly remove contaminants from the northerly plume inside and outside the north POC and partly disrupt the Roza transport pathway.

Several of the other alternatives would also be suitable as the preferred alternative.

- Alternative 4, which does not include dewatering the Hole, warrants consideration because dewatering the Hole would add costs, but the proportion of offsite contaminant migration through the Hole is not well understood and might be negligible. This alternative would offer the same first- and 10-year contaminant removal rates and restoration time frame as Alternative 6 at a lower total cost and lower unit cost per kg of VOCs removed.
- Alternative 2, which does not include any groundwater extraction outside of the P1, would still achieve comparatively high contaminant removal in a reasonable restoration time frame. Since it would require the fewest new facilities, it would be the most straightforward to implement.
- Alternative 3, which includes dewatering the Hole, would achieve the same contaminant removal and restoration time frame as Alternative 2 with only slightly higher total cost. This is because the existing evaporation pond has sufficient capacity for expanded P1 discharges and the discharge from dewatering the Hole.

Alternatives 5 and 7, in contrast, would achieve negligible additional contaminant removal for disproportionately higher costs. It is difficult to assign any value to the attendant decreased restoration time frame compared to other alternatives.

The present worth of Alternative 6 is discussed in this section for comparison with costs in the 2012 draft FS. Alternative 6 present worth calculations are provided in Appendix H. Whereas the component and alternative costs presented in Sections 6 and 7 are in unadjusted 2018 dollars, the 2012 draft FS presented costs in present worth discounted at 7 percent. The 7-percent discount rate is used for new calculations but applied based on a 10-year time frame for active P1 remediation, a 20-year time frame for completion of other active remedial measures, and a 25-year time frame for compliance with cleanup standards. The resulting present worth of Alternative 6 is $12,619,000.

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Figures

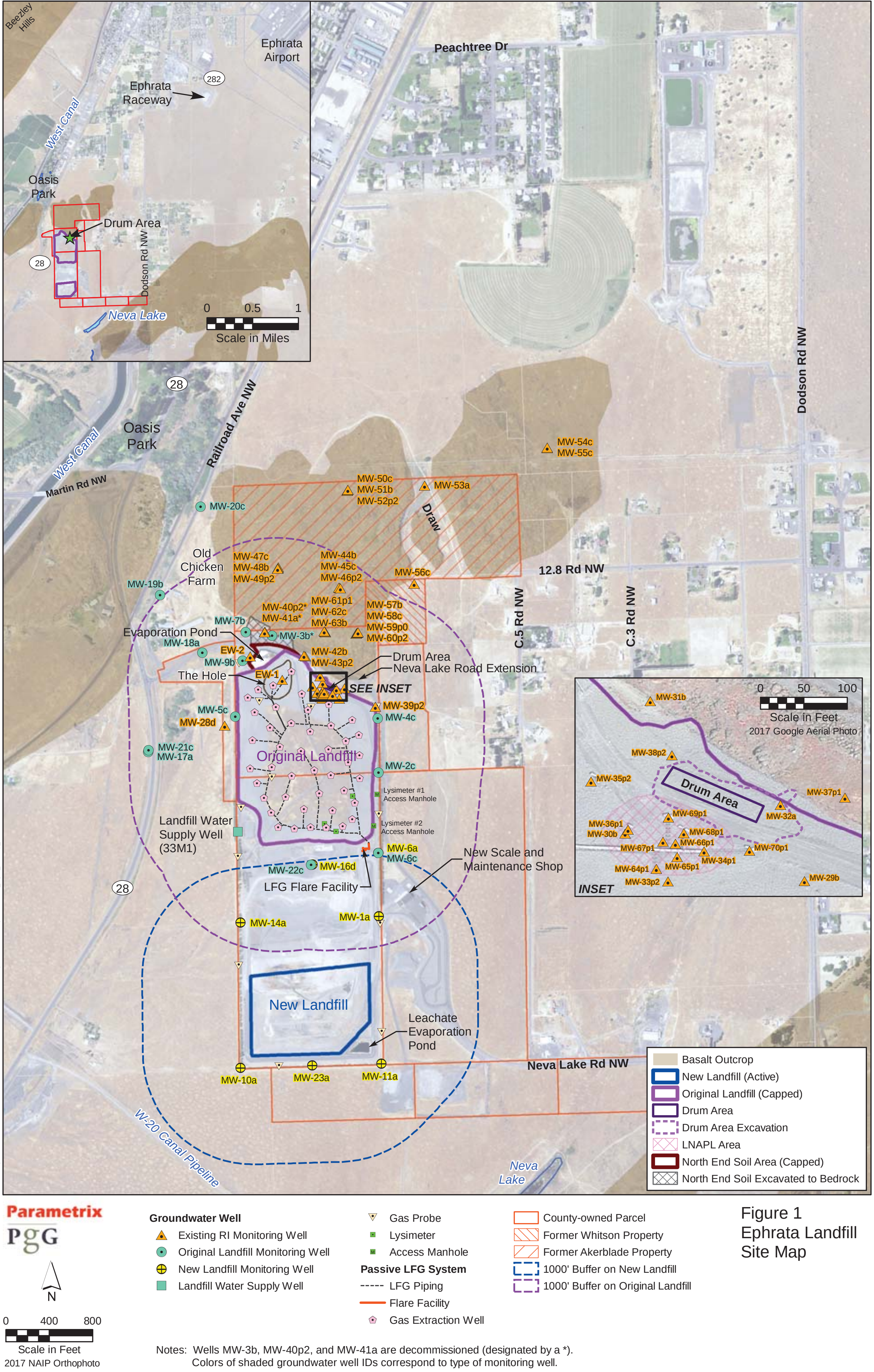
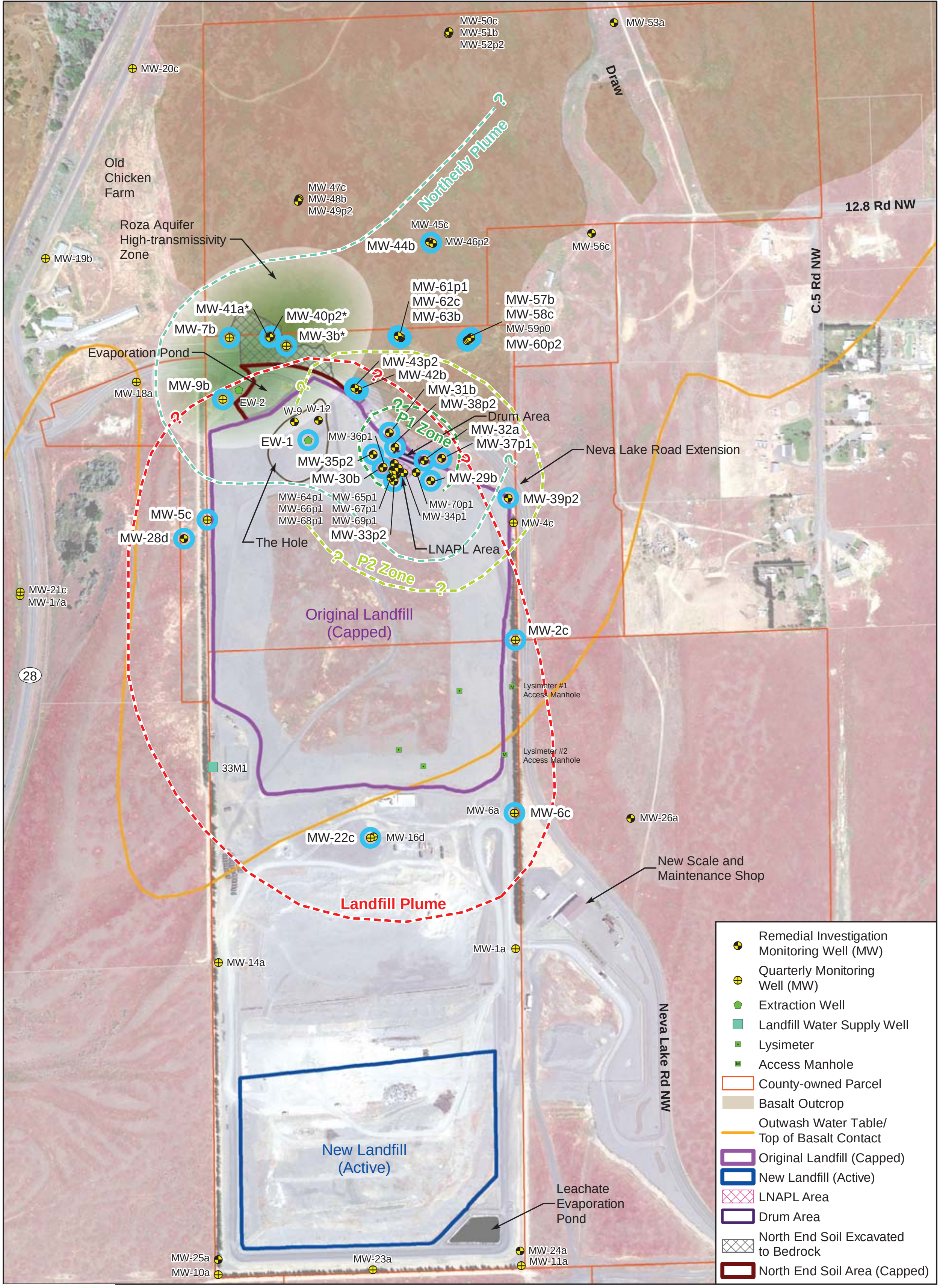


Figure 1
Ephrata Landfill
Site Map

Notes: Wells MW-3b, MW-40p2, and MW-41a are decommissioned (designated by a *).
Colors of shaded groundwater well IDs correspond to type of monitoring well.



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Parametrix
PGG

N

0 200 400
Scale in Feet
2011 NAIP Orthophoto

Approximate Extent of Groundwater Contamination (VOCs Above CULs)

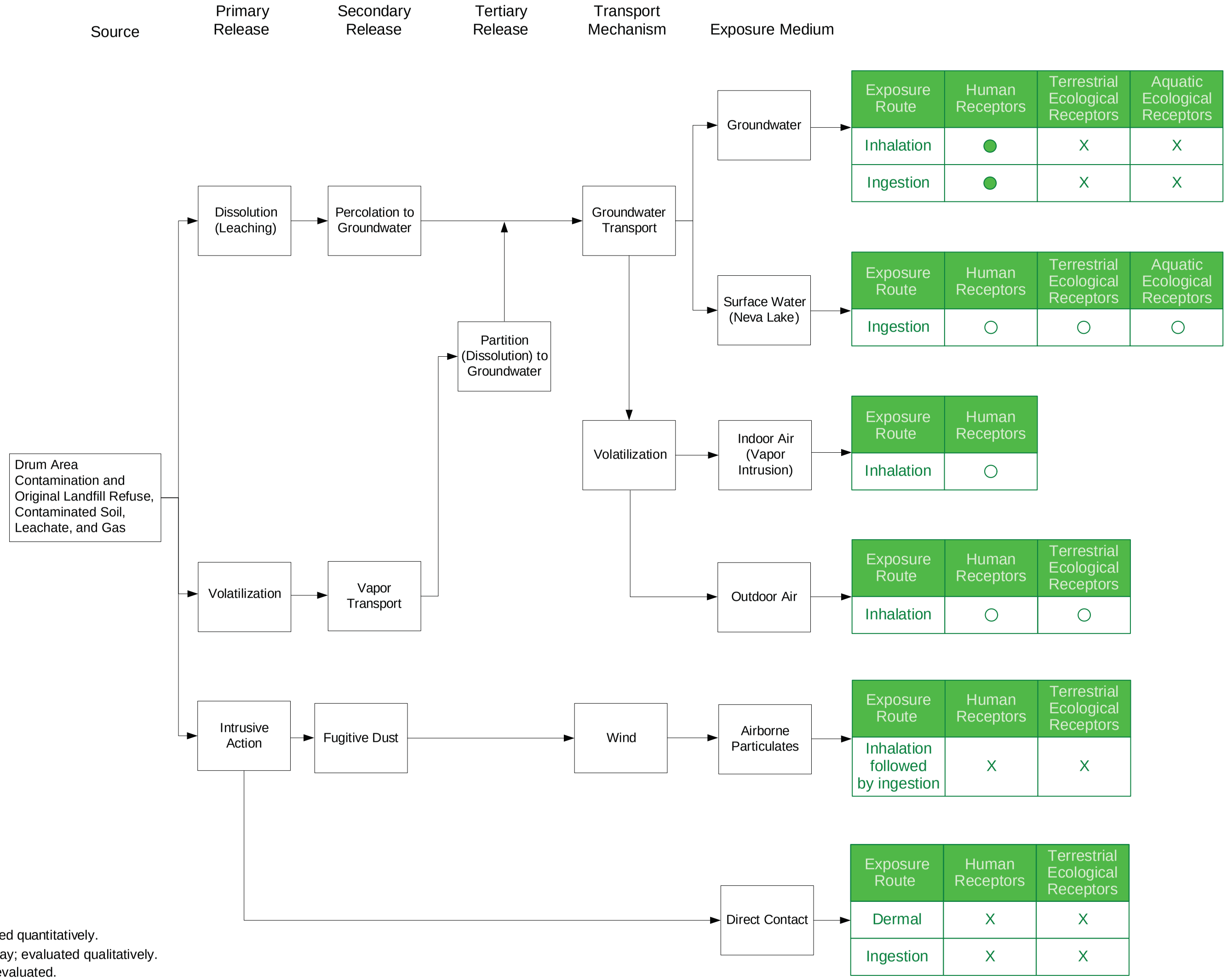
- P1 Zone
- P2 Zone
- Northerly Plume
- Landfill Plume

Roza Aquifer High-transmissivity Zone

Well Used to Identify IHSs

Note: Wells MW-3, MW-40p2, and MW-41a are decommissioned (designated by a *).

Figure 2
Groundwater Plumes



Exposure Route	Human Receptors	Terrestrial Ecological Receptors	Aquatic Ecological Receptors
Inhalation	●	X	X
Ingestion	●	X	X

Exposure Route	Human Receptors	Terrestrial Ecological Receptors	Aquatic Ecological Receptors
Ingestion	○	○	○

Exposure Route	Human Receptors
Inhalation	○

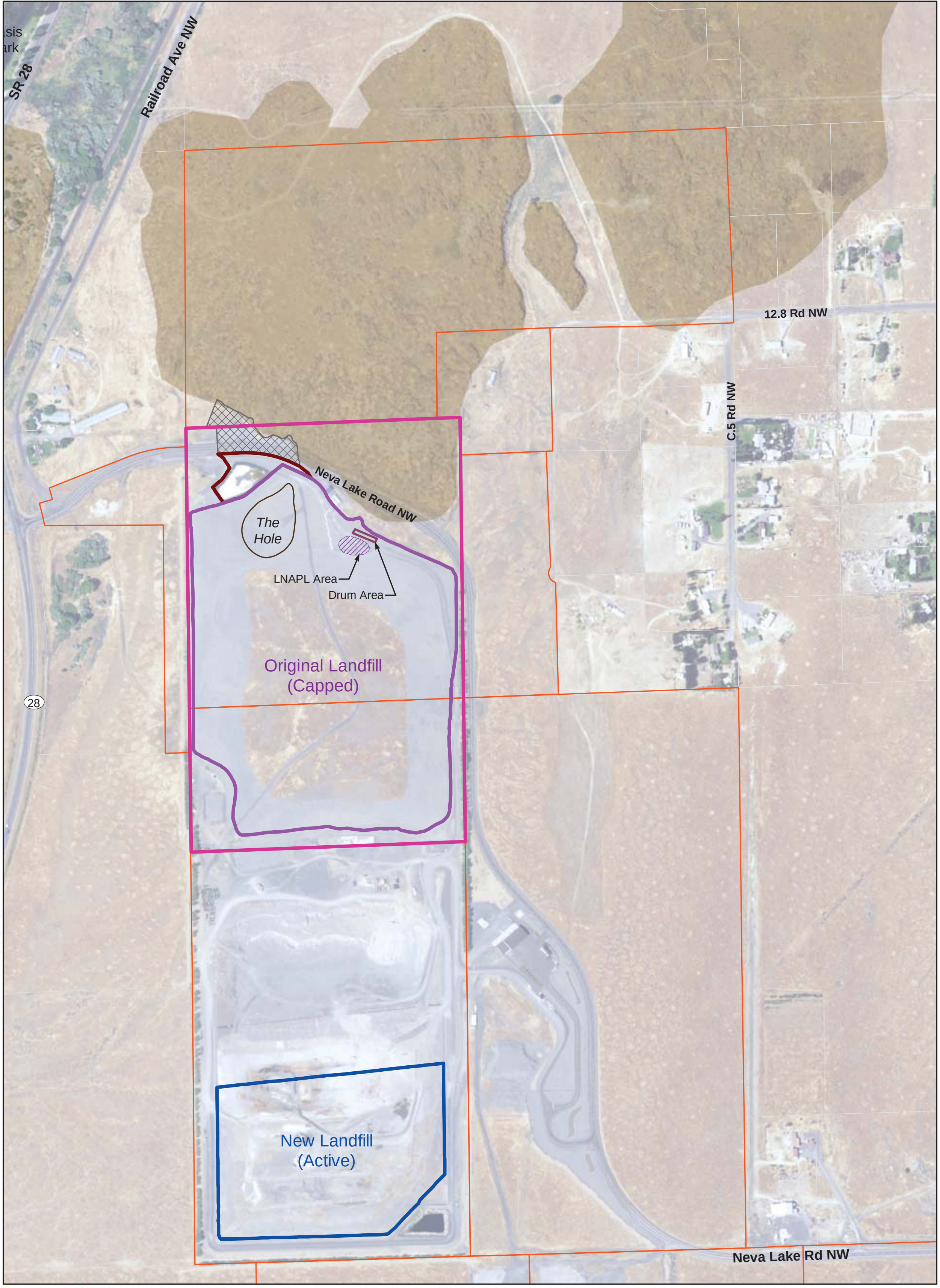
Exposure Route	Human Receptors	Terrestrial Ecological Receptors
Inhalation	○	○

Exposure Route	Human Receptors	Terrestrial Ecological Receptors
Inhalation followed by ingestion	X	X

Exposure Route	Human Receptors	Terrestrial Ecological Receptors
Dermal	X	X
Ingestion	X	X

● Complete exposure pathway; evaluated quantitatively.
○ Complete but minor exposure pathway; evaluated qualitatively.
X Incomplete exposure pathway; not evaluated.

Figure 3
Conceptual Site Model for Releases of Hazardous Substances at the Ephrata Landfill



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0 225 450

Scale in Feet

2011 NAIP Orthophoto

Groundwater Point of Compliance
Original Landfill (Capped)
New Landfill (Active)

▨ North End Soil Excavated to Bedrock
North End Soil Area (Capped)
County-owned Parcel
Basalt Outcrop

Figure 4
Ephrata Landfill
Groundwater Point
of Compliance

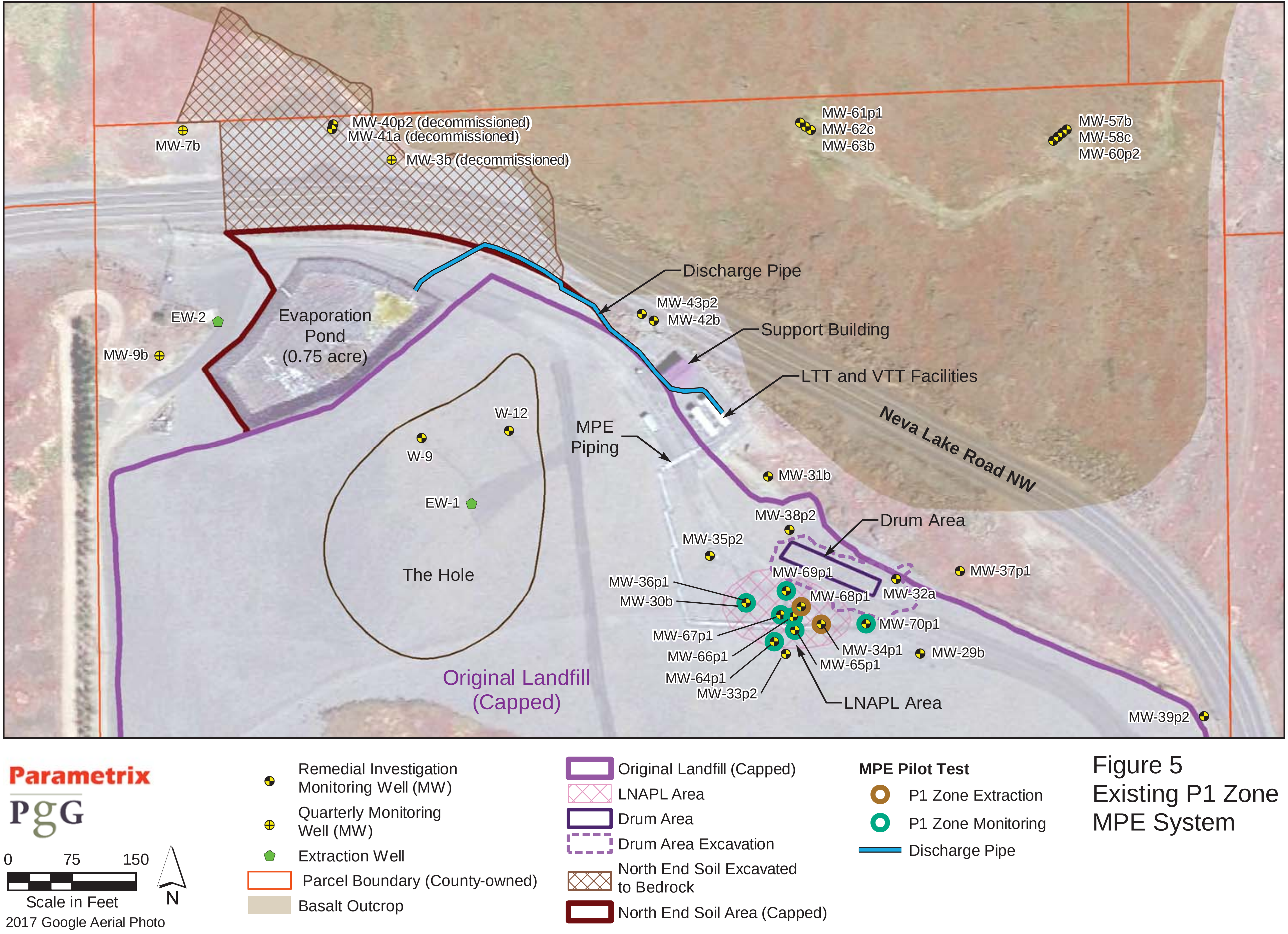

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Figure 5
Existing P1 Zone
MPE System

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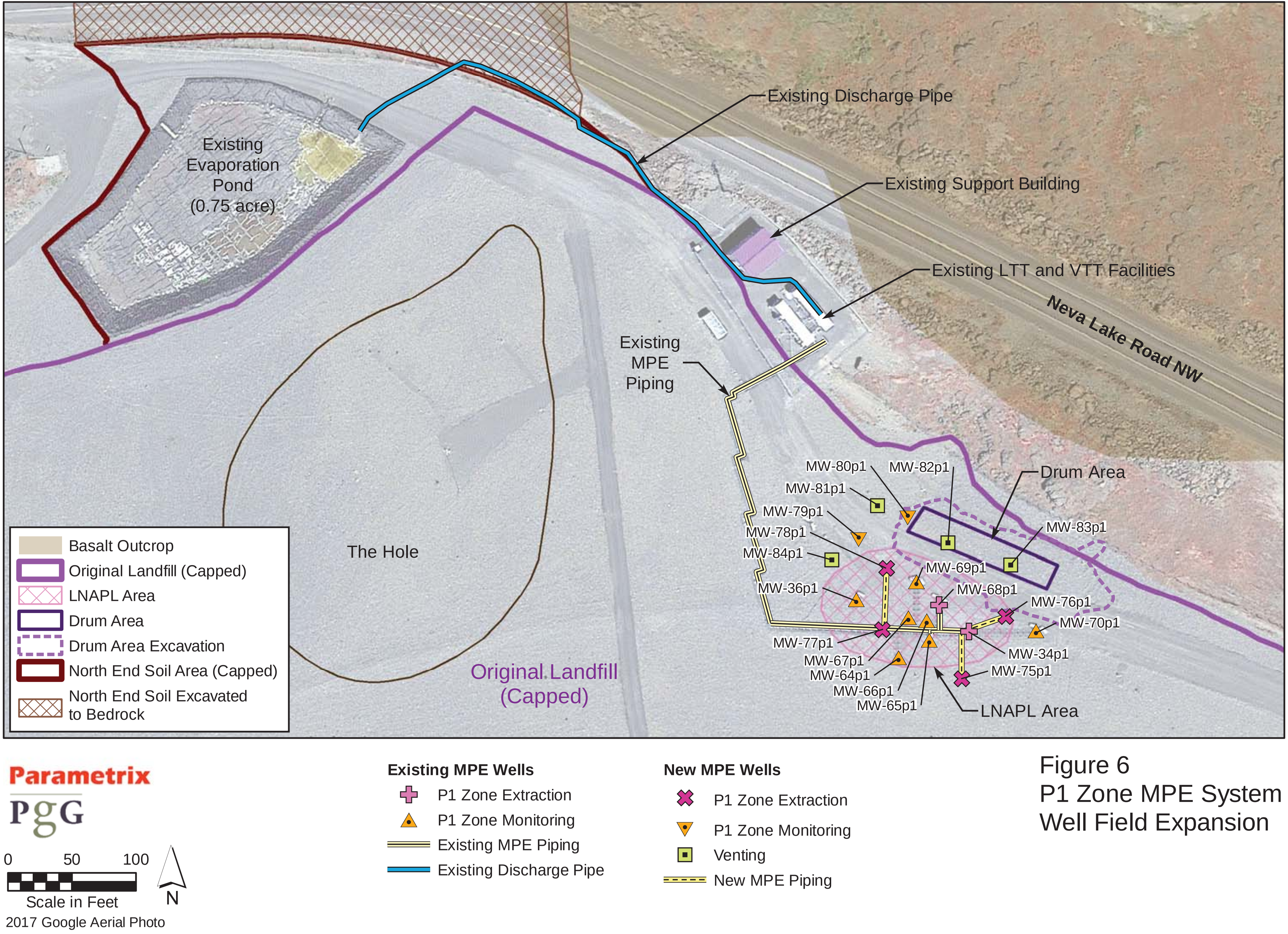
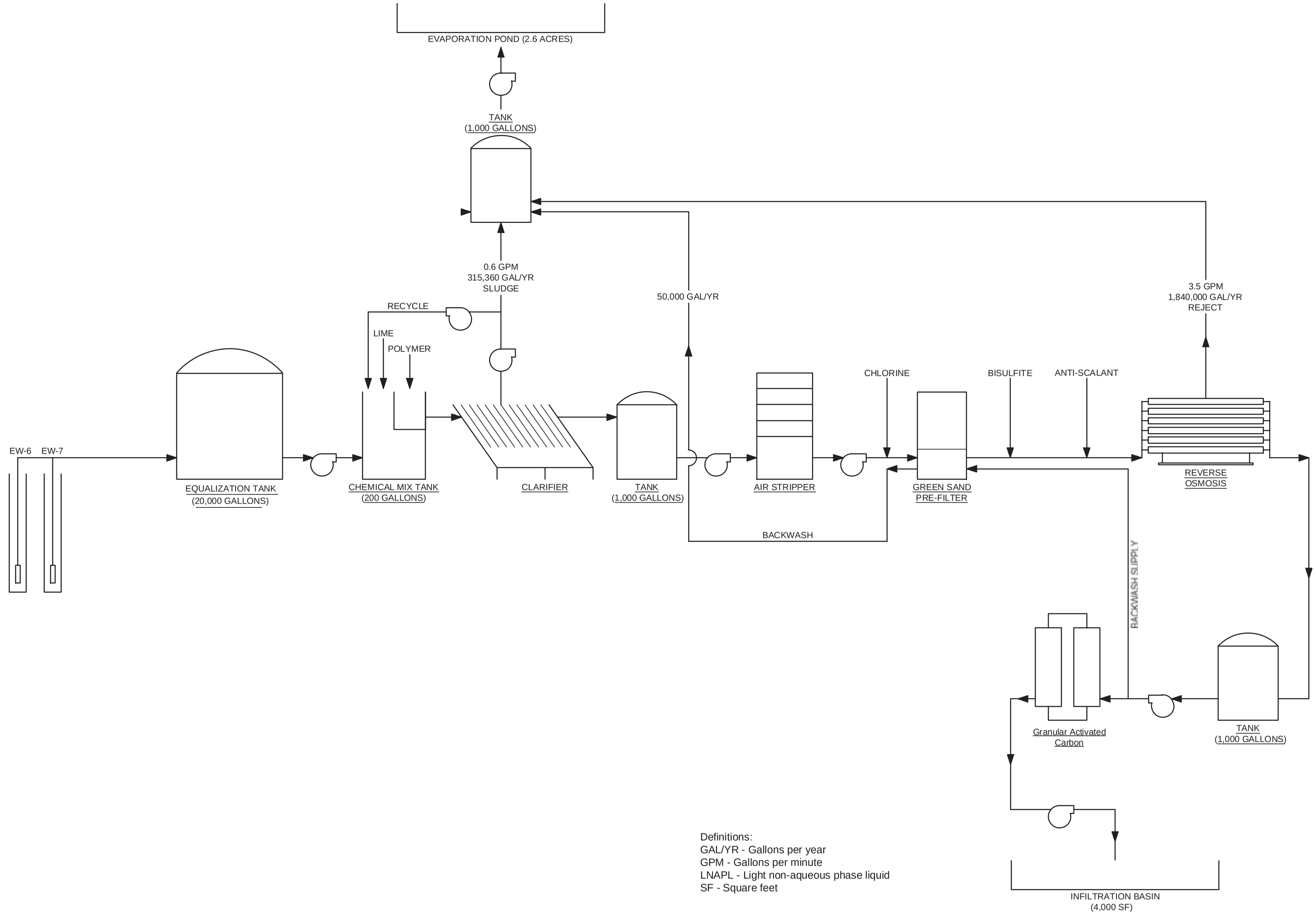


Figure 6
P1 Zone MPE System
Well Field Expansion

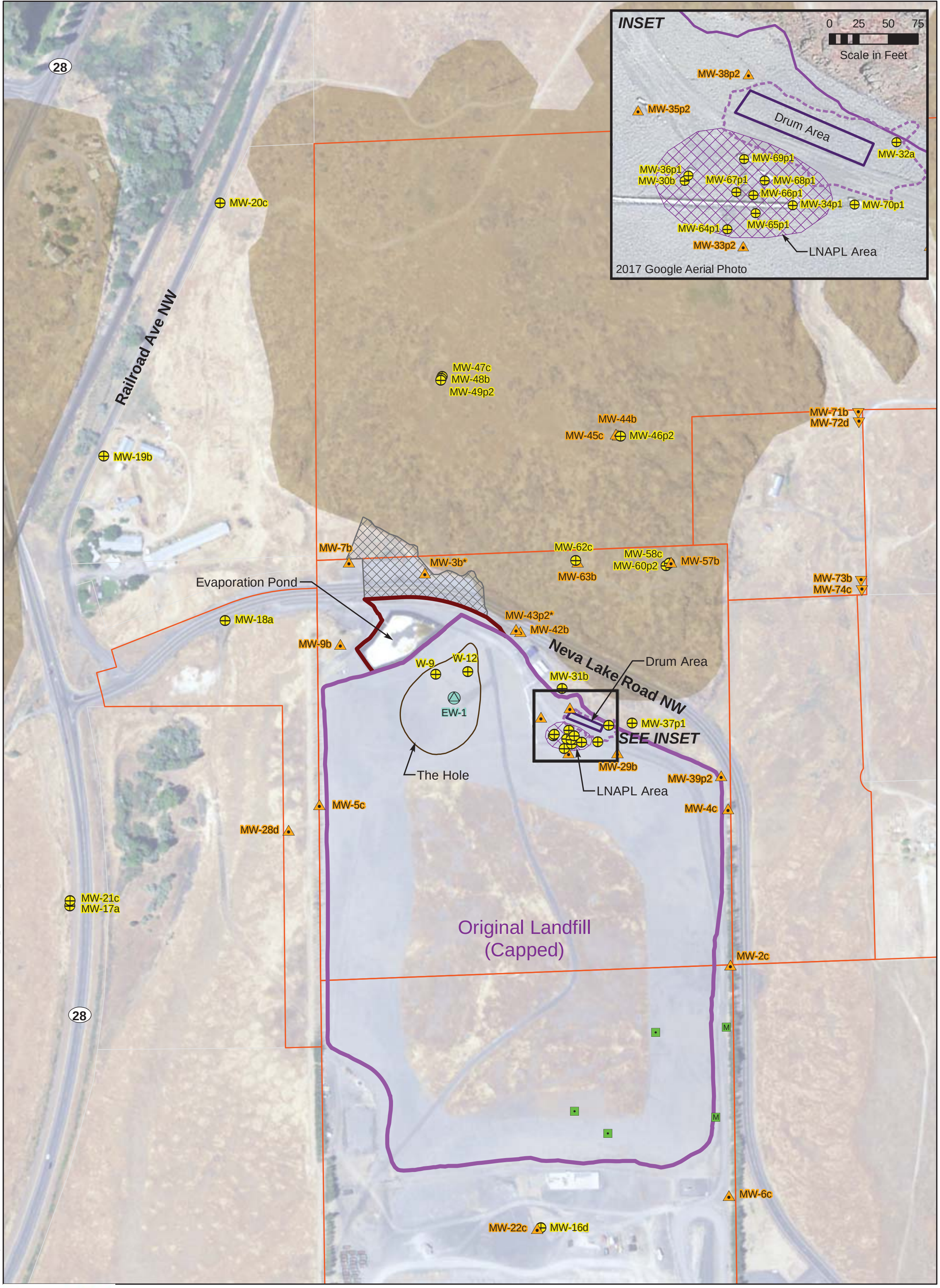


Definitions:
GAL/YR - Gallons per year
GPM - Gallons per minute
LNAPL - Light non-aqueous phase liquid
SF - Square feet

Parametrix

Notes:
Dimensions and capacities are based on planning-level engineering for FS purposes and are approximate.
Not to scale.

Figure 7
Pumped Groundwater Treatment System for Infiltration
Process Flow Diagram for the Ephrata Landfill



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Scale in Feet
2017 NAIP Orthophoto

Existing Monitoring Well
- ▲ Sample and Gauge
- ⊕ Gauge Only
- ▲ EW-1**

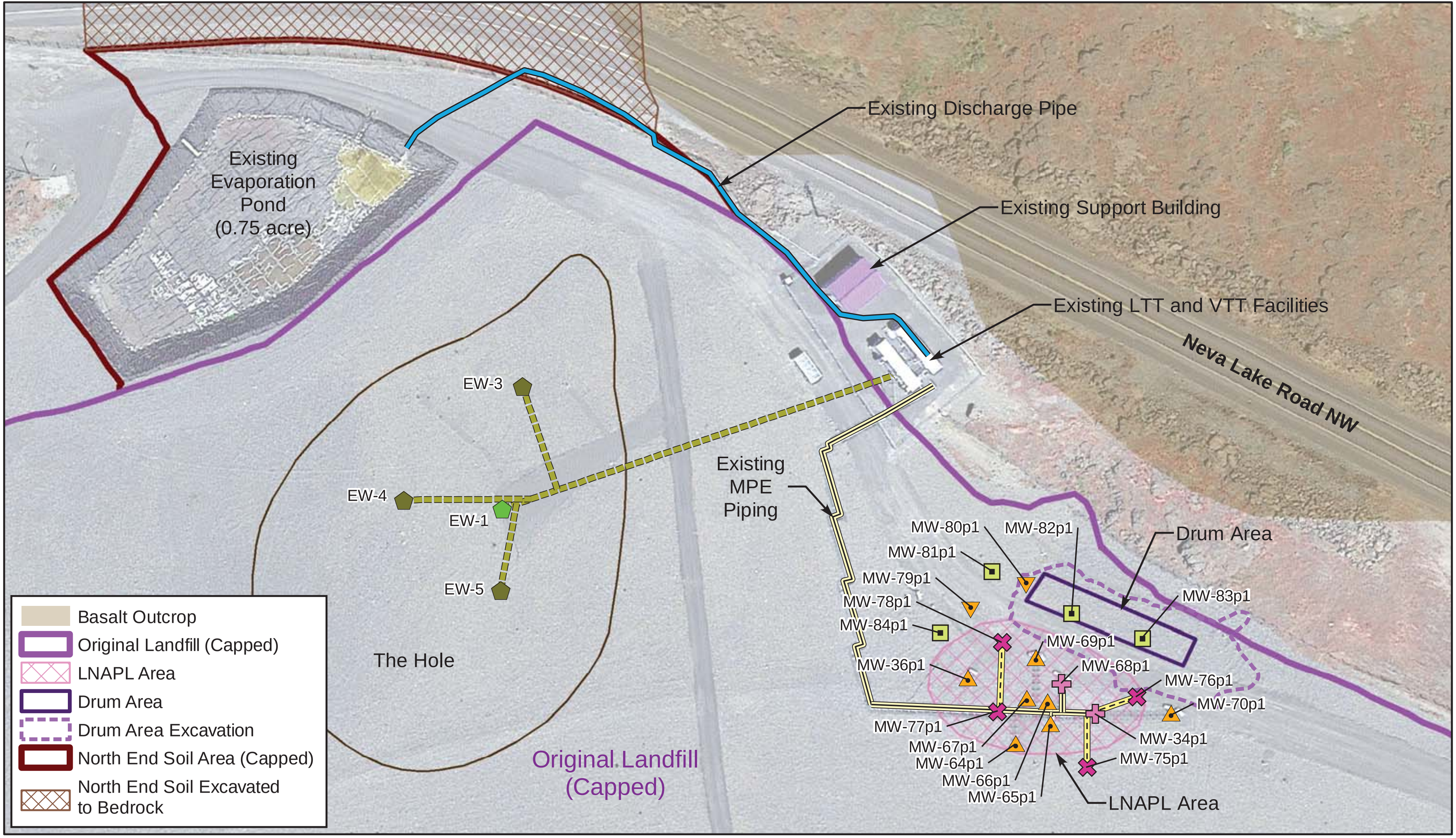
New Monitoring Well
- ▼ Sample and Gauge

- ▪ Lysimeter
- M Access Manhole
- ☐ County-owned Parcel
- ▨ Basalt Outcrop
- ☐ New Landfill (Active)
- ☐ Original Landfill (Capped)

- ▨ LNAPL Area
- ☐ Drum Area
- ☐ Drum Area Excavation
- ▨ North End Soil Excavated to Bedrock
- ☐ North End Soil Area (Capped)

Figure 8
Compliance Monitoring Wells Common to All Cleanup Action Alternatives

Notes: Wells MW-3b and MW-43p2 will be replaced (designated by a *).
** EW-1 sampled and gauged for Alternatives 1, 2, 4, and 5 and gauged only for Alternatives 3, 6, and 7.
Colors of shaded groundwater well IDs correspond to type of compliance monitoring well.



Existing MPE Wells
- ✚ P1 Zone Extraction
- ▲ P1 Zone Monitoring
- ═ Existing MPE Piping
- ━ Existing Discharge Pipe

New MPE Wells
- ✖ P1 Zone Extraction
- ▼ P1 Zone Monitoring
- ▣ Venting
- ╍ New MPE Piping

- ⬟ Existing Extraction Well
- ⬟ New Extraction Well
- ╍ New Groundwater and Air Piping

Parametrix
PgG

0 50 100
Scale in Feet
N
2017 Google Aerial Photo

Figure 9
Alternative 3
See Figure 1 for LFG System.

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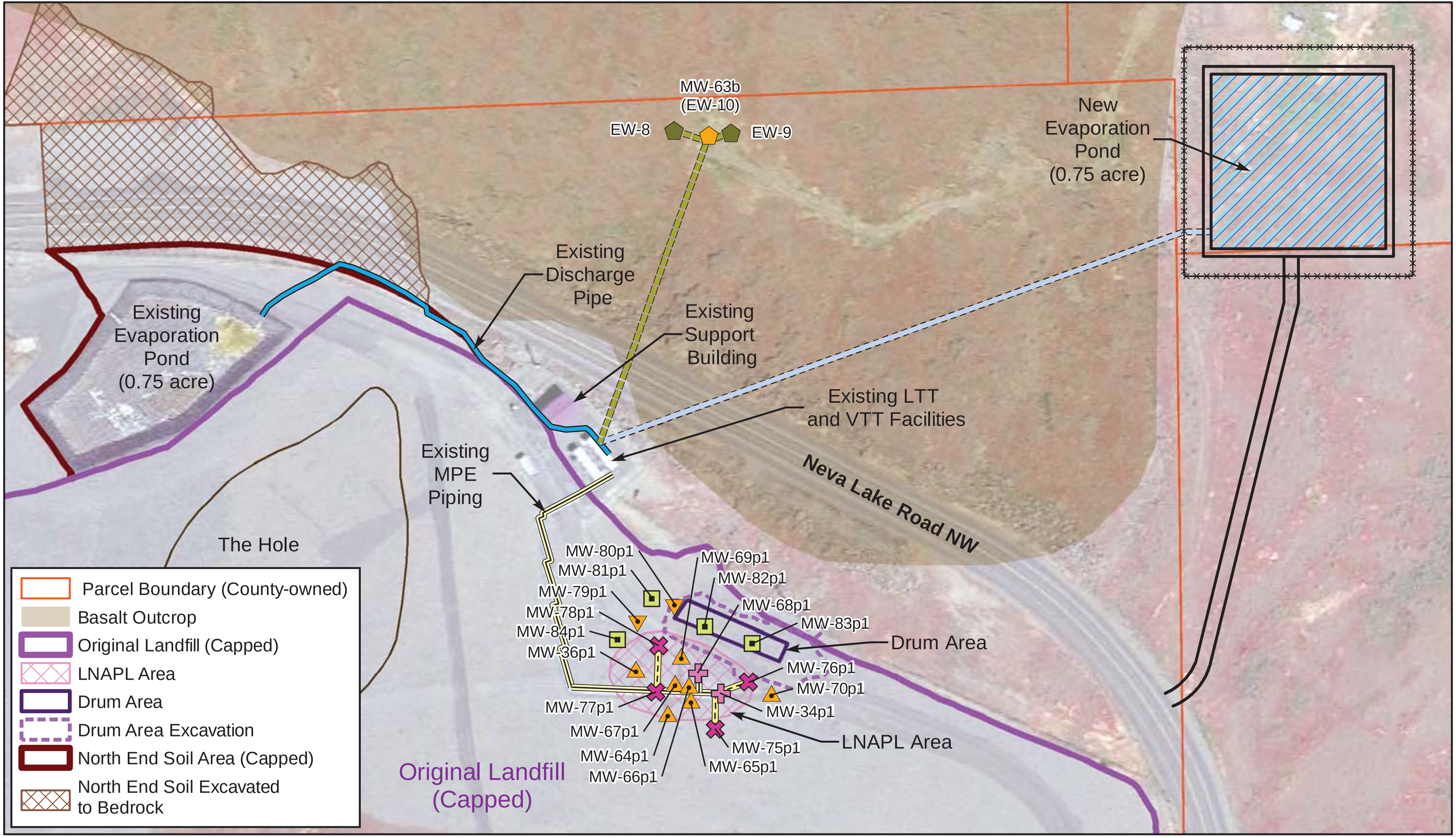

Parametrix

PGG

0 75 150
Scale in Feet
N
2017 Google Aerial Photo

Existing MPE Wells
- ✚ P1 Zone Extraction
- ▲ P1 Zone Monitoring
- ═ Existing MPE Piping
- ━ Existing Discharge Pipe

New MPE Wells
- ✖ P1 Zone Extraction
- ▼ P1 Zone Monitoring
- ▣ Venting
- ╌ New MPE Piping

- ⬟ Existing Monitoring Well*
- ⬟ New Extraction Well
- ▬ New Groundwater and Air Piping
- ╌ New Discharge Pipe
- ▨ Evaporation Pond
- ━ Access Road
- ×××× Chain Link Fence

* MW-63b would be replaced with an extraction well (EW-10).

Figure 10
Alternative 4

See Figure 1 for LFG System.

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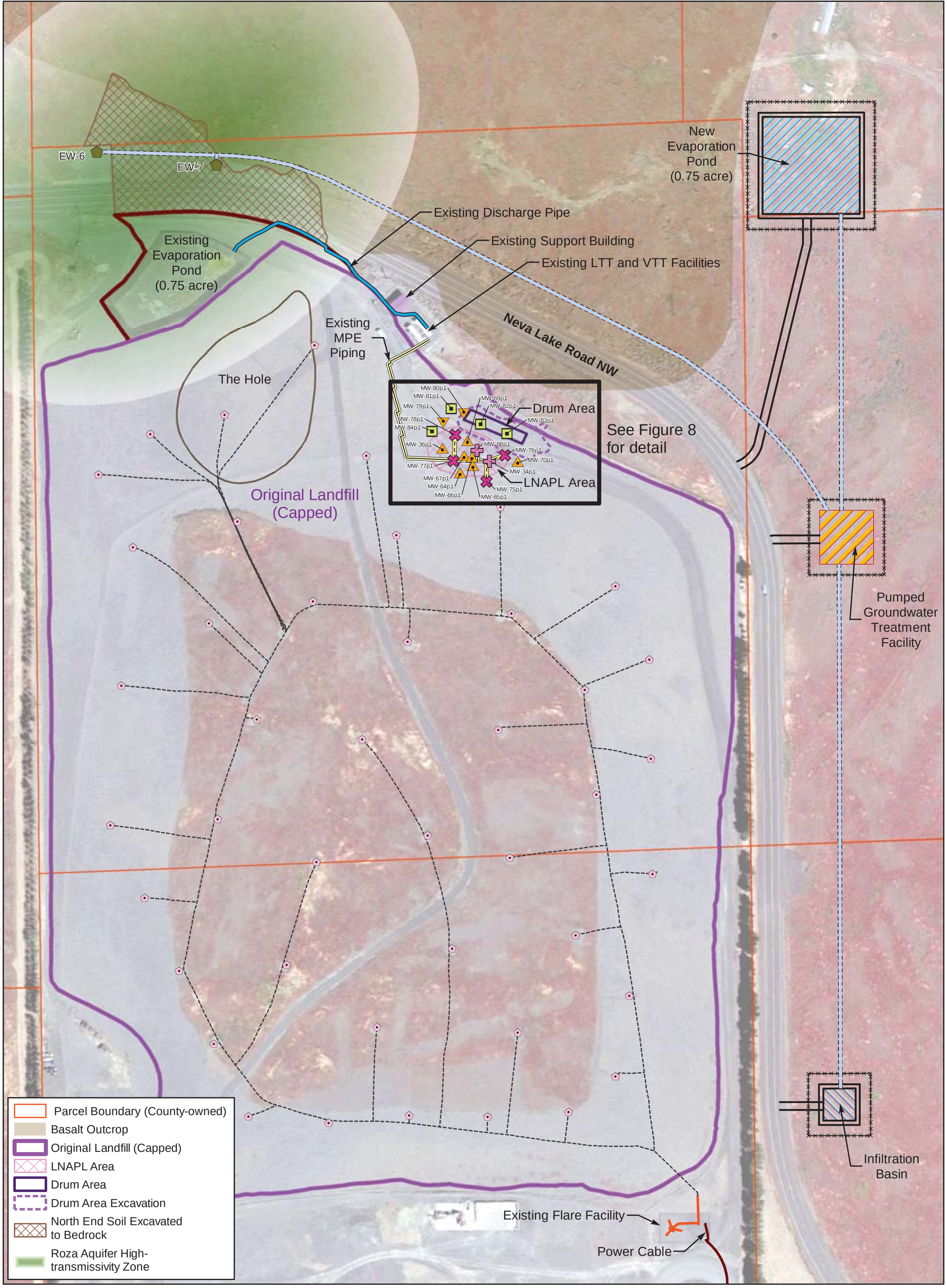

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Parametrix

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Existing MPE Wells
- ✚ P1 Zone Extraction
- ▲ P1 Zone Monitoring
- ═ Existing MPE Piping
- ━ Existing Discharge Pipe

New MPE Wells
- ✖ P1 Zone Extraction
- ▼ P1 Zone Monitoring
- ▣ Venting
- ═ New MPE Piping

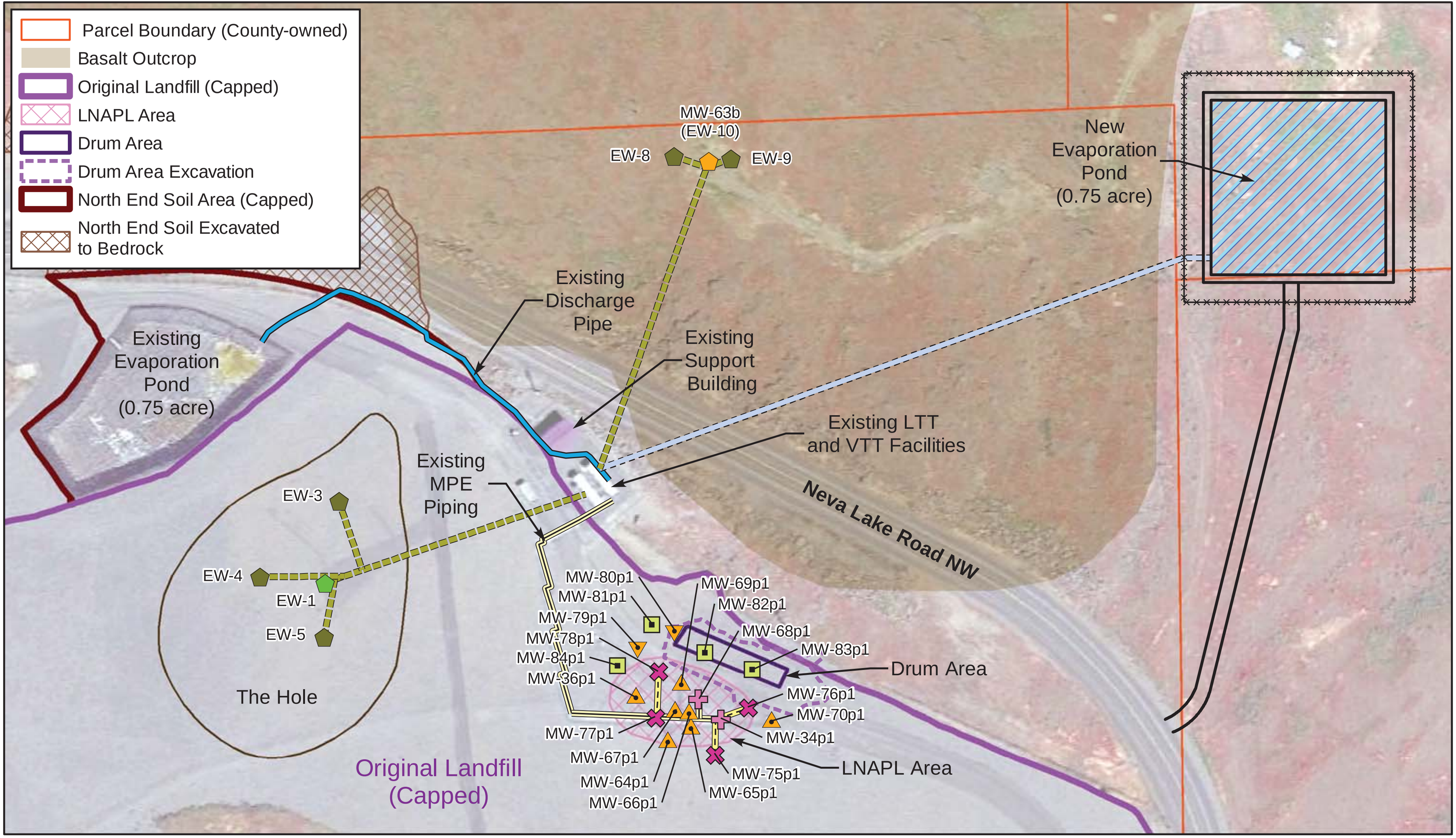
- ⬟ New Extraction Well
- ═ New Discharge Pipe
- ▨ Evaporation Pond
- ▨ Treatment Facility
- ▨ Infiltration Basin
- ━ Access Road
- ××× Chain Link Fence

LFG System
- ---- Existing LFG Piping
- ━ Existing Flare Facility
- ━ Power
- ⬟ Gas Extraction Well

N

0 175
Scale in Feet
2017 Google Aerial Photo

Figure 11
Alternative 5



Existing MPE Wells
- ✚ P1 Zone Extraction
- ▲ P1 Zone Monitoring
- ═ Existing MPE Piping
- ━ Existing Discharge Pipe

New MPE Wells
- ✖ P1 Zone Extraction
- ▼ P1 Zone Monitoring
- ▣ Venting
- ┅ New MPE Piping

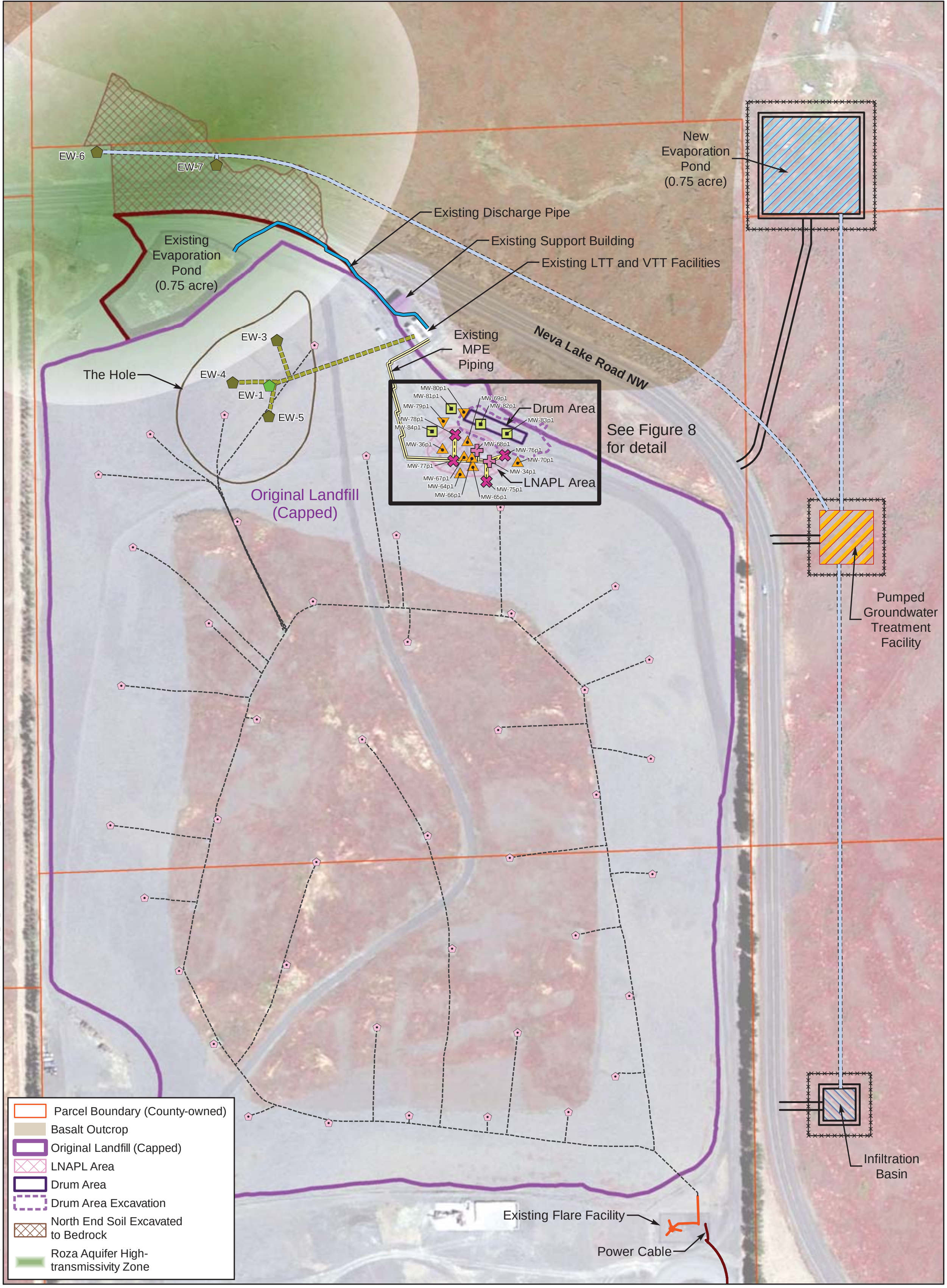
- ⬟ Existing Monitoring Well*
- ⬟ Existing Extraction Well
- ⬟ New Extraction Well
- ▬ New Groundwater and Air Piping
- ┅ New Discharge Pipe

- ▨ Evaporation Pond
- ━ Access Road
- ×××× Chain Link Fence

* MW-63b would be replaced with an extraction well (EW-10).

Figure 12
Alternative 6

See Figure 1 for LFG System.



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Parametrix
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Figure 13
Alternative 7

Tables

Table 1. Potential Applicable or Relevant and Appropriate Requirements

ARAR	Description	Applicability
Soil		
MTCA (WAC 173-340-740 and -173-340-747)	Regulates the investigation and cleanup of releases to the environment that may pose a threat to human health or the environment. Establishes cleanup levels for soil, including derivation of soil concentrations protective of groundwater.	MTCA cleanup levels are applicable to Site soil.
Groundwater		
EPA Underground Injection Control Regulations (40 CFR 144 and 146)	Regulates injection into underground sources of drinking water by specific classes of injection wells.	These regulations are relevant to the use of any cleanup technology involving injection into a drinking water aquifer.
Safe Drinking Water Act, Primary Drinking Water Regulations (40 CFR 141)	Protects the quality of public drinking water supplies through regulation of chemical parameters and constituent concentrations as MCLs.	MCLs are potentially relevant and appropriate where groundwater is a potential source of drinking water.
MTCA (WAC 173-340-720)	Regulates the investigation and cleanup of releases to the environment that may pose a threat to human health or the environment. Establishes cleanup levels for groundwater.	MTCA cleanup levels are applicable to Site groundwater.
State Water Code and Water Rights (Chapters 173-150 and 173-154 WAC)	Establishes rights of well owners to have adequate water supplies and establishes a permit program for groundwater withdrawal.	These regulations are applicable to groundwater extraction.
State Water Quality Standards for Ground Waters of the State of Washington (Chapter 173-200 WAC)	Protects the quality of ground waters for existing and future beneficial uses, including drinking water, through the regulation of chemical parameters and constituent concentrations as MCLs and MCL goals (MCLGs). Specifies how the point of compliance for meeting ground water quality criteria will be established.	MCLs and MCLGs are potentially relevant and appropriate where groundwater is a potential source of drinking water.
State Waste Discharge Permit Program (Chapter 173-216 WAC)	Requires that individual permits be obtained for discharge of materials from industrial, commercial, and municipal operations into ground and surface waters of the state and into municipal sewerage systems. This program does not apply to point source discharges regulated by the NPDES program (Chapter 371-220 WAC) or the Waste Discharge General Permit program (Chapter 173-226 WAC).	These regulations are potentially relevant to the discharge of treated groundwater.
Surface Water		
Clean Water Act Section 304 – Federal Ambient Water Quality (National Recommended Water Quality Criteria, November 2002) (EPA-822-R-02-047)	Provides chemical concentrations for acceptable ambient water quality.	These criteria are potentially relevant and appropriate to ambient surface water quality in, and point-source discharges to, surface water should cleanup activities result in a release to surface water.
Clean Water Act, NPDES (40 CFR 122-125) and Washington State NPDES Permit Program (WAC 173-220).	Requires that permits be obtained for point-source discharges of pollutants to surface water. Under this regulation, a point-source discharge to a surface water body cannot cause an exceedance of water quality standards in the receiving water body outside the mixing zone.	Substantive regulatory requirements of the NPDES permit program are potentially applicable to the direct discharge of treated groundwater to a surface water body.
Clean Water Act, National Toxics Rule (40 CFR 131.36)	Provides numeric criteria for priority toxic pollutants in point-source discharges to surface water.	This rule is potentially applicable to point-source discharges to surface water and landfill stormwater ditches should cleanup activities result in a release to surface water.
Clean Water Act, Pretreatment Regulations (40 CFR Part 503.5)	Limits pollutants in wastewater discharges to sanitary sewer systems to protect publicly owned treatment works from accepting wastewater that would damage their system or cause them to exceed their NPDES permit discharge limits.	These regulations are potentially applicable to the discharge of treated groundwater.
Stormwater Permit Program (40 CFR 122.26)	Requires use of BMPs and appropriate monitoring to ensure that stormwater runoff does not cause an exceedance of water quality standards in a receiving surface water body.	Substantive requirements of the general stormwater permit program for stormwater discharges associated with construction activities disturbing over 1 acre are potentially applicable to cleanup action components at the Site.
MTCA (WAC 173-340-730)	Regulates the investigation and cleanup of releases to the environment that may pose a threat to human health or the environment. Establishes cleanup levels for surface water.	MTCA cleanup levels may be applicable to the Site if cleanup activities result in a release to surface water.

Table 1. Potential Applicable or Relevant and Appropriate Requirements (continued)

ARAR	Description	Applicability
Stormwater Management (Chapter 173-220 WAC)	Requires use of BMPs and appropriate monitoring to ensure that stormwater runoff does not cause an exceedance of water quality standards in a receiving surface water body.	Substantive requirements of the general stormwater permit program for stormwater discharges associated with construction activities disturbing over 1 acre are potentially applicable to cleanup action components at the Site.
State Waste Discharge Permit Program (Chapter 173-216 WAC)	Requires that individual permits be obtained for discharge of materials from industrial, commercial, and municipal operations into ground and surface waters of the state and into municipal sewerage systems. This program does not apply to point source discharges regulated by the NPDES program (Chapter 371-220 WAC) or the Waste Discharge General Permit program (Chapter 173-226 WAC).	These regulations are potentially relevant to the discharge of treated groundwater.
Washington State Water Quality Standards for Surface Waters (Chapter 173-201A WAC)	Protects freshwater aquatic life by specifying protection criteria by surface water segment. Provides limitations on other parameters, such as turbidity, temperature, dissolved oxygen, and pH, for protection of organisms. Tributaries of waters whose uses are designated salmon and trout spawning, core rearing and migration, or extraordinary primary contact recreation are protected at the same level as the waters themselves.	Substantive requirements of this regulation are potentially applicable for cleanup action components affecting surface water.
Air		
National Ambient Air Quality Standards (40 CFR 50.6 and 50.12)	Provides acceptable ambient air quality levels for particulate matter and lead.	These standards are applicable to earth-moving activities, as well as treatment processes that may include mixing or other processes resulting in potential releases of particulates or lead.
National Emission Standards for Hazardous Air Pollutants (40 CFR 261)	Establishes specific emissions levels allowed for toxic air pollutants.	These standards are applicable to cleanup technologies that may emit toxic pollutants to the air.
Washington Clean Air Act and Implementing Regulations (Chapters 173-400, 173-460, 173-490 WAC)	Chapter 173-400 WAC: Requires air emissions at the Site boundary to fall below the acceptable source impact limit. Also requires control of fugitive dust emissions during construction and defines general emission discharge treatment requirements. Chapter 173-460 WAC: Requires systemic control of new sources emitting air pollutants. Chapter 173-490 WAC: Sets emission standards and source control for volatile organic compounds.	These regulations are applicable for air stripping and sparging cleanup technologies.
MTCA (WAC 173-340-750)	MTCA regulates the investigation and cleanup of releases to the environment that may pose a threat to human health or the environment. Establishes cleanup levels for air.	MTCA cleanup levels are applicable to outdoor and indoor air at the Site.
Miscellaneous		
Endangered Species Act (50 CFR 17 and 402)	Requires that federal agencies consider the effects of their proposed actions on federally listed species. Requires consultation between the agency proposing the action and the U.S. Fish and Wildlife Service or National Oceanic and Atmospheric Administration Fisheries, as appropriate. Requires preparation of a biological assessment to address the potential effects on listed species in the area and methods to minimize those effects.	The ESA is potentially applicable to cleanup actions at the Site because federally listed species could possibly use the area. Therefore, they could potentially be affected by cleanup actions conducted at the Site.
Native American Graves Protection and Repatriation Act (43 CFR 10)	Protects Native American burials from desecration through the removal and trafficking of human remains and “cultural items,” including funerary and sacred objects.	This Act is potentially applicable to cleanup actions at the Site because it is possible that the disturbance of Native American materials could occur as a result of work in subsurface excavations at the Site. Such materials are not known to be present at the Site, but could be inadvertently uncovered during soil removal.
National Historic Preservation Act (36 CFR 60, 63, and 800)	Requires federal agencies to consider the possible effects on historic sites or structures of actions proposed for federal funding or approval. Historic sites or structures as defined in the regulations are those on or eligible for the National Register of Historic Places, generally at least 50 years old.	This Act is potentially applicable to subsurface work at the Site. No such historic sites are known to be present in the area.
RCRA – Identification and Listing of Hazardous Waste (40 CFR 261-265, 270, and 271)	Defines those solid wastes that are subject to regulation as hazardous wastes, and lists specific chemical and industry-source wastes.	This Act is applicable to determining whether wastes are considered hazardous wastes under RCRA.
RCRA Land Disposal Restrictions (40 CFR 268)	Establishes standards for land disposal of RCRA hazardous waste. Requires treatment to diminish a waste’s toxicity and/or minimize contaminant migration.	These restrictions are applicable if cleanup activities generate and include land disposal of waste that is characterized as hazardous.

Table 1. Potential Applicable or Relevant and Appropriate Requirements (continued)

ARAR	Description	Applicability
RCRA Subtitle D Nonhazardous Waste Management Standards (40 CFR 257)	Develops standards for the management of non-hazardous wastes.	These standards are applicable if cleanup activities generate and include the management of non-hazardous wastes.
Department of Transportation of Hazardous Wastes (49 CFR 105-180)	Establishes specific U.S. Department of Transportation rules and technical guidelines for the off-site transport of hazardous materials.	These rules and guidelines are applicable to cleanup activities that involve the off-site transportation of hazardous waste.
SEPA (Chapter 192-11 WAC)	Requires a review of potential damage that occurs to the environment as a result of man's activities.	A SEPA checklist may be required prior to construction of a cleanup action component at the site.
Washington Hazardous Waste Management Act (Chapter 173-303 WAC)	Establishes standards for the generation, transport, treatment, storage, or disposal of designated dangerous waste in the state.	This regulation is potentially applicable to alternatives that would involve handling of contaminated media at the Site. The area of contamination policy allows contaminated media to be consolidated within the same area of a site without triggering RCRA or Washington dangerous waste regulations.
Washington Minimum Functional Standards for Solid Waste Handling (Chapter 173-304 WAC)	Defines requirements for solid waste management and disposal facilities. Establishes standards for handling and disposal of solid non-hazardous waste in Washington.	These standards apply to closure of a solid waste landfill, including capping, installation of a gas system, and environmental monitoring. Future site actions will comply with these regulations regardless of the cleanup action alternative selected.
Washington Solid Waste Handling Standards (Chapter 173-350 WAC)	Defines requirements for solid waste management and disposal facilities. Establishes standards for handling and disposal of solid non-hazardous waste in Washington.	These regulations are potentially applicable to solid non-hazardous wastes and are potentially relevant and appropriate to cleanup action components governing contaminated media management.
Washington Water Well Construction Act Regulations (Chapter 173-160 WAC)	Provides requirements for water well construction.	These regulations are potentially applicable to the installation, operation, or closure of supply, monitoring, and treatment wells at and around the Site.
Grant County Municipal Code (Title 13 – Water and Sewer)	Provides local standards for water supply and sanitary sewer.	This code is applicable if cleanup activities require a water supply or discharges to the sanitary sewer.
Grant County Municipal Code (Title 14 – Building and Construction)	Provides local standards for all building and construction activities, including stormwater management, building construction, and grading.	Plan reviews and building permits are not required, but planned facilities must meet substantive requirements of applicable codes.
Grant County Municipal Code (Title 24 – Environment)	Requires a review of potential damage that occurs to the environment as a result of man's activities in accordance with SEPA requirements.	A SEPA checklist may be required prior to construction of a cleanup action component.

Definitions:
BMP – Best management practice.
CFR – Code of Federal Regulations.
EPA – U.S. Environmental Protection Agency.
MCL – Maximum contaminant level.
MCLG – Maximum contaminant level goal.
MTCA – Model Toxics Control Act.
NPDES – National Pollutant Discharge Elimination System.
RCRA – Resource Conservation and Recovery Act.
SEPA – State Environmental Policy Act.
WAC – Washington Administrative Code.

Table 2. Identification of Initial Indicator Hazardous Substances for Groundwater

			MTCA Method B Groundwater (CLARC[1])					Groundwater				
Chemical	**CAS #**	**Units**	**Non-Cancer SFV**	**Src**	**Cancer SFV**	**Src**	**Minimum SFV**	**N**	**FOD (%)**	**Cmax**	**Cmax2**	**Initial IHS?[2]**
1,1,1-Trichloroethane	71-55-6	µg/L	16,000	I	n/a		16,000	401	9.7	5000	4200	NO
1,1,2-Trichloroethane	79-00-5	µg/L	32	I	0.77	I	0.77	401	3.2	35	25	NO
1,1-Dichloroethane	75-34-3	µg/L	1,600	P	7.7	C	7.7	401	96.3	5200	4500	**YES**
1,1-Dichloroethene	75-35-4	µg/L	400	I	n/a		400	408	52.9	920	710	**YES**
1,2-Dichloroethane (EDC)	107-06-2	µg/L	48	X	0.48	I	0.48	401	56.9	510	440	**YES**
1,2-Dichloropropane	78-87-5	µg/L	720	A	1.2	C	1.2	401	74.3	1200	1100	**YES**
1,2,4-Trimethylbenzene	95-63-6	µg/L	n/a		n/a		n/a	401	12.2	418	370	NO
1,3-Dichlorobenzene	541-73-1	µg/L	n/a		n/a		n/a	401	8.7	4.7	1.4	NO
1,3,5-Trimethylbenzene	108-67-8	µg/L	80	X	n/a		80	401	8.5	164	160	**YES**
1,4-Dichlorobenzene	106-46-7	µg/L	560	A	8.1	C	8.1	401	47.1	32	30	**YES**
2-Butanone (methyl ethyl ketone)	78-93-3	µg/L	4,800	I	n/a		4,800	401	2.2	9000	2600	NO
2-Hexanone	591-78-6	µg/L	n/a		n/a		n/a	401	0.7	340	73	NO
2-Methylphenol (o-cresol)	95-48-7	µg/L	400	I	n/a		400	24	8.3	510	150	NO
4-Isopropyltoluene	99-87-6	µg/L	n/a		n/a		n/a	401	3.7	3.67	3.6	NO
4-Methyl-2-pentanone (MIBK)	108-10-1	µg/L	640	H	n/a		640	401	2.7	3700	1000	NO
4-Methylphenol (p-cresol)	106-44-5	µg/L	800	A	n/a		800	29	10.3	430	170	NO
Acetone	67-64-1	µg/L	7,200	I	n/a		7,200	401	15.7	26000	12000	**YES**
Arsenic	7440-38-2	µg/L	4.8	I	0.058	I	0.058	347	89.6	16.4	16.3	**YES**
Benzene	71-43-2	µg/L	32	I	0.80	I	0.80	401	50.1	180	150	**YES**
bis(2-Ethylhexyl)phthalate	117-81-7	µg/L	320	I	6.3	I	6.3	80	13.8	13	11	**YES**
Bromobenzene	108-86-1	µg/L	n/a		n/a		n/a	401	14.0	4.0	3.2	NO
Chloroethane (ethyl chloride)	75-00-3	µg/L	n/a		n/a		n/a	401	43.9	1600	970	NO
Chloroform	67-66-3	µg/L	80	I	1.4	C	1.4	401	26.7	300	280	**YES**
Chloromethane	74-87-3	µg/L	n/a		n/a		n/a	401	1.0	1.6	1.3	NO
cis-1,2-Dichloroethene	156-59-2	µg/L	16	I	n/a		16	401	92.0	1600	1100	**YES**
Ethylbenzene	100-41-4	µg/L	800	I	n/a		800	401	16.7	1700	1610	**YES**
Iron, dissolved	7439-89-6	µg/L	11,200	P	n/a		11,200	352	39.8	34000	29400	**YES**
Manganese, dissolved	7439-96-5	µg/L	2,240	I	n/a		2,240	352	91.8	23100	22000	**YES**
Methylene chloride	75-09-2	µg/L	48	I	22	I	22	401	26.7	230	230	**YES**
n-Butylbenzene	104-51-8	µg/L	400	P	n/a		400	401	2.5	3.1	2.4	NO
Naphthalene	91-20-3	µg/L	160	I	n/a		160	401	8.7	301	81	NO
Nitrate as nitrogen	14797-55-8	mg/L as N	26	I	n/a		25.6	408	70.8	24.9	24.8	NO
o-Xylene	95-47-6	µg/L	1,600	S	n/a		1,600	401	18.2	2000	1800	**YES**
sec-Butylbenzene	135-98-8	µg/L	800	X	n/a		800	401	4.2	160	2.6	NO
Tetrachloroethene (PCE)	127-18-4	µg/L	48	I	21	I	21	408	78.2	31	24	**YES**
Toluene	108-88-3	µg/L	640	I	n/a		640	401	19.2	30000	24000	**YES**
Trichloroethene (TCE)	79-01-6	µg/L	4.0	I	0.54	I	0.54	408	94.1	180	61	**YES**
Vinyl Chloride	75-01-4	µg/L	24	I	0.029	I	0.029	408	73.3	1300	1100	**YES**
Xylene M+P	1330-20-7	µg/L	1,600	I	n/a		1,600	401	13.5	4800	4100	**YES**

Definitions:

Cmax – maximum (highest) concentration.

Cmax2 – 2nd highest concentration.

FOD – frequency of detection (as a percent).

IHS – indicator hazardous substance (FOD ≥ 5% AND [Cmax ≥ 2 x mininum SFV OR Cmax2 > minimum SFV]).

n/a – no SFV available (i.e., no toxicity value available).

SFV – standard formula value.

Src – source of toxicity value used to calculate SFV: I = IRIS, P = PPRTV; X = PPRTV appendix from EPA, A = ATSDR, C = CalEPA, H = HEAST, S = other EPA sources. Consistent with CLARC SFVs based on ATSDR and CalEPA sources (both Tier 3) are shown in red font.

Notes:

[1] MTCA Method B groundwater SFVs from Ecology's CLARC Database (August 2015 Update).

[2] Initial IHSs are chemicals that have at least 5% FOD and either (1) maximum concentration >= twice the minimum SFV or (2) maximum concentration and second highest concentration > minimum SFV.

Table 3. Refinement of Initial Indicator Hazardous Substances for Groundwater

Initial IHS	Retain as IHS?[1]	IHS Ranking[2]	N	FOD (%)	Frequency/ Mobility Rank	Maximum Value	Minimum SFV	Hazard Quotient	Toxicity Rank	Number of Results after 2012	Number of Exceedances after 2012	Percent Exceedances after 2012	Persistence Rank
1,1-Dichloroethane	**Yes**	**11**	**401**	**96.3**	**4**	**5,200**	**7.7**	**675**	**4**	**176**	**42**	**23.9**	**3**
1,1-Dichloroethene	No	3	408	52.9	2	920	400	2.3	1	176	0	0	0
1,2-Dichloroethane (EDC	**Yes**	**11**	**401**	**56.9**	**3**	**510**	**0.48**	**1,063**	**4**	**176**	**89**	**50.6**	**4**
1,2-Dichloropropane	**Yes**	**11**	**401**	**74.3**	**3**	**1,200**	**1.2**	**1,000**	**4**	**176**	**81**	**46.0**	**4**
1,3,5-Trimethylbenzene	No	1	401	8.5	0	164	80	2.1	0	176	4	2.3	1
1,4-Dichlorobenzene	**Yes**	**6**	**401**	**47.1**	**2**	**32**	**8.1**	**4.0**	**2**	**176**	**19**	**10.8**	**2**
Acetone	No	1	401	15.7	0	26,000	7,200	3.6	1	176	0	0	0
Arsenic	**Yes**	**11**	**347**	**89.6**	**4**	**16.4**	**0.058**	**283**	**3**	**134**	**129**	**96.3**	**4**
Benzene	**Yes**	**8**	**401**	**50.1**	**2**	**180**	**0.8**	**225**	**3**	**176**	**37**	**21.0**	**3**
bis(2-Ethylhexyl)phthalate	No	2	80	13.8	0	13	6.3	2.1	0	33	2	6.1	2
Chloroform	**Yes**	**6**	**401**	**26.7**	**1**	**300**	**1.4**	**214**	**3**	**176**	**10**	**5.7**	**2**
cis-1,2-Dichloroethene	**Yes**	**10**	**401**	**92.0**	**4**	**1,600**	**16**	**100**	**3**	**176**	**43**	**24.4**	**3**
Ethylbenzene	No	1	401	16.7	0	1,700	800	2.1	0	176	4	2.3	1
Iron, dissolved	No	3	352	39.8	2	34,000	11,200	3.0	1	175	0	0	0
Manganese, dissolved	**Yes**	**9**	**352**	**91.8**	**4**	**23,100**	**2,240**	**10**	**2**	**175**	**59**	**33.7**	**3**
Methylene chloride	No	3	401	26.7	1	230	22	10	2	176	0	0	0
o-Xylene	No	2	401	18.2	1	2,000	1600	1.3	0	176	3	1.7	1
Tetrachloroethene (PCE)	No	3	408	78.2	3	31	21	1.5	0	176	0	0	0
Toluene	No	5	401	19.2	1	30,000	640	47	2	176	6	3.4	2
Trichloroethene (TCE)	**Yes**	**12**	**408**	**94.1**	**4**	**180**	**0.54**	**333**	**4**	**176**	**97**	**55.1**	**4**
Vinyl Chloride	**Yes**	**11**	**408**	**73.3**	**3**	**1,300**	**0.029**	**44,828**	**4**	**176**	**135**	**76.7**	**4**
Xylene M+P	No	2	401	13.5	0	4,800	1600	3	1	176	4	2.3	1

Definitions:

FOD – frequency of detection (as a percent).

N – number of results.

SFV – standard formula value.

Notes:

[1] IHS if IHS Ranking is 6 or higher.

[2] IHS Ranking = Frequency/Mobility Rank + Toxicity Rank + Persistence Rank.

Table 4. Development of Initial Groundwater Cleanup Levels

			MTCA Method B Groundwater		Goundwater ARARs		Downward-adjusted ARARs			
Indicator Hazardous Substance	**CAS #**	**Units**	**Non-Cancer SFV**	**Cancer SFV**	**Federal Primary MCL**	**State Primary MCL**	**Adjusted Minimum ARAR[1]**	**Hazard Quotient**	**Excess Cancer Risk**	**Initial Cleanup Level**
1,1-Dichloroethane	75-34-3	µg/L	1,600	7.7	n/a	n/a	n/a	***No MCL available.***		7.7
1,2-Dichloroethane (EDC)	107-06-2	µg/L	48	0.48	5	5	4.8	0.1000	1.00E-05	4.8
1,2-Dichloropropane	78-87-5	µg/L	720	1.2	5	5	5	0.0069	4.17E-06	5
1,4-Dichlorobenzene	106-46-7	µg/L	560	8.1	75	75	75	0.1339	9.26E-06	75
Arsenic	7440-38-2	µg/L	4.8	0.058	10	10	0.58	0.1208	1.00E-05	0.58
Benzene	71-43-2	µg/L	32	0.80	5	5	5	0.1563	6.25E-06	5
Chloroform	67-66-3	µg/L	80	1.4	80	80	14	0.1750	1.00E-05	14
cis-1,2-Dichloroethene	156-59-2	µg/L	16	n/a	70	70	16	1.0000	---	16
Manganese, dissolved	7439-96-5	µg/L	2,240	n/a	n/a	n/a	n/a	***No MCL available.***		2,240
Trichloroethene (TCE)	79-01-6	µg/L	4.0	0.54	5	5	4	1.0000	7.41E-06	4
Vinyl Chloride	75-01-4	µg/L	24	0.029	2	2	0.29	0.0121	1.00E-05	0.29

Definitions:

ARAR – applicable or relevant and appropriate requirement.

MCL – maximum contaminant level.

n/a – no SFV available (i.e., no toxicity value available).

SFV – standard formula value.

Notes:

[1] Shaded cells identify minimum ARARs that were downward-adjusted for hazard and/or cancer risk.

Table 5. Development of Proposed Groundwater Cleanup Levels for the Ephrata Landfill

Indicator Hazardous Substance	CAS #	Units	Initial CUL	Backgr. Conc.	Proposed Downward-adjusted CUL	Excess Cancer Risk	Toxic Effect-specific Hazard Quotients (Ingestion)														
							Cardiovascular	Dermal	Developmental	Endocrine System	Gastrointestinal	Hematologic	Hepatic	Immune	Musculoskeletal	Nervous	Ocular	Reproductive	Respiratory	Urinary	Other
1,1-Dichloroethane	75-34-3	µg/L	7.7	-	7.7	1.00E-06	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0048	-
1,2-Dichloroethane (EDC)	107-06-2	µg/L	4.8	-	0.48	1.00E-06	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0100	-
1,2-Dichloropropane	78-87-5	µg/L	5	-	1.2	1.00E-06	-	-	-	-	-	-	-	-	0.0017	-	-	-	-	-	-
1,4-Dichlorobenzene	106-46-7	µg/L	75	-	8.1	1.00E-06	-	-	-	-	-	-	0.0145	-	-	-	-	-	-	-	-
Arsenic	7440-38-2	µg/L	0.58	14.7	14.7	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
Benzene	71-43-2	µg/L	5	-	0.8	1.00E-06	-	-	-	-	-	-	-	0.0250	-	-	-	-	-	-	-
Chloroform	67-66-3	µg/L	14	-	1.4	1.00E-06	-	-	-	-	-	-	0.0175	-	-	-	-	-	-	-	-
cis-1,2-Dichloroethene	156-59-2	µg/L	16	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9375	0.9375
Manganese, dissolved	7439-96-5	µg/L	2240	32	2240	-	-	-	-	-	-	-	-	-	-	1.0000	-	-	-	-	-
Trichloroethene (TCE)	79-01-6	µg/L	4	-	0.54	1.00E-06	0.1350	-	0.1350	-	-	-	-	-	-	-	-	-	-	-	-
Vinyl Chloride	75-01-4	µg/L	0.29	-	0.087	3.00E-06	-	-	-	-	-	-	0.0036	-	-	-	-	-	-	-	-
Total Sitewide Risk/Hazard						**1.00E-05**	**0.1350**	**0.0000**	**0.1350**	**0.0000**	**0.0000**	**0.0000**	**0.0356**	**0.0250**	**0.0017**	**1.0000**	**0.0000**	**0.0000**	**0.0000**	**0.9523**	**0.9375**

Definitions:

CUL – cleanup level.
n/a – not applicable.

Notes:

[1] Since the background concentration for dissolved arsenic (14.7 µg/L; see Appendix E) is higher than the lowest applicable standard (and PQL), the CUL cannot be set lower than the background level (per WAC 173-340-720(5)), and this IHS is not included in the calculations for total site risk and hazard.

Table 6. Screening of Groundwater Cleanup Technologies and Process Options

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
Source Area Groundwater (volatile organic compounds [VOCs])	Reduce or eliminate human exposure through ingestion of groundwater containing Site contaminants at concentrations that exceed cleanup levels (CULs). Prevent further migration of Site contaminants in concentrations exceeding CULs toward drinking water sources through source removal and containment.	Land Use Controls	Land Use Controls	Not Applicable.	This control is effective because it restricts the use of groundwater. It does not directly address contaminant removal or treatment.	This is an acceptable method for preventing human contact with hazardous media. It can be difficult to implement due to potential public resistance and the necessary cooperation of multiple agencies and local governments. Low O&M requirements.	Low	**Retained.**
		Containment	Vertical Barriers	**Slurry Wall—**A physical barrier that contains contaminated groundwater or diverts it from a downgradient receptor.	This is an effective technology for preventing horizontal migration of contaminants. It provides containment only; it does not treat groundwater or provide source removal. Because no active treatment is occurring, additional cleanup action may be required to control contaminant concentrations. Degradation of the slurry wall over time may occur.	This is a common, well-established, and accepted technology. It may be difficult to implement due to subsurface conditions and the complex basalt geology of the site. This approach has average O&M requirements.	High	Rejected due to implementability issues and cost.
			Hydraulic Containment	**Pumping—**Uses groundwater pumping to form a barrier and extract groundwater for treatment.	This is an effective technology for preventing contaminant migration. Groundwater modeling is often necessary to design a system to adequately prevent contaminant migration. It must be combined with a treatment technology for the extracted groundwater. This approach may be effective at the site for groundwater migration control if applied to specific aquifers. This is also an effective technology for dewatering of solid waste materials in the Hole and reducing the leaching potential of contaminants to groundwater.	This is a common, well-established, and accepted technology. It may be difficult to implement due to subsurface conditions and the complex basalt geology of the site. However, it may be easier to implement downgradient in the outwash material. This approach has high O&M requirements.	Medium to High	**Retained.**
			Active Landfill Gas Extraction	**Landfill Gas System Enhancements—**Extracts landfill gas using a vacuum-blower system, and destroys the extracted gas using a flare system.	This system is technically feasible and has been effective at landfills, including the Hansville Landfill in Hansville, Washington. It has been shown to be effective as a source control technique by reducing vinyl chloride and other VOC concentrations in groundwater within the covered landfill. However, Ephrata Landfill has experienced multiple refuse fires and the quality of gas available for extraction is poor. This technology would have an effect on the landfill plume, but a negligible effect on the northerly plume. LFG activation would tend to reduce methane in the MPE system. Vinyl chloride concentrations in original landfill gas are higher than in P1 vapor.	This common landfill technology is easy to implement, and the existing system is designed for conversion to an active system. However, the existing passive system is not designed for the higher air flows necessary to affect the northerly plume and cannot operate the old landfill and new landfill in tandem. This approach has average O&M requirements.	Medium	**Retained**, since reduction of methane in the MPE system would improve safety and might reduce vapor phase vinyl chloride movement from the original landfill to the P1 zone during soil vapor extraction (SVE).
		Collection/Treatment	*Ex-situ* Biological Treatment (pump and treat)	**Bioreactors—**Generically, a system that degrades contaminants in groundwater and soil with microorganisms.	A bioreactor may be an effective technology for treating chlorinated VOCs, but it is mostly in the pilot-testing phase. Bioreactors are prone to upset. Nuisance microorganisms can predominate and reduce treatment effectiveness. Low ambient temperatures can reduce the biodegradation rate.	Bioreactors are a well-developed technology that has been used in the treatment of municipal and industrial wastewater; however, only recent studies have been performed to evaluate the effectiveness of bioreactors in treating groundwater from hazardous waste sites. Although not commonly used for chlorinated compounds, several successful pilot projects have been completed. There are	High	Rejected due to effectiveness and implementability issues and cost.

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
						potential regulatory issues related to volatilization to the atmosphere. This approach has average O&M requirements.		
			Ex-situ Physical/Chemical Treatment (pump and treat)	**Air Stripping—**Removes VOCs from water by greatly increasing the surface area of the contaminated water exposed to air and inducing volatilization.	Air stripping is an effective technology for removing VOCs from groundwater. It is effective for removing more miscible compounds, such as vinyl chloride and methylene chloride. This technology does not destroy contaminants; VOCs are transferred directly from water to air. Additional waste streams are generated that require treatment.	This is a common, well-established, and accepted technology. Off-gas treatment by activated carbon adsorption or catalytic oxidation may be needed. This approach has high O&M requirements, including periodic column cleaning.	Medium	**Retained.**
				Adsorption – GAC—Removes contaminants by passing contaminated water through granular activated carbon (GAC).	GAC is an effective technology for removing most VOCs; however, its effectiveness is limited for water-soluble compounds, such as dichloroethane, acetone, and various ketones. It could potentially be used as a polishing step following treatment using a technology more applicable to water-soluble compounds. Carbon has a short-term duration, especially for high contaminant concentrations and would require a high frequency of O&M. This process requires transport and disposal or regeneration of spent carbon. This would be an effective technology for treatment of PCE and other less water-soluble compounds in groundwater.	This is a common, well-established, and accepted technology that is readily implementable. Logistical and economic disadvantages arise from the need to transport and decontaminate spent carbon. This approach has high O&M requirements, including monitoring of influent and effluent streams, regeneration and replacement of carbon, and backwashing.	Medium to High	**Retained.**
				Advanced Oxidation - UV Treatment—Uses ultraviolet (UV) oxidation as a destruction process to oxidize VOCs in water.	The system does not destroy all VOCs; instead, the contaminants may be vaporized and would require additional treatment.	UV treatment is an innovative groundwater treatment technology that has been used in full-scale groundwater treatment application for more than 10 years. Energy requirements can be very high. This approach has high O&M requirements.	High	Rejected due to effectiveness issues and cost.
				Separation – Filtration, Reverse Osmosis, and Other Membrane Processes—Separates contaminants from water by pressure-gradient forces or filtration.	This is an effective technology for removing VOCs from groundwater. Potential issues arise with interference from floating products, such as oil. Additional waste streams are generated that require treatment and disposal.	This is an accepted technology, with most processes commercially available; however, it is not commonly used for hazardous waste sites. It is mainly used as a pre- or post-treatment process. Reverse osmosis has a high potential for fouling of membranes if suspended solid levels are high. This approach has high O&M requirements.	High	**Retained.**
				Physical Separation—Separates contaminants from water via hydrophobic materials, material density, and other physical characteristics.	This is an effective technology for removing a wide variety of contaminants from groundwater. Potential issues arise with sizing of treatment structures. Additional waste streams are generated that require treatment and disposal.	This is an accepted technology with most processes commercially available; however, it is typically used for gross contamination and is mainly used as a pretreatment process. This approach has high O&M requirements.	Medium to High	**Retained.**
				Liquid/Dual-Phase Extraction—Removes various combinations of groundwater, phase-separate product (normally light non-aqueous phase liquid [LNAPL]), and sometimes vapor from the subsurface.	This is an effective technology for removing VOCs from groundwater and LNAPL from the subsurface. This is not a stand-alone technology and would require treatment of extracted liquid and vapor using another *ex-situ* treatment technology.	Liquid/dual-phase extraction is an established and accepted technology. Groundwater and LNAPL were extracted separately from the P1 zone near the drum area as part of an interim remedial action for the site. Groundwater was also extracted from the Hole as part of the interim action. LNAPL has not been observed in the Hole. This technology could be implemented with soil vapor extraction. This	High	**Retained.**

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
						approach has high O&M requirements.		
			Ex-situ Physical/Chemical Treatment Disposal (Note that treated water disposal is a serious feasibility issue due to strict regulatory treatment standards for disposal to a publicly owned treatment works, surface water, or groundwater.)	**Evaporation Pond—**Uses evaporation for treatment of VOCs in extracted groundwater.	An evaporation pond can be an effective technology for treatment of VOCs in groundwater. The extraction rate and volume for full-time groundwater extraction would be required to size the pond and determine ultimate feasibility.	Evaporation ponds are not commonly used for treatment of contaminated groundwater. There are potential regulatory issues related to volatilization to the atmosphere. This approach has average O&M requirements.	Low	**Retained.**
				Sprinkler Irrigation—Uses pressure to force water contaminated with VOCs through a sprinkler irrigation system.	This is an effective technology for removing VOCs from groundwater; however, sprinkler irrigation systems do not destroy contaminants. VOCs are transferred directly from water to the atmosphere. This technology is only applicable for very low concentrations of contaminants.	Sprinkler irrigation is a well-established and accepted technology that is readily implementable. There are potential regulatory issues related to volatilization to the atmosphere. There also is a potential for direct release to soil. This approach has low O&M requirements.	Low	Rejected due to effectiveness and implementability issues.
			In-situ Biological Treatment	**Monitored Natural Attenuation—**Allows natural subsurface processes, such as dilution, volatilization, biodegradation, and other physical and/or chemical processes, to reduce contaminant concentrations in the aquifer.	This is an effective method to reduce VOC contamination; however, it requires evaluation of contaminant degradation rates to determine if it is appropriate for a site. Current site conditions indicate some degradation of VOCs is occurring at the site.	This is an accepted technology that has been implemented at numerous sites. It is easy to implement because little to no action is required. A long-term groundwater monitoring system would be required to verify the effectiveness of this technology. Institutional controls may be required, and the site may not be available for re-use until contaminant levels are reduced. This approach has low O&M requirements.	Low	**Retained.**
				Phytoremediation—Uses trees or other vegetation to remediate contaminants in groundwater.	Phytoremediation has been successfully demonstrated to be an effective method to reduce VOCs in groundwater. The technology is limited to shallow groundwater. The success of remediation depends on establishing a selected plant community. The success of this technology may be seasonal, depending on location. Other climatic factors will also influence its effectiveness.	It is difficult to implement due to depth to groundwater contamination. This is not a fully accepted cleanup technology by many regulatory agencies. The establishment of the plants may require several seasons of irrigation, which could potentially mobilize contaminants into groundwater. There is a potential for high maintenance to ensure growth and plant life in more arid climates.	Low to Medium	Rejected due to effectiveness and implementability issues.
				Enhanced Bioremediation—Uses an electron donor and/or nutrients via various contact technologies (e.g., injection wells, recirculation wells) to stimulate indigenous bacteria to degrade contaminants.	Enhanced bioremediation is an effective technology for removing chlorinated VOCs from groundwater. Groundwater circulation can limit effectiveness if it allows contaminants to escape. Effectiveness can also be limited by the spacing of injection points and heterogeneity of the subsurface material. Effectiveness at this site may be complicated due to multiple contaminants with conflicting degradation environments.	This is an established and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. Pilot testing and microcosm testing may be needed to evaluate the use of enhanced bioremediation at the site before proceeding with full-scale cleanup action using this technology. This approach has high O&M requirements to ensure continued effectiveness of the contact technologies.	Medium	Rejected due to implementability issues.
			In-situ Physical/Chemical Treatment	**Permeable Reactive Barrier—**Treats contaminated groundwater as it flows through a permeable barrier composed of a reactive material.	This is an effective technology for preventing the horizontal migration of VOCs. It would not prevent potential vertical migration. The long-term effectiveness of reactive treatment walls has not been fully verified. Loss of reactive capacity may occur over time, and the reactive medium may require replacement.	This is a common, well-established, and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. Long-term operation (> 30 years) would be required if source areas are not removed and treatment of source area contamination is not completed. This approach has average O&M requirements.	High	Rejected due to effectiveness and implementability issues and cost.
				Electrical Resistance	This is an effective technology for	This is a well-established and accepted	High	Rejected due to

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
				Heating—Uses electrical current to heat soil and groundwater so contaminants are vaporized and collected for *ex-situ* treatment.	removing VOCs from groundwater and most types of soil. It requires vapor-phase extraction and treatment for off-gas generated by heating and contaminant volatilization. Hydraulic containment may be required in soil with high hydraulic conductivity for the technology to be effective. It is not very cost-effective for low groundwater contaminant concentrations.	technology; however, a limited number of vendors of this technology exist. It would be difficult to implement at the site due to subsurface conditions and the complex bedrock geology. Energy requirements can be very high. A performance monitoring program is required to assess the effectiveness of this technology. There are potential issues with heating of waste materials if used in the Hole, such as waste combustion and creation of hazardous byproducts. This approach has high O&M requirements.		effectiveness issues and cost.
				Chemical Oxidation—Causes rapid degradation of VOCs by injecting an oxidant, such as permanganate, into the aquifer.	Chemical oxidation is an effective technology for destruction of VOCs from groundwater and various types of soil. The effectiveness of this technology can be impacted by changes in soil permeability. Effectiveness is limited by low-permeability soils and rapid groundwater flow. This treatment can interfere with anaerobic degradation processes. Chemical oxidants can be incompatible with municipal solid wastes, which contain organic material that can be highly reactive with oxidants, forming hazard by products or starting fires. Chemical oxidants could interfere with the anaerobic degradation of chlorinated solvents in the subsurface. It also can potentially mobilize metals. With high concentrations of metals (e.g., manganese and iron) in the subsurface, precipitants from the use of chemical oxidants could plug the soil and fracture basalt matrices. The wide range of contaminants may preclude use of a single chemical oxidant. A treatability study and reaction transport modeling is normally required to assess feasibility.	This is a well-established and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. Proper and uniform distribution of oxidant can be difficult in very heterogeneous materials. Additional investigation would be needed to understand small-scale subsurface characteristics and design an injection program. A performance monitoring program is required to assess the effectiveness of this technology. This approach has high O&M requirements.	Medium to High	Rejected due to effectiveness and implementability issues and cost.
				Air Sparging—Creates a “stripper” that removes contaminants by volatilization by injecting air or other compatible gas through the contaminated aquifer.	Air sparging is an effective technology for removing VOCs; however, it can be less effective for many chlorinated VOCs. The effectiveness of this technology can be impacted by very small changes in soil permeability/heterogeneity, which can lead to localized treatment around the sparge points or leave areas untreated. Due to the large areas of low transmissivity subsurface materials, air sparging would not be effective at remediating large portions of the northerly plume. Oxygen added to the contaminated groundwater and possibly solid waste materials can enhance aerobic biodegradation of contaminants below and above the water table, but will have adverse effects on anaerobic degradation. This technology could potentially be used in conjunction with a	This is a well-established and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. Pilot testing may be needed to evaluate the use of air sparging at the site before proceeding with full-scale cleanup action using this technology. A performance monitoring program is required to assess the effectiveness of this technology. This approach has low O&M requirements.	Low to Medium	Rejected due to effectiveness and implementability issues.

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
					landfill gas extraction system or SVE.			
				Soil Vapor Extraction -- Uses vacuum pressure to remove VOCs and some semi-volatile organic compounds (SVOCs) from the soil.	SVE is an effective technology for removing VOCs and SVOCs. Groundwater pumps would be used in conjunction with SVE in the P1 zone to keep groundwater from rising into the unsaturated zone as a result of vacuum pressure and to increase the depth of the unsaturated zone. Soil with high moisture requires higher vacuums, hindering the operation of the SVE system. Soils with high organic content or soils that are extremely dry have a high sorption capacity of VOCs. These conditions limit the effectiveness of SVE. Soils with low permeability also limit the effectiveness of SVE.	This is a well-established and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. Pilot testing may be needed to evaluate the use of SVE at the site before proceeding with full-scale cleanup action using this technology. A performance monitoring program is required to assess the effectiveness of this technology. This approach has low O&M requirements.	Medium	**Retained.**
				Groundwater Circulation Well—Pumps groundwater to the surface to be aerated, removing most of the VOCs. The off-gas is then treated and water is re-injected.	These wells are an effective technology for removal and treatment of VOCs in groundwater. Vapors that are stripped off may require treatment before being discharged to the atmosphere. Subsurface heterogeneity can interfere with uniform flow in the aquifer around the well. Effectiveness can be limited by well construction, short-circuiting of groundwater extraction, and/or re-injection.	This is an established and accepted technology. It may be difficult to implement due to subsurface conditions and the complex bedrock geology of the site. A performance monitoring program is required to assess the effectiveness of this technology. Washington State regulations require that injected water meet strict water quality standards. This approach has high O&M requirements.	Medium to High	Rejected due to effectiveness issues and cost.
Plume Groundwater (VOCs)	Reduce or eliminate human exposure through ingestion of groundwater containing Site contaminants at concentrations that exceed cleanup levels (CULs).	Land Use Control	Land Use Controls	Not Applicable.	This control is effective because it restricts the use of groundwater. It does not directly address contaminant removal or treatment. It is likely only acceptable as a temporary measure.	This is an acceptable method for preventing human contact with hazardous media. It can be difficult to implement due to potential public resistance and the necessary cooperation of multiple agencies and local governments. This approach would need to address existing and future new wells. Low O&M requirements.	Low	**Retained.**
		Collection/Treatment	*Ex-situ* Physical Treatment (pump and treat) (Note that treated water disposal is a serious feasibility issue due to strict regulatory treatment standards for disposal to a publicly owned treatment works, surface water, or groundwater	**Air Stripping—**Removes VOCs from water by greatly increasing the surface area of the contaminated water exposed to air and inducing volatilization.	Air stripping is an effective technology for removing VOCs from groundwater. It is effective for removing more miscible compounds, such as vinyl chloride and methylene chloride. This technology does not destroy contaminants; VOCs are transferred directly from water to air. Additional waste streams are generated that require treatment.	This is a common, well-established, and accepted technology. Smaller systems for point-of-use treatment are available. Off-gas treatment by activated carbon adsorption or catalytic oxidation may be needed. This approach has average O&M requirements, including periodic column cleaning.	Medium	**Retained.**
				Adsorption – GAC—Removes contaminants by passing contaminated water through GAC.	GAC is an effective technology for removing most VOCs; however, its effectiveness is limited for water-soluble compounds, such as dichloroethane, acetone, and various ketones. It could potentially be used as a polishing step following treatment using a technology more applicable to water-soluble compounds. Carbon has a short-term duration, especially for high contaminant concentrations and would require a high frequency of O&M. This process requires transport and disposal or regeneration of	This is a common, well-established, and accepted technology that is readily implementable. Logistical and economic disadvantages arise from the need to transport and decontaminate spent carbon. This approach has average O&M requirements, including monitoring of influent and effluent streams, regeneration and replacement of carbon, and backwashing.	Low to High	**Retained.**

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
					spent carbon. This would be an effective technology for treatment of PCE and other less water-soluble compounds in groundwater.			
				Advanced Oxidation - UV Treatment—UV oxidation as a destruction process to oxidize VOCs in water.	This treatment was previously implemented at an offsite location (Whitson well) and was not effective. The system does not destroy all VOCs; instead, the contaminants may be vaporized and would require additional treatment.	UV treatment is an innovative groundwater treatment technology that has been used in full-scale groundwater treatment application for more than 10 years. Energy requirements can be very high. This approach has average O&M requirements.	High	Rejected due to effectiveness issues and cost.
				Separation – Filtration, Reverse Osmosis, and Other Membrane Processes—Separates contaminants from water by pressure-gradient forces or filtration.	This is an effective technology for removing VOCs from groundwater. Potential issues arise with interference from floating products, such as oil. Additional waste streams are generated that require treatment and disposal.	This is an accepted technology, with most processes commercially available; however, it is not commonly used for hazardous waste sites. It is mainly used as a pre- or post-treatment process. Reverse osmosis has a high potential for fouling of membranes if suspended solid levels are high. This approach has average O&M requirements.	High	Rejected due to implementability issues and cost.
			*In-sit*u Biological Treatment	**Monitored Natural Attenuation—**Allows natural subsurface processes, such as dilution, volatilization, biodegradation, and other physical and/or chemical processes, to reduce contaminant concentrations in the aquifer.	This is an effective method to reduce VOC contamination; however, it requires evaluation of contaminant degradation rates to determine if it is appropriate for a site. Current site conditions indicate some degradation of VOCs is occurring at the site. Source area removal (drums) and capping over residual contamination is completed, reducing the need for active remediation.	This is an accepted technology that has been implemented at numerous sites. It is easy to implement because little to no action is required. A long-term groundwater monitoring system would be required to verify the effectiveness of this technology. Institutional controls may be required, and the site may not be available for re-use until contaminant levels are reduced. This approach has low O&M requirements.	Low	**Retained.**
		Alternative Water Supply	Other	**New Drinking Water Well—**Installs a new drinking water well into an uncontaminated aquifer. This would include decommissioning the existing well on the property.	This approach would prevent direct exposure to contaminated groundwater by providing a clean drinking water source. Decommissioning existing uncased wells would eliminate a potential conduit for contaminated groundwater to migrate to other aquifers.	A new drinking water well is a common, well-established, and accepted approach. It is readily implementable using well-established technologies. Low O&M requirements.	Medium	Rejected, since an alternative water supply is no longer necessary due to the County's purchase of the Whitson property and conversion of the well.
				Connection to Local water System—Connects impacted residences to the existing City/County water supply system or a new local public water system with an uncontaminated source. This would include decommissioning existing wells.	This approach would prevent direct exposure to contaminated groundwater by providing a clean drinking water source. Decommissioning existing uncased wells would eliminate a potential conduit for contaminated groundwater to migrate to other aquifers.	Connection to a local water system is a common, well-established, and accepted approach. It is readily implementable using well-established technologies. Low O&M requirements.	Medium to High	Rejected, since an alternative water supply is no longer necessary due to the County's purchase of the Whitson property and conversion of the well.

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
Groundwater (inorganics)	Reduce or eliminate human exposure through ingestion of groundwater containing Site contaminants at concentrations that exceed cleanup levels (CULs).	Land Use Control	Land Use Controls	Not Applicable.	This control would be effective because it restricts the use of groundwater. It does not directly address contaminant removal or treatment.	This is an acceptable method for preventing human contact with hazardous media. It can be difficult to implement due to potential public resistance and the necessary cooperation of multiple agencies and local governments. Low O&M requirements.	Low	**Retained.**
		Collection/Treatment – Treated water disposal is a serious feasibility issue due to strict regulatory treatment standards for disposal to a publicly owned treatment works, surface water, or groundwater.	*Ex-situ* Physical Treatment (pump and treat)	**Adsorption - Activated Alumina—**A physical/chemical process by which ions in the feed water are adsorbed to the oxidized activated alumina surface.	Activated alumina treatment is an effective technology for removing inorganics from groundwater. Small point-of-use systems are available, which can include a simple filter-type cartridge. Other larger systems may require disposal or treatment of regeneration water.	This is a common, well-established, and accepted technology. Compact activated alumina treatment systems are available and can be used at wellhead locations or other onsite locations. It involves periodic regeneration or replacement of media. Regeneration processes require the handling of hazardous chemicals and generate sludge with potentially hazardous characteristics. This approach has average to high O&M requirements.	Medium	**Retained.**
				Adsorption – Manganese Greensand/Pyrolusite Filtration—Converts soluble forms of iron and manganese to insoluble forms by oxidizing with permanganate and then removing the iron/inorganics floc by filtration.	Greensand/Pyrolusite filtration is a relatively low-cost, effective, and proven technology for inorganics removal. Regenerative backwashing would be required to ensure the effectiveness of the filtration. Regeneration water would require onsite treatment to remove inorganics.	This is a common, well-established, and accepted technology. This inorganics removal process is normally used in larger-scale treatment applications and is not common for point-of-use treatment. Backwashing of the filter is necessary to remove accumulated sediments. This approach has high O&M requirements.	Medium	**Retained.**
				Separation – Membrane Filtration, Reverse Osmosis—Separates contaminants from water by pressure-gradient forces or filtration.	This is an effective technology for removing inorganics from groundwater. Inorganics removal efficiencies depend on the form of the inorganic ion, but are generally high. Manganese removal efficiencies by reverse osmosis are typically high. Point-of-use reverse osmosis units are capable of removing metals and other inorganics, including nitrates and sodium, as well as VOCs. Reverse osmosis performance is adversely affected by the presence of turbidity, silica, scale-producing compounds, and other constituents. This technology requires extensive pretreatment for particle removal and often pretreatment for dissolved constituents.	This is a common, well-established, and accepted technology for removing inorganics from groundwater. Compact reverse osmosis treatment systems are available and can be used at wellhead locations or other onsite locations. This approach has average to high O&M requirements.	High	**Retained.**
				Ion Exchange—Removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium.	Ion exchange is an effective technology for removing metals and other inorganics from groundwater. It has been effectively used in point-of-use applications for water softening. This technology can effectively remove certain inorganics; however, other inorganic materials, such as total dissolved solids and nitrate, can compete with the target inorganics and can affect the treatment time. Suspended solids and precipitated iron can cause clogging of ion exchange material. Systems containing high levels of these constituents may require pretreatment. Use of the ion-exchange process to	This is a common, well-established, and accepted technology. Point-of-use systems are available. Ion exchange resins require regeneration after they have absorbed to their capacity. The regenerative solution requires additional treatment. There are numerous types of resins; the appropriate resins for an application depend on 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. This approach has average O&M requirements.	Medium	**Retained.**

Table 6. Screening of Groundwater Cleanup Technologies and Process Options (continued)

Medium	Cleanup Action Objectives	Cleanup Action Category	Cleanup Technology[1]	Process Options	Technical Feasibility/Effectiveness	Implementability	Cost	Retained/Rejected[2]
					remove inorganics could require multiple ion-exchange units with different media. A primary disadvantage of ion exchange systems is the non-selective removing non-target ions.			
				Coagulation/Filtration—Alters the physical or chemical properties of suspended material to produce an agglomeration that will settle out of solution by gravity or will be removed by filtration.	Coagulation/filtration is an effective technology for removing metals and possibly other inorganic material. Additional waste streams are generated that require treatment and disposal.	Coagulation/filtration treatment produces inorganic-contaminated sludge requiring offsite disposal. Due to the amount of coagulant needed and the size of flash mixing basins and settling tanks, coagulation/filtration is not a point-of-use technology. This approach has high O&M requirements.	High	Rejected due to implementability issues and cost.
			In-situ Biological Treatment	**Monitored Natural Attenuation—**Allows natural subsurface processes, such as dilution, volatilization, biodegradation, and other physical and/or chemical processes, to reduce contaminant concentrations in the aquifer.	This is an effective method to reduce inorganic contamination; however, it requires evaluation of contaminant degradation rates to determine if it is appropriate for a site. Current site conditions indicate some degradation of inorganics is occurring.	This is an effective approach that has been implemented at numerous sites. A long-term groundwater monitoring system would be required to verify the effectiveness of this technology. Institutional controls may be required, and the site may not be available for re-use until contaminant levels are reduced. This approach has low O&M requirements.	Low	**Retained.**
		Alternative Water Supply	Other	**New Drinking Water Well—**Installs a new drinking water well into an uncontaminated aquifer. This would include decommissioning the existing well on the property.	This approach would prevent direct exposure to contaminated groundwater by providing a clean drinking water source. Decommissioning existing uncased wells would eliminate a potential conduit for contaminated groundwater to migrate to other aquifers.	A new drinking water well is a common, well-established, and accepted approach. It is readily implementable using well-established technologies. Low O&M requirements.	Medium	Rejected, since an alternative water supply is no longer necessary due to the County's purchase of the Whitson property and conversion of the well.
				Connection to Local water System—Connects impacted residences to the existing City/County water supply system or a new local public water system with an uncontaminated source. This would include decommissioning existing wells.	This approach would prevent direct exposure to contaminated groundwater by providing a clean drinking water source. Decommissioning existing uncased wells would eliminate a potential conduit for contaminated groundwater to migrate to other aquifers.	Connection to a local water system is a common, well-established, and accepted approach. It is readily implementable using well-established technologies. Low O&M requirements.	Medium to High	Rejected, since an alternative water supply is no longer necessary due to the County's purchase of the Whitson property and conversion of the well.

Definitions:
CUL - cleanup level
GAC - granular activated carbon
LNAPL - light non-aqueous phase liquid
O&M – operation and maintenance
PCE -- tetrachloroethene
SVE - soil vapor extraction
SVOC - semi-volatile organic compound
VOC - volatile organic compound

[1] Cleanup technologies, descriptions, and applicability to the site were primarily based on information from the Federal Remediation Technologies Roundtable website at www.ftr.gov, the CPEO website at http://www.cpeo.org/tree.html, and various related documents.

[2] The retained cleanup technologies result from qualitatively evaluating the potential technologies based on screening information prepared by EPA, CPEO, and other organizations for sites across the United States, using the screening criteria listed above, and are ultimately based on the experiences gained at similar sites and professional knowledge and judgment.

Table 7. Cleanup Action Component Summary

Component	Purpose	Location	1-Year VOC Removal (kg)[1]	10-Year VOC Removal (kg)[1]	Component Cost[2]
Contaminant Removal Components					
Existing P1 Zone MPE System Reactivation	Reduce groundwater contact with contaminants in the P1 zone, remove dissolved contaminants, create vadose zone. Remove organic contaminants from the vadose zone.	At the POC and All Areas Outside the POC	85	85	$3,121,000
P1 Zone MPE System Modifications and Well Field Expansion	Stop migration from source, reduce groundwater contact with contaminants in the P1 zone, remove dissolved contaminants, create vadose zone. Remove organic contaminants from the vadose zone.		240	240	$2,498,000
Groundwater Extraction from the Hole	Eliminate groundwater contact with refuse in the Hole, remove dissolved contaminants.		<1	<1	$775,000
LFG System Activation	Reduce LFG intrusion in the MPE system.		<1	<1	$233,000
Northerly Plume Hydraulic Capture (Treatment and Infiltration)	Disrupt the source of contaminants to the northerly plume at the POC, stopping and, to an extent, reversing contaminant migration north of the landfill. Reduce groundwater contaminant concentrations from the hydraulic capture of the northerly plume to below groundwater standards (WAC 173-200) for discharge to ground (infiltration). Provide a disposal option for hydraulic capture of the northerly plume treated groundwater.		13	61	$10,650,000
Targeted Pumping from the Northerly Plume	Reduce contaminant mass near where the center line of the northerly plume crosses the north end of the landfill parcel.		13	59	$578,000
Evaporation Disposal Components					
Evaporation, Existing Pond	Groundwater disposal option for volumes generated by pumping of the P1 zone and Hole.	County parcel	N/A	N/A	$384,000 to $558,000
Evaporation, Additional Capacity	Groundwater disposal option for volumes generated by pumping of the P1 zone, Hole, and targeted northerly plume.	County parcel	N/A	N/A	$1,020,000 to $1,595,000
Other Components					
Compliance Monitoring	Verify that the cleanup action achieves cleanup, or other performance standards, and that the cleanup action remains effective over time through installation of monitoring wells, sampling, and reporting. The scope of groundwater monitoring varies by alternative and may include sampling of discharge to evaporation pond to estimate pond emissions, sampling from treatment system, and SVE performance monitoring.	Existing and new monitoring wells, new facilities, depending on the selected alternative	N/A	N/A	$7,360,000 to $16,870,000
Institutional Controls	Measures to limit, or prohibit, activities that may interfere with the integrity of an interim action, or a cleanup action, or result in exposure to hazardous substances at the Site.	The Site	N/A	N/A	$7,800 to $215,220

Notes:

[1] Removal masses represent removal from Site media only.

[2] Costs are in 2018 dollars based on a compliance year time interval and as detailed in Appendix H.

Definitions:

LFG - landfill gas
MPE - multi-phase extraction
N/A – not applicable.
POC – point of compliance.
SVE – soil vapor extraction.
VOC – volatile organic compour

Table 8. Cleanup Action Alternative and Component Performance and Cost Summary

	Cost Summary[1]						
Component	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**
Contaminant Removal Components							
Existing P1 Zone MPE System Reactivation	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000	$3,121,000
P1 Zone MPE System Modifications and Well Field Expansion		$2,498,000	$2,498,000	$2,498,000	$2,498,000	$2,498,000	$2,498,000
Groundwater Extraction from the Hole			$775,000			$775,000	$775,000
LFG System Activation	$233,000	$233,000	$233,000	$233,000	$233,000	$233,000	$233,000
Northerly Plume Hydraulic Capture (Treatment and Infiltration)					$10,650,000		$10,650,000
Targeted Pumping from the Northerly Plume				$578,000		$578,000	
Evaporation Disposal Components							
Evaporation, Existing Pond	$384,000	$384,000	$384,000	$384,000	$558,000	$384,000	$558,000
Evaporation, Additional Capacity				$1,020,000	$1,020,000	$1,595,000	$1,020,000
Other Components							
Compliance Monitoring	$16,870,000	$10,620,000	$11,070,000	$8,590,000	$7,460,000	$8,920,000	$7,360,000
Institutional Controls	$11,640	$7,800	$7,800	$143,360	$215,220	$143,360	$215,220
Total Estimated Cost	**$20,619,640**	**$16,863,800**	**$18,088,800**	**$16,567,360**	**$25,755,220**	**$18,247,360**	**$26,430,220**

	Performance and Cost Comparison						
Basis of Comparison	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**
1-Year Removal of VOCs (kg)[2]	85	240	240	253	253	253	253
10-Year Removal of VOCs (kg)[2]	85	240	240	299	301	299	301
1-Year Cost per Unit of VOCs Removed ($/kg)	$242,507	$70,121	$75,215	$65,356	$101,600	$71,983	$104,263
10-Year Cost per Unit of VOCs Removed ($/kg)	$242,507	$70,121	$75,215	$55,317	$85,425	$60,927	$87,664
Estimated Years Until Compliance with Cleanup Standards	34 to 66	34	34	25	20	25	20
Estimated Years Until Completion of Active Measures	10	34	34	20	20	20	20

Notes:

[1] Costs are in 2018 dollars based on a compliance year time interval and as detailed in Appendix H.

[2] VOC removal from Site media only.

Definitions:

kg - kilogram.
LFG – landfill gas.
MPE – multi-phase extraction.

Table 9. Summary of Compliance Well Monitoring by Alternative

Alternative	Wells
1	**Existing Wells – Gauged and Sampled:** EW-1, MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-63b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-71b, MW-73b, MW-74c, MW-72d
2	**Existing Wells – Gauged and Sampled:** EW-1, MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-29b, MW-42b, MW-44b, MW-63b, MW-45c, MW-58c, MW-7b, MW-9b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-28d
	Existing Wells – Gauged Only[1]: W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW--30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1
3	**Existing Wells – Gauged and Sampled:** MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-63b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: EW-1, W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: EW-3, EW-4, EW-5, MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1
4	**Existing Wells – Gauged and Sampled:** EW-1, MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-63b (replacement as EW-10), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: EW-8, EW-9, MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1

Table 9. Summary of Compliance Well Monitoring by Alternative (continued)

Alternative	Wells
5	**Existing Wells – Gauged and Sampled:** EW-1, MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-63b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: EW-6, EW-7, MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1
6	**Existing Wells – Gauged and Sampled:** MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: EW-1, W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-63b (replacement as EW-10), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: EW-3, EW-4, EW-5, EW-8, EW-9, MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1
7	**Existing Wells – Gauged and Sampled:** MW-33p2, MW-35p2, MW-38p2, MW-39p2, MW-7b, MW-9b, MW-29b, MW-42b, MW-44b, MW-63b, MW-2c, MW-4c, MW-5c, MW-6c, MW-22c, MW-45c, MW-58c, MW-28d
	Existing Wells – Gauged Only[1]: EW-1, W-9, W-12, MW-34p1, MW-36p1, MW-37p1, MW-64p1, MW-65p1, MW-66p1, MW-67p1, MW-68p1, MW-69p1, MW-70p1, MW-46p2, MW-49p2, MW-60p2, MW-19b, MW-30b, MW-31b, MW-48b, MW-57b, MW-20c, MW-21c, MW-47c, MW-62c, MW-17a, MW-18a, MW-32a, MW-16d
	New Wells – Gauged and Sampled: MW-43p2 (replacement), MW-3b (replacement), MW-71b, MW-73b, MW-74c, MW-72d
	New Wells – Gauged Only[1]: EW-3, EW-4, EW-5, EW-6, EW-7, MW-75p1, MW-76p1, MW-77p1, MW-78p1, MW-79p1, MW-80p1, MW-81p1, MW-82p1, MW-83p1, MW84p1

[1] Although wells used for extraction would not be sampled individually, combined discharges to either an evaporation or treatment system would be sampled as part of compliance monitoring for the system.

Table 10. Comparison of Cleanup Action Alternatives to Objectives

Objective	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Threshold Requirements (WAC 173-340-360(2)(a)) - Section 7.1.1							
Protect human health and the environment.	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]
Comply with cleanup standards (years)[2].	34 to 66	34	34	25	20	25	20
Comply with ARARs (years)[2].	34 to 66	34	34	25	20	25	20
Provide for compliance monitoring.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Requirements (WAC 173-340-360(2)(b)) - Section 7.1.1							
Use permanent solutions to the maximum extent practicable[3].	Moderate contaminant removal	Comparatively high contaminant removal	Comparatively high contaminant removal	Comparatively high contaminant removal	Comparatively high contaminant removal	Comparatively high contaminant removal	Comparatively high contaminant removal
Provide for a reasonable restoration time frame (years).	34 to 66	34	34	25	20	25	20
Consider public concerns.	To be addressed through implementation of a public participation plan prepared by Ecology.						
Groundwater Cleanup Objectives - Section 7.1.2							
Prevent further migration of Site contaminants in concentrations exceeding CULs toward drinking water sources through source removal and containment[4].	Moderate contaminant removal and control	Comparatively high contaminant removal and moderate control	Comparatively high contaminant removal and moderate control	Comparatively high contaminant removal and moderate control	Comparatively high contaminant removal and high control	Comparatively high contaminant removal and moderate control	Comparatively high contaminant removal and high control
Reduce or eliminate human exposure through ingestion of groundwater containing Site contaminants at concentrations that exceed CULs.	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]

Definitions:

ARAR – applicable or relevant and appropriate requirement.
CUL – cleanup level.
POC – point of compliance.
SVE – soil vapor extraction.
VOC– volatile organic compound.

Notes

[1] Plume groundwater is not used anywhere that IHS concentrations exceed CULs. Potential use during restoration can be prohibited through institutional controls.

[2] Estimated year of attainment of CULs at the POC and all areas outside the POC.

[3] A permanent solution is not feasible because the Site includes the Ephrata Landfill. Alternatives are compared based on estimated VOC removal.

[4] VOC removal from Site media.

Table 11. Disproportionate Cost Analysis Summary

Alternative	Key Cleanup Action Components	1-Year VOC Removal (kg)[1]	10-Year VOC Removal (kg)[1]	Cost[2]	Incremental Cost (Compared to Alternative 2)	Benefits Evaluation		
						Favorable Elements	Unfavorable Elements	Incremental Benefits (Compared to Alternative 2)
1	● Existing P1 Zone MPE System Reactivation ● LFG System Activation ● Natural attenuation	85	85	$20,619,640	$3,755,840	● Protective with institutional controls ● Provides for compliance monitoring ● 34 to 66 year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent ● Less source removal	● None compared to Alternative 2
2 (Baseline)	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● LFG System Activation ● Natural attenuation	240	240	$16,863,800	$0	● Protective with institutional controls ● Provides for compliance monitoring ● 34-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent	● Not applicable
3	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● Groundwater Extraction from the Hole ● LFG System Activation ● Natural attenuation	240	240	$18,088,800	$1,225,000	● Protective with institutional controls ● Provides for compliance monitoring ● 34-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Hydraulic isolation of Hole contaminants ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent ● Comparatively low additional source removal	● Disrupts the groundwater contaminant migration pathway through the Hole
4	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● Targeted Pumping of Northerly Plume ● LFG System Activation	253	299	$16,567,360	($296,440)	● Protective with institutional controls ● Provides for compliance monitoring ● 25-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Contaminants removed directly from the northerly plume ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent	● More source removal ● Partial disruption of the northerly plume contaminant migration pathway ● Shorter restoration time frame
5	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● Northerly Plume Hydraulic Capture ● LFG System Activation	253	301	$25,755,220	$8,891,420	● Protective with institutional controls ● Provides for compliance monitoring ● 20-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Hydraulic capture of the northerly plume ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent ● Management of high groundwater volumes	● Hydraulic capture contravenes the northerly plume contaminant migration pathway ● Shorter restoration time frame
6	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● Groundwater Extraction from the Hole ● Targeted Pumping of Northerly Plume ● LFG System Activation	253	299	$18,247,360	$1,383,560	● Protective with institutional controls ● Provides for compliance monitoring ● 25-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Contaminants removed directly from the northerly plume ● Hydraulic isolation of P1 zone contaminants ● Hydraulic isolation of Hole contaminants ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent	● More source removal ● Partial disruption of the northerly plume contaminant migration pathway ● Disrupts the groundwater contaminant migration pathway through the Hole ● Shorter restoration time frame
7	● Existing P1 Zone MPE System Reactivation ● P1 Zone MPE System Modifications and Well Field Expansion ● Groundwater Extraction from the Hole ● Northerly Plume Hydraulic Capture ● LFG System Activation	253	301	$26,430,220	$9,566,420	● Protective with institutional controls ● Provides for compliance monitoring ● 20-year restoration time frame ● Continuous liquid and vapor phase contaminants removal ● Hydraulic isolation of P1 zone contaminants ● Hydraulic isolation of Hole contaminants ● Hydraulic capture of the northerly plume ● Reduced MPE methane levels, improving safety ● Reduced vinyl chloride intrusion into the P1 ● Reduced methane emissions	● Non-permanent ● Management of high groundwater volumes	● More source removal ● Hydraulic capture contravenes the northerly plume contaminant migration pathway ● Shorter restoration time frame ● Disrupts the groundwater contaminant migration pathway through the Hole

Notes:

[1] VOC removal from Site media.

[2] Costs are in 2018 dollars based on a compliance year time interval and as detailed in Appendix H.

Definitions:
kg – kilograms.
LFG – landfill gas.
MPE – multi-phase extraction.

Appendix A

Hydrogeologic and Contaminant Calculations in Support of Ephrata Landfill Feasibility Study

PACIFIC groundwater GROUP

HYDROGEOLOGIC AND CONTAMINANT CALCULATIONS
FEASIBILITY STUDY SUPPORT
EPHRATA LANDFILL

August 29, 2012

HYDROGEOLOGIC AND CONTAMINANT CALCULATIONS
FEASIBILITY STUDY SUPPORT
EPHRATA LANDFILL

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SIGNATURE

This report, and Pacific Groundwater Group's work contributing to this report, were reviewed by the undersigned and approved for release.

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1.0 INTRODUCTION

This report provides hydrogeologic and contaminant calculations performed in support of the cleanup actions being evaluated in the Feasibility Study (FS; Parametrix, 2012) for the Ephrata Landfill (Figure 1). Hydrogeologic calculations were performed to estimate groundwater extraction rates, extraction volumes, and number of wells for different cleanup action scenarios in the FS. Contaminant calculations were also performed to estimate source mass and source concentration used in the REMChlor fate and transport model of the northerly plume (PGG, 2012a), which also supports the FS. Additional contaminant calculations were also performed to estimate mass attenuation rates in the northerly plume.

Hydrogeologic calculations are presented below. Contaminant calculations are presented in the subsequent section.

Our professional services were performed, our findings obtained, and our report prepared in accordance with generally accepted hydrogeologic practices. This warranty is in lieu of all other warranties, expressed or implied.

2.0 HYDROGEOLOGIC CALCULATIONS

Hydrogeologic calculations were developed for the following scenarios in support of the FS:

1. Seasonal pumping of P1 source area groundwater (existing wells MW-34p1 and MW-36p1)
2. Long term (continuous) pumping of P1 source area groundwater
3. Long term (continuous) pumping of P2 source area groundwater
4. Seasonal pumping of groundwater in the Hole (existing well EW-1)
5. Dewatering of the Hole
6. Property boundary hydraulic containment (capture) of the northerly plume (Roza aquifer high transmissivity zone)
7. Property boundary hydraulic containment (capture) of the northerly plume (Roza aquifer low transmissivity zone)
8. End-of-plume hydraulic containment (capture) of the northerly plume (low transmissivity zone)

These scenarios correspond with certain cleanup action components described in the FS. The results of these calculations are presented as a range of estimated extraction rates and wells for each scenario based on uncertainty in input parameters. A single set of values (based on best-estimate input parameters) is recommended as the design basis for cleanup action components in the FS (Table 1). Calculations for each scenario are completed independent of other scenarios; however, some interference drawdown would be expected during simultaneous implementation of some scenarios. Aside from a few noted exceptions, the scenarios described herein correspond to cleanup action components in the FS (Parametrix 2012).

The following sections summarize the objectives and limitations for each of the above scenarios. The subsequent section then describes our technical approach and results of the calculations.

2.1 SCENARIO OBJECTIVES AND KEY ASSUMPTIONS

The objective and limitations of each scenario evaluated in these calculations are discussed below.

2.1.1 P1 Source Area – Seasonal Extraction

The objective of this scenario would be to remove source mass by seasonal pumping (approximately 200 days per year) in the P1 source area; an area immediately south of the drum removal area where light non-aqueous phase liquid (LNAPL) has been observed (Figure 1). The calculations assume the use of existing extraction wells (MW-34p1 and MW-36p1). Extraction rates in the P1 source area are limited by a maximum drawdown of about 2-ft in order to reduce the potential of pumping LNAPL. LNAPL would continue to be managed with absorbent socks under this scenario.

2.1.2 P1 Source Area – Long Term Extraction

The objectives of this scenario would be to remove source mass by continuous long term extraction of groundwater from the P1 source area. Continuous pumping would reduce vertical gradients, partially contain the source, and create an unsaturated zone for soil vapor extraction. For this calculation, we assume extraction rates are limited by a maximum drawdown of about 2-ft in order to reduce the potential of pumping LNAPL. However, the FS also contemplates pumping of total fluids (e.g. mixed phase) and *ex-situ* separation of LNAPL with long term pumping (Parametrix, 2012), which would support more drawdown.

2.1.3 P2 Source Area – Long Term Extraction

The P2 source area is present directly beneath the P1 source area, separated by about 10-ft of dense basalt. The objective of this scenario would be to remove source mass from the P2 source area; however, the extremely low transmissivity (T) of the P2 source area (0.2 ft^2/dy) limits the ability to do so.

P2 source area T (0.2 ft^2/dy) is about two orders of magnitude less than that of the overlying P1 (21 ft^2/dy). Continuous long-term pumping in such a low T zone is not technically feasible. To illustrate the technical challenge, groundwater sampling of the existing P2 source area wells (MW-33p2, MW-35p2, and MW-38p2) involves hand bailing the well dry and returning the next day, once the wells recover. Recovery the next day is still sometimes not sufficient to fill all sample bottles. Theoretically, a long-term sustainable pumping rate for this zone would be well below 0.1 gpm[1]. The low discharge rates achievable in the P2 source area would not provide for significant source removal. Based on these observations, we did not quantify extraction rates and volumes for this scenario, nor is it a component in the FS.

2.1.4 Groundwater from the Hole – Seasonal Extraction

The objective of this scenario would be to remove contaminant mass by resuming seasonal extraction (approximately 200 days per year) of groundwater from the Hole[2] (Figure 1) using the existing extraction well (EW-1). For this assessment, extraction rates were maximized while limiting the drawdown to 3-ft to 5-ft (available drawdown is about 5-ft in EW-1).

2.1.5 Groundwater from the Hole – Dewater

The objectives of this scenario would be to remove contaminant mass, reduce saturation of waste in the Hole, and to contain contaminant movement. Because the Hole is largely, if not completely, bounded by basalt, the dominant migration pathway is likely downward to the underlying Roza aquifer. The groundwater elevation in the underlying Roza aquifer is estimated[3] to be about 0.5 feet lower than the groundwater elevation in the Hole and the available drawdown in the Hole is about 5-ft. Thus, reversal of the vertical gradient appears to be a feasible option for containing contaminant movement. For this evaluation we assume complete dewatering of the Hole, but recognize complete dewatering may not be necessary for containment.

2.1.6 Northerly Plume – Property Boundary Hydraulic Containment in the Roza Aquifer Component

The objective of this scenario would be to hydraulically contain (capture) groundwater in the Roza aquifer along the northern landfill property boundary. This would stop or greatly reduce contaminant migration in the northerly plume beyond the landfill property boundary. The Roza aquifer is highly heterogeneous; however, based on aquifer tests of various Roza wells, there appears to be a much higher transmissivity area (high-T) near the northwest corner of the landfill (Figure 1). We have therefore divided the calculation into high-T and low-T area, as explained below.

Roza aquifer transmissivity in the vicinity of the landfill's maintenance shop (3,074 ft^2/dy) is orders of magnitude higher than Roza aquifer transmissivity measured elsewhere (2.8 ft^2/dy)[4]. The potential for groundwater extraction is therefore comparatively favorable in the high-T zone. Northerly plume hydraulic capture was evaluated along the property boundary in the high-T area and low-T area independently (Figure 1). However,

---

[1] The estimated transmissivity of the P2 zone (0.2 ft^2/dy) is about an order of magnitude lower than the low-T Roza area (2.8 ft^2/dy) and sustainable pumping rates in the low-T Roza area are calculated to be less than 0.1 gpm (see results for Roza containment in Low-T area).

[2] The Hole is a 20 ft deep depression in the basalt surface beneath the landfill. The lower 5 to 7 feet of soil/refuse within the Hole is saturated with groundwater over an area of about 1 acre (Figure 1).

[3] Based on measured water levels in Roza wells immediately northwest of the Hole (MW-3b, 7b, and 9b in Figure 1).

[4] Values based on geometric mean of measured values in the high-T zone and low-T zone.

pumping in the high-T area is expected to capture groundwater in both transmissivity zones (see Section 2.2.5 below).

2.1.7 Northerly Plume – End-of-Plume Hydraulic Containment in the Roza Aquifer Component

The objective of this scenario would be to hydraulically contain groundwater in the Roza aquifer component of the northerly plume near the location of the Whitson well (Figure 1) in order to stop contaminants from migrating further toward private wells. Groundwater in the Roza is believed to discharge laterally into alluvium within a bedrock draw just beyond the Whitson well (Figure 1). Some vertical migration to deeper aquifers may also occur near the Whitson well. This part of the Roza aquifer is thought to be a low T area based on the transmissivity measured in nearby well MW-44b (7 gpd/ft).

2.2 HYDROGEOLOGIC CALCULATIONS AND RESULTS

For each of the above scenarios we evaluated groundwater draw-down and capture associated with different combinations of wells and extraction rates. The software package AQTESOLV v4.5 (HydroSOLVE, Inc.) was used to predict drawdown associated with wells, pumping rates, and aquifer parameters for all but two of the above scenarios. The analytical model GFLOW (Haitjema Software) was used for the Roza high-T property boundary containment scenario. Seasonal P1 pumping was evaluated using estimates of sustainable pumping rates for MW-34p1 and MW-36p1 and prior pumping observations in MW-34p1. Generally, pumping rates were adjusted for each well until target drawdowns were achieved, based on hydrogeologic constraints in a particular area.

The results of this evaluation provide the basis for the number of wells, well spacing, extraction rates, and annual extraction volumes recommended for different cleanup action scenarios in the FS (Table 1). To capture some of the uncertainty in these calculations, we also include a range of values for each scenario (Table 2). Table 2 also provides an estimate of initial annual mass removed for each scenario based on the volume of extracted groundwater and the average groundwater concentrations measured in the target area. The initial annual mass removed is shown both for indicator hazardous substances (IHS) identified in the FS (Parametrix, 2012) and for total organic COCs[5]. Note that over 90% of the organic COC mass removal in the P1 source area is from the removal of toluene, ethylbenzene, and xylene (TEX) and ketone compounds[6].

The results for each scenario are discussed in detail below.

2.2.1 Seasonal P1 Pumping Results

For this scenario, extraction rates and volumes were based on estimates of sustainable pumping rates for MW-34p1 and MW-36p1 and observations of seasonal pumping already performed (PGG, 2011). Sustainable pumping rates for MW-34p1 and MW-36p1 (assuming no more than 2-ft of drawdown) are estimated to be 0.3 and 0.1 gpm respec-

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[5] Contaminants of concern (COCs) are identified in the RI (PGG, 2010 and 2012b).

[6] Ketone compounds are 2-butanone, 2-hexanone, 4-methyl-2-pentanone, and acetone.

tively. The pumping duration is assumed to be 200 days. Based on these assumptions, the recommended design groundwater extraction was 115,000 gallons/year (Table 1).

2.2.2 Long-Term P1 Pumping Results

For this scenario, we used AQTESOLV to predict drawdown after 5 years of pumping. Extraction rates and number of wells were based on maintaining approximately 2-ft drawdown in numerous wells while also maximizing the drawdown between wells throughout the P1 source area.

For this evaluation, we considered a range of T-values in the P1 zone. T-values were varied between a minimum (10 ft^2/dy), geometric mean (21 ft^2/dy), and maximum (51 ft^2/dy) value based on measured values in MW-34p1, MW-36p1 and MW-37p1 (Figure 1). A range of extraction wells was also considered in the evaluation. Between 2 to 9 wells were spaced uniformly within the P1 source area (P1 source area is shown in Figure 1). The aquifer storage (S) value was assumed to be 0.1 (this value assumes unconfined conditions will be achieved with long term pumping and that the P1 zone is a porous medium – as described in boring logs). Extraction rates were adjusted in AQTESOLV until the maximum predicted drawdown was similar to the target drawdown. The results indicate an annual extraction volume ranging from about 75,000 to 550,000 gallons with the best-estimated (recommended design basis) value being about 250,000 gallons (Tables 1, 2 and 3).

We also estimated a range in the ambient groundwater flux through the P1 source area using the average groundwater gradient between wells MW-34p1, MW-36p1, and MW-37p1 (0.02) and the range of T values in these wells. Based on this calculation, the ambient flux ranged from 86,500 gallons/year to 445,600 gallons/year with a best estimated value (based on geometric mean T-value) of 183,500 gallons/year (Table 4).

The annual groundwater extraction recommended for design purposes for the FS was 250,000 gallons (Table 1). This is slightly higher than the best estimated ambient groundwater flux and accounts for additional flux due to pumping.

2.2.3 Long-Term P2 Pumping Results

As mentioned in the objectives and limitations section above, this component is considered technically infeasible and was therefore not assessed.

2.2.4 Groundwater Pumping from the Hole Results

Groundwater extraction from the Hole considers both seasonal pumping and dewatering. The seasonal extraction calculation assumes pumping from the existing extraction well (EW-1) and the dewatering calculation assumes two conditions; one using the existing well and another using four wells spaced uniformly throughout the area of saturation in the Hole (the location of the Hole is shown in Figure 1). A single transmissivity value of 700 ft^2/dy was used for the calculation. This value was based on an earlier aquifer test of EW-1 (PGG, 2002). The aquifer storage value was assumed to be 0.1 (unconfined porous medium). We set a target drawdown of 3 to 5-ft for seasonal pumping and 5-ft for dewatering (estimated saturated thickness of the Hole at EW-1). The pumping duration for seasonal extraction was assumed to be 200 days and the pumping duration for a single cycle of dewatering was assumed to be about 40 to 70 days.

These parameters were used in AQTESOLV until the maximum predicted drawdown was similar to the target drawdown. We used the no flow boundary option in AQTESOLV to simulate the boundary of the basalt surrounding groundwater in the Hole.

The results indicate an annual extraction volume ranging from about 290,000 gallons (based on 3-ft of drawdown) to 430,000 gallons (based on 5-ft of drawdown) for seasonal pumping and 390,000 gallons (based on one existing well) to 440,000 gallons (based on four wells) for dewatering (Tables 2 and 5). The final recommended design annual groundwater extraction is 290,000 gallons for seasonal pumping and 390,000 gallons for dewatering (Table 1). Although the AQTESOLV results indicate 1 well can achieve 390,000 gallons per year for dewatering, a total of 4 wells are recommended for the design basis.

The volume of water in the Hole is estimated to be about 320,000 gallons[7]. This value is based on an estimated saturation volume of 8000 cubic yards in the Hole (PGG, 2010) and a porosity of 0.2. The ambient groundwater flux through the Hole is estimated to be about 46,000 gallons/year (Table 6). Given the relatively low ambient flux, subsequent annual volumes necessary to maintain a dewatered state in the Hole may be less than the first-time volume extraction.

2.2.5 Northerly Plume Containment at Property Boundary – Roza High-T Area Results

For this scenario, we assessed capture using 2 wells which would be installed along the property boundary in the high-T area (Figure 1). We used previous estimates of sustainable pumping rates and transmissivity (PGG, 2002) and evaluated the required extraction rates to achieve capture in the high-T area.

Given the potentially much larger volume of extractable groundwater in the high-T Roza area compared to other scenarios and the effects of an adjacent low-T zone (boundary effects), we used the analytical model GFLOW and particle tracking to evaluate capture. GFLOW is a 2-D steady-state analytic element groundwater flow model that allows for heterogeneities in aquifer properties.

For the GFLOW evaluation, we considered a range of T-values for the high-T area under a range of bounded aquifer conditions. The range in T-values was based on a previous analyses of Roza wells in the high-T area (EW-2, MW-3b, MW-7b and MW-9b) from an aquifer pumping test of EW-2 (PGG, 2002). The reported range in T-values from this earlier work (Table 2 in PGG, 2022) was based on analyses of both drawdown and recovery in multiple wells. For this current evaluation we used the 25th percentile of this dataset as a minimum estimate (1,200 ft^2/dy), the 75th percentile as a maximum estimate (7,890 ft^2/dy), and the geometric mean as the best-estimate (3,074 ft^2/dy). These values

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[7] The recommended extraction volume (390,000 gallons) for dewatering the Hole (Table 1) is somewhat larger than the volume of saturation calculation (320,000 gallons). A larger volume is recommended in the design because an increased gradient in the Hole due to drawdown will likely increase the discharge rate of groundwater into the Hole and therefore a larger volume of extractable groundwater will be available

were used in a 2-D, steady-state, GFLOW simulation for the Roza high-T zone under three aquifer bounded conditions:

- Infinitely unbounded high-T aquifer
- High-T aquifer partially bounded by low-T zone
- High-T aquifer fully bounded by low-T zone

Under all three conditions we assigned a uniform groundwater gradient of 0.0007 ft/ft towards the north calculated from Roza wells in the high-T area (MW-3b, MW-7b, and MW-9b). The unbounded aquifer condition assumed the high-T Roza zone extends infinitely in all directions. The fully bounded aquifer condition assumed the high-T Roza zone (Figure 1) was fully bounded by a low-T zone (T-value of 35 ft^2/dy)[8]. The partially bounded aquifer condition is a hybrid condition and assumed a low-T boundary around all but the southern portion of the high-T zone.

The range of extraction rates resulting from the GFLOW analysis were compared to calculations of the ambient groundwater flux across the high-T boundary. We also evaluated drawdown in the adjacent low-T Roza area due to pumping in the high-T area using an analytical solution for 1-D flow with a sudden change at a boundary. The results are discussed below.

The GFLOW results indicate a large range of estimated annual extraction volumes (Table 7); about 300,000 gallons (under the fully bounded condition) to 16,000,000 gallons (under the infinitely unbounded condition and maximum T). For comparison, the ambient groundwater flux through the high-T Roza area of the property boundary is estimated to be 1,120,000 to 7,320,000 gallons per year - based on the range in T-values (Table 8). Using the results of these analyses we propose an uncertainty range of 500,000 to 8,000,000 gallons per year be considered for this scenario (Table 2) with a recommended design value of 3,500,000 gallons (Table 1). The recommended design value is based on the ambient groundwater flux through the high-T area using the geometric mean T-value (3,000,000 gallons) plus additional flux from capture of the low-T area.

As mentioned, we also evaluated capture of the surrounding low-T area from pumping in the high-T area using an analytical solution for 1-D flow with a sudden change at a boundary (Kresic, 1997):

$\Delta H(x,t) = \Delta Ho * efc(\lambda)$

Where

$\Delta H(x,t)$	is the change in head with time and distance from the boundary
ΔHo	is the change in head at the boundary
$efc(\lambda)$	is the complementary error function $1-erf(\lambda)$
$erf(\lambda)$	is approximated as $\sqrt{[1-e(-4\lambda^2/\pi)]}$
λ	$= x/2\sqrt{a*t}$

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[8] Value based on geometric mean of all Roza wells in both zones. Same value used in the REMChlor fate and transport simulation.

x	is the distance from the boundary
a	is the aquifer diffusivity T/S
t	is time since head change at boundary
T	is the low-T aquifer transmissivity (3 ft^2/dy)[9]
S	is the aquifer storage (0.000025)[10]

Assuming a drawdown of 5-ft at the boundary between the high-T and low-T zones (value for ΔHo in above equation) the drawdown in the low-T area 1500-ft away from this boundary after 365 days is about 4-ft. The 4-ft drawdown at this distance suggests pumping in the Roza high-T area may capture much of the Roza low-T area, depending on the hydraulic continuity between the two areas. Note that the available drawdown in the Roza aquifer is estimated to be about 20-ft, therefore the drawdown achieved at the boundary could actually be greater than 5-ft.

2.2.6 Northerly Plume Containment at Property Boundary – Roza Low-T Area Results

For this scenario, we assessed capture using a line of extraction wells which would be installed near the property boundary in the low-T area (Figure 1). We used a single T- value of 2.8 ft^2/dy based on the geometric mean of all Roza wells in the low-T area and a confined aquifer storage value of $2.5x10^{-5}$ (value reported in PGG, 2002).

AQTESOLV was used to predict drawdown after 365 days of pumping using 1 to 9 wells. Extraction rates were adjusted to maintain approximately 15-ft of drawdown. Because the drawdown predicted in AQTESOLV assumes a flat water table it cannot be used to assess capture when a natural gradient also exists. We therefore imported gridded drawdown results from AQTESOLV into the contouring software package SURFER v8.0 (Golden Software, Inc.) and subtracted the drawdown grid from a second grid representing a uniform groundwater gradient. The uniform groundwater gradient (0.0014 ft/ft) was calculated using groundwater elevation data from Roza monitoring wells in the target area. The resulting grid was then contoured and visually assessed to infer capture along the boundary.

The results of this assessment indicate at least 5 wells would be necessary to potentially achieve capture along the low-T boundary; however, long-term sustainable pumping rates would be less than 0.1 gpm per well (Table 9). Maintaining such low discharge rates long-term is not considered to be feasible, and this scenario is not evaluated in the FS.

The ambient groundwater flux through the low-T area of the property boundary is estimated to be 9,000 gallons per year (Table 10) – three orders of magnitude less than the ambient flux through the high-T area of the property boundary (Table 8).

2.2.7 Northerly Plume Containment Roza Aquifer Component at End-of-Plume Results

For this scenario, we assessed capture using a line of extraction wells near the end of the Roza aquifer component of the northerly plume, which is assumed to be in the low-T area based on the T-value measured in nearby well MW-44b (Figure 1). We used a single

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[9] Based on geometric mean of all Roza wells except those in the High-T zone.
[10] Based on value reported in PGG 2002.

transmissivity value of 2.8 ft^2/dy based on the geometric mean of all Roza wells in the low-T area and a confined aquifer storage value of $2.5x10^{-5}$ (value reported in PGG, 2002).

An analysis method similar to that used for the low-T Roza capture at the property boundary (Section 2.2.6) was applied to this evaluation. AQTESOLVE was used to predict drawdown after 365 days for a number of wells and extraction rates adjusted to maintain the target drawdown. Gridded drawdown results were imported into SURFER and subtracted from a uniform groundwater gradient grid. Note that the gradient near the end of the Roza northerly plume (0.018 ft/ft)[11] is greater than the low-T area near the landfill property boundary (0.0014 ft/ft). The resulting grid was contoured and visually assessed to infer capture along the boundary.

The results indicate at least 15 wells would be necessary to potentially achieve capture at the end of the Roza aquifer component of the northerly plume; however, similar to the low-T property boundary evaluation, long-term sustainable pumping rates are less than 0.1 gpm for individual wells, which is not considered feasible (Table 11).

The ambient groundwater flux at the end of the northerly plume in the Roza aquifer component is estimated to be 124,300 gallons per year (Table 12).

3.0 CONTAMINANT CALCULATIONS

The following section summarizes the calculations of source mass and source concentrations used in the REMChlor model (PGG, 2012a). The subsequent section summarizes calculations used to estimate northerly plume mass attenuation rates.

3.1 SOURCE CALCULATIONS FOR MODEL INPUT

Source area contaminant calculations were required for input to the fate and transport model developed for the northerly plume (PGG, 2012a). A REMChor fate and transport model was developed to evaluate plume response to a number of FS cleanup action scenarios. The model is based on average Roza aquifer parameters although the modeled flow path also includes short segments of the P1 and P2 zones near the source. Required source input parameters for the model are the initial source mass (Mo) and initial source concentration (Co). The source is assumed to be dominantly associated with leakage from the removed drums (Figure 1). This section provides calculations for estimating Mo and Co for the following seven volatile organic compounds (VOC) simulated using REMChlor (PGG, 2012a):

- 1,2-Dichloropropane (1,2-DCP)
- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- cis-12-Dichloroethene (cis-1,2-DCE)

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[11] Gradient at end of plume is based on groundwater elevation data from wells MW-44b, MW-48b and MW-51b.

- Vinyl Chloride (VC)
- Benzene
- Methylene Chloride

A range of values for Co and Mo (minimum, maximum, and best-estimate; Table 13) were estimated using data collected during the Remedial Investigation [12] (PGG, 2010 and 2012b). The ranges in values are based on uncertainty in parameters used to perform the source calculations. The ranges were used to conduct part of the model sensitivity analysis (PGG, 2012a). The following sections summarize our approach and results for calculation of source mass (Mo) and source concentration (Co).

3.1.1 Source Mass

The range in source mass for each simulated VOC is based on estimates of minimum, maximum, and best-estimates of VOC mass in residual LNAPL and soils in the source area (Table 14). As explained below, the range of uncertainty in the source mass is based on compounded uncertainty in parameter values such that the minimum and maximum may be too extreme. We therefore narrowed the range of values assessed in the model by using the 25th and 75th percentiles rather than the minimum and maximum source mass (Table 14). The results of these calculations show that most of the source mass is in LNAPL and not soils (Table 14). The approach and results for calculating residual LNAPL and soil source mass are described below.

3.1.1.1 LNAPL Source Mass

LNAPL source mass is based on estimates of LNAPL volume (Table 15) and the concentration of VOCs in LNAPL (Table 16).

The LNAPL volume is calculated as:

$\mathrm{Vol}_{\mathrm{LNAPL}} = (\mathrm{Thickness}_{\mathrm{LNAPL}}) \times (\mathrm{Area}_{\mathrm{LNAPL}}) \times (\mathrm{Porosity}_{\mathrm{P1}}) \times (\mathrm{Residual\ Saturation}_{\mathrm{LNAPL}})$

LNAPL has only been observed in the P1 source zone. Therefore the thickness of the residual LNAPL zone was estimated to range from 1-ft (seasonal fluctuation of water table in P1 source zone) to 3-ft (average thickness of the P1 source zone) with a best-estimated value of 2-ft (Table 15).

The LNAPL area is estimated to range from 5,000 ft^2 to 17,000 ft^2 with a best-estimated value of 10,000 ft^2 (Table 15). This range is based on locations (wells and borings) where LNAPL has and has not been observed in the P1 zone (Figure 1).

The P1 zone is a permeable weathered basalt interflow zone with characteristics of granular sediment. The porosity of the P1 zone was therefore estimated to range from 0.1 to 0.3 with a best-estimated value of 0.2 (Table 15).

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[12] Except for a more recent LNAPL sample collected in 2011, all analytical data used in the contaminant calculations were collected during the RI (2008 to 2010).

The LNAPL residual saturation is the fraction of P1 porosity filled with LNAPL. A recent study of LNAPL saturation was conducted at 11 British Petroleum (BP) sites with 338 samples collected at various locations throughout the full depth of LNAPL impacted soils (Adamski, 2011). The result of that study indicated most soils had relatively low LNAPL saturations with LNAPL confined mainly to macropores (Adamski, 2011). The average LNAPL saturation in the 338 samples was 6% and most samples (80%) had LNAPL saturations less than 10% (Adamski, 2011). Based on the results of the BP study we estimate the residual LNAPL saturation in the P1 zone to range from 3% to 10% of the P1 porosity with a best-estimated value of 6% (Table 15).

Using the equation above and the ranges in values of LNAPL residual saturation, LNAPL thickness, P1 source area, and P1 porosity, we estimate the LNAPL volume to range from a minimum of 112 gallons to a maximum of 11,446 gallons with a best-estimated value of 1,795 gallons (Table 15). Note that the minimum and maximum are based on compounding the range in input parameter values so that the minimum and maximum represent extreme values.

<u>The LNAPL VOC mass is calculated as:</u>

$\text{Source Mass}_{\text{LNAPL}} = (\text{C}_{\text{LNAPL}})\text{x}(\text{Vol}_{\text{LNAPL}})\text{x}(\text{Density}_{\text{LNAPL}})$

Estimated VOC concentrations in LNAPL (C_{LNAPL} in above equation) are based on an LNAPL sample collected from well MW-34p1 in September 2011[13] (Table 16). Concentrations for benzene, methylene chloride, trichloroethene, and vinyl chloride are based on ½ the laboratory reporting limits because these VOCs were not detected in the LNAPL sample.

Using the range of estimated LNAPL volumes (Table 15) in the equation above with estimated values for C_{LNAPL} and the LNAPL density (0.87 kg/L), we calculated a range of VOC mass in LNAPL (Table 16).

3.1.1.2 Soil Source Mass

Soil source mass is based on estimates of the average concentration of VOCs in the adsorbed soil phase (Table 17) and the bulk mass of residual soils (Table 18):

$\text{Source Mass}_{\text{soil}} = (\text{C}_{\text{soil}})*(\text{Bulk Mass}_{\text{soil}})*(0.000001 \text{ kg/mg})$

Where

$\text{Source Mass}_{\text{soil}}$	is the source VOC mass in soils (kg)
C_{soil}	is the concentration of VOC sorbed on soil (mg/kg)
$\text{Bulk Mass}_{\text{soil}}$	is the bulk mass of residual soils in the source area (kg)

<u>Adsorbed Soil Phase Concentration</u>

Residual soil samples were collected in the drum excavation following drum removal (PGG, 2010). Many of the samples were collected from areas where LNAPL was ob-

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[13] The LNAPL sample was analyzed for VOCs by EPA Method 8260C by Friedman and Bruya, Inc. in Seattle, WA.

served, so the results may be biased high and not representative of adsorbed soil phase concentrations. We therefore estimated adsorbed phase soil concentrations (C_{soil}) in the source area using equilibrium partitioning calculations from groundwater (C_{water}) to soil (Table 17):

$C_{Soil} = Kd*C_{Water}$

The partitioning coefficient (Kd) was calculated using default values for the octanol-water partition coefficient (Koc) and organic carbon fraction of aquifer solids (foc) in Ecology's Cleanup Levels and Risk Calculations (CLARC) database:

Kd = Koc*foc

Adsorption of contaminants in basalt aquifers is typically considered to be relatively insignificant due to the absence of organic material (Sorenson et al, 1998) and we expect using the MTCA default value for the organic carbon fraction (0.1%) may overestimate the soil adsorbed phase. However, we have not found definitive references on adsorption specifically for the Wanapum basalt and have therefore used the MTCA values for calculating C_{soil}.

Adsorbed phase soil concentrations were calculated for soils in the drum area and soils in the P1 source area (Table 17). Groundwater concentrations (C_{water}) in the drum area were based on average concentrations observed in interstitial liquids and seeps within the excavation (PGG, 2010) and groundwater concentrations in the P1 source area were based on average concentrations observed in MW-34p1[14] (Table 17).

Bulk Mass of Residual Soils

The bulk mass of residual soil was calculated as:

$\text{Bulk Mass}_{soil} = (\text{Thickness}_{soil})*(\text{Area}_{soil})*(\text{Density}_{soil})$

The bulk residual soil mass (i.e. those soils with adsorbed phase VOCs) was calculated separately for residual soils in the drum area and soils in the P1 source area. We estimated a range of bulk residual soil mass in both areas based on uncertainty in the thickness and area of residual soils (Table 18). The bulk density of soil in both locations was assumed to be 1.5 kg/L (MTCA default value).

Within the drum area, residual soil thickness was estimated to range from 0.05 to 0.5-ft with a best estimated value of 0.1-ft (Table 18). These relatively low values for thickness take into account that most residual soils in the drum excavation were removed to the top of bedrock; however some residual soils could not be excavated (PGG, 2010). The residual soil area in the drum area is estimated to be 7,000 ft^2 (based on survey of drum excavation).

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[14] Groundwater concentrations measured in the interstitial liquids, seeps, and MW-34p1 may include an oil-phase and therefore may overestimate the dissolved phase concentration.

Within the P1 source area, the residual soil thickness and area were estimated to range from 1 to 3-ft and 5,000 to 17,000 ft^2 respectively (Table 18). These values are based on the same ranges for residual LNAPL in the P1 source area (Table 15).

<u>Source VOC Mass in Soils</u>

Using the calculations of adsorbed phase soil concentrations (Table 17) and the range of estimated bulk residual soil mass (Table 18); we estimated a best-estimate, minimum and maximum value for the soil source mass for each VOC (Table 19).

3.1.2 Source Concentration

The source concentration in the P1 source area (Co) used in the REMChlor model (PGG, 2012a) represents the dissolved phase contaminant concentration in contact with the source mass (Mo).

Since groundwater concentrations measured in the P1 source area (MW-34p1) may overestimate the dissolved phase concentration due to the presence of LNAPL, we used northerly plume mass flux calculations to estimate Co. This approach assumes the mass flux of IHS in the source area is the same as[15] the mass flux some distance downgradient of the source and that minimum IHS degradation occurs between the source area and nearby plume. This approach tends to underestimate Co, because some degradation of IHS does occur. Note that the high degradation rate of total VOCs (Section 3.2.1) is dominated by non-IHS compounds, which were not simulated by REMChlor.

The mass flux (J) is calculated as:

$J\ (ug/dy) = Q*C$

Where

Q is the volumetric groundwater flux (L/dy)
C is the dissolved phase VOC concentration (ug/L)

And

$J_{plume} = J_{source}$

To use this approach we estimated mass flux in both the high-T and low-T zones of the Roza aquifer downgradient of the P1 source area near the northern boundary of the landfill property (Figure 1). VOC groundwater concentrations in nearby Roza wells were contoured and spatially averaged along the boundary in both the low-T and high-T zones. The spatially averaged groundwater concentrations were used as a single representative value in each zone (Table 20). The volumetric groundwater flux (Q) in the high-T and low-T zones is based on the average groundwater gradient (i), geometric mean of hydraulic conductivity (K), and cross-sectional area (A) in each zone (Table 20):

$Q_{High\text{-}T} = K*I*A = (307.5\ ft/dy)*(0.00068)*(500\text{-}ft)*(10\text{-}ft) = 1046\ ft^3/dy$

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[15] Long-term monitoring at the site indicates groundwater concentrations are fairly stable (PGG, 2010).

$Q_{Low\text{-}T} = K*I*A = (0.28\ ft/dy)*(0.00143)*(840\text{-}ft)*(10\text{-}ft) = 3.4\ ft^3/dy$

The total plume mass flux (J) is the sum of the high-T and low-T plume mass flux (Table 20). Note that most of the plume mass flux is through the high-T area due to the much higher volumetric flux in this area.

The source area concentration (Co) is then calculated as:

$Co = J_{plume}/Q_{SourceArea}$

Where

$Q_{SourceArea} = K*I*A$

And

K*I = User specified Simulated Darcy Velocity = 5.1 m/yr (PGG, 2012a)

Using the above equation, we estimated a range in Co values (Table 20) based on a minimum, maximum, and best-estimated value for the cross-section P1 source area (Figure 1).

The results of this analysis show that the values of Co (best estimates) for most of the simulated VOCs are in the same order of magnitude as the average concentrations measured in MW-34p1 (Table 20), suggesting the method of using mass flux results in a reasonable estimate of the source concentration. The best-estimate value of Co for vinyl chloride (1303 ug/L); however, is almost twice as high as concentrations measured in MW-34p1 (maximum concentration was 750 ug/L; Table 20). This observation, along with documented reductive dechlorination of chloro-ethenes, suggests additional vinyl chloride is being generated through degradation processes along this portion of the plume path. A value of 1303 ug/L would therefore likely over-estimate the Co term in REMChlor. Therefore, the maximum observed value in MW-34p1 (750 ug/L) was used as the best-estimate Co value for vinyl chloride in the model (PGG, 2012a). All other Co values were based on the Mass Flux estimated values in Table 20.

3.2 ESTIMATED NORTHERLY PLUME MASS ATTENUATION

Groundwater geochemical screening at the site indicates there is strong to adequate evidence for anaerobic degradation occurring in the P1 and P2 source area as well as the Roza component of the northerly plume (PGG, 2010 Section 9.4). In support of the FS, we have used two independent methods to estimate mass removal as a result of natural attenuation within the portion of the northerly plume between the P1 source area and the Roza aquifer high-T property boundary (Figure 1).

The first method is based on estimates of mass flux (Section 3.2.1). With the mass flux method, the total organic COC mass flux is calculated for the P1 source area and the Roza aquifer high-T property boundary. The annual total organic COC mass removal is then estimated as the difference in mass flux between the two locations. Because this method uses flux along two transects of the plume that are assumed to encompass the entire plume width, attenuation with this method should only be due to the removal of mass and not due to dispersion, although there are other assumptions associated with this method (see below).

The second method uses a first order bulk attenuation rate and then calculates the mass attenuation over a one year period (Section 3.2.2). This method incorporates all attenuation processes (dispersion, degradation, sorption, and volatilization) and therefore estimating mass reduction requires adjustment for the effects of dispersion (see below).

The combined results of the two methods indicate total annual organic COC mass removal ranging from 130 kg/yr (lower bound) to 260 kg/yr (upper bound) with a recommended value of 200 kg/yr to be used in the FS (the recommended value is based on the mass flux method). Both methods include significant uncertainty due to dependence on groundwater velocity, which may vary by an order of magnitude due to the heterogeneity of basalt aquifers.

Both methods estimate bulk attenuation rates for organic COCs. As described in the RI (PGG, 2010), mass attenuation along this portion of the plume is dominated by the removal of TEX and ketone compounds (over 90%), which are not IHS.

3.2.1 Mass Attenuation Estimate - Mass Flux Method

The mass flux method estimates the mass loss due to degradation processes as the difference in mass passing through two points along a flow path. The total organic COC mass flux was estimated for the P1 source area and high-T Roza aquifer at the landfill property boundary (Figure 1). Key assumptions included in this method are:

- Plume equilibrium (steady state)
- Steady uniform flow
- Mass flux through the Roza high-T boundary represents all of the mass flux originating from the P1 source area.

As described in Section 3.1.2, the mass flux (J) is:

$J\ (ug/yr) = Q*C$

Where

Q is the volumetric groundwater flux (L/yr)
C is the dissolved phase VOC concentration (ug/L)

The attenuation of mass between these two locations is then calculated as:

Mass attenuation (ug/yr) = $J_{p1} - J_{Roza}$

Mass fluxes at the P1 source area and Roza high-T landfill property boundary are estimated at 206 kg/yr and 2 kg/yr, respectively. The difference between these mass fluxes indicates approximately 200 kg/yr mass loss due to degradation in the groundwater plume between the P1 source area and the landfill property boundary. Most (97%) of the change in mass is from the attenuation of TEX and ketone compounds (Table 21)[16].

3.2.2 Mass Attenuation Estimate - First Order Bulk Attenuation Rate Method

This method estimates the annual total organic COC attenuation using a first order bulk attenuation rate constant (k). The method for estimating the k-value is described below. The subsequent section describes how the k-value is used to estimate the annual total organic COC mass attenuation.

3.2.2.1 First Order Bulk Attenuation Rate Calculation

A first order bulk attenuation rate constant (k) for total organic COCs was estimated for the portion of the northerly plume which extends from the P1 source area to the high-T Roza aquifer at the landfill property boundary (Figure 1). For this calculation we used the method of plotting concentration versus distance developed by Newell and others for estimating first order bulk k-values (Newell et al, 2002). With this method, the bulk k-value represents attenuation of dissolved constituents due to *all* attenuation processes including dispersion, degradation, sorption, and volatilization.

First order attenuation is defined by the following equation:

$Ct = Co*e^{-kt}$

Where Co = the initial dissolved phase concentration (ug/L)

Ct = the concentration at some time (t) in the future (ug/L)

t = time (years)

k = the bulk attenuation rate constant (yr^{-1})

The method for estimating the bulk k-value involves the following steps (Newell et al, 2002):

1. Plot natural log of concentration versus distance
2. Fit a linear regression line to the data
3. Multiply the absolute value of the slope of the line by the contaminant velocity (seepage velocity divided by the retardation factor R) to derive k

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[16] A mass flux approach was also used to estimate the initial source mass concentration (Co) for select VOCs simulated in REMChlor (IHS, see Section 3.1.2). Application of the mass flux method to estimate Co assumed no degradation between the P1 source area and the Roza high-T property boundary. Although some degradation is occurring between the two locations, as mentioned in section 3.1.2, the Co values for all IHS(with the exception of vinyl chloride) were the same order of magnitude as the average concentrations measured in MW-31p1, suggesting the mass flux method provided reasonable estimate of Co values. Also note that the mass flux approach used in the development of Co (Table 20) used contoured groundwater concentrations for IHS whereas the calculations presented in Table 21 used the average organic COC concentrations measured in wells MW-3b and MW-7b. The two methods produce similar but slightly different values for groundwater concentrations along the high-T boundary.

Average organic COC concentrations measured in wells at three locations within the northerly plume between the P1 source area and the Roza aquifer high-T boundary were used for concentration-distance plots (step 1) (Figures 1 and 2, and Table 22):

- P1 Source Area (MW-34p1); at the source[17].
- Roza Aquifer midway between Source Area and Roza High-T property boundary (MW-42b); approximately 120 meters from the source.
- Roza Aquifer at the High-T property boundary (MW-3b and MW-9b); approximately 240 meters from the source.

Figure 2 shows a plot of the natural log of total organic COC concentration versus distance. A linear regression line (step 2) fitted to the data indicates a slope of -0.031.

The average contaminant velocity within this area of the northerly plume is estimated to be 100 m/yr[18]. This estimate is based on seepage velocities calculated for the P1 source area and the Roza aquifer high-T area as follows:

Seepage velocity = K*i/n

Where K = the hydraulic conductivity (ft/dy)

i = groundwater gradient

n = effective porosity (assumed to be 0.2)

P1 Source Area Seepage velocity = (7 ft/dy)*(0.02)/(0.2) = 0.7 ft/dy = 78 m/yr

Roza High-T Aquifer Seepage Velocity = (307 ft/dy)*(0.0007)/(0.2) = 1.1 ft/dy = 120 m/yr

For this calculation we assume a single average seepage velocity of 100 m/yr for the northerly plume between these two areas. Given the low organic content expected in basalt aquifers, we assume a retardation factor (R) of 1. Thus, the contaminant velocity (v_c) is also 100 m/yr.

Finally, the bulk attenuation rate (k) is calculated as (step 3):

k = absolute value of slope*vc = 0.031*100 = 3.1 yr^{-1}

A k-value of 3.1 corresponds to a half-life of 0.22 years:

$t_{½}$ = ln(0.5)/(-k) = ln(0.5)/(-3.1) = 0.22 years

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[17] Although the concentrations measured in MW-34p1 may over-estimate the dissolved phase concentration of some VOCs (due to the presence of LNAPL), the average concentrations measured in this well were deemed a reasonable approximation for the calculation.

[18] This value for contaminant velocity (100 m/yr) is higher than the value used in the REMChlor fate and transport model (25.5 m/yr). The value used in the REMChlor model is based on the average K-value measured in all Roza wells, including those located in the low-T area (PGG, 2012a).

This half-life suggests rapid degradation of COCs in the dissolved phase plume.

3.2.2.2 Annual Mass Attenuation Calculation

This section describes the method used to estimate the annual mass attenuation rate for total organic COCs using the rate constant discussed above. Two concentration profiles were developed assuming a unit cross section area (flow tube) using the first-order decay rate equation[19] (Section 3.2.2.1): a steady state concentration profile under current conditions; and the same steady state curve translated forward one-year (100 m) assuming no degradation. The area between the two curves represents the mass loss due to attenuation over the one year period (Figure 3). The mass loss along the flow tube is then multiplied by the cross-sectional area of the source area (45 m^2) to estimate the mass attenuation within the dissolved-phase plume[20].

This method yields a mass attenuation rate of 257 kg/year for organic COCs as an upper bound of the expected degradation rate (mass removal). This result is an upper bound because the method does not distinguish between change in concentration due to degradation and change in concentration due other processes (namely dispersion). The mass loss due to degradation decreases to approximately 130 kg/yr if dilution due to dispersion is assumed to account for 50% of the change in concentration; simulations of chloride attenuation suggest an approximately 50% decrease in concentration due to dispersion 240 meters downgradient of the landfill in the northerly plume (Figure 3 in PGG, 2012a).

4.0 REFERENCES

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[19] $C_t = C_o * e^{-kt}$.

[20] Plume cross sectional area (45 m^2), is consistent with the cross-sectional area used in the mass flux calculation at the P1 source area.

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Table 1. Recommended Groundwater Extraction Rates, Volumes, and Wells for FS Design

	Cleanup Action Scenarios Evaluated							
Parameter	Pump MW-34p1 and MW-36p1 (Seasonal Extraction)[1]	Long Term Exraction P1[2]	Long-Term Extraction P2	Pump EW-1 [Hole] (seasonal Extraction)[3]	Dewater Hole[4]	Roza High T (Property Boundary Capture)[5]	Roza Low T (Property Boundary Capture)[6]	Roza Low T (EOP Capture)[7]
Total Groundwater Discharge Rate (gpm)	0.4	0.5	Not Feasible (see text)	1	4	6	Not Feasible (see text)	
Pumping Duration (days)[8]	200	Infinite		200	70	Infinite		
Extraction Volume (gallons/year)	115,000	250,000		290,000	390,000	3,500,000		
Wells Required	2 Existing	5		1 Existing	4	2		
Well Spacing (ft)	90	50		NA	NA	160		

Notes

1. Based on seasonal pumping of P1 source zone for 200 days with 2-ft of drawdown in well. Sustainable pumping rates in MW-34p1 and MW-36p1 are estimated to be 0.3 and 0.1 gpm respectively
2. Based on long term sustainable pumping of P1 source zone (2-ft drawdown in well).
3. Based on seasonal pumping of the Hole for 200 days with 3 to 5-ft of drawdown in well (Existing well).
4. Although the calculations indicate 1 well can achieve the dewatering extraction volume (Table 5), a total of 4 wells are recommended for the design basis.
   Long term sustainable pumping rates may be less depending on the recharge rate to Hole.
   Ambient Darcy Flux in Hole = 46,000 gallons/year (minimum sustainable pumping rate). Given the Darcy flux, it may not be possible to dewater the Hole more than once per year.
5. Based on hydraulic containment by capture along High T boundary near landfill property boundary.
6. Based on hydraulic containment by capture along Low T boundary near landfill property boundary. Well discharge rate not likely feasible (very low).
7. Based on hydraulic containment by capture along Low T end of plume (EOP) boundary near Whitson well. Well discharge rate not likely feasible (very low).
8. Pumping duration (days) is per year.

Table 2. Summary of Groundwater Extraction Rates, Volumes, and Wells for Cleanup Action Scenarios

	Cleanup Action Scenarios Evaluated							
Parameter	Pump MW-34p1 and MW-36p1 (Seasonal Extraction)[1]	Long Term Exraction P1[2]	Long-Term Extraction P2	Pump EW-1 [Hole] (seasonal Extraction)[3]	Dewater Hole[4]	Roza High T (Property Boundary Capture)[5]	Roza Low T (Property Boundary Capture)	Roza Low T (EOP Capture)
Range of Total Groundwater Discharge Rate (gpm)	NA	0.15 to 1	Not Feasible (see text)	1 to 1.5	4 to 8	1 to 15	Not Feasible (see text)	Not Feasible (see text)
Recommended Design Total Groundwater Discharge Rate (gpm)	0.4	0.5		1	4	6		
Range of Groundwater Discharge Per well (gpm)	NA	0.1 to 0.4		1	2 to 4	0.5 to 7.5		
Pumping Duration (days)[6]	200	Infinite		200	40 to 70	Infinite		
Range Total Extracton Volume (gallons/year)	NA	75,000 - 550,000		290,000 - 430,000	390,000 - 440,000	500,000 - 8,000,000		
Recommended Design Total Water Extraction Volume (gallons/year)	115,000	250,000		290,000	390,000	3,500,000		
Range of Wells Required	2 Existing	2 to 10		1	1 to 4	2		
Well Spacing (ft)	90	30 to 90		NA	50 to 100	160		
Estimated VOC IHS Mass Removal[7]								
Avg Concentration of 1,2-DCP observed in component area (ug/L)	480	480		1.5	1.5	10		
Estimated 1,2-DCP Mass Removal (kg/yr)	0.2	0.5		0.002	0.002	0.1		
Avg Concentration of Benzene observed in component area (ug/L)	140	140		2.5	2.5	2		
Estimated Benzene Mass Removal (kg/yr)	0.1	0.1		0.003	0.004	0.03		
Avg Concentration of Methylene Chloride observed in component area (ug/L)	400	400		1	1	2		
Estimated Methylene Chloride Mass Removal (kg/yr)	0.2	0.4		0.001	0.001	0.03		
Avg Concentration of PCE observed in component area (ug/L)	13	13		0.05	0.05	0.5		
Estimated PCE Mass Removal (kg/yr)	0.01	0.01		0.0001	0.0001	0.01		
Avg Concentration of TCE observed in component area (ug/L)	11	11		1	1	1		
Estimated TCE Mass Removal (kg/yr)	0.005	0.01		0.001	0.001	0.01		
Avg Concentration of cis-1,2-DCE observed in component area (ug/L)	2440	2440		30	30	25		
Estimated cis-1,2-DCE Mass Removal (kg/yr)	1.1	2.3		0.03	0.04	0.3		
Avg Concentration of Vinyl Chloride observed in component area (ug/L)	355	355		75	75	25		
Estimated Vinyl Chloride Mass Removal (kg/yr)	0.2	0.3		0.1	0.1	0.3		
Avg Concentration of 1,1,1-TCA observed in component area (ug/L)	2,220	2,220		0.00	0.00	0.00		
Estimated 1,1,1-TCA Mass Removal (kg/yr)	1.0	2.1		0.00	0.00	0.00		
Avg Concentration of 1,1-DCE observed in component area (ug/L)	30	30		0.40	0.40	1.00		
Estimated 1,1-DCE Mass Removal (kg/yr)	0.01	0.03		0.0004	0.0006	0.01		
Avg Concentration of 1,2-DCA observed in component area (ug/L)	525	525		0.60	0.60	2.00		
Estimated 1,2-DCA Mass Removal (kg/yr)	0.2	0.5		0.001	0.001	0.03		
Avg Concentration of Chloroform observed in component area (ug/L)	34	34		0.00	0.00	0.00		
Estimated Chloroform Mass Removal (kg/yr)	0.01	0.03		0.00	0.00	0.00		
Avg Concentration of Toluene observed in component area (ug/L)	62,000	62,000		0.20	0.20	0.00		
Estimated Toluene Mass Removal (kg/yr)	27	59		0.0002	0.0003	0.00		
TOTAL MASS REMOVAL OF IHS VOCs (kg/yr)	30	65		0.12	0.17	0.91		
Estimated Total organic COC Mass Removal[9]								
Avg Concentration of Total organic COCs in component area (ug/L)	289,000	289,000		150	150	165		
TOTAL ORGANIC COC REMOVAL (kg/yr)	126	273		0.2	0.2	2.2		

Notes

1. Based on seasonal pumping of P1 source zone for 200 days with 2-ft of drawdown in well (maintain 2-ft head above pump). Sustainable pumping rates in MW-34p1 and MW-36p1 are estimated to be 0.3 and 0.1 gpm respectivel
2. Based on long term sustainable pumping of P1 source zone and potential mobilization of LNAPL towards wells (2-ft drawdown in well is assumed for current evaluation)
3. Based on seasonal pumping of the Hole for 200 days with 3 to 5-ft of drawdown in well (Existing well)
4. Based on dewatering Hole over 40 to 70 day period. Long term sustainable pumpig rates may be less depending on recharge rate to Hole. Ambient Darcy Flux through Hole = 46,000 gallons/year (min. sustainable pumping rate).
   Given Darcy flux, not likely possible to dewater Hole more than once per year
5. Based on hydraulic containment by capture along High T boundary near landfill property boundary
6. The pumping duration (days) is per year.
7. Mass Removal (kg) is calculated as the recommended design extracted groundwater (vol.) multiplied by the average groundwater concentration (mass/vol).
   Average concentrations based on data collected during the RI. P1 data from MW-34p1. Roza data from MW-3b and MW-7b. Hole data from 2008 extraction season (PGG, 2010
   Note that extracted groundwater may be diluted with cleaner groundwater over time as cleaner portions of the aquifer contribute to extracted groundwater. Thus the annual mass removal may be less than calculated above
9. Total VOC mass removal in the P1 source zone would be dominated by BTEX and Ketones

Table 3. P1 Source Area Long Term Groundwater Extraction - Aqtesolv Results

	Aqtesolve	Geometric Mean T[7]			Max T				Min T		
Parameters	Input/Output	2 Wells	5 Wells	7 Wells	2 Wells	5 Wells	7 Wells	9 Wells	2 Wells	5 Wells	7 Wells
Target Area[1]	Input	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft	160x80-ft
Discharge/well (gpm)	Input	0.15	0.10	0.07	0.40	0.2	0.15	0.12	0.07	0.05	0.04
Transmissivity (ft^2/dy)[2]	Input	21	21	21	51	51	51	51	10	10	10
Target DD in well (ft)	Input	2	2	2	2	2	2	2	2	2	2
Predicted DD in Well (ft)[3]	Output	2.1	2.4	2.0	2.5	2.2	2.2	2.2	1.9	2.2	2.3
Predicted DD in Source Area (ft)[4]	Output	1-2.1	1.6-2.4	1.6 to 2.2	1.3-2.5	1.6 to 2.2	1.7-2.2	1.7-2.2	0.8 to 1.9	1.4-2.2	1.6 to 2.3
Extraction Duration (days)	Input	5 yr	5 yr	5 yr	5 yr	5 yr	5 yr	5 yr	5 yr	5 yr	5 yr
Number of Wells	Input	2	5	7	2	5	7	9	2	5	7
Well Spacing (ft)[5]	Input	Existing 90-ft	80x50	50x50	Existing 90-ft	80x50	50x50	30x50	Existing 90-ft	80x50	50x50
Total Discharge Rate (gpm)	Input	0.3	0.5	0.49	0.8	1	1.05	1.08	0.14	0.25	0.28
Extracted Water Volume (gallons/yr)	Input	157,680	262,800	257,544	420,480	525,600	551,880	567,648	73,584	131,400	147,168
Aqtesolve Solution	Input	Neuman	Neuman	Neuman	Neuman	Neuman	Neuman	Neuman	Neuman	Neuman	Neuman
S or Sy[6]	Input	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aquifer Sat Thickness (ft)	Input	3	3	3	3	3	3	3	3	3	3

Notes

1. Based on an approximation of estimated LNAPL Extent in P1 Source Area (Figure 1)
2. Based on geometric mean, min, and max of MW-34p1, MW-36p1, and MW-37p1
3. Drawdown in well as predicted by Aqtesolv
4. Range of Drawdown predicted by Aqtesolv
5. Wells spaced uniformly in target area
6. Storage or Specific Yield (depending on if confined or unconfined)
7. Geometric mean calculated with MS Excel formula

Table 4. Estimated Ambient Groundwater Flux through P1 Source Area

Parameter Values	Geomean K	Min K	High K
K (ft/dy)	7	3.3	17
I (ft/ft)	0.02	0.02	0.02
A (160-ft long x 3-ft thickness)	480	480	480
Q (ft^3/dy) = KIA	67	32	163
Q (gpm)	0.35	0.16	0.85
Q (gallons/yr)	183,494	86,504	445,628

I = groundwater gradient based on average gradient measured in wells MW-34p1, MW-36p1, and MW-37p1

A = Estimated cross-sectional Source Area

Q = Groundwater Flux

Table 5. Groundwater Extraction from the Hole - Aqtesolv Results

Parameter	Aqtesolve Input/Output	Seasonal Pumping (EW-1)	Seasonal Pumping (EW-1)	Dewater (EW-1)	Dewater (4- wells)
Target Area[1]	250x250-ft	250x250-ft	250x250-ft	250x250-ft	250x250-ft
Discharge/well (gpm)[1]	Input	1.0	1.5	4.0	2.0
Transmissivity (ft^2/dy)[2]	Input	700	700	700	700
Target DD in well (ft)	Input	3	5	5	5
Predicted DD in Well (ft)	Output	3	5	5	5
Predicted DD in Hole (ft)	Output	3 to 3.3	4.5 to 5	4 to 5	4.5 to 5
Extraction Duration (days)	Input	200	200	67	38
Number of Wells	Input	1	1	1	4
Well Spacing (ft)	Input	NA	NA	NA	NA
Total Discharge Rate (gpm)	Input	1	1.5	4	8
Extraction Water Volume/Duration (gallons)	Input	288,000	432,000	385,920	437,760
Aqtesolve Solution[3]	Input	Neuman/NF Boundary	Neuman/NF Boundary	Neuman/NF Boundary	Neuman/NF Boundary
S or Sy	Input	0.1	0.1	0.1	0.1
Aquifer Sat Thickness (ft)	Input	5	5	5	5

Notes

1. Based on approximate area of saturation in Hole (1.5 acres)

1. PGG (2002) Extraction Report states a sustainable pumping rate rate of 1 to 2 gpm for EW-1

2. Transmissivity from 2002 Extraction Report (PGG, 2002)

3. A no flow boundary was used in Aqtesolve to simulate the boundary of the basalt surrounding groundwater in the Hole.

Table 6. Estimated Ambient Groundwater Flux through the Hole

Parameter	Value
K (ft/dy)	15
I (ft/ft)	0.0009
Area (250-ft long x 5-ft thickness)	1250
Q (ft^3/dy) = KIA	17
Q (gpm)	0.09
Q (gallons/year)	46,078

I = groundwater gradient based on average gradient measured in wells EW-1, W-9 and W-12

A = Estimated cross-sectional Source Area

Q = Groundwater Flux

Table 7. Northerly Plume Capture at Property Boundary (Roza High-T zone) - GFLOW Results

	Unbounded High T Zone			Partly Bounded High T Zone			Fully Bounded High T Zone		
Parameters	Geomean T	Max T	Min T	Geomean T	Max T	Min T	Geomean T	Max T	Min T
Length of High T Boundary	500	500	500	500	500	500	500	500	500
Discharge/well (gpm)	5	15	2.5	2.5	5	1	0.25	0.25	0.25
Transmissivity (ft^2/dy)[1]	3074	7890	1200	3074	7890	1200	3074	7890	1200
Extraction Duration (days)	Indefinite	Indefinite	Indefinite	Indefinite	Indefinite	Indefinite	Indefinite	Indefinite	Indefinite
Number of Wells	2	2	2	2	2	2	2	2	2
Well Spacing (ft)	166	166	166	166	166	166	166	166	166
Total Discharge Rate (gpm)	10	30	5	5	10	2	0.5	0.5	0.5
Extracted Water Volume (gallons/yr)[2]	5,256,000	15,768,000	2,628,000	2,628,000	5,256,000	1,051,200	262,800	262,800	262,800
Aquifer Sat Thickness (ft)	10	10	10	10	10	10	10	10	10

Notes

1. Based on previous aquifer pumping tests in high-T area (PGG, 2002).

2. GFLOW calculated extraction rates are those necessary to achieve capture (see text).

Table 8. Estimated Ambient Groundwater Flux through Roza High-T Area of Property Boundary

Parameter Values	Geomean K	Low K	High K
K (ft/dy)	307	120	789
I (ft/ft)	0.00068	0.00068	0.00068
A (500-ft long x 10-ft thickness)	5000	5000	5000
Q (ft^3/dy) = KIA	1,045	409	2,681
Q (gpm)	5	2	14
Q (gallons/yr)	2,854,300	1,116,900	7,321,900

I = groundwater gradient based on average gradient measured in wells MW-3b, MW-7b and MW-9b

A = Estimated cross-sectional High-T Area

Q = Groundwater Flux

Table 9. Northerly Plume Capture at Property Boundary (Roza Low-T zone) - ATESOLV Results

Parameters	Aqtesolve Input/Output	5 Wells (Geomean T)	9 Wells (Geomean T)
Length of Boundary	Input	840	840
Discharge/well (gpm)[1]	Input	0.065	0.040
Transmissivity (ft^2/dy)[2]	Input	2.8	2.8
Target DD in well (ft)	Input	15.0	15.0
Predicted DD in Well (ft)[3]	Output	16	18
Predicted DD along boundary (ft)[4]	Output	11 to 16	13 to 18
Extraction Duration (days)	Input	365	365
Number of Wells	Input	5	9
Well Spacing (ft)[5]	Input	200	100
Total Discharge Rate (gpm)	Input	0.33	0.36
Extraction Water Volume/Duration (gallons)	Input	170,820	189,216
Aqtesolve Solution	Input	Theis Confined	Theis Confined
S or Sy[6]	Input	2.50E-05	2.50E-05
Aquifer Sat Thickness (ft)	Input	10	10

Notes

1. Maintaining such low rates long term would be very difficult and is below our recommended threshold for pumping.
2. Based on geometric mean of all Roza wells in low-T area.
3. Drawdown in well as predicted by Aqtesolv
4. Range of Drawdown predicted by Aqtesolv
5. Wells spaced uniformly in target area
6. Storage or Specific Yield (depending on if confined or unconfined)

Table 10. Estimated Ambient Groundwater Flux through Roza Low-T Area of Property Boundary

Parameter Values	Value
K (ft/dy)	0.28
I (ft/ft)	0.0014
A (840-ft long x 10-ft thickness)	8400
Q (ft^3/dy) = KIA	3
Q (gpm)	0.017
Q (gallons/yr)	8,991

K-value based on geometric mean in low-T area

I = groundwater gradient based on average gradient measured in wells MW-3b, MW-7b and MW-9b

A = Estimated cross-sectional High-T Area

Q = Groundwater Flux

Table 11. Northerly Plume Capture at Roza End of Plume (Low-T zone) - ATESOLV Results

Parameters	Aqtesolve Input/Output	15 Wells (Geomean T)	30 wells (Geomean T)
Length of Boundary	Input	900	900
Discharge/well (gpm)[1]	Input	0.025	0.015
Transmissivity (ft^2/dy)[2]	Input	2.8	2.8
Target DD in well (ft)	Input	15.0	15.0
Predicted DD in Well (ft)[3]	Output	17	20
Predicted DD along boundary (ft)[4]	Output	14 to 17	17 to 20
Extraction Duration (days)	Input	365	365
Number of Wells	Input	15	30
Well Spacing (ft)[5]	Input	60	30
Total Discharge Rate (gpm)	Input	0.38	0.45
Extraction Water Volume/Duration (gallons)	Input	197,100	236,520
Aqtesolve Solution	Input	Theis Confined	Theis Confined
S or Sy[6]	Input	2.50E-05	2.50E-05
Aquifer Sat Thickness (ft)	Input	10	10

Notes

1. Maintaining such low rates long term would be very difficult and is below our recommended threshold for pumping
2. Based on geometric mean of all Roza wells in low-T area.
3. Drawdown in well as predicted by Aqtesolv
4. Range of Drawdown predicted by Aqtesolv
5. Wells spaced uniformly in target area
6. Storage or Specific Yield (depending on if confined or unconfined)

Table 12. Estimated Ambient Groundwater Flux through Roza Low-T Area near Roza End of Plume

Parameter Values	Value
K (ft/dy)	0.28
I (ft/ft)	0.018
A (900-ft long x 10-ft thickness)	9000
Q (ft^3/dy) = KIA	46
Q (gpm)	0.24
Q (gallons/yr)	124,301

K-value based on geometric mean in low-T area

I = groundwater gradient based on average gradient measured in wells MW-44b, MW-48b, and MW-51b (Figure 1)

A = Estimated cross-sectional High-T Area

Q = Groundwater Flux

Table 13. Initial Source Mass and Source Concentrations for Model Input

	Initial Source Mass (Mo)			Initial Source Concentration (Co)		
VOC[1]	Best-Esimate (kg)	Max (kg)	Min (kg)	Best-Esimate (ug/L)	Max (ug/L)	Min (ug/L)
Tetrachloroethene (PCE)	0.66	2.4	0.3	24	35	21
1,2-Dichloropropane	0.96	3.5	0.5	597	869	516
cis-1,2-Dichloroethene	3.50	12.8	1.9	1409	2050	1219
Benzene	0.30	1.1	0.2	113	164	98
Methylene chloride	1.51	5.5	0.8	154	224	133
Trichloroethene (TCE)	0.31	1.1	0.2	65	94	56
Vinyl chloride	0.30	1.1	0.2	750	1091	649

1. Seven volatile organic compounds simulated in REMChlor fate and transport model (PGG, 2012)

Table 14. Estimated Source Mass, Mo

VOC[1]	Best Estimate[2]			Minimum Estimate[2]			Maximum Estimate[2]			Alt. Min[3]	Alt. Max[3]
	LNAPL (kg)	Soil (Kg)	Total (kg)	LNAPL (kg)	Soil (Kg)	Total (kg)	LNAPL (kg)	Soil (Kg)	Total (kg)	25th Perc.	75th Perc.
Tetrachloroethene (PCE)	0.65	0.0075	0.66	0.04	0.00	0.04	4.14	0.03	4.17	0.4	2.4
1,2-Dichloropropane	0.94	0.0198	0.96	0.06	0.01	0.06	6.02	0.05	6.07	0.5	3.5
cis-1,2-Dichloroethene	3.42	0.0758	3.50	0.21	0.02	0.23	21.83	0.20	22.03	1.9	12.8
Benzene	0.30	0.0082	0.30	0.02	0.00	0.02	1.88	0.02	1.90	0.2	1.1
Methylene chloride	1.48	0.0315	1.51	0.09	0.01	0.11	9.41	0.15	9.56	0.8	5.5
Trichloroethene (TCE)	0.30	0.0133	0.31	0.02	0.01	0.02	1.88	0.06	1.95	0.2	1.1
Vinyl chloride	0.30	0.0059	0.30	0.02	0.00	0.02	1.88	0.02	1.90	0.2	1.1

Notes

1. Seven volatile organic compounds simulated in REMChlor fate and transport model (PGG, 2012)
2. Best estimated, minimum, and maximum based on range of parameters values used in source mass calculations (see text)
3. Alternative minimum and maximum based on 25th and 75th percentile of best-estimate, min, and max total.
   As explained in text, the min and max represent compounded uncertainty and extreme end members, therefore range narrowed with 25ht and 75th percentiles

Table 15. Estimated Residual LNAPL Volume in P1 Source Area

Range	LNAPL Residual Saturation (%)[1]	LNAPL Thickness (ft)[2]	P1 Source Area (ft^2)[3]	P1 Zone Porosity[4]	Estimated LNAPL Volume (gallons)[5]
Best-Estimate	6%	2	10,000	0.2	1,795
Minimum	3%	1	5,000	0.1	112
Maximum	10%	3	17,000	0.3	11,446

Notes

1. Residual LNAPL as a fraction of P1 porosity.
   Range based on analysis from 338 samples collected from 11 British Petroleum LNAPL sites (Adamski, 2011)
2. Range in thickness based on seasonal fluctuation of P1 water levels and the average thickness of P1 zone (see text)
3. P1 source area based on observations of LNAPL (see text)
4. Porosity range based on observation that the weathered P1 zone is similar to unconsolidated sediments
5. LNAPL Volume = (Thickness)*(Area)*(Porosity)*(Residual Saturation)*(7.481 gallons/ft^3)

Table 16. Estimated Residual LNAPL Mass in P1 Source Area

VOC	LNAPL Density (kg/L)	VOC Concentration in LNAPL (mg/kg)[1], (C_{LNAPL})	Best Estimate		Minimum Estimate		Maximum Estimate	
			LNAPL Volume (gallons), (Vol_{LNAPL})	VOC Mass in LNAPL (kg)[2], (Source $Mass_{LNAPL}$)	LNAPL Volume (gallons), (Vol_{LNAPL})	VOC Mass in LNAPL (kg)[2], (Source $Mass_{LNAPL}$)	LNAPL Volume (gallons), (Vol_{LNAPL})	VOC Mass in LNAPL (kg)[2], (Source $Mass_{LNAPL}$)
Tetrachloroethene (PCE)	0.87	110	1,795	0.65	112	0.04	11,446	4.14
1,2-Dichloropropane	0.87	160	1,795	0.94	112	0.06	11,446	6.02
cis-1,2-Dichloroethene	0.87	580	1,795	3.42	112	0.21	11,446	21.83
Benzene	0.87	50	1,795	0.30	112	0.02	11,446	1.88
Methylene chloride	0.87	250	1,795	1.48	112	0.09	11,446	9.41
Trichloroethene (TCE)	0.87	50	1,795	0.30	112	0.02	11,446	1.88
Vinyl chloride	0.87	50	1,795	0.30	112	0.02	11,446	1.88

Notes

1. Based on results from LNAPL sample collected in September 2011.
   Results for Benzene, Methylene Chloride, TCE and Vinyl Chloride based on 1/2 the detection limit (VOC was not detected in sample)
2. VOC Mass = (LNAPL Concentration)*(LNAPL Density)*(LNAPL Volume)*(3.78 L/gallon)*(0.000001 kg/mg)

Table 17. Estimated Adsorbed Phase Soil Concentrations (based on equilbrium partitioning)

	MTCA Kd Calculation[1]			Estimated Groundwater Concentration in Contact with Residual Soils[2] , (C_{gw})		Estimated Adsorbed Phase Soil Concentration[3] , (C_{soil})	
VOC	Koc (L/kg)	foc	Kd (L/kg)	Former Drum Excavation (ug/L)	P1 Area (ug/L)	Former Drum Excavation (mg/kg)	P1 Area (mg/kg)
Tetrachloroethene (PCE)	265	0.001	0.27	564	13	0.149	0.004
1,2-Dichloropropane	47	0.001	0.05	429	482	0.020	0.023
cis-1,2-Dichloroethene	35.5	0.001	0.04	2,086	2,441	0.074	0.087
Benzene	62	0.001	0.06	419	141	0.026	0.009
Methylene chloride	10	0.001	0.01	94,541	398	0.945	0.004
Trichloroethene (TCE)	94	0.001	0.09	4,435	11	0.417	0.001
Vinyl chloride	18.6	0.001	0.02	448	355	0.008	0.007

Notes

1. Partitioning coefficient (Kd) calculated with default values for octanol-water partition coefficient (Koc) and organic carbon fraction of aquier solids (foc)
in Ecology's Cleanup Levels and Risk Calculations (CLARC) database.
Kd = Koc*foc

2. Groundwater concentrations in former drum excavation based on average concentrations in interstital liquids and seeps collected during drum and soil removal (PGG, 2010)
Groundwater concentrations in P1 Area bawsed on average concentrations measured in well MW-34p1 (Figure 1)

3. Adsorbed Phase Soil Concentration = (Kd)*(Groundwater Concentration)*(0.001 mg/ug)

Table 18. Estimated Bulk Mass of Residual Soil

	Soil Thickness (ft)[1]		Soil Area (ft^2)[2]			Estimated Bulk Mass of Residual Soil (kg)[4]	
Range	Former Drum Excavation	P1 Area	Former Drum Excavation	P1 Area	Soil Density (kg/L)[3]	Former Drum Excavation	P1 Area
Best-Estimate	0.1	2	7000	10,000	1.5	29,733	849,504
Minimum	0.05	1	7000	5,000	1.5	14,866	212,376
Maximum	0.5	3	7000	17,000	1.5	148,663	2,166,235

Notes

1. Residual soils in former drum excavation were removed to the extent possible. The residual soil thickness is thus estimated to be less than 0.5-ft.
   Thickness of residual soils in P1 area estimated to have the same range as estimated LNAPL thickness (see Table 15).
2. Area of residual soils in former drum area based on estimated footprint of excavated contaminated soils.
3. Bulk density based on MTCA default value.
4. Mass of Soil = (Soil Thickness)*(Soil Area)*(Soil Density)*(28.32 ft^3/L)

Table 19. Estimated Adsorbed Phase Contaminant Mass in Residual Soils

A. Best-Estimated Adsorbed Phase Contamiant Mass[1]

	Soils in Former Drums			Soils in P1 Area			Total Soils
VOC	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Total VOC Mass in Soils (Kg)
Tetrachloroethene (PCE)	0.149	29,733	0.004	0.004	849,504	0.003	0.007
1,2-Dichloropropane	0.020	29,733	0.001	0.023	849,504	0.019	0.020
cis-1,2-Dichloroethene	0.074	29,733	0.002	0.087	849,504	0.074	0.076
Benzene	0.026	29,733	0.001	0.009	849,504	0.007	0.008
Methylene chloride	0.945	29,733	0.028	0.004	849,504	0.003	0.031
Trichloroethene (TCE)	0.417	29,733	0.012	0.001	849,504	0.001	0.013
Vinyl chloride	0.008	29,733	0.000	0.007	849,504	0.006	0.006

B. Minimum-Estimated Adsorbed Phase Contamiant Mass[1]

	Soils in Former Drums			Soils in P1 Area			Total Soils
VOC	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Total VOC Mass in Soils (Kg)
Tetrachloroethene (PCE)	0.149	14,866	0.002	0.004	212,376	0.001	0.003
1,2-Dichloropropane	0.020	14,866	0.000	0.023	212,376	0.005	0.005
cis-1,2-Dichloroethene	0.074	14,866	0.001	0.087	212,376	0.018	0.020
Benzene	0.026	14,866	0.000	0.009	212,376	0.002	0.002
Methylene chloride	0.945	14,866	0.014	0.004	212,376	0.001	0.015
Trichloroethene (TCE)	0.417	14,866	0.006	0.001	212,376	0.000	0.006
Vinyl chloride	0.008	14,866	0.000	0.007	212,376	0.001	0.002

C. Maximum-Estimated Adsorbed Phase Contamiant Mass[1]

	Soils in Former Drums			Soils in P1 Area			Total Soils
VOC	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Soil Concentration (mg/kg)	Mass of Soil (kg)	Contaminant Mass (kg)	Total VOC Mass in Soils (Kg)
Tetrachloroethene (PCE)	0.149	148,663	0.022	0.004	2,166,235	0.008	0.030
1,2-Dichloropropane	0.020	148,663	0.003	0.023	2,166,235	0.049	0.052
cis-1,2-Dichloroethene	0.074	148,663	0.011	0.087	2,166,235	0.188	0.199
Benzene	0.026	148,663	0.004	0.009	2,166,235	0.019	0.023
Methylene chloride	0.945	148,663	0.141	0.004	2,166,235	0.009	0.149
Trichloroethene (TCE)	0.417	148,663	0.062	0.001	2,166,235	0.002	0.064
Vinyl chloride	0.008	148,663	0.001	0.007	2,166,235	0.014	0.016

Notes

1. Contaminant Mass = (Soil Concentration)*(Mass of Soil)*(0.000001 kg/mg)

Table 20. Estimated VOC Mass Flux and Source Concentration, Co

																		Measured Concentrations in P1 Source Area			
	Low-T Area			High-T Area			Total Area	Darcy V[4]	Best Estimate[5]			Maximum Estimate[5]			Minimum Estimate[5]			MW-34p1			B-22-p1
VOC	GW. Conc.[1] (ug/L) (C)	GW Flux[2] (ft^3/dy) (Q)	VOC Mass Flux[3] (ug/dy) (J)	GW. Conc.[1] (ug/L) (C)	GW Flux[2] (ft^3/dy) (Q)	VOC Mass Flux[3] (ug/dy) (J)	Total Plume Mass Flux (ug/dy) (J)	(m/yr)	X-Sec Source Area (ft^2) (A)	GW Flux through Source Area[6] (ft^3/dy) (Q)	Source Conc.[7] (ug/L) (Co)	X-Sec Source Area (ft^2) (A)	GW Flux through Source Area[6] (ft^3/dy) (Q)	Source Conc.[7] (ug/L) (Co)	X-Sec Source Area (ft^2) (A)	GW Flux through Source Area[6] (ft^3/dy) (Q)	Source Conc.[7] (ug/L) (Co)	Avg Conc. (ug/L)	Max Conc (ug/L)	Min Conc. (ug/L)	P1 sample collected during drilling of MW-30b / Equivalent to MW-36p1 (ug/L)
Tetrachloroethene (PCE)	2.49	3.4	237	0.5	1046	14,679	14,916	5.10	480	22.00	24	330	15.12	35	555	25.44	21	13	21	5.8	700
1,2-Dichloropropane	40.37	3.4	3841	12.4	1046	368,154	371,995	5.10	480	22.00	597	330	15.12	869	555	25.44	516	482	810	160	360
cis-1,2-Dichloroethene	21.90	3.4	2084	29.6	1046	875,995	878,079	5.10	480	22.00	1,409	330	15.12	2,050	555	25.44	1,219	2441	5200	690	3000
Benzene	17.60	3.4	1675	2.3	1046	68,660	70,335	5.10	480	22.00	113	330	15.12	164	555	25.44	98	141	250	32	220
Methylene chloride	13.00	3.4	1237	3.2	1046	94,702	95,939	5.10	480	22.00	154	330	15.12	224	555	25.44	133	398	780	16	2800
Trichloroethene (TCE)	1.31	3.4	125	1.4	1046	40,130	40,255	5.10	480	22.00	65	330	15.12	94	555	25.44	56	11	20	1.9	580
Vinyl chloride[8]	7.50	3.4	714	27.4	1046	810,886	811,600	5.10	480	22.00	1,303	330	15.12	1,895	555	25.44	1,127	355	750	54	550

Notes

1. Based on estimated average groundwater concentration at property boundary using contoured groundwater data
2. Groundwater volumetric flux based on average gradient, geometric mean of hydraulic conductivity and cross-sectional area in Low-T and High-T area near landfill property boundary
3. J = C*Q*(28.32 L/ft^3)
4. Simualted Darcy velocity (see PGG, 2012)
5. Min, max, and best-estimate values of Co based on min, max, and best-estimate of source cross-section (x-sec) area (Figure 1)
6. Groundwater flux through source area = (Darcy Velocity)*(X-Sec Area)*(3.28 ft/m)*(1 yr/365 dy)
7. Source Concentration, Co = (Total Mass Flux)/(X-Sec Area)*(1 ft^3/28.32 L)
8. The predicted source concentration for vinyl chloride based on Mass Flux (1303 ug/L) is almost twice as high as concentrations measured in the P1 source area (750 ug/L max)
   This is likely due to additional vinyl chloride being generated through degradation processes along the plume flow path.
   The shaded values of Co for vinyl chloride are therefore likely to be over-estimated. We therefore used the maximum concentration measured in the P1 source area (750 ug/L) as our best estimate of Co for vinyl chloride in the REMChlor model (PGG, 2012a)
   Since the maximum and minimum Co values for the other VOCs are 1.45 and 0.86 times the best-estimate value respectively; the maximum and minimum Co values for vinyl chloride are estimated to be 1091 and 649 ug/L respectively.

Table 21. Total Organic COC Mass Flux Change Calculation - Northerly Plume (P1 source area to Roza high-T property boundary)

			P1 Source (MASS FLUX)				High T Roza Property Boundary (MASS FLUX)						MASS FLUX CHANGE
Organic Chemical of Concern (COC)	Units	Group	MW-34p1 Average (ug/L)	Horizontal Darcy Velocity^1 (m/yr)	Approx. Cross Section Area^2 (m^2)	Mass Flux based on Avg of MW-34p1 (g/yr)	MW-3b	MW-7b	Roza Average of Wells (ug/L)	Horizontal Darcy Velocity^3 (m/yr)	Appox. Cross-Section Area^4 (m^2)	Mass Flux (g/yr)	P1 - Roza Mass Flux (g/yr)
1,2-Dichloropropane	ug/L	12-DCP	482.00	16.00	44.62	344.08	10.22	9.07	9.65	24	464.75	107.59	236.49
Benzene	ug/L	BTEX	141.00	16.00	44.62	100.65	2.78	1.66	2.22	24	464.75	24.79	75.86
Ethylbenzene	ug/L	BTEX	4,614.29	16.00	44.62	3,293.96	0.20	0.10	0.15	24	464.75	1.67	3292.28
o-Xylene	ug/L	BTEX	3,900.00	16.00	44.62	2,784.06	0.26	0.23	0.25	24	464.75	2.75	2781.31
Toluene	ug/L	BTEX	61,714.29	16.00	44.62	44,055.41	0.10	0.10	0.10	24	464.75	1.12	44054.29
Xylene Isomers, M+P	ug/L	BTEX	10,585.71	16.00	44.62	7,556.73	0.20	0.20	0.20	24	464.75	2.23	7554.50
1,1,1-Trichloroethane	ug/l	Ethane	2,217.14	16.00	44.62	1,582.73	0.10	0.10	0.10	24	464.75	1.12	1581.62
1,1,2-Trichloroethane	ug/L	Ethane	33.00	16.00	44.62	23.56	0.10	0.10	0.10	24	464.75	1.12	22.44
1,1-Dichloroethane	ug/L	Ethane	2,728.57	16.00	44.62	1,947.82	10.49	17.00	13.75	24	464.75	153.32	1794.50
1,2-Dichloroethane (EDC)	ug/L	Ethane	526.00	16.00	44.62	375.49	1.45	2.07	1.76	24	464.75	19.65	355.84
Chloroethane	ug/L	Ethane	73.00	16.00	44.62	52.11	57.27	75.30	66.29	24	464.75	739.35	-687.24
1,1-Dichloroethene	ug/L	Ethenes	29.50	16.00	44.62	21.06	0.71	0.82	0.77	24	464.75	8.57	12.49
cis-1,2-Dichloroethene	ug/L	Ethenes	2,441.43	16.00	44.62	1,742.84	34.64	19.09	26.86	24	464.75	299.64	1443.20
Tetrachloroethene (PCE)	ug/L	Ethenes	13.40	16.00	44.62	9.57	0.17	0.34	0.26	24	464.75	2.85	6.71
Trichloroethene (TCE)	ug/L	Ethenes	10.95	16.00	44.62	7.82	1.33	0.92	1.13	24	464.75	12.59	-4.77
Vinyl Chloride	ug/L	Ethenes	354.67	16.00	44.62	253.18	30.58	16.92	23.75	24	464.75	264.91	-11.73
2-Butanone	ug/L	Ketone	39,366.67	16.00	44.62	28,102.32	1.25	1.25	1.25	24	464.75	13.94	28088.38
2-Hexanone	ug/L	Ketone	585.00	16.00	44.62	417.61	1.25	1.25	1.25	24	464.75	13.94	403.67
4-Methyl-2-Pentanone (MIBK)	ug/L	Ketone	21,500.00	16.00	44.62	15,348.01	1.25	1.25	1.25	24	464.75	13.94	15334.06
Acetone	ug/L	Ketone	136,000.00	16.00	44.62	97,085.07	8.05	4.27	6.16	24	464.75	68.69	97016.38
Methylene Chloride	ug/l	MC	398.00	16.00	44.62	284.12	1.95	2.88	2.41	24	464.75	26.92	257.19
1,2,4-Trimethylbenzene	ug/L	TMB	665.00	16.00	44.62	474.72	0.10	0.10	0.10	24	464.75	1.12	473.60
1,3,5-Trimethylbenzene	ug/L	TMB	253.33	16.00	44.62	180.84	0.10	0.10	0.10	24	464.75	1.12	179.73
1,3-Dichlorobenzene	ug/L	Other	5.65	16.00	44.62	4.03	0.30	0.23	0.27	24	464.75	2.97	1.06
4-Isopropyltoluene	ug/L	Other	0.50	16.00	44.62	0.36	0.10	0.10	0.10	24	464.75	1.12	-0.76
Bromobenzene	ug/L	Other	7.30	16.00	44.62	5.21	0.28	0.50	0.39	24	464.75	4.37	0.84
Chloroform	ug/L	Other	34.00	16.00	44.62	24.27	0.10	0.10	0.10	24	464.75	1.12	23.16
Chloromethane	ug/L	Other	0.50	16.00	44.62	0.36	0.10	0.10	0.10	24	464.75	1.12	-0.76
Naphthalene	ug/L	Other	200.00	16.00	44.62	142.77	0.60	0.25	0.43	24	464.75	4.74	138.03
n-Butylbenzene	ug/L	Other	8.30	16.00	44.62	5.93	0.10	0.10	0.10	24	464.75	1.12	4.81
sec-Butylbenzene	ug/L	Other	6.60	16.00	44.62	4.71	0.20	0.10	0.15	24	464.75	1.67	3.04
Bis(2-ethylhexyl) Phthalate	ug/L	SVOC	22.00	16.00	44.62	15.70	0.50	2.40	1.45	24	464.75	16.17	-0.47
2-Methylphenol	ug/L	SVOC	NS	16.00	44.62	NS	0.50	0.50	0.50	24	464.75	5.58	NS in P1
4-Methylphenol	ug/L	SVOC	NS	16.00	44.62	NS	0.50	0.50	0.50	24	464.75	5.58	NS in P1
SUM ORGANIC COC MASS FLUX (g/yr)						206,247						1,828	204,430
SUM ORGANIC COC MASS FLUX (kg/yr)						206						2	204
Percentage of change assoicated with TEX and Ketones													97%

Notes

1. P1 horizontal velocity based on geometric mean hydraulic conductivity (7 ft/dy) and groundwater gradient (0.02) associated with wells MW-34p1, MW-36p1, and MW-37p1.
2. Plume cross sectional area based on estimate of P1 source area: 160-ft by 3-ft
3. Roza high-T velocity based on geometric mean hydraulic conductivity (307 ft/dy) and groundwater gradient (0.0007) associated with wells MW-3b, MW-7b, and MW-9b
4. Plume cross sectional area based on estimate of high-T property boundary area: 500-ft by 10-ft

Shaded values uses 1/2 DL as the Concentration

NS = not sampled

Table 22. Concentration Data used for Bulk Attenuation Rate Calcualtion

VOC Chemical of Concern (COC)	Units	Group	MW-34p1 Average	MW-42b Average	Roza High T Average
1,2-Dichloropropane	ug/L	12-DCP	482.00	21.75	9.65
Benzene	ug/L	BTEX	141.00	1.60	2.22
Ethylbenzene	ug/L	BTEX	4,614.29	0.45	0.20
o-Xylene	ug/L	BTEX	3,900.00	0.50	0.25
Toluene	ug/L	BTEX	61,714.29	0.10	0.10
Xylene Isomers, M+P	ug/L	BTEX	10,585.71	0.50	0.20
1,1,1-Trichloroethane	ug/l	Ethane	2,217.14	0.10	0.10
1,1,2-Trichloroethane	ug/L	Ethane	33.00	0.10	0.10
1,1-Dichloroethane	ug/L	Ethane	2,728.57	43.00	13.75
1,2-Dichloroethane (EDC)	ug/L	Ethane	526.00	5.18	1.76
Chloroethane	ug/L	Ethane	73.00	260.00	66.29
1,1-Dichloroethene	ug/L	Ethenes	29.50	3.55	0.77
cis-1,2-Dichloroethene	ug/L	Ethenes	2,441.43	32.50	26.86
Tetrachloroethene (PCE)	ug/L	Ethenes	13.40	3.23	0.26
Trichloroethene (TCE)	ug/L	Ethenes	10.95	1.70	1.13
Vinyl Chloride	ug/L	Ethenes	354.67	7.75	23.75
2-Butanone	ug/L	Ketone	39,366.67	2.50	1.25
2-Hexanone	ug/L	Ketone	585.00	2.50	1.25
4-Methyl-2-Pentanone (MIBK)	ug/L	Ketone	21,500.00	2.50	1.25
Acetone	ug/L	Ketone	136,000.00	7.20	6.16
Methylene Chloride	ug/l	MC	398.00	5.98	2.41
1,2,4-Trimethylbenzene	ug/L	TMB	665.00	0.20	0.10
1,3,5-Trimethylbenzene	ug/L	TMB	253.33	0.10	0.10
1,3-Dichlorobenzene	ug/L	Other	5.65	0.40	0.27
4-Isopropyltoluene	ug/L	Other	0.50	0.10	0.10
Bromobenzene	ug/L	Other	7.30	0.45	0.39
Chloroform	ug/L	Other	34.00	0.10	0.10
Chloromethane	ug/L	Other	0.50	0.25	0.10
Naphthalene	ug/L	Other	200.00	0.25	0.60
n-Butylbenzene	ug/L	Other	8.30	0.10	0.10
sec-Butylbenzene	ug/L	Other	6.60	0.25	0.20
Bis(2-ethylhexyl) Phthalate	ug/L	SVOC	22.00	0.50	2.40
2-Methylphenol	ug/L	SVOC	NS	1.00	0.50
4-Methylphenol	ug/L	SVOC	NS	1.00	0.50
TOTAL	ug/L		288,918	407	165
TOTAL (natural log)			12.6	6.0	5.1

Notes
Shaded values represent non-detections and values are set to 1/2 lab detection limit
NS = not sampled
ug/L = micrograms per liter
Average concentration data based on data collected during the RI (PGG, 2010 and 2012b)
Roza High-T average based data from wells MW-3b and MW-7b

K:\PONY\Ephrata\CA_2005_JE0511\GIS\mxds\NorthEndSiteMap_RosaPlume.mxd,8/24/2012

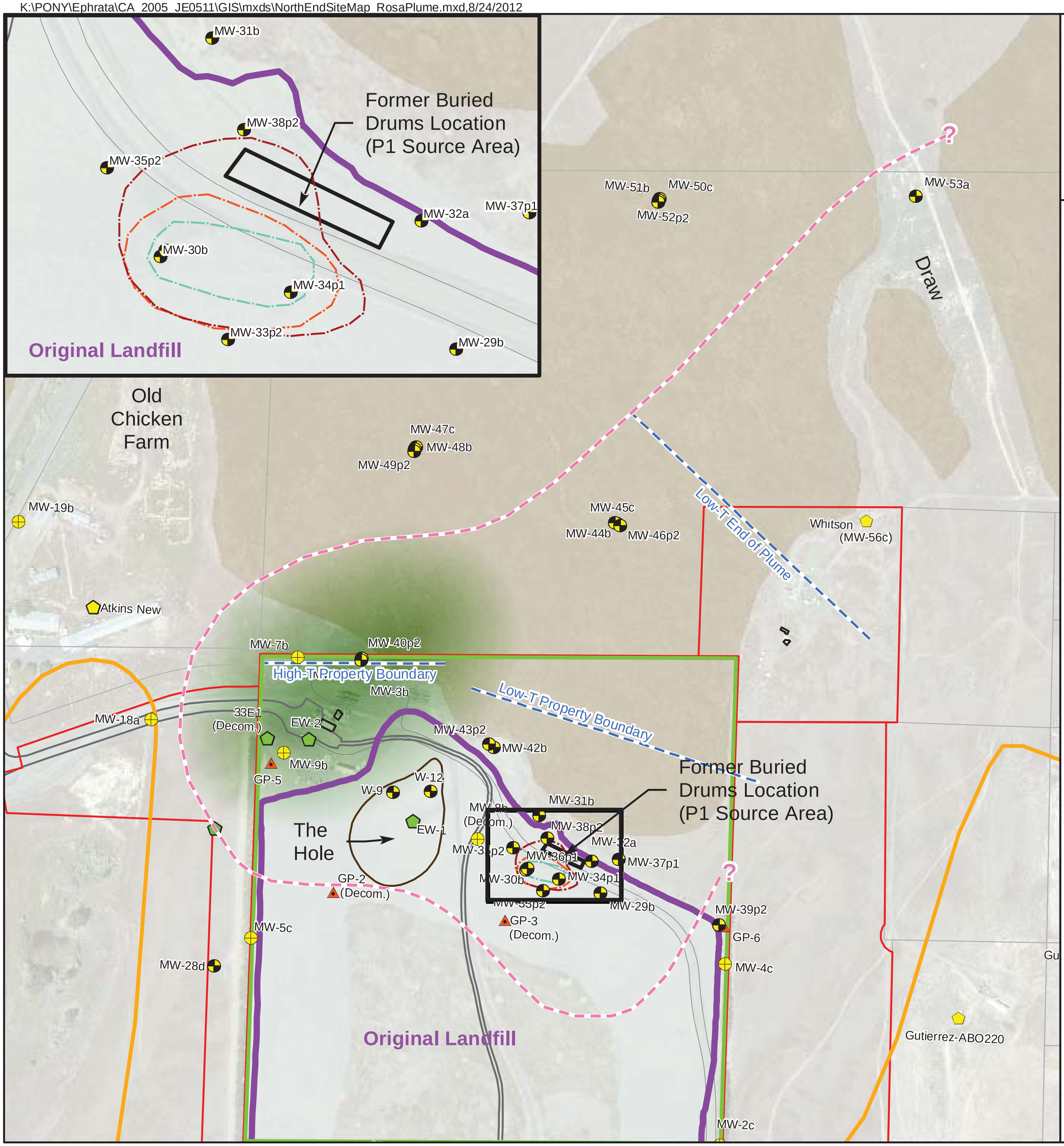


Figure 1

Ephrata Landfill
North End Site Map

Ephrata Landfill
RI/FS

PgG

- ⊕ Quarterly Monitoring Well (MW)
- ● Remedial Investigation Monitoring Well (MW)
  Locations A-G (Phase 2 RI Wells)
- ▲ Gas Probe (GP)
- ⬟ Other Wells
- ⬠ Sampled Off-site Wells
- ⬠ Other Off-site Wells
- ━ Outwash Water Table / Top of Basalt Contact
- ▨ Basalt Outcrops
- ▭ Extent of Refuse
- ▭ Permitted Landfill Property Boundary
- ▭ County Owned Parcels

Approximate Extent of Groundwter Contamination
(VOCs' Above RI Screening Levels)

- - - - Northerly Plume - Roza Aquifer
- ▨ Approximate Area of High-Transmissivity in Roza
- - - - Evaluated Roza Capture Boundaries

Approximate P1 Source Area

- ▭ Max
- ▭ Best Estimate
- ▭ Min

0 Feet 500

N

Figure 2

Total Organic COC Concentration vs. Distance - Northerly Plume

(Beteween Source Area and Roza Aquifer High-T Area at Property Boundary)

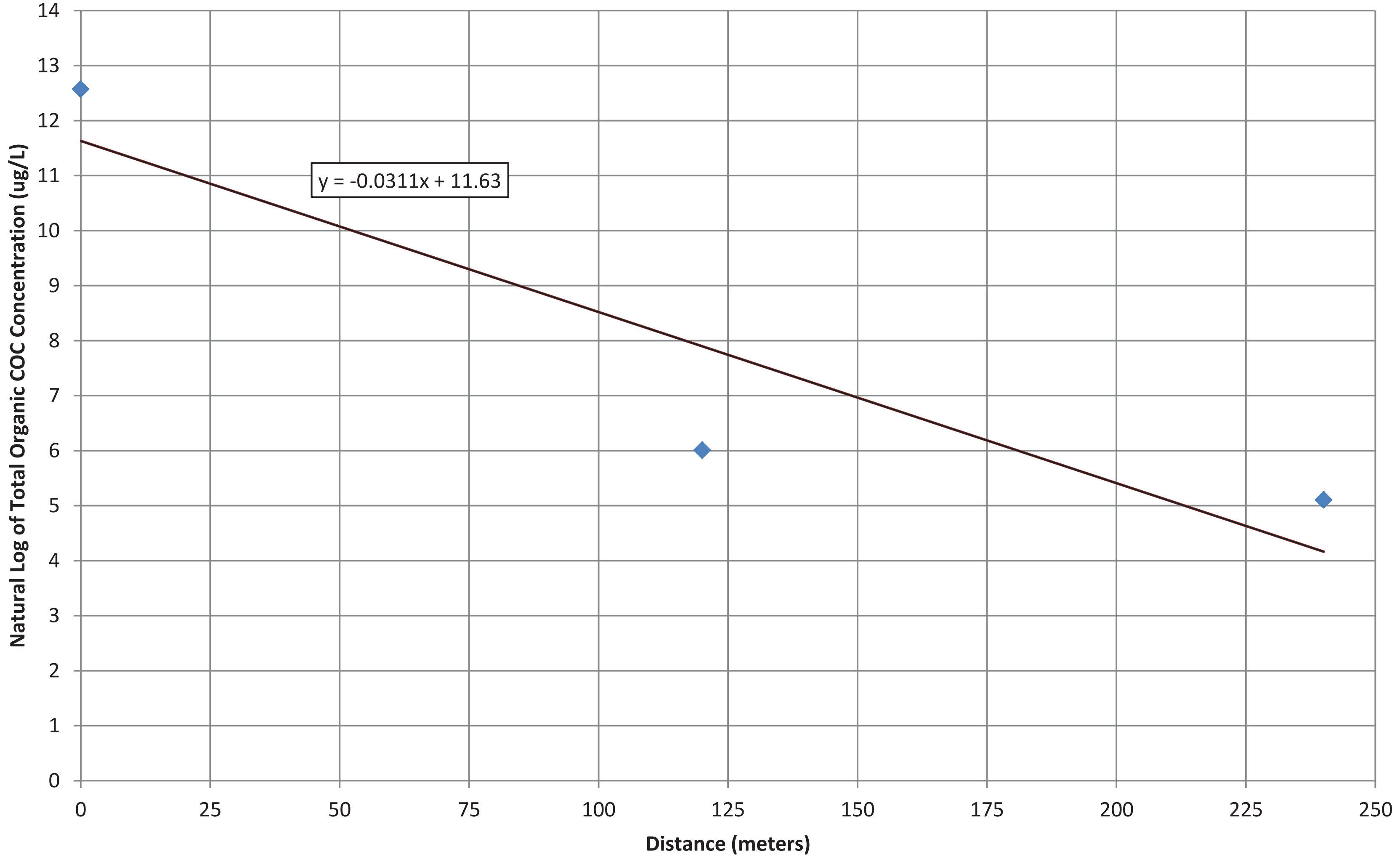
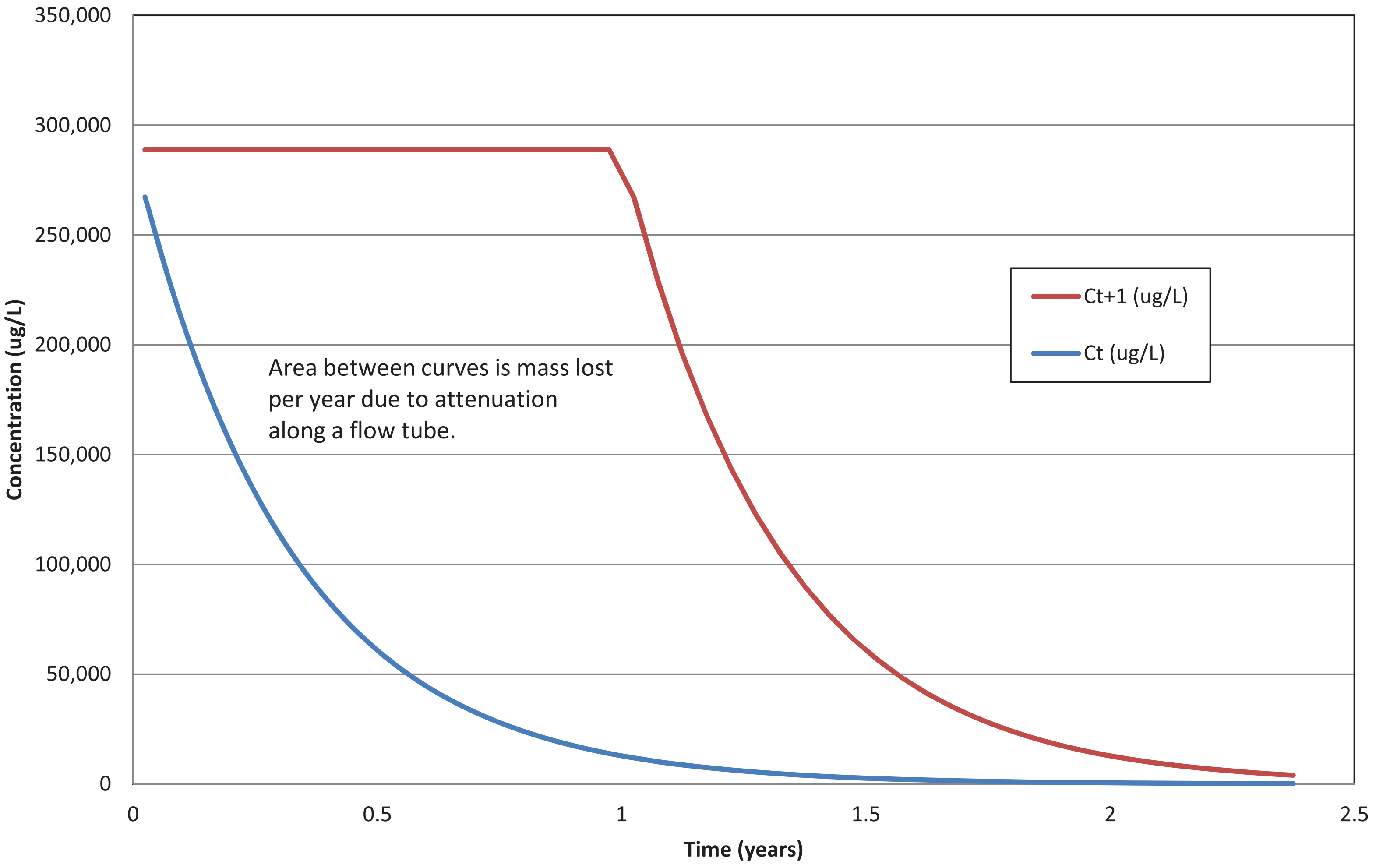


Figure 3

Annual Bulk Attenuation Rate Calculation

(Calculated concentration vs. time at current condition (t) and time step one year in future (t+1) with no attenuation)



Appendix B

Updated Extraction Volumes, Mass Removal Rates, and Restoration Time Frames for Selected Cleanup Action Components in the Revised Feasibility Study

Technical Memorandum

To: Grant County Public Works and City of Ephrata

From: Dawn Chapel (Pacific Groundwater Group)

Re: Updated Extraction Volumes, Mass Removal Rates, and Restoration Time Frames for Selected Cleanup Action Components in the Revised Feasibility Study 2018 Ephrata Landfill

Date: March 26, 2018

This memo summarizes new and updated calculations in support of the cleanup action components being evaluated in the revised Feasibility Study (FS; Parametrix, 2018). Specifically, this memo documents estimates of groundwater extraction volumes and total volatile organic compound (VOC) mass removal rates for different cleanup action components over a 10-year period. We also provide updated estimates of restoration time frames. The calculations presented are both updates to some of the older calculations presented in the 2012 draft FS (Appendix A [PGG 2012a] and B [PGG 2012b] in Parametrix, 2012) and new calculations in support of new or modified cleanup action components being considered in the revised FS.

Since 2012, additional site data have been collected to support updated calculations, including long-term monitoring of groundwater quality, drilling and testing of new wells at the northern Point of Compliance (POC), and a 4-month pilot test of Multi-Phase Extraction (MPE) in the P1 zone by the former drums (PGG, 2018 and Parametrix and PGG, 2018).

Cleanup action components in the revised FS that require estimates of extraction volumes and VOC mass removal rates are:

- Existing P1 Zone MPE System
- P1 Zone MPE System Well Field Expansion
- Groundwater Extraction from the Hole
- Northerly Plume Hydraulic Capture at the POC
- Targeted Pumping from the Northerly Plume at the POC
- Natural Attenuation

Groundwater Extraction from the Hole, Northerly Plume Hydraulic Capture, and Natural Attenuation were also cleanup action components in the 2012 draft FS. P1 Zone MPE (Existing and Expansion) is a modification of the P1 Pumping and SVE components in the 2012 draft FS, and Targeted Northerly Plume Pumping is a new cleanup action component.

Restoration time frames for cleanup action alternatives, which are combinations of more than one cleanup action component, are also required in the revised FS.

The following section provides a summary of extraction volumes and mass removal rates for cleanup action components. The last section provides estimated restoration time frames for cleanup action alternatives.

EXTRACTION VOLUMES AND VOC MASS REMOVAL RATES

The following sections present extraction volumes in gallons per year (gpy) and VOC mass removal rates in kilograms per year (kg/yr) over a 10-year period for each of the cleanup action components in the revised FS, except for P1 Zone MPE (Existing and Expansion). P1 Zone MPE calculations were performed separately by Parametrix (Appendix H in Parametrix, 2018). Calculations originally performed in 2012 that are still valid are noted where applicable.

GROUNDWATER EXTRACTION FROM THE HOLE

The objective of this cleanup action component is to dewater the Hole, remove contaminant mass and reduce chemical transport to underlying aquifers. Based on 2012 calculations, the volume of extraction the first year is estimated to be 390,000 gallons, followed by 46,000 gpy during subsequent years based on the groundwater flux through the Hole (PGG, 2012a).

Groundwater extraction from the Hole in 2008 showed total VOCs in groundwater increased from an initial concentration of 45 ug/L to relatively stable values of about 125 to 150 ug/L during the 2-month extraction period (PGG, 2009 – Phase 1 RI Data Report). Assuming an average constant value of 140 ug/L and 390,000 gallons extracted during the first year followed by 46,000 gpy each subsequent year, the VOC mass removal rate from the Hole is calculated to be 0.21 kg/yr during the first year and 0.02 kg/yr in subsequent years, for a total of 0.43 kg over a 10-year period (Table 1).

TARGETED PUMPING FROM THE NORTHERLY PLUME

The objective of this cleanup action component is to target mass removal in the highest contaminant concentration in the Roza aquifer (at the POC near MW-63b). Three Roza extraction wells with sustainable yields of 0.5 gallon per minute (gpm) are assumed for a total of 788,923 gpy. The sustainable yield is based on aquifer testing at MW-63b (PGG, 2017), but does not consider potential negative hydraulic boundaries that may limit yields over the long term.

Well MW-63b has only been sampled twice, once in 2016 when the well was originally installed and reported in the second RI Addendum (PGG, 2017) and again recently during the 1st quarter 2018 post-RI monitoring event. Total VOCs in 2018 (4,300 ug/L) were lower than the sample collected in 2016 (6,300 ug/L). Although two sampling events at MW-63b are not enough to evaluate long-term trends, long-term monitoring of the Roza aquifer 500 feet west of MW-63b (at MW-3b and MW-7b) indicates a long-term decreasing trend in total VOCs since 2008 (Figure 1). Therefore, a similar long-term decreasing trend is expected for the Roza at the location of MW-63b.

A first-order decay term was fitted to the MW-3b and MW-7b data to yield a first-order decay rate of -0.167 (yr^{-1}) with an R^2 of 0.8754 (Figure 1). Assuming concentrations at MW-63b are decreasing at a similar rate and a starting total VOC concentration based on the 2018 sample of MW-63b (4,300 ug/L), total VOCs at MW-63b are estimated to decrease due to natural attenuation to about 800 ug/L within 10 years. Assuming a constant extraction rate of 788,923 gpy for this cleanup action component, the VOC mass removal rate is estimated to decrease from 13 kg/yr to 2 kg/yr over the 10-year period for a total removal of 59 kg (Table 1).

NORTHERLY PLUME HYDRAULIC CAPTURE

The objective of this cleanup action component is to reduce migration of contaminants in the Roza aquifer north of the landfill. Based on 2012 calculations, a total extraction rate of 6 gpm from two extraction wells in the high-T Roza area for a total of 3,500,000 gpy would be required to capture the plume (PGG, 2012). This extraction rate is assumed to be constant for all 10 years and is within the range of the ambient groundwater flux estimated for the high-T Roza area - 1,120,000 to 7,320,000 gpy (PGG, 2012a).

Total VOC concentrations in the high-T Roza area were estimated over a 10-year period using the fitted decay term to MW-3b and MW-7b long-term dataset (Figure 1). Using a starting 1st-year (2018) concentration of 29 ug/L, concentrations are estimated to decrease to 7 ug/L after 10 years (Table 1). Assuming a 3,500,000 gpy extraction rate, the VOC mass removal rate from the high-T Roza area is estimated to decrease from 0.4 kg/yr to 0.1 kg/yr over the 10-year period.

Since pumping from the high-T Roza area is expected to capture the low-T Roza area in the vicinity of MW-63b, the total mass removal for this component is assumed to be the sum of the high-T mass removal rates and the mass removal estimated for targeted pumping in the vicinity of MW-63b, so that the VOC mass removal associated with this cleanup action component is estimated to decrease from 13 kg/yr to 2 kg/yr over the 10-year period for a total removal of 61 kg (Table 1).

NATURAL ATTENUATION

Total VOC mass removal under natural attenuation is due to natural degradation processes in the groundwater plume. For this component, we used the same mass flux method that was used in 2012 to estimate natural degradation in the Northerly Plume between the P1 source area and the POC (PGG, 2012a). The mass flux method assumes plume equilibrium, steady uniform flow, and that mass flux through the Roza at the POC represents all of the mass flux originating from the P1 source area. The mass flux (J) is:

$$J\ (ug/yr) = Q*C*CF \qquad [1]$$

Where

Q is the ambient volumetric groundwater flow rate (L/dy)

C is the dissolved phase total VOC concentration (ug/L)

CF is the conversion factor (days to years) for Q

The attenuation of mass between the two locations is then calculated as:

Mass attenuation (ug/yr) = $J_{p1} - J_{Roza}$ [2]

Where

J_{p1} = mass flux in the P1 source area

J_{Roza} = mass flux in the Roza at the POC (sum of low-T mass flux and high-T mass flux)

The volumetric groundwater flow rate (Q) is based on the average horizontal groundwater hydraulic gradient (i), representative hydraulic conductivity (K), and cross-sectional area (A):

Q = K*i*A [3]

The single volumetric groundwater flow rate through the high-T Roza area of the POC was previously calculated using average parameter values in that area as 1,046 ft^3/dy (PGG, 2012a). This value is still applicable for the calculation.

The volumetric groundwater flow rate through the low-T Roza area was previously calculated as 3.4 ft^3/dy (PGG, 2012a). Using new data collected since 2012, we updated the volumetric flow rate through the low-T Roza area of the plume as follows:

A transmissivity (T) of 15 ft^2/day and aquifer thickness (b) of 6 ft was estimated for the Roza at MW-63b (PGG 2017). This yields a K value of 2.6 ft/day (K=T/b). The average gradient in the Roza at MW-63b is estimated to be 0.002 ft/ft (Figure 8 in PGG 2017). The cross-sectional area of the Roza plume at this location is assumed to be 60 ft wide and 6 ft thick. The 60-ft width assumes a narrow plume at this location (the plume was not present in the Roza at MW-57b, about 300 feet east of MW-63b). The volumetric flow rate is therefore calculated to be:

Q = (2.6 ft/day)*(0.002 ft/ft)*(60 ft)*(6 ft) = 1.9 ft^3/dy

This updated value is slightly lower than the 2012 value of 3.4 ft^3/dy (PGG, 2012a).

The average groundwater discharge rate through the P1 source area was previously calculated using average parameter values in that area as:

K = 7 ft/dy

i = 0.02 (ft/ft)

A = 150 ft wide and 3 ft thick (best estimate of P1 LNAPL area in PGG 2012a)

Q = K*i*A = (7 ft/dy)*(0.02 ft/ft)*(150 ft)*(3 ft) = 63 ft^3/dy

Although the groundwater discharge rate in the P1 is primarily vertical to the underlying P2, the horizontal groundwater discharge rate is used for these calculations.

Although the mass flux method for estimating natural attenuation assumes plume equilibrium (i.e., a steady-state mass flux), we used the method to calculate decreasing mass fluxes over a 10-year period at each location assuming total VOC concentrations decrease over time (starting in 2018) at each location according to the first-order decay rate fitted to the long-term decreasing trend observed in MW-3b and MW-7b (see section above and Table 1 for predicted total VOC concentrations over time at each location). Equation 2 was then used to estimate time varying natural attenuation. Employing this method results in mass removal associated with natural attenuation decreasing from 54 kg/yr the first year to 12 kg/yr the tenth year, for a total 286 kg over the 10-year period (Table 1).

ESTIMATED RESTORATION TIME FRAMES FOR CLEANUP ACTION ALTERNATIVES

Estimates of northerly plume restoration time frames for cleanup action alternatives evaluated in the revised FS are provided in Table 2. These estimates are based on assumptions of source and plume containment associated with different cleanup action components, REMChlor simulations of similar proposed cleanup actions in 2012 (PGG 2012b), and estimated groundwater advection travel times between the location of an active measure and farthest downgradient plume location, as described below.

Northerly Plume Hydraulic Capture Restoration Time Frame

Northerly plume capture assumes the plume is completely contained at the POC effectively cutting off contaminants feeding the plume downgradient of the POC.

The restoration time frame for northerly plume capture was previously estimated to be 20 years based on REMChlor simulations for vinyl chloride (PGG 2012b). This estimate is still reasonable as vinyl chloride has the lowest preliminary cleanup level (0.087 ug/L). The 2012 REMChlor simulation was based on a vinyl chloride cleanup up level of 0.2 ug/L. Applying a cleanup level of 0.087 ug/L at the POC would have resulted in a 22-year restoration time frame predicted by REMChlor. This is not a significant difference, and a 20-year restoration time frame is assumed for this cleanup action component in the FS.

P1 Multi-Phase Extraction (MPE) – Expanded Well Field

Operation of an expanded MPE system is assumed to completely contain the source in the P1 zone, effectively cutting off contaminants in the P1 from feeding the plume downgradient of the P1 zone.

The restoration time frame for source containment is conservatively estimated to be up to 34 years. This estimate is based on an advective travel time of up to 34 years between the P1 source zone and the farthest downgradient end of the northerly plume center line in the Roza aquifer. The farthest downgradient location is estimated to be about 1875 feet, assumed to be at the location of the decommissioned Whitson well (MW-56c in Figure 2 of revised FS [Parametrix 2018]). The maximum travel time of 34 years is based on the time between when the Whitson well was first observed to contain site contaminants of concern and the time when the drums were first disposed of at the landfill (2009-1975 = 34 years). Using average properties for the Roza aquifer along the plume center line simulated in REMchlor results in an estimated groundwater seepage velocity of

84 ft/yr (PGG, 2012b), which indicates a 24-year travel time to the Whitson well. Given some uncertainty on when and if source containment is established, a 34-year restoration time frame is assumed for this cleanup action component.

Natural Attenuation

Natural attenuation assumes no active cleanup action and that source and plume contaminant concentrations continue to slowly degrade naturally over time.

The restoration time frame for natural attenuation is assumed to be greater than 66 years. This estimated is based on previous REMChlor simulations for natural attenuation of vinyl chloride, which estimated a restoration time frame of greater than 76 years starting in 2008 (PGG, 2012b). Given 10 years of natural attenuation has occurred since 2008 when the drums were removed, the new estimate is assumed to be greater than 66 years. Although the 2012 REMChlor simulation was based on a vinyl chloride cleanup level of 0.2 ug/L and not 0.087 ug/L, the 66-year time frame serves as a maximum restoration time frame estimate for cleanup action components that do not include complete source containment (Alternative 1).

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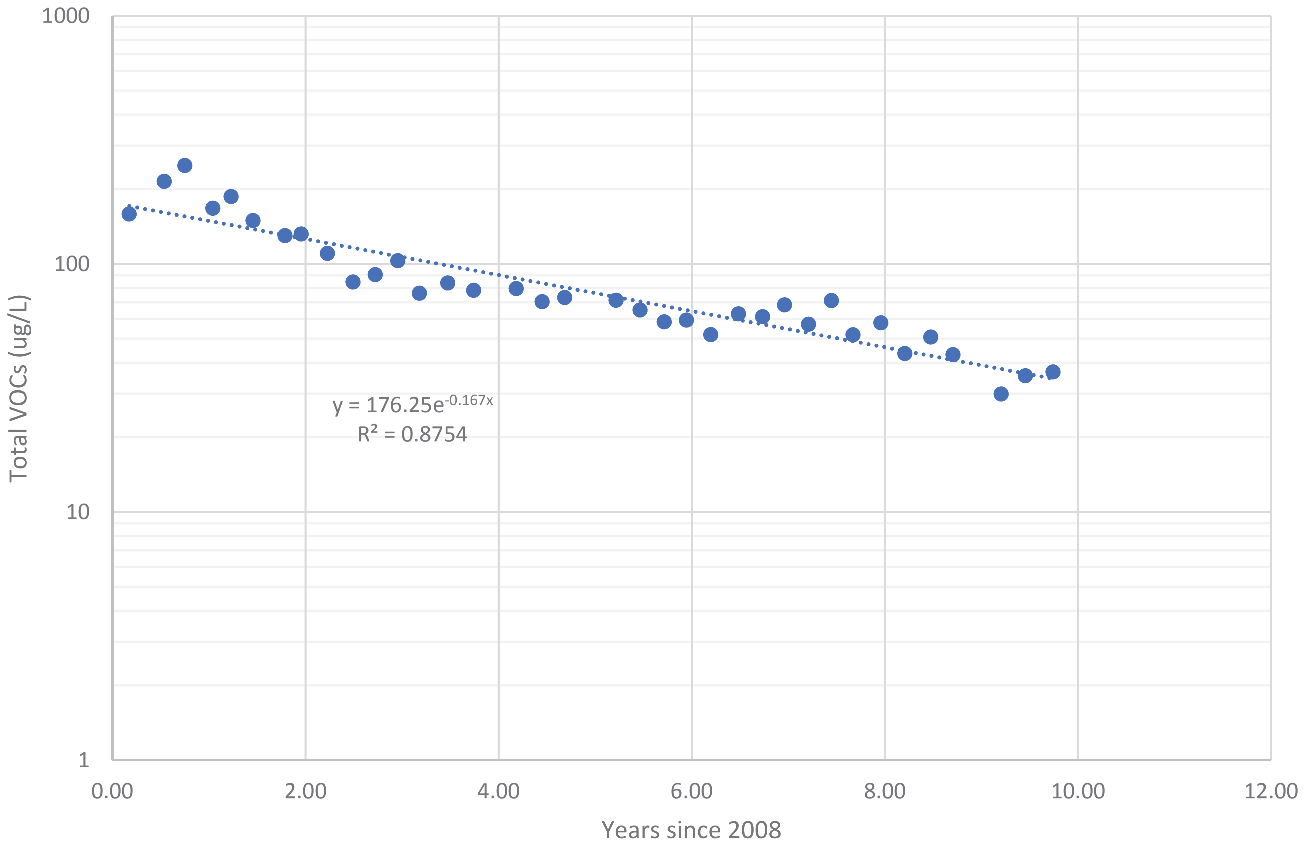
Table 1. Groundwater Extraction Rates and Total VOC Mass Removal Rates for Select Cleanup Action Components

	Groundwater Extraction from Hole			Targeted Pumping From Northerly Plume (Low T-Area Only)			Northerly Plume Hydraulic Capture (High-T and Low-T Areas)				Natural Attenuation					
											Mass Flux at POC^2			Mass Flux in P1 Source Area		
Year^1	Extraction Rate (gpy)	Total VOCs (ug/L)	VOC Mass Removal (kg/yr)	Extraction Rate (gpy)	Total VOCs in the Low-T Area (ug/L)	VOC Mass Removal (kg/yr)	Extraction Rate (gpy)	Total VOCs in High-T Area (ug/L)	VOC Mass Removal in Hight-T Area (kg/yr)	VOC Mass Removal for Entire POC Plume Capture [High T & Low T Areas] (kg/yr)	Low-T Ambient Mass Flux (kg/yr)	High-T Ambient Mass Flux (kg/yr)	Total Mass Flux at POC [High-T & Low-T Areas] (kg/yr)	Total VOCs in P1 Source Area (ug/L)	Mass Flux in P1 Soure Area (g/yr)	VOC Mass Removal (kg/yr)
1	390,000	140	0.21	788,923	4,300	13	3,500,000	29	0.4	13	0.3	0.08	0.4	76,395	55	54
2	46,000	140	0.02	788,923	3,079	9	3,500,000	25	0.3	9	0.3	0.06	0.3	64,646	46	46
3	46,000	140	0.02	788,923	2,605	8	3,500,000	21	0.3	8	0.2	0.05	0.3	54,703	39	39
4	46,000	140	0.02	788,923	2,205	7	3,500,000	18	0.2	7	0.2	0.04	0.2	46,290	33	33
5	46,000	140	0.02	788,923	1,866	6	3,500,000	15	0.2	6	0.2	0.04	0.2	39,170	28	28
6	46,000	140	0.02	788,923	1,579	5	3,500,000	13	0.2	5	0.1	0.03	0.2	33,146	24	23
7	46,000	140	0.02	788,923	1,336	4	3,500,000	11	0.1	4	0.1	0.03	0.1	28,048	20	20
8	46,000	140	0.02	788,923	1,130	3	3,500,000	9	0.1	3	0.1	0.02	0.1	23,734	17	17
9	46,000	140	0.02	788,923	957	3	3,500,000	8	0.1	3	0.1	0.02	0.1	20,084	14	14
10	46,000	140	0.02	788,923	809	2	3,500,000	7	0.1	2	0.1	0.02	0.1	16,995	12	12
Total Mass Removal after 10 yrs (kg)			0.43			59				61						286

Notes
gpy = gallons per year
ug/L = micrograms per liter
kg/yr = kilograms per year
g/yr = grams per year
1. Year 1 assumed to start in 2018
2. The mass flux (g/yr) = Q*C (where Q is the ambient volumetric flux and C is the total VOC concentration). Total VOCs (ug/L) in the Low-T and High-T area are shown in the Targeted Pumping and Northelry Plume Capture components above. See text for ambient groundwater flux.

Table 2. Summary of Estimated Restoration Time Frames for Cleanup Action Alternatives

Clean Up Action Alternatives	Components	Restoration Time Frame (years)	Basis
1	Existing P1 Zone MPE System and LFG Activation	34 to 66	Partial source containment
2	Existing and Expanded P1 Zone MPE System, LFG Activation	34	Source containment
3	Existing and Expanded P1 Zone MPE System, LFG Activation, Groundwater Extraction from Hole	34	Source containment
4	Existing and Expanded P1 Zone MPE System, LFG Activation, Targeted Pumping of Northerly Plume	20 to 34	Source containment and partial northerly plume hydraulic capture
5	Existing and Expanded P1 Zone MPE System, LFG Activation, Northerly Plume Hydraulic Capture	20	Northerly plume hydraulic capture
6	Existing and Expanded P1 Zone MPE System, LFG Activation, Groundwater Extraction from Hole, Targeted Pumping of Northerly Plume	20 to 34	Source containment and partial northerly plume hydraulic capture
7	Existing and Expanded P1 Zone MPE System, LFG Activation, Groundwater Extraction from Hole, Northerly Plume Hydraulic Capture	20	Northerly plume hydraulic capture



● Average Total VOCs in MW-3b and MW-7b

┈ Expon. (Average Total VOCs in MW-3b and MW-7b)

Figure 1. Average Total VOCs (ug/L) in MW-3b and MW-7b

PgG

Appendix C

REMChlor Fate and Transport Modeling in Support of Ephrata Landfill Feasibility Study

PACIFIC groundwater GROUP

REMCHLOR FATE AND TRANSPORT MODELING
FEASIBILITY STUDY SUPPORT
EPHRATA LANDFILL

August 29, 2012

REMCHLOR FATE AND TRANSPORT MODELING
FEASIBILITY STUDY SUPPORT
EPHRATA LANDFILL

Prepared for:

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August 29, 2012
JE0714
REMChlorModel_FSAppendix_Final_v2.docx

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TABLES

FIGURES

SIGNATURE

This report, and Pacific Groundwater Group's work contributing to this report, were reviewed by the undersigned and approved for release.

2651

Dawn Chapel

Dawn Chapel

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Hydrogeologist
Washington State Hydrogeologist No. 2651

1.0 INTRODUCTION

Fate and transport modeling of the Roza aquifer component of the northerly groundwater contaminant plume at the Ephrata Landfill was completed to support the Feasibility Study (FS). Specifically, the model was used to assess four scenarios, which correspond with certain cleanup action components described in the FS:

1. Natural Attenuation (NA)
2. Long Term Groundwater Extraction of P1 source area
3. Soil Vapor Extraction (SVE) in the P1 source area
4. Northerly Plume Capture in the Roza Aquifer at the Northern Landfill Property Boundary

The analytical model REMChlor (Falta, 2007) was selected to perform fate and transport modeling. Fate and transport modeling was performed for the four volatile organic compounds (VOCs) in the Roza aquifer component of the northerly plume that were identified as indicator hazardous substances (IHS) in the FS (Parametrix, 2012):

1. 1,2-dichloropropane (1,2-DCP)
2. Vinyl chloride (VC)
3. Benzene
4. Methylene Chloride

Model sensitivity was also assessed given the uncertainty in key input parameter values. Manganese is the fifth IHS in the Roza aquifer component of the northerly plume but it was not modeled.

The following sections describe the REMChlor model and our approach for using it to simulate the Roza aquifer component of the northerly plume. Subsequent sections describe model input parameters, model calibration, predictive simulations, and model uncertainty.

Our professional services were performed, our findings obtained, and our report prepared in accordance with generally accepted hydrogeologic practices. This warranty is in lieu of all other warranties, expressed or implied.

2.0 CONCEPTUAL MODEL AND MODEL ASSUMPTIONS

REMChlor is a 1-D fate and transport analytical model which assumes uniform groundwater flow and uses single, fixed values for hydrogeologic and chemical variables such as groundwater velocity, initial source concentration (Co), and initial source mass (Mo). REMChlor makes no assumption with regard to flow direction along its single spatial dimension (direction could be horizontal or vertical), and cannot simulate aquifer heterogeneities or hydraulic effects (such as changes in groundwater flow due to pumping);

however, it is capable of simulating the effects of source removal, enhanced plume decay, and NA.

We developed a REMChlor model to represent the center line of the Roza aquifer component of the northerly plume (Figure 1). The flow path along the plume center line extends northward from the P1 source area (by the former buried drums) and then northeastward and terminates at distance of about 575 m. This pathway is based on groundwater elevations and VOC concentrations observed in Roza aquifer wells. The contaminant transport pathway in the Roza aquifer is likely more complex with some contaminants being transported towards the Roza high transmissivity zone before migrating northward (Figure 1). This is one example of the simplified nature of the model.

Beyond 575 m along the plume center line, groundwater in the Roza is believed to discharge laterally into alluvium near a bedrock draw with some vertical migration to deeper aquifers also occurring. Enhanced vertical flow from the Roza aquifer to deeper aquifers may also have occurred through the Whitson domestic well[1] (Figure 1). Discharge and vertical migration of the plume to other aquifers is not simulated in the REMChlor model; however, these processes contribute to attenuation of the leading edge of the northerly plume by means of mixing, dilution, and evapotranspiration. The nature and extent of ground-water contamination is discussed in detail in the Remedial Investigation (RI) report (PGG, 2010).

REMChlor simulates depletion of the P1 contaminant source mass (kg) over time due to groundwater dissolution, source decay, and/or source removal (Figure 2). Groundwater dissolution of the source mass results in a source concentration (ug/L) over time which forms the upgradient boundary condition to the simulated dissolved phase groundwater plume (Figure 2). Contamination in the plume is transported downgradient along the 1-D flow path due to groundwater advection and dispersion. Dissolved phase concentrations are also depleted within the plume due to decay.

These model features allow predictive simulations for potential future source removal and/or enhanced plume decay cleanup actions, as well as NA. The model has many attractive features; however, it is a highly simplified approximation of the site and does not represent all the natural and engineered complexities.

2.1 REMCHLOR INPUT PARAMETERS

The following sections summarize REMChlor model input parameters for defining contaminant source, source remediation, groundwater plume transport, and plume decay. Below is an example of the REMChlor model interface:

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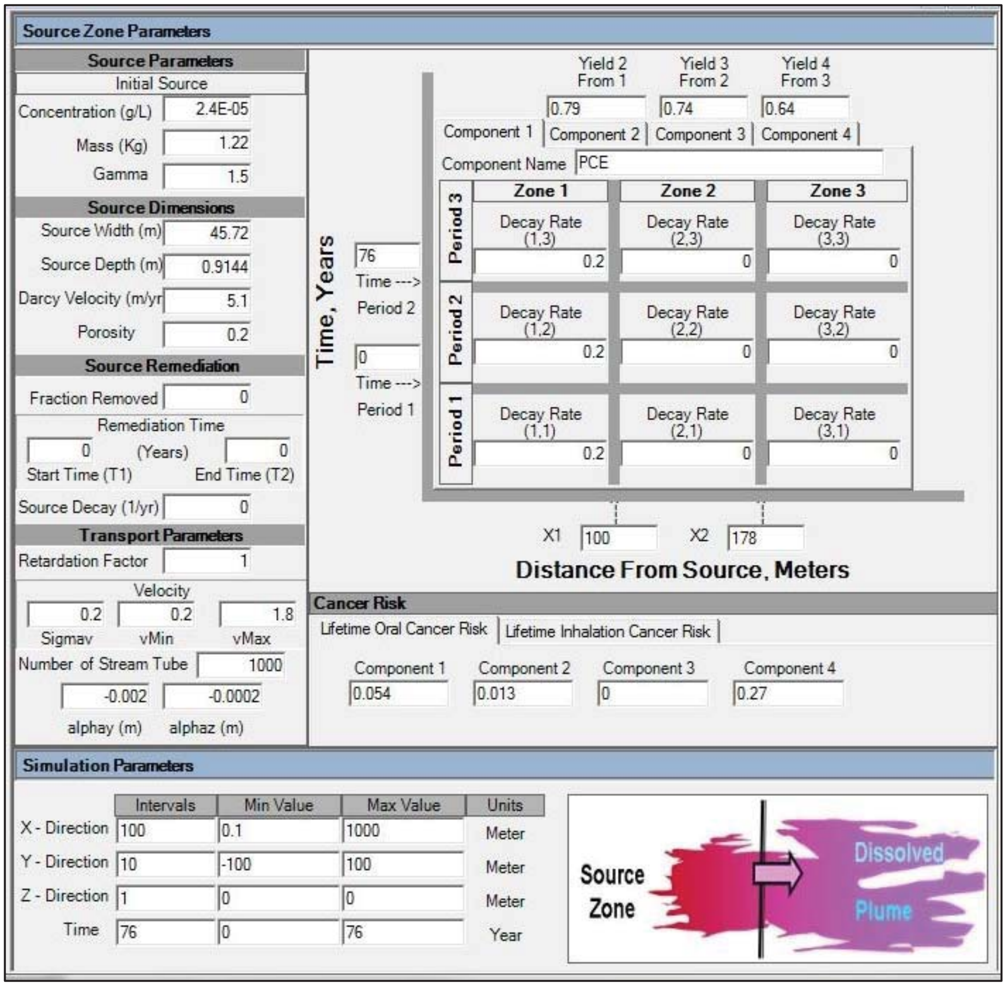
[1] The Whitson well was an open borehole from 19 to 294 feet below ground surface between 1997 when well was first drilled to 2012. In 2012 the bottom portion of the well was sealed and a new monitoring well was constructed in accordance with Chapter 173-160 WAC. The new well was constructed in the Interflow aquifer (The new well ID is MW-56c).



Initial Source

Concentration (g/L) 2.4E-05

Mass (Kg) 1.22

Gamma 1.5

Source Dimensions

Source Width (m) 45.72

Source Depth (m) 0.9144

Darcy Velocity (m/yr 5.1

Porosity 0.2

Source Remediation

Fraction Removed 0

Remediation Time (Years): Start Time (T1) 0; End Time (T2) 0

Source Decay (1/yr) 0

Transport Parameters

Retardation Factor 1

Velocity: Sigmav 0.2; vMin 0.2; vMax 1.8

Number of Stream Tube 1000

alphay (m) -0.002; alphaz (m) -0.0002

Yield 2 From 1: 0.79; Yield 3 From 2: 0.74; Yield 4 From 3: 0.64

Component 1 | Component 2 | Component 3 | Component 4

Component Name PCE

76 Time ---> Period 2

0 Time ---> Period 1

	Zone 1	Zone 2	Zone 3
Period 3	Decay Rate (1,3) 0.2	Decay Rate (2,3) 0	Decay Rate (3,3) 0
Period 2	Decay Rate (1,2) 0.2	Decay Rate (2,2) 0	Decay Rate (3,2) 0
Period 1	Decay Rate (1,1) 0.2	Decay Rate (2,1) 0	Decay Rate (3,1) 0

X1 100 X2 178

Cancer Risk – Lifetime Oral Cancer Risk

Component 1	Component 2	Component 3	Component 4
0.054	0.013	0	0.27

Simulation Parameters

	Intervals	Min Value	Max Value	Units
X - Direction	100	0.1	1000	Meter
Y - Direction	10	-100	100	Meter
Z - Direction	1	0	0	Meter
Time	76	0	76	Year

2.1.1 Source Model Input Parameters

Source model parameters include source zone dimensions (width and depth), source mass (kg), initial source concentration (g/L), and gamma (a user specified term in REMChlor). In REMChlor, the source mass is depleted over time as contaminants move downgradient with groundwater from the source zone. As such, the depletion of the source mass is also a function of the groundwater velocity assigned to the model. Faster velocity results in a more rapid depletion of the source mass.

The source concentration (the concentration in groundwater in contact with the source) also decreases over time as the source mass is depleted. The relationship between source mass depletion and associated source concentration is defined in REMChlor using a power function and gamma is the exponent which determines the relationship. A gamma-value of 1.0 results in a 1:1 relationship between the decrease in source mass and corresponding decrease in source concentration. Gamma values greater than 1 result in rapid decrease in source concentration at early time followed by a slow decrease in later time (this is known as the “tailing effect” and represents matrix diffusion conditions where the source is dominantly in low permeability zones). In contrast, gamma values less than 1 result in slow decrease in source concentration at early time followed by rapid decrease at later time. A gamma value of 0 is a unique case that results in a constant source concentration until the source mass is fully depleted (Falta, 2007).

2.1.2 Source Remediation Parameters

Source remediation is simulated in REMChlor as a human-caused reduction in source mass over a specified period of time. Input parameters include mass fraction removed from the source and the start and end year of the source removal. REMChlor also allows for a constant first order source decay rate which reduces the source mass over time by other processes besides dissolution and flushing (Falta, 2007).

2.1.3 Plume Transport Parameters

Plume transport parameters include Darcy velocity (m/yr), porosity, retardation, and dispersivity. In REMChlor the longitudinal dispersion (alpha-x) is scale dependent and represented using a number of streamtubes that have a normal velocity distribution with a mean velocity (Vmean) and standard deviation (σ):

alpha-x = $\text{Sigmav}^2/2*\text{Xmean}$

Where Sigmav = the coefficient of variation for the velocity distribution
= σ^2/Vmean. (Sigmav is user specified)

Xmean = the average advective front location.

The upper and lower bounds of the streamtube velocity distribution are user specified and defined by:

vMin-normalized = minimum normalized streamtube velocity (a value of zero suggested)

vMax-normalized = maximum normalized streamtube velocity (a value of 1+4*Sigmav suggested)

Ideally Vmin-normalized and Vmax-normalized are symmetrical around 1.0 (Falta, 2007).

Transverse (alpha-y) and vertical (alpha-z) dispersivities are user specified and can be constant or scale dependent in REMChlor. Scale dependent dispersivity values are calculated in REMChlor as proportional to the distance from the source (Falta, 2007).

2.1.4 Plume Decay Parameters

REMChlor simulates the destruction of contaminant concentrations in the plume as a result of reductive dechlorination, biodegradation, and other destructive processes through the use of plume decay parameters. Plume decay parameters include user specified first order decay rates (yr-1) and parent/daughter yield coefficients. REMChlor can simulate both the chemical decay of the parent product and the associated production and decay of daughter products through the use of yield coefficients. Up to three daughter products in the decay pathway from a parent product can be simulated in REMChlor (e.g. TCE, cis-

1,2-DCE and VC from PCE). Decay rates for parent and daughter products can vary in time and space, with up to three spatial and temporal plume decay zones available.

3.0 APPROACH FOR USING REMCHLOR

Our approach for using REMChlor was to first calibrate the model to current plume conditions and then run the calibrated model into the future to assess plume attenuation over time under different scenarios which correspond with certain cleanup action components described in the FS.

The following chemicals were simulated:

- Chloride
- 1,2-Dichloropropane (1,2-DCP)
- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- cis-12-Dichloroethene (cis-1,2-DCE)
- Vinyl Chloride (VC)
- Benzene
- Methylene Chloride

These chemicals include VOC IHS identified in the FS for the Roza aquifer northerly plume component, additional chloro-ethenes that are part of the degradation pathway for vinyl chloride, and chloride, which was used to calibrate the dispersion term. Each chemical is simulated independently using REMChlor. Note that for the chloro-ethenes, daughter products produced during the decay of a parent product (e.g. TCE, cis-1,2-DCE, and VC from PCE) were added to subsequent model results of those chemicals as parent products. This method of super-positioning model results was deemed necessary because site conditions indicate the source mass is composed of relatively high concentrations of daughter products (e.g. cis-1,2-DCE and VC). Super-positioning of model results was also used to simulate the historical development of the current plume followed by attenuation of the future plume as described below. This approach of super-positioning of REMChlor results has been used at other sites (Henderson et al, 2009) and was discussed with the developers of REMChlor as a feasible approach.

3.1 APPROACH FOR SIMULATING CURRENT AND FUTURE PLUME

The super-position method for simulating the current and future VOC plumes involved running two simulations. The first simulation began in 1975 (year of drum burial) and modeled the historical development of the current plume assuming a constant continuous source concentration up until completion of interim actions in 2008 (drum removal). The historical constant source concentration was assumed to be the same as the current source concentration (see Section 4.1 below). At completion of interim actions the historical source concentration was assumed to be zero and this first simulation continued to model the plume into the future with a zero source concentration. This type of changing source concentration (constant concentration until 2008 followed by a zero concentration) was achieved in REMChlor by using a gamma value of 0 and calculating the required initial source mass such that it was fully depleted by 2008. The purpose of the first model was to create a current plume configuration that the second model was then superimposed upon.

The second simulation began in 2008 and modeled the plume 76 years out (2084) assuming a source concentration that slowly decreased over time as the finite source mass is depleted. The finite source mass was specified based on post-interim action residual source data (see Section 4.1 below). The initial source concentration was the same as the historical source concentration used in the first model and was estimated using a mass flux approach (see Section 4.1 below). A decreasing source concentration in the second model was achieved by using a gamma value greater than 0.

Concentrations in the future plume were then calculated using the super-position method by adding the results of the first and second models.

4.0 MODEL INPUT PARAMETERS

Model input parameter values are shown in Table 1 and discussed individually below.

4.1 SOURCE PARAMETERS

Source geometry, mass, and concentrations for chloride and VOCs are described below.

4.1.1 Chloride

The chloride source was assumed to be associated with the original landfill. The source width and depth for the chloride source was assumed to be 1000-ft long (perpendicular to groundwater flow) and 10-ft deep. This geometry was based on the approximate cross section of the Roza aquifer along the northern edge of the landfill (1000-ft) and the average thickness of the Roza aquifer (10-ft).

The source mass for the chloride model (Table 1) was assumed to be infinite and assigned an arbitrary large value (10^9 kg) so that the source was never depleted during the simulation. The source concentration was assigned an average concentration based on observed concentrations in the source area by the former drums and the Roza aquifer in the vicinity of the shop (1.0 g/L). For the chloride simulation we assumed the source concentration was constant and continuous and therefore used a gamma value of 0 (Table 1).

4.1.2 Volatile Organic Compounds (VOCs)

The source for each VOC was assumed to be dominantly associated with the former drums and residual contamination in the P1 zone. The source width and depth for each VOC was assumed to be 150-ft and 3-ft respectively. This geometry was based on the best estimate of the approximate length of the P1 source area perpendicular to groundwater flow (150-ft) and the average thickness of the P1 zone (3-ft). The P1 source area was assumed to be the approximate area where light non-aqueous phase liquids (LNAPL) are estimated to occur in the P1 zone.

The initial source mass value (Mo) for each simulated VOC was different in the first and second models (Table 1). The value of Mo in the first model was calculated using REMChlor equations (Falta, 2007) such that it is fully depleted by 2008. The value of Mo in the second model was calculated based on estimates of source mass in residual soil and LNAPL by the former drums (PGG, 2012a).

The initial source concentration (Co) for each simulated VOC was the same in both the first and second models (Table 1) and was based on a calculation of plume mass flux (PGG, 2012a)[2]. The plume mass flux was assumed to be the same as the mass flux through the source area Q*Co (g/yr). REMChlor uses the Darcy velocity (q) to calculate the groundwater flux through the source area (Q), where Q = q*A with A being the cross-sectional dimension of the source area. Since Q is a fixed parameter in REMChlor, the value of Co was calculated as the concentrations required to make Q*Co equal to the plume mass flux (PGG, 2012a).

Minimum and maximum values in Mo and Co were also estimated based on uncertainty in the source area dimension (PGG, 2012a). Model sensitivity to the values of Mo and Co was tested in subsequent model runs (see Section 7 below).

4.1.3 Gamma

A gamma value of 0 was used to simulate a constant continuous source for the chloride simulation and the first model in the VOC simulations (Table 1). A gamma value of 1.5 was used for the second model in the VOC simulations (Table 1). Gamma values for most sites are thought to range from 0.5 to 2.0 (Newell et al, 2011). As mentioned above, gamma values greater than 1 are generally assigned to sites with high heterogeneity and where matrix diffusion from low permeability zones is expected to result in long-term “tailing” of contaminant concentrations. We therefore expect a representative gamma value between 1 and 2 for the Ephrata site and chose 1.5 as a “middle” value.

The sensitivity of gamma was tested in subsequent model runs (see Section 7 below).

4.1.4 Source Remediation

For the model calibration and predictive simulation of NA we assume no source remediation (Table 1). Source remediation parameters were adjusted later during the predictive simulation of other scenarios (see Section 6 below).

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[2] Because the observed concentrations in the P1 source area may include LNAPL, and therefore overestimate dissolved phase concentrations, a mass flux approach was developed for estimating the initial source concentration (Co) for each simulated VOC in REMChlor. However, since vinyl chloride is created through the degradation of PCE, TCE and cis-1,2-DCE downgradient from the source, the mass flux approach resulted in an overestimated Co value for vinyl chloride at the source (PGG, 2012a). We therefore used the observed concentration in the P1 source area for vinyl chloride, which was less than that calculated using the mass flux approach (PGG, 2012a).

4.2 TRANSPORT PARAMETERS

Groundwater transport parameters are described below.

4.2.1 Darcy Velocity

The Darcy velocity or specific discharge rate (q) was assumed constant in all model simulations and was set equal to the best estimate of specific discharge in the Roza Aquifer (5.1 m/yr). This value was derived using the geometric mean hydraulic conductivity (K) for the Roza aquifer (3.5 ft/d) and the average groundwater gradient (i) in the Roza aquifer along the northerly plume centerline (0.013)[3]:

$q = K*i = 3.5*0.013 = 0.0455$ ft/dy = 5.1 m/yr

The actual discharge rate in the aquifer; however, is expected to be highly variable at different locations. This is one example of the simplified nature of the model.

Assuming a porosity (n) of 0.2, the groundwater seepage velocity (v) was calculated to be:

$v = q/n = 5.1 / 0.2 = 25.5$ m/yr (84 ft/yr)

In REMChlor, the Darcy velocity (q) is also used to calculate the groundwater flux (Q) through the source zone area (A):

$Q = q*A = 0.0455$ ft/dy * (150-ft x 3-ft) = 20.5 ft^3/dy = 212 m^3/yr

The groundwater velocity parameter therefore effects the simulation of both the plume and the source mass attenuation over time. This is another example of the simplified nature of the model. In essence, REMChlor simulates the source mass as if it is within the Roza aquifer, whereas in Ephrata the source mass is actually in the overlying P1 zone.

The mass flux through the source area is Q*Co (g/yr). Since a separate groundwater flux (Q) cannot be assigned to the source area in REMChlor; the initial source mass (Co) was calculated based on estimates of mass flux through the source area (PGG, 2012a).

Model sensitivity to the Darcy velocity was tested in subsequent model runs (see Section 7 below).

4.2.2 Porosity

The porosity of the Roza aquifer was assumed to be 0.2. This is consistent with our interpretation that the weathered zone of the Roza aquifer is a porous medium.

4.2.3 Retardation Factor

The retardation factor (Rf) for a particular contaminant is the ratio between the rate of groundwater movement and rate of contaminant movement:

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[3] The groundwater gradient was calculated using water level data collected in March, June and September 2011.

$Rf = v/vc$

Where v = groundwater seepage velocity

vc = contaminant velocity

When $v = vc$, $Rf = 1$.

For organic chemicals, the dominant process contributing to retardation is adsorption of the contaminant to solid surfaces and Rf is calculated as:

$Rf = 1 + [\rho b/n]*Kd$

Where ρb = aquifer bulk density

n = aquifer porosity

Kd = partitioning coefficient associated with the aquifer and contaminant

Because organic chemicals partition primarily onto the organic carbon fraction of an aquifer (foc), Kd values are commonly estimated using the value of the organic carbon fraction of aquifer solids (foc) and the octanol-water partition coefficient (Koc):

$Kd = Koc*foc$

Koc values are chemical specific and are readily available in Ecology's Cleanup Levels and Risk Calculations (CLARC) online database and other sources; however, the foc is aquifer specific. MTCA recommends using a value of 0.001 in the absence of field data. However, sorption in basalt aquifers is typically considered to be relatively insignificant due to the absence of organic material (Sorenson et al, 1998). We have not been able to find any definitive references on sorption specifically for the Wanapum basalt in the literature.

Given the low organic content expected in the Roza basalt aquifer, we expect that the MTCA default values for deriving Kd values could result in an over prediction of retardation and therefore an under prediction of the contaminant velocity. Given this uncertainty, we took the approach of regarding the groundwater velocity term in REMchlor as a contaminant velocity term and set the retardation factor equal to 1.0 for all VOCs.

Our best estimate for the groundwater seepage velocity was 25.5 m/yr (see Section 4.2 above) and we estimated a minimum (12.5 m/yr) and maximum (91 m/yr) contaminant velocity based on field observations (see Section 7.0 below).

While the Rf parameter affects the contaminant velocity in REMChlor, it does not affect the groundwater flux (Q) through the source zone area. This distinction could be important because the groundwater flux (Q) controls the mass flux (Q*Co) through the source area which effects the source mass depletion rate (Drate):

$Drate = Q*Co/Mo$ [dy-1]

Where Q = groundwater flux (constant)

Co = source concentration

Mo = source mass

Treating the groundwater velocity term in REMChlor as a contaminant velocity term and setting the retardation value equal to 1.0 could result in an under prediction of source depletion if retardation is in fact an important process.

However, as explained in Section 4.1.2 above, we have estimated the mass flux through the source area (Q*Co) outside of REMChlor and fixed this value in REMChlor by adjusting Co. Therefore, the potential for underestimating the source depletion rate by using a retardation factor of 1 is eliminated.

The chloride plume was also assumed to not be retarded by sorption processes and therefore an Rf value of 1.0 was used for the Chloride Model (Table 1).

4.2.4 Dispersivity Parameters

As discussed above, the dispersivity parameters (Sigmav, vMin-normalized, vMax-normalized, alpha-y, and alpha-z) were adjusted during calibration of the chloride model to current chloride concentrations. Final calibrated values are shown in Table 1 and discussed below in Section 5.0.

4.3 PLUME DECAY RATES

Plume decay rates were adjusted during calibration of the VOC models to current concentrations. Decay rates were adjusted within the range of values reported in the literature (U.S. Geological Survey, 2006; Aronson and Howard, 1997; U.S. EPA, 1999; and Suarez and Rifai, 1999). Final model calibrated values are shown in Table 1 and discussed further in Section 5.0 below. Plume decay rates were assumed to be zero for the chloride model.

4.4 SIMULATED TIME

Development of the current chloride plume was assumed to occur over a 53 year period (1955 to 2008). The start date of 1955 is about 10 years after operation of the landfill first began and when groundwater levels at the site increased significantly in response to the Columbia Basin Irrigation project. The start of the irrigation project is likely when groundwater in the Hole first developed.

Development of the VOC plume was assumed to occur over a 34 year period, from the initial burial of the drums in 1975 to the removal of drums and associated soils in 2008. The future plume was simulated for an additional 76 years to 2084.

5.0 MODEL CALIBRATION RESULTS

Targets used in the calibration are discussed below followed by a discussion of the calibration results. Calibration results are shown as simulated concentration profiles (Figures 3 through 10) along the plume center line (Figure 1). The plume center line extends from the source area (0 m) to the approximate extent of the Roza aquifer component of the northerly plume (575 m).

5.1 TARGETS

Except for groundwater concentrations at the source, concentration targets representing current conditions along the plume center line were developed by contouring RI groundwater data from Roza aquifer wells and the Whitson well. The groundwater concentration at the source (Co) was based on calculations of plume mass flux (Q*Co) as described above in Section 4.1.2

Concentration targets are shown in Table 2. The furthest target from the source area is the Whitson well at 1400-ft, which is completed through multiple aquifers, including the Roza. Data collected from the Whitson well is therefore a mixture between aquifers and the concentration in the Roza aquifer at this location is likely higher than what is observed in the Whitson well. This furthest target was therefore qualified as “greater than” (Table 2).

5.2 CHLORIDE CALIBRATION RESULTS

The results of the calibrated chloride simulation are shown in Figure 3. The best fit to target data was achieved with a Sigmav = 0.2. This is equivalent to a longitudinal dispersivity of 6 meters at a distance of 1000-ft, which is similar to those reported in Gelhar et al (1992) for a distance of 1000-ft. Scale dependent transverse and vertical dispersivities were 0.002 and 0.0002 respectively, which is equivalent to 0.6 and 0.06 meters at a distance of 1000-ft.

5.3 1,2-DCP CALIBRATION RESULTS

The 1,2-DCP model was calibrated relatively well to the target concentration values (Figure 4). The best fit to the targets was achieved with a relatively low decay rate of 0.055 (yr-1) assigned to all three plume decay zones (Table 1). We did not find available published data on decay rates for 1,2-DCP; however the rate of degradation of 1,2-DCP in the environment is thought to be relatively slow (U.S. EPA, 1979).

5.4 PCE CALIBRATION RESULTS

The PCE model was calibrated relatively well to the target concentration values (Figure 5). The best fit to the targets was achieved with a decay rate of 0.2 (yr-1) assigned to plume decay zone 1 and a zero decay rate assigned to zones 2 and 3 (Table 1). This value is within the range reported in the literature.

5.5 TCE CALIBRATION RESULTS

The TCE model was calibrated relatively well to the target concentration values (Figure 6). The best fit to the targets was achieved with a decay rate of 0.7 (yr-1) assigned to plume decay zone 1, a decay rate of 0.1 (yr-1) assigned to zone 2, and a zero decay rate assigned to zone 3 (Table 1). These values are within the range reported in the literature.

5.6 CIS-1,2-DCE CALIBRATION

The cis-1,2-DCE model was calibrated relatively well to the target concentration values (Figure 7). The best fit to the targets was achieved with a decay rate of 0.7 (yr-1) assigned to plume decay zone 1, a decay rate of 0.2 (yr-1) assigned zone 2, and a zero decay rate assigned to zone 3 (Table 1). These values are within the range reported in the literature.

5.7 VINYL CHLORIDE CALIBRATION RESULTS

The vinyl chloride model was calibrated relatively well to the target concentration values except for the target at 85 m (Figure 8). The target for vinyl chloride at 85 m (10 ug/L) was based on data projected from Roza well MW-42b (Figure 1); however, in order to match the observed concentration of vinyl chloride at the Whitson well (> 5 ug/L at 427 m), a modeled concentration of 150 ug/L was required at 85 m.

The concentration of vinyl chloride is highly variable near the north end of the landfill. Concentrations were over 500 ug/L in some wells near the source area, about 60 ug/L in the Hole (approximately 100 meters west from the source); and about 30 ug/L in the Roza aquifer at MW-3b (approximately 200 meters northwest from the source). Thus the accuracy of projected data points for vinyl chloride near the source can be questionable.

For the calibration we honored the observed concentration target at the Whitson well (target at 427 m) at the expense of the projected target at 85 m. Final calibration was achieved with a decay rate of 0.5 (yr-1) assigned to plume decay zones 1 and 2 and zero decay rate assigned to zone 3 (Table 1). These values are within the range reported in the literature.

5.8 BENZENE CALIBRATION RESULTS

The benzene model was calibrated relatively well to the target concentration values except for the target at 293 m (Figure 9). The target for benzene at 293 m (30 ug/L) was based on data projected from Roza well MW-44b (Figure 1). Even with plume decay rates set to zero, the model could not simulate a concentration of 30 ug/L at 293 m given a source concentration of 113 ug/L. The simulated concentration at 293 meters is about 1/3 the target value (10 ug/L). The higher target value suggests the historic mass and source concentration may be different than our current assumptions. Thus, plume attenuation and restoration time periods may be longer than predicted by the model. The concentration of benzene measured in MW-44b during the RI has shown a decreasing trend from 39 ug/L in September 2009 to 25 ug/L in September 2010 (PGG, 2012b), suggesting the plume may be re-equilibrating from an elevated past source concentration.

The final calibration uses a decay rate of zero assigned to all three plume decay zones (Table 1).

5.9 METHYLENE CHLORIDE CALIBRATION RESULTS

The methylene chloride model was calibrated relatively well to the target concentration values (Figure 10). The best fit to the targets was achieved with a decay rate of 0.01 (yr^{-1}) assigned to all three plume decay rate zones (Table 1). These values are within the range reported in the literature.

6.0 MODEL PREDICTIVE SIMULATIONS

The calibrated models were used to perform predictive simulations for the following scenarios, which correspond with certain cleanup action components described in the FS:

1. NA
2. Long Term Groundwater Extraction of P1 source area
3. SVE in the P1 source area
4. Northerly Plume Capture in the Roza Aquifer at the Northern Landfill Property Boundary

The main simulation goal was to estimate IHS concentrations in groundwater over time at various points along the northerly plume centerline. Of interest were:

1. The point at which the northerly plume centerline crosses the north landfill property boundary, which is proposed in the FS as a point of compliance (POC), and

2. The time intervals (restoration time frames) needed under each scenario for IHS concentrations to be reduced to clean up levels (CUL) at the POC and/or at locations downgradient of the POC (Figure 1).

Simulation results were used to evaluate IHS attenuation (changes in plume concentrations over time) and restoration time frames (Table 3). For these simulations, NA and P1 Pumping were assumed to start in 2008, whereas SVE and northerly plume capture were assumed to start in 2013.

Table 3 also shows the locations within the plume (either at the POC or some distance downgradient of the POC) estimated to take the longest time for IHS concentrations to be reduced to CULs. Under NA and SVE, the longest time to meet CULs occurs at the POC. Under northerly plume capture, the longest time to meet CULs occurs at the EOP or between the POC and EOP (methylene chloride). Under P1 Pumping the locations depends on the individual IHS (Table 3).

The simulated effects of NA were combined with the results of each of the other scenarios. However, combinations of P1 pumping, SVE, and northerly plume capture (e.g. active measures) were not simulated. P1 pumping would be needed to create a vadose zone for SVE, and northerly plume capture could accompany any of the other scenarios. Although combinations of active measures were not evaluated, conducting multiple actions would likely reduce plume concentrations more than conducting each action exclusively. Therefore, the restoration time frame would probably be shorter than predicted for the individual actions.

A detailed discussion for each scenario follows.

6.1 NATURAL ATTENUATION

The simulation for NA involved running the calibrated models out into the future with no change to model input parameters. Attenuation of the plume was the result of source depletion due to groundwater dissolution, and plume attenuation due to advection, dispersion, and plume decay (Figure 11). NA was simulated as starting in 2008 and continuing to the end of the simulation (2084).

NA simulation results for each IHS are presented below. Simulated plume concentration profiles are plotted for years 2013, 2018, 2028, 2038 and 2043 for each IHS (Figures 12-15). Also plotted is the CUL for each IHS in the Roza aquifer component for the northerly plume and the POC at the north landfill property boundary (Figure 1).

6.1.1 1,2-DCP Results (NA)

The NA simulation for 1,2-DCP shows concentrations attenuating over time (Figure 12), with concentrations estimated to be in compliance by the year 2063; a 55 year restoration time period (Table 3).

6.1.2 Vinyl Chloride Results (NA)

The NA simulation for vinyl chloride shows concentrations attenuating over time (Figure 13), with concentrations estimated to be in compliance sometime after the year 2084 (the last time step in the model); a restoration time period greater than 76 years (Table 3).

The results of the vinyl chloride simulation show plume concentrations closest to the source (near 0 meters in Figure 13) attenuate significantly over time. However, concentrations increase immediately downgradient of the source before decreasing (Figure 13). The simulated increase in concentrations downgradient from the source is due to vinyl chloride being generated from the decay of PCE, TCE, and cis-1,2-DCE.

6.1.3 Benzene Results (NA)

The NA simulation for benzene shows concentrations attenuating over time (Figure 14), with concentrations estimated to be in compliance by the year 2058; a 50 year restoration time period (Table 3).

6.1.4 Methylene Chloride Results (NA)

The NA simulation for methylene chloride shows concentrations attenuating over time (Figure 15), with concentrations estimated to be in compliance by the year 2079; a 71 year restoration time period (Table 3).

6.2 P1 LONG TERM GROUNDWATER PUMPING

The simulation for P1 long term groundwater pumping considers additional mass removed in extracted groundwater beyond that already removed with natural dissolution of the source area. We did not consider additional mass removed with LNAPL[4]. The limited drawdown available in the P1 source area makes it impossible to hydraulically reverse the vertical gradient by pumping the P1. Hydraulic containment of the P1 source area is therefore not possible simply by pumping the P1. However, implementation of long term pumping would remove source mass over time and contribute to faster rates of source depletion compared to that simulated under NA.

The annual amount of mass removed over time M(t) was estimated using the design extraction volume per year for P1 pumping (PGG, 2012a) and the estimated source concentration over time C(t):

$$M(t) = C(t)*V \qquad [1]$$

Where

V = extracted groundwater volume per year

$$C(t) = [M(t)/Mo]^{\Gamma} * Co \qquad [2]$$[5]

Mo = initial source mass

Co = initial source concentration

Γ = gamma (1.5)

The design extraction volume per year for the P1 was estimated to be 250,000 gallons (PGG, 2012a). Since the extracted groundwater is likely to be diluted with cleaner groundwater being drawn in from less contaminated portions of the aquifer, and achieving 250,000 gallons per year may be difficult, we assumed that only 50% (125,000 gallons per year) is extracted at the relatively high source concentration.

The values of M(t) and C(t) over time were estimated using the equations 1 and 2 above through an iterative process. For the first time step, M(t) was calculated using the initial source concentration Co as the value for C(t). The resulting value for M(t) was then input into equation 2 to calculate a new value for C(t) which was then used in equation 1

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[4] Extractable LNAPL volume calculated is expected to be relatively low (possibly only a few gallons per year), and the IHS mass removed with LNAPL is expected to be relatively low compared to that removed with extracted groundwater.

[5] REMChlor power function relationship between source concentration and source mass (Falta, 2007)

for calculation of M(t) in the next time step. This process was continued for each time step in the model. Values of M(t) over time were then plotted and the REMChlor time depended equation for M(t) was fitted to the plotted data by adjusting the source decay term (λ):

$$M(t) = \{(-QCo/\lambda Mo^{\Gamma})+(Mo^{1-\Gamma}+QCo/\lambda Mo^{\Gamma})e^{(\Gamma-1)\lambda t}\}^{\Gamma/1-\Gamma} \qquad [3]$$ [6]

As mentioned, REMChlor does not simulate pumping and hydraulic effects; thus the reduction in source mass over time was simulated in REMChlor using the fitted source decay term (Figure 16).

The source decay term in REMChlor is required to be constant throughout the duration of the simulation, so this scenario was simulated as starting in 2008 and continuing through 2084 (Table 4). Results for each IHS are presented below.

6.2.1 1,2-DCP Results (P1 Long Term Pumping)

The P1 Pumping simulation for 1,2-DCP shows concentrations attenuating with time (Figure 17), with concentrations estimated to be in compliance by the year 2039; a 31 year restoration time period (Table 3).

6.2.2 Vinyl Chloride Results (P1 Long Term Pumping)

The P1 Pumping simulation for vinyl chloride shows concentrations attenuating over time (Figure 18), with concentrations estimated to be in compliance by the year 2047; a 39 year restoration time period (Table 3).

Similar to the NA simulation, the results of the P1 Pumping simulation shows vinyl chloride concentration profiles increase downgradient of the source before decreasing (Figure 18). This is due to additional vinyl chloride generated from the decay of PCE, TCE, and cis-1,2-DCE.

6.2.3 Benzene Results (P1 Long Term Pumping)

The P1 Pumping simulation for benzene shows concentrations attenuating over time (Figure 19), with concentrations estimated to be in compliance by the year 2040; a 32 year restoration time period (Table 3).

6.2.4 Methylene Chloride Results (P1 Long Term Pumping)

The P1 Pumping simulation for methylene chloride shows concentrations attenuating over time (Figure 20), with concentrations estimated to be in compliance by the year 2046; a 38 year restoration time period (Table 3).

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[6] Equation (4) in Falta (2007)

6.3 SOIL VAPOR EXTRACTION

The SVE simulation considers additional source mass removal from the P1 area beyond that already removed with natural dissolution. The estimated source mass removal associated with SVE in the FS is 50% of the source mass (Parametrix 2012).

Source removal in REMChlor was assumed to occur over a four year period and was simulated using the linear Source Fraction Removed parameter (Figure 21 and Table 5) and setting the start of removal at model year 5 (2013) and ending at model year 9 (2017). Thus 5 years of natural attenuation occurs before the start of SVE in the model simulation. In contrast, the simulation of SVE performance in order to calculate an initial organic COC mass removal rate for Table 11 of the FS main text assumed exponential decay of 50% of the current source mass. Therefore, the initial (one year) mass removal rate in FS Table 11 is greater than simulated in REMChlor, but the ultimate source reduction is assumed to be 50% in both sets of calculations.

SVE will also require long term groundwater pumping from the P1 source area in order to create a vadose zone for vapor extraction. The SVE simulations did not include source mass removed with P1 groundwater pumping. As mentioned above, active measures were simulated independently (i.e. no simulations were conducted for combinations of active measures). However, all simulations do include the simulated effects of NA.

SVE simulation results for each IHS are presented below.

6.3.1 1,2-DCP Results (SVE)

The SVE simulations for 1,2-DCP (Figure 22) shows concentrations attenuating over time. 1,2-DCP concentrations were estimated to be in compliance by the year 2058; a 45 year restoration time period (Table 3).

6.3.2 Vinyl Chloride Results (SVE)

The SVE simulation for vinyl chloride (Figure 23) shows concentrations attenuating over time. Vinyl chloride concentrations were estimated to be in compliance by the year 2083; a 70 year restoration time period (Table 3).

6.3.3 Benzene Results (SVE)

The SVE simulation for benzene (Figure 24) shows concentrations attenuating over time. Benzene concentrations were estimated to be in compliance by the year 2049; a 36 year restoration time period (Table 3).

6.3.4 Methylene Chloride Results (SVE)

The SVE simulation for methylene chloride (Figure 25) shows concentrations attenuating over time. Methylene chloride concentrations were estimated to be in compliance by the year 2043; a 30 year restoration time period (Table 3).

6.4 NORTHERLY PLUME CAPTURE AT LANDFILL PROPERTY BOUNDARY

The northerly plume capture simulations assume the northerly plume is hydraulically captured at the north landfill property boundary. Hydraulic capture would be achieved by pumping from a high transmissivity zone of the Roza aquifer which underlies a portion of that area (Figure 1). This scenario would interrupt the main pathway of IHS feeding the downgradient northerly plume.

REMChlor cannot simulate the hydraulic effects of pumping. We therefore simulated plume containment by forcing plume concentrations to zero upgradient of the landfill property boundary. For this simulation we assumed plume containment is achieved within one year of pumping (starting in 2013). The landfill property boundary is located about 178 m north (downgradient) from the source along the Roza northerly plume center line (Figure 1). Plume concentrations were artificially forced to zero in REMChlor by assuming an artificially high plume decay rate at all locations between 0 and 178 m (Table 6 and Figure 26). Thus plume attenuation simulated downgradient of 178 m (i.e. the landfill property boundary) is an approximation of what would be expected under conditions of hydraulic capture. Because of this approach, the results of this simulation are only valid downgradient (north) of the landfill property boundary along the plume center-line (i.e. for distances greater than 178 m).

Continuing hydraulic containment beyond the restoration time frame could be needed to maintain the effectiveness of northerly plume capture. Although concentrations downgradient of the property boundary may decrease below a CUL after a given period of time with this action, continued pumping may be required if the source has not been sufficiently depleted (i.e. if pumping were to stop before sufficient source depletion, plume expansion could resume).

Northerly Plume Capture simulation results for each IHS are presented below.

6.4.1 1,2-DCP Results (Northerly Plume Capture)

The northerly plume capture simulation for 1,2-DCP shows concentrations attenuating relatively rapidly with time (Figure 27), with concentrations estimated to be in compliance by the year 2032; a 19 year restoration time period (Table 3).

6.4.2 Vinyl Chloride Results (Northerly Plume Capture)

The northerly plume capture simulation for vinyl chloride shows concentrations attenuating relatively rapidly with time (Figure 28), with concentrations estimated to be in compliance by the year 2033; a 20 year restoration time period (Table 3).

6.4.3 Benzene Results (Northerly Plume Capture)

The northerly plume capture simulation for benzene shows concentrations attenuating relatively rapidly with time (Figure 29), with concentrations estimated to be in compliance by the year 2032; a 19 year restoration time period (Table 3).

6.4.4 Methylene Chloride Results (Northerly Plume Capture)

The northerly plume capture simulation for methylene chloride shows concentration attenuating relatively rapidly with time (Figure 30), with concentrations estimated to be in compliance by the year 2023; a 10 year restoration time period (Table 3).

7.0 MODEL SENSITIVITY

The results of the simulations presented above used our best estimates for model input parameters (Table 1). However, given simplifying model assumptions (Section 2) and uncertainty in model parameter values, there is uncertainty in the simulation results and estimated restoration time periods (Table 3).

To address some of the model uncertainty, we conducted a model sensitivity assessment for the 1,2-dichlropropane simulation under NA. For this assessment we tested the sensitivity of the model results to a range of values in four key model input parameters:

1. Contaminant Velocity
2. Initial Source Mass (Mo)
3. Initial Source Concentration (Co)
4. Gamma

For this assessment we varied the value of a single parameter while leaving all other parameter values equal to the best-estimated value (Table 7). The sensitivity assessment for each parameter used a minimum and maximum value within the range of uncertainty we estimated for each parameter. The range of uncertainty in each parameter is discussed below followed by a discussion of the sensitivity assessment results.

7.1 CONTAMINANT VELOCITY RANGE OF UNCERTAINTY

The range of contaminant velocities was estimated using field observations.

The minimum contaminant velocity was based on the minimum velocity required for contaminants to be transported from the P1 source area to the Whitson well within 34 years (the time between initial drum burial and first documentation of contamination at the Whitson well). The Whitson well is located approximately 1400 feet along the plume center line from source area (Figure 1) and the minimum contaminant velocity (vmin)[7] was initially calculated as follows:

Initial vmin = (1400 feet/34 years) = 41.2 ft/yr = 12.5 m/yr

REMChlor input uses a user specified Darcy velocity (q) that is divided by a user specified porosity to derive the groundwater seepage velocity (v). Thus model input for the minimum velocity is:

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[7] vmin and vmax velocity is different from the vMin-normalized and vMax-normalized in Table 7 (see Section 2.1.3 for discussion of vMin-normalized and vMax-normalized).

Initial qmin = vmin*n = 12.5 m/yr*0.2 = 2.5 m/yr

Due to the effects of dispersion, simulated concentrations of 1,2-DCP actually continued to increase after 34 years. Monitoring of the Whitson well since 2009 shows the concentrations of 1,2-DCP to be relatively stable, we therefore increased the minimum velocity until relatively stable concentrations were simulated at this location at this time:

Final qmin = 4 m/yr (Table 7)

Final vmin = Final qmin/n = 4/0.2 = 20 m/yr

The maximum contaminant velocity was based on field data from MW-44b. The concentration of 1,2-DCP in MW-44b has shown a slow increasing trend with some variability since monitoring first began in 2009, suggesting the attenuation effects of drum removal in 2008 have not reached MW-44b as of 2011. MW-44b is located approximately 900 feet along the pathway from the former drums and the maximum contaminant velocity (vmax) was calculated as:

vmax = (900 feet/3 years) = 300 ft/yr = 91 m/yr

qmax = 91 m/yr*0.2 = 18 m/yr (Table 7)

Our best-estimate value of the Darcy velocity (q) calculated from aquifer parameters (5.1 m/yr), as described in Section 4.2.1 above, falls within this range of values calculated from observed contamination (4 m/yr to 18 m/yr).

Use of historic data to infer current contaminant velocity assumes that historic conditions are similar to current conditions. Historic pumping of groundwater north of the landfill could cause this assumption to be invalid.

7.2 INITIAL SOURCE MASS RANGE OF UNCERTAINTY

To assess the sensitivity of the model to the initial source mass (Mo), we ran the model using the maximum (3.5 kg) and minimum (0.5 kg) Mo values estimated for 1,2-DCP (Table 7). The best-estimated value for Mo is 0.96 kg. The range in Mo values was based on estimated ranges of residual source mass in LNAPL and soil by the former drums (PGG, 2012a).

7.3 INITIAL SOURCE CONCENTRATION RANGE OF UNCERTAINTY

As explained in Section 4.1.2 above, the initial source concentration (Co) is based on a calculation of Roza plume mass flux and the assumption that the Roza plume mass flux is the same as the mass flux (Q*Co) through the source area (PGG, 2012a)[8]. REMChlor uses the Darcy velocity (q) to calculate the groundwater flux through the source area (Q), where Q = q*A with A being the cross-sectional dimension of the source area. The best-

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[8] The mass flux approach results in an overestimated value for vinyl chloride; therefore, the observed concentration in the P1 source area was used for vinyl chloride. All other simulated VOCs used the mass flux approach (see PGG, 2012a for discussion on the development of the initial source concentration).

estimate value of Co (597 ug/L) was therefore based on calculations of plume mass flux and a best estimate of the dimension of the source area (A).

Given the uncertainty in the dimension of the source area, we estimated a maximum (869 ug/L) and minimum (516 ug/L) value for Co (Table 7) based on estimated maximum and minimum dimension of the source area (PGG, 2012a). Note that with our approach for simulating the current and future plume independently (Section 2.0), the value of the initial source mass (Mo) in the first model had to be adjusted so that it was fully depleted by 2008 given the value of Co (Table 7).

7.4 GAMMA RANGE OF UNCERTAINTY

To assess the sensitivity of the model to gamma, we ran the model using the minimum and maximum range of gamma values expected for the Ephrata site (gamma = 1 and gamma = 2). As discussed in Section 2.1.1, the relationship between source mass and source concentration is defined in REMChlor using a power function and gamma is the exponent which determines the relationship. Gamma values for most sites are thought to range from 0.5 to 2.0 and values greater than 1 are generally assigned to sites with high heterogeneity and where matrix diffusion from low permeability zones are expected to result in long-term “tailing” of contaminant concentrations. We therefore expect a representative range of gamma value between 1 and 2 for the Ephrata site, with the best-estimated value being 1.5 (Table 7).

7.5 MODEL SENSITIVITY RESULTS

The sensitivity assessment for the range of uncertainty in the above model parameters was performed on the model simulation of 1,2-DCP for NA. The results of the sensitivity assessment were evaluated by comparing the simulated concentration at the landfill property boundary in the year 2038; 30 years after the start of NA (Figure 31). The range of simulated concentrations for each model parameter (vertical line in Figure 31) shows the sensitivity of the model to that parameter uncertainty. The larger the range, the more sensitive the model was to the parameter uncertainty. These results show that the most sensitive model parameter was the source mass. The uncertainty in source mass (Table 7) resulted in simulated concentration of 1,2-DCP ranging from 23.7 ug/L to 1.2 ug/L at the landfill property boundary 30 years after the start of NA(Figure 31).

The range of simulated concentrations was also relatively large for the uncertainty in groundwater velocity, with concentrations ranging from 1.1 to 5.9 ug/L; while the sensitivity to source concentration and gamma was noticeably lower (Figure 31).

Collectively, the results of the sensitivity assessment show that the uncertainty in a single model input parameter can lead to an approximate ten-fold range in the predicted concentrations (1.2 to 23.7 ug/L). From our experience, a ten-fold range due to uncertainty is not uncommon for groundwater models.

There was also at least a 44 year uncertainty in the simulated restoration time period for 1,2-DCP under NA given the range in source mass. Given the uncertainty in source mass, the minimum simulated restoration time period for 1,2-DCP un-der NA was 32 years and the maximum simulated restoration time period was greater than 76 years – end of model simulation.

This sensitivity assessment did not combine the uncertainty in key model parameters; rather each parameter was analyzed independently. Combining the uncertainty in key parameters would result in a larger range of simulated plume concentrations and restoration time periods.

Figure 31 also plots the best estimate simulated concentration (4.4 ug/L) at the landfill property boundary after 30 years and the CUL for 1,2-DCP (1 ug/L). This shows that even within the range of single-value uncertainties, all NA simulations for 1,2-DCP result in concentrations being above the CUL at the landfill property boundary 30 years after the start of NA(Figure 31).

7.5.1 Discussion of Model Sensitivity

Although we did not conduct an uncertainty analysis of 1,2-DCP for the active measure scenarios, a 10-fold range in simulated plume concentrations at the landfill property boundary would also be expected for the P1 Groundwater Pumping and SVE scenario (based on uncertainty in the source mass term). However, both of these active measures would result in lower plume concentrations over time compared to the NA scenario.

The model simulation for northerly plume capture is not expected to be sensitive to the source mass parameter since this simulation assumed the plume was cut off from the source at the landfill property boundary. The model uncertainty for this scenario is mainly associated with the seepage velocity (v) parameter and related effects on plume geometry and attenuation downgradient of the landfill property boundary. The range in estimated seepage velocities was used to estimate a range of uncertainty in simulated restoration time periods (although differences in plume geometry and dispersion would also contribute to differences in restoration time periods). The average seepage velocity was estimated to range between 20 m/yr and 91 m/yr with the best estimate being 25.5 m/yr. The range in restoration time period was thus estimated as:

v/vmin = 25.5/20 = 1.3 times longer than the best estimated restoration time.

v/vmax = 25.5/91 = 0.3 times longer (ie: shorter) than the best estimated restoration time.

The simulated restoration time period for northerlry plume capture using the best-estimated value of seepage velocity was about 20 years for all IHS except Methylene Chloride which was 10 years (Table 3). Thus, even using the minimum seepage velocity, the simulated restoration time period (1.3 times longer) would likely still be less than 30 years.

The uncertainty in simulated plume concentrations and restoration time periods for other IHS under NA, P1 pumping, and SVE would be somewhat different than 1,2-DCP given the differences in source mass depletion rates for each IHS.

The source mass depletion rate in REMchlor is defined as:

Drate = Q*Co/Mo [dy-1]

Where Q = groundwater flux (constant)

Co = source concentration

Mo = source mass

Source mass depletion rates based on best estimate values for the above parameters are presented in Table 8.

Vinyl chloride has been identified as the most challenging IHS to achieve compliance (i.e. simulated longest restoration time period under all scenarios). Despite having the highest source mass depletion rate (Table 8), vinyl chloride continued to persist in groundwater due to the creation of new vinyl chloride during the breakdown of PCE, TCE, and cis-1,2-DCE (all of which have relatively lower depletion rates). In particular, cis-1,2-DCE, with the highest values of Co and Mo, was the largest contributor to the simulated persistence of vinyl chloride. Furthermore, vinyl chloride has a very low CUL (0.2 ug/L).

The uncertainty in the predicted vinyl chloride concentrations and associated restoration time periods under NA, P1 Pumping and SVE is likely at least as great as that estimated for 1,2-DCP because new vinyl chloride is simulated as being created from the breakdown of other chlorinated ethenes. The simulated restoration time period for vinyl chloride under the four simulated scenarios (using our best-estimates of model input parameters) was (Table 3):

1. NA > 76 years
2. P1 Pumping = 39 years
3. SVE = 70 years
4. Roza Capture = 20 years

Given the uncertainty in model parameters discussed above, NA, P1 pumping and SVE may not achieve compliance for vinyl chloride within 30 years. However, northerly plume capture is estimated to achieve vinyl chloride compliance in a 30-year timeframe within the range of assessed model uncertainty..

8.0 REFERENCES

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Table 1. REMChlor Model Calibration Parameter Values

		REMChlor MODELS														
MODEL INPUT PARAMETERS	Calibration Parameter	Chloride	1,2-Dichloropropane		Tetrachloroethene (PCE)		Trichloroethene (TCE)		cis-1,2-Dichloroethene		Vinyl Chloride		Benzene		Methylene Chloride	
			1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model
Source Parameters[1]																
Source Width (ft)	No	1000	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Source Depth (ft)	No	10	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Initial Source Mass; Mo (kg)	No	1.E+09	4.33	0.96	0.17	0.66	0.47	0.31	10.22	3.50	5.44	0.30	0.82	0.30	1.12	1.51
Initial Source Concentration; Co (g/L)	No	1	0.000597	0.000597	0.0000240	0.0000240	0.000065	0.000065	0.001409	0.001409	0.00075	0.00075	0.000113	0.000113	0.000154	0.000154
Gamma	No	0	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5
Source Remediation Parameters																
Source Fraction Removed	No	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remediation Start Year	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Remediation End Year	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Souce Decay (1/yr)	No	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Transport Parameters																
Darcy Velocity; q (m/yr)	No	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Porosity	No	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Retardation Factor	No	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sigmav	Yes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
vMin (Normalized)	Yes	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
vMax (Normalized)	Yes	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
alpha-y (m)[2]	Yes	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
alpha-z (m)[2]	Yes	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Plume Decay (Component 1)[3]																
Time Period 1 (year)[4]	No	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time Period 2 (year)	No	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
X1 (meters)[5]	Yes	178	178	178	100	100	100	100	100	100	100	100	100	100	100	100
X2 (meters)	Yes	304	304	304	178	178	178	178	178	178	178	178	178	178	178	178
Zone 1/Period 1 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0.2	0.2	0.7	0.7	0.7	0.7	0.5	0.5	0	0	0.01	0.01
Zone 2/Period 1 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0.1	0.1	0.2	0.2	0.5	0.5	0	0	0.01	0.01
Zone 3/Period 1 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Zone 1/Period 2 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0.2	0.2	0.7	0.7	0.7	0.7	0.5	0.5	0	0	0.01	0.01
Zone 2/Period 2 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0.1	0.1	0.2	0.2	0.5	0.5	0	0	0.01	0.01
Zone 3/Period 2 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Zone 1/Period 3 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0.2	0.2	0.7	0.7	0.7	0.7	0.5	0.5	0	0	0.01	0.01
Zone 2/Period 3 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0.1	0.1	0.2	0.2	0.5	0.5	0	0	0.01	0.01
Zone 3/Period 3 Decay Rate (1/yr)	Yes	0.0	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Simulation Time[6]																
Start Year	No	1955	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008
End Year	No	2008	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084

Notes

[1] See Appendix B in Feasibility Study for development of source mass and source concentration values

[2] Negative values for alpha-y and alpha-z are used as a flag in REMChlor to indicate the values are scale dependent.
Values are actually calculated as absolute in the simualtion.

[3] REMChlor can simulate up to four components in a 1st order chemical decay reaction. One parent product (component 1) and up to three daughter products (components 2, 3 and 4) can be simulated through the use of plume decay rates and yield coefficients.
Only the pararent component was simulated for 1,2-DCP, Benzene and Methylene Chloride. Daughter product components for chlorinated ethenes (PCE, TCE, cis-1-2-DCE, VC) were simulated to estimate contribution to VC from reductive dechlorination.
Note that the same decay rates used to simulate a particular chlorinated ethene as a parent product were used to simulate it as a daugher product.
For example the decay rates assigned to vinyl chloride as a parent product were the same decay rates assigned to vinyl chloride as a breakdown component for PCE, TCE, and cis-1,2-DCE.

[4] Different plume decay rates can be assigned at various times during the simulaiton. Up to three time periods with different decay rates in each zone (see note 5 below) can be simulated.
The three time periods are specified by parameter Time Period 1 and Time Period 2 which breaks the time period into 0 to Time Period 1 (1st time period); Time Period 1 to Time Period 2 (2nd time period); and Time Period 2 to end of simulaiton (3rd time period).
For model calibration the plume decay rates for a given location (zone) were assumed constant over time.

[5] Different plume decay rates can be assinged at various distance from the source. Up to three locations (zones) with different decay rates can be defined downgradient of the source.
The three zones are specified by parameter X1 and X2 which breaks the plume length into 0 to X1 meters (zone 1); X1 to X2 meters (zone 2); and X2 to end of plume (zone 3)
For model calibration the plume decary rates were either the same in all three zones, or higher decay rates were used closer to source area. All decay rates are within values reported in the literature.

[6] The simulation time is model specific (see text for details)

Table 2. Concentration Targets for Current Condition Simulation

Chloride		PCE		TCE		cis-1,2-DCE		Vinyl Chloride		Methylene Chloride		1,2-DCP		Benzene	
Plume Distance (ft)	Concentration (mg/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)	Plume Distance (ft)	Concentration (ug/L)
1	1000	1	24	1	65	1	1409	1	750	1	154	1	597	1	113
960	400	400	3	520	1	320	30	280	10	960	12	1000	25	960	30
1400	>90	1400	>0.5	1400	>0.3	800	7	1400	>5	1400	>0.7	1400	>5	1400	>1
						1400	>3.0								

Note:

Chloride concentrations at 1-ft are based on average concentrations in the P2 source area zone and Roza aquifer by the original shop area.

VOC concentrations at 1-ft are based on values for the source concentration (Co) in Model.

Concentrations at 1400-ft are based on data from the Whitson domestic well which until recently (July 2012) was completed through multiple aquifers (most likely including the Roza).

Due to completion of Whitson well, concentrations in the Roza aquifer at the Whitson location are likely higher that data collected from the Whitson well. Targets therefore qualified as "greater than".

All other target concentrations are based on observed and contoured data from Roza aquifer wells.

Table 3. Simulated IHS Restoration Times and Plume Concentrations at the Northern Landfill Property Boundary

SIMULATED RESTORATION YEAR

IHS	CUL (ug/L)	Simulated Scenario			
		NA 2008 Start Year	P1 Pump 2008 Start Year	SVE 50% 2013 Start Year	Roza Capture 2013 Start Year
1,2-Dichloropropane	1	2063	2039	2058	2032
Vinyl Chloride	0.2	>2084	2047	2083	2033
Benzene	1	2058	2040	2049	2032
Methlyene Chloride	5	2079	2046	2043	2023

SIMULATED YEARS UNTIL RESTORATION

IHS	CUL (ug/L)	Simulated Scenario			
		NA 2008 Start Year	P1 Pump 2008 Start Year	SVE 50% 2013 Start Year	Roza Capture 2013 Start Year
1,2-Dichloropropane	1	55	31	45	19
Vinyl Chloride	0.2	>76	39	70	20
Benzene	1	50	32	36	19
Methlyene Chloride	5	71	38	30	10

SIMULATED PLUME AREA WITH LONGEST RESTORATION TIME

IHS	CUL (ug/L)	Simulated Scenario			
		NA 2008 Start Year	P1 Pump 2008 Start Year	SVE 50% 2013 Start Year	Roza Capture 2013 Start Year
1,2-Dichloropropane	1	POC	EOP	POC	EOP
Vinyl Chloride	0.2	POC	POC	POC	EOP
Benzene	1	POC	EOP	POC	EOP
Methlyene Chloride	5	POC	POC	POC	b/t POC and EOP

SIMULATED CONCENTRATION AT NORTH PROPERTY BOUNDARY AFTER 30 YEARS COMPARED TO CURRENT CONCENTRATION

IHS	CUL (ug/L)	Simulated Scenario				CURRENT CONCENTRATION (2008)
		NA 2008 Start Year	P1 Pump 2008 Start Year	SVE 50% 2013 Start Year	Roza Capture 2013 Start Year	
1,2-Dichloropropane	1	4.4	0.8	2.3	0.0	67
Vinyl Chloride	0.2	1.6	0.4	0.8	0.0	16
Benzene	1	2.8	0.7	1.3	0.0	19
Methlyene Chloride	5	12.4	7.2	5.5	0.0	24

Restoration time frames based on model simulations of plume attenuation to below the CUL at and/or downgradient of the POC.

Simulation of vinyl chloride requires simluation of other VOCs in chlorinated ethene degradation pathway (PCE-TCE-DCE-VC)

Note that relatively high concentration and mass of cis-1,2-dichloroethene (DCE) in the source area contributes to persistence of vinyl chloride

All simulated scenarios include the effects of NA

CUL = cleanup level derived in Feasibility Study

POC = Point of Compliance developed in the Feasibility Study. The northern POC is the landfill property boundary.

NA = Natural Attenuation

SVE = Soil Vapor Extraction

EOP = End of Plume

IHS = Indicator Hazardous Substance

Table 4 Model Parameter Values for Predictive Simulation - P1 Source Area Long Term Groundwater Extraction

(Simulated Start Year of P1 Extraction FS Component = 2008)

Model Paremeters Changed to Simulate this FS Component are Shaded Below	1,2-Dichloropropane		Tetrachloroethene (PCE)		Trichloroethene (TCE)		cis-1,2-Dichloroethene		Vinyl Chloride		Benzene		Methylene Chloride	
	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model
Source Remediation Parameters[1]														
Source Fraction Removed	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Remediation Start Year	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Remediation End Year	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Souce Decay (1/yr)	0	0.07	0	0.007	0	0.03	0	0.055	0	0.19	0	0.05	0	0.018
Simulation Time	NA	NA												
Start Year	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008
End Year	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084

Notes

[1] A first order source decay rate was used to simulate source mass removal with long term groundwater extraction.

Because the source decay must begin at the start of the simulation (i.e. it can be time varying) this FS component starts in 2008.

Since the first model simulates the source mass going to zero by 2008 , it is only necessary to assign the source decay to the second model.

See text for details on this approach.

Table 5 Model Parameter Values for Predictive Simulation - Soil Vapor Extraction (SVE)

(Simulated Start Year of SVE FS Component = 2013)

Model Paremeters Changed to Simulate this FS Component are Shaded Below	1,2-Dichloropropane		Tetrachloroethene (PCE)		Trichloroethene (TCE)		cis-1,2-Dichloroethene		Vinyl Chloride		Benzene		Methylene Chloride	
	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model
Source Remediation Parameters[1]														
Source Fraction Removed	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5	0	0.5
Remediation Start Year	NA	5	NA	5	NA	5	NA	5	NA	5	NA	5	NA	5
Remediation End Year	NA	9	NA	9	NA	9	NA	9	NA	9	NA	9	NA	9
Souce Decay (1/yr)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Simulation Time														
Start Year	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008
End Year	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084

Notes

1 The source fraction removed parameter was used to simulate SVE

SVE is estimated to remove 50% of the source mass within the first few years of operation

For the predictive simulation the source mass removal was assumed to occur over a four year period (2013 to 2017)

Table 6 Model Parameter Values for Predictive Simulation - Roza Plume Capture

(Start Year of Roza Capture FS Component = 2013)

	1,2-Dichloropropane		Tetrachloroethene (PCE)		Trichloroethene (TCE)		cis-1,2-Dichloroethene		Vinyl Chloride		Benzene		Methylene Chloride	
Model Paremeters Changed to Simulate this FS Component are Shaded Below	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model
Plume Decay (Component 1)														
Time Period 1 (year)[1]	40	5	40	5	40	5	40	5	40	5	40	5	40	5
Time Period 2 (year)	76	76	76	76	76	76	76	76	76	76	76	76	76	76
X1 (meters)[2]	178	178	100	100	100	100	100	100	100	100	100	100	100	100
X2 (meters)	304	304	178	178	178	178	178	178	178	178	178	178	178	178
Zone 1/Period 1 Decay Rate (1/yr)	0.055	0.055	0.2	0.2	0.7	0.7	0.7	0.7	0.5	0.5	0	0	0.01	0.01
Zone 2/Period 1 Decay Rate (1/yr)	0.055	0.055	0	0	0.1	0.1	0.2	0.2	0.5	0.5	0	0	0.01	0.01
Zone 3/Period 1 Decay Rate (1/yr)	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Zone 1/Period 2 Decay Rate (1/yr)	20.2	20.2	17	17	18	18	22	22	21	21	18.55	18.55	18.86	18.86
Zone 2/Period 2 Decay Rate (1/yr)	0.055	0.055	17	17	18	18	22	22	21	21	18.55	18.55	18.86	18.86
Zone 3/Period 2 Decay Rate (1/yr)	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Zone 1/Period 3 Decay Rate (1/yr)	20.2	20.2	17	17	18	18	22	22	21	21	18.55	18.55	18.86	18.86
Zone 2/Period 3 Decay Rate (1/yr)	0.055	0.055	17	17	18	18	22	22	21	21	18.55	18.55	18.86	18.86
Zone 3/Period 3 Decay Rate (1/yr)	0.055	0.055	0	0	0	0	0	0	0	0	0	0	0.01	0.01
Simulation Time	NA	NA												
Start Year	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008
End Year	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084

Notes

[1] To simulate Roza Plume Capture at the landfill property boundary a large plume decay rate was assigned to Zones 1 and/or 2 for Period 2 and 3.
This results in plume concentrations going to zero at the landfill property boundary within 1 to 2 years of the start of this FS component (starting in 2013 and continuing to end of simulation).

[2] To simulate Roza Plume Capture at the landfill property boundary an artificially large plume decay rate was assigned from 0 to 178 meters (zone 1 for 1,2-DCP and zone 1 and zone 2 for the other chemicals)
This results in all plume concentrations from near the source to 178 meters going to zero (area upgradient of landfill property boundary).
With this approach, results are only used to assess plume attenuation downgradient of the landfill property boundary (locations greater than 178 meters).

Table 7. Model Parameter Values Tested in Model Sensitivity Assessment

(Sensitivity Assessment Performed on Simulation of 1,2-dichloropropane under MNA)

Model Paremeters Changed to Simulate this FS Component are Shaded Below	Best Estimate Values		Gamma = 1		Gamma = 2		Max Source Mass		Min Source Mass		Max Source Concentration[1]		Min Source Concentration[1]		Max Velocity (qmax)[2]		Min Velocity (qmin)[2]	
	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model	1st Model	2nd Model
Source Parameters																		
Source Width (ft)	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Source Depth (ft)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Initial Source Mass; Mo (kg)	4.33	0.96	4.33	0.96	4.33	0.96	4.33	3.50	4.33	0.50	6.30	0.96	3.74	0.96	4.33	0.96	4.33	0.96
Initial Source Concentration; Co (g/L)	0.000597	0.000597	0.000597	0.000597	0.000597	0.000597	0.000597	0.000597	0.000597	0.000597	0.000869	0.000869	0.000516	0.000516	0.000169	0.000169	0.000761	0.000761
Gamma	0	1.5	0	1	0	2	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5
Transport Parameters																		
Darcy Velocity; q (m/yr)	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	18	18	4	4
Porosity	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Retardation Factor	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sigmav	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
vMin (Normalized)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
vMax (Normalized)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
alpha-y (m)	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
alpha-z (m)	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002	-0.0002
Simulation Time	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Start Year	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008	1975	2008
End Year	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084	2051	2084

Notes

[1] Sensitivity runs involving changes in source concentration include changing the source mass in the first model in order to achieve a source mass that depletes to zero by 2008

[2] Sensitivity runs involving changes in groundwater velocity include changing the source concentration to values that maintain the same mass flux (Q*Co) through the source area as the calibrated model

Table 8. Source Mass Depletion Rates for Simulated VOCs

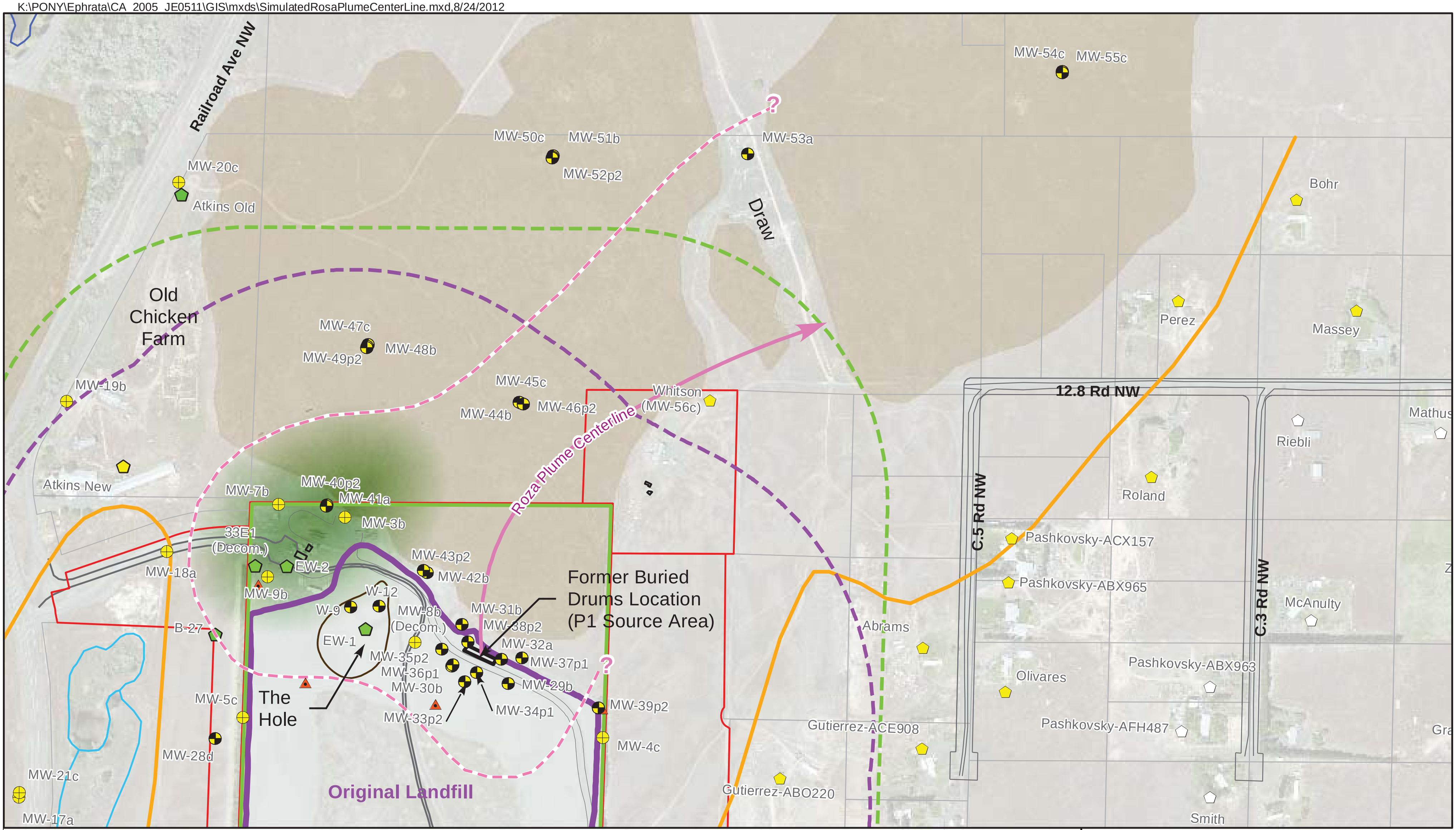
Simulated VOC	D_{rate}[1]	Co (ug/L)	Mo (kg)	Q (ft^3/dy)
Tetrachloroethene (PCE)	0.008	24	0.66	20
Methylene chloride	0.021	154	1.51	20
Trichloroethene (TCE)	0.043	65	0.31	20
cis-1,2-Dichloroethene	0.083	1409	3.50	20
Benzene	0.077	113	0.30	20
1,2-Dichloropropane	0.128	597	0.96	20
Vinyl chloride[2]	0.515	750	0.30	20

Notes

1 D_{rate} = Source mass depletion rate in REMCHlor = Q*Co/Mo [yr^{-1}]
Where Q is the simulated groundwater flux through the source area (constant)
Co is the initial source concentration
Mo is the initial source mass

2 Despite having the highest source mass depletion rate, vinyl chloride continues to persist in groundwater due to the creation of new vinyl chloride during breakdown of PCE, TCE, and cis-1,2-DCE.

K:\PONY\Ephrata\CA_2005_JE0511\GIS\mxds\SimulatedRosaPlumeCenterLine.mxd,8/24/2012



⊕ Quarterly Monitoring Well (MW)

● Remedial Investigation Monitoring Well (MW)
Locations A-G (Phase 2 RI Wells)

▲ Gas Probe (GP)

⬟ Other Wells

⬟ Sampled Off-site Wells

⬠ Other Off-site Wells

— Outwash Water Table / Top of Basalt Contact

▨ Basalt Outcrops

☐ County Owned Parcels

Approximate Extent of Groundwter Contamination (VOCs' Above RI Screening Levels)

- - - Roza Plume

☐ Extent of Refuse

☐ Permitted Landfill Property Boundary

1000-ft Buffers

☐ from Refuse

☐ from Permitted Landfill Property Boundary

→ Simulated Roza Northerly Plume Center Line

🟩 Approximate Area of High-Transmissivity in Roza

N

0 Feet 500

2011 Bing Aerial Photo

Figure 1

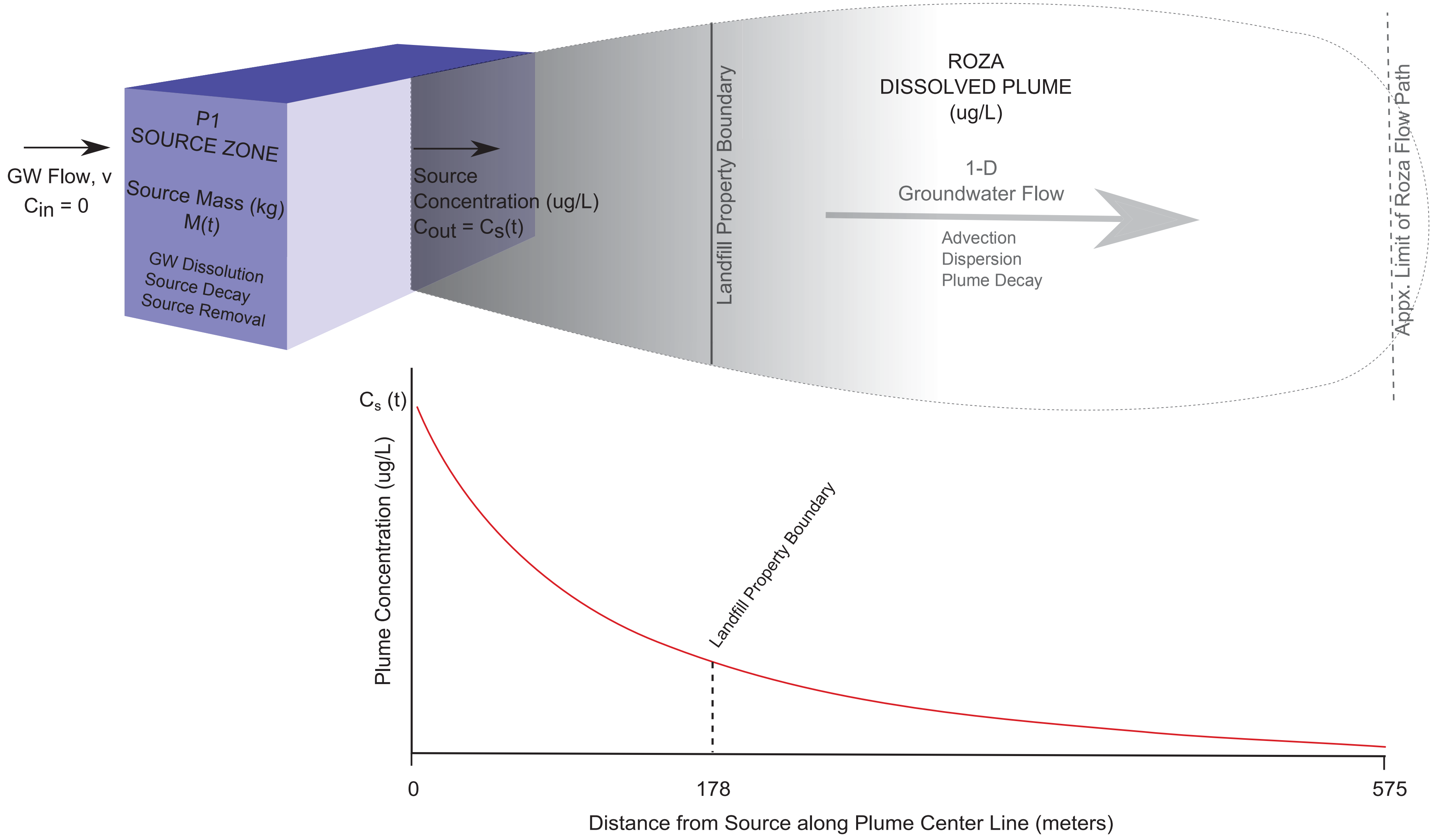
Simulated Roza Aquifer Northerly Plume Center Line

Ephrata Landfill
RI/FS

PgG

Source Mass/Source Concentration Relationship:

$$C_S(t)/C_o = [M(t)/M_o]^{Gamma}$$



v = groundwater velocity (m/yr)
C = Concentration (ug/L)
M = Mass (kg)
t = time (years)
GW = groundwater

Figure 2 Conceptual REMChlor Model

Ephrata Landfill RI/FS

Figure 3
Simulated Current Chloride Concentrations - Roza Northerly Plume

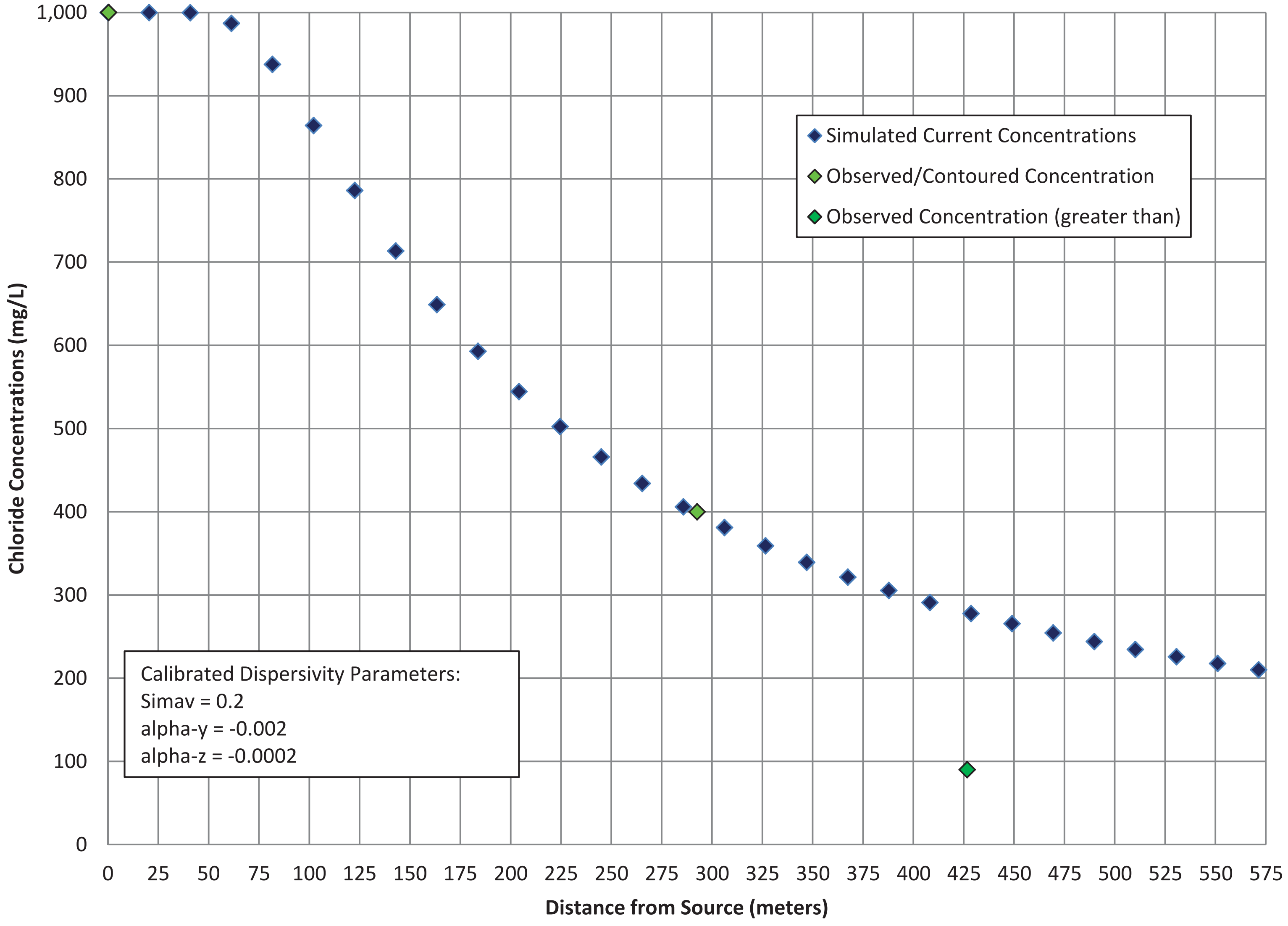


Figure 4

Simulated Currrent 1,2-DCP Concentration Profile - Roza Northerly Plume

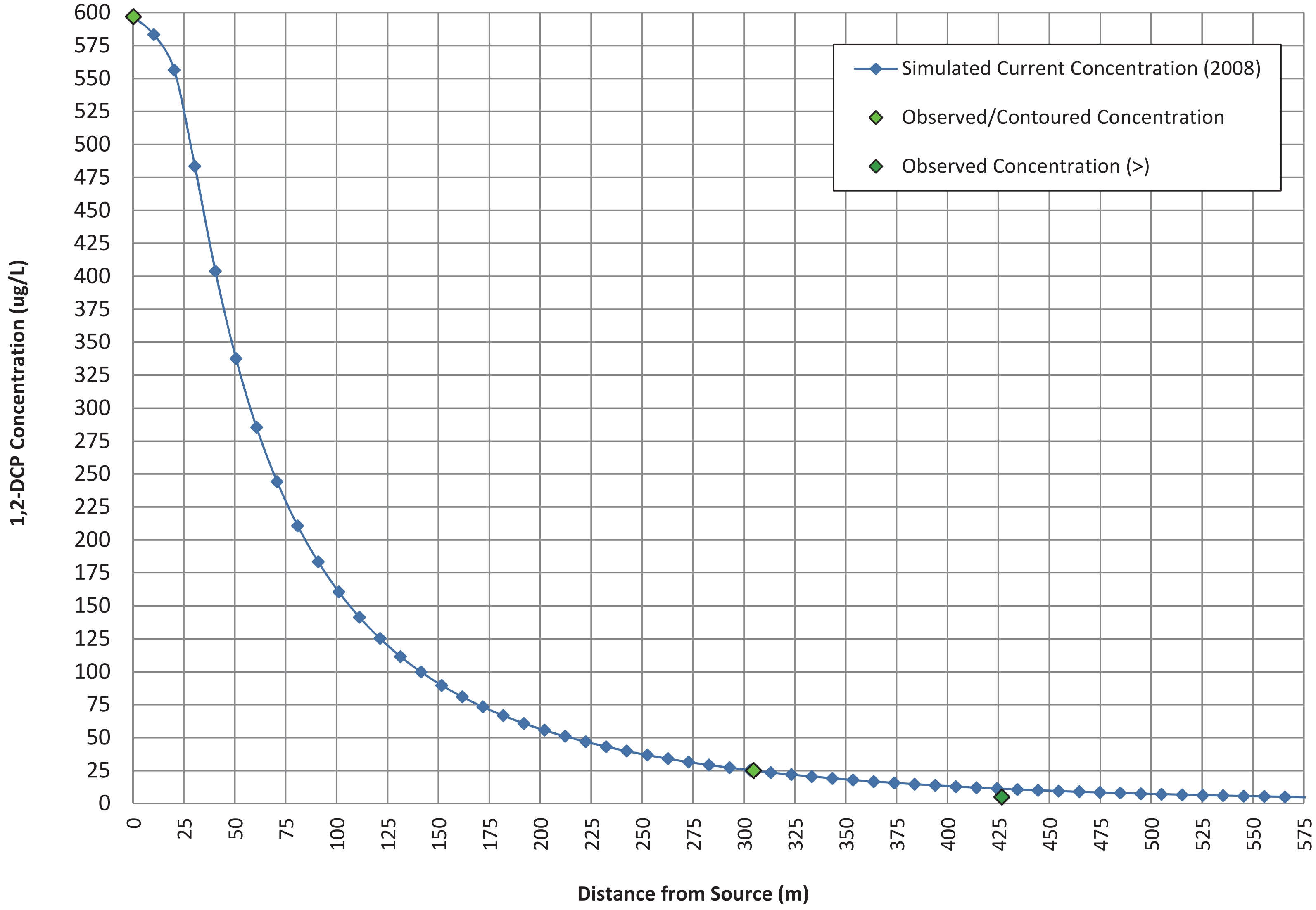


Figure 5

Simulated Currrent PCE Concentration Profile - Roza Northerly Plume

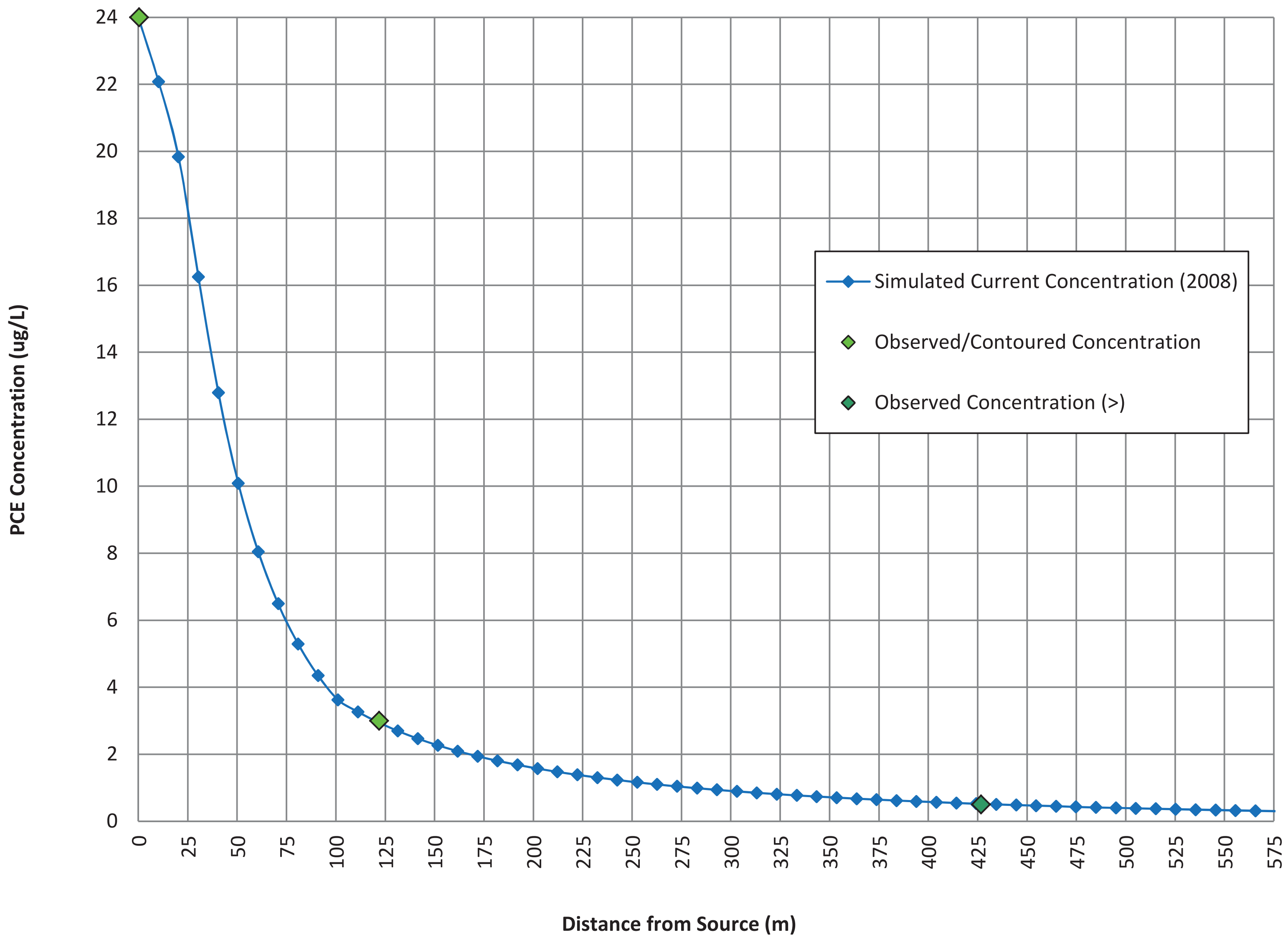


Figure 6

Simulated Currrent TCE Concentration Profile - Roza Northerly Plume

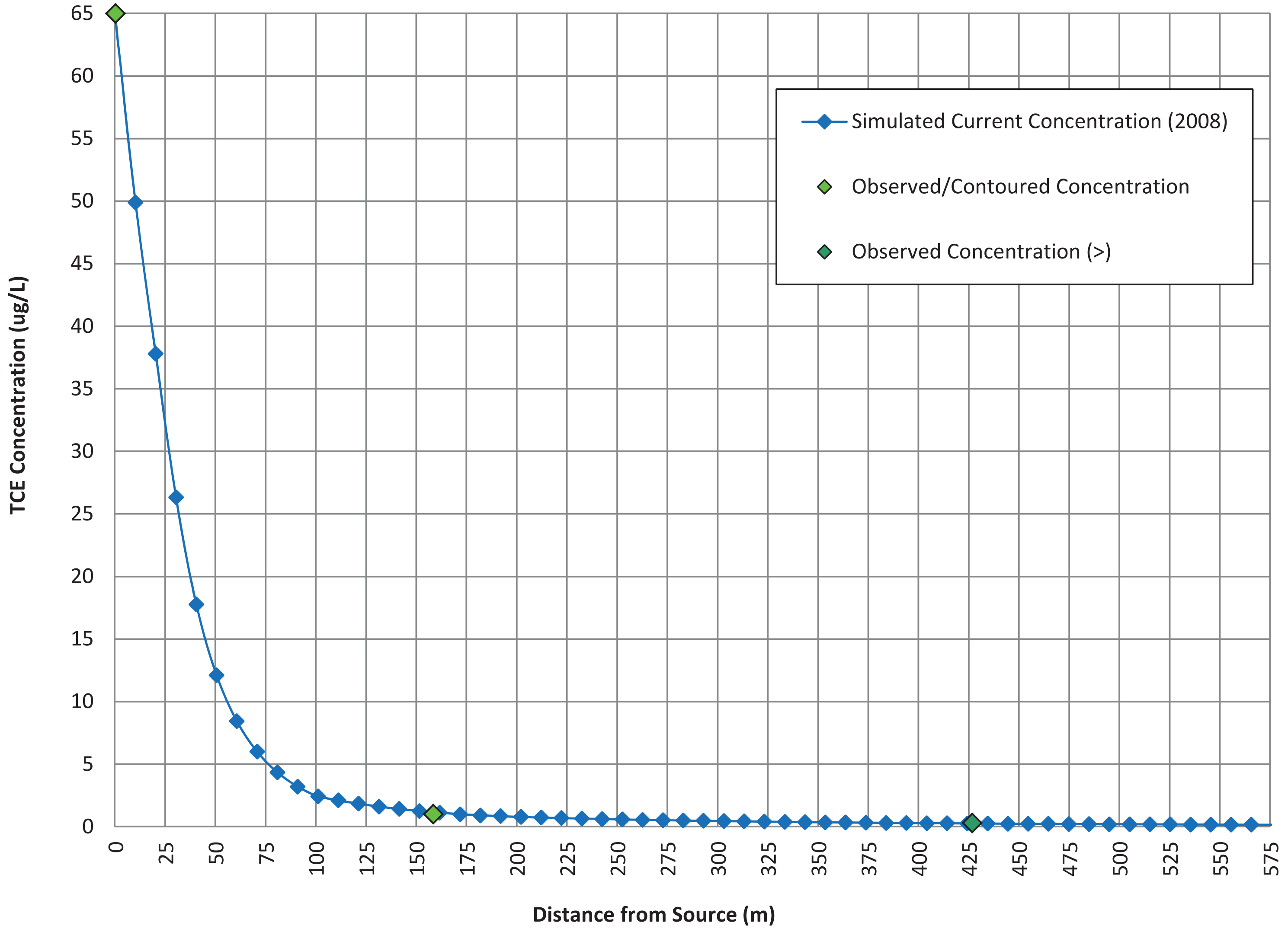


Figure 7

Simulated Currrent cis-1,2-DCE Concentration Profile - Roza Northerly Plume

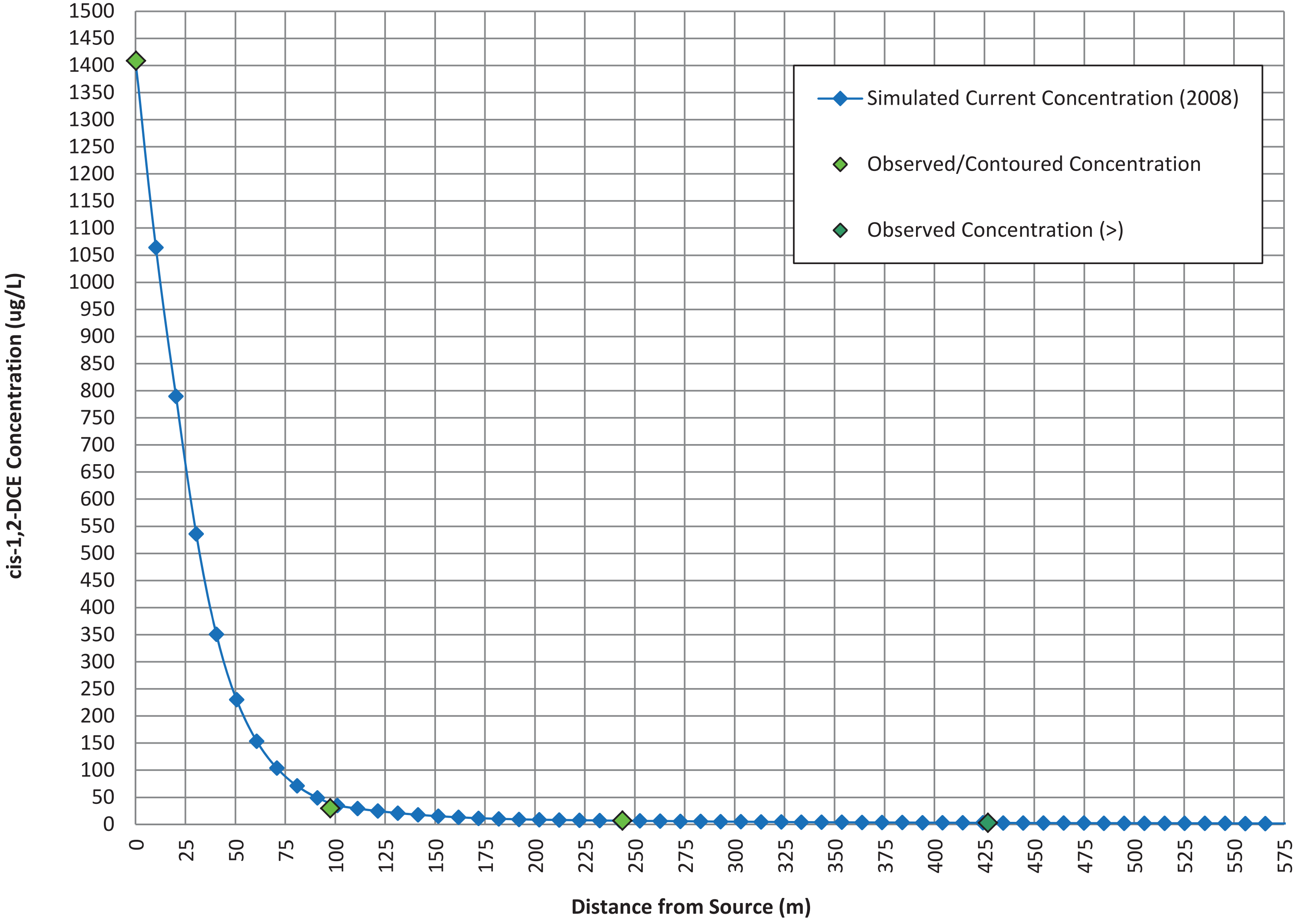


Figure 8
Simulated Currrent Vinyl Chloride Concentration Profile - Roza Northerly Plume

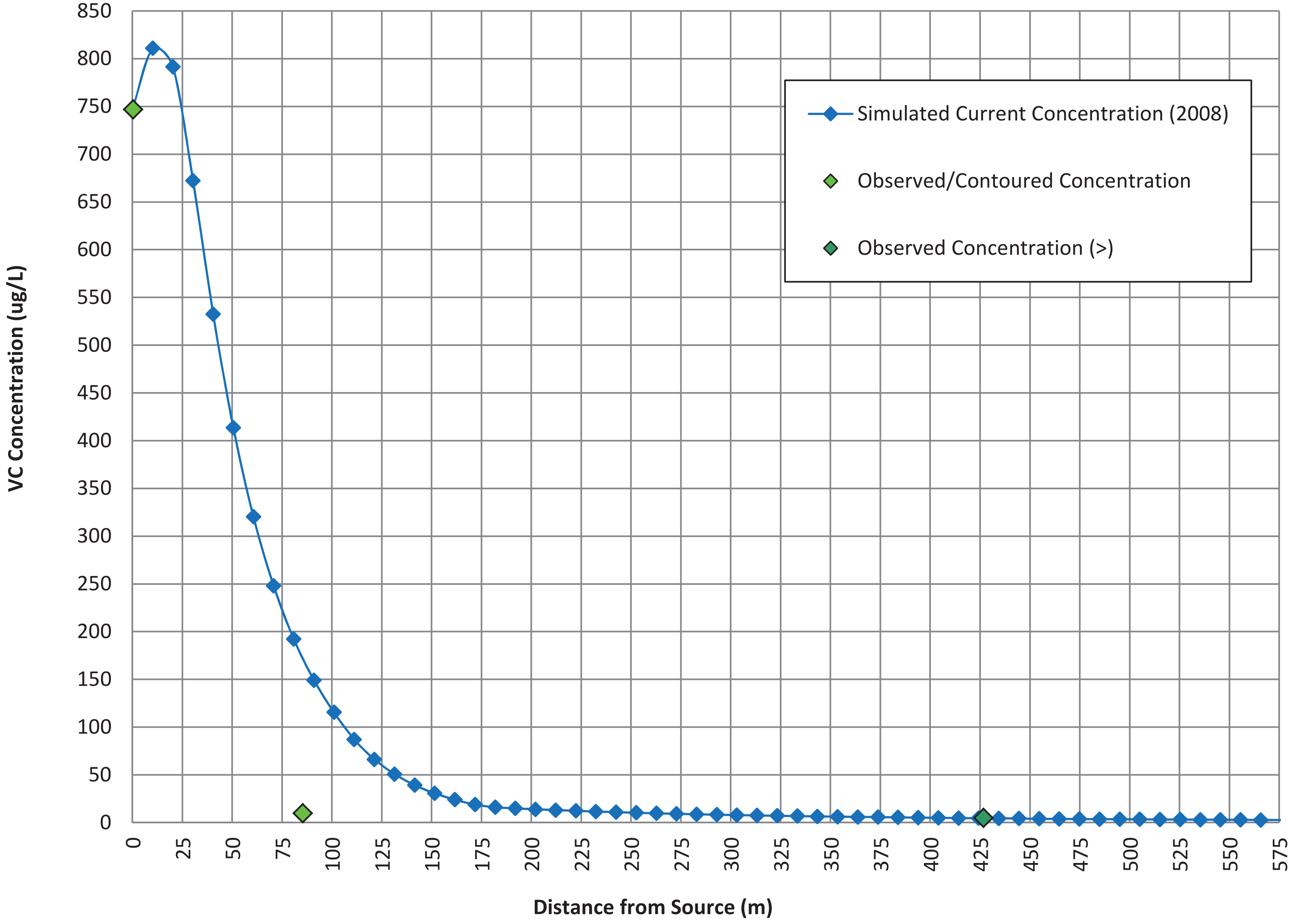


Figure 9

Simulated Currrent Benzene Concentration Profile - Roza Northerly Plume

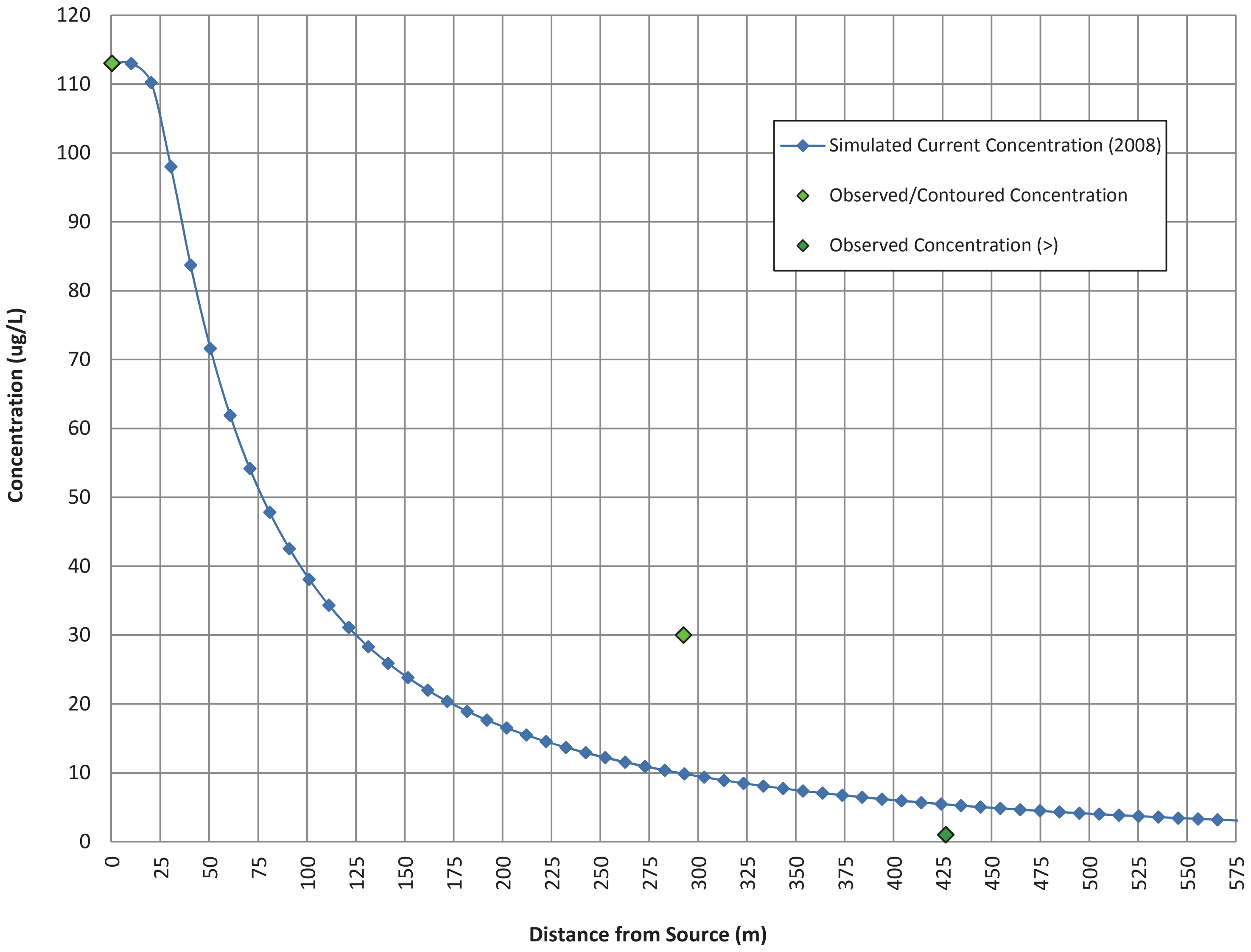
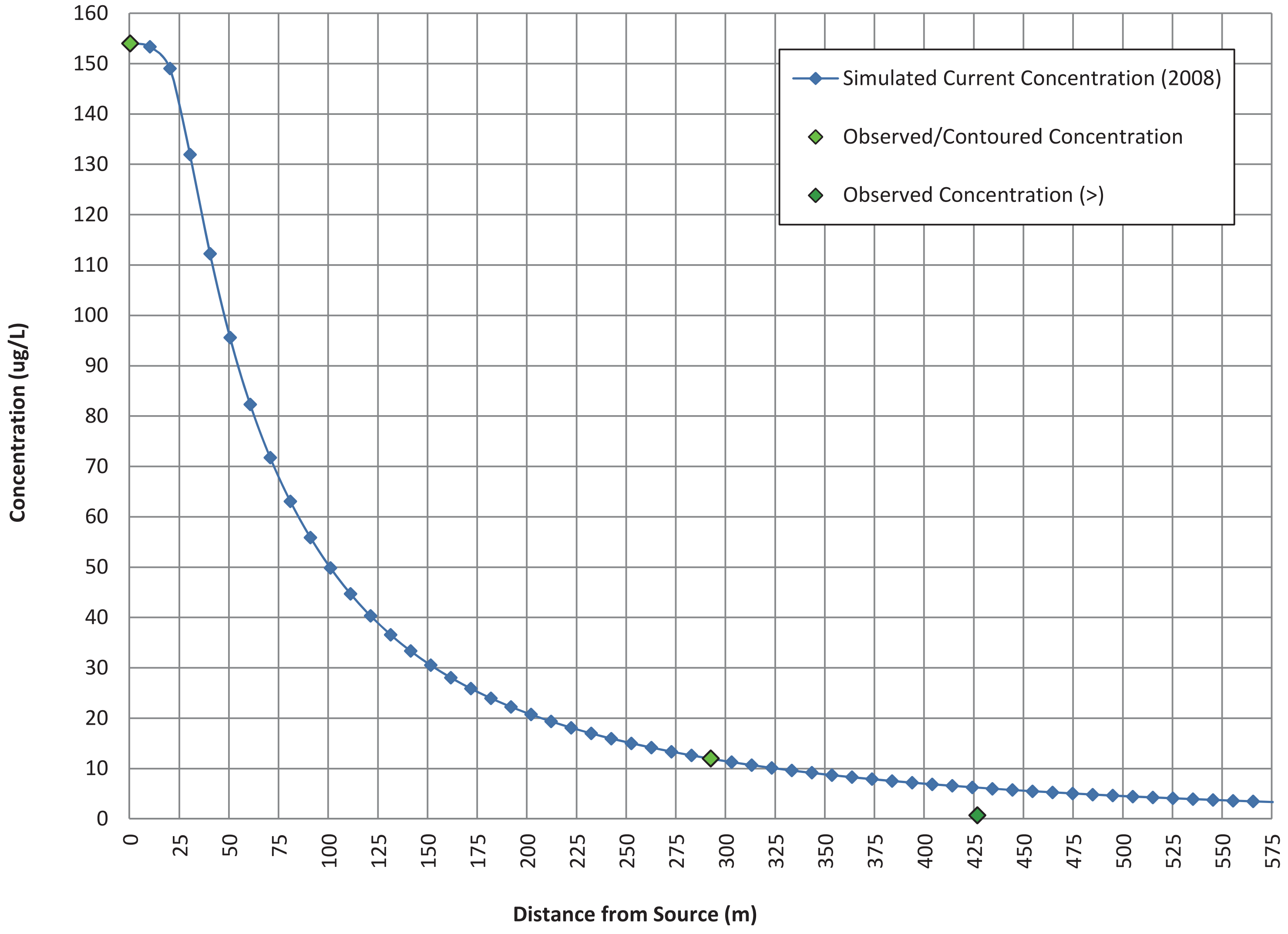


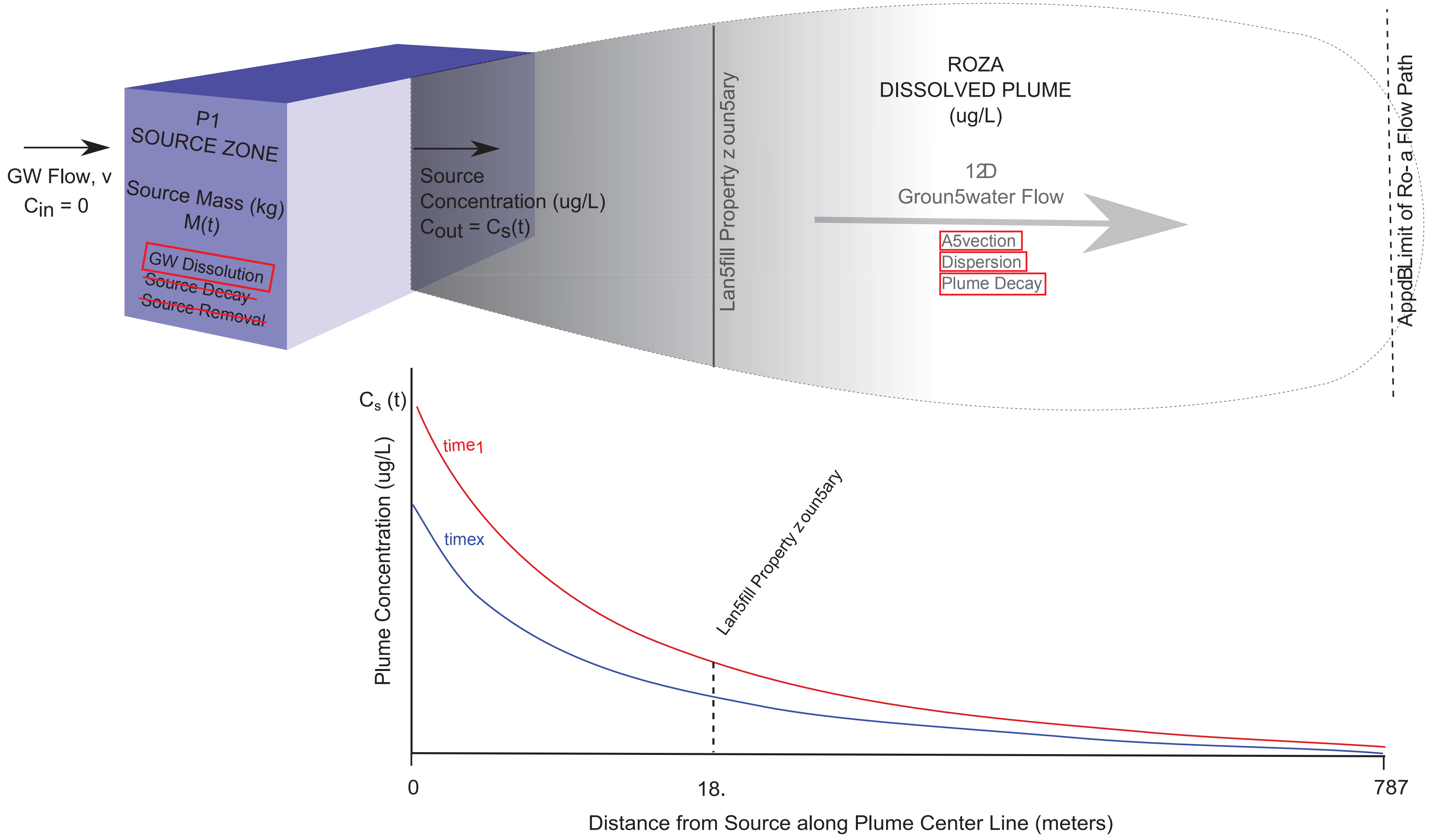
Figure 10

Simulated Currrent Methylene Chloride Concentration Profile - Roza Northerly Plume



Source Mass/Source Concentration Relationship:

$$C_S(t)/C_o = [M(t)/M_o]^{Gamma}$$



Source an5 Plume processes use5 to simulate this component are highlighte5 in re5B
Processes not simulate5 are crosse5 out in re5B

Figure 11 Conceptual REMChlor Mo5el 2Natural Attenuation

Ephrata Lan5fill RI/FS

Figure 12
Simulated Future 1,2-DCP Concentration Profiles - Roza Northerly Plume
(FS Component: Natural Attenuation)

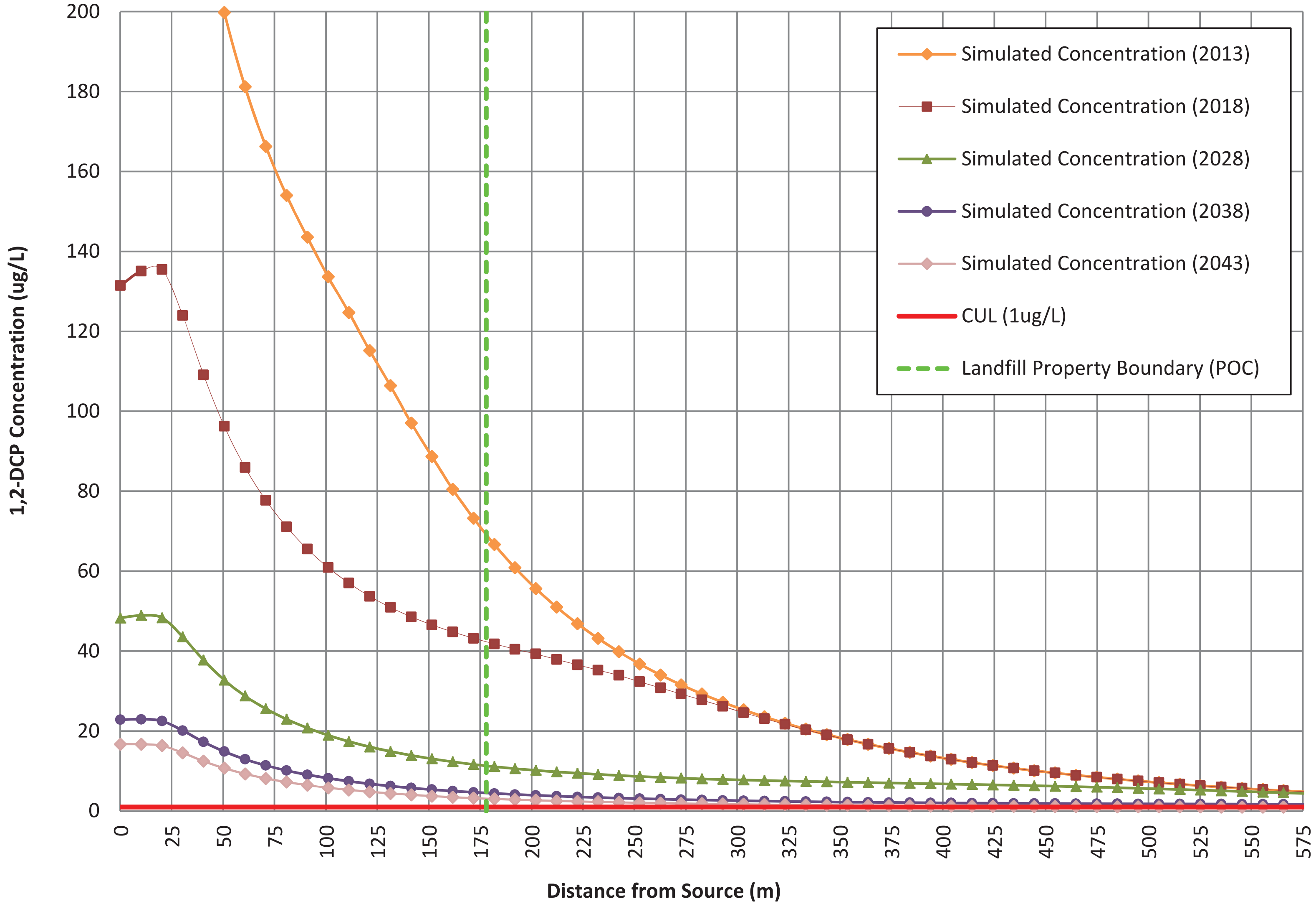


Figure 13
Simulated Future Vinyl Chloride Concentration Profiles - Roza Northerly Plume
(FS Component: Natural Attenuation)

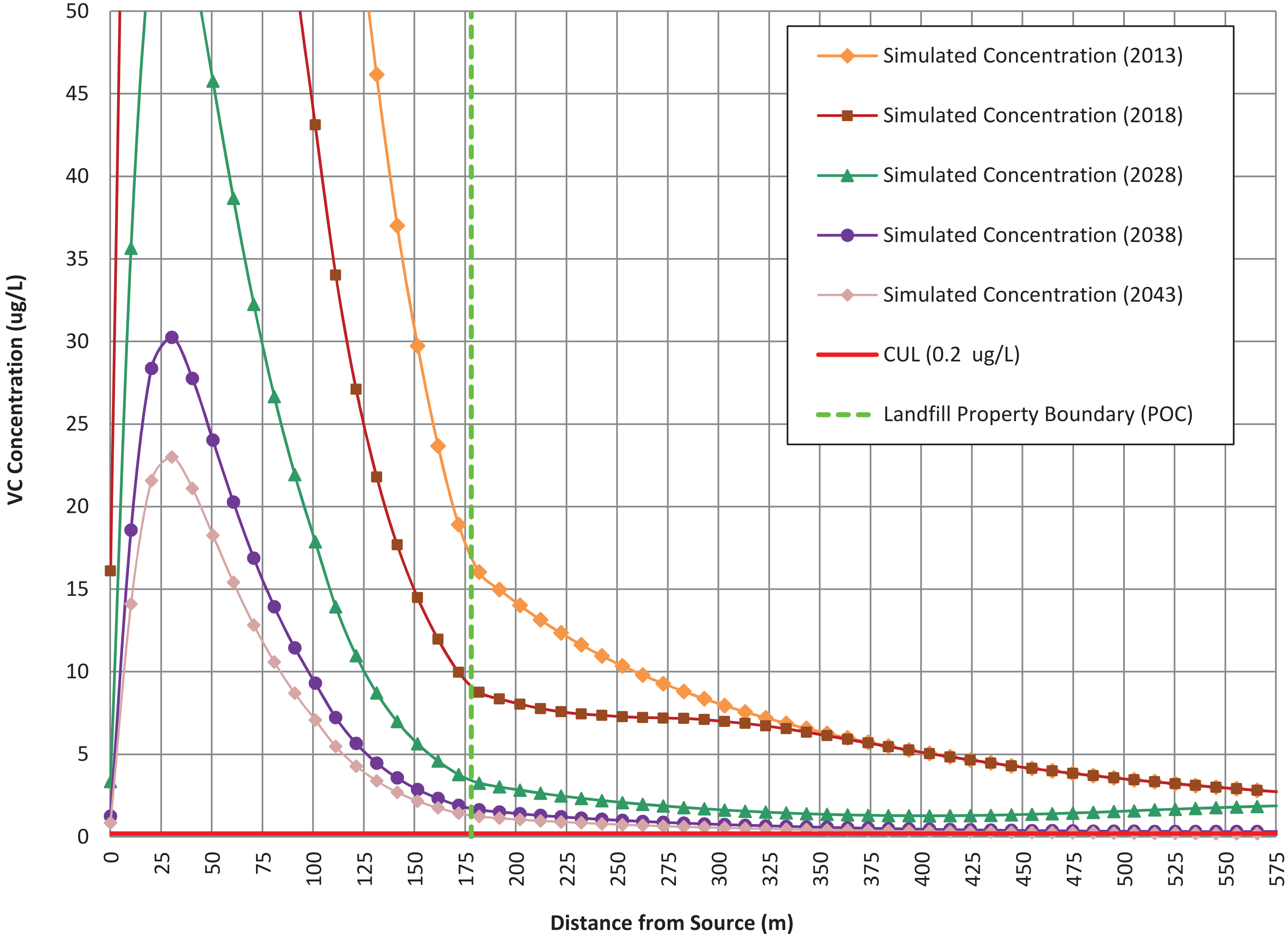


Figure 14

Simulated Future Benzene Concentration Profiles -Roza Northerly Plume

(FS Component: Natural Attenuation)

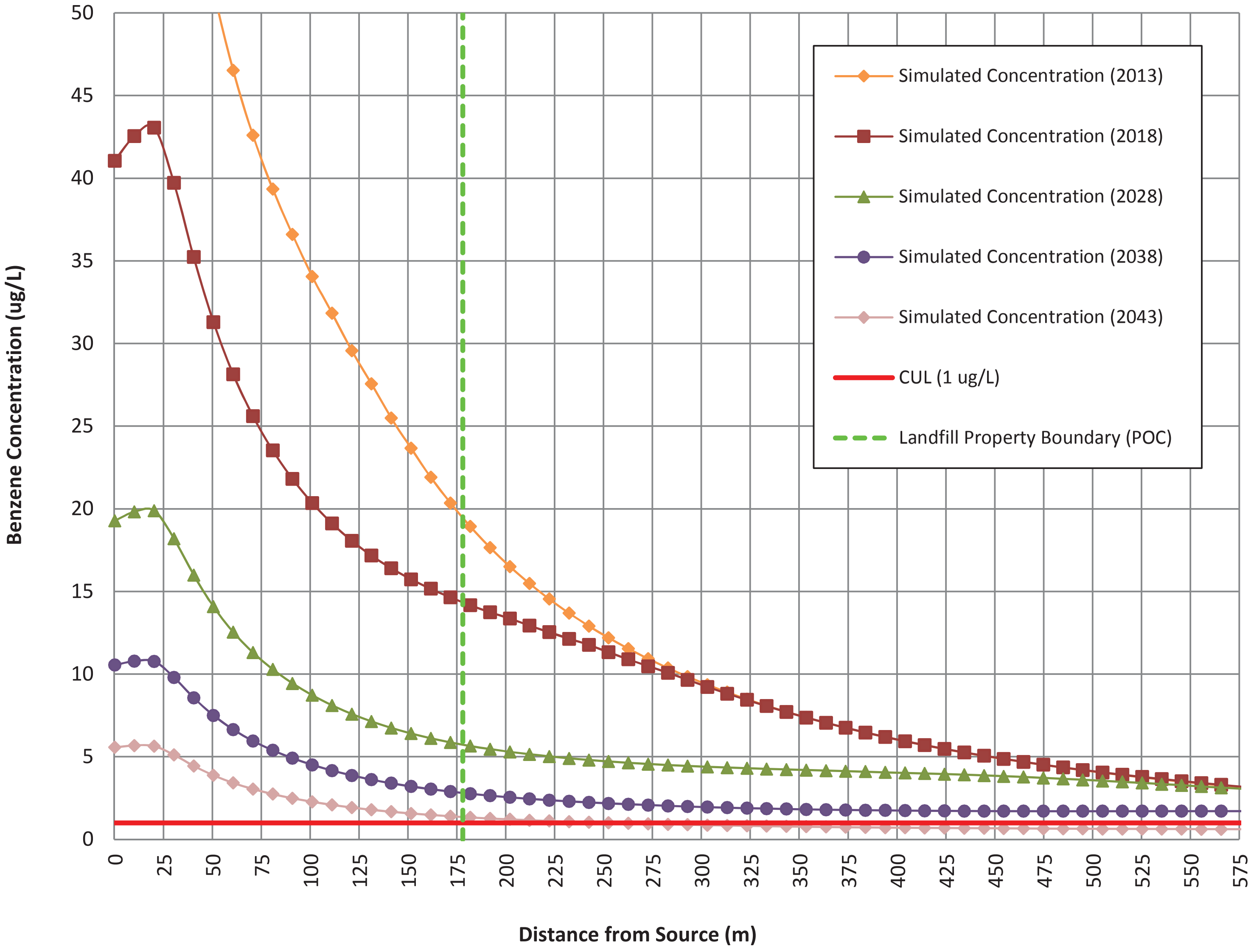
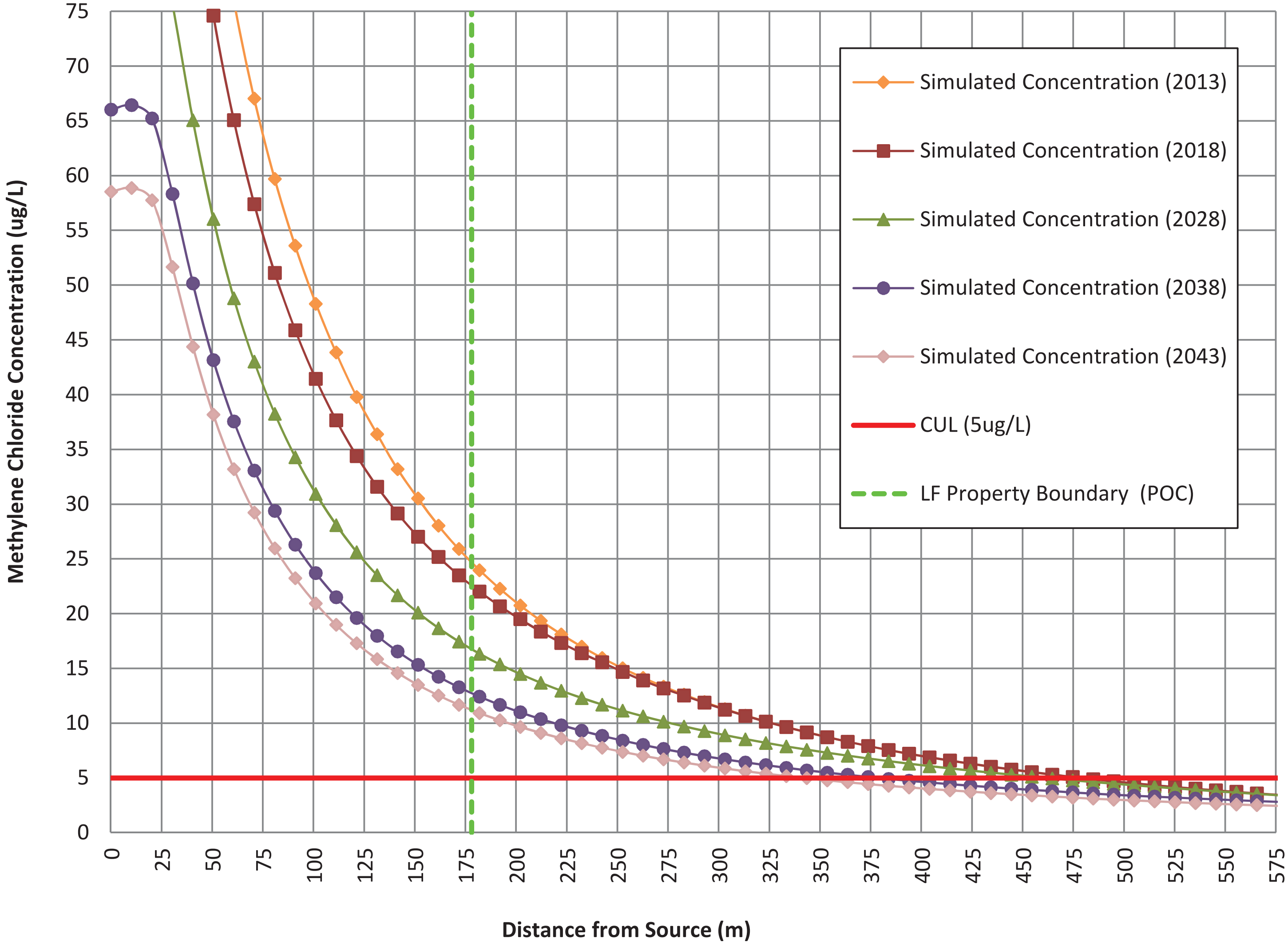


Figure 15

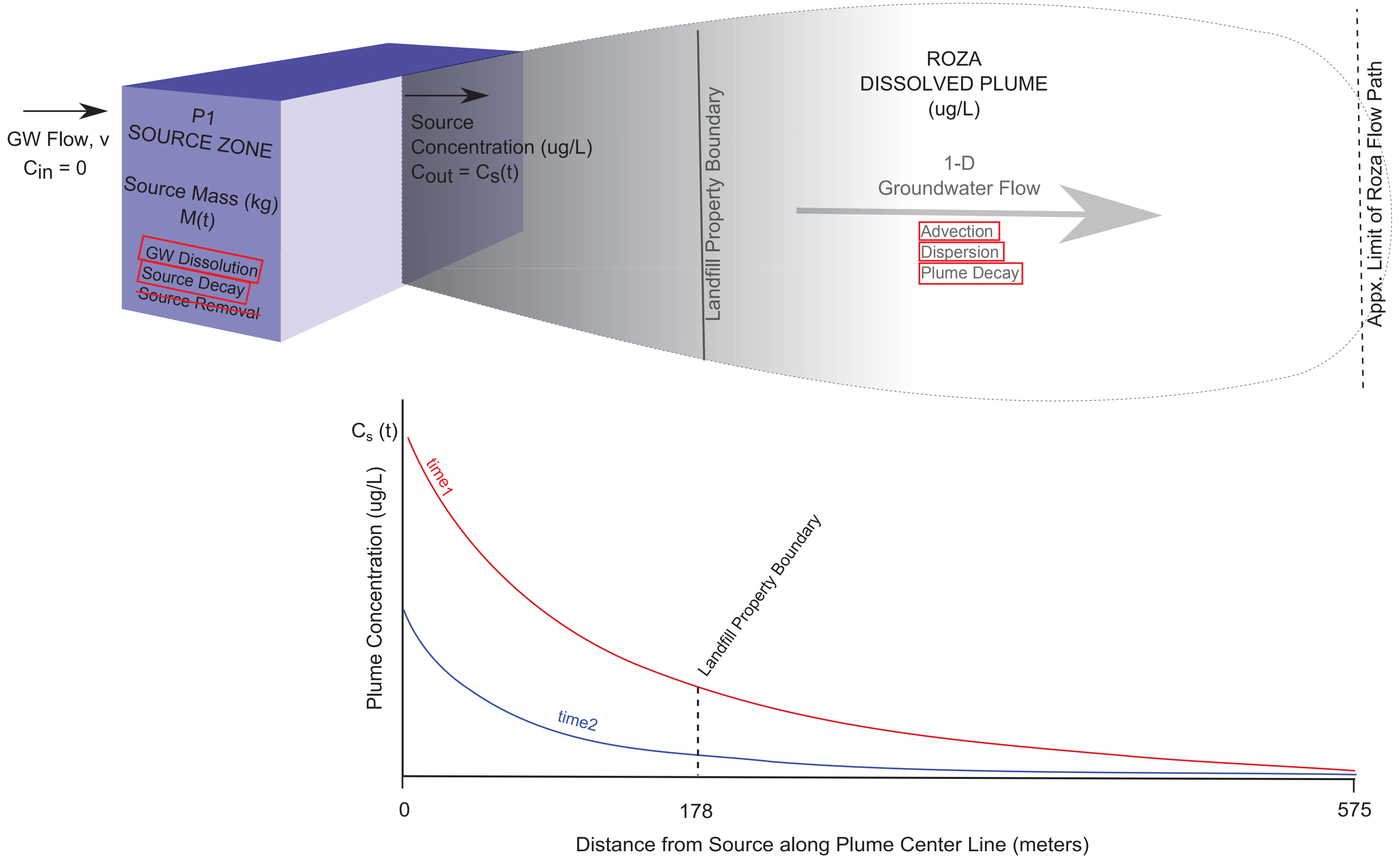
Simulated Future Methylene Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: Natural Attenuation)



Source Mass/Source Concentration Relationship:

$$C_S(t)/C_o = [M(t)/M_o]^{Gamma}$$



Source and Plume processes used to simulate this component are outlined in red.
Processes not simulated are crossed out in red.

Figure 16 Conceptual REMChlor Model -
P1 Source Area Long Term Pumping

Ephrata Landfill RI/FS

Figure 17

Simulated Future 1,2-DCP Concentration Profiles - Roza Northerly Plume

(FS Component: P1 Long Term Groundwater Pumping)

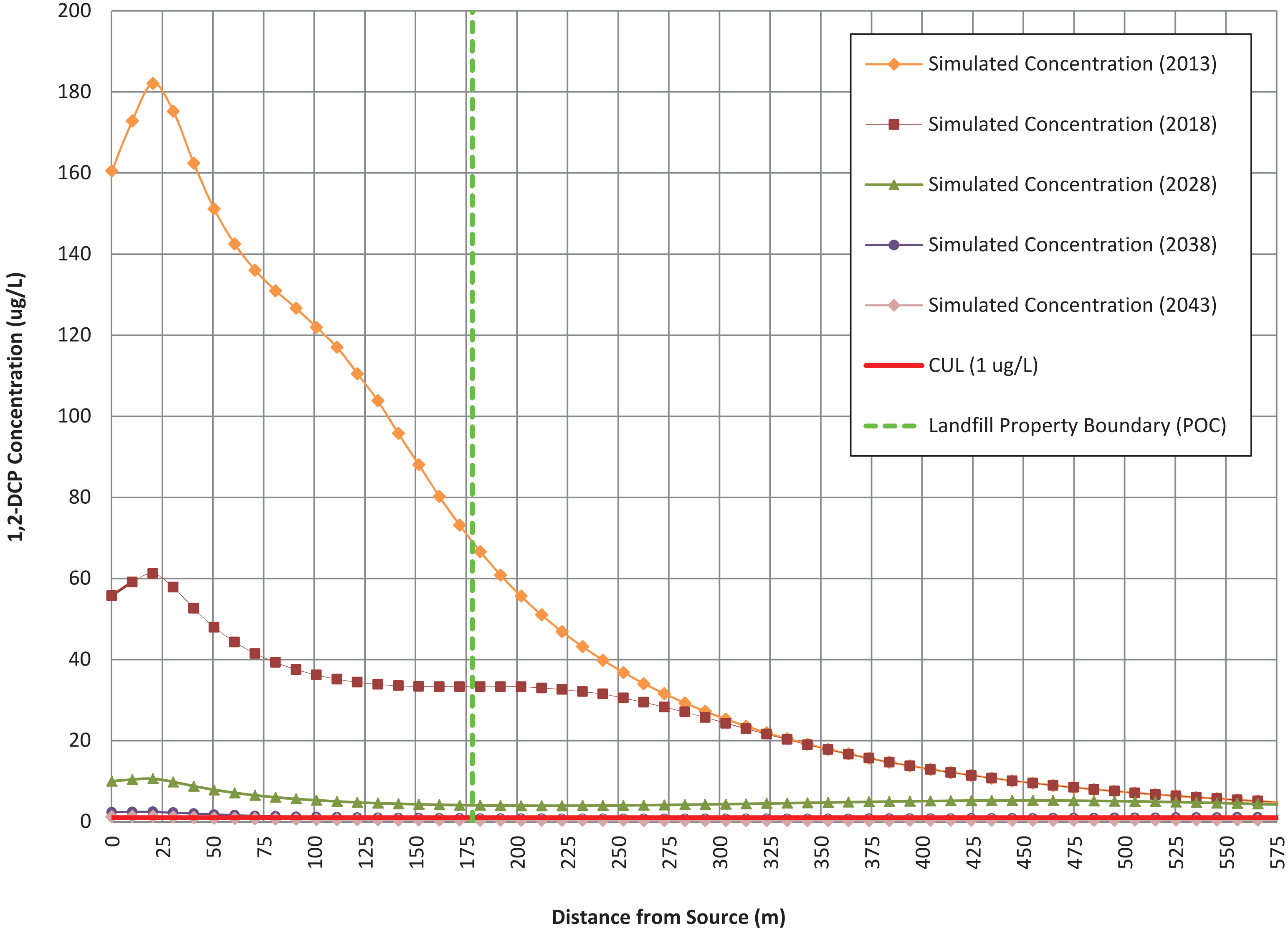


Figure 18

Simulated Future Vinyl Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: P1 Long Term Groundwater Pumping)

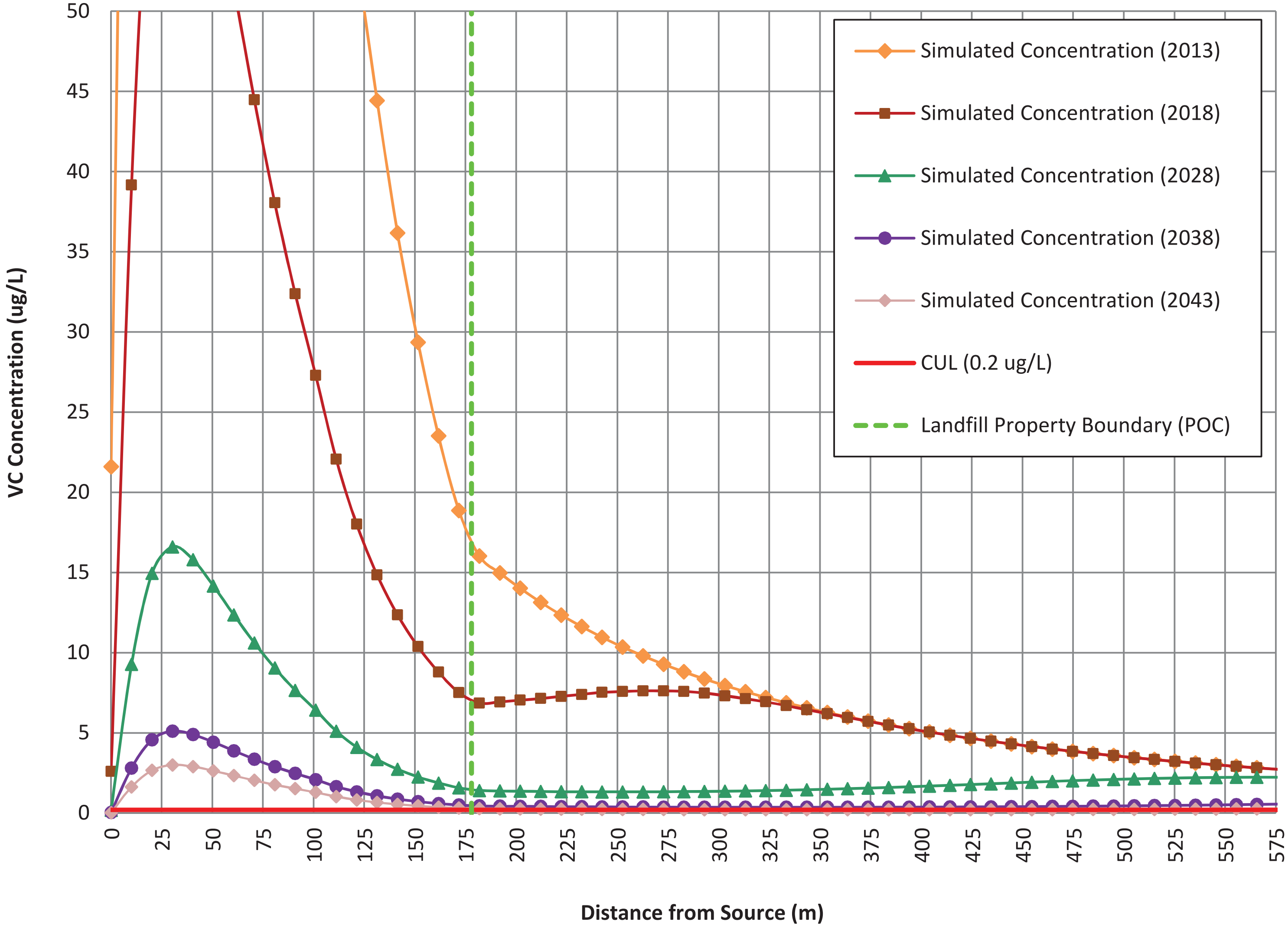


Figure 19

Simulated Future Benzene Concentration Profiles -Roza Northerly Plume

(FS Component: *P1 Long Term Groundwater Pumping*)

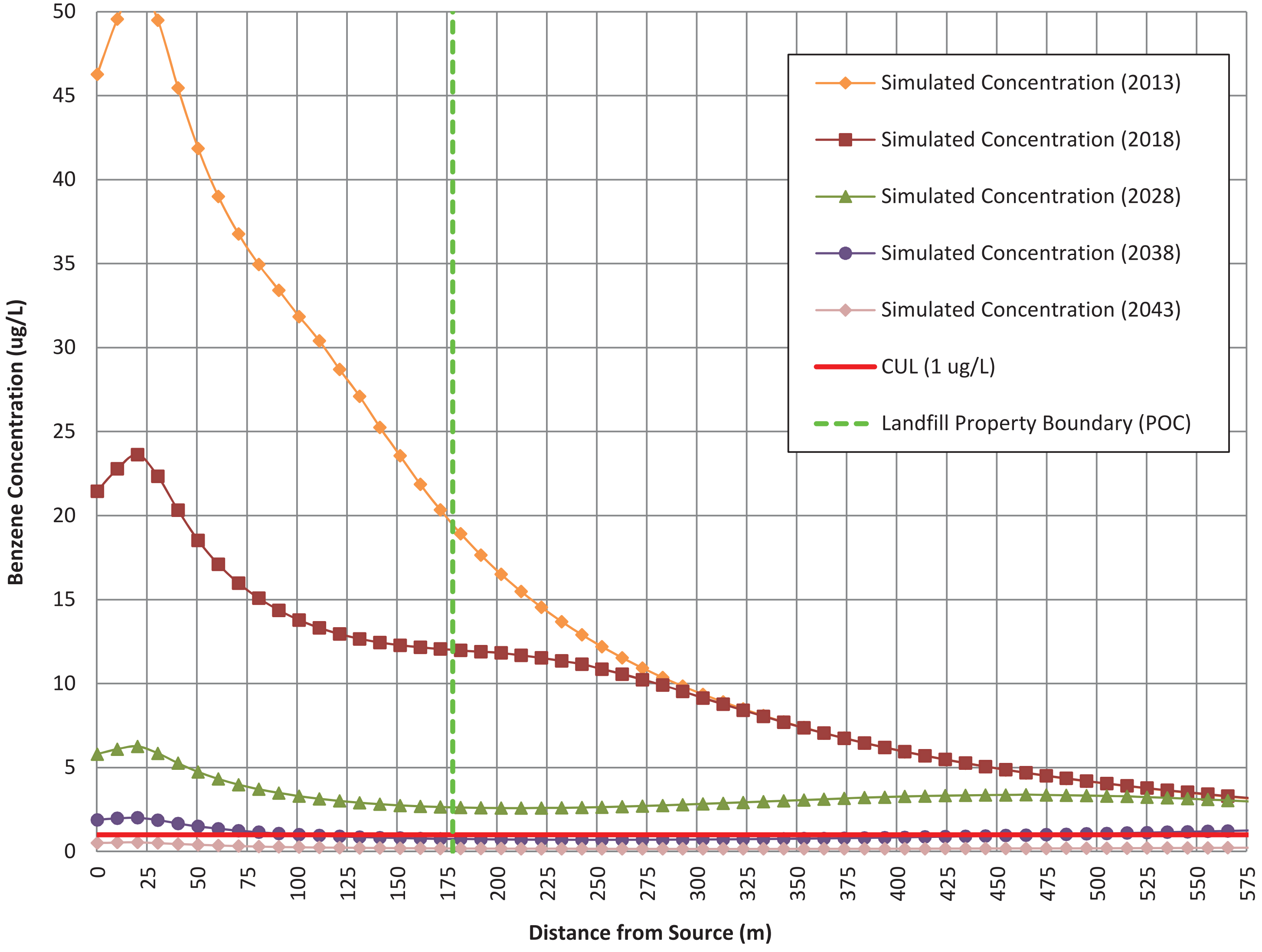
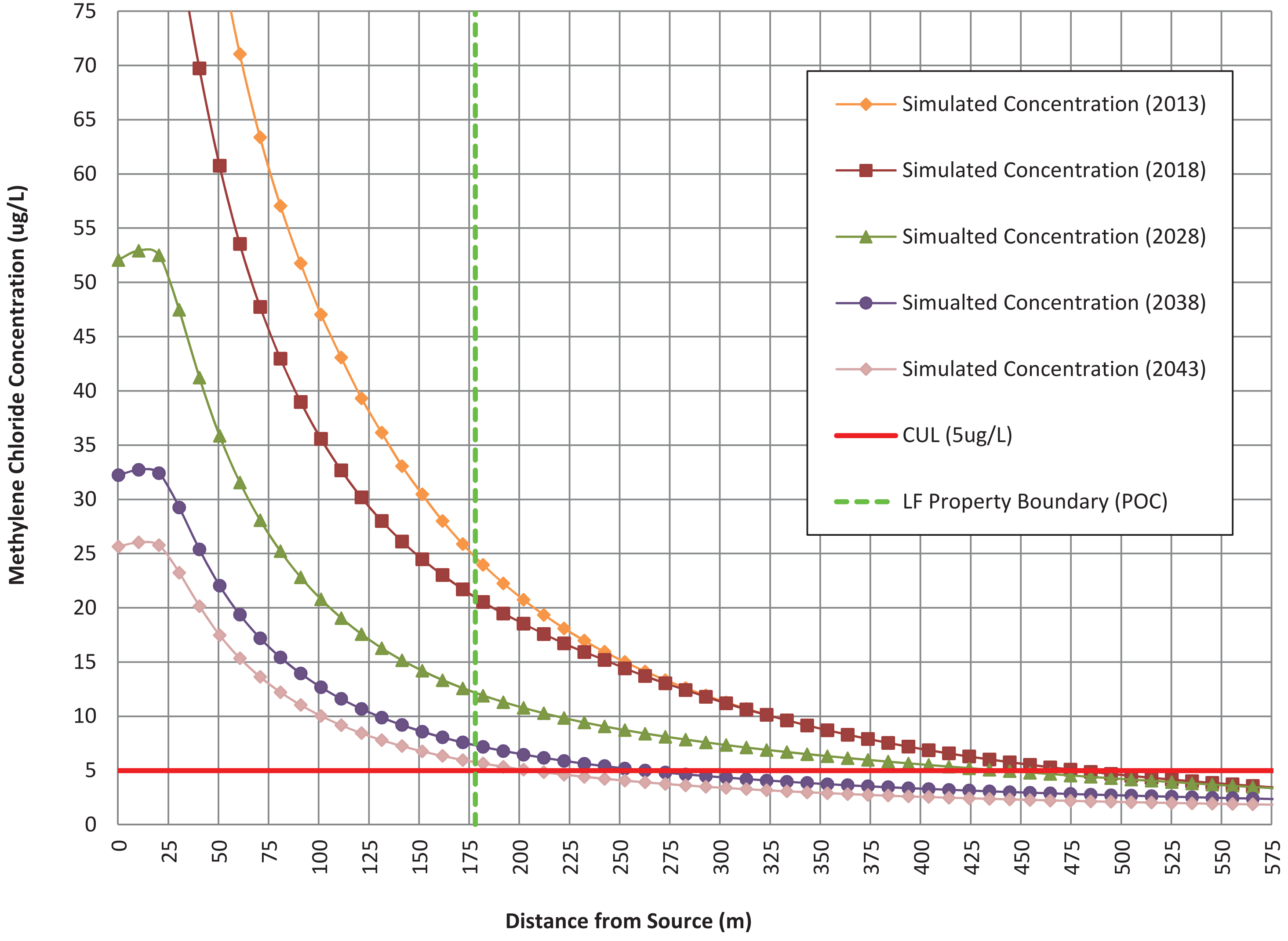


Figure 20

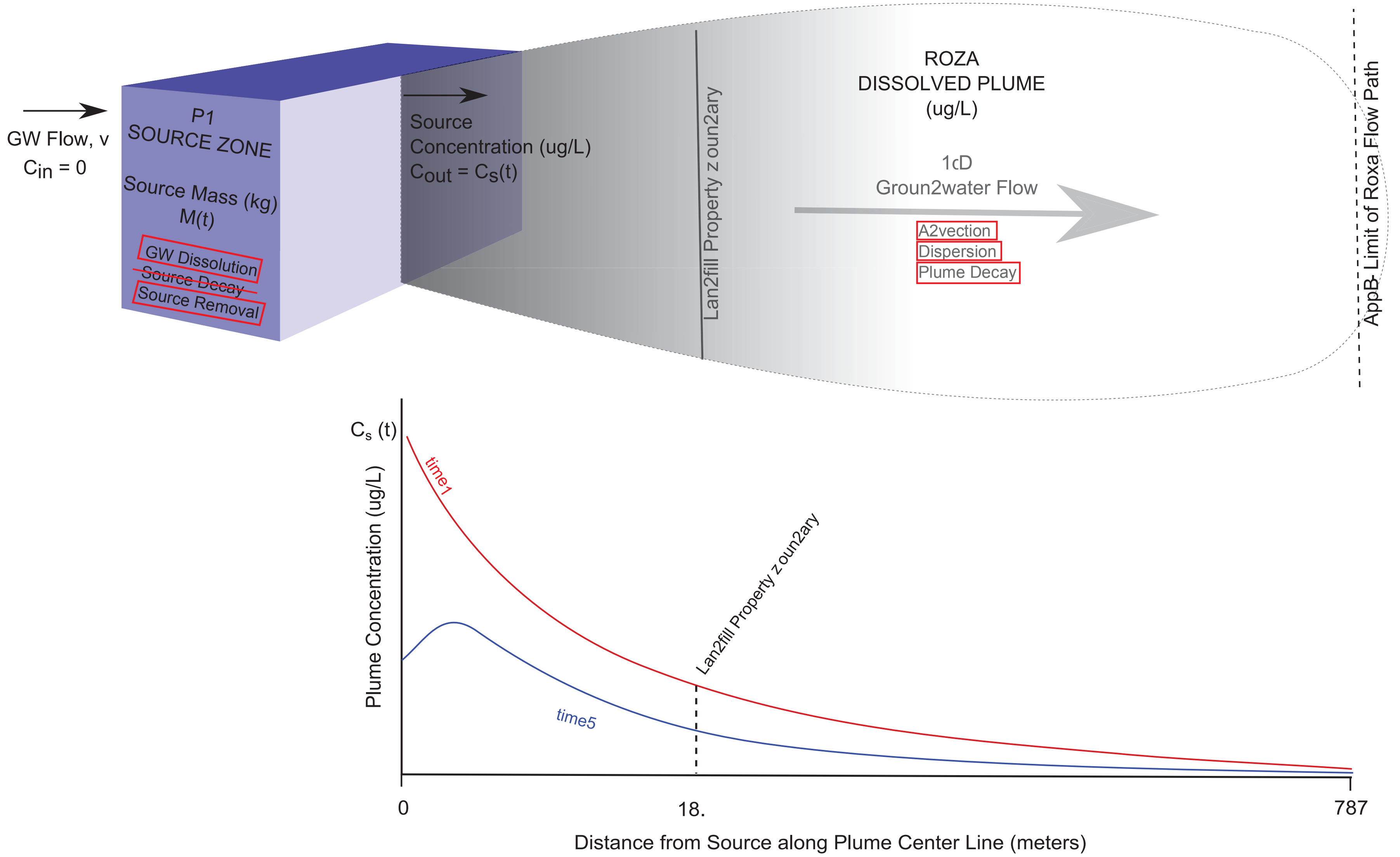
Simulated Future Methylene Chloride Concentration Profiles -Roza Northerly Plume

(FS Component: *P1 Long Term Groundwater Pumping*)



Source Mass/Source Concentration Relationship:

$C_S(t)/C_o = [M(t)/M_o]^{Gamma}$



Source an2 Plume processes use2 to simulate this component are outline2 in re2-
Processes not simulate2 are crosse2 out in re2-

Figure 51 Conceptual REMChlor Mo2el d
Soil Vapor EBtraction (SVE)

Ephrata Lan2fill RI/FS

Figure 22
Simulated Future 1,2-DCP Concentration Profiles - Roza Northerly Plume
(FS Component: SVE as 50% Source Removal)

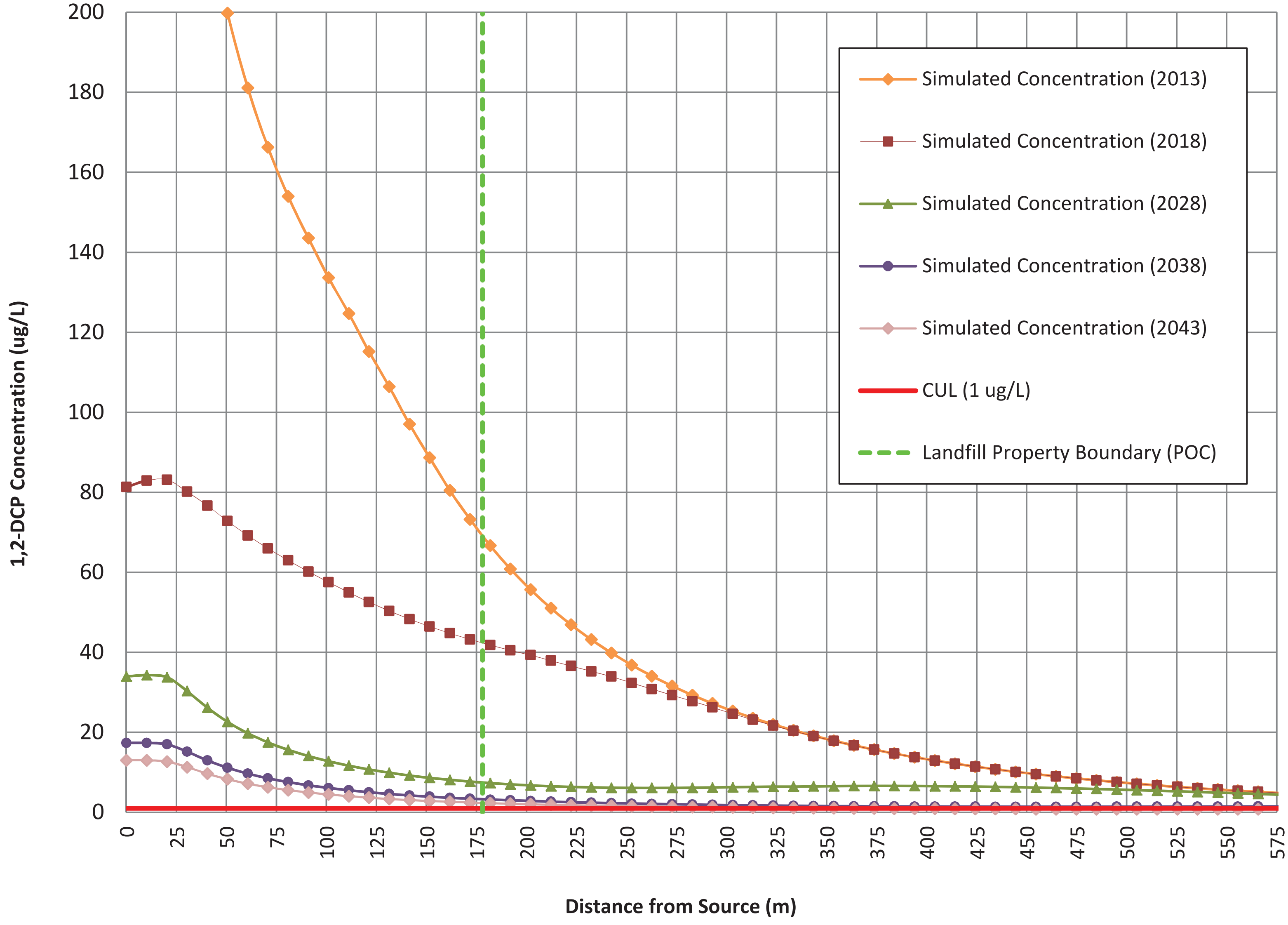


Figure 23

Simulated Future Vinyl Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: SVE as 50% Source Removal)

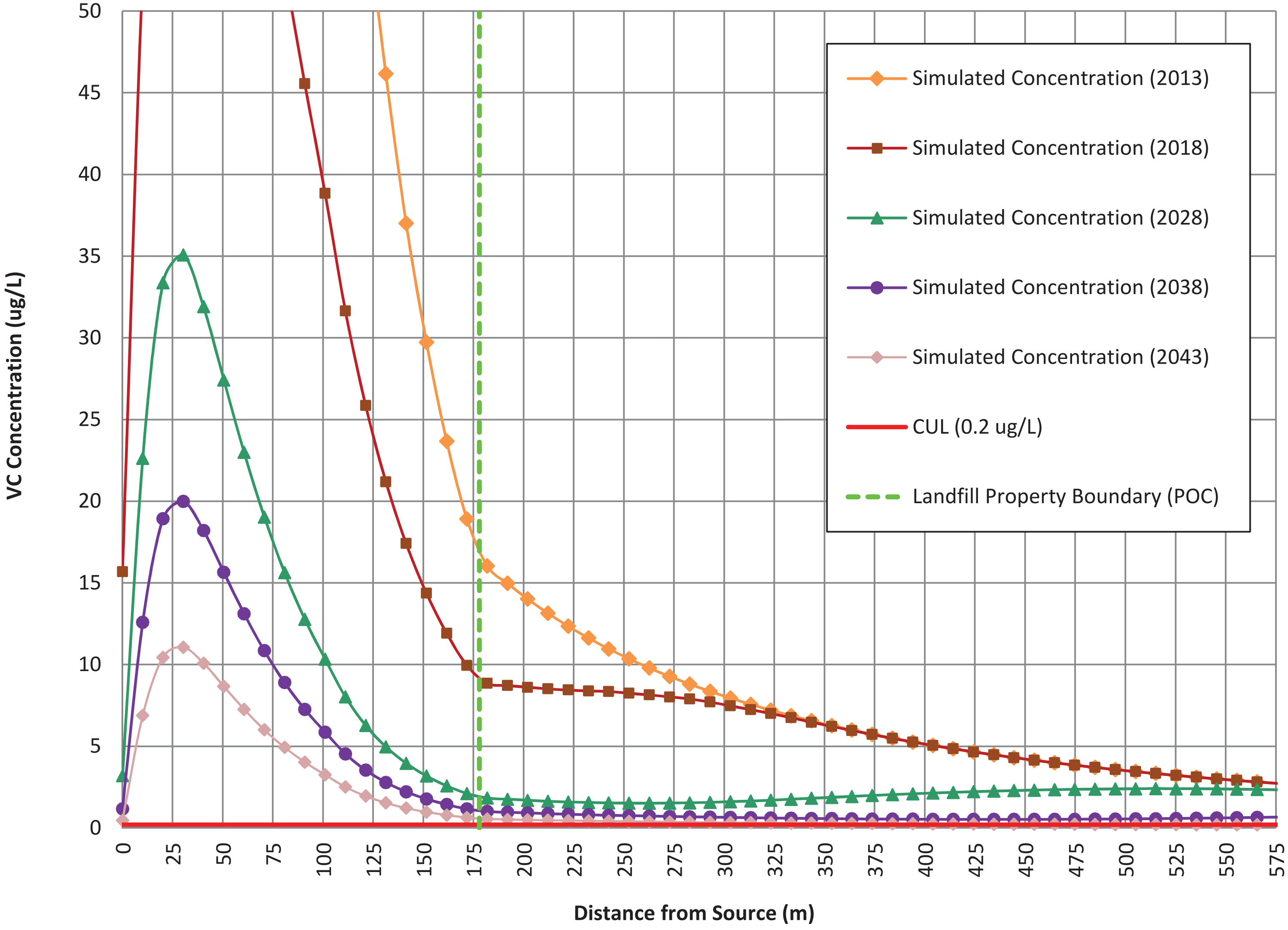


Figure 24

Simulated Future Benzene Concentration Profiles - Roza Northerly Plume

(FS Component: SVE as 50% Source Removal)

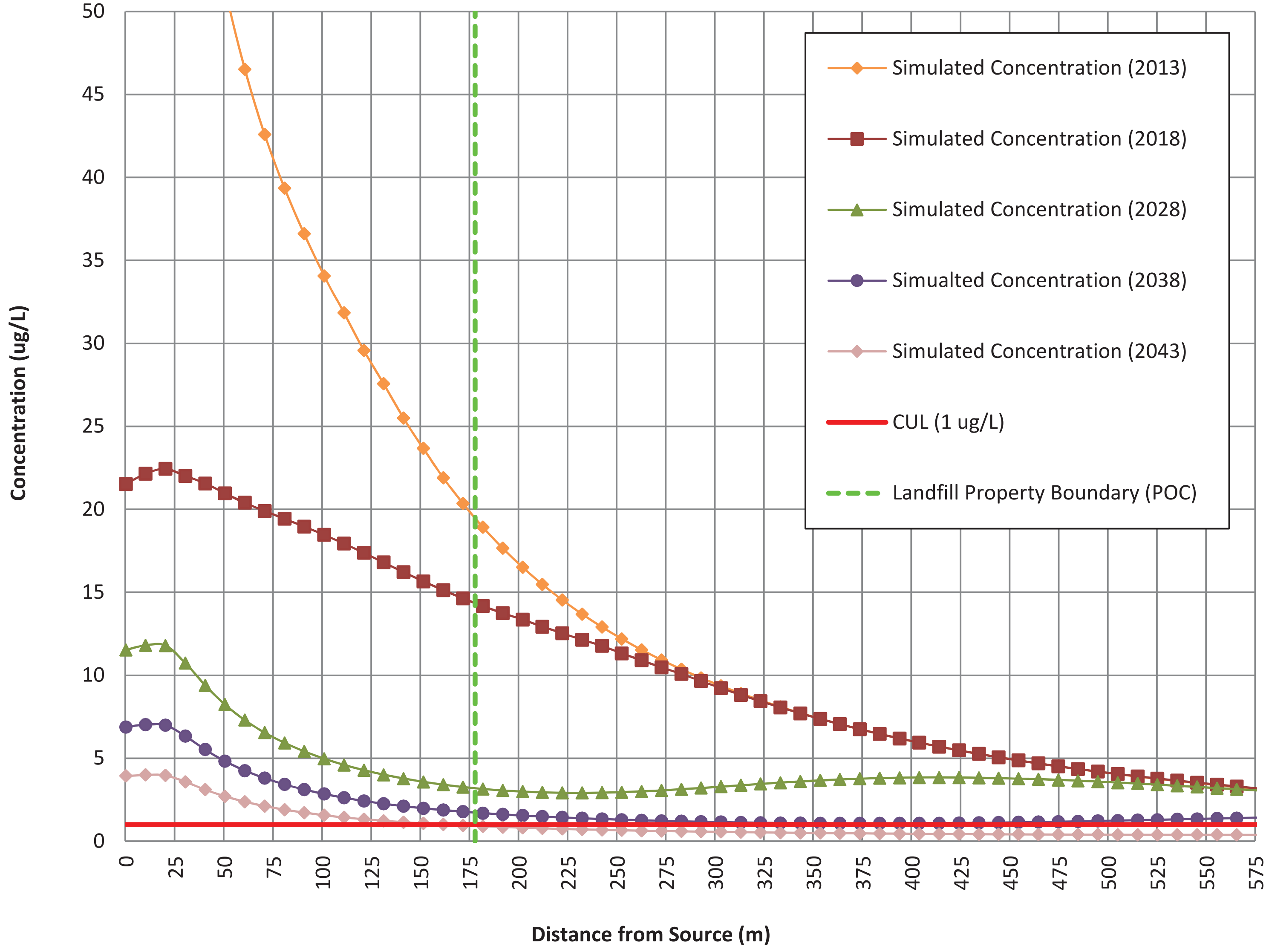
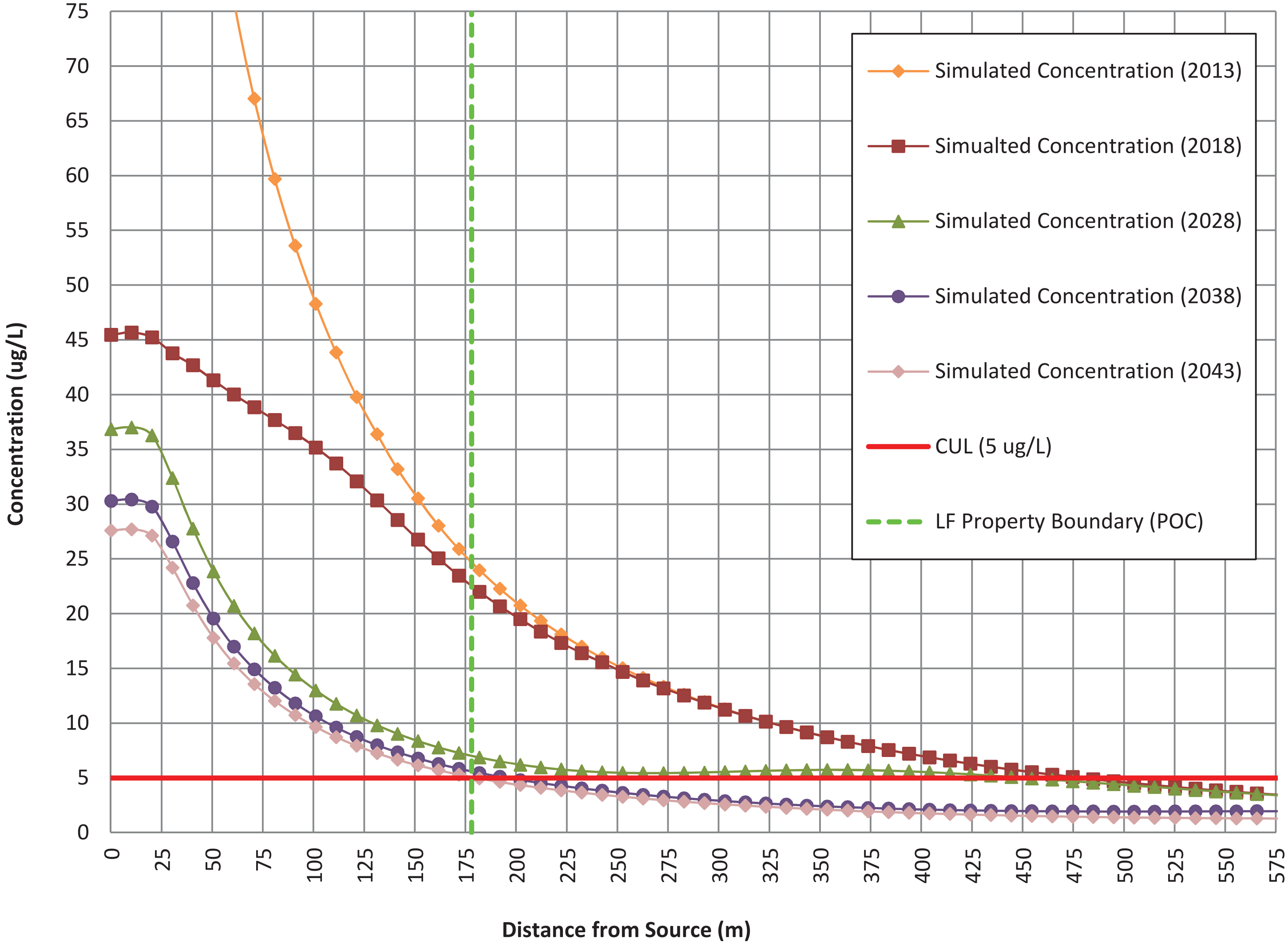


Figure 25

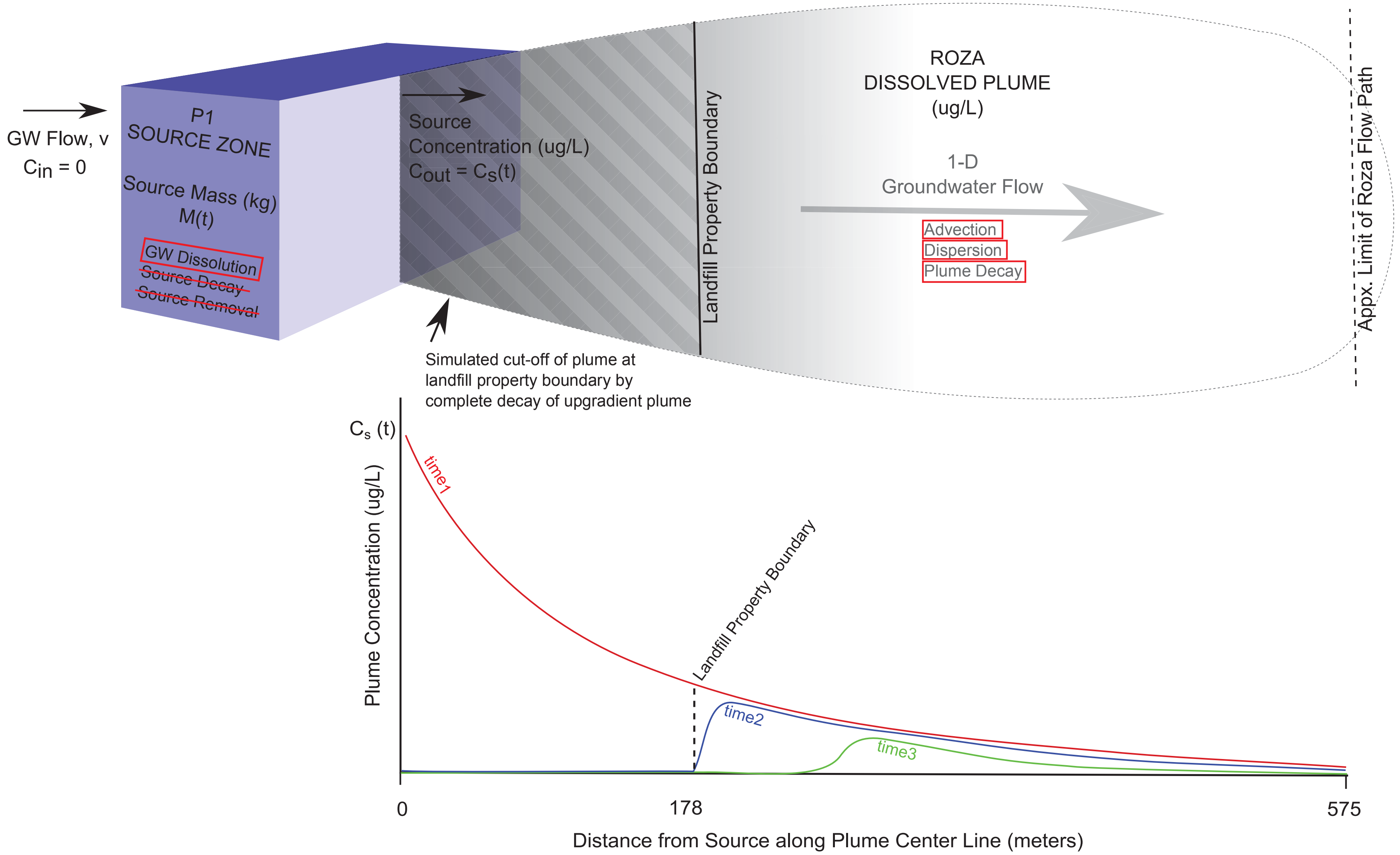
Simulated Future Methylene Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: SVE as 50% Source Removal)



Source Mass/Source Concentration Relationship:

$$C_S(t)/C_o = [M(t)/M_o]^{Gamma}$$



Source and Plume processes used to simulate this component are outlined in red. Processes not simulated are crossed out in red.

For this component the plume decay term was increased between 0 and 152 meters to simulate cut-off of plume at landfill property boundary (hatched area in plume above)

Figure 26 Conceptual REMChlor Model - Roza Plume Capture

Ephrata Landfill RI/FS

PgG

Figure 27

Simulated Future 1,2-DCP Concentration Profiles - Roza Northerly Plume

(FS Component: Roza Plume Capture at Landfill Property Boundary)

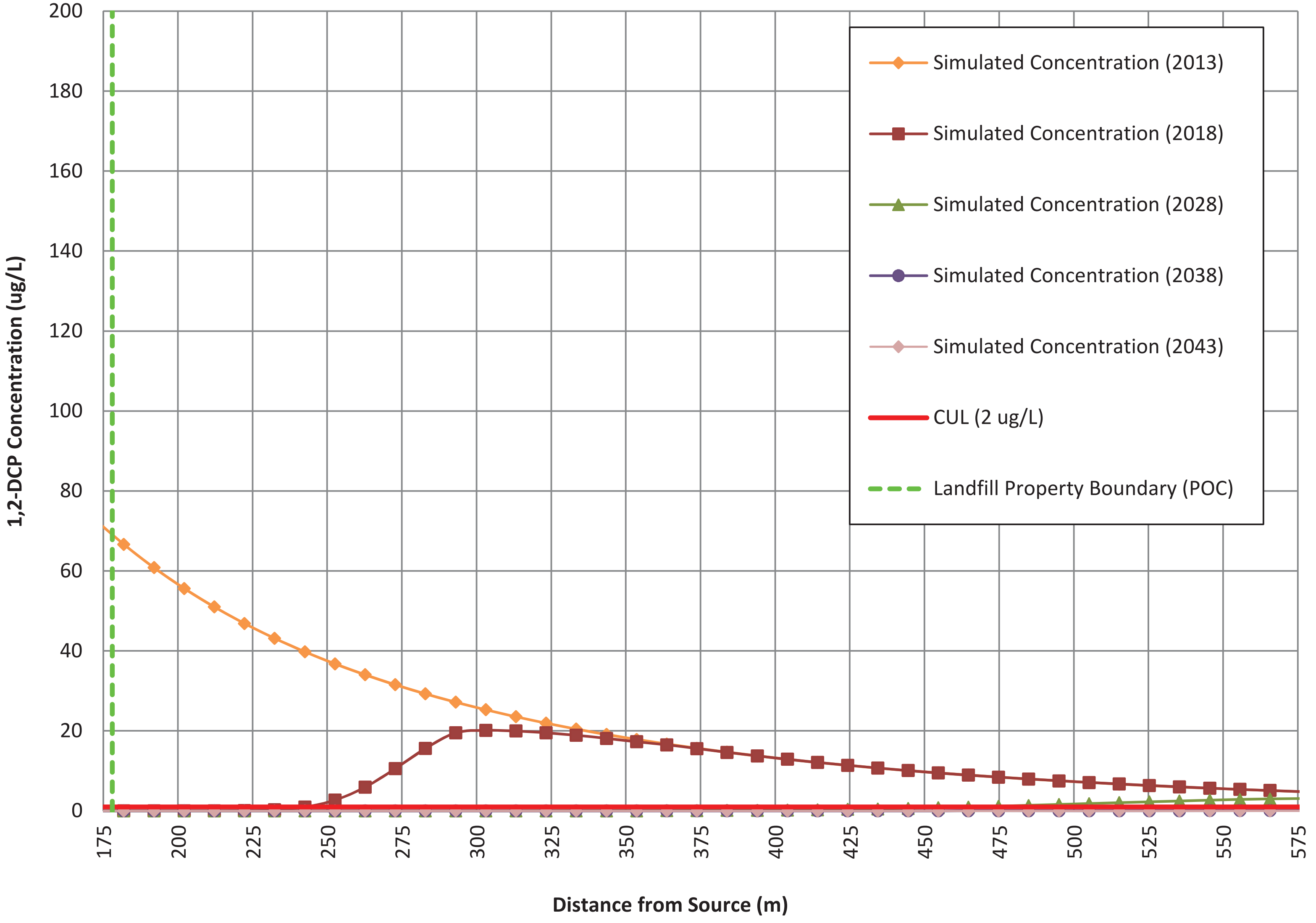


Figure 28

Simulated Future Vinyl Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: Roza Plume Capture at Landfill Property Boundary)

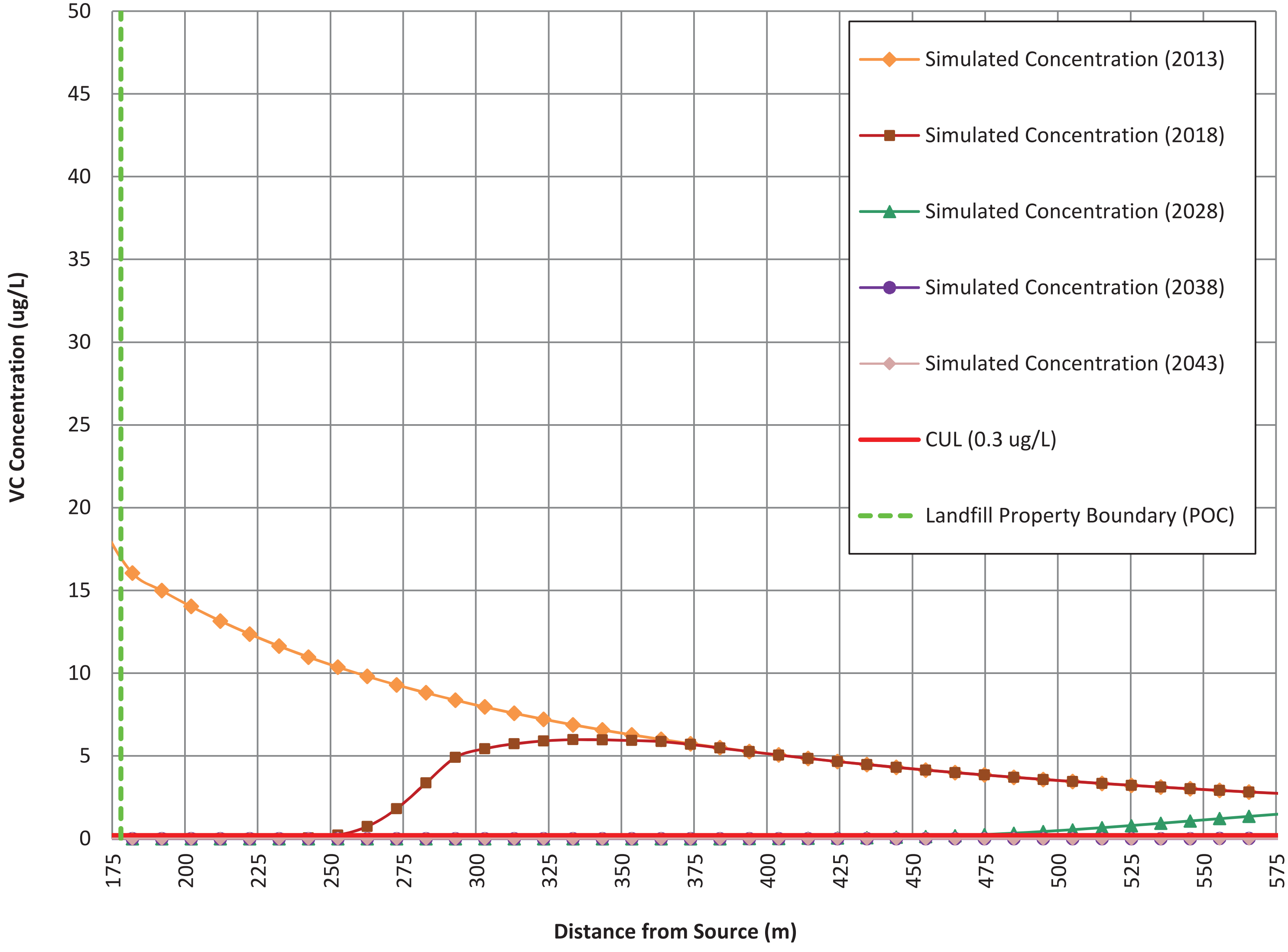


Figure 29

Simulated Future Benzene Concentration Profiles - Roza Northerly Plume

(FS Component: Roza Plume Capture at Landfill Property Boundary)

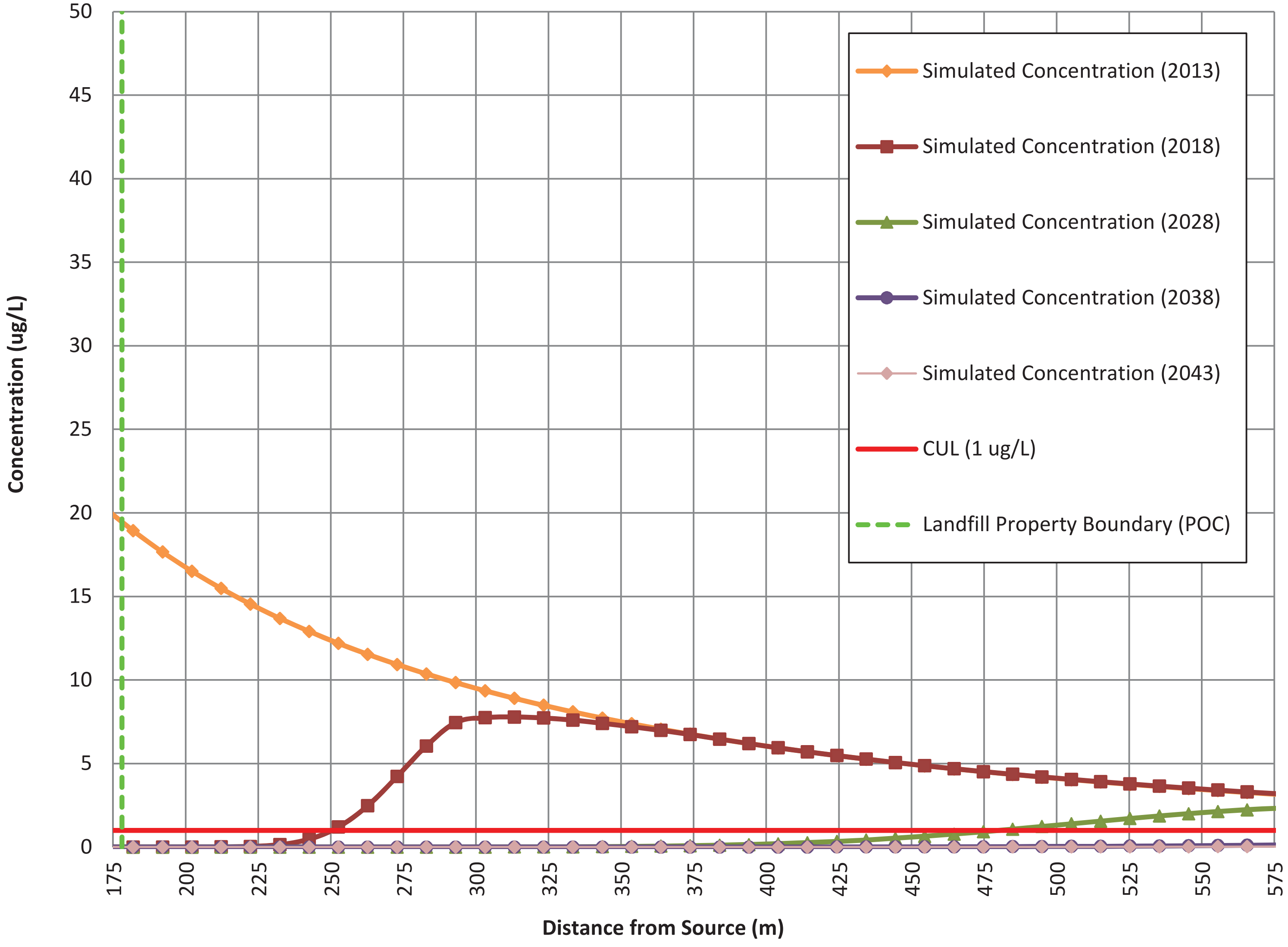


Figure 30

Simulated Future Methylene Chloride Concentration Profiles - Roza Northerly Plume

(FS Component: Roza Plume Capture at Landfill Property Boundary)

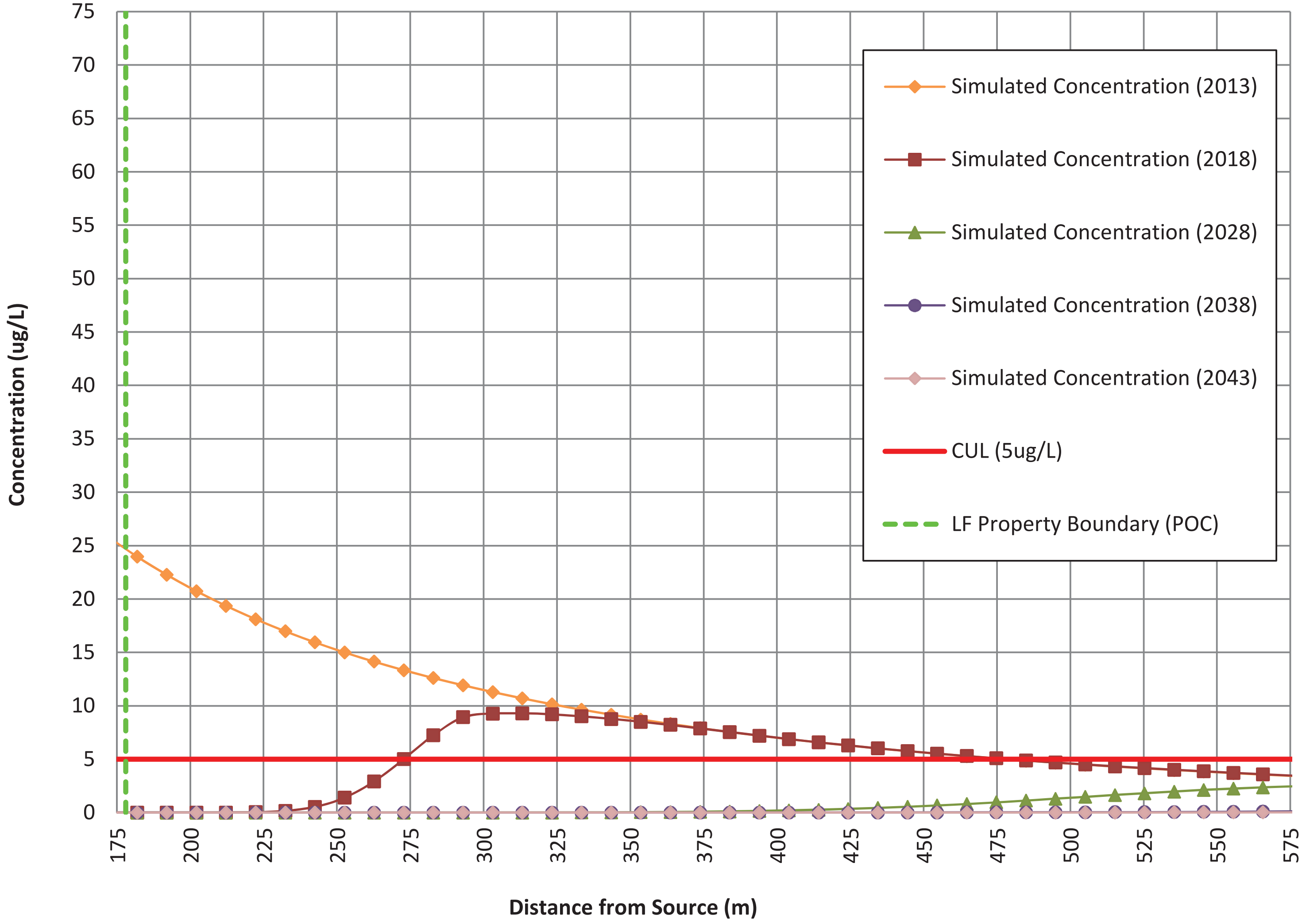
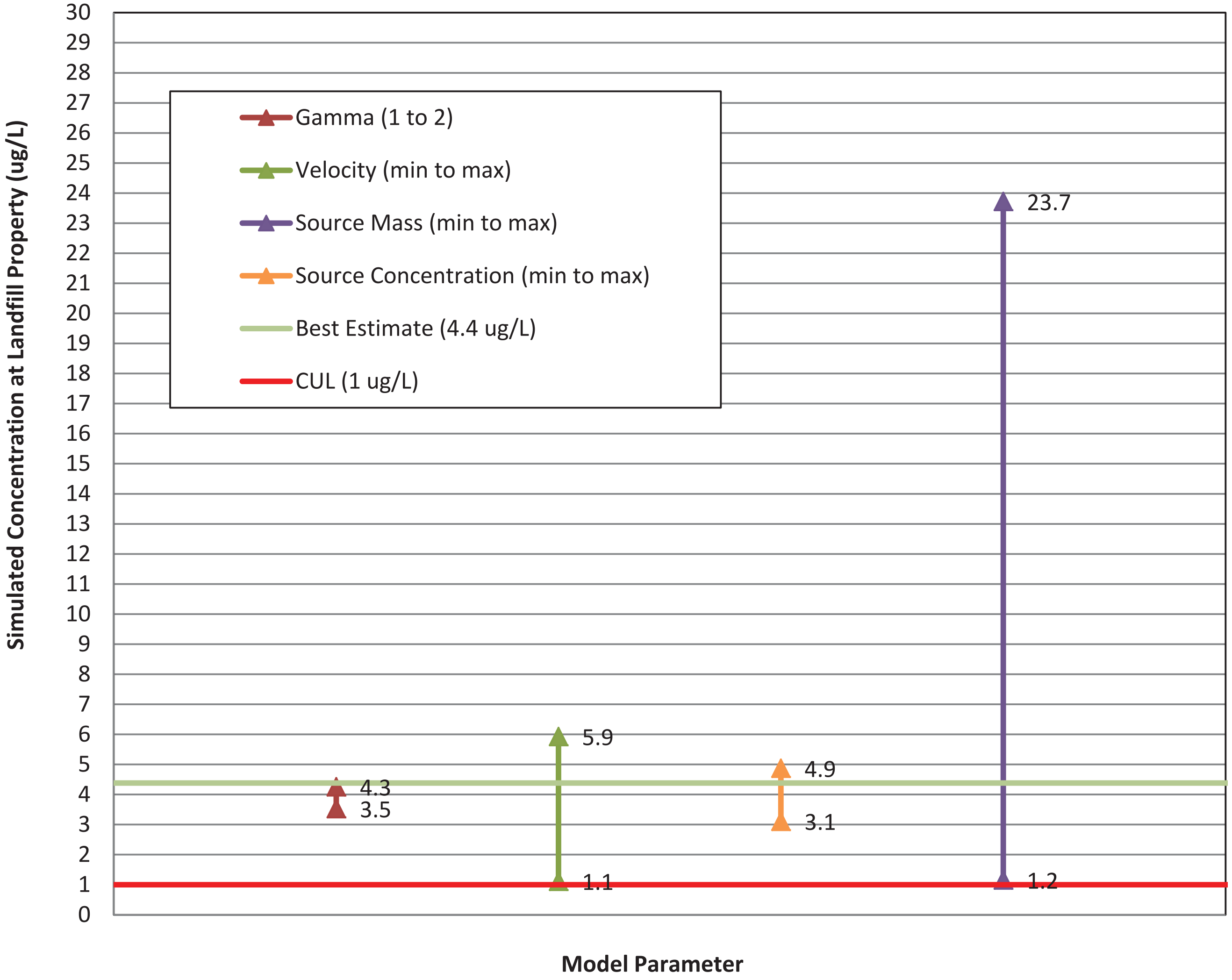


Figure 31

Model Sensitivity to Key Model Parameters

1,2-DCP Simulated Concentration under NA (2038)



Appendix D

Identification of Indicator Hazardous Substances and Development of Cleanup Levels

Appendix D

Identification of Indicator Hazardous Substances and Development of Cleanup Levels

This appendix describes the groundwater data and approach used to identify indicator hazardous substances (IHSs) and develop proposed cleanup levels (CULs).

1. GROUNDWATER DATA

Groundwater data collected for the Remedial Investigation (RI), quarterly landfill monitoring, and interim remedial actions (Pacific Groundwater Group [PGG] 2010, 2012, 2017) were used to identify IHSs. As discussed in Section 4 of the feasibility study (FS), people could be exposed to groundwater contaminants.

Groundwater data collected from 2008 through June 2017 from the following set of 29 wells were used to identify contaminants in groundwater as IHSs:

- Roza aquifer (on site or at the point of compliance [POC]): MW-3b, MW-7b, MW-9b, MW-29b, MW-30b, MW-31b, MW-42b, MW-57b, and MW-63b
- Roza aquifer (off site): MW-44b
- Interflow aquifer (at the POC): MW-2c, MW-5c, MW-6c, MW-22c, MW-58c, and MW-62c
- Frenchman Springs aquifer (at the POC): MW-28d
- Onsite P1 and P2: MW-37p1, MW-39p2, MW-40p2, MW-41a, and MW-43p2
- P1 and P2 (at the POC): MW-60p2 and MW-61p1
- Drum area (on site): MW-32a, MW-33p2, MW-35p2, and MW-38p2
- The Hole: EW-1

The PLPs and Washington State Department of Ecology (Ecology) agreed to well and groundwater data sets for identifying IHSs in 2014 (23 wells, 2008 through 2012 RI data) that were considered representative of site groundwater not in direct contact with light non-aqueous phase liquid (LNAPL). In addition to those wells and data, the data set described above also includes six new wells installed at the northern POC and monitoring data collected from 2012 through June 2017. The six new wells are those installed at the northern POC in 2016 that had at least one volatile organic compound (VOC) detected in April 2016 samples. Monitoring data from the last 5 years provide information about recent contaminant levels at the site.

Table D-1 lists the wells and collection dates for groundwater samples used to identify IHSs and develop CULs. Groundwater contaminant data are summarized (sample size, frequency of detection, maximum detected concentration, and second-highest detected concentration) in Table D-2 for groundwater data.

2. IDENTIFICATION OF INDICATOR HAZARDOUS SUBSTANCES

This section describes how IHSs were identified using cancer and non-cancer Method B groundwater standard formula values (SFVs)[1] for residential exposure that were obtained from the Ecology's Cleanup Levels and Risk Calculation (CLARC) data tables.

The following method was used to identify initial groundwater IHSs using the data set described above:

- Eliminate from consideration contaminants with no available toxicity values (SFVs) in the CLARC data tables.
- Eliminate from consideration contaminants with detection frequencies less than 5 percent.
- Calculate the minimum SFV for each contaminant.
- Identify a contaminant as a potential IHS if either:
    - ➢ Two or more concentrations exceed the minimum SFV, or
    - ➢ Any single concentration is at least twice the minimum SFV.

The elimination of contaminants with detection frequencies less than 5 percent considered the potential for contaminants detected at low detection limits (DLs) but not detected at higher DLs, as well as any contaminants with a limited data set indicating concentrations that could contribute significantly to overall site risk and hazard. Data sets for contaminants with detections frequencies less than 5 percent were examined for these possible cases. No additional potential IHSs were identified based on high DLs or limited data sets.

Following the method summarized above, 22 initial groundwater IHSs were identified (Table D-2). These initial groundwater IHSs were further evaluated to identify those substances that contribute a small portion of the overall threat to human health and the environment at the site and could be eliminated from consideration as IHSs per Washington Administrative Code (WAC) 173-340-703(2). The 22 initial IHSs were ranked based on detection frequency, mobility, toxicity, and persistence, which are listed in WAC 173-340-703(2) as factors evaluated when eliminating individual hazardous substances from further consideration.

Natural background, thoroughness of testing, and degradation by-products are the other factors listed at WAC 173-340-703(2). Arsenic is the only initial IHS for which a natural background concentration has been established. VOC background concentrations are presumed to be zero, so no further consideration was given to ranking initial IHSs based on background concentration. The site has been extensively monitored and sampled since the start of the RI in 2007, and testing for all the initial IHSs has been similarly thorough; thus, no further consideration was given to ranking based on the thoroughness of testing. The initial IHS list includes degradation by-products, so that factor was considered, although no specific rank was assigned based on whether an initial IHS is a degradation by-product.

Ranks of 0 to 4 were assigned based on 20-percent quantiles for the variables of interest (frequency, mobility, hazard quotient, and percent of minimum SFV exceedances after 2012):

- The frequency/mobility ranking was based on frequency of detection. Substances detected more frequently (and in more wells, thus reflecting more mobility) were ranked higher. Since the wells are spatially distributed, frequency of detection is also indicative of mobility.

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[1] The MTCA Method B groundwater SFVs in the CLARC data tables are based on the ingestion and inhalation pathways.

- The toxicity ranking was based on hazard quotient. Substances exceeding minimum SFVs by higher ratios were ranked higher.
- The persistence ranking was based on number of exceedances in the past 5 years (after 2012[2]). Substances that continue to exceed minimum SFVs over time were ranked higher.

For each initial IHS, the three ranks were then summed to provide an overall ranking (IHS ranking) of 0 to 12. Substances with higher IHS rankings are comparatively more frequent, mobile, toxic, and persistent than the other initial IHSs overall. Substances with IHS rankings of 6 or higher were retained as IHS for developing CULs, as described below. Table D-3 provides results of this evaluation.

Applying the above method with a threshold IHS ranking of 6 eliminated several initial IHSs that:

- Either did not exceed the minimum SFV or had less than 1 percent exceedances of the minimum SFV at the POC or beyond: 1,1-dichloroethene, 1,3,5-trimethylbenzene, acetone, ethylbenzene, iron (dissolved), methylene chloride, o-xylene, tetrachloroethene, toluene, and xylene M+P.
- Have not exceeded the minimum SFV since 2012 (earlier for some substances in some wells): 1,1-dichlorothene, iron (dissolved), methylene chloride, and tetrachloroethene.

The persistence ranking reflects significant decreasing concentration trends observed in the data set. Total VOC concentrations in MW-35p2 and MW-38p2 near the drum area decreased by more than an order of magnitude from 2008 to 2013. Decreasing trends in total VOCs have also occurred in several Interflow and Roza aquifer wells (PGG 2017).

3. DEVELOPMENT OF CLEANUP LEVELS

Although Ecology will establish final CULs in the Ephrata Landfill cleanup action plan, proposed CULs were developed for the 11 IHSs to evaluate cleanup alternatives, including treatment options, costs, and restoration timeframes in the FS.

3.1 CLEANUP LEVEL CALCULATIONS

The following steps were followed to develop CULs for the IHSs identified based on residential groundwater exposure.

1. For each IHS, an initial CUL was determined from groundwater maximum contaminant levels (MCLs) (40 Code of Federal Regulations [CFR] 141.61) and MTCA Method B SFVs per WAC 173-340-720(4)(b) and 705.
   a. For each IHS with a state or federal MCL, this standard was used as the initial CUL. If necessary, this value was downward-adjusted so that the individual excess cancer risk did not exceed $1x10^{-5}$ and the hazard quotient (HQ) did not exceed 1 based on Method B SFVs, per WAC 173-340-705(5).
   b. For each IHS without an MCL, the most stringent (lowest) Method B SFV was used as the initial CUL.
2. Downward adjustments were made to individual initial CULs, if needed, to account for overall (sitewide) excess cancer risk, per WAC 173-340-705(4). As needed, individual CULs were downward-adjusted so that sitewide excess cancer risk did not exceed $1x10^{-5}$.

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[2] Although 10 wells have not been sampled since 2012, the remaining 19 wells include several on-site wells, the P2 wells in the drum area, and POC wells. The 19 wells sampled since 2012 are MW-61p1, MW-33p2, MW-35p2, MW-38p2, MW-60p2, MW-3b, MW-7b, MW-9b, MW-42b, MW-44b, MW-57b, MW-63b, MW-2c, MW 5c, MW-6c, MW-22c, MW-58c, MW-62c, and MW-28d.

3. Downward adjustments were also made to individual initial CULs, if needed, to account for sitewide toxic effects, per WAC 173-340-705(4). Non-cancer toxic effects (hazard indexes) based on CULs reflect additive effects of IHSs with similar chronic toxic effects on individual human organ/system groups, per WAC 173-340-708(5)(b). The identification of toxic effects for individual IHSs is discussed in Section 4.2.
4. Per WAC 173-340-720(7), CULs were not set below laboratory reporting limits (practical quantitation limits) or natural background concentrations. CULs adjusted to natural background concentrations were not included in the total site risk and hazard calculations.

Per WAC 173-340-720(7), the CUL for arsenic was set at its natural background concentration (Appendix D) and excluded from the total site risk and hazard calculations.

Table D-4 shows the calculation of initial CULs using Method B groundwater SFVs and MCLs. Table D-5 summarizes the development of CULs (i.e., proposed) using downward-adjustment for individual contaminants based on sitewide risk for the groundwater exposure pathway. The identification of toxic effects for individual IHSs is discussed in the following section.

3.2 TOXIC EFFECTS

Under MTCA regulations, chemicals with similar types of toxic effects are assumed to be additive unless scientific evidence is available to demonstrate otherwise (WAC 173-340-708(5)(b)). This section summarizes how toxic effects were identified for groundwater IHSs and used to assess non-cancer human health risk for the downward adjustment of initial CULs.

EPA's Integrated Risk Information System (IRIS) database was used to identify toxic effects for IHSs. For individual chemicals, IRIS categorizes toxic effects into the following 15 organ/system groups based on the study data used to derive toxicity values (EPA 2017):

- **Cardiovascular** – Includes heart and blood vessels (including arteries, capillaries, and veins).
- **Dermal** – Relating to the skin, which consists of two main layers, the epidermis and dermis. Also includes hair follicles, sweat glands, sebaceous glands, and nails.
- **Developmental** – A lifestage that includes the period prior to conception (either parent), the prenatal period, and the postnatal period to the time of sexual maturation. Developmental effects may be detected at any point in the lifespan of the organism, and include: (1) death of the developing organism, (2) structural abnormality, (3) altered growth, and (4) functional deficiency. Teratogenicity is generally used to refer to malformations only (i.e., a permanent structural change that may adversely affect survival, development, or function).
- **Endocrine** – Includes the thyroid gland, parathyroid, hypothalamus, pineal gland, adrenal gland, pituitary gland, pancreas (see also Gastrointestinal), thymus (see also Immune), and testis and ovary (see also Reproductive).
- **Gastrointestinal** – Includes mouth/oral cavity (including tongue), esophagus, stomach, pancreas (see also Endocrine), small intestine (including duodenum, jejunum, and ileum), and large intestine (including cecum, colon, rectum, and anus).
- **Hematologic** – Includes blood plasma, red blood cells (erythrocytes), platelets (thrombocytes), and bone marrow (where blood cells are produced). White blood cells (leukocytes) are part of the Hematologic system, but are included under the Immune system because of their role in the body's defense against infectious organisms and foreign substances.
- **Hepatic** – Includes liver, bile duct, and gall bladder.
- **Immune** – Includes white blood cells (leukocytes; see also Hematologic), bone marrow, thymus, spleen, and lymphatic system.

- **Musculoskeletal** – Includes muscle, connective tissue (ligaments, tendons, and cartilage), and bones.
- **Nervous** – Includes the central nervous system (CNS; brain and spinal cord) and peripheral nervous system (PNS; nerves and ganglia that relay information between the CNS and other parts of the body to regulate sensory, motor, and autonomic processes).

  Neurotoxicity involves structural or functional changes in the CNS or PNS. Structural changes include neuroanatomical or histologic alterations. Functional changes include neurochemical alterations (e.g., neurotransmitter levels), neurophysiological alterations (e.g., nerve conduction), or behavioral effects (e.g., learning; sensory function).

  Developmental neurotoxicity is neurotoxicity manifest during development, including changes to the growth or organization of CNS or PNS structures, as well as alterations to the appearance or maturation of different nervous system functions (see also Developmental).
- **Ocular** – Includes all parts of the eyeball (lens, retina, cornea, etc.), the muscles that position the eye, eyelids, lachrymal/lacrimal glands, and, in some non-human species, the Hardarian gland.
- **Reproductiv**e – Includes alterations to the male or female reproductive organs, related endocrine system (see also Endocrine), or pregnancy outcomes. Manifestations may include adverse effects on onset of puberty, gamete production and transport, reproductive cycle normality, sexual behavior, fertility, gestation, parturition, lactation, developmental toxicity, premature reproductive senescence, or modification in other functions dependent on the integrity of the reproductive system.

  Female reproductive structures include the uterus, endometrium, ovaries, including eggs, follicles, and corpora lutea (see also Endocrine), fallopian tubes, cervix, vagina, and vulva. Also includes mammary gland and breast.

  Male reproductive structures include the testes (see also Endocrine), epididymides, and vas deferens (including sperm); scrotum; seminal vesicles; coagulating glands; prostate gland; and penis. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.
- **Respiratory** – Includes the nasal passages, pharynx, larynx, trachea, bronchi, and lungs.
- **Urinary** – Includes the kidneys, ureter, urinary bladder, and urethra. Also referred to as the excretory or renal system. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.
- **Other**

Toxic effects for each IHS were identified as those affected organ/system groups associated with non-cancer effects via groundwater ingestion. Some of the IHSs were not included in the IRIS database. For those IHSs with toxicity values from sources other than IRIS, those sources were also used to identify corresponding toxic effects. Where information was available, only chronic effects (i.e., not subchronic or acute effects) were considered for identification of toxic effects. Table D-6 identifies the individual organ/system groups affected by each IHS.

4. REFERENCES

EPA (U.S. Environmental Protection Agency). 2017. IRIS Descriptions of Organs/Systems. Available at https://www.epa.gov/iris/iris-descriptions-organssystems. Accessed June 12, 2017.

PGG (Pacific Groundwater Group). 2010. Draft Remedial Investigation Report, Ephrata Landfill. Prepared for Grant County Public Works and City of Ephrata. September 3.

PGG. 2012. Addendum to Remedial Investigation Ephrata Landfill (Agency Draft). Technical Memorandum prepared by PGG. August 28, 2012.

PGG. 2017. Remedial Investigation Addendum 2 Ephrata Landfill. Report prepared by PGG. December 22, 2017.

TABLES

Table D-1. Groundwater Data Used to Identify Indicator Hazardous Substances and Develop Cleanup Levels for Ephrata Landfill

Wells	Sampling Date Range	Number of Sampling Events
RI and Quarterly Monitoring Wells		
EW-1	April 2008 to August 2009	9
MW-29b, MW-30b, MW-31b, MW-32a, MW-37p1	November 2008 to June 2010	4
MW-39p2, MW-40p2	August 2009 to September 2010	5
MW-41a, MW-43p2	September 2009 to September 2010	4
MW-2c, MW-3b, MW-5c, MW-6c, MW-7b, MW-9b, MW-22c, MW-28d, MW-33p2, MW-35p2, MW-38p2, MW-42b, MW-44b	March 2008 to June 2017	55
Wells Installed for MPE Pilot Study and Additional Monitoring Wells Installed along the Northern POC		
MW-57b, MW-58c, MW-60p2, MW-61p1, MW-62c, MW-63b	April 2016	1

Table D-2. Identification of Initial Indicator Hazardous Substances for Groundwater

			MTCA Method B Groundwater (CLARC[1])					Groundwater				
Chemical	**CAS #**	**Units**	**Non-Cancer SFV**	**Src**	**Cancer SFV**	**Src**	**Minimum SFV**	**N**	**FOD (%)**	**Cmax**	**Cmax2**	**IHS?[2]**
1,1,1-Trichloroethane	71-55-6	µg/L	16,000	I	n/a		16,000	401	9.7	5000	4200	NO
1,1,2-Trichloroethane	79-00-5	µg/L	32	I	0.77	I	0.77	401	3.2	35	25	NO
1,1-Dichloroethane	75-34-3	µg/L	1,600	P	7.7	C	7.7	401	96.3	5200	4500	**YES**
1,1-Dichloroethene	75-35-4	µg/L	400	I	n/a		400	408	52.9	920	710	**YES**
1,2-Dichloroethane (EDC)	107-06-2	µg/L	48	X	0.48	I	0.48	401	56.9	510	440	**YES**
1,2-Dichloropropane	78-87-5	µg/L	720	A	1.2	C	1.2	401	74.3	1200	1100	**YES**
1,2,4-Trimethylbenzene	95-63-6	µg/L	n/a		n/a		n/a	401	12.2	418	370	NO
1,3-Dichlorobenzene	541-73-1	µg/L	n/a		n/a		n/a	401	8.7	4.7	1.4	NO
1,3,5-Trimethylbenzene	108-67-8	µg/L	80	X	n/a		80	401	8.5	164	160	**YES**
1,4-Dichlorobenzene	106-46-7	µg/L	560	A	8.1	C	8.1	401	47.1	32	30	**YES**
2-Butanone (methyl ethyl ketone)	78-93-3	µg/L	4,800	I	n/a		4,800	401	2.2	9000	2600	NO
2-Hexanone	591-78-6	µg/L	n/a		n/a		n/a	401	0.7	340	73	NO
2-Methylphenol (o-cresol)	95-48-7	µg/L	400	I	n/a		400	24	8.3	510	150	NO
4-Isopropyltoluene	99-87-6	µg/L	n/a		n/a		n/a	401	3.7	3.67	3.6	NO
4-Methyl-2-pentanone (MIBK)	108-10-1	µg/L	640	H	n/a		640	401	2.7	3700	1000	NO
4-Methylphenol (p-cresol)	106-44-5	µg/L	800	A	n/a		800	29	10.3	430	170	NO
Acetone	67-64-1	µg/L	7,200	I	n/a		7,200	401	15.7	26000	12000	**YES**
Arsenic	7440-38-2	µg/L	4.8	I	0.058	I	0.058	347	89.6	16.4	16.3	**YES**
Benzene	71-43-2	µg/L	32	I	0.80	I	0.80	401	50.1	180	150	**YES**
bis(2-Ethylhexyl)phthalate	117-81-7	µg/L	320	I	6.3	I	6.3	80	13.8	13	11	**YES**
Bromobenzene	108-86-1	µg/L	n/a		n/a		n/a	401	14.0	4.0	3.2	NO
Chloroethane (ethyl chloride)	75-00-3	µg/L	n/a		n/a		n/a	401	43.9	1600	970	NO
Chloroform	67-66-3	µg/L	80	I	1.4	C	1.4	401	26.7	300	280	**YES**
Chloromethane	74-87-3	µg/L	n/a		n/a		n/a	401	1.0	1.6	1.3	NO
cis-1,2-Dichloroethene	156-59-2	µg/L	16	I	n/a		16	401	92.0	1600	1100	**YES**
Ethylbenzene	100-41-4	µg/L	800	I	n/a		800	401	16.7	1700	1610	**YES**
Iron, dissolved	7439-89-6	µg/L	11,200	P	n/a		11,200	352	39.8	34000	29400	**YES**
Manganese, dissolved	7439-96-5	µg/L	2,240	I	n/a		2,240	352	91.8	23100	22000	**YES**
Methylene chloride	75-09-2	µg/L	48	I	22	I	22	401	26.7	230	230	**YES**
n-Butylbenzene	104-51-8	µg/L	400	P	n/a		400	401	2.5	3.1	2.4	NO
Naphthalene	91-20-3	µg/L	160	I	n/a		160	401	8.7	301	81	NO
Nitrate as nitrogen	14797-55-8	mg/L as N	26	I	n/a		25.6	408	70.8	24.9	24.8	NO
o-Xylene	95-47-6	µg/L	1,600	S	n/a		1,600	401	18.2	2000	1800	**YES**
sec-Butylbenzene	135-98-8	µg/L	800	X	n/a		800	401	4.2	160	2.6	NO
Tetrachloroethene (PCE)	127-18-4	µg/L	48	I	21	I	21	408	78.2	31	24	**YES**
Toluene	108-88-3	µg/L	640	I	n/a		640	401	19.2	30000	24000	**YES**
Trichloroethene (TCE)	79-01-6	µg/L	4.0	I	0.54	I	0.54	408	94.1	180	61	**YES**
Vinyl Chloride	75-01-4	µg/L	24	I	0.029	I	0.029	408	73.3	1300	1100	**YES**
Xylene M+P	1330-20-7	µg/L	1,600	I	n/a		1,600	401	13.5	4800	4100	**YES**

Definitions:

Cmax – maximum (highest) concentration.

Cmax2 – 2nd highest concentration.

FOD – frequency of detection (as a percent).

IHS – indicator hazardous substance (FOD ≥ 5% AND [Cmax ≥ 2 x mininum SFV OR Cmax2 > minimum SFV]).

n/a – no SFV available (i.e., no toxicity value available).

SFV – standard formula value.

Src – source of toxicity value used to calculate SFV: I = IRIS, P = PPRTV; X = PPRTV appendix from EPA, A = ATSDR, C = CalEPA, H = HEAST, S = other EPA sources. Consistent with CLARC SFVs based on ATSDR and CalEPA sources (both Tier 3) are shown in red font.

Notes:

[1] MTCA Method B groundwater SFVs from Ecology's CLARC Database (August 2015 Update).

[2] IHSs are chemicals that have at least 5% FOD and either (1) maximum concentration >= twice the minimum SFV or (2) maximum concentration and second highest concentration > minimum SFV.

Table D-3. Refinement of Initial Indicator Hazardous Substances for Groundwater

Initial IHS	Retain as IHS?[1]	IHS Ranking[2]	N	FOD (%)	Frequency/ Mobility Rank	Maximum Value	Minimum SFV	Hazard Quotient	Toxicity Rank	Number of Results after 2012	Number of Exceedances after 2012	Percent Exceedances after 2012	Persistence Rank
1,1-Dichloroethane	**Yes**	**11**	**401**	**96.3**	**4**	**5,200**	**7.7**	**675**	**4**	**176**	**42**	**23.9**	**3**
1,1-Dichloroethene	No	3	408	52.9	2	920	400	2.3	1	176	0	0	0
1,2-Dichloroethane (EDC)	**Yes**	**11**	**401**	**56.9**	**3**	**510**	**0.48**	**1,063**	**4**	**176**	**89**	**50.6**	**4**
1,2-Dichloropropane	**Yes**	**11**	**401**	**74.3**	**3**	**1,200**	**1.2**	**1,000**	**4**	**176**	**81**	**46.0**	**4**
1,3,5-Trimethylbenzene	No	1	401	8.5	0	164	80	2.1	0	176	4	2.3	1
1,4-Dichlorobenzene	**Yes**	**6**	**401**	**47.1**	**2**	**32**	**8.1**	**4.0**	**2**	**176**	**19**	**10.8**	**2**
Acetone	No	1	401	15.7	0	26,000	7,200	3.6	1	176	0	0	0
Arsenic	**Yes**	**11**	**347**	**89.6**	**4**	**16.4**	**0.058**	**283**	**3**	**134**	**129**	**96.3**	**4**
Benzene	**Yes**	**8**	**401**	**50.1**	**2**	**180**	**0.8**	**225**	**3**	**176**	**37**	**21.0**	**3**
bis(2-Ethylhexyl)phthalate	No	2	80	13.8	0	13	6.3	2.1	0	33	2	6.1	2
Chloroform	**Yes**	**6**	**401**	**26.7**	**1**	**300**	**1.4**	**214**	**3**	**176**	**10**	**5.7**	**2**
cis-1,2-Dichloroethene	**Yes**	**10**	**401**	**92.0**	**4**	**1,600**	**16**	**100**	**3**	**176**	**43**	**24.4**	**3**
Ethylbenzene	No	1	401	16.7	0	1,700	800	2.1	0	176	4	2.3	1
Iron, dissolved	No	3	352	39.8	2	34,000	11,200	3.0	1	175	0	0	0
Manganese, dissolved	**Yes**	**9**	**352**	**91.8**	**4**	**23,100**	**2,240**	**10**	**2**	**175**	**59**	**33.7**	**3**
Methylene chloride	No	3	401	26.7	1	230	22	10	2	176	0	0	0
o-Xylene	No	2	401	18.2	1	2,000	1600	1.3	0	176	3	1.7	1
Tetrachloroethene (PCE)	No	3	408	78.2	3	31	21	1.5	0	176	0	0	0
Toluene	No	5	401	19.2	1	30,000	640	47	2	176	6	3.4	2
Trichloroethene (TCE)	**Yes**	**12**	**408**	**94.1**	**4**	**180**	**0.54**	**333**	**4**	**176**	**97**	**55.1**	**4**
Vinyl Chloride	**Yes**	**11**	**408**	**73.3**	**3**	**1,300**	**0.029**	**44,828**	**4**	**176**	**135**	**76.7**	**4**
Xylene M+P	No	2	401	13.5	0	4,800	1600	3	1	176	4	2.3	1
Ranking Criteria				Minimum Threshold	Rank			Minimum Threshold	Rank			Minimum Threshold	Rank
80th Percentile				87.3	4			323	4			43.6	4
60th Percentile				55.3	3			79	3			16.9	3
40th Percentile				31.9	2			4	2			2.7	2
20th Percentile				17.0	1			2.2	1			0.3	1
Minimum				8.5	0			1.3	0			0	0

Definitions:

FOD – frequency of detection (as a percent).

N – number of results.

SFV – standard formula value.

Notes:

[1] IHS if IHS Ranking is 6 or higher.

[2] IHS Ranking = Frequency/Mobility Rank + Toxicity Rank + Persistence Rank.

Table D-4. Development of Initial Groundwater CULs

			MTCA Method B Groundwater		Goundwater ARARs		Downward-adjusted ARARs			
Indicator Hazardous Substance	**CAS #**	**Units**	**Non-Cancer SFV**	**Cancer SFV**	**Federal Primary MCL**	**State Primary MCL**	**Adjusted Minimum ARAR[1]**	**Hazard Quotient**	**Excess Cancer Risk**	**Initial Cleanup Level**
1,1-Dichloroethane	75-34-3	µg/L	1,600	7.7	n/a	n/a	n/a	***No MCL available.***		7.7
1,2-Dichloroethane (EDC)	107-06-2	µg/L	48	0.48	5	5	4.8	0.1000	1.00E-05	4.8
1,2-Dichloropropane	78-87-5	µg/L	720	1.2	5	5	5	0.0069	4.17E-06	5
1,4-Dichlorobenzene	106-46-7	µg/L	560	8.1	75	75	75	0.1339	9.26E-06	75
Arsenic	7440-38-2	µg/L	4.8	0.058	10	10	0.58	0.1208	1.00E-05	0.58
Benzene	71-43-2	µg/L	32	0.80	5	5	5	0.1563	6.25E-06	5
Chloroform	67-66-3	µg/L	80	1.4	80	80	14	0.1750	1.00E-05	14
cis-1,2-Dichloroethene	156-59-2	µg/L	16	n/a	70	70	16	1.0000	---	16
Manganese, dissolved	7439-96-5	µg/L	2,240	n/a	n/a	n/a	n/a	***No MCL available.***		2,240
Trichloroethene (TCE)	79-01-6	µg/L	4.0	0.54	5	5	4	1.0000	7.41E-06	4
Vinyl Chloride	75-01-4	µg/L	24	0.029	2	2	0.29	0.0121	1.00E-05	0.29

Definitions:

ARAR – applicable or relevant and appropriate requirement.

MCL – maximum contaminant level.

n/a – no SFV available (i.e., no toxicity value available).

SFV – standard formula value.

Notes:

[1] Shaded cells identify minimum ARARs that were downward-adjusted for hazard and/or cancer risk.

Table D-5. Development of Proposed Groundwater CULs

							Toxic Effect-specific Hazard Quotients (Ingestion)														
Indicator Hazardous Substance	**CAS #**	**Units**	**Initial CUL**	**Backgr. Conc.**	**Proposed Downward-adjusted CUL**	**Excess Cancer Risk**	**Cardiovascular**	**Dermal**	**Developmental**	**Endocrine System**	**Gastrointestinal**	**Hematologic**	**Hepatic**	**Immune**	**Musculoskeletal**	**Nervous**	**Ocular**	**Reproductive**	**Respiratory**	**Urinary**	**Other**
1,1-Dichloroethane	75-34-3	µg/L	7.7	-	7.7	1.00E-06	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0048	-
1,2-Dichloroethane (EDC)	107-06-2	µg/L	4.8	-	0.48	1.00E-06	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0100	-
1,2-Dichloropropane	78-87-5	µg/L	5	-	1.2	1.00E-06	-	-	-	-	-	-	-	-	0.0017	-	-	-	-	-	-
1,4-Dichlorobenzene	106-46-7	µg/L	75	-	8.1	1.00E-06	-	-	-	-	-	-	0.0145	-	-	-	-	-	-	-	-
Arsenic	7440-38-2	µg/L	0.58	14.7	14.7	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]	n/a[1]
Benzene	71-43-2	µg/L	5	-	0.8	1.00E-06	-	-	-	-	-	-	-	0.0250	-	-	-	-	-	-	-
Chloroform	67-66-3	µg/L	14	-	1.4	1.00E-06	-	-	-	-	-	-	0.0175	-	-	-	-	-	-	-	-
cis-1,2-Dichloroethene	156-59-2	µg/L	16	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9375	0.9375
Manganese, dissolved	7439-96-5	µg/L	2240	32	2240	-	-	-	-	-	-	-	-	-	-	1.0000	-	-	-	-	-
Trichloroethene (TCE)	79-01-6	µg/L	4	-	0.54	1.00E-06	0.1350	-	0.1350	-	-	-	-	-	-	-	-	-	-	-	-
Vinyl Chloride	75-01-4	µg/L	0.29	-	0.087	3.00E-06	-	-	-	-	-	-	0.0036	-	-	-	-	-	-	-	-
Total Sitewide Risk/Hazard						**1.00E-05**	**0.1350**	**0.0000**	**0.1350**	**0.0000**	**0.0000**	**0.0000**	**0.0356**	**0.0250**	**0.0017**	**1.0000**	**0.0000**	**0.0000**	**0.0000**	**0.9523**	**0.9375**

Definitions:

CUL – cleanup level.
n/a – not applicable.

Notes:

[1] Since the background concentration for dissolved arsenic (14.7 µg/L; see Appendix D) is higher than the lowest applicable standard (and PQL), the CUL cannot be set lower than the background level (per WAC 173-340-720(5)), and this IHS is not included in the calculations for total site risk and hazard.

Table D-6. Organs/Systems Affected by Each Indicator Hazardous Substance (Chronic Non-cancer Effects Only for Ingestion)

			Organ/System														
Chemical[1]	**CAS #**	**Source**[2]	**Cardiovascular**	**Dermal**	**Developmental**	**Endocrine System**	**Gastrointestinal**	**Hematologic**	**Hepatic**	**Immune**	**Musculoskeletal**	**Nervous**	**Ocular**	**Reproductive**	**Respiratory**	**Urinary**	**Other**
1,1-Dichloroethane	75-34-3	P														X	
1,2-Dichloroethane (EDC)	107-06-2	X														X	
1,2-Dichloropropane	78-87-5	P									X						
1,4-Dichlorobenzene	106-46-7	A							X								
Arsenic	7440-38-2	I	X	X													
Benzene	71-43-2	I								X							
Chloroform	67-66-3	I							X								
cis-1,2-Dichloroethene	156-59-2	I														X	X
Manganese, dissolved	7439-96-5	I										X					
Trichloroethene (TCE)	79-01-6	I	X		X												
Vinyl Chloride	75-01-4	I							X								

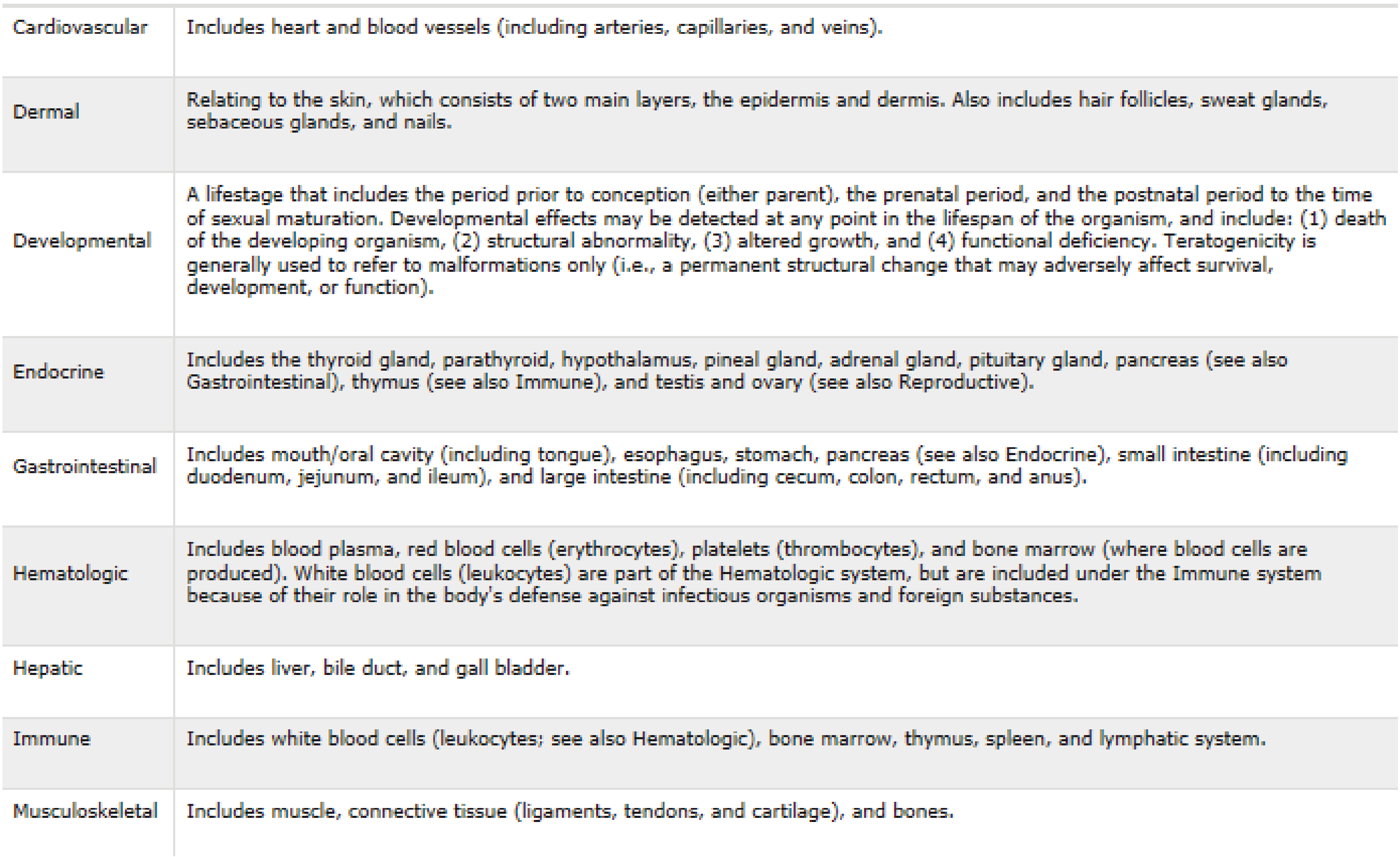
Notes:

[1] Chemicals identified as final indicator hazardous substances for development of proposed cleanup levels.

[2] Toxicity value sources: I = IRIS, P = PPRTV, X = PPRTV appendix (EPA), A = ATSDR, C = CalEPA. SFVs based on ATSDR and CalEPA sources (both Tier 3) are shown in red font.

Table D-6. Organs/Systems Affected by Each Indicator Hazardous Substance (Chronic Non-cancer Effects Only for Ingestion) (continued)

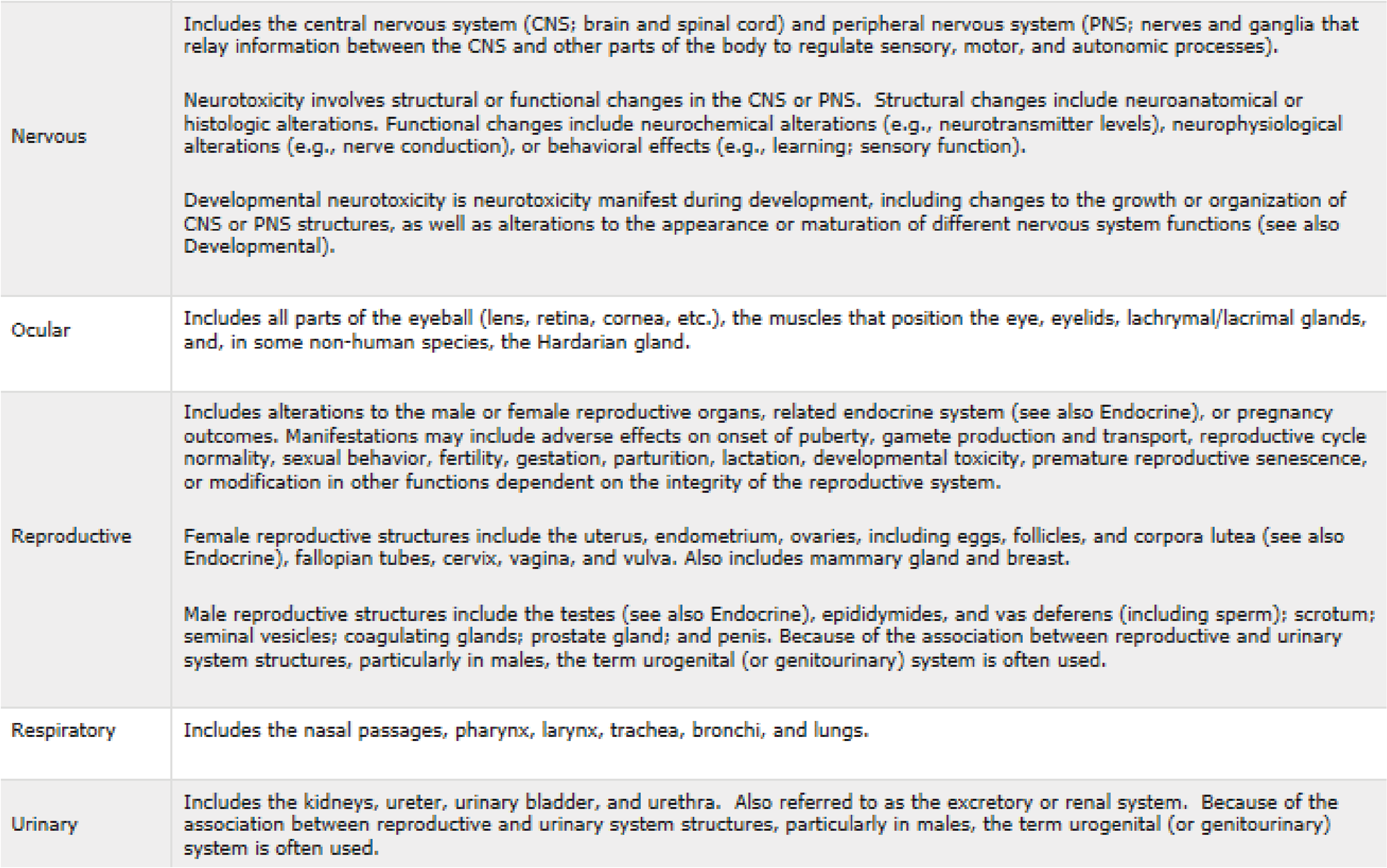
IRIS Organs/Sytems:



Cardiovascular	Includes heart and blood vessels (including arteries, capillaries, and veins).
Dermal	Relating to the skin, which consists of two main layers, the epidermis and dermis. Also includes hair follicles, sweat glands, sebaceous glands, and nails.
Developmental	A lifestage that includes the period prior to conception (either parent), the prenatal period, and the postnatal period to the time of sexual maturation. Developmental effects may be detected at any point in the lifespan of the organism, and include: (1) death of the developing organism, (2) structural abnormality, (3) altered growth, and (4) functional deficiency. Teratogenicity is generally used to refer to malformations only (i.e., a permanent structural change that may adversely affect survival, development, or function).
Endocrine	Includes the thyroid gland, parathyroid, hypothalamus, pineal gland, adrenal gland, pituitary gland, pancreas (see also Gastrointestinal), thymus (see also Immune), and testis and ovary (see also Reproductive).
Gastrointestinal	Includes mouth/oral cavity (including tongue), esophagus, stomach, pancreas (see also Endocrine), small intestine (including duodenum, jejunum, and ileum), and large intestine (including cecum, colon, rectum, and anus).
Hematologic	Includes blood plasma, red blood cells (erythrocytes), platelets (thrombocytes), and bone marrow (where blood cells are produced). White blood cells (leukocytes) are part of the Hematologic system, but are included under the Immune system because of their role in the body's defense against infectious organisms and foreign substances.
Hepatic	Includes liver, bile duct, and gall bladder.
Immune	Includes white blood cells (leukocytes; see also Hematologic), bone marrow, thymus, spleen, and lymphatic system.
Musculoskeletal	Includes muscle, connective tissue (ligaments, tendons, and cartilage), and bones.

Table D-6. Organs/Systems Affected by Each Indicator Hazardous Substance (Chronic Non-cancer Effects Only for Ingestion) (continued)

IRIS Organs/Sytems (continued):



Nervous	Includes the central nervous system (CNS; brain and spinal cord) and peripheral nervous system (PNS; nerves and ganglia that relay information between the CNS and other parts of the body to regulate sensory, motor, and autonomic processes). Neurotoxicity involves structural or functional changes in the CNS or PNS. Structural changes include neuroanatomical or histologic alterations. Functional changes include neurochemical alterations (e.g., neurotransmitter levels), neurophysiological alterations (e.g., nerve conduction), or behavioral effects (e.g., learning; sensory function). Developmental neurotoxicity is neurotoxicity manifest during development, including changes to the growth or organization of CNS or PNS structures, as well as alterations to the appearance or maturation of different nervous system functions (see also Developmental).
Ocular	Includes all parts of the eyeball (lens, retina, cornea, etc.), the muscles that position the eye, eyelids, lachrymal/lacrimal glands, and, in some non-human species, the Hardarian gland.
Reproductive	Includes alterations to the male or female reproductive organs, related endocrine system (see also Endocrine), or pregnancy outcomes. Manifestations may include adverse effects on onset of puberty, gamete production and transport, reproductive cycle normality, sexual behavior, fertility, gestation, parturition, lactation, developmental toxicity, premature reproductive senescence, or modification in other functions dependent on the integrity of the reproductive system. Female reproductive structures include the uterus, endometrium, ovaries, including eggs, follicles, and corpora lutea (see also Endocrine), fallopian tubes, cervix, vagina, and vulva. Also includes mammary gland and breast. Male reproductive structures include the testes (see also Endocrine), epididymides, and vas deferens (including sperm); scrotum; seminal vesicles; coagulating glands; prostate gland; and penis. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.
Respiratory	Includes the nasal passages, pharynx, larynx, trachea, bronchi, and lungs.
Urinary	Includes the kidneys, ureter, urinary bladder, and urethra. Also referred to as the excretory or renal system. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.

Appendix E

Background Arsenic Concentrations in Groundwater for the Ephrata Landfill Remedial Investigation/Feasibility Study

Technical Memorandum

To: Charlie Wisdom and Linda Logan (Parametrix, Inc.)

From: Dawn Chapel and Charles Ellingson (Pacific Groundwater Group)

Re: Background Arsenic Concentrations in Groundwater for the Ephrata Landfill RI/FS

Date: January 25, 2011

This memorandum provides an improved assessment of background concentrations for dissolved arsenic in groundwater for the Ephrata Landfill RI/FS. An arsenic background concentration of 3.0 ug/L was presented in the Remedial Investigation Report (PGG, 2010b) [1]. The RI value was based on groundwater data collected from 18 wells completed in basalt aquifers with concentrations ranging from 0.10 to 4.30 ug/L (Table 1). The wells chosen for the RI assessment were those that did not have detections of volatile organic compounds (VOCs) and were therefore not likely impacted by the Landfill. However, it was noted in the RI that arsenic concentrations were generally higher in the Outwash aquifer with concentrations ranging from 2.5 to 10.0 ug/L. The higher concentration of arsenic in the Outwash aquifer is likely natural and related to differences in aquifer mineralogy; however; groundwater data from Outwash aquifer wells were not used in the RI assessment because of low level detections of VOCs.

The imroved assessment presented in this memo includes expanding the groundwater arsenic dataset to include data from the U.S. Geological Survey (USGS) National Water Quality Assessment (NAWQA) for Grant County. Inclusion of the NAWQA dataset expands the arsenic dataset from 18 wells to 51 wells (Table 1). Using the same approach as presented in the RI to define background, a Shapiro-Wilkes W-test for normality was performed on the expanded dataset. The results indicate the expanded dataset is best approximated as a log-normal distribution and, in accordance with MTCA (WAC 173-340-709), the 90th percentile of the expanded dataset is therefore used to define background. Based on this analysis, the more appropriate background value for dissolved arsenic in groundwater for the RI/FS is 14.7 ug/L (Table 2).

The following paragraphs provide a more detailed summary of the updated assessment.

The background concentration of dissolved arsenic in groundwater was updated by expanding the RI background dataset to include additional groundwater data from the USGS NAWQA dataset for Grant County, Washington. The Grant County NAWQA dataset includes 33 sample stations with sample dates ranging from 2002 to 2010. NAWQA sample stations are located mainly south of the Ephrata Landfill (Figure 1). NAWQA stations were either sampled once in 2002 or five times during the eight year period. For stations sampled multiple times, the maximum con-

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[1] The RI background arsenic concentration is based on the 80th percentile of the dataset. A Shaprio-Wilkes test for non-normality indicated the dataset more closely matched a normal distribution compared to a log-normal distribution. Based on WAC 173-340-709, the 80th percentile is used to define background for normal distributions.

centration was used, which is similar to the approach used with the RI dataset (PGG, 2010b). Concentrations of dissolved arsenic in groundwater from the NAWQA dataset[2] range from 0.90 to 45.42 ug/L (Table 1 and Figure 1).

Although aquifer information is not provided in the NAWQA dataset, most NAWQA wells are fairly shallow (less than 50 feet deep), suggesting many are completed in the Outwash aquifer. The distributions of the RI and NAWQA datasets overlap (Figure 2).

Using the same approach as presented in the RI to define background, a Shapiro-Wilkes W-test for normality was performed on the expanded dataset. In accordance with WAC 173-340-709, background concentrations are defined as the upper 90th percentile for log-normally distributed data, the upper 80th percentile for normally distributed data, or four times the 50th percentile for either distribution if this value is lower. The results of the statistical test indicate the distribution of the expanded dataset is best approximated as log-normal and background is defined as the 90th percentile, 14.7 ug/L (Table 2).

State of Washington
Hydrogeologist
2651
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Dawn Chapel

Dawn Chapel

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[2] One NAWQA sample had a very high concentration of 116.39 ug/L (USGS Station ID 465748119340601). This sample was considered an outlier and omitted from the analysis.

Table 1. Data Used to Define Background Concentrations of Dissolved Arsenic in Groundwater

Station ID	Data Source[1 and 2]	Concentration (ug/L)
Bolyard Deep	Ephrata Landfill RI	0.10
MW-50c	Ephrata Landfill RI	0.60
MW-52p2	Ephrata Landfill RI	0.70
MW-49p2	Ephrata Landfill RI	0.70
MW-4c	Ephrata Landfill RI	1.00
Olivares	Ephrata Landfill RI	1.00
MW-48b	Ephrata Landfill RI	1.60
MW-47c	Ephrata Landfill RI	1.70
MW-51b	Ephrata Landfill RI	2.00
MW-16d	Ephrata Landfill RI	2.00
Country Boys	Ephrata Landfill RI	2.20
Gutierrez-ACE908	Ephrata Landfill RI	2.40
Bohr	Ephrata Landfill RI	2.50
MW-20c	Ephrata Landfill RI	3.00
Gutierrez-ABO220	Ephrata Landfill RI	3.10
Atkins New	Ephrata Landfill RI	3.40
Atkins Old	Ephrata Landfill RI	4.00
Moore	Ephrata Landfill RI	4.30
464535119430501	USGS NAWQA	0.89
470844119182501	USGS NAWQA	1.68
471449119522801	USGS NAWQA	1.83
473008119174901	USGS NAWQA	2.57
465325119405201	USGS NAWQA	3.04
465631119432901	USGS NAWQA	3.13
470904119190401	USGS NAWQA	3.32
465533119344601	USGS NAWQA	3.36
465755119254901	USGS NAWQA	3.47
465319119305701	USGS NAWQA	4.44
465531119315501	USGS NAWQA	4.48
465303119284201	USGS NAWQA	4.73
465852119210801	USGS NAWQA	4.86
470759119143101	USGS NAWQA	4.91
470805119140501	USGS NAWQA	4.98
471120119485901	USGS NAWQA	5.52
475205119050401	USGS NAWQA	5.79
465457119214701	USGS NAWQA	6.57
470801119293601	USGS NAWQA	7.49
464418119432901	USGS NAWQA	7.76
465330119243001	USGS NAWQA	8.34
470850119323501	USGS NAWQA	8.62
470145119131101	USGS NAWQA	10.21
470803119480001	USGS NAWQA	11.40
470430119334801	USGS NAWQA	11.41
471013119433401	USGS NAWQA	11.41
465509119371501	USGS NAWQA	13.50
465958119080301	USGS NAWQA	14.68
475119119074001	USGS NAWQA	15.54
470152119432301	USGS NAWQA	20.55
470056119063801	USGS NAWQA	41.19
465738119322001	USGS NAWQA	44.19
465821119365401	USGS NAWQA	45.42

Notes

1 . Data from RI/FS wells were the same as presented in the RI report (PGG, 2010b).
The RI wells included Site monitoring wells and sampled private wells that did not have detections of volatile organic compounds (VOCs).
RI well values are the maximum concentration observed in each well since 2001.

2. Except for a single outlier value of 116.4 ug/L at station #465748119340601, USGS values include all NAWQA groundwater samples collected in Grant County for analysis of dissolved arsenic.
USGS data were collected between 2002 and 2010. Stations were either sampled once in 2002 or five times over the 8 year period.
For stations sampled on five occassions, the maximum value was used.

Table 2. Statistics and Background Concentrations of Dissolved Arsenic in Groundwater

Statistics/Background	Value
No. Stations	51
p-value (normal-dist.)[1]	0.00
p-value (log normal dist.)[1]	0.29
minimum (ug/L)[2]	0.10
maximum (ug/L)	45.42
mean (ug/L)	7.40
50th Percentile (ug/L)	4.00
80th Percentile (ug/L)	10.21
90th Percentile (ug/L)	14.68
Background (ug/L)[3]	14.68

Notes

1. p-values are from Shapiro-Wilk W test for non-normality. A low p-value (<0.05) rejectes these data as being from a normal or log normal distribution
   For the purposes of defining background, a log normal distribution was assumed (test with the higher p-value)
2. Values are in micrograms-per-liter (ug/L)
3. Background defined as 90th percentile for log normal distribution in accordance with WAC 173-340-209

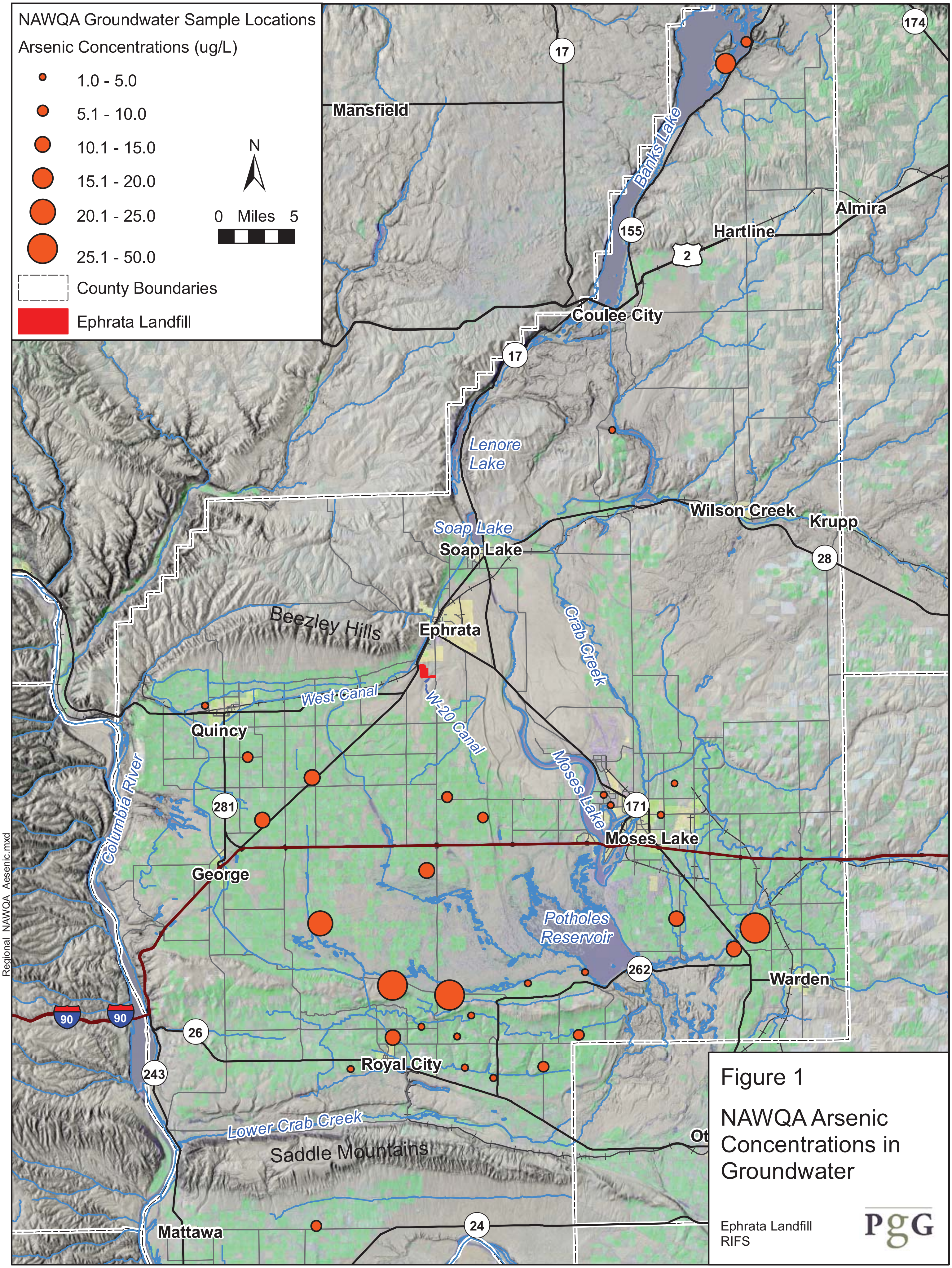

Figure 1

NAWQA Arsenic Concentrations in Groundwater

Ephrata Landfill
RIFS

PGG

Regional NAWQA Aesenic.mxd

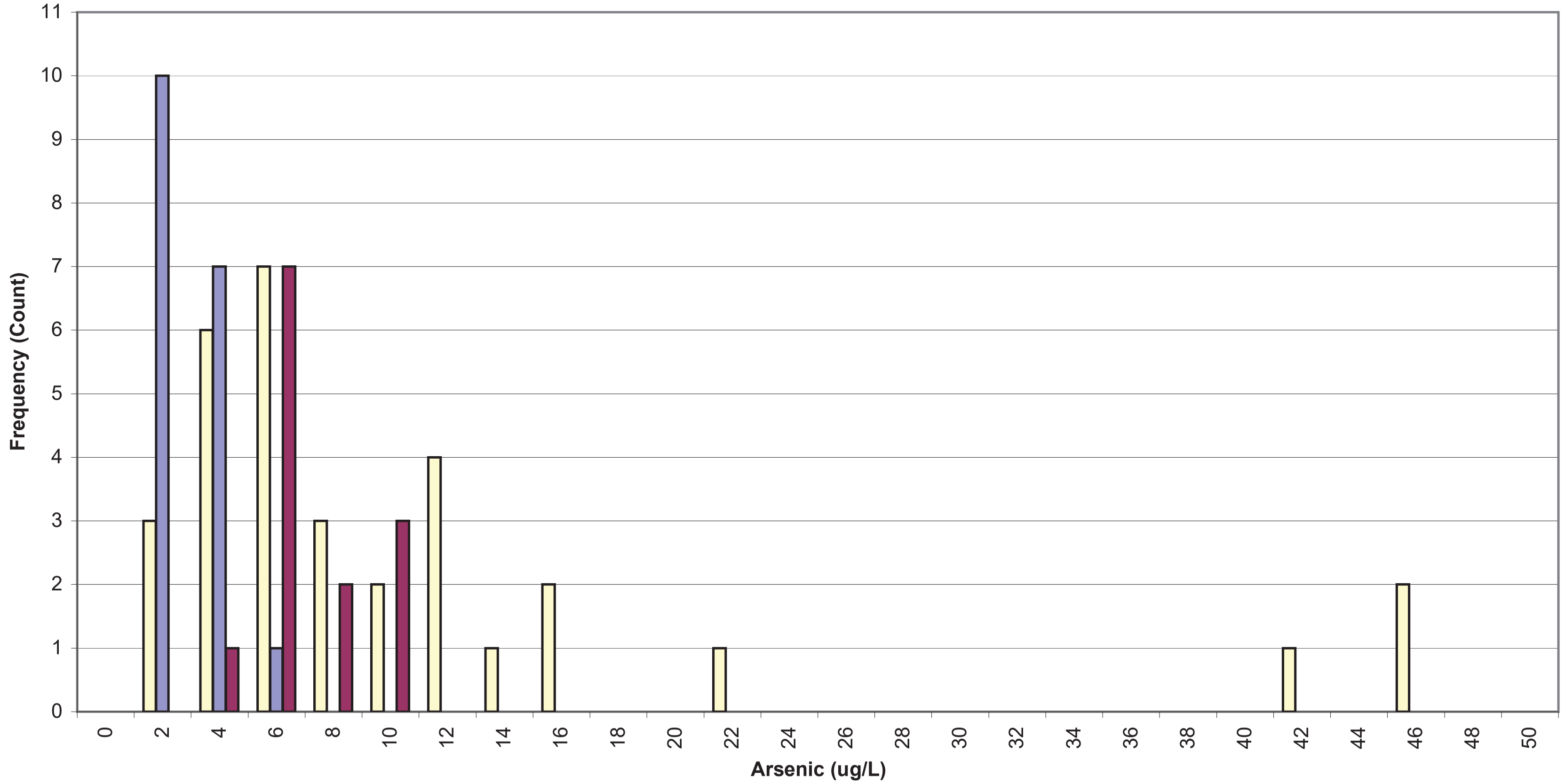

Figure 2. Distribtuion of Dissolved Arsenic Concentation in Groundwater

Ephrata RI/FS
JE0714

PgG

Appendix F

Wastewater Disposal or Circulation to Ground

CELEBRATING 25 years
PACIFIC groundwater GROUP

Internal Technical Memorandum

To: Brian Pippin and Blaine Hardy (Parametrix, Inc.)
From: Pony Ellingson and Dawn Chapel (Pacific Groundwater Group)
Re: Wastewater Disposal or Circulation to Ground
Date: April 17, 2012

State of Washington
Hydrogeologist
631
Licensed Geologist
Charles Ellingson

This memo responds to Parametrix' request for evaluation of ground-based water disposal options for potential remedial actions at Ephrata Landfill. Discharges up to 15 gpm are possible, which would be derived from remedial groundwater extraction from the Roza aquifer, Hole, and P1 source zone (in order of decreasing discharge rate).

1) DEFINITIONS
   a) *Percolate* means to dispose of water to the ground above the water table. Galleries, infiltration ponds, and dry wells all percolate.
   b) *Inject* means to force water into a well that is completed below the water table.
   c) *Disposal* means to percolate or inject water from the treatment system to the ground, without the intent of enhancing source removal or hydraulic control.
   d) *Circulation* means to percolate or inject water from the treatment system into the ground with intent to enhance remediation. Two circulation schemes are considered:
      i) *Gradient control* means to percolate or inject the water where it will create a groundwater mound or ridge that helps control contaminant migration.
      ii) *Flushing* means to percolate or inject the water where it will encounter contaminants and help flush them from a source zone towards extraction wells.

2) REGULATIONS
   a) WAC 173-200. Groundwater Quality Criteria. Regulation that requires discharges of waste to the ground to be treated to AKART. Includes "anti-degradation" policy. Based on background groundwater quality or in the absence of background, numeric criteria which are similar to Drinking Water MCLs, but more extensive. Check with Ecology Toxics Cleanup Program for possible exemptions to treatment standards within hydraulically controlled areas undergoing remediation.
   b) WAC 173-216 State Waste Discharge Permit program. Requires all discharges of wastewater to the ground to be permitted. Uses Groundwater Quality Criteria as performance standard.
   c) WAC 173-340 MTCA. Cleanup regulation. Regulation does not deal directly with disposal or circulation of treated wastewater but precedent exists in State. Contact Toxics Cleanup Program to improve understanding of disposal and circulation at remediation sites.
   d) WAC 173-218 Underground Injection Control (UIC). Classifies/prohibits/permits injection wells. Class V wells include "injection wells used for remediation wells receiving

fluids intended to clean up, treat or prevent subsurface contamination" (WAC 173-218(a)(x)). Ecology UIC coordinator referred PGG to Toxics Cleanup Program for details on Class V UIC wells used in remediation projects regulated by the State. PGG did not follow up with Toxics Cleanup Program.

3) QUALITATIVE INPUT

UIC Well

Any well used for percolation or injection would be a Class V UIC well. We found no written restriction on which formation a Class V well can discharge to[1] but discussion with Ecology TCP is warranted at some point.

Circulation

We do not recommend circulation in the P1 source zone unless application of surfactants or heat shows this to be better than other source reduction actions. It would be possible to circulate groundwater through the P1 source zone and enhance removal of source mass; however, the high source mass and comparatively low groundwater concentrations for PCE at the source indicates that without addition of surfactants or heat, this action is not likely to be competitive with non-groundwater source removal actions (eg: SVE). Circulation would conflict with SVE because it would raise the water level in P1 and reduce the vadose zone where SVE is effective. Therefore we do not recommend this action unless surfactants or heat are evaluated and found to be better than other actions.

Circulation in the Hole is not recommended because it would require increasing water levels within refuse. The Hole and high Transmissivity (T) Roza zone provide the only high T zones where capture of contaminants can occur with relatively few wells. The bounded nature of both of these high T zones promotes containment and capture, without circulation.

Circulation in the Roza aquifer high T zone is not recommended. The high T zone is where we want to focus drawdown to capture contaminants both locally and from considerable distance to the east with the goal of capturing the entire Roza plume at the property boundary. Although we might be able to finesse the areas where heads are lowered by pumping (property line), and raised by injection (possibly near MW-9b), the overall effect would be to *reduce drawdown*. We thus expect circulation in the high T zone to reduce our ability to capture contaminants from the Roza in areas remote from the pumping center (eg: low T zone) which would reduce our ability to capture the entire Roza plume at the property boundary.

Circulation by injection into the Roza low T zone (eg: near MW-44b and Whitson) might be used to reverse groundwater flow and enhance capture of the northerly plume from extraction wells placed at the property boundary in the high T zone. However, many wells would be required to dispose of 15 gpm in the low T zone. PGG will evaluate this option further if requested.

Disposal

Because of the small footprint of the local high-T Roza zone, it would not be possible to dispose of water there without influencing the Roza extraction system. Thus the effect of disposal is similar to circulation and is not recommended.

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[1] Class IV wells must discharge to the formation the water came from.

The outwash formation is preferred for water disposal. From a hydraulic standpoint the outwash aquifer is an easy formation in which to percolate or inject water. Its use would not interfere with any remedial action, and it is not used for water supply. Percolation is generally more favorable than injection because it should be cheaper and in some cases reduces regulatory hurdles and treatment requirements. Substantial thicknesses of unsaturated outwash occur west, east, and south of the landfill. Percolation through a small infiltration pond should be possible to the east or south, whereas a dry well (UIC) would likely be required to the west because silt occurs at land surface (above the outwash).

Permitting an infiltration pond likely requires a State Waste Discharge permit. It should be possible to obtain if treatment standards meet AKART and water quality meets numerical groundwater quality criteria of WAC 173-200. The permit conditions might focus on assuring that infiltration does not occur if the treatment system fails. Use of a dry well to the west might require a UIC permit in addition to a State Waste Discharge Permit.

Disposal memo v1 041812*.docx*
JE0714

Appendix G

P1 Vapor Phase VOC Removal Calculations

Parametrix
ENGINEERING . PLANNING . ENVIRONMENTAL SCIENCES

719 2ND AVENUE, SUITE 200 | SEATTLE, WA 98104 | P 206.394.3700

TECHNICAL MEMORANDUM

DATE:	March 29, 2018
TO:	Grant County Public Works and City of Ephrata
FROM:	Brian Pippin, PE
SUBJECT:	P1 Vapor Phase VOC Removal Calculations
CC:	File
PROJECT NUMBER:	553-1860-012
PROJECT NAME:	Ephrata Landfill RI/FS Engineering Services

INTRODUCTION

This memo summarizes calculations of vapor-phase volatile organic compound (VOC) removal from the P1 zone. These calculations support cleanup action alternatives described in the revised draft feasibility study (FS) (Parametrix 2018). In summary, vapor-phase VOC removal observations during the multi-phase extraction (MPE) pilot test (pilot test), which are summarized in the pilot test interim remedial action report (Parametrix and Pacific Groundwater Group [PGG] 2018), were used to develop a straightforward vapor-phase VOC removal model, which was then applied to MPE alternatives evaluated in the FS.

BRIAN PIPPIN
30383
03-29-18

EVALUATION OF PILOT TEST OBSERVATIONS

The pilot test interim remedial action report (Parametrix and PGG 2018) describes vapor extraction from two P1 wells (MW-34p1 and MW-68p1). This involved vapor extraction at three system vacuum settings (3.5, 7.0, and 12.5 in. Hg) with corresponding average vapor flows of 40, 60, and 75 standard cubic feet per minute (scfm), respectively. Excluding outliers, 17 vapor samples collected from July 3 to October 3, 2017, were analyzed. The total VOC concentration results fit the following exponential decay equation:

$$C_t = C_0 e^{kt}$$

Where: C_t = VOC concentration on day t (ppm)
C_0 = Starting VOC concentration (ppm)
e = Euler's number ≈ 2.71828 (a mathematical constant)
k = Constant (1/day)
t = Elapsed time (days)

Pilot test observations, excluding outliers, fit the above exponential decay equation with C_0 = 590.17 ppm and k = -0.041/day with a Pearson product moment correlation coefficient of R^2 = 0.8742. The cumulative VOC removal was calculated by multiplying the time interval since the prior sample (number of days) by the average concentration during that interval (ppm) and flow (scfm). This involved conversion based on the molar volume (24.45 L/mol) and a weighted average molar mass of the P1 VOC concentrations during the pilot test (99.2 g/mol), which is largely weighted by observed toluene, xylene, and ethylbenzene concentrations. Although the above exponential model asymptotically approaches zero concentration within 1 year, it is more likely that some small but finite total VOC concentration will be observed in extracted P1 vapor for some time. That would increase VOC removal over time, but not enough to significantly alter comparisons or conclusions in the FS; thus, this small amount is excluded from these calculations. Figure 1 shows the observed total VOC concentrations and cumulative removal and the modeled values. Further details are provided in the attached calculation tables.

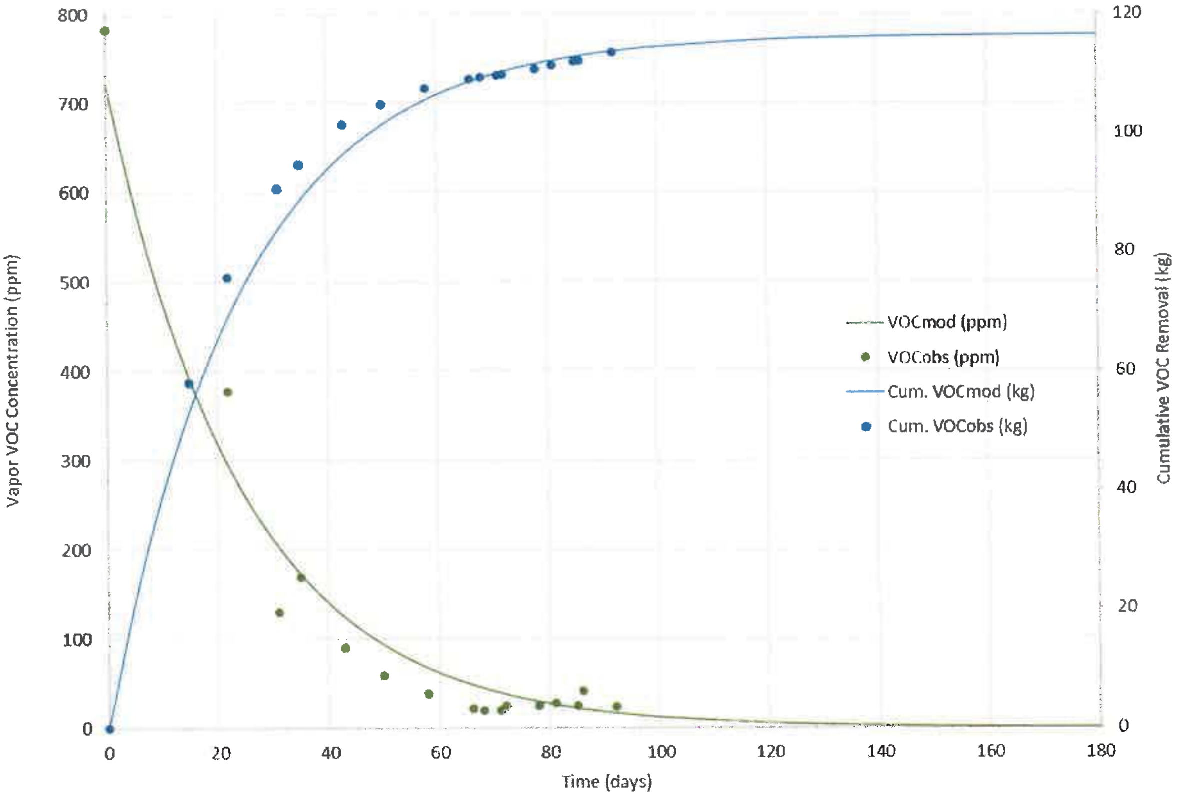

Figure 1. Observed v. Modeled P1 Vapor Phase VOC Removal During Pilot Test

Figure 2, which is Figure 1 from Hiller and Gudemann 1989, demonstrates the consistency of the above concentration model with published findings. The report depicts six case studies of PCE and TCE vapor extraction and is reported to also be representative for soil vapor extraction (SVE) sites involving aromatic hydrocarbons. The report also describes that longer-term contaminant removal at low rates can be significant compared to the initial high removal rates, which decrease rapidly. Longer term contaminant removal at low concentration might not be well predicted by the exponential decay model discussed above.

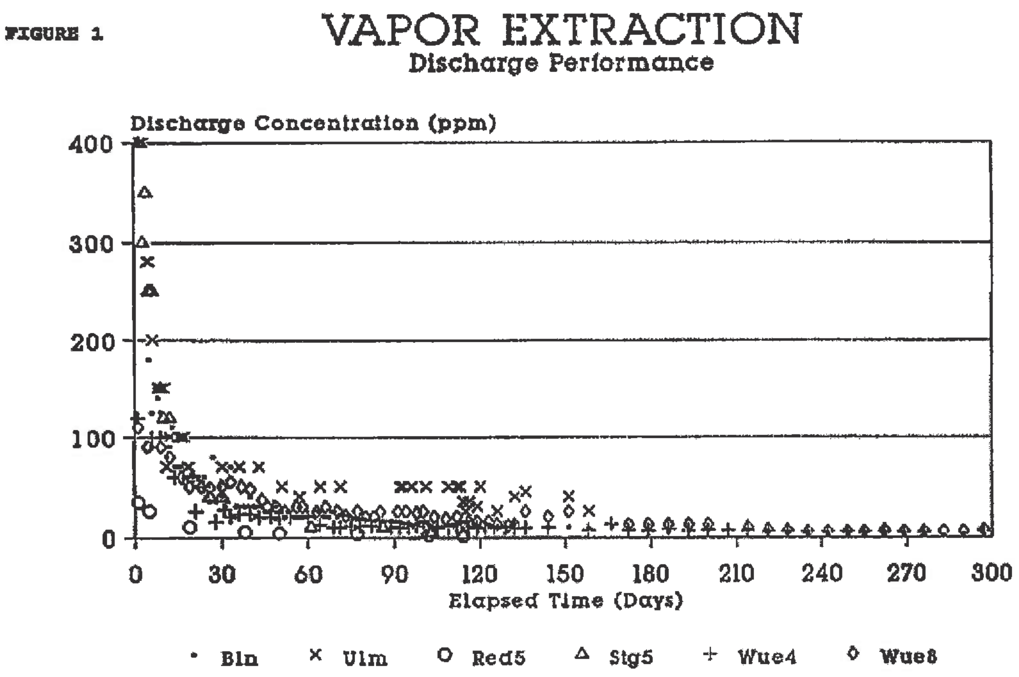

Figure 2. Figure 1 from Hiller and Gudemann (1989).

As mentioned above, the pilot test was performed at three vacuum settings, which corresponded with three flow rates. The cumulative mass removal calculations rely on flow as one variable. The concentration model above does not include flow. Since over 80 percent of the vapor-phase VOC mass removal during the pilot test occurred during the 3.5 in. Hg and 40 scfm step, flow increases were excluded and these cumulative flow calculations were based on a constant 40 scfm. Had the pilot test been performed entirely at 3.5 inches-Hg and 40 scfm, the same total VOC concentrations and cumulative mass removal would likely have been achieved in a slightly longer time interval.

PROJECTION FOR EXISTING MPE SYSTEM

The FS evaluates resumption of existing MPE system operation as one cleanup action alternative (Alternative 1 in the FS). Since dissolved and vapor-phase VOCs were removed from the P1 zone during the pilot test, the initial vapor-phase total VOC concentration when vapor extraction with the existing system resumes is assumed to be less than the concentrations observed when vapor extraction first started (i.e., 782 ppm excluding outliers). Projections for Alternative 1 assume the following:

- Initial vapor-phase total VOC concentration of 500 ppm
- 3.5 in. Hg vacuum
- 40 scfm vapor flow

Using these variables in the VOC removal model results in 81 kg of total VOCs removed in the first year, as shown in the attached calculation tables. However, actual total VOC removal might increase slightly over time depending on asymptotic VOC concentrations.

PROJECTION FOR EXPANDED MPE SYSTEM

The FS also evaluates expansion of the MPE system with new extraction and monitoring wells in the P1 zone (Alternative 2 in the FS). New MPE wells are expected to produce lower vapor flow on average because P1 permeability is expected to be lower on average than observed in the pilot test MPE wells. However, new wells closer to the drum area are assumed to have a starting total VOC concentration of 700 ppm, similar to the observed starting concentration during the pilot test. For Alternative 2, the average vapor yield per new well is based on pilot test observations of MW-68p1 at 3.5 in. Hg, which was about 13 scfm (i.e., 52 scfm with four wells). MW-68p1 yielded lower vapor flow than MW-34p1 during the pilot test and is considered to be representative of likely vapor yields in the expansion area. Projections for the expansion area in Alternative 2 assume the following:

- Initial vapor-phase total VOC concentration of 700 ppm
- 3.5 in. Hg vacuum
- 52 scfm vapor flow

Using these variables in the expansion area, the VOC removal model results in 147 kg of total VOCs removed from new wells in the first year, for a total of 228 kg including the existing MPE well production, as shown in the attached calculation tables. However, actual total VOC removal might increase slightly over time depending on asymptotic VOC concentrations.

REFERENCES

Hiller, D. and H. Gudemann. 1989. Analysis of vapor extraction data from applications in Europe. Proceedings of Third International Conference on New Frontier for Hazardous Waste Management (September 10-13). EPA/600/8-89/072. Pittsburgh, PA.

Parametrix. 2018. Revised Draft Ephrata Landfill Feasibility Study. Prepared by Parametrix, Seattle, WA. March 2018.

Parametrix and Pacific Groundwater Group. 2018. Multi-Phase Extraction Pilot Test Interim Remedial Action Ephrata Landfill. Prepared by Parametrix, Seattle, WA. February 2018.

VOC vapor model

VOC Removal Model

Day	VOC_{mod} (ppm)	Cum. VOC_{mod} (kg)
0	720	0
5	587	22
10	478	39
15	389	53
20	317	65
25	258	75
30	210	82
35	171	89
40	140	94
45	114	98
50	93	101
55	76	104
60	62	106
65	50	108
70	41	110
75	33	111
80	27	112
85	22	113
90	18	113
95	15	114
100	12	114
120	5.3	116
140	2.3	116
160	1.0	116
180	0.449	116
365	0.000	117
730	0.000	117

Variable	Description	
40	x (ft3/m), standard, based on observed 2 well flow at 3.5 in. Hg	
720	C0 (ppm)	590 ppm is the y intercept of an exponential curve fit of P1 vapor results
-0.041	k	-0.041 is the decay coefficient of an exponential curve fit of P1 vapor results
99.2	M (g/mol), bM = 99.2 (g/mol), bulk vapor, based on average of observed toluene, xylene, and ethylbenzene concentrations	

Equations

ppm=(ug/m3)*24.45/M/1000 https://www.markes.com/Resources/Frequently-asked-questions/How-do-I-convert-units.aspx

ug/m3=1000*ppm*M/24.45

ug/ft3 = ug/m3*(0.028317)m3/ft3

ug/min = ug/ft3*(x)ft3/min

ug/day = ug/min*1440min/day

kg/day = ug/day*1e-9 kg/ug

Preliminary Calculation

1.65E-04	1.00E-09	1440	0.028317	1000	24.5
	kg/ug	min/day	m3/ft3	L/m3	L/mol

Model: $C_t = C_0e^{kt}$

Alt 1 model

VOC Removal Model - Alt. 1, Restart Existing MPE

Day	VOC_{mod} (ppm)	Cum. VOC_{mod} (kg)
0	500	0
5	407	15
10	332	27
15	270	37
20	220	45
25	179	52
30	146	57
35	119	62
40	97	65
45	79	68
50	64	70
55	52	72
60	43	74
65	35	75
70	28	76
75	23	77
80	19	78
85	15	78
90	12	79
95	10	79
100	8	79
120	3.6	80
140	1.6	81
160	0.7	81
180	0.312	81
365	0.000	81
730	0.000	81

Variable	Description	
40	x (ft3/m), standard, based on observed 2 well flow at 3.5 in. Hg	
500	C0 (ppm)	590 ppm is the y intercept of an exponential curve fit of P1 vapor results
-0.041	k	-0.041 is the decay coefficient of an exponential curve fit of P1 vapor results
99.2	M (g/mol), 1M = 99.2 (g/mol), bulk vapor, based on average of observed toluene, xylene, and ethylbenzene concentrations	

Equations

ppm=(ug/m3)*24.45/M/1000 https://www.markes.com/Resources/Frequently-asked-questions/How-do-I-convert-units.aspx

ug/m3=1000*ppm*M/24.45

ug/ft3 = ug/m3*(0.028317)m3/ft3

ug/min = ug/ft3*(x)ft3/min

ug/day = ug/min*1440min/day

kg/day = ug/day*1e-9 kg/ug

Preliminary Calculation

1.65E-04	1.00E-09	1440	0.028317	1000	34.5
	kg/ug	min/day	m3/ft3	L/m3	L/mol

Model: $C_t = C_0 e^{kt}$

Alt. 1

MW-34p1 & MW-68p1, 3.5 in. Hg, 40 scfm, C_0 = 500 ppm

Alt 2 model

VOC Removal Model - Alt. 2, Restart Existing and Add Four MPE Wells

Day	VOC_{mod} (ppm)	Cum. VOC_{mod} (kg)	Combined Cum. VOC_{mod} (kg)
0	700	0	0
5	570	27	42
10	465	49	77
15	378	68	105
20	308	82	128
25	251	94	146
30	205	104	161
35	167	112	174
40	136	119	184
45	111	124	192
50	90	128	199
55	73	132	204
60	60	135	208
65	49	137	212
70	40	139	215
75	32	140	217
80	26	142	219
85	21	143	221
90	17	143	222
95	14	144	223
100	12	145	224
120	5.1	146	226
140	2.3	147	227
160	1.0	147	228
180	0.437	147	228
365	0.000	147	228
730	0.000	147	228

Variable	Description
52	x (ft3/m), standard, based on observed 2 well flow at 3.5 in. Hg
700	C0 (ppm) 590 ppm is the y intercept of an exponential curve fit of P1 vapor results
-0.041	k -0.041 is the decay coefficient of an exponential curve fit of P1 vapor results
99.2	M (g/mol), M = 99.2 (g/mol), bulk vapor, based on average of observed toluene, xylene, and ethylbenzene concentrations

Equations

ppm=(ug/m3)*24.45/M/1000 https://www.markes.com/Resources/Frequently-asked-questions/How-do-I-convert-units.aspx

ug/m3=1000*ppm*M/24.45

ug/ft3 = ug/m3*(0.028317)m3/ft3

ug/min = ug/ft3*(x)ft3/min

ug/day = ug/min*1440min/day

kg/day = ug/day*1e-9 kg/ug

Preliminary Calculation

1.65E-04	1.00E-09	1440	0.028317	1000	24.5
	kg/ug	min/day	m3/ft3	L/m3	L/mol

Model: $C_t = C_0 e^{kt}$

Alt. 2

Four new MPE wells, 3.5 in. Hg, 52 scfm, C0 = 700 ppm

(adds 4 wells at assumed lower air permeability and higher C0)

Appendix H

Detailed Cost Estimates

Opinion of Probable Cost for Existing MPE System Operation

Item	Capital Cost[1]	O&M Cost 10-Year Cumulative Cost[2]
Equipment Replacement[3]	$105,000	
Sampling and Analysis		$100,000
Operation and Maintenance		$1,580,000
Shut Down and Secure System	$15,000	
Contingency (25%)	$30,000	$420,000
Project Management, Engineering, Permitting (30%)	$45,000	$630,000
Construction Subtotal	**$195,000**	
Sales Tax	$13,050	$182,700
O&M Subtotal		**$2,913,000**
TOTAL		**$3,121,000**

Definitions:

MPE – multi-phase extraction.
O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 10 years of operation.

[3] Assumes some equipment may need to be replaced within the first 10 years.

Opinion of Probable Cost for MPE System Expansion

		O&M Cost
Item	**Capital Cost**[1]	**Cumulative Cost**[2]
MPE System Modifications	$941,300	
New Wells and Equipment	$320,000	
Sampling and Analysis		$20,000
Operation and Maintenance		$155,000
Shut Down and Secure System	$5,000	
Contingency (25%)	$316,575	$43,750
Project Management, Engineering, Permitting (30%)	$474,863	$65,625
Construction Subtotal	**$2,057,738**	
Sales Tax	$137,710	$19,031
O&M Subtotal		**$303,000**
TOTAL		**$2,498,000**

Definitions:

MPE – multi-phase extraction.
O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 10 years of operation.

Opinion of Probable Cost for Groundwater Extraction from the Hole

Item	Capital Cost[1]	O&M Cost Cumulative Cost[2]
New Wells and Equipment	$374,200	
Sampling and Analysis		$20,000
Operation and Maintenance		$51,000
Shut Down and Secure System	$2,000	
Contingency (25%)	$94,050	$17,750
Project Management, Engineering, Permitting (30%)	$141,075	$26,625
Construction Subtotal	**$611,325**	
Sales Tax	$40,912	$7,721
O&M Subtotal		**$123,096**
TOTAL		**$775,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 10 years of operation.

Opinion of Probable Cost for LFG Activation

Item	Capital Cost[1]	O&M Cost Cumulative Cost[2]
New Equipment	$54,616	
Sampling and Analysis		$20,000
Operation and Maintenance		$55,000
Shut Down and Secure System	$5,000	
Contingency (25%)	$14,904	$18,750
Project Management, Engineering, Permitting (30%)	$22,356	$28,125
Construction Subtotal	**$96,876**	
Sales Tax	$6,483	$8,156
O&M Subtotal		**$130,000**
TOTAL		**$233,000**

Definitions:

LFG – landfill gas.
O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 10 years of operation.

Opinion of Probable Cost for Northerly Plume Hydraulic Capture

		O&M Cost
Item	**Capital Cost[1]**	**Cumulative Cost[2]**
New Wells and Equipment	$143,200	
Treatment Train Building and Utilities	$1,148,936	
Treatment Train Ex-situ Treatment System	$1,161,001	
Infiltration Basin	$13,484	
Sampling and Analysis		$220,000
Operation and Maintenance		$3,446,500
Shut Down and Secure System	$54,240	
Contingency (25%)	$605,215	$911,625
Project Management, Engineering, Permitting (30%)	$907,823	$1,367,438
Construction Subtotal	**$4,033,900**	
Sales Tax	$271,969	$398,297
O&M Subtotal		**$6,343,859**
TOTAL		**$10,650,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 20 years of operation.

Opinion of Probable Cost for Targeted Pumping from the Northerly Plume

		O&M Cost
Item	**Capital Cost[1]**	**Cumulative Cost[2]**
New Wells and Equipment	$189,400	
Sampling and Analysis		$40,000
Operation and Maintenance		$102,000
Shut Down and Secure System	$2,000	
Contingency (25%)	$47,850	$35,500
Project Management, Engineering, Permitting (30%)	$71,775	$53,250
Construction Subtotal	**$311,025**	
Sales Tax	$20,815	$15,269
O&M Subtotal		**$246,019**
TOTAL		**$578,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 20 years of operation.

Opinion of Probable Cost for Existing Evaporation Pond

Item	Capital Cost[1]	O&M Cost 10-Year Cumulative Cost[2]	O&M Cost 20-Year Cumulative Cost[3]
Operation and Maintenance		$100,000	$200,000
Shut Down and Secure System	$121,716		
Contingency (25%)	$30,429	$25,000	$50,000
Project Management, Engineering, Permitting (30%)	$45,644	$37,500	$75,000
Construction Subtotal	**$197,789**		
Sales Tax	$13,237	$10,875	$21,750
O&M Subtotal		**$173,375**	**$346,750**
TOTAL		**$384,000**	**$558,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 10 years of operation.

[3] Cumulative cost in 2018 dollars based on 20 years of operation.

Opinion of Probable Cost for Additional Evaporation Capacity

	Small (0.75 acre) Sized Evaporation Pond		Medium (1.5 acres) Sized Evaporation Pond	
		O&M Cost		O&M Cost
Item	**Capital Cost[1]**	**Cumulative Cost[2]**	**Capital Cost[1]**	**Cumulative Cost[2]**
Installation and Equipment	$266,784		$476,784	
Sampling and Analysis				
Operation and Maintenance		$200,000		$200,000
Shut Down and Secure System	$121,716		$243,432	
Contingency (25%)	$97,125	$50,000	$180,054	$50,000
Project Management, Engineering, Permitting (30%)	$145,687	$75,000	$270,081	$75,000
Construction Subtotal	**$631,312**		**$1,170,351**	
Sales Tax	$42,249	$21,750	$78,323	$21,750
O&M Subtotal		**$346,750**		**$346,750**
TOTAL		**$1,020,000**		**$1,595,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 20 years of operation.

Opinion of Probable Cost for Compliance Monitoring

Item	Alternative 1		Alternative 2		Alternative 3		Alternative 4		Alternative 5		Alternative 6		Alternative 7	
		O&M Cost		O&M Cost		O&M Cost		O&M Cost		O&M Cost		O&M Cost		O&M Cost
	Capital Cost[1]	Cumulative Cost[2]	Capital Cost[1]	Cumulative Cost[3]	Capital Cost[1]	Cumulative Cost[3]	Capital Cost[1]	Cumulative Cost[3]	Capital Cost[1]	Cumulative Cost[4]	Capital Cost[1]	Cumulative Cost[3]	Capital Cost[1]	Cumulative Cost[4]
Monitoring Well Installation/Decommissioning	$204,899		$219,228		$223,527		$243,587		$222,094		$247,885		$226,392	
Environmental General Reporting	$24,478	$2,287,207	$24,478	$1,271,069	$24,478	$1,271,069	$24,478	$1,145,693	$24,478	$1,223,904	$24,478	$1,145,693	$24,478	$984,854
Quarterly Groundwater Monitoring (Years 1-5)		$999,521		$1,151,763		$1,189,730		$1,187,211		$1,187,211		$1,225,178		$1,225,178
Semi-annual Groundwater Monitoring (Years 6+)		$8,697,367		$5,017,816		$5,304,520		$3,582,356		$2,686,767		$3,780,083		$2,835,062
Contingency (25%)	$51,225	$3,053,204	$54,807	$1,891,939	$55,882	$1,973,106	$60,897	$1,507,457	$55,523	$1,305,068	$61,971	$1,566,381	$56,598	$1,285,895
Project Management, Engineering, Permitting	$79,285	$1,450,002	$84,658	$883,882	$86,270	$916,349	$93,793	$717,552	$85,733	$644,418	$95,405	$741,122	$87,345	$612,843
Construction Subtotal	**$359,887**		**$383,171**		**$390,157**		**$422,754**		**$387,828**		**$429,739**		**$394,813**	
Sales Tax	$22,283	$0	$23,841	$0	$24,309	$0	$26,490	$0	$24,153	$0	$26,958	$0	$24,620	$0
O&M Subtotal		**$16,487,302**		**$10,216,468**		**$10,654,774**		**$8,140,270**		**$7,047,367**		**$8,458,457**		**$6,943,833**
TOTAL		**$16,869,000**		**$10,623,000**		**$11,069,000**		**$8,590,000**		**$7,459,000**		**$8,915,000**		**$7,363,000**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Cumulative cost in 2018 dollars based on 66 years of compliance monitoring.

[3] Cumulative cost in 2018 dollars based on 25 years of compliance monitoring.

[4] Cumulative cost in 2018 dollars based on 20 years of compliance monitoring.

Opinion of Probable Cost for Institutional Controls

	Cost (2018 Dollars)						
Item	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative 6**	**Alternative 7**
Physical Institutional Controls	$2,400	$2,400	$2,400	$51,200	$84,400	$51,200	$84,400
Administrative & Legal (15%)	$360	$360	$360	$7,680	$12,660	$7,680	$12,660
Planning, Permitting, Engineering (40%)	$960	$960	$960	$20,480	$33,760	$20,480	$33,760
O&M (5% annually)[1]	$7,920	$4,080	$4,080	$64,000	$84,400	$64,000	$84,400
TOTAL	**$11,640**	**$7,800**	**$7,800**	**$143,360**	**$215,220**	**$143,360**	**$215,220**

Definitions:

O&M – operation and maintenance.

Notes:

[1] Cumulative cost in 2018 dollars based on estimated time to complete active remediation.

Opinion of Probable Cost for Alternative 6 - Present Worth

Item	Capital Cost[1]	O&M Cost Present Worth[2]
Institutional Controls (25 Years)	$79,360	$29,833
Compliance Monitoring (25 Years)	$271,408	$5,339,570
Existing MPE System (10 Years)	$0	$2,051,482
Existing Evaporation Pond (0.75 acre) (20 Years)	$0	$223,265
MPE System Expansion (10 Years)	$2,022,638	$215,449
LFG System Activation (10 Years)	$67,041	$101,316
Groundwater Extraction from the Hole (10 Years)	$586,300	$94,273
Targeted Pumping from the Northerly Plume (20 Years)	$275,275	$135,459
Evaporation Pond (0.75 acre) (20 Years)	$433,524	$237,037
Construction Subtotal	**$3,735,545**	
Sales Tax	$247,336	$208,758
O&M Subtotal		**$8,636,444**
TOTAL		**$12,619,000**

Definitions:

LFG - landfill gas
MPE – multi-phase extractionsoil vapor extraction.
O&M – operation and maintenance.

Notes:

[1] Cost in 2018 dollars.

[2] Present worth is based on the specified period of operations using a 7% annual discount rate per EPA Guidance.